Stratigraphy and Refractory Clayrocks of the Dakota Group Along the Northern Front Range, Colorado

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By KARL M. WAAGÉ

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Stratigraphic details of the Lytle and South Platte formations in the Denver area with emphasis on the distribution of the refractory clayrocks

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STRATIGRAPHY AND REFRACTORY CLAYROCKS OF THE DAKOTA GROUP ALONG THE NORTHERN FRONT RANGE, COLORADO

By Karl M. Waagé

ABSTRACT

Clayrocks of the Dakota group (Cretaceous) include variegated claystone in the Lytle formation and gray to black clay shale and minor amounts of gray claystone in the overlying South Platte formation. The latter formation has been the chief source of clayrock for the refractory-ware industry in the Denver-Golden area since the late 1860's, but most of the refractory shale in the area has been mined.

Lytle clayrock is refractory only in a thin leached zone at the South Platte contact. Although locally present throughout the northern foothills, refractory clayrock deposits in this zone are mostly too variable in thickness and quality to be commercial.

South Platte clayrocks change from kaolinitic to illitic as the formation changes from a deltaic facies in the southern part of the foothills of the northern Front Range to a dominantly marine facies in the northern part. Only the kaolinitic clayrocks have the property of refractoriness. Consequently, refractory clayrock deposits are limited to the deltaic facies; approximately to that part of the northern foothills south of the latitude of Boulder. Principal source beds for refractory clayrock are the uppermost subdivisions of the South Platte formation; the Van Bibber shale member is the chief source and the overlying first sandstone is a secondary source. Much of the Van Bibber member was removed by erosion prior to the deposition of the first sandstone, which accounts for the erratic distribution of refractory clayrock within the deltaic facies.

The report deals chiefly with the detailed stratigraphy of the deltaic facies of the South Platte formation, and with the distribution of its clayrocks. Refractory clayrock deposits other than those mined, or known but not available to the local industry, are at best minor potential sources of unproven commercial value.

The deltaic facies of the South Platte formation is part of an extensive area of deltaic deposits that once covered central and most of southeastern Colorado. The bulk of Colorado's refractory clayrocks occur in these deposits and most originated during a single episode of swamp formation. Extensive reserves of refractory clayrock in south-central Colorado are the nearest supply to replace the diminishing clayrock resources in the Denver-Golden area.

INTRODUCTION

REFRACTORY CLAYROCK IN EASTERN COLORADO

In eastern Colorado clay shale and claystone of refractory grade occur in beds of the Dakota group and its equivalents, in the Laramie formation, and in the Dawson arkose. The Dakota group is by far the most important commercial source; refractory clayrock has been mined from it in parts of Jefferson, Douglas, Pueblo, Fremont, and Las Animas Counties. Clayrock of refractory grade in the Dawson arkose has been mined from one small area at Calhan, El Paso County. The Laramie clayrocks are largely nonrefractory. The minor quantities of Laramie clayrock that are of refractory grade are intimately mixed with clayrock of lower grade, and consequently the formation is not a commercial source for refractory products.

The early history of the discovery and use of refractory clayrock in Colorado is not well documented, doubtless because clayrock lacked both the value and the glamour to compete in interest with the precious metals, with coal, and with iron, all being sought and exploited along the Front Range at about the same time. Even the clayrock itself was overlooked at first. Lakes (1909, p. 449) notes that the early ore smelters at Golden, located within sight of the hogback containing the Dakota refractory clay shale, used refractory brick imported from Wales.

Colorado's first production of refractory clayrock was at Golden in Jefferson County, during the late 1880's. Ries and Leighton (1909, p. 73) note that "Dakota fire clays were mined here as early as 1864 or 1865." However, the first documented use of the clayrock was that made in 1866 by Henry Bell who, according to Ries and Leighton (1909, p. 73) . . ."in prospecting for coal found a bed of fire clay and used it in making fire brick." Hollister (1867, p. 406) mentions a "fire clay" used by the Bell and Co. brick works at Golden, and Berthoud (1880, p. 372) records the ". . . erection of a brewery and fire-brick works at Golden . . ." in 1867. Wallihan's Directory for 1871 lists a single refractory products plant, the Golden City Pottery and Fire Brick Works, Henry Bell, proprietor. In a brief summary on Golden, Wallihan (1871, p. 319) notes an "extensive pottery and fire brick manufactory," and "three yards for the manufacture of ordinary brick." Discounting its change in name, Bell's enterprise appears to have been the only refractory-products plant in Golden, and in Colorado, until the 1870's.

