Refractory Clay Deposits of South-Central Colorado

GEOLOGICAL SURVEY BULLETIN 993

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By KARL M. WAAGÉ

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A description of the refractory and semirefractory clays in the Purgatoire formation and Dakota sandstone

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By Karl M. Waagé

ABSTRACT

Refractory and semirefractory clays have been mined since the 1890's from outcropping pre-Benton Cretaceous rocks in the foothills and high plains of western Pueblo and eastern Fremont Counties, Colo. The dominantly sandy strata that contain the clays are of early Cretaceous age and form the Purgatoire formation—which is subdivided into a lower sandy unit, the Lytle sandstone member, and an upper shaly unit, the Glencairn shale member—and the Dakota sandstone. Flint clay high in alumina (averaging 35 percent Al_2O_3) is restricted to a clay-bearing member, herein named the Dry Creek Canyon member of the Dakota sandstone. Low-grade refractory clay and semirefractory plastic clay are associated with the flint clay and also occur in lenses at the top of the Glencairn shale member of the Purgatoire formation and, in at least one locality, in the top of the Dakota sandstone.

The Dry Creek Canyon member, which occurs as irregular isolated remnants within the Dakota sandstone, was once continuous throughout the Canon City embayment area and extended southeastward into Huerfano County. It was eroded from most of this area during two periods of channeling, one nearly contemporaneous with the deposition of the clay and a second preceding the deposition of the upper part of the Dakota sandstone. Stratigraphic studies suggest that the clay sediment of the Dry Creek Canyon member was derived from a kaolinitic residual mantle developed on local Cretaceous land areas and deposited in a body of fresh water.

Most of the refractory clay produced has come from the Dry Creek Canyon member of the Dakota sandstone in the Turkey Creek district of northwestern Pueblo County. Detailed surface mapping and studies of the mines in this district indicate reserves of about 4 million short tons, of which about 2½ million tons is flint clay.

In the Rock Creek area of the Beulah district reserves of as much as 750,000 short tons of refractory clay, of which at least 35 percent is flint clay, are indicated by several drill holes and mine workings

Insufficient exposures and lack of subsurface information prevent estimates of reserve tonnage in the other districts. Subsurface explorations of the Dry Creek Canyon member of the Dakota sandstone in accessible areas adjacent to known clay bodies is recommended, and further surface exploration needs to be done in areas of Dakota and Purgatoire outcrop remote from transportation.

INTRODUCTION

THE PRESENT STUDY

A field investigation of the occurrences of high-alumina refractory clay in the Cretaceous formations of south-central Colorado was made by the writer for the Geological Survey between November 1943 and July 1944. At this time the refractory clay was considered as a possible source of alumina, from which metallic aluminum might be recovered, and the primary purpose of the work was to estimate the probable recoverable tonnage of high-alumina flint clay averaging 35 percent or more in alumina. However, clays are not yet mined anywhere in the United States as ores of metallic aluminum and the present commercial value of the clays described in this report depends primarily on their refractoriness. The field work was concentrated around the active mining districts, and in addition a reconnaissance study of the clay-bearing formations over most of the area was made in search of additional deposits of the flint clay. In the latter part of the summer of 1950, the area was revisited for three weeks in order to bring the information on mining up to date and to restudy certain details of the stratigraphy.

ACKNOWLEDGMENTS

The writer is indebted to many individuals for their courteous cooperation and assistance. Mr. F. J. Helwig, president of the Standard Fire Brick Co., Mr. William J. Thomas, president of the Pueblo Clay Products Co., Mr. Arthur Wands of Stone City, Mr. William Grigg, who was superintendent of the old Diamond Fire Brick Co. in Canon City, Mr. D. M. Rice of the Laclede Christy Co. of Colorado, which took over the Diamond holdings, and Mr. Charles Freeman of the Freeman Fire Brick Co., were especially helpful in giving considerable information on their mining operations and by contributing the analyses of the clays (pp. 95–97) of this report. Thanks are due Mr. Jay D. Thomas of the Pueblo Clay Products Co. for his kindness and the information he gave from his long experience working with the clays of eastern Colorado, and Mr. Edwin O. Eve of the Standard Fire Brick Co. for his assistance on many field trips.

LOCATION OF THE CLAY DEPOSITS

Deposits of refractory clay are found in Cretaceous formations at several localities in eastern Fremont and western Pueblo Counties and adjacent parts of Custer, Huerfano, and Las Animas Counties, Colo. Figure 1, an index map of the area investigated for clay, shows the outcrop pattern of the rock formations that contain refractory clay in lenticular bodies of erratic areal distribution. Also shown is the location of the several clay-mining districts and areas mentioned in this report.

Within the area shown on figure 1, the clay-bearing strata crop out in the foothills of the Rocky Mountain Front Range and are also at the surface over large parts of the Great Plains. In eastern Fremont

Base from Colorado State Geologic Map

FIGURE 1.—Index map of refractory clay areas of south-central Colorado.

County a plains area roughly triangular in shape lying between the south end of the Front Range and the Wet Mountains forms a reentrant in the Rocky Mountain front. The reentrant, which is called the Canon City embayment for the town near its west end, is traversed by the southeastward-flowing Arkansas River. Clay-bearing strata crop out in hogbacks and cuestas that extend in an east-west direction along the north side of the Canon City embayment and in the hogbacks and foothills at the west end of the embayment. The areas in which these strata lie constitute the Penrose and Canon City districts. Along most of the south side of the Canon City embayment the clay-bearing beds are not exposed.

The hogbacks of clay-bearing strata along the north side of the Canon City embayment extend eastward into the northwest corner of Pueblo County joining the north-south belt of hogbacks paralleling the Front Range in an area of prominent foothills, where over 12 square miles of clay-bearing strata are exposed. This area is here called the Turkey Creek district for the stream that flows along its eastern edge.

South of the Canon City embayment along the front of the Wet Mountains the clay-bearing formations reappear in the vicinity of Wetmore, Custer County, and from there southeastward into Pueblo County are exposed in foothills paralleling the mountain front. In southwest Pueblo County the clay-bearing strata crop out over a broad area extending out onto the plains from the cuesta flanking the Wet Mountains. The major part of this broad area lies east and northeast of the town of Beulah and constitutes the Beulah district.

Southeast of the Beulah district, in south-central and southeastern Pueblo County and adjoining parts of Huerfano and Las Animas Counties, the clay-bearing formations are exposed at the surface of the plains over an area more than 300 square miles in extent lying between the Huerfano and Apishapa Rivers. Here the topography is somewhat different from that of the Great Plains and is essentially a low plateau of flat-lying strata cut by numerous steep-walled canyons, some exceeding 400 feet in depth and affording excellent exposures of the clay-bearing strata.

Although clay is mined both in the foothills and on the plains, most of the mining activity has been in eastern Fremont and western Pueblo Counties in areas accessible by truck or by rail to Pueblo or Canon City. The southeastern part of the area, which has a great expanse of clay-bearing strata, lacks settlements and is, for the most part, remote from transportation facilities.

PREVIOUS GEOLOGIC WORK

The general geology of the part of Colorado containing the clay deposits herein described is set forth in reports on the ground water resources of the Arkansas River valley in Colorado by Gilbert (1896) and Darton (1906). Parts of the area are covered by geologic maps of the Geologic Atlas series of the U. S. Geological Survey, namely the Pueblo quandrangle (Gilbert, 1897), the Walsenburg quadrangle (Hills, 1900), the Pikes Peak quadrangle (Cross, 1894), and the Apishapa quadrangle (Stose, 1912). Little has been written about the clays themselves. Butler (1914) describes the geologic distribution of the useful clays and shales of eastern Colorado and gives data, by counties, on many samples as to the manner of occurrence and value of the sampled materials, their physical characteristics and, for some samples, their ceramic and chemical properties. Since Butler's work was of a general nature his report contains no specific information on the refractory clay deposits of the area in question other than descriptions of a few spot samples. A brief summary of the material contained in the present report was given by Waagé (in Vanderwilt, 1947, pp. 236–239) and more recently Argall (1949, pp. 89–109) has reviewed what is known concerning the clay industry of Colorado.

STRATIGRAPHY OF THE CLAY-BEARING FORMATIONS

CLASSIFICATION OF THE CLAY-BEARING ROCKS

In southeastern Colorado, south of Colorado Springs and east of the Rocky Mountain front, deposits of refractory clay occur in Cretaceous strata lying between the Jurassic Morrison formation and the Cretaceous Graneros shale. These strata generally consist of two massive sandstone units separated by a middle unit of shale with interbedded sandstone. In the early geologic reports on the region this tripartite sequence was included in the Dakota sandstone and was considered to be Late Cretaceous in age. In 1905 Darton (p. 120) announced the occurrence of marine fossils in the middle shale unit, in Prowers County. The fossils were identified by T. W. Stanton as Early Cretaceous (Washita) forms. In the same year Stanton (1905, pp. 661–663, 666–667) reported discoveries of the same fauna in the middle shale along the Purgatoire River south of La Junta and on Oil Creek north of Canon City. In 1912, Stose (pp. 3–4) restricted the name Dakota, in the Apishapa quadrangle, which covers parts of Pueblo, Otero, Huerfano, and Las Animas Counties, to the upper sandstone and named the middle shale and lower sandstone the Purgatoire formation, which was assigned to the Lower Cretaceous.

In 1916 Finlay (pp. 7–8) mapped the Purgatoire formation in the Colorado Springs quadrangle and subdivided it into two members, the Glencairn shale member and the Lytle sandstone member corresponding, respectively, to the middle shale and lower sandstone of the tripartite sequence. In the present study the Dakota sandstone is regarded as subdivided into three parts by the recognition of a clay-bearing unit, the Dry Creek Canyon member, in its middle part. The stratigraphic relations and lithologic character of the subdivisions of the Purgatoire and Dakota strata are summarized graphically in figure 2.

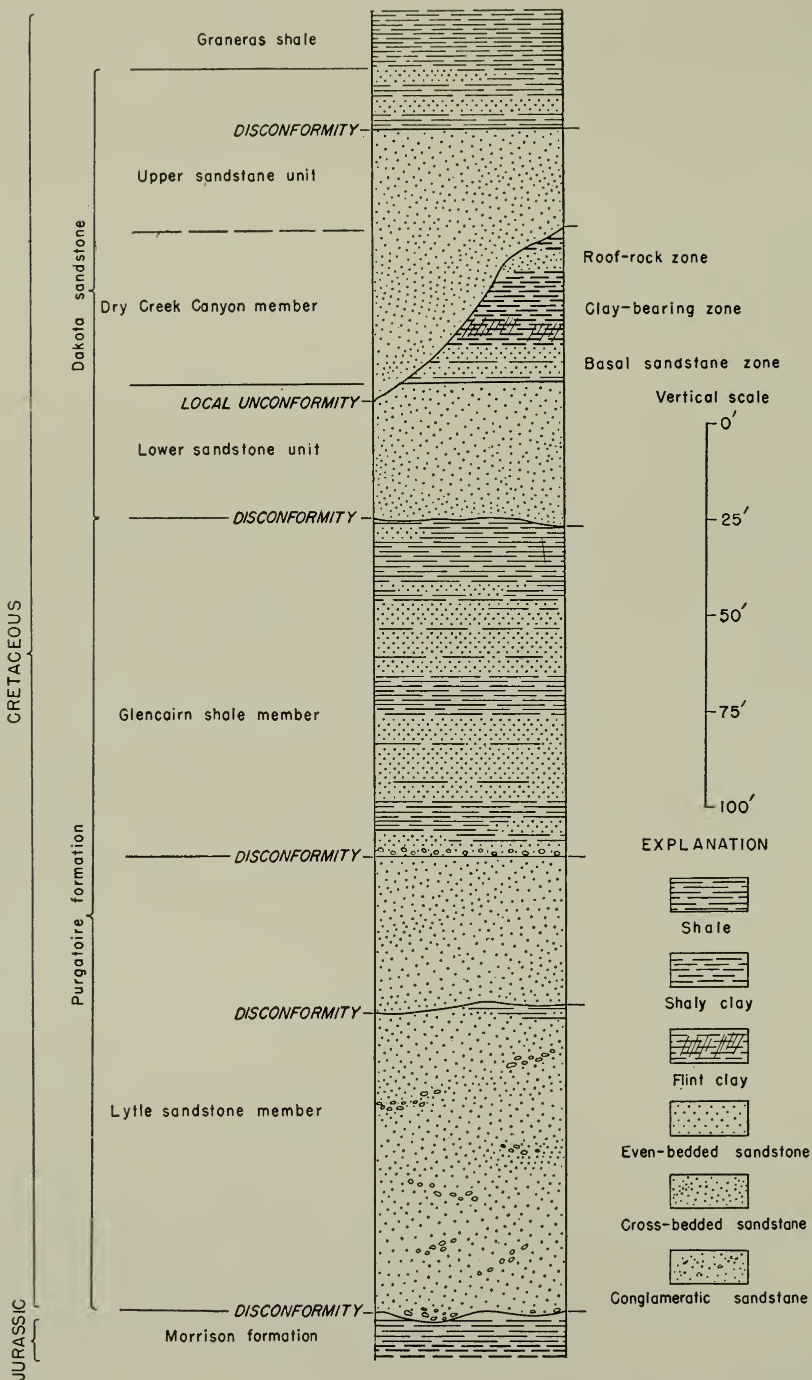

FIGURE 2.—Generalized section of the Purgatoire and Dakota formations in south-central Colorado.

With the exception of the map of the Apishapa quadrangle and of a small part of northwestern Pueblo County shown on the map of the Colorado Springs quadrangle, the geologic maps covering the area investigated for refractory clay are too old to show the subdivisions of the original tripartite "Dakota." However, in the Economic Geology sheet of the Walsenburg quadrangle map (Hills, 1900) the clay bed shown within the "Dakota sandstone" is at the top of the Purgatoire formation and serves to indicate the position of its contact with the Dakota. Gilbert's (1897) Economic Geology map of the Pueblo quadrangle, also shows a subdivision of the "Dakota sandstone" based on the occurrence of clay. However, he distinguished a clay-bearing "upper part of the Dakota formation" instead of a single bed and the line of division falls within what is now recognized as the Glencairn shale member of the Purgatoire formation.

With few exceptions all clay mines examined in the area, those being worked and the abandoned mines, are in either the Dry Creek Canyon member of the Dakota or the Glencairn shale member of the Purgatoire. The exceptions are several small abandoned workings in the Canon City district that are in the basal strata of the Graneros shale, and the Shamblin mine of the Standard Fire Brick Co., in the Capers area, which is in the upper sandstone unit of the Dakota. High-alumina flint clay is found only in the Dry Creek Canyon member of the Dakota. Plastic clay occurs in the other zones and also in association with the flint clay of the Dry Creek Canyon member.

PURGATOIRE FORMATION

The Purgatoire formation, which ranges from 200 to 250 feet in thickness, consists of an upper shaly member and a lower member of sandstone and conglomerate (fig. 3). It overlies the Morrison formation unconformably and locally has a basal conglomerate. The upper contact between the shale and clay of the Purgatoire and the massive sandstone of the overlying Dakota is, in some places, marked by an erosional unconformity. In other places the Purgatoire grades upward into the Dakota through a thin transition zone of interbedded shale and sandstone.

Two distinct subdivisions of the Purgatoire formation are recognizable throughout the area that was examined for clay. These appear to be equivalent to Finlay's subdivisions of the Purgatoire in the Colorado Springs quadrangle (Finlay, 1916, pp. 7–8): the (lower) Lytle sandstone member and the (upper) Glencairn shale member. Finlay's description of the members is not sufficiently detailed to indicate certainly that these units correspond exactly to the subdivisions of the Purgatoire recognized in this report. However, the discrepancy, if any, is not great and the names Lytle member and

FIGURE 3.—Exposure of complete section of the Purgatoire formation at Parkdale, Fremont County. *Mc,* contact of the Morrison formation and the Lytle sandstone member of the Purgatoire formation; *Gc,* contact of the Lytle sandstone and Glencairn shale members of the Purgatoire formation; *Dc,* contact of the Glencairn shale member of the Purgatoire formation and the Dakota sandstone.

Glencairn member are extended to include the subdivisions of the Purgatoire in Fremont, Pueblo, and Huerfano Counties.

LYTLE SANDSTONE MEMBER

The Lytle sandstone member of the Purgatoire formation consists of a lower unit of massive, poorly sorted, white sandstone and conglomeratic sandstone that locally contains beds of variegated clay, and an upper unit of brown-weathering medium-grained, locally conglomeratic sandstone, with intercalated beds of dark gray shale. The white sandstone in the lower unit is the most distinctive part of the member and, in some places, occupies two-thirds or more of its total thickness. On weathered outcrops the white sandstone is commonly colored light buff and has a pinkish cast contributed by the oxidation of minute specks of ferruginous matter in the sandstone. In some places the sandstone has a red stain contributed from intercalated beds of red clay. The grain size of the white sandstone is dominantly medium and fine, but its most conspicuous and diagnostic feature is the coarse-grained and conglomeratic sandstone that locally occurs in lenses and thin beds throughout the unit. Chert and quartzite pebbles are the chief coarse constituents. The white sandstone is cross-laminated and appears either as a single massive unit or in thick lenticular beds separated by zones of variegated clay.

The upper part of the Lytle sandstone member consists of medium-grained to conglomeratic, brown-weathering sandstone interbedded with varying amounts of dark gray, silty to sandy shale. In some places the shale is absent and the sandstone appears as an unbroken unit but more commonly one or more beds of shale are present. In color and texture the upper part of the Lytle is more like the rocks in the overlying Glencairn shale member but in structure, which varies from fine cross lamination to coarse cross bedding, it resembles the underlying white sandstone. The contact with the white sandstone is in some places disconformable and shows local channels incised in the upper part of the white sandstone unit. The contact with the overlying Glencairn member is marked by a persistent disconformity which is expressed as a planed surface truncating the cross lamination in the sandstone.

The upper brown-weathering sandstone of the Lytle member appears to be present only in the west half of the Canon City embayment. It is prominent in the Skyline Hogback and in exposures along Oil Creek and Wilson Creek, but it appears to be absent in the Turkey Creek district and elsewhere in Pueblo and Huerfano Counties. In these latter areas the lower massive white sandstone is in disconformable contact with the overlying Glencairn member.

The contact of the Lytle sandstone member of the Purgatoire formation with the underlying Morrison formation is not everywhere clear-cut. The base of the unit is not exposed in the type area of the member, so there is no handy reference section. Solution of this stratigraphic problem is beyond the scope of this report. Preliminary results of studies of the Lytle equivalent elsewhere in eastern Colorado indicate that the unit has a sandy phase in which it consists entirely of conglomeratic sandstone and is between 120 and 150 feet thick. This phase is locally present in the Canon City embayment area but is far more typical to the southeast in the Walsenburg and Apishapa quadrangles. More typical of the Canon City embayment area is a shaly phase, in which the sandstone is interbedded with zones of variegated clay and shale that are lithologically like the underlying Morrison formation. Locally, as in the road cut along the Skyline Hogback at Canon City, variegated clay predominates over sandstone in the lower part of the unit and identification of the Morrison contact is difficult.

GLENCAIRN SHALE MEMBER

The Glencairn shale member of the Purgatoire formation consists of alternating units of olive-brown, thin-bedded sandstone and gray and black shale totaling between 70 and 100 feet in thickness. A common sequence is three units of shale alternating with three units of sandstone. The uppermost unit is shale which ranges from 5 to 30 feet thick and is the thickest and most persistent of the shale units, It consists of gray and black shale which is locally silty and sandy. Where the shale is silty or sandy it commonly contains thin interbedded greenish sandstone with worm trails on the bedding surfaces. In some places the uppermost shale unit is relatively free of sand and contains bodies of dark gray to black, slightly indurated, plastic clay shale that is locally of value as a semirefractory clay.

The middle and lower shale units are generally thinner and more sandy than the upper shale. In many places the middle shale is highly carbonaceous and in both the Turkey Creek and Canon City districts contains thin beds of impure coal, locally as much as 18 inches thick. The lower shale unit consists of interbedded sandstone, sandy shale, and light gray shale.

The sandstone units that separate the zones of shale are characteristically even-bedded, medium- to fine-grained buff to olive-brown sandstone. The individual sandstone beds seldom exceed a foot in thickness and in many places are separated by thin partings of sandy shale. The pattern of six alternating units of shale and sandstone within the Glencairn shale member is typical of this member in the Canon City embayment area, although this pattern is obliterated locally by thickening of the sandstone units at the expense of the shale units.

The lower sandstone unit of the Glencairn shale member, the thinnest of the three, is commonly between 5 and 10 feet thick. At the base of the sandstone, and commonly separated from it by a thin bed

FIGURE 4.—Exposures of the top of the Lytle sandstone member and most of the Glencairn shale member of the Purgatoire formation on Skyline Hogback, Canon City. Sandstone capping the crest is upper of two sandstone zones in the Glencairn. *Gc*, contact of the Lytle sandstone and the Glencairn shale members of the Purgatoire formation.

of silty shale, is a bed of conglomeratic sandstone from 2 to 18 inches thick. This conglomeratic bed rests on a planed surface that truncates the cross lamination in the underlying Lytle sandstone. Exposures of the conglomerate were found at numerous localities in the Turkey Creek and Canon City districts and in the Cucharas River canyon area in Huerfano County. It is also recorded in sections of the Purgatoire formation described from the Apishapa quadrangle (Stose, 1912, p. 4). The most accessible exposure of the conglomerate is along the road cut, shown on figure 4, on Skyline Drive northwest of Canon City. The disconformity at the base of the conglomerate appears to persist throughout the area studied for clays and to extend into adjacent areas.

FOSSILS

The Purgatoire formation contains few fossils. Carbonaceous matter is locally common in both the Lytle and Glencairn members but it is poorly preserved and has not yielded identifiable plant remains.

The only marine fossils heretofore reported from the Purgatoire formation in the area studied are those recorded by Stanton and Stose. Stanton (1905, pp. 666–667) states that the fossils from the locality on Oil Creek north of Canon City include "*Pholadomya scancti-sabae* Roemer, a *Tapes(?)*, a *Lingula* and a small mactroid shell, all of which occur in the Kiowa shales of Kansas." Stose (1912, p. 4) gives the following list identified by Stanton from collections in the Apishapa quadrangle:

Avicula sp.
Pecten? sp.
Pholadomya cf. *sanctae-sabae* Roemer
Trigonia? sp.
Protocardia? sp.
Tapes? sp.

Both collections are from beds within the Glencairn shale member of the Purgatoire.

The three shale units of the Glencairn member of the Purgatoire formation were sampled in the Canon City district and marine fossils were found in the upper shale. These include a small microfauna of dominantly arenaceous Foraminifera, some sponge spicules and an unidentifiable tellinid pelecypod. The other shale units yielded no evidence of marine or brackish water origin.

DAKOTA SANDSTONE

Throughout a large part of southeastern Colorado the Dakota sandstone is a prominent, cliff-forming unit averaging about 100 feet in thickness and consisting largely of fine- and medium-grained cross-laminated sandstone. In contrast with the lighter colored, rounded exposures of the less resistant Lytle sandstone member at the base of the Purgatoire formation the Dakota crops out in sharp ledges and weathers to deep shades of brown, buff, and red. The basal contact of the Dakota with the Glencairn shale member of the Purgatoire is locally disconformable. The contact with the overlying Graneros shale is conformable through a transition zone of alternating sandstone and shale.

In some places the Dakota sandstone includes, in its middle part, a zone of shale, clay, and thin, even-bedded sandstone that is disconformable with the sandstone beds above and below it. This distinctive zone of dominantly argillaceous strata is found in isolated bodies which are interpreted as remnants of a once-continuous lithologic unit. The remnants have a wide distribution in parts of eastern Fremont, Pueblo, Huerfano, Las Animas, and Otero Counties. The name Dry Creek Canyon member is given to this zone for exposures around the clay mines of the Pueblo Clay Products Co. in Dry Creek Canyon approximately one-quarter mile northeast of Stone City in the Turkey Creek district, Pueblo County. In the canyon the relation of the member to the surrounding parts of the Dakota sandstone and the details of the sequence of beds within the member are clearly shown in and between abandoned mine entries in the S½NW¼ SE¼ sec. 26, T. 18 S., R. 67 W.

Where the Dry Creek Canyon member of the Dakota sandstone is present, in whole or in part, the sandstone beds above and below it appear as distinct units. No formal names are given to these sandstone units but to facilitate description they will be referred to in this report as the upper sandstone unit and the lower sandstone unit of the Dakota.

LOWER SANDSTONE UNIT

The lower sandstone unit of the Dakota generally consists of massive, medium-grained finely cross-laminated sandstone. Locally the sandstone is grossly cross-bedded and appears as platy, irregular beds on the weathered outcrop. A basal zone of more even-bedded sandstone transitional downward into the Glencairn shale member of the Purgatoire formation is commonly present. Where this basal zone is absent the massive, cross-laminated sandstone is in sharp contact with the Glencairn shale member.

The lower sandstone unit is between 25 and 35 feet thick and is more consistent in thickness than the other units of the Dakota sandstone. On the outcrop it is generally lighter in color than the sandstone of the upper sandstone unit; the color varies from gray-white to buff and reddish brown. Many exposures of the upper 2 or 3 feet of the lower sandstone unit are stained a dark red brown. On fresh surfaces the sandstone is generally dirty white with fairly numerous ferruginous specks in the upper few feet.

The contact with the Dry Creek Canyon member of the Dakota sandstone is sharp and is featured by an abrupt lithologic change from cross-laminated, massive sandstone to even-bedded white sandstone and intercalated shaly beds, which appear to have been deposited on a planed surface. The surface truncates the cross-lamination in the lower sandstone unit and, as a rule, is covered with a thin crust of ferruginous sandstone resembling desert varnish (figs. 5, 6). This disconformity is present at the top of the lower sandstone unit in all sections where it was observed in contact with the Dry Creek member.

FIGURE 5.—The Dry Creek Canyon member of the Dakota sandstone on the west wall of Dry Creek Canyon. *U,* contact with the upper sandstone unit; *L,* contact with the lower sandstone unit.

DRY CREEK CANYON MEMBER

The Dry Creek Canyon member of the Dakota sandstone consists of three lithologic zones which are consistent in their general character and relative stratigraphic position throughout the area studied. The most conspicuous of these is a zone of plastic and flint clay in the middle part of the member. This clay-bearing zone is of economic importance as the principal source of refractory clay for the clay-products industry in the Pueblo-Canon City area. The clay-bearing zone is generally separated from the underlying lower sandstone unit of the Dakota by a zone of even-bedded white sandstone with some interbedded shale. An upper zone of alternating sandstone, clay, and clay shale forms the roof rock of the clay-bearing zone and lies between it and the upper sandstone unit of the Dakota, which overlies the Dry Creek Canyon member disconformably. Channeling prior to the deposition of the upper sandstone unit has removed part or all of the Dry Creek Canyon member over large parts of the area studied. The following composite section, based on numerous measured sections in the type area, illustrates the character of the member where all three zones of lithology are preserved.

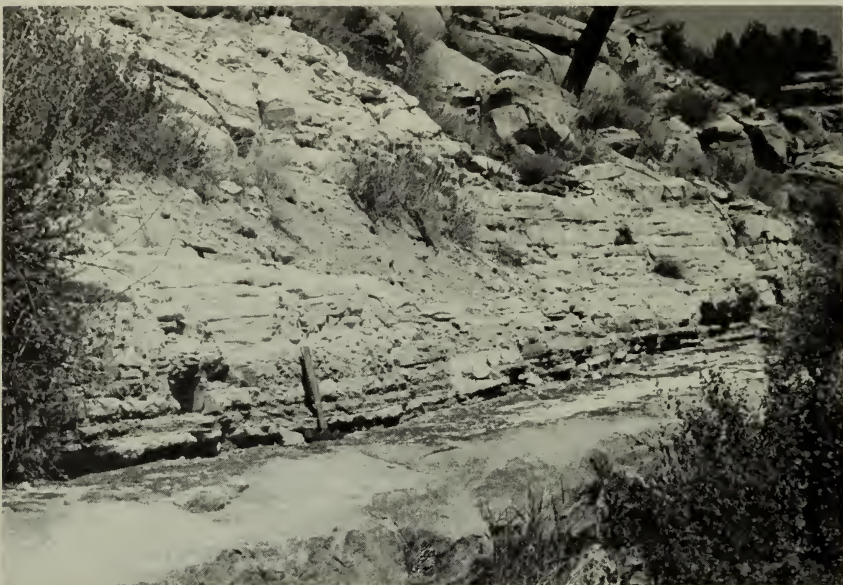

FIGURE 6.—Close-up of lower part of Dry Creek Canyon member of Dakota sandstone. The hammer head rests on the planed surface of the lower sandstone unit.

Composite section of the Dry Creek Canyon member of the Dakota sandstone from exposures along Dry Creek Canyon in the S½NW¼SE¼ sec. 26, T. 18 S., R. 67 W., Pueblo County

	Feet
Dakota sandstone:	
Upper sandstone unit (in part): Sandstone, medium-grained, massive, cross-laminated, weathers red-brown to buff	10–25
Disconformity.	
Dry Creek Canyon member:	
Sandstone, fine-grained, thin- to thick-bedded, soft white to hard green, with intercalated sandy gray clay shale and blue-gray plastic clay. Contains carbonaceous matter and in some places identifiable plant remains. The roof-rock zone	0–27
Clay, commonly an upper bed of blue-gray to black plastic clay and a lower bed of flint clay and sandy flint clay. The clay-bearing zone	0–18
Sandstone, fine- to medium-grained, even-bedded, compact, gray to white, with intercalated thin layers of carbonaceous shale, blue-gray siltstone, and gray sandy shale. Plant remains locally present. The basal sandstone zone	0–10
Disconformity.	
Lower sandstone unit.	

The basal zone of even-bedded sandstone is the least variable zone in the Dry Creek Canyon member. In a few places, however, this zone is absent and the flint clay is in contact with the lower sandstone unit, a circumstance that suggests the presence of low prominences on the eroded surface of the lower sandstone unit during the deposition of the lower part of the Dry Creek Canyon member.

The average thickness of the basal sandstone in the type area of the member is about 6 ft. Little variation is shown within local areas and beds only 2 or 3 in. thick may be traced for several thousand feet. Included shaly beds are more abundant in the lower half of the zone along with sandstone that contains much fragmental plant material. Details of the basal sandstone zone in the Dry Creek Canyon member are given in the following section.

Section of basal part of the Dry Creek Canyon member of the Dakota sandstone, west wall of Dry Creek Canyon in the S½NW¼SE¼ sec. 26, T. 18 S., R. 67 W., Pueblo County

	Ft.	in.
Dry Creek Canyon member.		
Clay-bearing zone (in part):		
Flint clay, increasingly sandy in lower 2 feet	5	
Sandstone, fine- to medium-grained, with flint clay matrix, no bedding evident, fracture rough-conchoidal		6
Basal sandstone zone:		
Sandstone, fine-grained, even-bedded, white, compact	4	
Sandstone, medium-grained, grayish-white, weathers rusty gray, stem-like plant fragments	1	
Sandstone, fine- to medium-grained, thin-bedded, gray, interbedded with siltstone and carbonaceous shale	2	
Sandstone, fine-grained, argillaceous, blue-gray, and sandy shale. Fragments of conifer stems and cones	1	
"Paper" shale, gray to brown		2–6
Disconformity.		
Lower sandstone unit.		

The clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone is a complex zone whose outstanding feature is the occurrence of several types of clay in specific stratigraphic positions within the bed. Where the two common types of clay, plastic and flint clay, occur together in the same bed the flint clay consistently underlies the plastic clay.

The flint clay is a light gray claystone with conchoidal fracture. It becomes increasingly sandy in its basal portion and grades downward into the basal sandstone zone of the member through a thin zone of sandstone with flint clay matrix (see geologic section above). Above, the flint clay is in sharp contact with the overlying plastic clay. More than one variety of clay is commonly present in the plastic clay portion of the bed. The most common type is light bluish-gray to dark gray with semiconchoidal to blocky fracture; it breaks down to a plastic mass in water. A second type, locally present at the base of the plastic clay, is a tough, black semiplastic clay. An inch or two of peculiar yellow-weathering, waxy clay, here called the "marker bed," commonly separates the black semiplastic clay from the overlying plastic clay. (See fig. 9, p. 22 and fig. 10, p. 23.)

A sandy zone, referred to here as the roof-rock zone, overlies the clay-bearing zone of the Dakota sandstone. It is the uppermost of the three zones in the Dry Creek Canyon member and it exhibits the greatest lithologic variability. Commonly the roof-rock is represented by 2 to 6 feet of interbedded sandstone, clay shale, and sandy clay, but the lithology of individual sections differs greatly within a score of feet in a horizontal direction. Sandstone varies from fine- to medium-grained and generally is either in soft, porous, gray-white beds or hard, compact, tan beds with a greenish cast. In many places the sandstone beds contain rounded pellets of sandy clay. Beds of intercalated clay show evidence of reworking and in many places contain impure streaks of flinty clay and pockets of sand. The clay shale appears to owe its rude fissility in part to carbonaceous matter present on the bedding surfaces.

The relation of the roof-rock zone to the underlying clay-bearing zone of the Dry Creek Canyon member is not very distinct. In some places the plastic clay appears to grade both vertically and laterally into the roof rock through increasingly sandy beds or by the intercalation of layers of sandstone. Most commonly, however, a disconformity is present at the contact of the two zones and it is obvious that the sediments of the roof-rock zone were deposited in channels incised in the underlying clay. Local thinning of the clay-bearing zone by the channeling is fairly common. Individual channels measured on the outcrop range in breadth from a few feet to somewhat over 150 feet.

A few roof-rock channels were found that penetrate the clay-bearing zone. Deeper channels, possibly penetrating the base of the Dry Creek Canyon member, were not observed but a peculiar stratigraphic feature suggests their former presence. In some exposures remnants of roof-rock channel fills are found flanking channels filled by the upper sandstone unit where the Dry Creek Canyon member has been cut out. This relationship, shown diagrammatically in figure 7, indicates the superposition of channels of the upper sandstone unit on channel fills in some of the roof-rock channels. Only the broadest bodies of roof-rock channel fills appear to have been subject to such superposition. In the few exposures showing superposition of channels, the roof-rock channels are intersected by the channels of the upper sandstone unit just above the base of the Dry Creek Canyon member. This suggests that the roof-rock channels were incised at least as deep as the base of the member and probably into the lower sandstone unit. Examples of superposition of the channels are too numerous to be considered chance occurrences. They are interpreted as resulting from persistence of the sites of major drainage courses from the time they were first established, during cutting of the roof-rock channels, until the time of deposition of the fills in the channels of the upper sandstone unit.

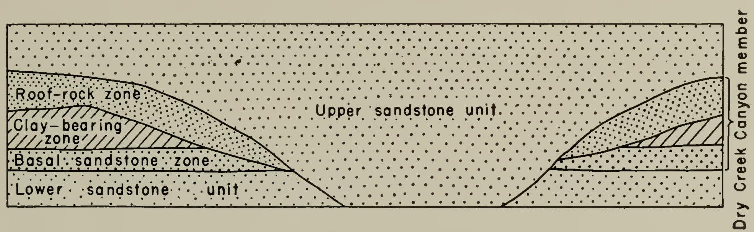

FIGURE 7.—Superposition of channel deposits within the Dakota sandstone.

UPPER SANDSTONE UNIT

The upper sandstone unit of the Dakota sandstone ranges in thickness from 50 to 100 feet and overlies the Dry Creek Canyon member disconformably. The unit consists of three parts:

A lower part, 20 to 80 feet thick, consists of sandstone, medium-grained, even-bedded to massive, cross-laminated, weathering to shades of brown, red-brown, and red on the outcrop.

The middle part of the unit is a zone of soft, argillaceous, gray-white sandstone 5 to 10 feet thick, that locally grades laterally into sandy shale and is capped by a very hard, quartzitic, pinkish-brown sandstone, 1 to 4 feet thick, which commonly contains vertical tubes showing lamellar fillings concave upward. In most areas of outcrop the Dakota is stripped to this quartzitic sandstone.

In the upper part of the unit, between the quartzitic sandstone bed and the base of the overlying Graneros shale, are from 15 to 20 feet of alternating sandstone and shale, which are transitional into the Graneros. The contact of Dakota and Graneros is drawn at the top of the highest bed of hard, fine-grained sandstone in this sequence. The transition beds are not generally resistant and underlie grassy slopes.

The following composite section is characteristic of the upper sandstone unit. The principal local variations occur above the quartzitic sandstone bed.

Composite section of the upper sandstone unit of the Dakota sandstone representing exposures along Dry Creek Canyon in the NW¼SE¼ sec. 26, T. 18 S., R. 67 W., Pueblo County

Graneros shale.	
Dakota sandstone, upper sandstone unit:	*Feet*
Sandstone, hard, compact, ripple-marked, brown, in layers 6 to 12 in. thick alternating with gray sandy shale	13
Sandstone, slabby, ripple-marked, locally cross-laminated, brown to buff in color	2
Sandy shale, gray, carbonaceous; and soft gray sandstone	3
Sandstone, very hard, quartzitic, pinkish-brown, with vertical tubular structures locally developed	1½
Sandstone and bluish-gray shale	10
Disconformity.	
Sandstone, massive to relatively thin- and even-bedded, cross-laminated, weathers red-brown, buff, and brown	25–30
Disconformity.	
Dry Creek Canyon member.	

The cross-laminated sandstone that forms the basal bed of the upper sandstone unit is an aggregation of numerous channel fills which generally resemble one another in lithology. The erosion of the initial channels in which these fills were deposited removed the Dry Creek Canyon sediments from most of the area that they covered. The depth of incision of the channels into the underlying strata is variable; hence the base of the upper sandstone unit is not everywhere in contact with the same stratigraphic unit. At some localities the channel cutting completely eroded away both the Dry Creek Canyon member and the lower sandstone unit, and the upper sandstone unit was deposited in channels incised in the Glencairn shale member of the Purgatoire formation. A rather persistent disconformity, similar to that at the contact of the lower sandstone unit and the Dry Creek Canyon member, appears at the top of the cross-laminated sandstone that forms the lower part of the upper sandstone unit. The overlying softer sandstone and shale apparently were deposited on a fairly even surface that locally truncates the cross bedding.

UNIFORM BODIES OF DAKOTA SANDSTONE

Over large parts of the area of Dakota sandstone outcrop in southeastern Colorado the Dry Creek Canyon member was removed by the channeling that preceded the deposition of the upper sandstone unit. In such circumstances the Dakota appears as a single unit composed of lenses of cross-laminated sandstone between 60 and 100 feet thick. It characteristically forms a sheer cliff face weathering to shades of brown. In a few places that are marginal to deposits of the Dry Creek Canyon member local disconformities in the Dakota are marked by thin intraformational conglomerates composed of rounded pellets of siliceous, shaly clay and shale. In most places, however, the disconformities are not obvious and individual channel sandstones cannot be distinguished. The following section is typical of uniform bodies of Dakota sandstone.

Section of the Dakota sandstone along east wall of Turkey Creek south of Teller Reservoir in the SE¼SW¼NW¼ sec. 31, T. 18 S., R. 66 W., Pueblo County

	Feet
Dakota sandstone:	
Beds transitional into Graneros shale	not exposed
Sandstone, hard, quartzitic, with vertical tubular structures	1–4
Sandstone, even-bedded, slabby, argillaceous, gray, with minor amounts interbedded gray shale	5
Disconformity.	
Sandstone, massive, cross-laminated, weathers to buff, brown, and red-brown	50–70
Disconformity.	
Purgatoire formation, Glencairn shale member: Shale and clay, dark gray, sandy, with thin interbeds of hard, greenish-buff sandstone	10–?

In bodies of uniform Dakota sandstone it is difficult to demonstrate the presence of or prove the absence of the lower sandstone unit because of its lithologic similarity to the upper sandstone unit. In most of the areas occupied by such bodies, the lower sandstone unit is not recognizable and it is considered likely that the Dakota of these areas consists only of the upper sandstone unit. In some places the disconformity at the base of the upper sandstone unit can be traced through continuous exposures from areas occupied by remnants of the Dry Creek Canyon member into the uniform phase of the Dakota; this has been done along the west rim of the canyon of Cucharas River in sec. 19, T. 26 S., R. 64 W., Huerfano County; along the canyon of Wilson Creek north of Canon City in the S½SE¼ sec. 4, T. 18 S., R. 70 W. and along the canyon of Turkey Creek in the SW¼, sec. 7, T. 18 S., R. 66 W. In these localities the disconformity in question cuts across both the Dry Creek Canyon member and the lower sandstone unit, bringing the upper sandstone unit into contact with the Glencairn shale member of the Purgatoire formation. In some places, the cross cutting is abrupt, being complete within a few hundred feet; in other places it is gradual, extending as much as a quarter of a mile before penetrating the lower sandstone unit.

One area that includes most of the large hogback east of Beulah, in the Beulah district, contains an abnormally thick and coarse sequence of the Purgatoire and Dakota formations. Gilbert (1897, p. 3) reports that this sequence is 650 feet thick and consists mostly of sandstone. This is the only area where conglomeratic sandstone was found in the Dakota. This abnormal development of the Dakota was not studied in detail but the conspicuous local thickening and coarsening of the beds suggest a local deltaic deposit. From Beulah eastward, northeastward, and northward, the Dakota thins gradually to its typical thickness.

FOSSILS

Fragmentary plant remains are common throughout the Dakota sandstone, but identifiable remains have been found only at the top and base of the Dry Creek Canyon member. From two small lots collected at these horizons, the plants listed below were identified by Mr. Roland W. Brown of the U. S. Geological Survey. A thorough search would doubtless yield larger collections.

Plants from the basal white sandstone, Dry Creek Canyon member, sec. 26, T. 18 S., R. 67 W., Dry Creek Canyon area.

Anemia fremonti Knowlton, *Gleichenia* sp., and *Sequoia condita* Lesquereux (cones and foliage).

Top of plastic clay zone, Entry 2, Rock Creek mine of the Standard Fire Brick Co. Rock Creek area.

Anemia fremonti Knowlton, *Geinitzia* sp., and *Salix* sp.

Fossil wood was found in many places in the soft sandstone and sandy shale underlying the hard quartzitic sandstone of the upper sandstone unit. The wood occurred as logs, some of which appeared to be water-worn. Most of the wood was too poorly preserved to show cellular structure.

The tubular structures in the quartzitic sandstone in the upper part of the upper sandstone unit are probably borings of some type. Three forms are common: *Scolithus*-like simple vertical tubes less than a quarter of an inch in diameter, large vertical tubes with lamellar filling concave upward, and U-shaped tubes. All types extend from the top of the quartzite bed and to varying depths within the bed.

In the Rock Creek area shale beds in the transition zone at the top of the Dakota sandstone contain Foraminifera. Over 90 percent of the forms recovered from these beds belong to the genus *Globigerina*, a rather paradoxical occurrence of marine fossils in shale that is highly carbonaceous and is overlain by plant-bearing sandstone apparently of terrestrial origin. The microfauna is identical with that found in the lower 40 feet of the overlying Graneros shale.

CHANNEL DEPOSITS WITHIN THE DAKOTA SANDSTONE

The present limited distribution of bodies of refractory clay is a result of periods of subaerial erosion during the deposition of the Dakota sandstone in which most of the Dry Creek Canyon member was removed. The extent of the erosion is suggested by the distribution of known remnants of the Dry Creek Canyon member, shown in figure 8. As large parts of the areas of Dakota outcrop lack exposures of the middle part of the formation and as much of the outcrop was not examined, other remnants of the Dry Creek Canyon member undoubtedly are present. Nevertheless, it is estimated that about four-fifths of the total area where the Dakota is exposed at the surface in eastern Fremont, western Pueblo, and northeastern Huerfano Coun-

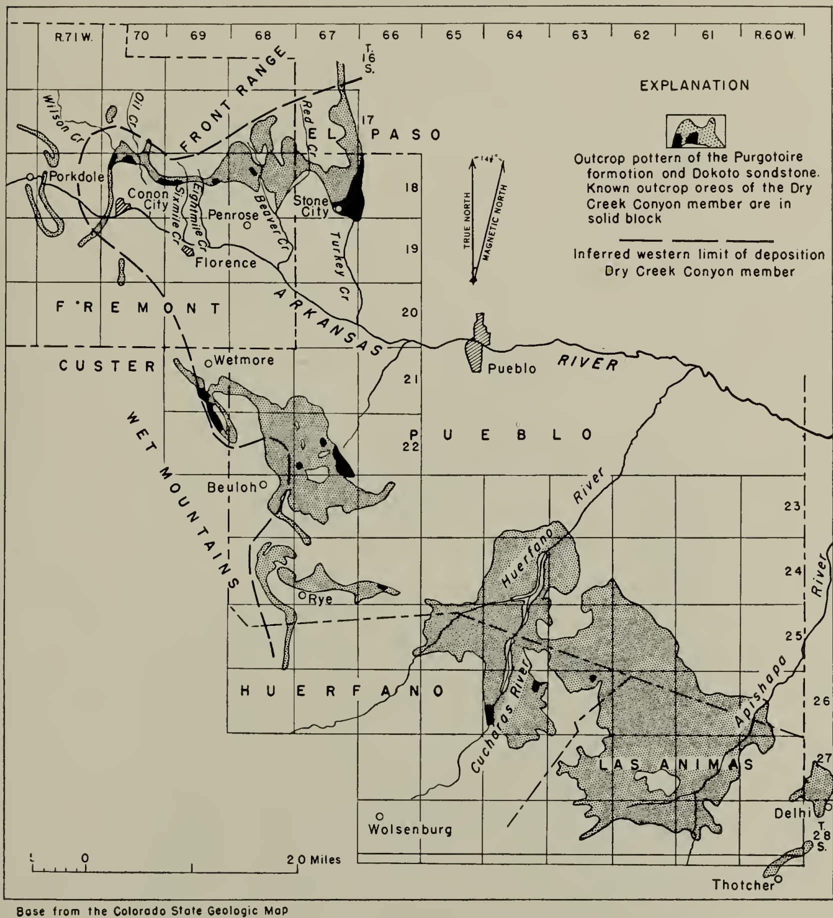

FIGURE 8.—Areal distribution of the Dry Creek Canyon member of the Dakota sandstone in south-central Colorado.

ties lacks the Dry Creek Canyon member. Probably less than one-third of the remaining fifth, where the member is present, contains clay bodies of minable grade and thickness.

The erosion of the Dry Creek Canyon member of the Dakota sandstone was accomplished during two distinct periods of localized channel cutting, one prior to the deposition of the roof-rock sediments and one prior to the deposition of the basal sandstone of the upper sandstone unit. A brief study of the channels and the channel fills was made in some of the clay-mining districts to determine whether the channel fills showed any areal pattern. In general the deposits are too complex and variable to permit interpolation between the few exposures available for study. Only the Turkey Creek district afforded exposures continuous enough to permit mapping and detailed study of the channel-filled sandstones. Plotting of the inferred trend of channel fills in this district has given a rough delineation of clay bodies that serves as a basis for estimating reserves and predicting possible extensions of mine workings. The patterns of channel fills and clay bodies are shown on plates 3 and 4.

KINDS OF CHANNEL DEPOSITS

The two principal kinds of channel deposits in the Dakota sandstone are the roof-rock channel fills and the channel fills of the upper sandstone unit. They are distinct from one another in lithology and each can be recognized without difficulty on the outcrop. Channel deposits of the upper sandstone unit are the most common. These

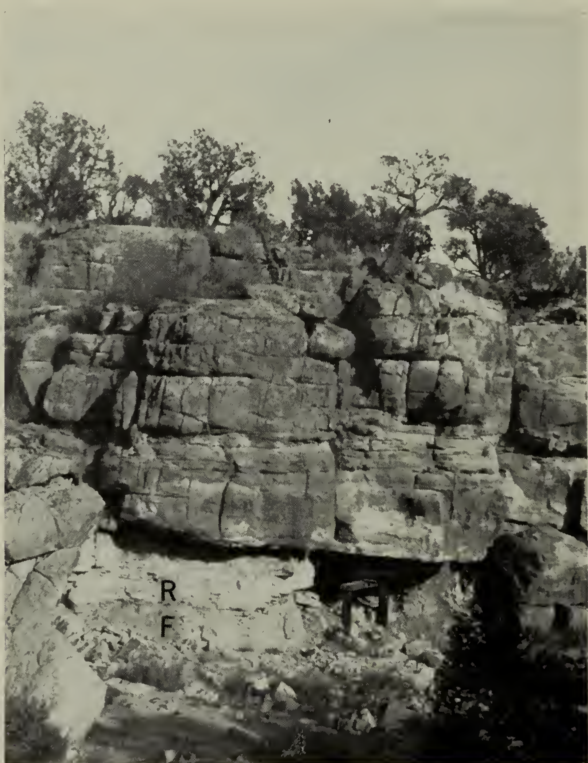

FIGURE 9.—Clay-bearing zone of the Dry Creek Canyon member of the Dakota standstone in Dry Creek Canyon. Roof rock, *R*, rests disconformably on flint clay, *F*.

FIGURE 10.—Seven-foot bed of flint clay of the Dry Creek Canyon member of the Dakota sandstone under a lens of roof-rock sandstone in Dry Creek Canyon. Floor of the entry is sandstone with interstitial flint clay.

occur as fills of single channels, as multiple deposits in many coalescing channels, and as complex channel fills that form the massive sandstone of the uniform phase of the Dakota.

The deposits filling the channels of the first period of erosion after deposition of the clay bed constitute the roof-rock phase of the Dry Creek Canyon member (see p. 16). The roof-rock channel fills are easily distinguished by their content of shale and clay, presumably derived from the underlying clay bed. The sandstone in the fills, also distinctive, is generally fine-grained and occurs either in beds of hard, greenish-buff sandstone with some shaly partings or in beds of softer, light-gray to white sandstone. The relative content of shale, sandy shale, and sandstone in the channel fills is variable. The breadth and depth of incision of individual channels filled by deposits of the roof-rock phase generally cannot be determined because of the removal of most of the deposits by later cutting of the channels in which the fills at the base of the upper sandstone unit were deposited. Complete roof-rock bodies as much as 150 feet in breadth have been found, but the central parts of broader roof-rock channel deposits were removed by superposition of later channels (see p. 16). The gently sloping floors on which the marginal parts of the broader channel fills rest suggest that they were shallow in section. No roof-rock deposits have been found in contact with beds below the upper 10 feet of the lower sandstone unit.

Channel fills of the second period constitute the basal part of the upper sandstone unit of the Dakota sandstone. These fills are entirely of sandstone. The most distinctive characters of the fills are the complete lack of shaly beds and the uniformity of grain size. In most places the fills consist of lenses of medium-grained sandstone with vague to prominent foreset bedding. The weathered color ranges from dark red brown through brown and buff to yellow gray. A less common fill, found locally in single channels between 100 and 400 feet in breadth, consists of even-bedded white and gray sandstone with fine cross lamination.

Individual channel deposits cannot be distinguished in areas where the Dakota is in the uniform phase and appears as a single unit of sandstone. In areas where remnants of the Dry Creek Canyon member are present bodies of channel fill are readily discernible and show considerable range in size and in depth of incision. Channel fills of the upper sandstone unit include single channel deposits that range in size from small, local, canoe-shaped bodies cutting into the Dry Creek Canyon member at high angles to broader bodies 100 to 500 feet in breadth that are continuous for thousands of feet. In many places the single channel deposits are closely spaced and appear to branch and coalesce forming a multiple deposit that cuts up the clay bed of the Dry Creek Canyon member into bodies too small and discontinuous to mine economically.

A third type of deposit consisting of a complex mass of channel fills appears to be an extension of the uniform phase of the Dakota sandstone into the marginal parts of the remnant areas. In some places these complex channel deposits extend well into the remnant areas in broad, elongate bodies, but they are most numerous around the edges of the remnants.

The complex channel deposits of the remnant areas, and also the Dakota sandstone in the uniform phase (see p. 18), occupy channels cut to and into the Glencairn shale member of the Purgatoire formation. The larger single channel deposits and the multiple channel deposits in the remnant areas occupy channels cut into, but not through, the lower sandstone unit. The smaller single channel deposits occupy channels cut to varying depths within the Dry Creek Canyon member.

INTERPRETATION

The stages in the formation of the channel deposits are shown diagrammatically in figure 11. The extent of erosion prior to deposi-

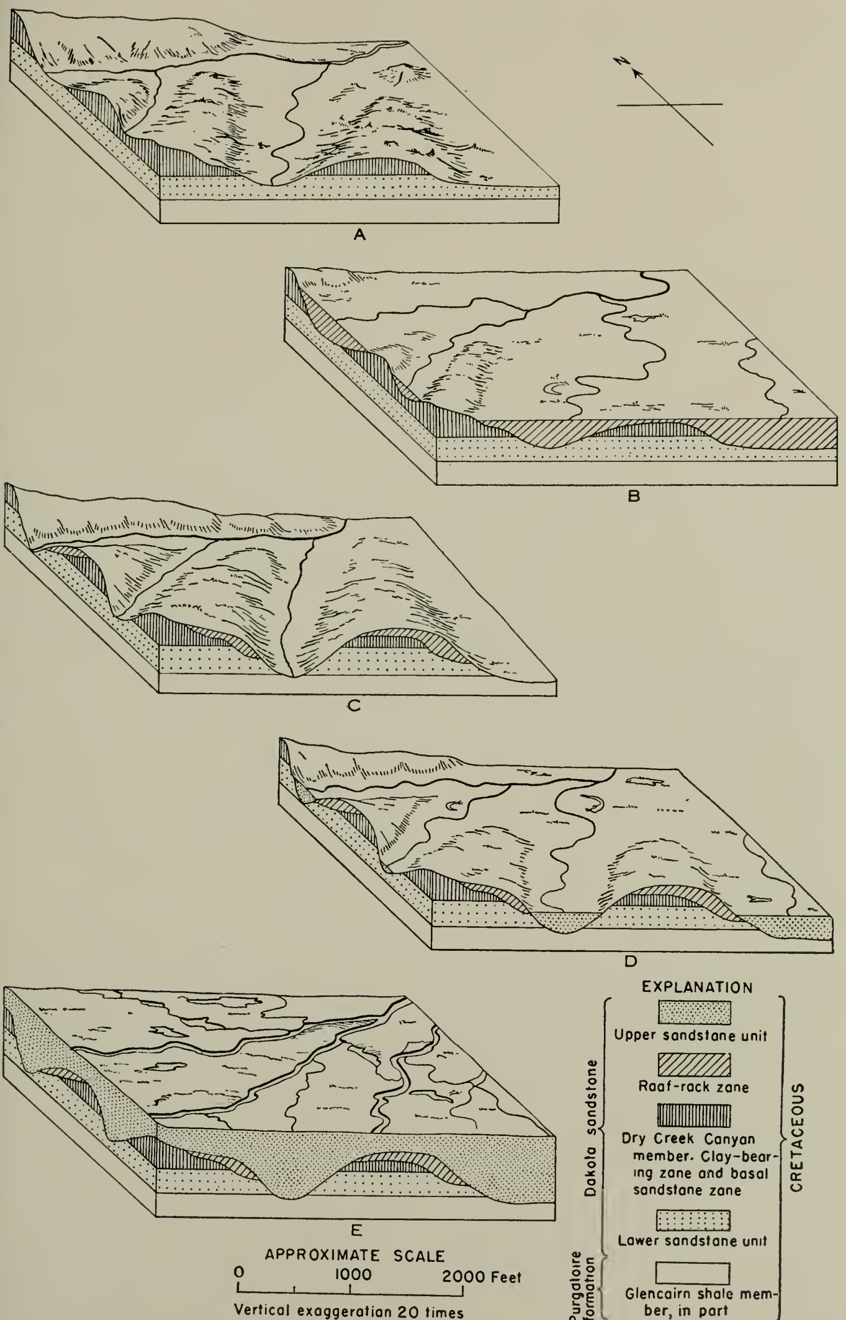

FIGURE 11.—Stages in the development of channel deposits in the Dakota sandstone.

tion of the roof-rock channel fills is not known. The presence of remnants of these fills along the edges of channel deposits of the upper sandstone unit suggest that the erosion was extensive and probably reduced the Dry Creek Canyon sediments to remnants along the divides between the main drainage courses. The depth of the first stage of erosion is also unknown, but the lack of any roof-rock sediment in contact with beds below the upper part of the lower sandstone unit suggest that the larger drainage courses reached a base level within this unit and did not penetrate the Dakota.

The second period of channeling began after the channels of the first period had been at least partially filled with roof-rock sediment by aggrading streams. Evidence of the persistence of drainage channels from the first to the second period probably indicates that aggradation of the roof-rock channels was not completed before the second period of down cutting was initiated. Channels of the second period cut to a deeper base level, the major drainage channels reaching and cutting laterally in the uppermost part of the Glencairn shale member of the Purgatoire formation while tributary channels cut to shallower depths in the remnant areas. Erosion removed most of the roof-rock fill and reduced the remnants of the Dry Creek Canyon member to their present size and distribution. Rapid aggradation probably prevented the complete removal of the remnants by streams cutting laterally. The sand deposited to form the basal bed of the upper sandstone unit filled the concavities that had been cut in the underlying beds and covered the remnants of the Dry Creek Canyon member. The intricate pattern of lenses of cross-laminated sandstone in the upper sandstone unit are suggestive of deposits in anastomosing drainage ways typical of the distributary patterns of drainage found on deltas.

The direction of drainage during the formation of the channel deposits is obscure. In the Turkey Creek district the single and multiple channel deposits trend roughly to the northeast although their courses are irregular. No evidence as to direction of flow is conclusive. In the Beulah district the drainage appears to have been to the east and northeast outward from the local deltaic deposit.

CORRELATION AND AGE OF THE PURGATOIRE AND DAKOTA FORMATIONS

CORRELATION WITH NORTHEASTERN COLORADO

Subdivision of the Dakota sandstone in the Fremont-Pueblo County area into the Dry Creek Canyon member and informal units of sandstone above and below it adds two units to the originally tripartite sequence of Purgatoire and Dakota strata. As a result local sections of the sequence show five units; three units of sandstone separated by two shaly units. To prevent confusion of this sequence with the five units of the Dakota group of northeastern Colorado, it is considered advisable to reiterate what is known of the correlation of beds between the two areas.

The Purgatoire and Dakota formations have been recognized as divisions of the pre-Benton Cretaceous strata only as far north along the Front Range as Perry Park, Douglas County, where Richardson (1915) employed these formation names in his description of the geology of the Castle Rock quadrangle. North of Perry Park the pre-Benton Cretaceous beds are generally called the Dakota group (Lee, 1923) and five units recognized within it are informally designated the lower sandstone, lower shale, middle sandstone, middle shale, and upper sandstone. The most significant features of this section are the presence of the presumed Washita fauna in the middle shale unit (Reeside, 1922) and the character of the lower shale unit which locally is said to consist of variegated shale. It is the lower shale unit that complicates correlation with the Purgatoire and Dakota sequence in southeastern Colorado as no similar unit has as yet been reported from that area.

According to Lee (1927, pp. 20–21), who has described in detail the changes that take place in the pre-Benton Cretaceous beds from central Colorado northward into Wyoming, the variegated lower shale of the Dakota group thins southward and eventually lenses out within the sandstones of the Lytle member of the Purgatoire formation. Lee correlates the Lytle member of southeastern Colorado with the lower sandstone, lower shale, and middle sandstone of the Dakota group. The middle shale and upper sandstone he correlates with the Glencairn shale member of the Purgatoire and the Dakota sandstone respectively.

Preliminary results of a study, now in progress, of the clay-bearing Dakota group in the Denver basin are at variance with some of Lee's correlations. The lower sandstone and lower (variegated) shale are doubtless equivalent to the Lytle sandstone member of the Purgatoire formation but the shale is interbedded with the sandstone and does not occur in a fixed position relative to it, thus it cannot be mapped as a distinct unit. The middle sandstone in northeastern Colorado is a considerably thickened lateral equivalent of the lower of the three sandstone units of the Glencairn shale member of the Purgatoire. This correlation of the middle sandstone is based on its position above the disconformity between the Lytle and Glencairn members, a marked stratigraphic break that has now been traced throughout northeastern Colorado. The upper sandstone is equivalent to the Dakota sandstone and its subdivisions in the Canon City embayment area. No equivalent of the Dry Creek Canyon member has been recognized in northeastern Colorado.

AGE RELATIONSHIPS

The Early Cretaceous fossils found in the Glencairn shale member of the Purgatoire formation and its equivalents have for many years been the only direct faunal evidence as to the age of the Purgatoire and Dakota beds. The recognition of this fauna as being Washita (Stanton, in Darton, 1905) in age instigated the separation of the Purgatoire formation from the original "Dakota sandstone," which was accepted by many geolgists as Late Cretaceous in age on the basis of fossil plants. The Purgatoire fauna is a sparse one in south-central Colorado. The locality Two Buttes, in Prowers County, where this fauna was collected by Darton (1905, p. 120) and later augmented by Stanton (1905, p. 663) and others, is the nearest locality to the type Purgatoire that has yielded diagnositc Early Cretaceous fossils. Here *Gryphaea corrugata* and *Pachydiscus brazoensis* have been found. Neither of these fossils has been reported from any part of the western interior to the west or northwest of the Two Buttes locality. Stanton (1905, p. 665) and, later, Reeside (1922, p. 200) stressed the marked change in the Purgatoire fauna, northwestward from Two Buttes and areas to the south in Oklahoma and New Mexico, brought about by the progressive disappearance of diagnostic species.