During the 1870's the names of other refractory-ware plants at Golden appear in various references. Among these are the Cambria Fire-Brick Co., Fischer, Koenig and Co., and the Golden Pressed and Fire-Brick Co. In Denver, the manufacture of refractory ware from Golden clayrock was begun in 1876. By 1882 refractory clayrock mined at Golden was being shipped to refractory-ware plants in Pueblo as well as Denver, and by 1895 most of the principal producers of refractory ware in Colorado were established. These included the Golden Fire Brick Co., the Denver Sewer Pipe and Clay Co., the Denver Fire Clay Co., and the Standard Fire Brick Co. of Pueblo. In the early 1890's, all of these producers were using clay shale of the Dakota from the hogbacks north and south of Golden.

Sources of refractory clayrock other than those at Golden were not exploited until the mid-1890's, although considerable prospecting had been done in the Dakota group at a number of other places. Ries and Leighton (1909, p. 73) note that the Dakota clayrocks in the hogback just south of the South Platte River in Douglas County were mined by 1896; and that the Dakota clayrocks ". . . near Parkdale [Fremont County] were worked at least as early as 1896 by the Standard Fire Brick Co. of Pueblo, and four years later, or in 1900, fire-brick manufacture based on Dakota clays was begun at Canon City . . ." The refractory clayrock in the Dakota near Delhi, Las Animas County, was also exploited about 1895 by the Standard Fire Brick Co. of Pueblo.

Early in the 1900's mining began in several other deposits of refractory clayrock. Richardson (1911) reports that the clayrock in the Dawson arkose around Calhan, El Paso County, is rumored to have been mined first in 1903. In 1906 the U.S. Zinc Co. opened a mine in clayrock of the Dakota group on Turkey Creek in northwestern Pueblo County, and in the same year the Standard Fire Brick Co. of Pueblo began working clayrock in the top of the Purgatoire formation near Capers in the south-central Pueblo County.

The U.S. Zinc Co.'s holding on Turkey Creek was the first refractory clayrock deposit mined in Colorado that was not adjacent to rail or within easy access to it. The clayrock was hauled by wagon from Turkey Creek to Pueblo until 1917, when the Colorado Railroad was built into Stone City. At that time the U.S. Zinc Co.'s mine was abandoned and mining operations were begun around Stone City by the Turkey Creek Stone, Clay and Gypsum Co., whose clayrock holdings were taken over in the same year by the Pueblo Clay Products Co. The most recently exploited area of refractory clayrock deposits lies near the head of Rock Creek east of Beulah in southwestern Pueblo County; it also is remote from railroads. Commercial production of clayrock from the Dakota in this area was begun about 1939 by the Standard Fire Brick Co.

From about 1910 to the present, the dominance of the Golden clayrock in the refractory-ware industry in eastern Colorado gradually lessened as the deposits in the Arkansas River valley area were exploited. Since the late 1930's some Arkansas River valley clayrock has been used in Denver to supplement the output from the

Golden area. The continuous mining of clayrock in the Dakota in the Golden area since 1866 has revealed that the high-grade refractory clayrock does not persist indefinitely along the hogback as was once believed, but appears to be limited to the Golden area and a smaller area south of the South Platte River in Douglas County. Today practically all of the easily accessible clayrock has been mined, and the refractory-ware plants in the Denver-Golden area are faced with a diminishing local supply.