Fossils recorded from the shale in the Purgatoire formation in south-central Colorado, while not diagnostic in themselves, are found in association with the diagnostic fossils at Two Buttes and other localities in western Oklahoma and northeastern New Mexico. The Purgatoire formation and its equivalents along the Rocky Mountain front in Colorado have thus generally been considered to be Washita in age (Reeside, 1922, p. 200). Collections of microfossils from the Purgatoire of the Canon City embayment have elements in common with the microfauna of the Lower Cretaceous Kiowa shale of Kansas described by Loeblich and Tappan (1950, pp. 1–15), although the assemblage is considerably less varied.

The Dakota sandstone of south-central and southeastern Colorado has been considered to be Late Cretaceous by most geologists. Positive evidence as to the age of the Dakota of this area and its equivalents in adjacent areas (Upper sandstone of the Dakota group in northeastern Colorado; Muddy sandstone member of Thermopolis shale of central and southeastern Wyoming; Newcastle sandstone of the Black Hills region) was lacking until 1951 when faunal evidence indicating an Early Cretaceous age for the Dakota was forthcoming from two different sources. Crowley (1951, pp. 83–90) announced the occurrence of an Early Cretaceous microfauna in the Newcastle sandstone of the Black Hills region, and Cobban and Reeside (1951, pp. 1892–1893) announced the recognition of the Early Cretaceous *Gastroplites* and *Neogastroplites* faunas, hitherto known only from the Lower Cretaceous rocks of Canada, in the Mowry shale and equivalent strata in Montana, Wyoming and northwestern Colorado. Both of these discoveries are in areas remote from south-central Colorado and although it is conceivable that the Dakota sandstone of this area is younger than the Newcastle sandstone it is not likely that it is younger than the Mowry shale. The Mowry has not been recognized as a lithologic unit south of Larimer County in Colorado and the characteristic siliceous shale of this formation is not present in the Graneros shale of south-central Colorado. However, the first fossils of undoubted Late Cretaceous age encountered in the Graneros shale are about 60 feet above the base of the formation and the shale in this 60-foot interval, while not siliceous, differs from the overlying shale in being harder, darker in color, and generally not calcareous. Other than fish scales and undiagnostic Foraminifera no fossils have been found in the lower part of the Graneros and the possibility remains that it is a facies of the Mowry. In summary, the entire sequence of Purgatoire and Dakota strata in south-central Colorado is probably Lower Cretaceous although positive evidence to support this has not been found in this area.

REFRACTORY CLAY DEPOSITS

DEFINITION AND CLASSIFICATION

The term refractory clay is applied to clays that possess to an extraordinary degree the ability to withstand high temperatures without melting. The term "fire clay," often employed in the same sense, is objectionable because it is commonly misapplied to any clay underlying a coal bed regardless of whether or not the clay possesses refractoriness. This property depends primarily on the chemical composition of the clay and secondarily on its texture.

Classification of refractory clays is based on the approximate temperatures at which they fuse. The fusion point of a clay is generally determined by preparing a small cone from a ground sample and firing it along with a graded series of test cones whose fusion points are known. The classification employed in this report, modified from that of Ries (Ries, Kummel, and Knapp, 1904, p. 100), is as follows:

Classification of refractory clays

Grade category	Range in fusion points	Approximate temperature range
High-grade refractory clay	Cone 30 and above	over 1650 C.
Semirefractory clay	Cones 27 to 29	1605 C–1650 C.
Low-grade refractory clay	Cones 20 to 26	1530 C–1605 C.

Where data on actual cone of fusion or burning properties are not available, determination of whether or not the clay sampled in the course of the field work is refractory clay may be based on chemical analyses. In general all clay of fine texture, low in fusible impurities, and containing a relatively high percentage of Al_2O_3 can be classed as refractory clay.

CLAY OF GLENCAIRN SHALE MEMBER OF THE PURGATOIRE FORMATION

The clay deposits of the Glencairn shale member occur as tabular lenses at or near the top of the member. The individual clay bodies range in size from small lenses a few inches thick and 3 or 4 square feet in area to large deposits from 5 to 20 feet thick occupying several hundred acres. The margins of the clay bodies are irregular and generally are marked by outward gradation of the clay into shale and sandy shale with thin interbedded deposits of platy sandstone. In some places intercalation of hard sandstone beds has broken and thinned the clay bodies to an extent that would make mining them uneconomical. At a few localities channels filled with sandstone of the overlying Dakota sandstone are incised into the upper part of the Glencairn member but do not appear to have restricted the areal distribution of any of the known clay bodies.

The clay of the Glencairn shale member of the Purgatoire formation is bluish black to light blue gray, tough plastic clay of relatively low refractoriness. On fresh cuts it is generally massive and has a rough, irregular, blocky fracture. The greatest variation in the clay occurs around the margins of the clay bodies where shaly, silty, and sandy clay is common. Lenses and pockets of these rocks are also present within some of the clay bodies. The clay bed commonly grades downward into a sandy clay which in turn grades downward into sandstone or sandy shale. In some places the top of the bed is in sharp contact with the basal sandstone of the Dakota; in other places it is separated from the Dakota by a zone of shale or sandy shale.

Analyses furnished by the companies producing clay in Fremont and Pueblo Counties show that the chemical composition of the minable clays of the Glencairn member is fairly constant; the range in composition is given in the following table. Normally the ratio of silica to alumina is about 3 : 1, and the ferric oxide plus other fusible impurities amounts to less than 5 percent of the total. Where impure clay is present in the Glencairn the impurities, which include sand, limonite, gypsum, and carbonaceous matter, are generally visible. The content of total alumina averages about 23 percent, and the highest content for the samples analyzed, 28 percent, is probably too low to encourage use of these clays as low-grade sources of metallic aluminum.

Range in composition of the clay of the Glencairn shale member of the Purgatoire formation in eastern Fremont and western Pueblo Counties, Colo.

[Analyses furnished by Standard Fire Brick Co. of Pueblo and the Diamond Fire Brick Co. of Canon City, Colo.]

	Percent		Percent
SiO_2	56 –68	CaO	Trace— 0.6
Al_2O_3	19.5–28	MgO	0.2– 1.0
Fe_2O_3	.5– 2.5	Loss by ignition	9.5–12.5

The clay of the Glencairn shale member utilized by the local fire brick companies is a low-grade refractory to semirefractory clay that burns to a light cream color. The clay is commonly used in a mix with refractory flint clay (from the Dry Creek Canyon member of the Dakota sandstone) for manufacturing various refractory products. It is also used alone for manufacture of the lower grades of refractory bricks, terra cotta, conduits, and other products.

CLAY OF THE DRY CREEK CANYON MEMBER OF THE DAKOTA SANDSTONE

CHARACTER OF THE CLAY

The most valuable clay deposits in southeastern Colorado occur in a zone of the Dry Creek Canyon member. The clay-bearing zone consists of an upper bed of plastic and semiplastic clay separated by a sharp contact from a lower bed of flint clay. The flint clay is a high-alumina, white- to buff-burning refractory clay and is fairly constant in character throughout the area. The upper bed is the more variable of the two and locally includes several types of plastic clay and sandy clay. A light blue-gray to black plastic clay is the most common type in the plastic clay bed and generally constitutes its entire thickness. A second clay type that is fairly hard, jet black and semiplastic occurs locally between the plastic and the flint clay beds. These two types are referred to in the present report as the plastic and semiplastic clays, respectively. They are of better grade than the clay of the Glencairn shale member of the Purgatoire formation being white- to buff-burning, semirefractory to refractory with a total alumina content ranging from 27 to 33 percent. A thin bed of yellow to gray plastic clay, herein called the "marker bed," occurs at the top of the black semiplastic clay.

FLINT CLAY

The flint clay of the Dry Creek Canyon member is a hard, light-gray to light blue-gray, fine-grained clay with a conchoidal to semiconchoidal fracture (fig. 12). On the outcrop it breaks down into small, smooth, shell-like fragments. Within the mines it can be removed from the face in large blocks. Much of it has a soapy feel on fresh surfaces and is locally referred to as "soapstone."

Run-of-mine flint clay from the Dry Creek Canyon member averages 35 percent or more in alumina and meets the minimum requirements established by the U. S. Bureau of Mines for the alumina content of clays that might serve as sources of metallic aluminum. Its economic importance, however, stems primarily from its use as a high-grade refractory clay. It burns white, fuses between cones 31 and 36, and is used in the manufacture of high-grade refractory products.

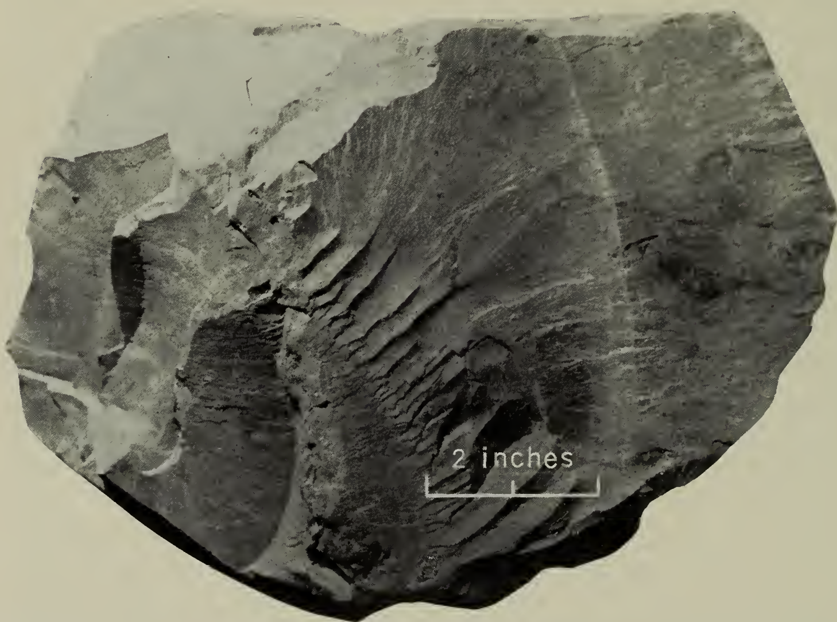

FIGURE 12.—Flint clay from the Dry Creek Canyon member of the Dakota sandstone.

The chemical composition of the flint clay in the Dry Creek Canyon member is fairly constant. The only major variation in composition is in the relative content of silica and alumina. Fusible impurities in the clay average less than 5 percent of the total composition in both sandy and nonsandy flint clay. None of the flint clay contained sufficient quantity of fusible impurities to affect its grade measurably. Selected analyses of samples of typical flint clay are given in the following table. The first four analyses are of relatively nonsandy flint clay, the fifth is of a sandy flint clay, and the sixth is of the entire flint clay bed and includes the very sandy clay at the base.

Representative analyses of flint clay from the Dry Creek Canyon member of Dakota sandstone

	1	2	3	4	5	6
Silica (SiO_2)	47.77	45.49	48.48	48.72	51.00	53.03
Alumina (Al_2O_3)	35.21	36.35	35.12	35.31	31.26	30.74
Ferric oxide (Fe_2O_3)	.55	1.03	1.53	.37	1.71	.77
Titania (TiO_2)	1.32	1.27	.51	.72	.79	1.08
Lime (CaO)	.60	.44	.35	None	.21	.43
Magnesia (MgO)	.39	.02	.18	.02	.16	.47
Loss by ignition	14.58	15.02	13.96	14.64	13.27	13.54
Total	100.42	99.62	100.13	99.78	98.40	100.06

1. Nellie Helen mine, Turkey Creek district. Flint clay at entry. Analysis by Mellon Inst., Pittsburgh, Pa.
2. Standard Fire Brick Co. mine, entry 1, Rock Creek area. Upper 1½ feet of flint clay bed. N. Davidson, U. S. Geol. Survey, analyst.
3. Laclede Christy Co., Deer Hill mine, Wilson Creek area, Canon City district. Spot sample of clean flint clay. N. Davidson, U. S. Geol. Survey, analyst.
4. Sample locality 7, prospect 1, Turkey Creek district. Channel sample of 4½ feet of exposed flint clay. S. H. Cress, U. S. Geol. Survey, analyst.
5. Location same as 3. Sandy flint clay. N. Davidson, U. S. Geol. Survey, analyst.
6. Dry Creek Canyon mine of Pueblo Clay Products Co. Turkey Creek district. Channel sample from top of flint clay to floor of mine at entry. W. W. Brannock, U. S. Geol. Survey, analyst.

The only significant change in grade of the flint clay is brought about by the increase of its silica content at the expense of the alumina. This coincides with an observable increase of free silica in the form of quartz grains. Thus a rough approximation of the grade can be made from an examination of the flint clay with a hand lens. The variation, shown in the following table, in the composition of flint clay that appears to be free of sand or shows very few scattered sand grains is typical.

Range in composition of nonsandy flint clay from the Dry Creek Canyon member of the Dakota sandstone

	Average	Minimum	Maximum	No. of analyses
RANGE IN CONTENT OF SILICA AND ALUMINA				
Silica (SiO_2)	48.73	44.25	51.00	[1] 51
Alumina (Al_2O_3)	35.69	33.51	39.40	[1] 51
RANGES IN CONTENT OF FLUXIBLE IMPURITIES AND TiO_2				
Ferric oxide (Fe_2O_3)	1.02	0.16	2.87	62
Titania (TiO_2)	1.00	.50	1.39	33
Lime (CaO)	.23	None	.72	37
Magnesia (MgO)	.20	None	.73	39

[1] Flint clay from all areas.

Although sandy flint clay locally occurs in different parts of the flint clay bed it is typical only of the basal portion where it constitutes a zone of transition between the flint clay and the sandstone at the base of the Dry Creek Canyon member. This sandy transition zone, which varies in thickness, determines the lower limit of minable clay.

In the table that follows partial analyses of samples of successive portions of the flint clay bed illustrate the change in grade from top to bottom of the bed brought about by the increase in sand. In most places the change involves a gradual increase downward in the amount of sand; in other places the sandy zone consists of alternating sandy and less sandy layers, or is split into an upper and lower part by a thin bed of good flint clay.

Variation in silica and alumina content of successive parts of the flint clay bed shown by two series of samples

[Samples from the Rock Creek mines of the Standard Fire Brick Co.]

Entry 1 [1]				Entry 2 [2]			
Zone [3]	SiO_2	Al_2O_3	Sample interval in feet	Zone	SiO_2	Al_2O_3	Sample interval in feet
A	44.25	35.81	0–1.5	A	48.6	39.4	0–3.5
B	47.43	33.51	1.5–2.5	B	49.0	35.0	3.5–4.5
C	58.84	25.94	2.5–3.5	C	64.1	26.8	4.5–6.5
C	60.62	24.35	3.5–5.5	D	77.0	16.0	6.5–7
D	71.17	15.97	5.5–6				

[1] From analyses by N. Davidson, U. S. Geol. Survey
[2] From analyses by Colorado Fuel & Iron Co.
[3] Zones within the flint clay bed (in descending order)
A Flint clay
B Flint clay, slightly sandy
C Sandy flint clay
D Sandstone, with flint clay matrix

In addition to the persistent sandy zone at the base of the flint clay bed, sand occurs locally in the clay as scattered grains, or as concentrations in the form of blebs and small lenses. In certain areas the entire flint clay bed grades laterally into sandy, impure flint clay. Two types of lateral gradation are recognizable. In the first the nonsandy portion of the clay bed becomes more and more sandy laterally to a point beyond which the entire flint clay interval is sandy. The change is generally accompanied by a gradual thinning of the flint clay bed. This type of gradation occurs locally in all of the clay districts.

The second type of gradation is a relatively sudden appearance of sandy zones and dirty clay zones in the flint clay bed. The entire flint clay interval commonly consists of sandy, impure flint clay or mixed clay types including fragmental flint clay. The change in the clay-bearing zone of the Dry Creek Canyon member between the Diamond Flint mine and the Deer Hill mine in the Wilson Creek area of the Canon City district (see p. 82) is illustrative of this type of lateral gradation that seems to occur in areas peripheral to the known limits of the member.

Carbonaceous matter is commonly present in the uppermost part of the flint clay bed where plant fragments are sparsely scattered through the clay. Locally the persistent sandy zone at the base of the flint clay is also carbonaceous, but the carbon appears to be of bituminous character and is concentrated enough to give the sandy clay a dirty black color.

Subordinate types of flint clay are present locally and appear to result from the mixture of sand, carbonaceous matter, and impure clay substances with the typical light gray flint clay. None of these impure flint clays is distinctive enough in character to be considered as a separate type; generally one grades into another and into good flint clay.

Fragmental flint clay was found only in the Wilson Creek area where it occurs in lenses in the flint clay bed of the Diamond Flint mine and the Deer Hill mine. Flint clay of several colors, ranging from relatively pure to siliceous clay, occurs as fragments in a matrix of somewhat silty gray flint clay. The most conspicuous fragments are subangular pellets of hard, light-gray to white, porceleanous clay. Thin beds of this clay type occur in the clay bed of the Deer Hill mine (see p. 82) which is located less than a mile to the north across the canyon of Wilson Creek.

SEMIPLASTIC CLAY

The semiplastic clay is a black, fairly hard, dense, clay with a splintery to poorly developed conchoidal fracture. It forms thin lenticular bodies that are locally present between the flint clay and plastic clay of the Dry Creek Canyon member of the Dakota sandstone, and its volume is consistently less than that of either the flint clay or plastic clay. The semiplastic clay is most common in the Stone City area of the Turkey Creek district; it also is present locally elsewhere in Turkey Creek district, in the Penrose district, and in the Rock Creek area of the Beulah district. Clay miners in the area call this clay the "black flint" clay. The carbonaceous matter responsible for the jet black color of the semiplastic clay may be, in part, bituminous in character. Locally the content of carbonaceous matter is so high that the rock can be called a bone coal.

The semiplastic clay is similar to the plastic clay in composition although locally it has a slightly higher content of alumina. As this does not exceed 34 percent, the clay does not qualify as a potential source of alumina. Analyses of semiplastic clay are given in the following table. As a refractory clay the semiplastic clay is similar in its fusion properties to the plastic clay but is a less desirable clay because of its carbon content. Special firing is necessary in burning the raw semiplastic clay to prevent its showing a black core when removed from the kiln.

Representative analyses of black semiplastic clay from the Dry Creek Canyon member of the Dakota sandstone

	Sample 1	Sample 2
Silica (SiO_2)	51. 02	50. 27
Alumina (Al_2O_3)	33. 32	27. 61
Ferric oxide (Fe_2O_3)	. 06	1. 36
Titania (TiO_2)	1. 00	. 95
Lime (CaO)	None	. 71
Magnesia (MgO)	Tr.	. 70
Loss by ignition	14. 50	17. 87
Total	99. 90	99. 47

1. Dry Creek Canyon mine of Pueblo Clay Products Co., Turkey Creek district. Analysis of composite sample from several localities within mine. Colorado Fuel & Iron Co., analyst.
2. Same locality as sample 1. From mouth of south entry east wall of canyon. W. W. Brannock, U. S. Geol. Survey, analyst.

CLAY OF THE MARKER CLAY BED

A thin bed of clay rarely exceeding 4 inches in thickness overlies the black semiplastic clay. It is of no known economic value but is a distinctive unit whose presence is generally indicative of certain grade changes within the clay bed. For want of a more satisfactory descriptive name this bed is called the "marker" clay bed.

The marker clay bed consists of yellowish-green to gray plastic clay that has many of the physical characteristics of a bentonite. It weathers to a crusty yellow-white mass on the outcrop, and in the fresh state it more than doubles its volume when immersed in water. Petrographic examination of the clay was made by V. T. Allen of the Geological Survey who reports (1944, written communication) that

> The appearance and properties of * * * (the Marker clay bed) * * * resemble those of some bentonites. In thin section relict volcanic textures are absent so that this clay cannot be properly called bentonite. It is composed of a mixture of kaolinite, beidellite, quartz and organic matter. The kaolinite forms books and worm-like masses 0.1 to 0.3 mm. long. Some of the layers of kaolinite arranged as books include some plates that are pleochroic and have high birefringence suggesting the derivation of this kaolinite from biotite.

Where the underlying black semiplastic clay is absent the marker bed is generally absent also. In a few places the marker bed rests on the flint clay, but this relationship appears to be limited to areas immediately adjacent to semiplastic clay bodies where the marker bed has a slightly greater lateral extent than the semiplastic clay beneath it.

PLASTIC CLAY

The plastic clay varies in color from light gray and blue gray to black. Generally it has a massive to blocky structure, becoming shaly at the top of the bed or where the clay is sandy. It is compact and tough and breaks with a splintery to rough blocky fracture (fig. 13). Commonly it contains considerable carbonaceous matter which is disseminated in fine particles in the darker-colored clay. In the lighter-colored clay carbonaceous matter occurs as plant fragments ranging in size from small particles to entire leaves. Some carbon of bituminous character may be present in the black plastic clay but, if so, it is probably a minor constituent.

The principal variations in the plastic clay are those brought about by differences in the amount and local concentration of visible impurities such as sand and carbonaceous matter. In most places the upper, light-colored part of the plastic clay bed is sandy, somewhat shaly and contains plant fragments. This clay slakes rapidly in water

FIGURE 13.—Plastic clay from the Dry Creek Canyon member of the Dakota sandstone.

but shows little plasticity. The darker plastic clay below is rarely sandy and slakes rapidly to form a sticky, plastic mass. A minor variation in the type of plastic clay is found locally in the Dry Creek Canyon mines in the Turkey Creek district. Here thin beds of a hard, soapy, light-blue plastic clay, approaching a semiflint clay in character, are interbedded with the typical plastic clay.

Chemical analyses show that the plastic clay is low in fusible impurities and possesses a relatively high alumina content for plastic clays of its type. However, none of the clay is sufficiently high in alumina to qualify as a good low-grade ore of metallic aluminum. Only rarely does it attain a total alumina content as high as 32 percent.

The normal average alumina content for the best nonsandy types of plastic clay is between 29 and 30 percent. The darker clay is generally of better grade because it is less sandy than the lighter-colored clays. Selected analyses of the plastic clay are given below.

Representative analyses of plastic clay from the Dry Creek Canyon member of the Dakota sandstone

	1	2	3	4
Silica (SiO_2)	50.79	52.31	53.77	54.7
Alumina (Al_2O_3)	30.46	31.24	28.30	30.7
Ferric oxide (Fe_2O_3)	2.30	.64	1.83	
Titania (TiO_2)	.75	.88	.80	
Lime (CaO)	.36	None	.50	
Magnesia (MgO)	.92	.30	.70	
Loss by ignition	13.82	13.77	13.33	
Total	99.50	99.14	99.23	

1. Average analysis of raw plastic clay shipped during 1933 from Dry Creek Canyon mine of Pueblo Clay Products Co., Stone City area, Turkey Creek district. Colorado Fuel & Iron Co., analyst.
2. Three feet of plastic clay overlying flint clay; sample locality 5, prospect 7, Turkey Creek Canyon, Turkey Creek district, S. H. Cress, U. S. Geol. Survey, analyst.
3. Dry Creek Canyon mine, Pueblo Clay Products Co., near south entry, east wall of canyon, W. W. Brannock, U. S. Geol. Survey, analyst.
4. Average of four partial analyses of plastic clay from Rock Creek mines of Standard Fire Brick Co., Colorado Fuel & Iron Co., analyst.

The plastic clay of the Dry Creek Canyon member of the Dakota sandstone is refractory clay of better grade than the plastic clay in the Glencairn shale member of the Purgatoire formation. The fusion point averages about cone 29 and commonly tests as high as cone 31 for individual samples. Thus it generally qualifies as a good semirefractory clay and locally reaches refractory grade. It is chiefly a white-burning clay and rarely shows development of black cores on firing.

MINERALOGIC COMPOSITION OF THE FLINT AND PLASTIC CLAYS

A brief study of several thin sections of the clay from the Dry Creek Canyon member was made by V. T. Allen of the Geological Survey. He reports (1944, written communication,) that the clays of the Dry Creek Canyon member

> are composed principally of kaolinite. In the flint clays the kaolinite is fine grained. In the plastic clays some of the kaolinite is present as plates, books, and worm-like masses which may reach 0.1 to 0.2 mm. in length. The chief impurities are: quartz in grains from 0.004 to 0.05 mm., muscovite, up to 0.05 mm. in length, and minor amounts of nontronite and organic matter.

The predominance of kaolinite in the flint clay of the Dry Creek Canyon member is also indicated by the similarity in composition of the clay to the theoretical composition of kaolinite, shown in the following table.

Composition of flint clay from the Dry Creek Canyon member of the Dakota sandstone compared with the theoretical composition of kaolinite

	1	2
Silica (SiO_2)	46.5	46.83
Alumina (Al_2O_3)	39.5	37.42
Ferric oxide (Fe_2O_3)	-----	0.58
Titania (TiO_2)	-----	0.86
Lime (CaO)	-----	------
Magnesia (MgO)	-----	------
Loss by ignition	14.0	14.51
Total	100.0	100.20

1. Kaolinite, theoretical composition according to formula, $Al_2O_3.2SiO_2.2H_2O$.
2. Flint clay, Dry Creek Canyon member of the Dakota sandstone, Turkey Creek district, Pueblo County, Colo. S. H. Cress, U. S. Geol. Survey, analyst.

PROPERTIES OF THE CLAY TYPES

Fourteen samples of clay taken from the Dry Creek Canyon member of the Dakota sandstone at different localities were submitted for testing to the Raw Materials Branch, Industrial Minerals Division, of the U. S. Bureau of Mines. The clay samples were tested under the direction of T. A. Klinefelter, chief of the Raw Materials Branch, whose report on the tests is paraphrased below. The results of the tests are given in tables 1 through 6; the location of the samples tested and a chemical analysis of each is given on pp. 95–101. The fusion points or pyrometric cone equivalents (P. C. E.) of the samples are appended to table 6.

All of the samples have fusion points above cone 30 and qualify as high-grade refractory clays. Eleven samples have fusion points over cone 33 and rate as "super heat duty" clay, according to industrial classification, whereas the remaining samples, fusing at cones 31 and 32 rate as "high heat duty" clays.

The characteristics of all samples, both in the raw state and after heat treatments at 1,800 F, 2,000 F, 2,200 F, 2,300 F, and 2,400 F, show that the clays undergo slow uniform changes and withstand a great temperature range. All of the samples could be tested several cones higher with little or no change. Only two samples, 8 and 25, show any real indications of vitreous structure.

Shrinkages, in both the dry and fired states, are all about average. The figures for water of plasticity, shown in table 1, indicate that none of the samples are very plastic.

None of the samples showed cracking under fairly rapid drying conditions. The samples did not include any of the bentonitelike clay of the marker bed, a potential cause of defects on drying, but it is not likely that the small quantity of marker clay bed mined in proportion to the other clay types would be sufficient to affect the run-of-mine product.

TABLE 1.—*Properties of the clays of the Dry Creek Canyon member of the Dakota sandstone in the raw state*

Sample	Location by area	Clay type	Color	Water of plasticity	Percent dry shrinkage	Dry defects [1]	Plastic working qualities
8	Stone City.	Plastic.	Gray.	25	5	None.	Very smooth.
80	Hell Canyon.	do	Dark gray.	21	5	do	Fairly smooth.
81	do	do	do	18	4	do	Short.
25	Rock Creek.	do	do	22	5	do	Smooth and sticky.
9	Stone City.	Black semiplastic.	Black.	23	5	do	Fairly smooth.
12	do	Flint.	Light gray.	20	5	do	Short.
13	do	do	do	21	4	do	Very short.
71	Hell Canyon.	do	Gray.	19	5	do	Short.
72	do	do	Light gray.	19	5	do	Do.
75	do	do	Gray.	19	5	do	Do.
76	do	do	do	20	5	do	Do.
34	Rock Creek.	do	do	20	5	do	Do.
64	Wilson Creek.	do	do	19	5	do	Fairly smooth.
86	Cucharas Canyon.	do	do	21	4	do	Short.

[1] None of the samples showed defects on drying.

TABLE 2.—*Characteristics of the clays, Dry Creek Canyon member, Dakota sandstone, when treated by heat at* 1,800 F (*about cone* 07)

Sample	Clay type	Color	Hardness	Porosity	Percent shrinkage
8	Plastic.	Pinkish.	Scratches.	Porous.	7.5
80	do	do	Fairly hard.	Very porous.	9.5
81	do	do	Scratches.	do	7.5
25	do	do	do	do	6.0
9	Black semiplastic.	do	do	do	7.5
12	Flint.	do	do	do	7.5
13	do	do	Soft.	do	5.0
71	do	Light buff.	Soft, crumbly.	do	5.0
72	do	Pinkish.	do	do	6.0
75	do	do	do	do	7.5
76	do	do	Soft.	do	7.5
34	do	Light buff.	Scratches.	do	5.0
64	do	do	do	do	6.0
86	do	Pinkish.	Soft.	do	4.0

TABLE 3.—*Characteristics of the clays of the Dry Creek Canyon member of the Dakota sandstone when treated by heat at* 2,000 F (*about cone* 04½)

Sample	Clay type	Color	Hardness	Porosity	Percent shrinkage
8	Plastic.	Pinkish.	Scratches.	Porous.	12.5
80	do	do	Hard.	Very porous.	9.5
81	do	Light gray.	Scratches.	do	8.0
25	do	Pinkish.	do	do	6.0
9	Black semiplastic.	do	do	do	8.0
12	Flint.	do	do	do	7.5
13	do	do	Soft.	do	7.0
71	do	Light buff.	Soft, crumbly.	do	5.0
72	do	do	do	do	7.0
75	do	Pinkish.	do	do	9.0
76	do	Light gray.	Scratches.	do	7.5
34	do	Light buff.	do	do	7.5
64	do	do	do	do	7.5
86	do	Pinkish.	Soft.	do	6.0

TABLE 4.—*Characteristics of the clays of the Dry Creek Canyon member of the Dakota sandstone when treated by heat at* 2,200 F (*cone* 5)

Sample	Clay type	Color	Hardness	Porosity	Percent shrinkage
8	Plastic.	Light gray.	Steel hard.	Porous.	12.5
80	do	Light buff.	Hard.	Very porous.	12.5
81	do	Light gray.	Scratches.	do	10.0
25	do	do	do	do	9.0
9	Black Semiplastic.	Gray.	do	do	9.0
12	Flint.	Light gray.	do	do	10.0
13	do	do	do	do	9.0
71	do	Grayish.	Soft, crumbly.	do	8.0
72	do	Light buff.	do	do	8.0
75	do	do	do	do	10.0
76	do	do	Scratches.	do	7.5
34	do	Offwhite.	Steel hard.	do	9.0
64	do	Light buff.	do	Porous.	10.0
86	do	do	Scratches.	Very porous.	6.0

TABLE 5.—*Characteristics of the clays of the Dry Creek Canyon member of the Dakota sandstone when treated by heat at 2,300 F (cone 8)*

Sample	Clay type	Color	Hardness	Porosity	Percent shrinkage
8	Plastic.	Light gray.	Steel hard.	Low porosity.	12.5
80	do	Light buff.	do	Very porous.	12.5
81	do	Light gray.	Scratches.	do	10.0
25	do	do	Steel hard.	Porous.	9.0
9	Black semiplastic.	Gray.	Scratches.	Very porous.	9.0
12	Flint.	Light gray.	do	do	10.0
13	do	do	do	do	9.0
71	do	Grayish.	Soft, crumbly.	do	8.0
72	do	Light buff.	do	do	9.0
75	do	do	do	do	10.0
76	do	do	Scratches.	do	7.5
34	do	Offwhite.	Steel hard.	Porous.	9.0
64	do	Light buff.	do	do	10.0
86	do	do	Scratches.	Very porous.	6.0

TABLE 6.—*Characteristics of the clays of the Dry Creek Canyon member of the Dakota sandstone when treated by heat at 2,400 F (cone 12) and cone of fusion of the clays*

Sample	Clay type	Color	Hardness	Porosity	Percent shrinkage	P. C. E. (cone of fusion)
8	Plastic.	Gray.	Steel hard.	Low porosity.	12.5	32
80	do	Light buff.	do	Very porous.	12.5	33
81	do	Light gray.	Scratches.	do	10.0	34
25	do	Buff.	Steel hard.	Porous.	10.0	31
9	Black semiplastic.	Gray.	do	do	11.0	32
12	Flint.	Light gray.	do	do	11.0	33.5
13	do	do	Easily scratches.	Very porous.	10.0	34
71	do	Offwhite.	Scratches.	do	8.0	35
72	do	Grayish.	do	do	9.5	34
75	do	Light buff.	do	do	10.0	35.5
76	do	do	do	do	8.0	34.5
34	do	Offwhite.	Steel hard.	do	9.0	35
64	do	Light cream.	do	Porous.	10.0	34
86	do	Light buff.	Scratches.	Very porous.	6.0	33

STRATIGRAPHIC RELATIONS OF THE CLAY TYPES

The different kinds of clay in the Dry Creek Canyon member of the Dakota sandstone are arranged in a definite succession within the clay-bearing zone, each clay type occupying a fixed position relative to the other clay types. Details of the clay-bearing zone are shown in the section below; the thicknesses given indicate the approximate range in thickness for the individual beds throughout the area studied.

Composite section of the clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone

	Feet
Roof-rock zone: Sandstone, soft gray-white to hard greenish-buff, interbedded with light gray sandy plastic clay and clay shale	1–8
Clay-bearing zone:	
Clay, plastic, light to dark gray and black	1–12
Clay, plastic, soapy, yellow-green to gray; the marker bed	0–0.4
Clay, semiplastic, dense, black	0–8
Flint clay, light gray, slightly sandy at base	1–6
Flint clay, sandy, light gray to black	0.5–2
Basal sandstone zone:	
Sandstone with flint clay matrix	0.5–1
Sandstone, medium-grained, even-bedded, white	3–5

In the clay-bearing zone of the Dry Creek Canyon member of Dakota sandstone the most common sequence of beds consists of a basal bed of flint clay overlain by a bed of plastic clay, the contact between which is sharp and in some places definitely disconformable. This sequence is laterally gradational into a second, more complex sequence in which the semiplastic clay and marker clay beds are present along with the flint clay and plastic clay in the order shown in the section above. In the simple flint clay-plastic clay sequence, the two clay beds are, as a rule, about equally thick and the flint clay reaches its maximum thickness. In the second, more complex, sequence the plastic and semiplastic clays constitute the bulk of the clay-bearing zone and the flint clay is thin. The local bodies of semiplastic and plastic clay are a common feature of the clay-bearing zone in the mining districts and they serve as an important criterion in delimiting the extent of the high-alumina flint clay. Representative sections of the clay-bearing zone from the several districts are shown in figure 14.

The bodies of plastic and semiplastic clay vary in size and shape. In the mine workings that are extensive enough to permit delineation of the bodies they are irregularly elongate and change in breadth from place to place. The largest plastic clay body observed has been traced for half a mile and probably continues for a considerable distance. The greatest width in the part of this body that could be studied is 700 feet; the least, 50 feet. The areal pattern of this and other similar

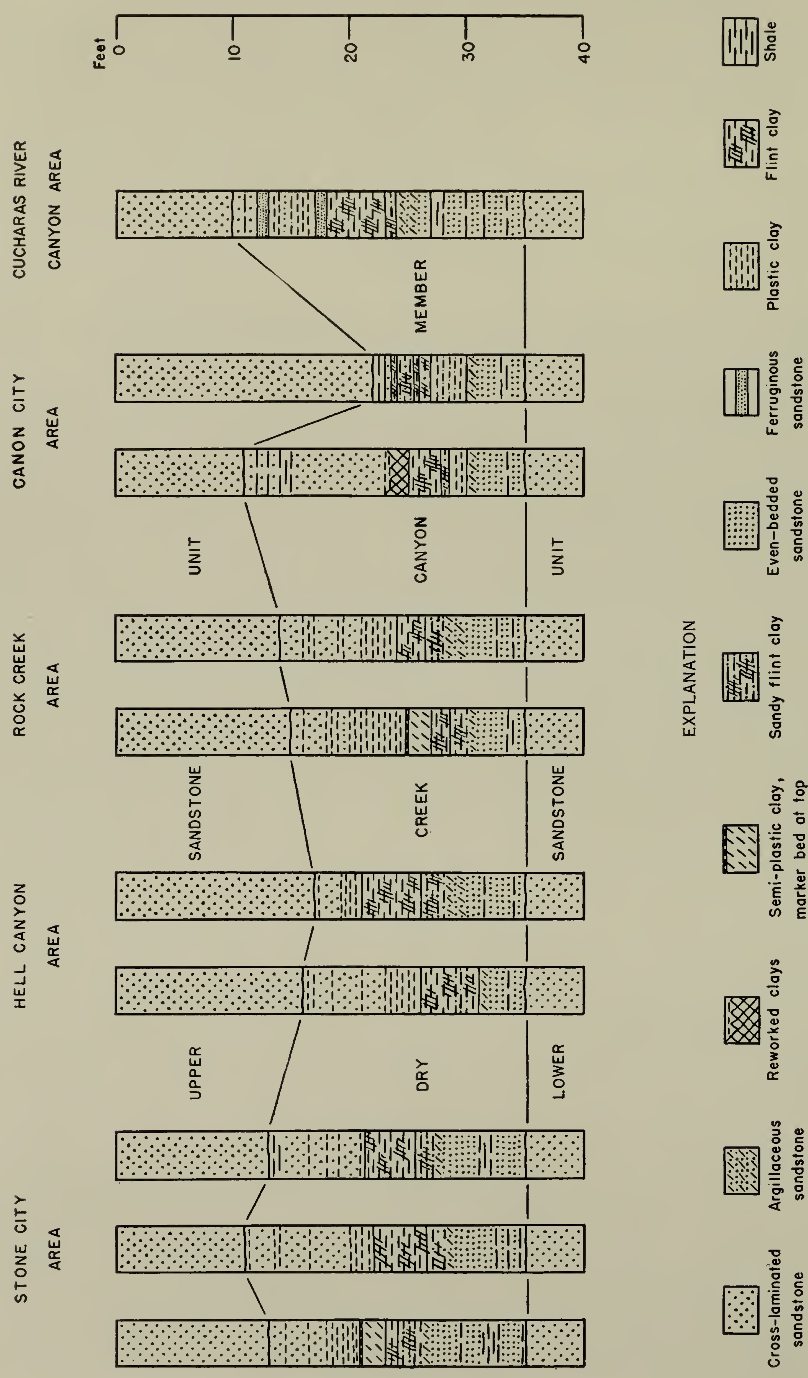

FIGURE 14.—Columnar sections of the Dry Creek Canyon member of the Dakota sandstone.

bodies suggests that they represent a channel-fill type of deposit. In sections of the bodies seen in the mines the black semiplastic clay appears to fill channellike depressions in the flint clay bed. This is shown graphically in the cross sections of the clay-bearing zone in figure 15. The thickest bodies of plastic clay are commonly found where the semiplastic clay bodies are present. At a few places the plastic clay occurs in thick, narrow bodies resembling channel fills; relations at the margins of these bodies indicate that the channeling that preceded deposition of the plastic clay has cut out the semiplastic clay.

The semiplastic clay appears to grade abruptly downward into the underlying flint clay and the gradation is generally complete within an inch. Both the black semiplastic clay and the flint clay are disconformable with the overlying marker clay bed, and, where the marker bed is absent, with the plastic clay. The marker bed can generally be traced laterally from where it lies disconformably on the semiplastic clay to where it lies disconformably on the flint clay. However, where it extends for any appreciable distance beyond the bodies of semiplastic clay, it pinches out at the contact of the flint and plastic clay.

The plastic clay bed appears to have had a different origin than the flint clay bed, and the clay-bearing zone as a whole is interpreted as a complex unit. The relationships of the black semiplastic clay, which is commonly absent where the flint clay approaches its maximum thickness, are not clear. The evidence suggests that this clay formed under different conditions from the other clay types or represents a phase of deposition more closely associated with the formation of the flint clay bed. The marker bed has apparently had a history independent of the other clay types.

ORIGIN OF THE CLAY

SEDIMENTARY ORIGIN

The clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone is a complex bed containing several types of clay, the purest of which is the flint clay at the base of the bed. Stratigraphic relations of the other clay types indicate that they were deposited on top of the flint clay zone and are, therefore, sedimentary clays. The flint clay itself is also a sedimentary clay that shows no features indicating enrichment by leaching of a clay bed in place, either by surface or ground waters. Decrease in grade of the flint clay downward is entirely accounted for by an increase in the quantity of quartz grains and does not resemble a profile of weathering. The gradation of the clay into the underlying sandstone, which has inter-

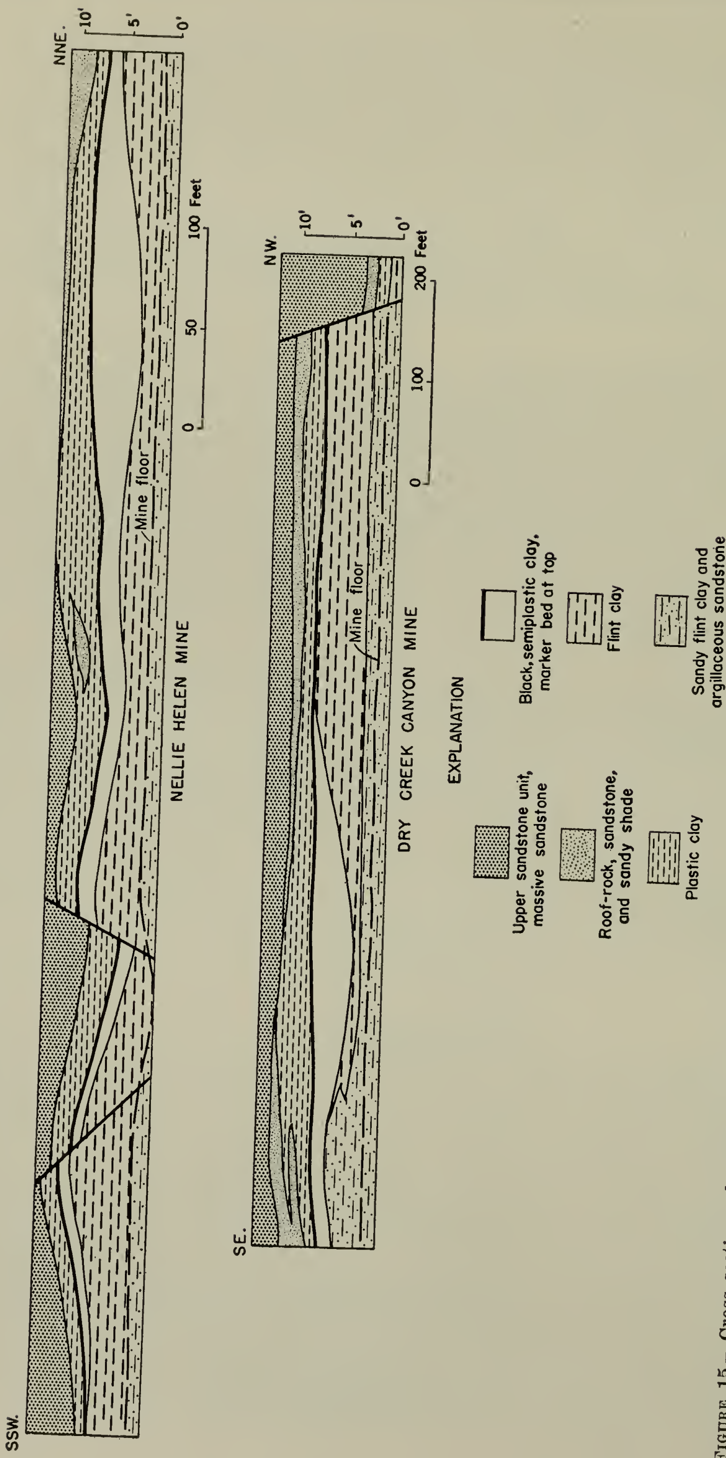

FIGURE 15.—Cross sections showing lateral variation in the clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone in mines of the Stone City area.

stitial clay as pure as that at the top of the flint clay bed, is clearly a depositional feature.

The flint clay bed does not appear to have become indurated prior to the deposition of the sandstones of the upper sandstone unit of the Dakota. No angular fragments, such as would be derived from a hard flint clay bed, are present at the base of any of the channel fills that cut into or penetrate the clay. The fragmental flint clay found in the Canon City district (see p. 35) occurs only within the clay-bearing zone and is interpreted as an intraformational structure formed only around the edges of the basin of deposition where the clay sediment was subject to exposure to the air at times of low-water level. Thin layers of flint and semiflint clay are present in some places within channel fills of the roof-rock zone but none of the flint clay in these layers is fragmental; wherever it can be seen it grades imperceptably into surrounding plastic clay. Inclusions of sandy clay are locally common at the base of some of the channel fills of the upper sandstone unit but these are rounded and in some places pressed against one another indicating plasticity at the time of deposition.

Judging from the texture of the flint clay, it must have been deposited as a homogeneous, exceedingly fine sediment. Possibly it was deposited as colloidal material which recrystallized to form kaolinite, as has been postulated by Galpin (1912) for certain flint clays.

SOURCE OF CLAY SEDIMENT

The kaolinitic sediment of the clay beds in the Dry Creek Canyon member of the Dakota sandstone is believed to have been derived from a residual mantle that developed on one or more land areas located approximately along or slightly west of the northerly-trending axes of the Front Range and the Wet Mountains. Evidence of a land area near the north end of what is now the Wet Mountains is afforded by the local deltaic deposit in the Purgatoire and Dakota strata northeast of Beulah (see p. 19). In this same area Gilbert (1897) has described the overlap of the Morrison formation by the Dakota and farther to the south Hills (1900) mapped the Dakota as overlapping the Paleozoic rocks and resting directly on the pre-Cambrian granite. On a paleogeographic map of the Dakota sandstone in Colorado, Lovering (1929, p. 88) shows a land area at the south end of the Front Range northwest of Canon City and cites evidence suggesting that the Dakota was never deposited in this area. Although some of these examples of overlap need careful rechecking in the field, it is conceivable that land areas on which a residual mantle could have been formed were present both north and south of the Canon City embayment area during deposition of the Dry Creek Canyon member.

The evidence of overlap of the Dakota sandstone on all formations down to the pre-Cambrian granite indicates a wide variety of source rock on which a residual kaolinitic mantle could have developed. Other factors necessary to produce a rich residual mantle are proper climate and sufficient time. The Dakota flora is generally considered to be indicative of a warm-temperate to subtropical climate and the abundance of carbonaceous matter present in the Purgatoire and Dakota formations suggests humidity. Direct evidence is lacking that would indicate the length of time available for the formation of a kaolinitic mantle on the local highlands. Lovering (1929, p. 86) speculates that

> It is probable that any crustal movements which occurred in the interval between the close of the Morrison and the great marine invasion [Benton] had little magnitude. The Front Range highland was probably a series of low hills rising from a broad piedmont plain during Lower Cretaceous(?) time and it is impossible to say how much of the highland remained uncovered at the beginning of Upper Cretaceous time.

LOCUS OF DEPOSITION

The areas containing remnants of the Dry Creek Canyon member of the Dakota sandstone and its included clay bed are shown on figure 8. The extent of the unit prior to the erosion responsible for its present limits cannot be estimated from evidence afforded by these remnants. Only the original western limit of the member can be inferred from its local character. In the Wilson Creek area of the Canon City district, the Penrose district, the Wetmore area, and parts of the Beulah district irregularly bedded sections of the member show less flint clay and more silty and sandy material than is typical and in some places show mixture of the clay types. These features are interpreted as indicating deposition near the edges of the area in which the Dry Creek Canyon member was formed. The inferred western limit of deposition is shown on figure 8.

The character of the sediments of the Dry Creek Canyon member of the Dakota sandstone indicates that they were deposited in relatively shallow fresh water. Not enough of the member remains to indicate whether this water was in a swampy or marshy terrain with broad expanses of open water or was a single large shallow body. The similarity of sections of the Dry Creek Canyon member in the different remnant areas suggests that they were deposited either in a single body of open water or contemporaneously in several connected bodies of open water under almost identical conditions. The site of deposition, whatever its character, was large. Remnants of the member have been found as far out on the high plains as southeastern Pueblo County, approximately 75 miles southeast of the westernmost remnants along Wilson Creek in the Canon City district. The north-south distance between the remnants in the Turkey Creek district and those in the Cucharas area in Huerfano County is over 50 miles. These distances probably do not measure the full extent of the member as they correspond merely to the size of the area studied. Undoubtedly additional remnants will be found beyond these limits.

INFERRED DEPOSITIONAL HISTORY

Though the inferences involved in outlining the sequence of events that took place during the deposition of the Dry Creek Canyon member of the Dakota sandstone are based largely on the sedimentary features of the member, they are admittedly speculative. One of the most significant features of the Dry Creek Canyon member is the striking resemblance of the sequence of beds within it to that of a cyclothem. In the Maryland coal measures (Waage, 1950, p. 46) the four basic parts of a typical cyclothem, which is a sequence of beds repeated again and again in cyclical fashion, are the basal sandstone, the underclay, the coal bed, and the roof shale. These four parts find their analogs in the basal sandstone, the flint clay bed, the carbonaceous semiplastic clay and the platy to shaly plastic clay of the Dry Creek Canyon member, a circumstance which suggests that the depositional history of this member is similar to that of a cyclothem.

The even-bedded white sandstone at the base of the Dry Creek Canyon member, resting on a planed surface of the fluvial sandstone of the lower sandstone unit of the Dakota, indicates a transgressive interlude during which the upper part of the lower sandstone unit was reworked and redeposited in a body of standing water. The interlude may have been a local result of a slight rise in sea level in a eustatic region that impounded a considerable body of water or a large swamp area within a coastal plain. Into this, sluggish streams from low land masses bordering the area of deposition on the west, might have carried fine sediment derived from a residual mantle.

The source material of the flint clay bed, consisting of very fine kaolinitic sediment, may have been deposited in quiet areas of open water, away from the swampy edges of the area of deposition. As deposition progressed the swampy vegetation may have encroached on the bodies of open water with the result that the flint clay bed in the marginal areas is not as thick as in the areas that remained as open water. Locally a kaolinitic clay high in carbonaceous matter was deposited. This latter sediment, now represented by the carbonaceous semiplastic clay, was probably deposited subsequent to the parent flint clay bed. Although the transition from one clay to the other locally appears to be gradational the gradation takes place within about an inch, and if the material of the flint clay bed was a soft muck when the carbonaceous clay was deposited, no sharp contact could be expected. Irregularities on the surface of the flint clay bed may have determined the locus of deposition of the carbonaceous clay. The tendency for this latter clay to form elongate bodies like channel fills suggests that the depressions in which it was deposited were, at least in part, formed by currents. There is no evidence to support postulation of a period of subaerial erosion of the material of the flint clay bed prior to deposition of the carbonaceous clay.

The source of the carbonaceous matter in the clay was undoubtedly the swamp area. The typical sequence in which lenses of this black clay lie above the structureless flint clay and below the slightly shaly plastic clay resembles closely the sequence of underclay, coal and roof shales typical of swamp deposits of the coal measures. Indeed the black semiplastic clay would qualify as bone if the proportion of its carbonaceous matter to the clay fraction were slightly greater. It is conceivable that accumulation of vegetable matter in the swamp area barely kept pace with its decomposition so that only the more resistant hydrocarbons remained to mix with the clay sediment. The viscous black muck so formed settled into the depressions in the parent flint clay bed.

A break in sedimentation apparently followed deposition of the black clay sediment as the subsequently deposited marker clay bed locally rests with a sharp contact on the semiplastic and flint clay. The spotty distribution of the marker bed in and adjacent to the areas of semiplastic carbonaceous clay, may mean that it was deposited locally in the modified irregularities of the basin floor, or that it covered the entire basin floor but was removed from the higher areas by subsequent current action.

The origin of the marker clay bed demands some special explanation. Since its composition, so far as known, suggests no special mode of origin, its stratigraphic relations furnish the only basis for speculation. Though it is not a bentonite (see p. 36), its field relations are identical to those of bentonites and, whatever the original source of the material in the marker bed, it was probably transported and deposited by the wind in the same manner as the volcanic ash from which bentonites are derived.

Sedimentation in the basin was accelerated after deposition of the marker clay bed and the less pure and sandy clay of the plastic zone was deposited. At first the rapidly filling basin of deposition was probably a broad marsh crossed by numerous streams and plastic clay was the principal sediment that formed, although some sandy clay was also deposited. Rejuvenation of these streams brought deposition to an end and they cut channels into the underlying sediments. Broad straths were developed along the major drainage channels leaving the sediments of the clay beds as interfluvial remnants.

When the streams again began to aggrade, the interbedded sandstone, shale, and clay of the roof-rock zone were deposited. This deposition continued until a second period of channeling was initiated which cut the channels in which the sandstones of the upper sandstone unit of the Dakota were deposited.

CLAY OF UPPER SANDSTONE UNIT OF THE DAKOTA SANDSTONE

Throughout most of the area studied a bed of soft argillaceous sandstone and sandy shale overlies the basal massive, cross-laminated sandstone of the upper sandstone unit of the Dakota and is in turn overlain by a hard bed of quartzitic sandstone (see pp. 17–18). Locally the sandy shale grades laterally into a shaly, sandy, plastic clay which is generally of no economic value. However, a small minable deposit of this clay occurs at one locality.

In the Capers area at the site of the now abandoned Shamblin mine of the Standard Fire Brick Co. the clay bed ranges from 4½ to 6 feet in thickness in the mined area where it lies from 3 to 6 feet below the surface. The mine roof is formed by the thin-bedded, platy, brown-weathering sandstone typical of the Dakota and Graneros transition zone. The clay is a tough plastic clay similar to the clay of the Glencairn shale member of the Purgatoire formation but is in general more shaly. The upper one-third of the bed is a light blue-gray clay in which sandstone lenses are common. Locally these lenses form channel-fill deposits several feet thick, the increase in thickness having taken place at the expense of the clay. The clay of the lower part is dark blue to black in color. An average of five analyses of the clay furnished by the Standard Fire Brick Co. is given below.

	Percent
Silica (SiO_2)	59.51
Alumina (Al_2O_3)	26.33
Ferric oxide (Fe_2O_3)	1.63
Lime (CaO)	0.28
Magnesia (MgO)	0.69
Loss by ignition	11.33
Total	99.77

The principal factors that determined the economic value of the Shamblin clay body were the ease with which the clay could be recovered and the proximity of the operation to the mining and transportation facilities of the large Vulcan mine at Capers. Similar small bodies of clay possibly exist at this same horizon but the top of the upper sandstone unit of the Dakota is of little value as a horizon for refractory clay.

CLAY MINING DISTRICTS

GEOLOGIC SETTING

Within the area studied (fig. 1) the clay-bearing Purgatoire and Dakota formations are exposed in two distinct types of terrain: in foothills flanking the mountains and in plateaulike areas on the plains east of the mountains. In both situations the two formations occur in a well-defined succession of strata, shown in the columnar section on figure 16, that varies little in character and thickness throughout the area. As the two clay-bearing formations are the most resistant units in this succession they form conspicuous topographic features wherever they crop out.

In the foothills the Dakota and Purgatoire strata form the "Dakota" hogback. This prominent feature varies in cross section from a sharp hogback where the dip of the beds is steep to that of a broad cuesta where the dip is low. In many places the dip slope of the hogback, or cuesta, is stripped to the top of the upper sandstone unit of the Dakota. Along the base of the foothills slope the Dakota dips under a valley developed on the nonresistant shale of the overlying Graneros formation. The opposite side of the valley is formed by a slope capped by the resistant Timpas limestone. Just above the foot of the slope that is capped by the Timpas a bench formed by the Greenhorn limestone rests on the Graneros shale and is separated from the Timpas limestone by the Carlile shale. Where the dip of the strata of the "Dakota" hogback is steep, the Greenhorn and Timpas limestones form smaller hogbacks parallel to it.

The scarp face of the "Dakota" hogback is rimmed by a cliff of Dakota sandstone that rises above a steep slope with local rock ledges developed on the weaker sandstone and shale of the Purgatoire formation. In many places the talus-covered lower half to two-thirds of the slope includes the nonresistant strata of the Morrison formation and the underlying redbeds of the Lykins formation.

Canyons that have been cut through the hogbacks and incised in the broad dip slopes of the cuestas afford easy access to the local clay bodies and permit mining up dip from entries in the canyon walls.

On the high plains a broad upwarp extends southeastward from southwestern Pueblo County bringing the Dakota sandstone to, or near the surface over large areas of Pueblo, Huerfano, and Las Animas Counties (see fig. 1). In contrast to the typical gently rolling topography of the plains, the area underlain by the flat-lying Dakota sandstone has a plateaulike topography. The major streams have cut deep canyons through the Dakota exposing the Purgatoire and underlying formations. In some places buttes and mesas capped by the Timpas limestone are present on the divides between the canyons.

System	Series	Formation		Thickness in feet	Description
CRETACEOUS	Upper Cretaceous	Timpas			Gray limestone
CRETACEOUS	Upper Cretaceous	Carlile		150	Gray to black shale, zone of yellow-weathering sandstone at top
CRETACEOUS	Upper Cretaceous	Greenhorn		50	Gray limestone and shale
CRETACEOUS	Upper Cretaceous —?—?—	Graneros		200	Gray to black shale
CRETACEOUS	Lower or Upper Cretaceous —?—?—	Dakota		100	Chiefly massive cross-laminated sandstone. Clay-bearing unit, the DRY CREEK CANYON MEMBER, present locally in middle
CRETACEOUS	Lower Cretaceous	Purgatoire		80	GLENCAIRN SHALE MEMBER, interbedded shale and sandstone. Clay present locally in upper 25 ft
CRETACEOUS	Lower Cretaceous	Purgatoire		120	LYTLE SANDSTONE MEMBER, sandstone and conglomeratic sandstone
JURASSIC		Morrison		240	Gray to green clay and marl, interbedded sandstone and calcareous concretions in upper part, gypsiferous in lower part
PERMIAN(?)		Lykins		180	Red sandy shale
PERMIAN		Lyons			Red sandstone and conglomerate

FIGURE 16.—Generalized columnar section of rocks in the refractory-clay mining districts of Fremont, Pueblo, and Huerfano Counties, Colo.

Strike faults, a common structural feature in the area, are responsible for numerous southeast-trending low escarpments of Dakota sandstone.

In the plateaulike areas of outcrop of the Dakota sandstone, local clay bodies are exposed in the canyon walls and, in a few places, along the fault escarpments. Outcrops in the steep-sided canyons are difficult to reach, except where shallow feeder canyons permit access, and clay bodies can best be worked by shaft or slope mines.

MINING AND PRODUCTION

Clay of refractory and semirefractory grade has been mined in south-central Colorado since the 1890's. Clay beds in the Purgatoire formation in the Parkdale area west of Canon City and near Delhi in Las Animas County (fig. 1) were among the deposits worked earliest. In eastern Fremont County the principal mining activity has been in the vicinity of Canon City. Here the clay of the Purgatoire and, to a lesser extent, the clay of the Dakota have been mined from the numerous hogbacks at the west end of the Canon City embayment. In Pueblo County clay has been mined from three separate areas. The clay of the Dakota is mined in the Turkey Creek district where the "Dakota" hogbacks east and south of the Front Range join in a southeastward-plunging anticline, and along Rock Creek in the Beulah district where the clay bed is exposed in a fault scarp in flat-lying Dakota strata. The clay bed of the Purgatoire is mined from flat-lying strata near Capers, Huerfano County, just north of the county line in Pueblo County.

Three of the four refractory-products companies now operating in the area—the Standard Fire Brick Co. and the Pueblo Clay Products Co. in Pueblo, and the Laclede Christy Co. of Colorado—operate all the working clay mines in the area with the exception of one mine in the Turkey Creek district which is operated by Mr. Arthur Wands of Stone City. The Freeman Fire Brick Co. in Canon City is at present purchasing all of its raw clay, chiefly from the Pueblo Clay Products Co. Both the Standard Fire Brick Co. and the Laclede Christy Co. of Colorado utilize their clay production in the manufacture of refractory products of various types and grades. The Pueblo Clay Products Co. sells raw and calcined clay to the market. Most of the raw clay produced from Wands' mine goes to the Denver Fire Clay Co. of Denver, Colo.; some goes to the Freeman Fire Brick Co.

During the past decade most of the production of high-grade refractory clay from the Dakota beds has come from the Turkey Creek district and the Rock Creek area of Pueblo County. Production of raw clay from these two areas during the five-year period, 1945 through 1949, was 181,600 short tons, or an average yearly production of about 36,000 short tons. Mines in the Turkey Creek district have accounted for two-thirds of the total production. In Fremont County production of clay of the Dakota sandstone during the same five-year period was about 12,000 short tons.

As the flint and plastic clay are mined together it is not possible to give an accurate figure for the flint clay production alone. Records of the Pueblo Clay Products Co. for the period 1945 through 1949 indicate that about 40 percent of the raw clay taken from their mines in the Turkey Creek district was flint clay. On the basis of measured sections of the clay beds of the Dakota sandstone in other clay bodies this percentage is judged to be between 5 and 10 percent higher than the average for the area as a whole.

TURKEY CREEK DISTRICT

LOCATION AND SUBDIVISIONS

The Turkey Creek district lies in northwest Pueblo County where the Dakota and Purgatoire formations crop out over a roughly triangular area of about 18 square miles east of Red Creek and on, and to the west of Turkey Creek in T. 18 S., R. 67, and 68 W. (See index map, fig. 1.) The district includes one area in which clay is mined and one area where refractory clay occurs in undeveloped though minable bodies in the Dry Creek Canyon member of the Dakota sandstone. The clay-mining area, which is called the Stone City area, lies along the southwest edge of the Turkey Creek district between the settlement of Stone City (population, approximately 50) and the east line of T.18S., R.67W. This area includes all abandoned clay mines and those being worked in the Turkey Creek district. The undeveloped area, which is called the Hell Canyon area, lies north of the Stone City area along Turkey Creek on the east side of the district and includes all the territory in the Turkey Creek district, outside of the Stone City area, where clay is present in the Dry Creek Canyon member of the Dakota. Outcrops of the Dakota sandstone elsewhere in the Turkey Creek district do not contain the Dry Creek Canyon member.

GEOLOGY

Geologic formations from the Permian Lyons formation to the Cretaceous Timpas limestone are exposed in and immediately adjacent to the Turkey Creek district. The distribution of these formations is shown on the geologic map of the Turkey Creek district, plate 1.

The Turkey Creek district lies on and near the crest of an anticline, whose axis plunges southeastward away from the south end of the Front Range. Gilbert (1897, p. 4) called the crest of the structure in Pueblo County the Turkey arch. To the northwest in the Colorado Springs quadrangle the structure has been called the Red Creek anticline; in this report it is called the Turkey Creek anticline. Within the Turkey Creek district the anticline is characterized by abruptly dipping flanks and a broad, relatively flat top. It is asymmetrical with the steeper dips on the west limb. Strike faults, in most places downthrown to the west, are common on the west limb.

Over most of the Turkey Creek district the anticline has been stripped to the Purgatoire and Dakota beds. These formations crop out in a low arch at plains level near the axis of the structure and rise to the northwest where they underlie a relatively flat-topped upland. In the northwestern part of the district the structure broadens and the less resistant underlying formations are exposed on the axis. This broadening is expressed topographically by the abrupt termination of the upland of Purgatoire and Dakota beds in a steep northwest-facing escarpment exposing the Morrison formation and overlooking a large grassy flat, called Sullivan Park, developed on the underlying Permian(?) redbeds of Lykins formation. The east limb of the anticline is continuous north toward Colorado Springs, with the Purgatoire and Dakota beds forming a hogback flanking the Front Range. The west limb veers abruptly southwestward up the Canon City embayment where it forms the hogback along the south end of the Front Range. Here the dips are lower and the Purgatoire and Dakota beds are exposed in broad cuestas.

Only the clay of the Dry Creek Canyon member of the Dakota sandstone is known to be of minable grade and thickness in the Turkey Creek district. It is doubted that any minable bodies of plastic clay are present in the Glencairn shale member of the Purgatoire formation. Generally this member is poorly exposed and underlies broad grassy flats in the upland and wash-covered benches along the canyons. Exposures of the upper clay-bearing part of the Glencairn member show that it consists predominantly of sandy clay and shale with considerable intercalated sandstone.

STONE CITY AREA

The Stone City area occupies about 2½ square miles of the area of Dakota and Purgatoire outcrop along the southwest limb of the Turkey Creek anticline and extends across the axis of the structure in the vicinity of Turkey Creek. This area forms the south end of the relatively flat-topped, intricately dissected upland underlain by the Dakota and Purgatoire formations. The mining settlement of Stone City lies in the E½SE¼SW¼ sec. 26, T. 18 S., R. 67 W., in a narrow valley that is underlain by the Graneros shale and is bounded by the Dakota and Purgatoire upland to the northeast and by a northeastfacing escarpment of the Greenhorn, Carlile, and Timpas formations to the southwest. The geology of the area is shown on plate 2.

LOCAL STRUCTURE

Gentle dips prevail throughout the Stone City area. The Dakota strata dip 9° to 15° along the southwest limb of the anticline in the vicinity of Stone City. Their dip decreases slightly to the southeast along the strike and ranges from 5° to 10° where the Dakota dips under the Graneros shale east of Turkey Creek. Dips less than 6° prevail where the strata begin to flatten out toward the axis of the structure. This decrease in dip is rather abrupt, at a distance of a quarter to half a mile northeast of the contact of the Dakota with the alluvium in the valley, and is marked in the N½ Sec. 36, T. 18 S., R. 67 W., by a monoclinal fold that becomes a fault along the strike. The dip also steepens down dip under the valley in the Graneros shale in the vicinity of Stone City. Some of the old mine tunnels are said to have been abandoned because of an increase in dip of as much as 25°.

Monoclinal folding and strike faulting of the type just described, with the faults becoming monoclines along the strike, are common in the Stone City area. For the most part these are minor structures, the faults seldom exceeding 6 feet in displacement. However, three faults with sufficient throw to halt mining of the clay occur in zones of displacement which coincide roughly with the abrupt changes in dip mentioned above. The more important of these three zones extends diagonally across the north half of sec. 36, T. 18 S., R. 67 W. from the SW¼SW¼NE¼ sec. 36 into the southwest corner of the SW¼SW¼ sec. 25, T. 18 S., R. 67 W. For convenience this zone will be referred to as the Connor Canyon displacement.

The Connor Canyon displacement consists principally of a strike fault in the northwest part, extending gradually southeastward into a sharp monoclinal fold which in turn dies out still farther to the southeast. The strike fault is downthrown on the south side and shows a maximum displacement of 50 to 60 feet in the center of the N½NW¼NW¼ sec. 36; the sharp monoclinal fold dips southwestward as much as 60° in the middle of the S½NE¼NW¼ sec. 36; the dip is about 40° where Connor Canyon crosses the monocline; and the maximum dip is between 25° and 30° on the west wall of Turkey Creek canyon. Across the canyon, on the east wall, there is no evidence of the flexure so it must die out in the space between the canyon walls.

Relationships at the northwest end of the Connor Canyon displacement are obscure. Within about 700 feet northwestward from the area of maximum measured displacement that has been mentioned, the throw of the strike fault decreases gradually to less than 35 feet and the main fault terminates in a complex zone consisting of a broad shattered belt and several auxiliary faults of minor displacement. The displacement appears to end abruptly in this complex area, but one or more of the auxiliary faults may continue for some distance to the northwest or die out in a vague monoclinal fold. These major features of the Connor Canyon displacement are paralleled within 50 feet by subsidiary faults, commonly of less than 3 feet throw.

The second zone of displacement is believed to occur beneath the alluvium-filled valley underlain by the Graneros shale. In the vicinity of the Nellie Helen mine in the SW¼SW¼NW¼ sec. 36, T. 18 S., R. 67 W., an omission of at least 45 feet of the Dakota section is indicated between the outcrop of the Dry Creek Canyon member at the mine entry and the Dakota and Graneros contact exposed in a gulley in the valley floor just south of the entry. It seems logical to assume that this discrepancy is brought about by a fault, downthrown to the south, which is present beneath the alluvium between the two outcrops. This inferred fault lies in a position analogous to the zone of steepened dips that is said to have determined a limit to which the clay could be mined under Stone City. This steepening of the dip may indicate the presence of a monclinial fold along a continuation of the displacement represented by the inferred fault at the Nellie Helen mine.

The third major displacement is a fault that shows on the east wall of Turkey Creek canyon in about the center of the SE¼SE¼ sec. 36, T. 18 S., R. 67 W., and continues to the southeast into the NW¼NW¼ sec. 6, T. 19 S., R. 66 W. It appears on the west wall of the canyon in the SW¼NW¼SE¼ sec. 36, T. 18 S., R. 67 W. and dies out to the northwest within the section. As in the other two displacements the downthrow is to the south; the throw is beween 30 and 40 feet and brings the top of the lower sandstone unit of the Dakota into contact with the upper sandstone unit.

CLAY DEPOSITS

The Stone City area contains extensive deposits of flint clay and plastic clay in the Dry Creek Canyon member of the Dakota sandstone and is the principal area producing refractory clay from this member. A description of the local character of the clay deposits of the Stone City area need not be given here because this area includes the type area for the Dry Creek Canyon member and contains the exposures that served as a basis for description of the typical development of the clay beds (see pp. 31 to 45). The distribution of the clay bodies and the stratigraphic features limiting their extent are shown on plate 3. Analyses of clays from the Stone City area are given on page 98 (nos. 8 to 24 inclusive).

CLAY MINES

Clay mining in the Stone City area was begun about 1906 when the U. S. Zinc Co. opened a mine on Turkey Creek. From 1906 to 1917 clay was hauled from the mine by wagon to the company's plant at Pueblo. In 1917, when the Colorado Railroad was built into Stone City from Pueblo, the mine of the U. S. Zinc Co. was abandoned and operations were moved to Stone City for easy access to the railroad. The railroad still serves the area and has loading facilities at Stone City and at a station in the center of the NW¼ sec. 1, T. 19S., R. 67W.

Mining operations in the clay at Stone City were begun in 1917 by the Turkey Creek Stone, Clay, and Gypsum Co., but were taken over in the same year by the Pueblo Clay Products Co. Kilns were set up at the mines and both raw and calcined clay have been shipped since that date. The principal purchasers of the clay have been the manufacturers of refractory products in Pueblo and Canon City and manufacturers of iron and zinc products in different parts of the western interior.

At present (1950) the Pueblo Clay Products Co. is working the clay from three entries, one in Dry Creek Canyon about a quarter of a mile northeast of Stone City and two in Spring Canyon about three-eighths of a mile southeast of Stone City. A single shaft kiln with a maximum capacity of about 25 tons of calcined clay per day is in operation in Dry Creek Canyon. Not more than 25 percent of the clay mined is calcined, the remainder is sold raw. In 1950 the company purchased a plant in Pueblo equipped with several shaft kilns and crushers. This plant is expected to have a production capacity of from 50 to 60 tons per day of crushed, calcined clay.

In 1927 Arthur J. Wands started operating the Nellie Helen mine about 1 mile southeast of Stone City and has been mining clay intermittently since that date. Although a kiln was once operated at the mine entry it has not been in use for many years and all clay is being shipped raw. Essentially the entire production from the Nellie Helen mine has gone to the Denver Fire Clay Co. at Denver.

DRY CREEK CANYON MINE

The Dry Creek Canyon mine is operated by the Pueblo Clay Products Co. from an entry at the mouth of Dry Creek Canyon in the northwest corner SW¼SE¼ sec. 26, T. 18S., R. 67W. The mine is in a clay body lying between Dry Creek Canyon and Spring Canyon, the next canyon to the east along the strike. The approximate area occupied by mine workings and the inferred distribution of clay are shown on plate 3. The clay has been worked up and down dip from the present entry and from several abandoned entries farther up the east wall of Dry Creek Canyon. Active mining is now down dip along the southwest face of the mine; the area to the north is abandoned.

A version of the room and pillar system of mining has been used; pillars have been pulled in some parts of the north extremity of the mine in the vicinity of the strike fault. The estimated tonnage recovered from the mined-out area is about 274,000 tons of which somewhat less than half was flint clay. The clay is hauled by donkey from the mine to the loading platform and to the shaft kiln less than 100 yards southwest of the entry on the opposite side of Dry Creek Canyon. Some of the clay is shipped raw and some is burned.

Possible extensions of the present workings are limited chiefly to unmined areas down dip to the south and southwest, but sufficient tonnage of flint clay is probably present north of the strike fault in the northeast part of the clay body to warrant installation of additional workings beyond the fault.

SPRING CANYON MINES

The Pueblo Clay Products Co. operates two mines in Spring Canyon in the southeast corner SW¼SE¼ sec. 26, T. 18 S., R. 67 W. One entry is in the northwest wall of the canyon about 60 yards from its mouth, the other is in the southeast wall about 100 yards from the mouth.

The northwest entry, the workings of which join those of the Dry Creek Canyon mines, was opened in 1948 to work the clay lying between Spring Canyon and the advancing face of the Dry Creek Canyon mine. The entry in the southeast wall was opened in the early 1940's. Most of the clay taken from this entry has come from the area southwest of the strike fault in the southwest corner SE¼SE¼ sec. 26, T. 18 S., R. 67 W. A broad channel-like body of sandy clay prevented mining to the east and southeast but this has been tunneled through and a minable thickness of clay is being worked in the middle of the north edge of NE¼NE¼ sec. 25, T. 18 S., R. 67 W. Some of the clay from both the northwest and southeast mine entries in Spring Canyon is trucked to the loading station at Dry Creek Canyon; some of it is trucked directly to refractory products plants in Canon City.

NELLIE HELEN MINE

The Nellie Helen mine has its entry at the base of a low, south-facing escarpment of Dakota sandstone in the SE¼SW¼SW¼NW¼ sec.

36, T. 18 S., R. 67 W.; the extent of the mine workings is shown on plate 3. This mine, from which over 100,000 tons of clay have been mined to date (1950), is owned and operated by Mr. Arthur J. Wands of Stone City and most of the clay mined is trucked to the loading station of the Colorado Railroad on Turkey Creek and shipped to the Denver Fire Clay Co., Denver, Colorado. Although there is a kiln at the mine, all clay is now being shipped raw.

SNOWDEN ENTRY

In the next canyon southeast of Spring Canyon the Pueblo Clay Products Co. has a prospect in which the clay beds of the Dry Creek Canyon member are exposed. A short assessment tunnel, the Snowden entry, was opened in the northwest wall of the canyon in the center of NE¼NE¼ sec. 35, T. 18 S., R. 67 W. The company plans to use this entry to work the clay in the west half of this quarter section.

ABANDONED WORKINGS

Essentially all the clay body has been mined out in the entire area bounded by Dry Creek Canyon, the channel-cut areas to the north and northwest (see pl. 3), and the abrupt steepening of dip to the southwest. The minable clay in the spur between the east and west forks of Dry Creek Canyon has also been taken out. The mining was done from numerous entries, chiefly on the west side of Dry Creek Canyon in theW½NW¼SE¼ sec. 26, T. 18 S., R. 67 W. One entry is in the west wall of the next canyon west in about the center of the E½NE¼SE¼ sec. 26, T. 18 S., R. 67 W. The tonnage recovered from these workings is not recorded but on the basis of their areal extent about 300,000 tons is probably a fair estimate. Sizable pillars have been left in some parts of the workings but the volume of clay left may not be sufficient to warrant reopening the mines. The clay was mined by the Pueblo Clay Products Co.

The only other abandoned mining operation in the Stone City area is the old mine of the U. S. Zinc Co., whose partially caved entry is in the east wall of the canyon of Turkey Creek just north of the middle of the south line of the SE¼SE¼ sec. 36, T. 18 S., R. 67 W. The approximate area mined is shown on plate 3. Between 60,000 and 80,000 tons of flint clay is reported to have been mined. The condition of the mine did not permit complete examination of the working faces and it is not certainly known whether or not the limit of the clay was reached to the southeast. Channel cutouts are present north and south of the mine but whether or not they coalesce to the southeast is not known. Drilling would be necessary to determine whether the old workings could be extended profitably to the southeast. This mine, the first in the area, was formerly leased and operated by the

U. S. Zinc Co.'s plant at Pueblo. At present the land is privately leased.

RESERVES

Tonnage estimates are based on the areal distribution of the clay bed where it equals or exceeds 5 feet in thickness. On plate 3 the location of areas of minable clay is shown, along with the factors limiting their extent. Primary among these factors are the cutouts, or channels along which erosion has thinned and cut out the clay bed. The limits of the cut-out areas have been determined as accurately as possible from the evidence available, but between actual outcrops reserves are inferred. As the area of minable clay depends on the actual limits of the cut-out areas, which can be outlined more definitely only by drilling or mining, all reserves in the Stone City area must be classed as "indicated", or where outcrop evidence is lacking as "inferred".

Calculation of flint clay tonnage is based on an average thickness of 5 feet of flint clay for those areas underlain by a typical sequence of clay-bearing strata, such as that shown in the second columnar section for the Stone City area in figure 14, and an average thickness of 2 feet of flint clay for those areas where the plastic clay predominates. The acre-tonnage factor is 10,000 short tons and represents the recoverable acre-tonnage of a 5-foot clay bed.

The estimated reserves of high-alumina flint clay in the Stone City area, including the minor amounts of flint clay in areas where plastic clay predominates, are as follows:

	Short tons
Indicated flint clay	656, 000
Inferred flint clay	326, 000
Total	982, 000

Estimated reserves of refractory and semirefractory grade plastic clay, not including the plastic clay in areas where flint clay is the dominant type, are as follows:

	Short tons
Indicated plastic clay	246, 000
Inferred plastic clay	180, 000
Total	426, 000

The total estimated tonnage of plastic and flint clay is 1.4 million short tons. This figure represents recoverable tonnage in areas accessible from the outcrop or from present mine workings.

FUTURE PROSPECTING

Because of the considerable tonnage of known clay deposits there is little need for subsurface prospecting in the Stone City area. Some clay bodies doubtless extend down dip under the valley on the Graneros shale. Diamond drilling would be required to determine the distribution of such deposits. Presumably these extensions contain a large quantity of clay that could be recovered by sinking one or more shafts in the valley and mining up dip. Because of the expense of deep mining it is most unlikely that these potential sources of clay will be exploited before the more accessible large reserves in the Hell Canyon area have been brought into production.

In two parts of the Stone City area a few exploratory holes might prove profitable in determining possible extensions of old workings. One of these parts is in the northeast corner of SE¼ SW¼ sec. 26, T. 18 S., R. 67 W., where there is doubt as to whether the clay-bearing zone is pinching out to the west or whether the old workings west of Dry Creek Canyon were not mined to the floor of the clay bed. The second area is that containing the old U. S. Zinc Co. mine in the southeast corner sec. 36, T. 18 S., R. 67 W., and northeast corner sec. 1, T. 19 S., R. 67 W. Here drilling would be warranted to determine possible extension of the clay body to the southeast beyond the abandoned workings. Southeast of this area the Dakota sandstone underlying the large flat on the Graneros shale in sections 6 and 7, T. 19 S., R. 66 W., is a second potential source of deep clay that could be mined up dip from shafts.

HELL CANYON AREA

The Dry Creek Canyon member of the Dakota sandstone is locally present over an area of about 5 square miles in the center and along the east side, of the Turkey Creek district. This area, named the Hell Canyon area for one of its larger drainage courses, lies north and northeast of the Stone City area in sections 13, 24, 25, in parts of sections 14, 23, 26, T. 18 S., R. 67 W., and in the E½ of sections 18, 19, 30, T. 18 S., R. 66 W. The east half of the area is crossed by Turkey Creek which has cut a broad canyon in the Dakota and Purgatoire beds. Another deep canyon, Hell Canyon, runs southeast through the center of the area, joining Turkey Creek just north of Teller Reservoir in the center of the S½SE¼SW¼ sec. 30, T. 18 S., R. 66 W. In addition to the canyon of Turkey Creek and Hell Canyon, numerous tributary canyons are cut into the Dakota and Purgatoire beds.

ACCESSIBILITY

Only that part of the Hell Canyon area east of Turkey Creek is accessible by road. The dissected upland west of the creek has a few trails and old logging roads that could be opened for vehicles without much difficulty but these are not passable at present. Areas of minable clay between Turkey Creek Canyon and Hell Canyon could best be reached by reopening the old fording place on Turkey Creek between the Brooks ranch and Teller Reservoir in the SW¼NW¼ sec. 30, T. 18 S., R. 66 W. From here old wood roads that could be reopened lead to all bodies of minable clay in this part of the area. The part of the area southwest of Hell Canyon can be reached by an old road that extends up the dip slope on the Dakota sandstone just southeast of Spring Canyon. The area east of Turkey Creek is easily accessible as it is mostly open prairie and is crossed by numerous passable roads and trails.

GEOLOGY AND CLAY DEPOSITS

Structurally the Hell Canyon area lies chiefly on the northward-striking east limb of the Turkey Creek anticline; the southwest end lies along the axis. The dips in few places exceed 5° and average about 3°. There are no major faults in the area. The geology and the general location of clay bodies that may be minable in the Hell Canyon area are shown on plate 4.

The Dry Creek Canyon member of the Dakota sandstone in the Hell Canyon area differs slightly from that of the Stone City area in the following respects: The roof-rock zone is more persistently developed throughout the Hell Canyon area and channels occupied by the roof-rock sediments are as important as the channels occupied by fills of the upper sandstone unit in determining the limits of minable clay bodies. The principal clay type of the area is flint clay. Although plastic clay is locally developed to a considerable thickness, no large bodies of predominantly plastic clay like those in the Stone City area were observed. The flint clay in the Hell Canyon area in many places contains quartz grains sparsely scattered throughout its entire thickness and the basal sandy flint clay is commonly thicker than it is in the Stone City area. The scattered sand grains appear to make little difference in the analyses of the clay, in fact, the flint clay in Hell Canyon has a slightly higher average alumina content than the flint clay in the Stone City area.

Columnar sections of the bed in parts of the Hell Canyon area are shown on figure 15. Analyses of the clays are given on page 100, analyses 71 to 81, inclusive.

CLAY MINES

With one exception the clay bodies in the Hell Canyon area have been developed only by prospect pits and assessment holes. The exception is an entry, called the Meadow mine,[1] 1 mile airline east-northeast of Stone City in the SE¼NE¼NW¼SW¼ sec. 25, T. 18 S., R. 67 W. This entry was opened for a period of three months during 1945 by the Pueblo Clay Products Co. and approximately 600 tons

[1] This is the Pueblo Clay Products Co. name for the mine referred to as the "Walker mine" by Argall (1949, p. 100).

of clay, predominantly flint clay, was removed. The clay was hauled down hill by truck over an access road that joins the access road between Stone City and the Spring Canyon mines just southeast of Spring Canyon. The Meadow mine is in the southwest corner of a large clay body (see prospect 5, p. 67) and may become one of the larger clay mines in the district after mining of clay in the more accessible Stone City area has become unprofitable.

RESERVES

The clay-bearing zone of the Dry Creek Canyon member is considered to be of economic value where the total thickness of flint and plastic clay is 5 feet or more. The limits of areas of minable clay cannot be accurately determined without subsurface exploration but in most places geologic controls indicate their probable extent. As the belts along which the clay is cut out are in the nature of channels occupied by the overlying upper sandstone unit, attempts have been made to trace the courses of such channels through the area (see pl. 4), and they have been taken into consideration in limiting the extent of clay bodies. However, it is not possible to infer their courses satisfactorily everywhere, and the outcrops of the clay are the only limits of the bodies that are surely known. Aside from the outcrops and the inferred channels other limiting factors that cannot be determined from surface evidence alone include: the local thickening of the roof-rock zone of the Dry Creek Canyon member at the expense of the clay bed; the presence of local channels, or branches from known channels, which are not evident on the outcrop; and the position of the limit, in a clay body that is thinning gradually in a given direction, beyond which the thickness of clay is insufficient for economical mining.

The estimated reserves of high-alumina flint clay in the Hell Canyon area are as follows:

	Short tons
Indicated flint clay	800,000
Inferred flint clay	725,000
Total flint clay	1,525,000

The reserve of plastic clay, which constitutes at least one-third of the normal clay bed section in the Hell Canyon area, is estimated at half that of the flint clay or 762,500 short tons. The estimated reserves of flint clay and plastic clay together therefore total 2,287,500 short tons.

The areas of clay that may possibly be minable fall into two categories depending on the amount of evidence available to determine their limits. In group *A* of the prospective areas at least two sides of the body have known or inferred limits and the outcrop shows a clay bed of minable thickness and grade. Tonnage estimates based on group *A* prospects are considered to be "indicated" clay reserves. In group

B only one side of the body has a known limit and this shows a minable grade and thickness of clay. Certain areas showing little or no surface evidence of minable clay, but extensive enough to contain unexposed bodies of clay, are noted as possible areas for subsurface exploration.

The average thickness of the flint clay is taken as 4 feet, which is probably a little less than the true average. Possible recovery per acre, based on percentage of recovery in the mines of the Stone City area, is taken as 8,000 tons per acre for an overall thickness of 4 feet. The available tonnage of plastic clay was not calculated; this type of clay is highly variable in thickness and throughout the area is probably subordinate in amount to the flint clay. Location of the prospective areas described below is shown on the map of the Hell Canyon area, plate 4.

GROUP A PROSPECTS

Prospect 1 of the group *A* areas is located on the divide between two small tributaries of Turkey Creek in the N½NE¼NW¼ sec. 24, T. 18 S., R. 67 W. and extends into the NE¼NW¼NW¼ of section 24. The clay body crops out on its north and south sides. To the west its thickness decreases gradually owing to channeling associated with the roof rock and the limit of mining is inferred. The eastern limits of the body are also inferred. At the east end of the south crop line the clay bed is cut out by channeling; the east end of the north crop line is obscured by slump. The average thickness of flint clay on the outcrop is 4 feet; that of the plastic clay is 1 to 2 feet. The chemical composition of the flint clay, which contains scattered sand grains, is given in analyses 78 and 79. The roof of the clay consists of alternating sandstone and shale of the roof-rock phase of the Dry Creek Canyon member.

Prospect 2 is a small area of clay that lies south of prospect 1 on the opposite side of the canyon in the center of the NW¼ sec. 24, T. 18 S., R. 67 W. It is a roughly triangular area with its northeast limit along the outcrop and its southeast limit along a fairly well established channel-cut area. On the west it is limited by gradual reduction in thickness of the clay, due to channeling associated with roof-rock beds. The average thickness of the fiint clay is 4 feet, that of the plastic clay is 2 to 5 feet. The composition of the flint clay, which contains scattered sand grains, is given in analysis 75; that of the plastic clay, which thickens toward the west side of the body and also contains scattered sand grains, is given in analysis 80. The roof of the clay is poor, consisting of shaly clay and sandstone of the roof-rock zone overlain by fractured remnants of the upper sandstone unit. Possibly the body could be strip mined with heavy equipment.

Prospect 3 occupies most of the SE¼NW¼ sec. 24, T. 18S., R. 67W., except for the northwest corner. The outcrop forms the limit of the body on the northeast and southwest sides; the northwest limit is the fairly well established channel-cut area that limits prospect 2 on the southeast. The southeast limit is assumed to be determined by an apparent thinning of the clay to less than minable thickness, but the outcrop is obscured, and clay of minable thickness may extend farther to the east and southeast. Average thickness of the flint clay is 4 feet; that of the plastic clay is 2 feet. The roof consists chiefly of massive sandstone of the upper sandstone unit of the Dakota. The flint clay is similar in character to that of prospects 1 and 2, which were once part of the same clay body. The composition of a sample of the flint clay in prospect 3 is given in analysis 77.

Prospect 4 occupies a small area in the northeast corner of the SE¼SW¼ and the northwest corner of the SW¼SE¼ sec. 24, T. 18S., R. 67W. The south limit of the body is on the outcrop; the east and northeast limits are against a well-defined channel-cut area. The body may extend northward as a long, narrow deposit between cut-out areas on the east and west, but it is more likely that these cut-out areas coalesce. The average thickness of the flint clay is 4 feet; that of the plastic clay is 1.5 feet. The roof consists of roof-rock sandstone overlain by massive sandstone of the upper sandstone unit of the Dakota. The flint clay is not as sandy as in prospects 1, 2 and 3.

Prospect 5 is a large area occupying the south three-quarters of the SE¼NW¼, most of the E½SW¼NW¼, and portions of both the NE¼SW¼ and NW¼SW¼ sec. 25, T. 18 S., R. 67 W. The area is limited on the north and in the south and southeast by the outcrop. The west limit is inferred to be against an obscure channel cutout. The east limit is inferred to be where the flint clay appears to thin to less than 4 feet. Channel cutouts along the south limit of the clay body appear to be local but may extend well into the body. The average thickness of flint clay is 4 feet; that of plastic clay is 2 to 3 feet. Selected samples (analyses 71, 72, and 73) suggest that the content of alumina in the flint clay of this area is consistently high. Black semiplastic clay is locally present in small quantities. Plastic clay exceeds 2 feet in thickness at some places but is not predominant in any of the areas in which it has been observed. Shaly beds of the roof-rock zone of the Dry Creek Canyon member of the Dakota sandstone are present in the east half of the area; in the west half the massive upper sandstone unit of the Dakota rests directly on the clay. The Meadow mine of the Pueblo Clay Products Co. (see p. 64) was opened in the southwest corner of the clay body but no appreciable tonnage of clay has been taken from it to date. Two short assessment tunnels are open near the center of the north outcrop.

Prospect 6 is a small area lying chiefly in the NW¼SW¼SE¼ and extending into the southeast corner of the NE¼SW¼ of sec. 25, T. 18S., R. 67W. The northeast and southwest limits are along the outcrop; the northwest and southeast limits lie along well defined channel cutouts. The average thickness of the flint clay is 4 feet; that of the plastic clay is 2 feet. The north half of the clay body has a good roof with a thin roof-rock zone and thick, massive sandstone above. In the south half the roof rock thickens and the overlying sandstone thins and is badly jointed. The flint clay (analysis 74) is locally sandy.

GROUP B PROSPECTS

Prospect 7 occupies a large area along the east third of the SE¼ sec. 13, T. 18 S., R. 67 W. and extends an unknown distance eastward into the SW¼ sec. 18, T. 18 S., R. 66 W. The only limit of this area that has been located is the outcrop of clay that extends for about half a mile north along the east wall of Turkey Creek canyon from a point near the southeast corner of sec. 13, T. 18 S., R. 67 W. An old shaft that shows flint clay on the dump and is said to be 80 feet deep is a little over a quarter mile due east of the north end of the clay outcrop. Tonnage estimates are based on a roughly rectangular area between the outcrop and a north-south line drawn through the old shaft. The thickness of clay penetrated by the shaft is not known. Subsurface exploration would be necessary to determine the actual extent of minable clay. The average thickness of flint clay on the outcrop is 4 feet, that of the plastic clay is 1 to 3 feet. The flint clay contains sparsely scattered sand grains but is of good grade (analysis 76). The plastic clay attains local thicknesses of 3 to 5 feet and is also of good grade (analysis 81).

AREAS FOR SUBSURFACE EXPLORATION

Several tracts within the Hell Canyon area that are known to include the Dry Creek Canyon member of the Dakota sandstone show little or no clay on the outcrop of the clay-bearing zone. Where such tracts are relatively large they may nevertheless contain minable clay bodies in the subsurface and therefore are considered worthy of prospecting. For this purpose test pitting would be impracticable as the thick (25 feet) basal sandstone of the upper sandstone unit of the Dakota is present everywhere over the Dry

Creek Canyon member and diamond drilling would be necessary. The average depth of drill holes would be about 40 feet.

The broad eastward-sloping flat underlain by the upper sandstone unit of the Dakota sandstone east of Turkey Creek is large enough to contain several bodies of minable clay. Prospect 7 is the only part of this flat that shows evidence of clay and drilling would be warranted in order to delimit the clay body in that vicinity. Elsewhere along the outcrop on the east wall of Turkey Creek canyon the clay bed of the Dry Creek Canyon member is generally absent. Exploratory drilling might nevertheless be warranted in other parts of the flat on the chance that unexposed clay bodies may be present. It is believed that the minimum amount of drilling necessary to explore the area would be involved in a pattern of drill-holes on 800-foot centers.

In the upland portion of the Hell Canyon area west of Turkey Creek some of the larger areas underlain by the Dakota sandstone are bordered by outcrops that locally show minable thicknesses of clay, though most of it is no more than a foot or two thick and in some places it has been completely cut out by channeling. In areas adjacent to outcrops along which evidence of clay persists in this manner exploratory drilling may be justifiable in view of the possibility that the clay may increase to minable thickness back from the outcrop. Several such areas are described below; these areas, with a few exceptions, are in T. 18 S., R. 67 W.

An elongate area of outcrop of the Dakota sandstone which is considered to offer the best possibility of containing minable clay, occupies the southwest corner of section 25 and extends north-northeast along the west side of the section into the W½SW¼NW¼ sec. 25 and SE¼NE¼ sec. 26. The north end of this area lies just west of the large clay body of prospect 5 and clay of minable thickness and grade is exposed at a number of places along the outcrops bordering the area. The clay is not exposed continuously for appreciable distances at any of these places.

A remnant of the Dakota sandstone lies across the west half of the line between sections 24 and 25. The west end of this remnant, in the vicinity of the corner shared in common by sections 23, 24, 25, and 26, may possibly contain a small clay body.

A broad expanse of outcrop of the Dakota sandstone occupies most of the NE¼ sec. 25 and the southeast corner SE¼ sec. 24, T. 18 S., R. 67 W., and extends southeastward into the E½ sec. 30, T. 18 S., R. 66 W. The Dry Creek Canyon member exposed around the margins of this outcrop shows extensive cutouts and little clay. Presence of minable clay bodies is nevertheless considered to be at least remotely possible because of the relatively great distances between outcrops.

TOTAL RESERVES IN THE TURKEY CREEK DISTRICT

Estimates of reserves of refractory clay in short tons for the Turkey Creek district as a whole are listed below:

	Indicated	Inferred	Total
Flint clay:			
Stone City area	656, 000	326, 000	982, 000
Hell Canyon area	800, 000	725, 000	1, 525, 000
Totals	1, 456, 000	1, 051, 000	2, 507, 000
Plastic clay:			
Stone City area	246, 000	180, 000	426, 000
Hell Canyon area	----------	762, 500	762, 500
Totals	246, 000	942, 500	1, 188, 500

The tonnages listed for plastic clay in the Stone City area do not include the plastic clay of those areas where the flint clay is the predominant clay type. It is estimated that the plastic clay in these areas totals about 300,000 short tons. Adding this figure to the reserves given above, the total refractory clay recoverable in the Turkey Creek district is approximately 4 million short tons.

BEULAH DISTRICT

The Beulah district (fig. 1) includes a large area underlain by the Dakota sandstone which locally contains the Dry Creek Canyon member. Clay is mined from this member in the Rock Creek area in the southeastern part of the district. Reconnaissance study was made of an area of about 40 square miles lying to the east and northeast of the settlement of Beulah, Pueblo County, and traversed in the southern part by State Route 76 which runs between Beulah and Pueblo. The area occupies the south part of T. 21 S., R. 67 W., the whole of T. 22 S., R. 67 W., a small part of the southeast corner of T. 21 S., R. 68 W., and the east half of T. 22 S., R. 68 W.

GEOLOGY AND CLAY DEPOSITS

The eastern part of the Beulah district consists of a broad flat developed on the Dakota sandstone. Along the western edge of the district the Dakota caps the dip slope of a cuesta flanking the east slope of the Wet Mountains. The entire area is broken by numerous northwest-trending strike faults, seldom exceeding 100 feet in displacement, the majority of which are downthrown on the east. The east boundary of the area is marked by a strike fault that brings the Dakota to the surface. The basal beds of the Graneros shale crop out over limited areas in the eastern part of the district. The Purgatoire formation is exposed in many canyons which cut through the Dakota in the western part of the flat.

In general the Dakota sandstone of the Beulah district is both thicker and considerably coarser in texture than is normal for that formation elsewhere in Pueblo County. In the cuesta east and northeast of Beulah, the Dakota is over 200 feet thick and consists of massive, cross-laminated sandstone that is locally conglomeratic; both the Purgatoire and Dakota beds here consist chiefly of sandstone forming what may be a local deltaic deposit that, according to Gilbert (1897), reaches a maximum total thickness of over 600 feet. The Dakota thins abruptly to the east and is between 120 and 150 feet thick over most of the district.

The Dry Creek Canyon member of the Dakota sandstone is locally present in the southeastern part of the district and at a few scattered localities near the foot of the dip slope of the hogback in the southwestern part of the district. At several places in the Beulah district sections of the clay-bearing zone that are sandy throughout and show a mixture of clay types suggest that this district lies along the edge of the basin in which the Dry Creek Canyon member was deposited. The local deltaic deposit in the Purgatoire and Dakota formations in the hogback northeast of Beulah supports this belief.

The clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone contains refractory flint clay and plastic clay along Rock Creek in the southeast corner of the district but is not known to contain flint clay in economic quantity elsewhere in the district. In the Rock Creek area the average section of the clay-bearing zone resembles the sections in the Turkey Creek district although the plastic clay bed is consistently thicker.

ROCK CREEK AREA

The Rock Creek area is in the southeast part of the Beulah district in sections 22, 23, 26, 27, 34, and 35, T. 22 S., R. 67 W., Pueblo County. The area lies about 14 miles southwest of Pueblo near Colorado State Route 76, locally known as the Beulah Road. Mining operations in the Rock Creek area are confined to a small area in sections 26 and 35, T. 22 S., R. 67 W., which lies about 1½ miles south of Route 76. Clay mined here is carried by truck to Pueblo. The area is accessible by road, but the nearest railroad is at Pueblo.

GEOLOGY

The areal geology of the Rock Creek area is shown on plate 5. The major portion of the area is a broad flat underlain by the Dakota sandstone. A few canyons cut by Rock Creek and its tributaries afford the only outcrops of the Dakota on the flat. In the east half of the area a zone of strike faults upthrown to the west brings the lower part of the Dakota into contact with the Graneros shale and, locally, the uppermost part of the Dakota. This fault zone is marked by an eastward-facing escarpment locally exposing most of the Dakota but not its basal contact with the Purgatoire formation. A valley lying east of the fault scarp is occupied by the Graneros shale and

Recent alluvium. East of the valley a high westward-facing escarpment composed of Graneros shale, Greenhorn limestone and Carlile shale, is capped by several feet of the basal Timpas limestone.

The Dakota sandstone of the Rock Creek area is variable in character. What may be the base of the formation is exposed in only one place in the area, where Rock Creek crosses the fault scarp in the southeast corner of the NW¼ sec. 26, T. 22 S., R. 67 W. Here the Dakota totals about 120 feet in thickness and exposes the following section.

Section of Dakota sandstone exposed where Rock Creek crosses fault scarp in sec. 26, T. 22 S., R. 67 W

Dakota sandstone:	
Upper sandstone unit:	*Feet*
Sandstone, medium- to fine-grained, platy, weathers to buff, interbedded with dark gray sandy shale in upper part	15
Sandstone, medium-grained, massive, cross-laminated, with stringers of coarse-grained sandstone in basal part	25–50
Disconformity.	
Dry Creek Canyon member (in part):	
Flint clay, very sandy, brownish gray, and argillaceous sandstone	0–5
Sandstone, dark gray, argillaceous, grading into light gray, fine-grained even-bedded sandstone	0–10
Disconformity.	
Lower sandstone unit:	
Sandstone, medium-grained, massive, cross-laminated, light gray	50
Outcrop obscured, appears to be in part softer, gray to buff, even-bedded sandstone	3–5
Slope wash covers remaining 25 feet to bottom of Rock Creek Canyon.	

The base of this section, although covered by slope wash, appears to be in nonresistant strata and suggests that the upper part of the Glencairn shale member of the Purgatoire formation may be present. Elsewhere in the area no complete section of the Dakota is exposed.

The Dry Creek Canyon member of Dakota sandstone appears to be present in its entirety at only two places in the Rock Creek area. In the vicinity of the old mine entries along the fault in the center of the N½N½ sec. 35 and in the SE¼SW¼ sec. 26, T. 22 S., R. 67 W., the member is generally present although locally it is completely cut out by channels. It is also present where the canyon of Snake Creek cuts the escarpment just west of the Rock Creek fault in the NW¼NW¼ SE¼ and the SE¼SE¼NE¼ sec. 22, T. 22 S., R. 67 W.

The Rock Creek area is traversed by a northwestward-trending zone of discontinuous strike faults, downthrown to the east (see pl. 5). Details of this fault zone, called the Rock Creek fault, are locally obscured by slump and talus, but at any one locality along the displacement the major part of the throw appears to be taken up by a single fault. Auxiliary faults are common locally and the displacement is accurately designated a fault zone rather than a single fault. The throw on the Rock Creek fault can be measured fairly accurately except at the north and south limits of the area where Graneros shale is faulted against Graneros shale; here the trace of the fault is obscure. In the middle part of the area the maximum throw, from 60 to 90 feet, occurs between Snake Creek and Rock Creek. South of Rock Creek the throw varies considerably in amount but seldom exceeds 40 feet.

A broad shallow anticline, the axis trending southwest approximately normal to the Rock Creek fault, is present in the south half of the area. It is a low, relatively flat-topped arch with a somewhat steeper dip on the north limb than on the south. Minor faults, some laterally forming monoclines, parallel the anticlinal axis and are responsible for slight offsets in the scarp of the Rock Creek fault. These cross faults are common in the mining area and one between mine entries 1 and 3 is responsible, along with the north dip of the strata, for the discrepancy in the elevation of entries 1 and 3 which has led to the erroneous belief that these entries are in different clay beds.

CLAY DEPOSITS

In the Rock Creek area outcrops of the clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone are scarce. Along the eastward-facing scarp of the Rock Creek fault the clay, where present, is generally obscured by talus and slump. On the flat prairies west of the fault very few canyons have been incised to a sufficient depth to expose the clay horizon. The clay in the mines ranges from 3 to 15 feet in thickness and averages between 6 and 7 feet. The following section is typical for the clay-bearing zone in the Rock Creek area.

Composite section of the clay-bearing zone of the Dry Creek Canyon member of the Dakota sandstone from sections in the Rock Creek mines of the Standard Fire Brick Co.

	Feet
Upper sandstone unit forming mine roof: Sandstone, generally massive.	
Clay beds:	
Clay, plastic, gray; generally contains sandy beds or thin beds of sandstone in lower part; forms roof-rock zone	0–2
Clay, plastic, dark gray to black, massive, weathers bluish gray. High content of finely divided carbonaceous material	3–10
Intermediate zone, may be absent or represented by one of the following rock types	0–4
Clay, semiplastic, silty to sandy, brownish gray.	
Clay, semiplastic, hard, black, overlain by 2-inch marker clay bed.	
Flint clay, gray to brownish-gray, containing variable amounts of fine sand and some carbonaceous matter	0–10
Flint clay, sandy, grading into fine-grained sandstone with flint clay matrix, dark gray to dark brown	1–5
Sandstone of mine floor.	

The principal local deviations from this generalized section are the gradual thickening of the sandy roof-rock zone at the expense of the plastic clay; the gradual introduction, laterally, of fine sand and silt in the upper part of the flint clay bed; and the local absence of the high-grade upper part of the flint clay bed in places where the black semiplastic clay is abnormally thick. All of these deviations directly or indirectly affect the high-alumina flint clay. The roof-rock channel fills may be small and constitute a local sand lens within the plastic clay or they may be large and replace the entire clay bed over considerable areas.

Lateral change in grade of the flint clay by the introduction of fine sand is a common feature in the Rock Creek mines, especially in entries 1 and 2. This change reduces the flint clay to the status of sandy flint clay and the alumina content decreases to below 35 percent. The chief physical change is a gradual roughening of the usually smooth (flinty) surface accompanied by a slight color change from gray to brownish gray.

CLAY MINES

The only mining in the Rock Creek area has been done by the Standard Fire Brick Co. of Pueblo. Since 1939 the company has opened three entries in exposures of the clay along the Rock Creek fault scarp and has opened a slope mine west of the fault. Of these mines, collectively called the Rock Creek mines, only the slope mine is in operation at the present writing (1950). Two short prospect tunnels on Snake Creek and one on Rock Creek are the only other entries into the clay bed in the Rock Creek area.

The Rock Creek mines are owned and operated by the Standard Fire Brick Co., which hauls the clay in trucks to the company's kilns at Pueblo. In 1939 three entries were made in the clay where it is exposed in the scarp of the Rock Creek fault. Entries 1 and 2 are in the northwest corner of the NE¼ sec. 25, T. 22 S., R. 67 W. Entry 3 is in the SE¼ NE¼ SE¼ SW¼ sec. 26, T. 22 S., R. 67 W. These entries were worked at different times up to 1948 by which time they were essentially mined out to the limiting sandy areas and channel cutouts to the north, south, and west. No figures are available on the total tonnage of clay removed from these three entries but it is judged to be about 80,000 short tons, 25 or 30 percent being flint clay. Throughout the entries the average thickness of the flint clay was about 2.5 feet and of the plastic clay between 3 and 3½ feet. The flint clay exceeded 4 feet in thickness in very few places. Analyses of clays from the three entries are given on p. 99, numbers 25 to 49 and 51 to 56 inclusive.

In February 1948, after several diamond-drill holes in the flat west of the fault showed that clay was present beyond the western limits of the three crop entries, a slope was put down to the clay bed through 36 feet of the upper sandstone unit in the SE¼SW¼SW¼ sec. 26, T. 22 S., R. 67 W. Since that time this slope mine has been producing clay at the rate of about 1,000 short tons a month. By September of 1950 the workings of the mine had not reached any limiting channel cutouts or sandy areas. The flint clay and plastic clay beds together vary in thickness between 10 and 17 feet, the maximum thickness known in any area for the clay beds of the Dry Creek Canyon member. The flint clay portion of the bed is from 5 to 10 feet thick; the average thickness of the plastic clay is about 6 feet. Beds of sandstone are common in the plastic clay zone and one at the base of the zone is persistent.

The size of the new clay body tapped by the Rock Creek slope mine is unknown as no parts of it crop out. The drill hole records available indicate that it underlies a large part of the S½SW¼ sec. 26, south of the northeast-trending fault, and the N½NW¼ sec. 35, T. 22 S., R. 67 W. It may extend well beyond these quarter sections to the north, west, and south.

Two prospect tunnels are located on Snake Creek just west of the Rock Creek fault in the NE¼NE¼SE¼ and the SE¼SE¼NE¼ sec. 22, T. 22 S., R. 67 W. The first, prospect 1, consists of a 15-foot tunnel into the clay-bearing zone in the south wall of the shallow canyon of Snake Creek; the second, prospect 2, is farther west up the canyon in the north wall. Both prospects are in the Dry Creek Canyon member of the Dakota sandstone. The following section from prospect 1, illustrates the character of the clay-bearing zone in both tunnels.

Section of Dry Creek Canyon member of Dakota sandstone exposed in prospect 1

	Feet
Upper sandstone unit:	
Clay, plastic, sandy, platy, gray	1.5
Flint clay, bluish-gray, with scattered thin beds of plastic clay	3
Clay, plastic, shaly, somewhat sandy highly carbonaceous, dark gray	1.5
Sandstone, argillaceous, gray to brown	2.5
Sandstone, fine-grained, even-bedded, light gray	5
Shale, sandy, carbonaceous	1
Lower sandstone unit.	

The plastic clay bed as developed in the Rock Creek mines is either cut out in the Snake Creek prospects or has given way laterally to a reworked zone of mixed flint and plastic clay. Pockets of good flint clay are present in both prospects but because of the mixture of clay types the grade is not consistent. Partial analyses of samples from prospect 1 are given on page 99, analyses 62 and 63.

The clay-bearing zone of the Dry Creek Canyon member is exposed in an old prospect in the canyon of Rock Creek just west of the Rock

Creek fault near the center of the SE¼NW¼ sec. 26, T. 22 S., R. 67 W. A bed of predominantly plastic clay is underlain by a thin bed of sandy flint clay; neither is of minable grade or thickness. Partial analyses of samples from this locality are given in analyses 57 through 61.

MINES AND PROSPECTS IN OTHER AREAS

Only one small abandoned clay mine has been found in the Beulah district outside the Rock Creek area. One prospect has also been visited and others probably are present in the less accessible parts of the district. The following section of the clay-bearing zone of the Dry Creek Canyon member is exposed at the entry to abandoned mine workings on the south side of an eastward-trending canyon tributary to Galbeth Creek in the SE¼ sec. 16, T. 22 S., R. 67 W.

Section of Dry Creek Canyon member of Dakota sandstone exposed in SE¼ sec. 16, T. 22. S., R. 67 W.

Dry Creek Canyon member:	*Feet*
Sandstone, hard, gray (roof-rock)	2
Clay, plastic, dark blue-gray to black, thinly interbedded with gray sandstone	3–8
Flint clay, moderately sandy to very sandy, blue to brownish-gray, with scattered beds of good flint clay	3
Sandstone, hard, carbonaceous, with flint clay matrix (mine floor)	1
Sandstone, even-bedded, white	10–15

There is considerable plastic clay but the flint clay is not of minable grade and thickness, and little clay appears to have been taken from the mine. The clay body is cut out by channels to the east, west, and south, but may possibly extend to the north.

The clay bed exposed at a prospect in the Dry Creek Canyon member of the Dakota sandstone on the property of Bernard Henratty, about the center of the north line of sec. 31, T. 22 S., R. 67 W., on the north side of a small canyon about 500 feet northwest of Henratty's house, consists chiefly of sandy flint clay of poor grade. Minor streaks of sand-free flint clay are present in the upper part. About 7 feet of sandy clay and clayey sandstone is exposed.

CANON CITY DISTRICT

LOCATION AND SUBDIVISIONS

The Canon City district includes all the outcrop areas of clay-bearing strata, shown on the index map (fig. 1) west of Sixmile Creek in eastern Fremont County. For convenience in discussing the clay deposits, the district is subdivided geographically into the Parkdale, Grape Creek, Skyline Hogback, Wilson Creek, and Oil Creek-Sixmile Creek areas. Clay has been mined in all of the areas. The principal source is the Glencairn shale member of the Purgatoire formation, the flint clay of the Dry Creek Canyon member of the Dakota having been found in minable bodies only in the Wilson Creek area.

CLAY-BEARING BEDS

The clay-bearing formations in the Canon City district are similar in their general character to those of the Turkey Creek district. The Purgatoire formation averages about 200 feet in thickness and the Glencairn and Lytle members are recognizable throughout the area. The thin sandstones intercalated with the shale in the Glencairn of the Turkey Creek district increase in thickness westward along the north side of the Canon City embayment. Along with this thickening, the Glencairn changes locally to a predominantly arenaceous member with only minor shaly zones. The most persistent shale zone in the Glencairn is at the very top of the member, immediately underlying the Dakota sandstone. Commonly the shale contains plastic clay of economic grade and thickness.

The Dakota sandstone locally contains the Dry Creek Canyon member but over most of the district that member has been cut out by channeling prior to the deposition of the upper sandstone unit. Part or all of the member is present in the north end of the Skyline Hogback area, the Wilson Creek area, and parts of the Oil Creek and Sixmile Creek area.

CLAY MINING

A great deal of clay has been mined in the vicinity of Canon City since the 1890's both by clay-products companies and independent operators, but only the principal clay producers of recent years are mentioned in this report, the scope of which does not permit an historical survey of the mining. The biggest holders of property containing refractory clay in the area have been the Diamond Fire Brick Co. and the Jewett Fire Brick Co. The Diamond Fire Brick Co. has had the most extensive holdings and the longest record of operation. In December of 1949 its properties, including its plant in Canon City, were taken over by the Laclede Christy Co. of Colorado. The Jewett Fire Brick Co. was dissolved prior to the Second World War. In 1946 its mines and its plant in Canon City were controlled by the Pioneer Brick Works and operated until the early part of 1948. About one year later, in the spring of 1949, the Freeman Fire Brick Co. took over the old Jewett holdings and plant from the Pioneer Brick Works. One clay-products company outside Canon City, the Standard Fire Brick Co. of Pueblo, has holdings in the Canon City district.

CLAY DEPOSITS

A summary of the significant features of the clay deposits in the several areas of the Canon City district is given in the following paragraphs. Only the flint clay deposit of the Wilson Creek area has been given more than cursory study; this deposit is discussed in a separate section.

PARKDALE AREA

The Parkdale area includes two synclines, consisting for the most part of Mesozoic strata, isolated in a terrain of granitic rocks. The Dakota and Purgatoire formations are locally present around the edges of the synclines where they crop out in the steep hogbacks. The town of Parkdale lies at the north end of one syncline; the second syncline lies northeast of Parkdale and underlies the area known as Twelvemile Park.

In the Twelvemile Park syncline, clay from the Glencairn member of the Purgatoire formation was mined for a short time during the early 1930's by Harold Jewett and Vern St. John. The mine, known as the Currant Creek placer, is located in the SW¼ sec. 30, T. 17 S., R. 71 W., where Currant Creek cuts through the "Dakota" hogback on the northeast limb of the syncline.

In the Parkdale syncline the Standard Fire Brick Co. has an open pit mine, the McIntyre mine, located on the north side of McIntyre Gulch at the foot of the hogback near the center of the N½ sec. 24, T. 18 S., R. 72 W., about 2½ miles by road southwest of Parkdale. The clay, which has been worked intermittently, appears to be in the Glencairn shale member of the Purgatoire formation. It consists of about 6 to 8 feet of light to dark blue-gray, tough, plastic clay that underlies a ledge of massive sandstone. Layers of white semi-plastic clay several inches thick are included in the clay body. Partial analysis of the plastic clay is given in analysis 92.

A short-lived stripping operation, the River Clay mine, was worked by the Standard Fire Brick Co., in 1944. This was located on the southwest bank of the Arkansas River in the northeast corner NW¼ sec. 18, T. 18 S., R. 71 W., about one-eighth of a mile northwest of Parkdale. The deposit is in the lower third of the Graneros shale. It is a dark blue-gray to black clay shale, a few carloads of which is reported to have been used as a low-grade refractory clay. No analysis of the clay is available but the composition of similar clay shale from the Graneros shale in Pueblo County is given in analyses 1 and 2. The deposit was mined by strip methods after removal of 2 to 5 feet of overburden consisting of river gravels.

GRAPE CREEK AREA

The Grape Creek area includes the hogback extending south of Canon City through sec. 6, T. 19 S., R. 70 W., and sections 12 and 13, T. 19 S., R. 71 W. In the hogback the Glencairn shale member of the Purgatoire formation is 80 to 90 feet thick and consists of dark gray carbonaceous shale with interbeds of sandstone as much as 4 feet thick. Bodies of plastic clay occur locally in the upper 10 to 20 feet of the unit. The Dakota sandstone lacks the Dry Creek Canyon member and consists of a single unit of massive sandstone. The clay of the Glencairn member has been mined in the area since the early 1900's; abandoned mine workings are located along the hogback south from the Arkansas River. These were once operated by the Diamond Fire Brick Co., the Jewett Fire Brick Co., and one independent operator. The clay was semirefractory plastic clay; chemical composition of a sample is given in analysis 89. Essentially all of the accessible clay of the Glencairn in the area has been removed.

A clay shale in the Dakota and Graneros transition beds was also worked in small operations along the Grape Creek hogback. This material was not refractory and was used for making brick.

SKYLINE HOGBACK AREA

The Skyline Hogback extends north of the Arkansas River from Canon City through sections 32, 29, 20, 17, and 8, T. 18 S., R. 70 W. The north line of section 8 is taken as the north boundary of the area. The clay-bearing formations in the hogback are similar in character to those in the Grape Creek area with two exceptions: the Glencairn member of the Purgatoire formation becomes increasingly more sandy north along the hogback, and the Dry Creek Canyon member of the Dakota sandstone is locally present in the north end of the area.

Abandoned mines in the Glencairn shale member of the Purgatoire formation along the hogback were operated by the Jewett and Diamond Fire Brick companies. The mine most recently in operation along the hogback is the Climax mine, operated between 1945 and 1947 by the Pioneer Brick works in the SW¼ sec 8, T. 18 S., R. 70 W., about 3 miles northwest of Canon City. The clay is plastic and semiplastic and is locally as much as 6 feet thick. Tests of the clay have shown some samples to fuse as high as cone 31. The Climax mine is probably in clay of the Glencairn member rather than in that of the Dry Creek Canyon member of Dakota sandstone. The Dry Creek Canyon member is exposed in a small abandoned open pit farther north along the hogback in section 8 where plastic clay was taken from the upper part of the clay-bearing zone. The lower part of the zone is argillaceous sandstone or very sandy flint clay. No flint clay of good quality is present and this part of the clay-bearing zone appears to be highly sandy throughout the north end of the Skyline Hogback. Most of the accessible high-grade clay in the Skyline Hogback area has been removed, though a slight possibility remains that additional bodies of clay may be present in the Dry Creek Canyon member of the Dakota in the north end of the hogback.

As in the Grape Creek area some of the clay shale at the base of the Graneros shale has been mined locally for low-grade clay, a large amount of which is still available.

OIL CREEK AND SIXMILE CREEK AREA

Purgatoire and Dakota strata cap a southeastward-trending cuesta, which locally takes the form of a hogback, between Oil Creek and Sixmile Creek in the northeast part of T. 18 S., R. 70 W., and the northwest part of T. 18 S., R. 69 W. The Glencairn shale member of the Purgatoire contains considerable sandstone in the vicinity of Oil Creek but becomes more shaly eastward. The local remnants of the Dry Creek Canyon member of the Dakota sandstone, which is absent over most of the area, are not known to contain flint clay bodies of minable grade or thickness. In the east end of the area a 5- to 8-foot bed of dark blue-gray plastic clay from the top of the Glencairn member was mined intermittently during the 1940's by both the Standard Fire Brick Co. of Pueblo and the Diamond Fire Brick Co. of Canon City. The Standard mine is in the NE¼NW¼ sec. 20, T. 18 S., R. 69 W. Composition of clay samples from this mine is given in analyses 90 and 91. The Swastika mine of the old Diamond Fire Brick Co. is located in the NE¼SE¼SE¼ sec. 18, T. 18 S., R. 69 W. and is in the same clay bed as the Standard mine.

FLINT CLAY OF THE WILSON CREEK AREA

The Wilson Creek area includes cuestas capped by the Dakota and Purgatoire formations extending around the northwest end of a syncline that pitches southeastward. Most of the outcrop area of clay-bearing formations lies on either side of Wilson Creek in sections 31, 32, and 33, T. 17 S., R. 70 W., and sections 4, 5, and 6, T. 18 S., R. 70 W. In this area the Glencairn shale member of the Purgatoire consists of alternating beds of dark gray carbonaceous shale and buff, even-bedded sandstone. South of Wilson Creek in sections 3, 4, and 5, T. 18 S., R. 70 W., from 50 to 75 percent of the Glencairn is sandstone; north of the creek in these sections the sandstone is seldom less than 75 percent of the member and locally the member is almost entirely sandstone. The clay in the Glencairn has not been mined in this area, doubtless because of its sandy character.

The Dry Creek Canyon member of the Dakota commonly is present beneath about 3 square miles in the south-central part of the area in parts of sections 3, 4, 5, 8, and 9, T. 18 S., R. 70 W. It includes a minable flint clay bed in the S½ sec. 4, southwest corner of section 3, and the NW¼ sec. 9, T. 18 S., R. 70 W. Elsewhere in the Wilson Creek area this member is present locally but is not known to contain flint clay of minable grade or quantity.

Exposures of the Dry Creek Canyon member are fairly continuous along Wilson Creek canyon from about the center of the SW¼ sec. 4, to about the center of the W½SW¼ sec. 3, T. 18 S., R. 70 W. To the north exposures are numerous in the dissected bluffs bordering the creek and in the south ends of tributary canyons. South of Wilson Creek the only exposures of the Dry Creek Canyon member are in the south wall of the canyon; beyond the canyon wall the Dakota sandstone dips under the overlying Graneros shale.

CLAY MINES

The clay body has been mined both north and south of Wilson Creek. Deer Hill mine lies north of Wilson Creek in the E½SE¼ sec. 4 and W½SW¼ sec. 3, T. 18 S., R. 70 W., and consists of a number of entries into a nearly flat-lying clay-bearing zone of the Dry Creek Canyon member. South of Wilson Creek the clay-bearing zone was reached by a shaft, the Diamond Flint mine, just south of the rim of the canyon in SW¼SW¼ sec. 4, T. 18 S., R. 70 W. Both mines were opened by the Diamond Fire Brick Co. and have been operating intermittently since the First World War. The Laclede Christy Co. of Colorado now controls these holdings.

The Diamond Flint mine, opened in 1918, is the larger of the two mines. Workings extend to the crop along the wall of Wilson Creek canyon and the Laclede Christy Co. has put in an entry on the crop. Records of the Diamond Flint mine have been lost but it is estimated that the Diamond Fire Brick Co. took approximately 5,000 tons of flint clay from the mine before 1944. Since that time it has been idle until 1950 when the Laclede Christy Co. reopened it. Within the mine the dip of the clay-bearing zone of the Dry Creek Canyon member averages about 30° to the southwest. The face shows a thickness of clay between 6 and 7 feet, of which the relatively nonsandy flint clay constitutes between 3 and 4 feet. Channels locally thin and cut out the clay-bearing zone within the mine.

CHARACTER OF THE CLAY-BEARING ZONE

In the limited area described above the Dry Creek Canyon member of the Dakota sandstone contains a clay-bearing zone that shows pronounced lateral variation. North of Wilson Creek in the vicinity of the Deer Hill mine the zone is predominantly a hard, gray to dark gray and black, sandy flint clay which runs less than 30 percent Al_2O_3. South of Wilson Creek the clay exposed on the canyon wall and in the Diamond Flint mine is predominantly a gray flint clay, with a few sandy streaks, that generally has an alumina content of 35 percent or more. The following sections show the physical characteristics of the clay-bearing zone north and south of Wilson Creek.

Composite section of the Dry Creek Canyon member of the Dakota sandstone from sections taken at entries of the Deer Hill mine of the Diamond Fire Brick Co.

	Feet
Roof-rock zone:	
Sandstone, cross-laminated, buff	3+
Shale, sandy, carbonaceous, gray to brown	0.5
Clay-bearing zone:	
Clay, flinty, sandy, light to dark gray, bluish-weathering. A few beds less than 6 inches thick of light gray porcellaneous flint clay at top and base	3–5
Clay, semiplastic, sandy, carbonaceous, brownish-black	3–5
Basal sandstone zone: Sandstone, argillaceous, even-bedded, gray to white, with local thin beds of dark sandy shale	3–?

Section of Dry Creek Canyon member of the Dakota sandstone at outlet of Diamond Flint mine on south wall of Wilson Creek canyon

	Feet
Upper sandstone unit (basal part): Sandstone, massive to even-bedded, buff	10+
Disconformity.	
Dry Creek Canyon member:	
Roof-rock zone:	
Sandstone, argillaceous, soft gray and dark gray, sandy clay	3
Sandstone, massive, cross-laminated; weathers buff; thin lenses sandy plastic clay	10
Disconformity.	
Clay-bearing zone:	
Clay, semiflint, sandy, gray-brown to blue-gray, semiconchoidal fracture (reworked zone ?)	2.5
Flint clay, light to dark gray, locally fragmental, few sandy streaks in middle part, slightly sandy in basal 6 inches	3.5
Plastic clay, dark gray	1.5
Sandstone, argillaceous, dark blue, and sandy clay	0.5
Basal sandstone zone: Sandstone, fine-grained, even-bedded, gray to white with thin interbedded dark sandy shale	4

The composition of a run-of-mine sample of the predominantly sandy flint clay in the vicinity of Deer Hill is given in analysis 67. That of the sandy flint clay of the upper half of the bed in the Deer Hill mine is given in analysis 65 and that of a spot sample of the light gray procellaneous flint clay from the same section, in analysis 66. Analyses of the clay taken from the Diamond Flint mine on the south rim of Wilson Creek canyon are given in analyses 68, 69, and 70. These samples were probably handpicked specimens of the best flint clay. The composition of a channel sample of the upper 6 feet of the clay zone in the Diamond Flint mine, including sandy flint clay, is represented by analysis 64.

A marked change in the character and grade of the clay takes place in the area between the Diamond Flint and Deer Hill mines, an area occupied by the canyon of Wilson Creek. No section showing high-grade flint clay in quantity was found north of the creek and the outcrop area of the good flint clay is limited to a small area on the south wall of the canyon in the vicinity of the Diamond Flint mine.

POSSIBLE EXTENSIONS OF THE FLINT CLAY BODY

North of Wilson Creek no study was made of possible continuations of the clay of the Deer Hill mine to the northwest in the broad cuesta of Purgatoire and Dakota strata that extends into sections 32 and 33, T. 17 S., R. 70 W. The Dakota has been eroded from most of this area but remnants of it just north of Wilson Creek west of Deer Hill may contain clay of minable grade and thickness.

South of Wilson Creek, surface evidence is insufficient to furnish a basis for determining the possible extensions of the clay body in the vicinity of the Diamond Flint mine. The clay-bearing zone is cut out by channels over large parts of the Wilson Creek area. Cutouts limiting the body of flint clay in question to the west and east can be seen in the Wilson Creek canyon in the northeast corner of section 5 and in the southwest corner of section 3, T. 18 S., R. 70 W., respectively. How far these cutouts extend to the south and west would have to be determined by drilling. Where theDakota crops out on the west limb of the syncline along the west side of section 5, T. 18 S., R. 70 W., the clay-bearing zone is locally present in the southwest quarter section but no flint clay of good grade is present. Considerable amounts of flint clay may underline much of section 9 and the east half of section 8, T. 18 S., R. 70 W., although both cutouts and lateral changes in grade can be expected to occur throughout the area of possible extension of the Diamond Flint mine clay body.

The body of flint clay in the Diamond Flint mine lies on the east limb of a south pitching syncline, near the north end of that structure. Dips on the east limb of the syncline average between 25° and 30° to the south-southwest; those on the steeper west limb, which forms the Skyline Hogback, average between 40° and 50°. The dip of the clay bed is so steep that engines must be used to haul the loaded cars up-dip to the shaft. The depth of the clay body in the area of possible extension would in some places prohibit economic recovery of the clay.

The possible reserves of the flint clay cannot be estimated from any available data. The high-alumina clay in question may be a small pocket of limited extent or could conceivably extend over a large area. Both structural and stratigraphic features doubtless limit the minable area. If the character and distribution of the Dry Creek Canyon member of the Dakota elsewhere in the Canon City district can be taken as typical and applied to that part of the Wilson Creek area under consideration, the possibility of discovering any large body of high-grade clay is remote.

PENROSE DISTRICT

The Penrose district, between the Canon City district and the Turkey Creek district, comprises the outcrop areas of Purgatoire and Dakota strata along the north side of the Canon City embayment. These outcrop areas are coextensive with two broad cuestas lying between 4 and 10 miles north and northeast of the town of Penrose (see fig. 1). The westernmost of these two areas lies between Sixmile Creek and Beaver Creek, the other area lies between Beaver Creek and Red Creek.

Little is known about the clay deposits of the Penrose district, as they have not been systematically prospected. No clay has been mined in the Beaver Creek and Red Creek area and only a very small volume has been recovered from the Sixmile Creek and Beaver Creek area. Neither area is near any railroad and the roads giving access to large parts of both areas are inadequate.

The Glencairn shale member of the Purgatoire formation is sandy in its upper, clay-bearing part, in the few scattered exposures observed. Doubtless areas of sand-free clay are locally present but no prospects or claims in the clay of the Glencairn member are known. Remnants of the Dry Creek Canyon member of the Dakota sandstone are present in many parts of the Penrose district. In some places the clay-bearing zone is of minable thickness but appears to be rather persistently sandy; in others it is very thin or is completely replaced by argillaceous sandstone.

Two entries have been made into the clay-bearing zone of the Dry Creek Canyon member in the Sixmile Creek and Beaver Creek area. In 1949 the Freeman Fire Brick Co. made an entry, the Purple Heart mine, into the old Jewett holdings west of Beaver Creek, which occupy N½SW¼ and S½NW¼ sec. 4, T. 18 S., R. 68 W. Clay was removed for testing but no mining operations were started before September 1950. The Love Charm mine was opened by the Pioneer Brick Works in holdings occupying a large part of the E½ sec. 1, T. 18 S., R. 69 W.; the Freeman Fire Brick Co., which succeeded the Pioneer, mined about 1,000 tons of clay from this mine before operations were halted where the clay-bearing zone begins to pinch a short distance from the outcrop.

The section of the clay-bearing zone in the Purple Heart mine is similar to that in the Love Charm mine, which is given below.

Section of the Dry Creek Canyon member of the Dakota sandstone at the entry of the Love Charm mine of the Freeman Fire Brick Co.

	Ft	in.
Roof-rock zone: Sandstone, interbedded with sandy claystone, shale and minor amounts of plastic clay	4	6
Clay-bearing zone:		
Clay, plastic, sandy, light blue-gray	2	
Clay, soft, white to yellow (weathered); the marker clay bed		4
Clay, carbonaceous flint and semiflint, some shaly partings	3	
Clay, gray to dark gray, silty to sandy flint	2	6
Sandstone, argillaceous, with zones and fragments of siliceous flint clay	2	4
Clay, silty to sandy flint and semiflint gray becoming dark gray downward	2	6
Basal sandstone zone: Claystone, sandy, grading to gray to white, even-bedded, argillaceous sandstone with interbeds of sandy shale and sandy claystone	4–?	

The clay at the Purple Heart mine is somewhat less sandy but both mines exhibit a section of clay considerably more sandy than the sections of clay in the Stone City and Rock Creek areas. The sandy flint clay from both mines fuses between cone 32½ and cone 33. No analyses are available but an increase in silica content at the expense of alumina is indicated by the sand content.

The clay deposits of the entire Penrose district cannot reasonably be evaluated on the basis of the clay bodies exposed in the Purple Heart and Love Charm mines and a few other prospects and outcrops. Much more surface exploration is needed and the entire Dakota outcrop should be searched thoroughly before definite conclusions can be drawn about the possibilities for valuable refractory bodies in this district. Nevertheless, the present outlook for discovery of such bodies is somewhat discouraging in view of the circumstance that the clay bodies of the Dry Creek Canyon member found here to date are small, are not widespread, and are persistently sandy.

CLAY DEPOSITS IN ADJACENT COUNTIES

WETMORE AREA, CUSTER COUNTY

The Purgatoire and Dakota formations crop out in the northeast corner of Custer County. One area of outcrop consists of a continuation northwestward of the "Dakota" cuesta of the Beulah district of Pueblo County. This cuesta trends westward north of the Beulah district and forms the north limb of an anticline where it crosses the

Custer-Pueblo County line in about the center of the east line of T. 21 S., R. 69 W. In Custer County the anticline dies out at Hardscrabble Creek in the center of the township and the Purgatoire and Dakota strata continue to the northwest in a prominent hogback along the Wet Mountains. The hogback continues to Adobe Creek in section 8, T. 21 S., R. 69 W.; northwest of that creek it is cut out by faulting and does not reappear over any appreciable area along the mountain front between Adobe Creek and the Grape Creek area of the Canon City district. Because occurrences of clay have been reported along the hogback west and southwest of Wetmore in parts of sections 8, 9, 16, T. 21 S., R. 69 W., outcrops have been examined where Fourmile Creek and Watson Gulch cut the hogback. Although largely covered with slope wash, these outcrops show some plastic clay at the top of the Purgatoire formation. Except for local streaks the clay is sandy and no sizable body of minable clay is indicated. The Dry Creek Canyon member of the Dakota is not present in the vicinity.

A narrow belt of outcrop of the Purgatoire and Dakota formations is exposed around the edge of a syncline that lies chiefly in the south-central part of T. 21 S., R. 69 W. and the NE¼ of T. 22 S., R. 69 W. The syncline area begins about 4 miles south of Wetmore on Colorado State Route 96. Dakota and Purgatoire strata in the steeply-dipping west limb of the syncline were examined at several localities between North and South Hardscrabble Creeks. Outcrops of clay in this area are in the Dry Creek Canyon member of the Dakota.

A road cut on Colorado State Route 274, on the north bank of South Hardscrabble Creek, exposes a section through the eastward-dipping "Dakota" hogback in the SE¼SE¼, sec. 11, T. 22 S., R. 69 W. A 13-foot bed of clay, sandy clay, and sandstone underlies what is probably the upper sandstone unit of the Dakota. Dips on outcrops are as high as 60° to the east with abrupt flattening evident east of the hogback. The clay bed is not similar to the typical section of the clay-bearing zone of the Dry Creek Canyon member. Two beds of sandy plastic clay are present in the outcrop; an upper bed immediately underlying the sandstone is between 3 and 5 feet thick and a second bed 3 feet thick is separated from it by 4½ feet of sandstone and sandy clay. The composition of the clay of the upper bed is given in analysis 83 and the lower bed in analysis 82. Neither bed is of value as a refractory clay.

On the south bank of South Hardscrabble Creek opposite outcrop 1, a second outcrop of the clay under the upper sandstone unit of the Dakota is present. Though the clay-bearing zone is largely covered by wash and vegetation, flint clay crops out near its base along the road gutter. The total thickness of the flint clay was not measurable but at least 2 feet is present. The upper part of the zone is probably plastic clay; some sandstone is present with the plastic clay. A sample of the flint clay was taken and its composition is given in analysis 84.

Neither of the South Hardscrabble outcrops appears to indicate a minable body of clay. The section in outcrop 1 is believed to be a channel deposit of the roof-rock zone which has cut out the typical clay beds. In outcrop 2 at least the basal part of the flint clay bed is present.

The Dry Creek Canyon member of the Dakota sandstone is exposed along the east bank of Middle Hardscrabble Creek, just east of Colorado State Route 274 in the southwest corner of the SE¼SE¼NE¼ sec. 33, T. 21 S., R. 69 W. Here a 2- to 3-foot clay bed consists of slightly sandy flint clay, with some nonsandy layers, that grade downward into hard bluish sandy flint clay and argillaceous sandstone. The clay is overlain by 20 feet of massive sandstone and underlain by even-bedded, hard sandstone. The clay-bearing zone is replaced by overlying sandstone just south of the outcrop and cannot be traced far to the north. About one-half mile northwest of the outcrop, where Colorado State Route 96 and North Hardscrabble Creek cut the hogback, the Dakota section exposed shows no trace of the Dry Creek Canyon member. The Middle Hardscrabble outcrop is in essentially horizontal strata and lies near the center of the northwest end of the syncline.

The poor showing at the outcrops and the unfavorable mining conditions that are likely to be met because of the local structure, appear to be sufficient reasons for eliminating the mining potentialities of the Wetmore area from serious consideration. However, additional surface prospecting around the margins of the syncline, and drilling in the central part of the structure, would be required in order to evaluate definitely the possibilities for mining clay in this area.

CAPERS AREA, HUERFANO AND PUEBLO COUNTIES

A brief investigation was made of a mining area at Capers, north and northeast of the Mustang School which lies in section 7, T. 25 S., R. 65 W., Huerfano County, Colorado. The area is situated on either side of the Huerfano-Pueblo County line and includes one working and two abandoned mines as well as numerous prospects. The geology of the area is shown on the Walsenburg quadrangle (Hills, 1900).

The Standard Fire Brick Co. of Pueblo is the only operator in the area. Mining was started in 1906 and has been more or less continuous since that time except for a period of a year and a half in 1932 and 1933. The principal operation has been the Vulcan mine located at Capers, a small mining settlement in the center of the south line of section 31, T. 24 S., R. 65 W., Pueblo County. This mine was closed in the spring of 1948 and later a new operation, the Black Cut mine was begun in the S½SE¼NE¼, sec. 31, T. 24 S., R. 65 W., about 1 mile northeast of the Vulcan mine. A third operation, the Shamblin mine, which has been abandoned for many years, lies about 2½ miles southeast of the Vulcan mine in the southwest corner of section 3, T. 25 S., R. 65 W., just over the county line in Huerfano County.

Only plastic clay is present in the Capers area. The Vulcan and Black Cut mines are in the clay bed at the top of the Glencairn shale member of the Purgatoire formation and the Shamblin mine is in a local clay body in the top of the Dakota sandstone. The Dakota outcrop was examined briefly for several miles east of the area, but the Dry Creek Canyon member, although partially present locally, does not contain minable clay.

The Vulcan mine was worked by the Standard Fire Brick Co. from a shaft in about the center of the N½NW¼ sec. 6, T. 25 S., R. 65 W., just southeast of the settlement of Capers. The 85-foot shaft penetrates 20 feet of Graneros shale and 65 feet of Dakota sandstone to the clay bed at the top of the Glencairn shale member of the Purgatoire formation. The clay is a dark gray semiplastic clay ranging from 9 to 20 feet in thickness; its composition is given in analyses 93 to 97, inclusive. The nearest outcrop of the clay bed is 1 mile to the northeast, on Apache Creek. Until 1926, 300,000 tons of clay were mined and up to 1948, when it was abandoned, at least another 200,000 tons were mined.

The Shamblin workings consist of several abandoned entries in the southwest corner of section 3 and the southeast corner of section 4, T. 25 S., R. 65 W., just east of the tracks of the Denver and Rio Grande Western Railroad and the Colorado Southern Railroad. The clay bed is only 3 or 4 feet below the surface and is in the top of the upper sandstone unit of the Dakota. It is light to dark blue-gray and black plastic clay ranging in thickness from 4½ to 6 feet. The workings have collapsed and the tonnage recovered is not known. The same clay was also mined at one time in an old shaft near the Vulcan mine at Capers.

The Black Cut mine is in the clay of the Glencairn shale member of the Purgatoire formation and is probably a continuation of the same clay body worked by the Vulcan mine. The clay is similar in character to the Vulcan clay. The mine entry is in a limited outcrop of the clay exposed in a fault scarp.

CUCHARAS CANYON AREA, HUERFANO COUNTY

In the northeast corner of Huerfano County in the west half of T. 26 S., R. 64 W., and the southwest quarter of T. 25 S., R. 64 W., the

Cucharas River crosses an outcrop area of Dakota sandstone brought to the surface at the crest of the Apishapa anticline. From the north end of the Cucharas Reservoir in section 31, T. 26 S., R. 64 W., northward into Pueblo County the river has cut a deep canyon completely exposing the Dakota and Purgatoire formations and much of the Morrison formation. In one part of the canyon the Morrison and the uppermost beds of the Badito formation are exposed. A reconnaissance study of the Purgatoire and Dakota formations was made along this canyon from the Cucharas Reservoir to the Huerfano-Pueblo County line in section 15, T. 25 S., R. 64 W.

GEOLOGY

The areal geology along the canyon of Cucharas River is shown in the Walsenburg folio (Hills, 1900). At the time this folio was published the original "Dakota" formation had not yet been separated into the Dakota sandstone (restricted) and the Purgatoire formation. However, the distribution of the Purgatoire and Dakota is indicated on the Economic Geology sheet of the Walsenburg folio by the position of the "fire clay bed" of the "Dakota" which is actually the clay at the top of the Glencairn shale member of the Purgatoire.

In the Purgatoire formation of the Cucharas River canyon area the massive, coarse-grained, conglomeratic sandstone of the Lytle sandstone member is at least twice as thick as the overlying Glencairn shale member, although the thickness of the formation as a whole, 200 to 250 feet, is about the same as the Turkey Creek district. The Glencairn locally contains beds of blue-black plastic fire clay. This clay is generally concentrated in the uppermost 10 to 20 feet of the member. Throughout the canyon of Cucharas River exposures of this clay bed are predominantly sandy. However, as this part of the formation is often obscured by a grassy talus-covered slope or bench, it is quite possible that minable bodies of plastic clay are present in the area.

The Dakota sandstone is the rim rock of the canyon wall and consists predominantly of sandstone with minor amounts of sandy shale. Parts of the Dry Creek Canyon member are present at scattered localities but only one area was found where the clay-bearing zone in this member attains a minable grade and thickness for any appreciable distance. The Dakota varies in thickness between 80 and 110 feet and is very similar in character to the Dakota of the Turkey Creek district. Usually it is in the uniform phase, as a result of the deep channeling of the upper sandstone unit which locally cuts into the Purgatoire.

Where the Dry Creek Canyon member of the Dakota sandstone is present, the upper sandstone unit consists chiefly of even-bedded to massive, gray, cross-laminated sandstone which locally weathers to odd turretlike forms along the canyon rim. Above this lies a bed of soft sandy shale that is capped by a layer of quartzitic sandstone which in turn is overlain by alternating sandstone and shale transitional into the Graneros shale. The lower sandstone unit consists of 25 to 40 feet of massive, cross-laminated, sandstone that weathers to brown.

CLAY DEPOSITS

The Dry Creek Canyon member of the Dakota sandstone is present over local areas in sections 30 and 31, T. 26 S., R. 64 W., and in section 6, T. 27 S., R. 64 W. In these sections it is poorly developed and no surface indication of clay bodies of minable grade and thickness was found. One area where a minable body of clay is indicated lies in section 19, T. 26 S., R. 64 W. A geologic map of this area showing the distribution of the clay on the outcrop is given on figure 17. The clay is exposed on the north and south sides of a small canyon tributary to the Cucharas River canyon in the NW¼ and northwest part of the NE¼ of section 19. South of the tributary canyon the clay bed generally includes too much sand to be of value. North of the tributary canyon the bed is cut out locally and in some places is obscured by slope wash. Between these areas the exposures are good and the clay-bearing zone shows the following section.

Generalized section of the Dry Creek Canyon member of the Dakota sandstone, sec. 19, T. 26S., R. 64W., Huerfano County.

Upper sandstone unit.	
Disconformity.	
Dry Creek Canyon member:	*Feet*
Clay, plastic, sandy, gray	2
Sandstone with ferruginous matrix	0–1
Clay, plastic, blue-gray to green-gray	3–7
Sandstone with ferruginous matrix	1
Flint clay, scattered sand grains and sandy streaks in basal 6 inches	2–6
Flint clay, sandy, grading to sandstone with flint clay matrix	4
Sandstone, white, massive to even-bedded, interbedded with sandstone with flint clay matrix and sandy shale	7
Disconformity.	
Lower sandstone unit.	

The bed of ferruginous sandstone separating the flint and plastic clay appears to be a persistent feature. Locally it becomes thicker at the expense of the flint clay and in one instance at least it appears to cut out the entire flint clay bed. The zone of similar lithology in the upper part of the clay bed is not so persistent.

The grade of the flint clay may be too low to make it usable as a possible source of alumina. One sample of a 4½-foot flint clay bed was made; its composition is given in analysis 86. The relatively low

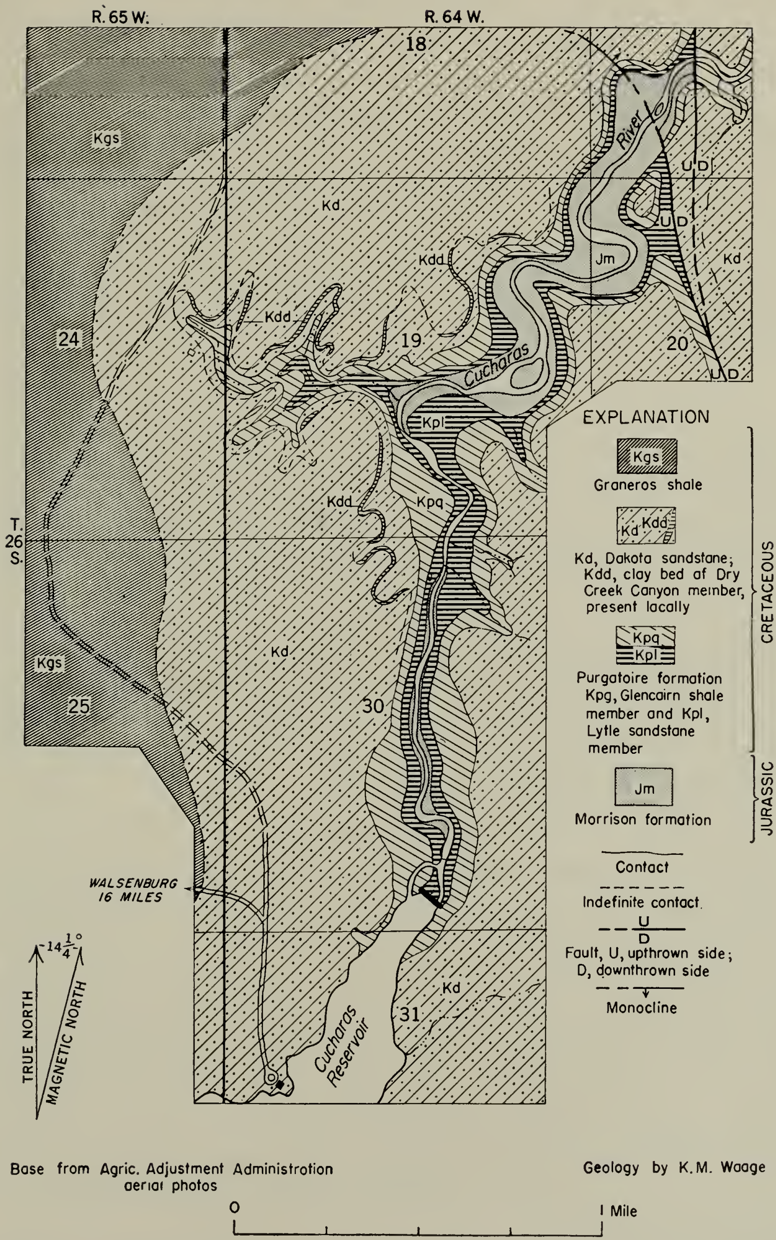

FIGURE 17.—Geologic map of a portion of the Cucharas River canyon area, Huerfano County, Colo.

alumina content may be the result of inclusion in the sample of sandy clay from the base of the bed. The upper 3 or 4 feet of the clay locally shows sand-free flint clay and probably, therefore, contains as much as 35 percent alumina.

The area underlain by flint clay 4 feet or more thick cannot be accurately delimited as there is no subsurface information as to the extent of the clay body underground to the north and northwest of the outcrop area. On the west rim of Cucharas canyon the clay bed is cut out in the northeast corner of the section and does not reappear to the north with minable thickness. The trend of the south edge of this cutout could not be determined so it is not possible to place a north boundary on the clay area. Subsurface exploration would be necessary to determine the extent of the clay body.

APPRAISAL

A considerable body of flint and plastic clay may be present west of Cucharas canyon in section 19, T. 26 S., R. 64 W., but drilling would be necessary to prove this. Whether such drilling is merited or not would depend chiefly on the demand for flint clay. The area, which is relatively inaccessible, is about 18 miles from Walsenburg by road and prairie trails, and about 14 miles by existing roads from the Denver and Rio Grande Western Railroad just east of Walsenburg.

Judging from the evidence on the outcrop, the canyon area of Cucharas River warrants drilling to determine whether the clay body exposed on the north side of the tributary canyon extends for any distance to the north and northwest. It is possible that most of the NW¼ of section 19 is underlain by minable clay.

FUTURE PROSPECTING

Few of the factors which affect the distribution, character, and grade of the clays of the Dry Creek Canyon member of the Dakota sandstone are of use in guiding future prospecting. The limits of the region over which the member was once deposited can only be inferred because of its subsequent removal locally, as well as over large areas, by erosion preceding the deposition of the upper sandstone unit of the Dakota. However, those portions of Fremont, Pueblo, El Paso, Custer, and Huerfano Counties shown on figure 1 can be considered to constitute the optimum area for the occurrence of the Dry Creek Canyon member. Over much of this area the Dakota lies too far below the surface to be of economic value even if the clay bed is present.

Considerable surface prospecting for clay at one time or another has already been carried on in the more easily accessible areas where the Dakota sandstone crops out. These areas include the hogbacks of the Front Range and the Wet Mountains, the Canon City embayment area, the Turkey Creek district, and most of the fault-bordered Dakota flats in southwestern Pueblo County. As much of this prospecting was not systematic and was done in days when access to the more remote parts of these areas was not economically feasible, some areas deserve careful re-examination for clay deposits. Among the more important areas in this category are the Penrose district and the outcrop areas of the Dakota in southwestern Pueblo County around the settlement of Rye (see fig. 1).

Surface prospecting for the clay bed of the Dry Creek Canyon member of the Dakota sandstone remains to be undertaken over much of the large area of Purgatoire and Dakota outcrop in eastern Huerfano and adjacent counties. This area should also be explored for the clays of the Glencairn member of the Purgatoire formation which at present are being mined at Capers in the northwest corner of the area and have in the past been mined in the vicinity of Thatcher in the southwestern part of the area. Both of these mining localities are near railroads, but most of the area between them is remote from such transportation facilities and is crossed only by a few dirt roads and trails, so that any clay deposits in this area would have to be of good grade and considerable size to be mined economically.

Very little subsurface exploration for the clay of the Dakota sandstone has been carried out in the districts described in this report chiefly because most mines start from entries on the outcrop and no attempts are made to determine the size of a clay body before mining operations are initiated. In some areas drilling to outline the extent, tonnage, and grade of known unmined bodies of clay in the Dry Creek Canyon member or to explore for new extensions of mined-out bodies might be profitable. The localities where such drilling is considered advisable have been mentioned in this report under the names of the various areas described. Exploratory drilling for the clays of the Dakota where there is no surface evidence of their presence is not advisable except in the vicinity of active or prospective mining areas or where some previous subsurface work has indicated the presence of the Dry Creek Canyon member.

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ANALYSES OF CLAY SAMPLES

Ninety seven analyses of clay from the several clay beds described in this report are given on the following pages. Under the column headed "Clay units," clay from the Graneros shale is designated *G.*, from the upper sandstone unit of the Dakota sandstone *U. D.*, from the Dry Creek Canyon members *D. C. C.*, and from the Glencairn shale member of the Purgatoire formation *G. M.* A list of the sample localities containing any information available on the individual samples follows the analyses.

The majority of the analyses were furnished by the clay companies operating in the area, some were furnished by individuals, and others were made in connection with the field work for this bulletin.

TABLE 7.—*Analyses of clay samples*

Analysis No.	Clay unit	Clay type	Analyst	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Ignition loss	Total
1	G.	Plastic clay shale.	Colorado Fuel & Iron Co.	58.8	19.5	3.9		1.4	1.8	11.6	97.0
2	do	do	do	60.5	17.15	4.4		2.2	2.0	9.95	96.2
3	U. D.	Clay shale.	do	51.22	33.75	2.02		.22	.50	12.83	100.54
4	do	Plastic clay.	do	63.00	24.00	1.74		.20	.75	10.20	99.89
5	do	do	do	63.16	22.75	1.57		.44	1.06	10.60	99.04
6	do	Plastic clay shale.	do	63.01	24.40	1.26		.19	.60	10.55	100.01
7	do	Plastic clay.	do	57.16	26.78	1.55		.38	.57	12.47	98.91
Averaged analysis for Nos. 3 to 7 inclusive				59.51	26.33	1.63		.28	.69	11.33	99.77
8	D. C. C.	Plastic clay.	W. W. Brannock, U. S. Geol. Survey.	53.77	28.30	1.83	0.80	.50	.70	13.33	99.23
9	do	Semiplastic clay.	do	50.27	27.61	1.36	.95	.71	.70	17.87	99.47
10	do	Flint clay.	do	53.03	30.74	.77	1.08	.43	.47	13.54	100.06
11	do	do	do	49.58	33.57	.70	1.12	.36	.35	14.17	99.85
12	do	do	do	48.85	34.04	.86	1.07	.12	.30	14.62	88.86
13	do	do	do	48.30	34.14	.89	1.04	.16	.25	14.82	99.60
14	do	do	do	49.41	33.51	.94	1.05	.19	.32	14.32	99.74
15	do	do	do	48.69	33.67	1.03	1.22	.16	.36	14.46	99.59
16	do	Plastic clay.	Colorado Fuel & Iron Co.	50.79	30.46	2.40	.75	.36	.92	13.82	99.45
17	do	do	do	58.93	35.34	2.78	.87	.42	1.06		99.34
18	do	Flint clay.	do	48.33	34.89	.65	1.04	.25	.29	14.00	99.45
19	do	do	do	56.20	40.57	.76	1.21	.29	.33		99.26
20	do	Semiplastic clay.	do	51.02	33.32	.06	1.00	None	Trace	14.50	99.90
21	do	Flint clay.	Mellon Inst.	47.77	35.21	.55	1.32	.60	.39	14.58	100.42
22	do	do	Colorado Fuel & Iron Co.	50.30	36.88	1.23			.36	10.60	99.37
23	do	do	do	56.30	41.30	1.37			.40		99.37
24	do	do	U. S. Zinc Co.	49.0	35.8	.8				13.9	99.5
25	do	Plastic clay.	N. Davidson, U. S. Geol. Survey.	60.62	21.83	3.03	.70	.28	.53	11.01	98.00
26	do	Flint clay.	do	49.78	30.77	2.87	1.03	.24	.05	14.56	99.30
27	do	do	do	47.43	33.51	1.32	1.15	.49	.05	14.40	98.35
28	do	Flint clay (minor sand).	do	58.84	25.94	1.94	1.28	.48	.01	11.19	99.68
29	do	Flint clay (sandy).	do	60.62	24.35	2.44	.90	.11	.73	10.59	99.74
30	do	Sandstone, flint matrix.	do	71.17	15.97	1.53	.89	.07	.51	7.35	97.49
31	do	Flint clay (minor sand).	do	48.13	32.15	1.77	1.02	.05	.36	14.15	97.63
32	do	Flint clay.	do	45.49	36.35	1.03	1.27	.44	.02	15.02	99.62
33	do	do	do	44.25	35.51	2.22	1.28	.72	.01	15.10	99.09
34	do	do	do	46.47	35.81	1.55	1.39	.08	.01	14.45	99.76
35	do	do	Colorado Fuel & Iron Co.	50.0	35.0						
36	do	Flint clay (minor sand).	do	54.0	32.0						
37	do	Flint clay (very sandy).	do	67.0	24.0						

TABLE 7.—*Analyses of clay samples*—Continued

Analysis No.	Clay unit	Clay type	Analyst	Analysis							
				SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Ignition loss	Total
38	D. C. C.—con.	Sandstone, flint matrix.	Colorado Fuel & Iron Co.—Con.	69.0	22.0						
39	do	Flint and plastic clay.	do	56.6	29.5						
40	do	Plastic clay.	do	56.7	31.7						
41	do	Flint clay.	do	48.6	39.4						
42	do	Sandy flint.	do	64.1	26.8						
43	do	Flint clay.	do	49.0	35.0						
44	do	do	do	57.0	41.0						
45	do	Total seam (?).	do	55.0	31.0						
46	do	Plastic clay.	do	62.0	26.0						
47	do	Sandstone flint matrix.	do	62.0	26.0						
48	do	Plastic clay.	do	65.0	21.0						
49	dc	Flint clay.	do	50.0	36.0						
50	do	Plastic clay.	do	54.0	30.0						
51	do	Flint clay.	do	51.0	36.0						
52	do	Sandstone clay matrix.	do	77.0	16.0						
53	do	Flint clay.	do	50.0	35.0						
54	dc	Sandy plastic clay.	do	54.0	29.0						
55	do	Plastic clay.	do	54.4	32.4						
56	do	Flint clay.	do	47.7	38.1						
57	do	Plastic clay (?).	do		32.55						
58	do	do	do		32.47						
59	do	Plastic clay (?).	do		30.80						
60	do	Sandy clay.	do		21.24						
61	do	do	do		29.21						
62	do	Flint and plastic clay (?).	do	47.7	36.66						
63	do	Sandy flint.	do	45.76	30.75						
64	do	Flint clay (sandy).	N. Davidson, U. S. Geol. Survey.	51.93	31.93	2.22	0.69	0.21	0.02	13.31	99.47
65	do	do	do	51.00	31.26	1.71	.79	.21	.16	13.27	98.40
66	do	Flint clay.	do	48.48	35.12	1.53	.51	.35	.18	13.96	100.13
67	do	Flint clay (sandy).	(?).	64.89	32.89	1.20		.52	.17		99.67
68	do	Flint clay.	Colorado Fuel & Iron Co.	50.98	34.88	1.62		.21	Trace	11.98	95.67
69	do	do	do	46.80	37.24	2.05		Trace	.22	14.98	100.49
70	do	do	do	54.50	42.74	1.09		.36	.58		99.27
71	do	do	S. H. Cress, U. S. Geol. Survey.	48.03	36.10	.30	.74	None	None	14.56	99.73
72	do	do	do	46.83	37.42	.58	.86	None	None	14.51	100.20
73	do	do	do	45.88	37.47	.70	.80	None	None	15.34	100.19
74	do	Flint clay (some sand).	do	49.60	32.36	1.10	1.00	.64	.32	14.45	99.47
75	do	Flint clay (slightly sandy).	do	50.71	33.74	.16	.50	.38	.26	14.42	100.17
76	do	Flint clay.	do	48.91	35.19	.83	1.02	None	.12	13.82	99.89
77	do	do	do	51.04	33.12	.92	.92	Nonc	Nonc	14.24	100.24
78	do	do	do	48.72	35.31	.37	.72	None	.02	14.64	99.78

79	do	do	do	50.24	34.85	.55	.96	None	None	13.75	100.35
80	do	Plastic clay.	do	52.35	29.64	1.29	1.17	.91	.47	14.52	100.35
81	do	do	do	52.31	31.24	.64	.88	None	.30	13.77	99.14
82	do	Plastic clay, sandy.	do	62.06	22.31	2.03	.76	None	None	10.05	97.21
83	do	Plastic clay, sandy.	do	61.75	22.80	2.08	.68	None	None	9.50	96.81
84	do	Flint clay.	do	52.96	33.83	.53	1.14	None	None	10.48	98.94
85	do	do	do	51.02	34.44	.40	.80	None	None	13.08	99.74
86	do	Flint clay and sandy flint.	W. W. Brannock, U. S. Geol. Survey.	52.49	31.43	.73	1.17	.41	.19	13.24	99.66
87	G. M.	Sandy plastic.	Colorado Fuel & Iron Co.	78.4	10.4	2.5		1.3	1.4	5.1	99.1
88	do	do	Blackwell Zinc Co.	80.0	7.7	2.7		.9	.8	4.9	97.0
89	do	Plastic.	(?).	58.34	26.29	2.69		Trace	.67	12.40	100.32
90	do	do	Colorado Fuel & Iron Co.	61.7	21.8	1.2		Trace	1.0	13.4	99.1
91	do	do	do	63.4	21.1	1.3		Trace	.7	11.4	97.9
92	do	do	do	63.6	19.7	.5					
93	do	do	do	62.48	22.31	2.18		.64	.30	10.43	98.34
94	do	do	do	68.08	19.50	1.9		.22	.27	9.44	99.41
95	do	do	do	60.27	23.19	2.5		.32	.32	11.26	97.86
96	do	do	do	61.30	23.65	2.2		.18	.18	11.64	99.15
97	do	do	do	62.14	23.88	1.7		.30	.30	10.80	99.12
Averaged analysis for numbers 93 to 97 inclusive				62.85	22.50	2.09		0.33	0.27	10.71	98.75

Stratigraphic position and location of clay samples

Graneros shale: Pueblo County, Rock Creek area:

1. Along Snake Creek just east of Dakota fault scarp in sec. 22, T. 22 S., R. 67 W. Within lower 20–30 feet of Graneros. Plastic clay shale.
2. Same as 1.

Upper sandstone unit of Dakota sandstone: Pueblo County, Mustang area:

3. Shamblin mine, Standard Fire Brick Co., southwest corner of sec. 3, T. 25 S., R. 65 W. Sample of upper half of clay bed, light-blue brittle laminated clay.
4. Shamblin mine. Lower half of clay bed. Dark-blue plastic clay, somewhat gritty.
5. Shamblin mine. Run-of-mine sample.
6. Shamblin mine. Gray plastic clay.
7. Shamblin mine. Blue-black plastic clay.

Dry Creek Canyon member of the Dakota sandstone:

Pueblo County, Turkey Creek district, Stone City area:

8. Dry Creek Canyon mine, Pueblo Clay Products Co. Plastic clay just within entry.
9. Dry Creek Canyon mine. Semiplastic ("black flint") clay within entry.
10. Dry Creek Canyon mine. Flint clay within entry. Channel sample to mine floor.
11. Abandoned entry of Dry Creek Canyon mine. Flint clay.
12. Spring Canyon mine, Pueblo Clay Products Co. Flint clay from along north tunnel.
13. Nellie Helen mine. Flint from within mine.
14. Prospect in center of the NE¼NE¼ sec. 35, T. 78 S., R. 67 W. Flint clay, channel sample including some sandy flint.
15. Abandoned mine of U. S. Zinc Co. on Turkey Creek. Flint clay from within entry.
16. Dry Creek Canyon mine, Pueblo Clay Products Co. Averaged analysis for plastic clay shipped over one year period (ca. 1933).
17. Same as 16, but burned samples.
18. Dry Creek Canyon mine. Average analysis for flint clay shipped over one year period 1933.
19. Same as 18, but burned samples.
20. Dry Creek Canyon mine, semiplastic ("black flint") clay. Analysis on composite sample, probably includes some overlying plastic.
21. Nellie Helen mine. Flint clay at mine entry.
22. Nellie Helen mine. Flint clay from within mine.
23. Same as 22, but burned sample.
24. Abandoned mine of U. S. Zinc Co. on Turkey Creek. Averaged analysis of 23 analyses of flint clay covering 55 carloads (ca. 3,000 tons). Averaged figure per carload.

Pueblo County, Beulah district, Rock Creek area.

Samples from the Rock Creek mines of the Standard Fire Brick Co.

25. Entry 3, within mine. Channel sample of plastic clay from roof to top of flint clay. Thickness sampled 4 feet.
26. Entry 3. Channel sample of flint clay, thickness sampled 2½ feet. From near west end of mine.
27. Entry 1, north tunnel near west end. Spot sample of upper 1 foot of flint clay, slightly sandy.
28. Same as 27. Spot sample of 1 foot of sandy flint clay immediately under 27.

Dry Creek Canyon member of Dakota sandstone—Continued

Pueblo County, Beulah District, Rock Creek area—Continued

Samples from the Rock Creek mines of the Standard Fire Brick Co.—Con.

29. Same as 27. Spot sample of 1 foot of sandy flint clay immediately under 28.
30. Same as 27. Spot sample of sandstone with flint clay matrix underlying 29 and about 42 inches below top of flint clay.
31. Entry 1, south tunnel near west end. Upper 1½ feet of blue, sandy, flint clay.
32. Entry 1, south tunnel about 100 feet east of 31. Upper 1½ feet of flint clay.
33. Entry 1, south tunnel about 100 feet east of 32. Upper 1½ feet of flint clay.
34. Entry 2, west end north fork main tunnel. Sample of 2½ feet of flint clay.
35. Entry 1. Flint clay at entry. Spot sample.
36. Entry 3. Channel sample of entire clay bed at entry.
37. Entry 1, within entry. Bottom 42 inches of bed, sandy flint clay.
38. Entry 1, within entry. Bottom 42 inches of bed, sandstone with flint clay matrix.
39. Entry 1. Channel sample of clay bed.
40. Entry 2. Upper 36 inches of bed, blue-black plastic clay.
41. Entry 2. 42 inches of flint clay below 40.
42. Entry 2. 30 inches of sandy flint clay below 41. (Zone of sandy flint.)
43. Entry 2. Sandy flint clay. Between 41 and 42.
44. Entry 2. Burned sample, probably flint.
45. Rock Creek clay, burned sample. Position not designated.
46. Entry 2. Upper 36 inches of clay bed in zone of dark plastic clay, this sample may have included some sandy plastic clay.
47. Entry 2. Gray sandy flint clay near bottom of clay bed.
48. Entry 2. Plastic clay, sandy.
49. Entry 2. Channel sample of flint clay bed.

Sample from Eseley well in the SW¼NW¼ sec. 35, T. 22 S., R. 67 W.

50. Position uncertain, reported to be 15 feet from top of clay "vein". Two clay beds encountered, could be either Dakota or Purgatoire.

Samples from the Rock Creek mines of the Standard Fire Brick Co.

51. Entry 1. Flint clay 5 feet above 52.
52. Entry 1. Sandy flint clay and sandstone with flint clay matrix. Just above entry floor.
53. Entry 2. Channel sample of clay bed (chiefly flint).
54. Entry 3. Sandy, gray plastic clay at top of bed.
55. Entry 3. Upper 3–3½ feet of bed, dark-blue to black plastic clay.
56. Entry 3. Flint clay below 55.
57, 58, 59, 60, 61. Samples from old clay prospect in canyon of Rock Creek just west of the Rock Creek fault near the center of the SE¼NW¼ sec. 26, T. 22 S., R. 67 W. The clay is chiefly plastic with some sandy flint clay. Clay types of individual sample not known.
62. Snake Creek prospect 1. South wall of canyon of Snake Creek, northeast corner of the SE¼ sec. 22, T. 22 S., R. 67 W. Sample of upper 56 inches of bed, predominantly blue-gray flint.
63. Snake Creek prospect 1. Hard argillitic sandstone and minor sandy plastic and sandy flint clay underlying interval of sample 62.

Dry Creek Canyon member of Dakota sandstone—Continued

Fremont County, Canon City district:

64. Diamond Flint mine, south wall of Wilson Creek canyon in the SW¼ SW¼ sec. 4, T. 18 S., R. 70 W. Sample of bed of flint and sandy flint clay within entry on canyon wall.
65. Deer Hill mine of Diamond Fire Brick Co. on Deer Hill in the SE¼ SE¼ sec. 4, T. 18 S., R. 70 W. Sample of upper half of clay bed. Gritty to very sandy flint clay with streaks of nonsandy flint clay.
66. Deer Hill mine. Spot sample of nonsandy flint clay from upper half of clay bed.
67. Deer Hill Mine. Run-of-mine sample, predominantly sandy flint clay.
68, 69, 70. Diamond Flint Mine of Diamond Fire Brick Co. Samples of flint clay from within mine. Interval not designated. Probably spot samples.

Pueblo County, Turkey Creek district, Hell Canyon Area (for sample localities see plate 4):

71. Prospect 5. Upper 2½ feet of 5-foot flint clay bed.
72. Prospect 5. Lower 2½ feet of 5-foot flint clay bed. (Underlies 71).
73. Prospect 5. Channel sample of 5-foot flint clay bed.
74. Prospect 6. Upper 4 feet of 5-foot flint clay bed.
75. Prospect 2. Sample of 4-foot flint clay bed.
76. Prospect 7. Composite sample of upper 2 or 3 feet of flint clay locally exposed along east wall of Turkey Creek canyon.
77. Prospect 3. Sample of 4-foot clay bed.
78. Prospect 1. Sample of upper 2½ and lower 2 feet of 5-foot flint clay bed.
79. Prospect 1. Sample of 4½-foot flint clay bed.
80. Prospect 2. Lower 3 feet of 4-foot bed of plastic clay overlying flint clay.
81. Just south of sample 76, prospect 7. Sample of 3 feet of plastic clay overlying flint clay.

Custer County, Wetmore area:

82. South Hardscrabble prospect 1. Lower bed of sandy plastic clay.
83. Same as 82. Upper bed of sandy plastic clay.
84. South Hardscrabble prospect 2. Flint clay, position in bed obscured by slope wash.
85. Middle Hardscrabble prospect 1. Channel samples of 2½-foot bed of flint and sandy flint clay.

Huerfano County, Cucharas area:

86. Prospect at north end of gully in northeast corner of the SE¼NW¼ sec. 19, T. 26 S., R. 64 W. Sample of 4½ feet gray flint clay and sandy flint clay.

Glencairn shale member of the Purgatoire formation

Pueblo County, Turkey Creek district, Stone City area:

87. Prospect near base of west wall of Turkey Creek canyon just south of Teller Reservoir, sec. 36, T. 18 S., R. 67 W. About 15–20 feet below contact of Dakota and Purgatoire in sandy shales of Glencairn member.
88. Same as 87.

Glencairn shale member of the Purgatoire formation—Continued

Fremont County, Canon City district:

89. From workings of old mine of the Diamond Fire Brick Co. on "Diamond Placer" lease, Grape Creek area, sec. 14, T. 19 S., R. 71 W. Plastic blue-gray clay at top of Glencairn member of Purgatoire formation.
90. Old analysis of plastic clay from mine of the Standard Fire Brick Co. in the NE¼NW¼ sec. 20, T. 18 S., R. 69 W., Oil Creek-Sixmile Creek area. From upper 15 feet of Glencairn member of Purgatoire formation.
91. Recent analysis of plastic clay from same locality as 90.
92. McIntyre mine of Standard Fire Brick Co., Parkdale area, north of McIntyre gulch at foot of mountain on west side of Webster park. Probably top of Glencairn member of Purgatoire formation.

Pueblo County, Capers area:

93. Plastic clay from Vulcan mine. Upper part of Glencairn member of the Purgatoire formation.
94. Same as 93.
95. Same as 93.
96. Same as 93.
97. Same as 93.

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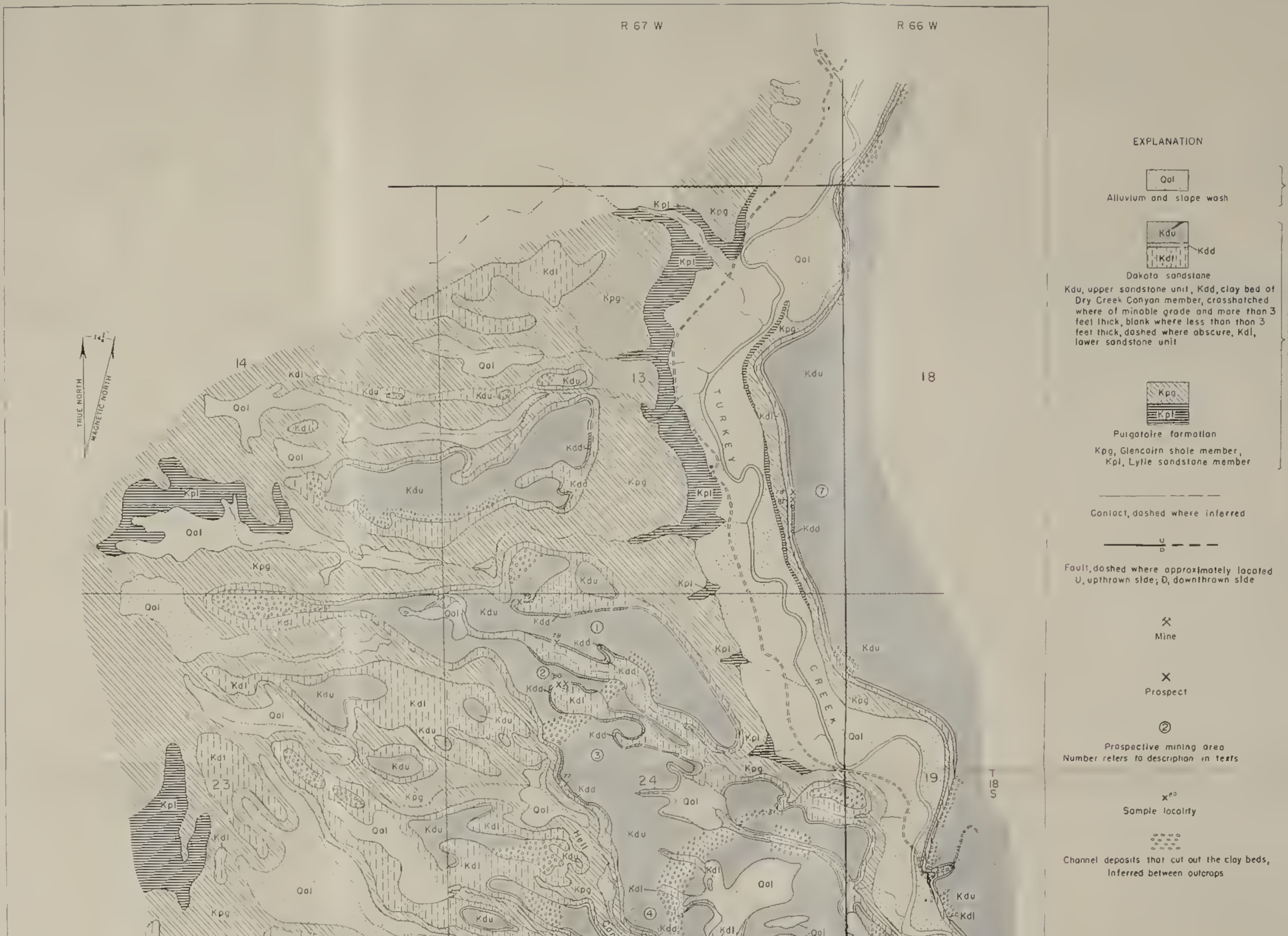
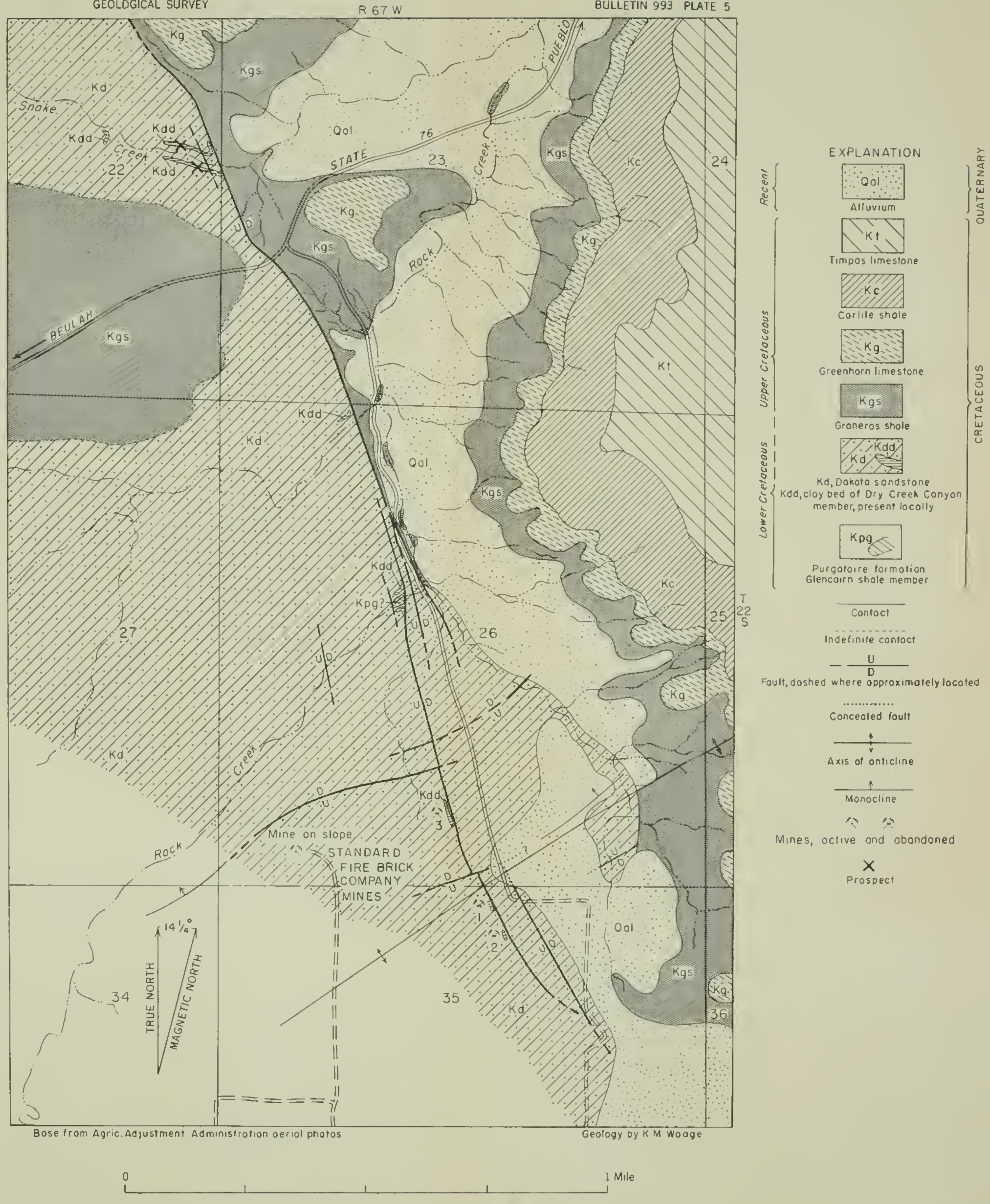


GEOLOGY AND DISTRIBUTION OF CLAY IN THE HELL CANYON AREA, TURKEY CREEK DISTRICT, PUEBLO COUNTY, COLORADO



GEOLOGIC MAP OF THE ROCK CREEK AREA, PUEBLO COUNTY, COLORADO

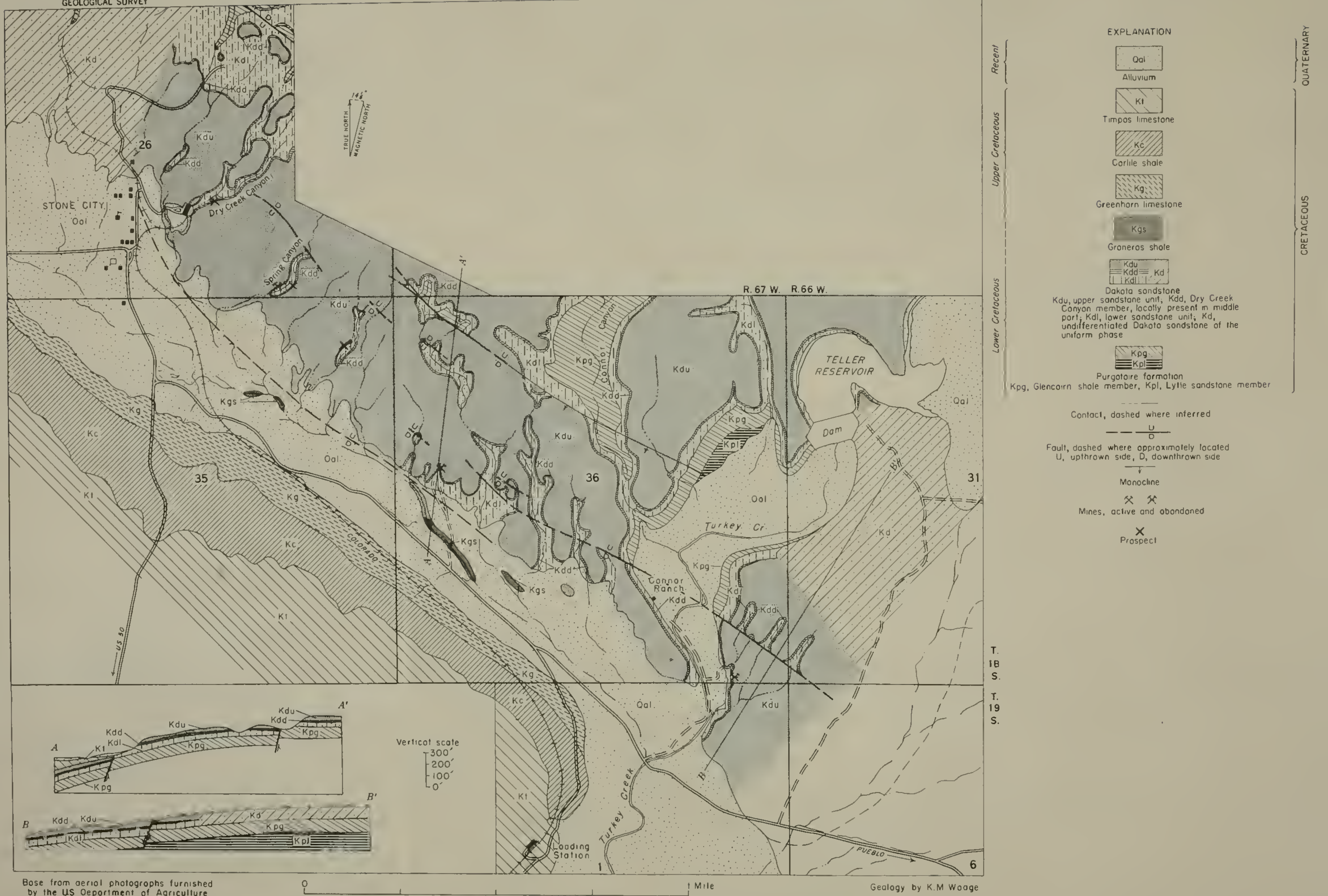
232819 O—52 (In pocket) No. 5

Based from Agric. Adjustment Administration aerial photos

Geology by K.M. Waage, 1944

DISTRIBUTION OF MINABLE CLAY IN THE STONE CITY AREA, TURKEY CREEK DISTRICT, PUEBLO COUNTY, COLORADO

232819 O—52 (In pocket) No. 3



GEOLOGIC MAP OF THE STONE CITY AREA, TURKEY CREEK DISTRICT, PUEBLO COUNTY, COLORADO

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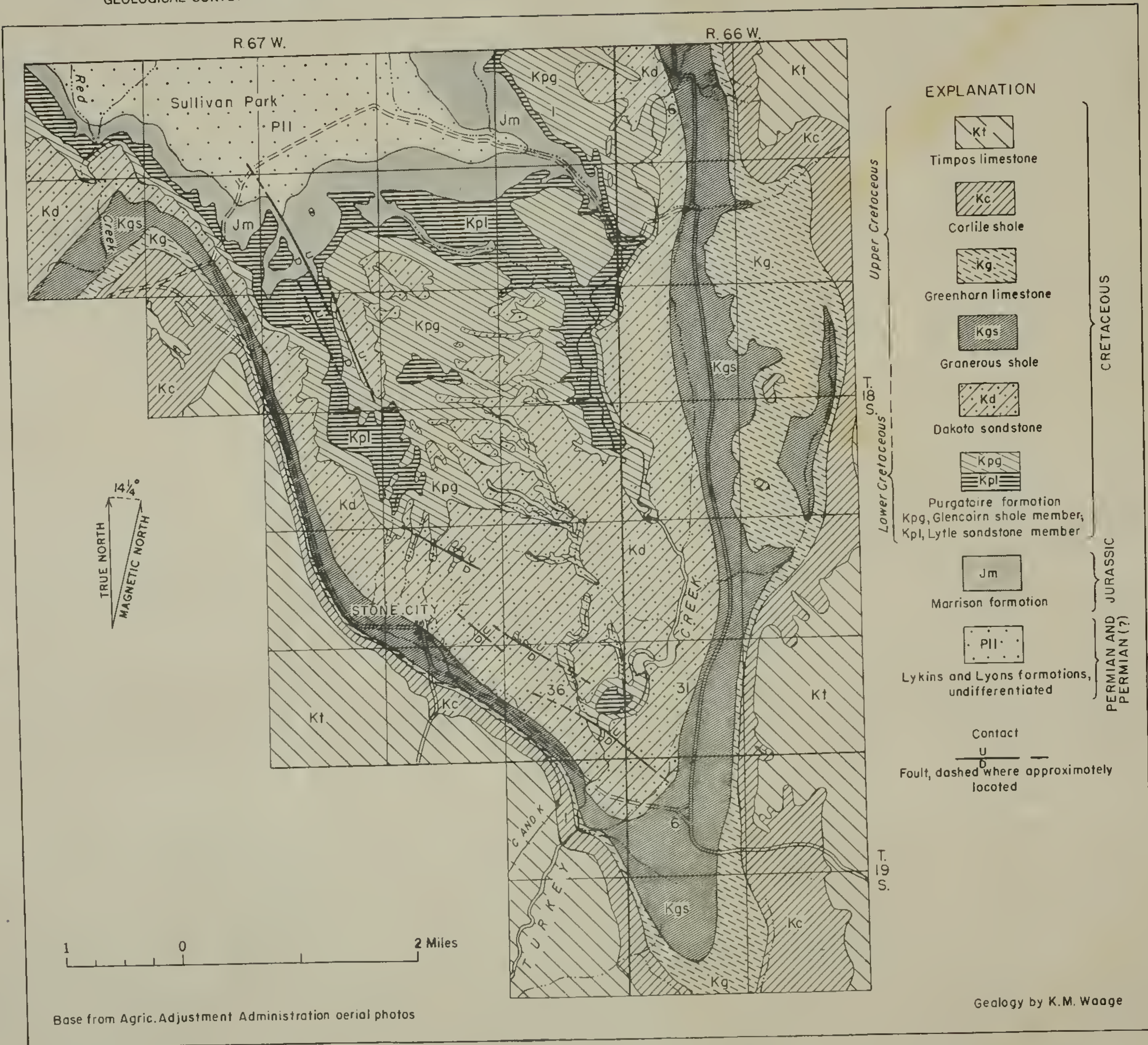

GEOLOGIC MAP OF THE TURKEY CREEK DISTRICT, PUEBLO COUNTY, COLORADO

232819 O—52 (In pocket) No. 1