The centers for manufacture of refractory ware in the Arkansas River valley area—Canon City and Pueblo—obtain most of their raw, high-grade clayrock from the Turkey Creek district and the Rock Creek area in Pueblo County. Some clayrock is still being mined around Canon City, but this area has reached the same low stage in reserves as the Golden area. It differs from the Golden area in being near areas of known and potential reserves in Pueblo County. Other than the Turkey Creek district and Rock Creek area of Pueblo County, which together contain the bulk of eastern Colorado's easily accessible reserves of high-grade refractory clayrock, the few known mineable clayrock deposits of the Dakota are too remote from transportation to be of interest to the industry at the present time.

The literature on refractory clayrocks in eastern Colorado is not extensive. Much of it is of a general nature, and much of it is old and out of date. Richardson (1911) reported briefly on the clayrocks in the Dawson arkose at Calhan in El Paso County. Early papers on the Dakota clayrocks at Golden include those by Eldridge (1896a), and Ries (1897a, and 1897b). The 1897a reference to Ries is the first comprehensive paper on the refractory-ware industry in Colorado; his 1897b paper is but a condensation of it. Eldridge's paper deals with the stratigraphy and lithology of the clayrocks around Golden. Other papers published prior to 1912 in which reference is made to Colorado refractory clayrocks can be found in Jones' (1914) helpful bibliography of Colorado geology.

Subsequent to 1912 the most comprehensive study of Colorado clayrocks is that made by Butler (1914). This work is essentially a compendium listing the location, character, uses, and geologic occurrence of many of the easily accessible, and some of the less accessible, outcrops of clayrock in eastern Colorado; it has served as a valuable guide in prospecting.

Recent studies of Colorado clayrocks include a summary of their geologic occurrence and distribution in the Denver-Golden area (Waagé, 1952, p. 373–390) and a study of the refractory clayrock deposits in the Arkansas River valley area (Waagé, 1953). The clayrock and clay products industry in Colorado have also been briefly reviewed in recent years (Vandewilt, 1947, p. 232–235, 239–240; Argall, 1949, p. 89–109). A comprehensive report on the "Refractory clay deposits of Colorado" by Van Sant (1959) was received just before the present report went to the printers. Van Sant's report replaces that of Butler (1914); it not only brings Butler's report up to date but is far more detailed and informative.

PRESENT STUDY AND ACKNOWLEDGMENTS

Investigation of the refractory clayrocks in the northern foothills was made by the Geological Survey during the summers of 1951 and 1952. The chief objective was to find out what limits the distribution of refractory-grade clayrock in the area. As a consequence this report of the investigation is largely a stratigraphic study.

The first part of the field investigation included the entire northern foothills belt, shown in figure 1, from northern Larimer County to the fault-terminated end of the Dakota hogback on Indian Creek, Douglas County. Following the prospecting method described by Grim and Rowland (1944), samples of clayrocks from many sections measured throughout this area were tested by thermal analysis to reveal the dominant clay mineral. Distribution of the dominantly kaolinitic clayrocks, together with field data, served to limit the area in which commercial quantities of refractory clayrock could occur to that part of the northern foothills south of Eldorado Springs. In the second part of the investigation the clayrock units in the Dakota group south of Eldorado Springs were studied in detail and mapped at a scale of 1:10,000. Edward Taylor and John P. McDowell assisted in the fieldwork in 1951 and 1952 respectively.

The help of the clay-products companies and miners was essential to the study, and I am indebted to them for their willing cooperation. I am especially grateful for the kind assistance of the following: Mr. Mueller of the Golden Fire Brick Co., Messrs. Shepard, Breitweiser, and Bennetts of the Denver Fire Clay Co., Messrs. Temple, Griggs, and Chase of the Denver Sewer Pipe and Clay Co., and Mr. Robinson of the Robinson Brick and Tile Co.

The thermal analyses were made by Takashi Fugii and V. Rama Murthy who used the laboratory facilities of the Department of Geology at Yale University and were supported by the Shell Research Fund of that department. The X-ray Geiger-counter spectrometer tests of selected samples were made at the soils laboratory of the Connecticut Agricultural Experiment Station, New Haven, with the generous help of Dr. Tsuneo Tamura.

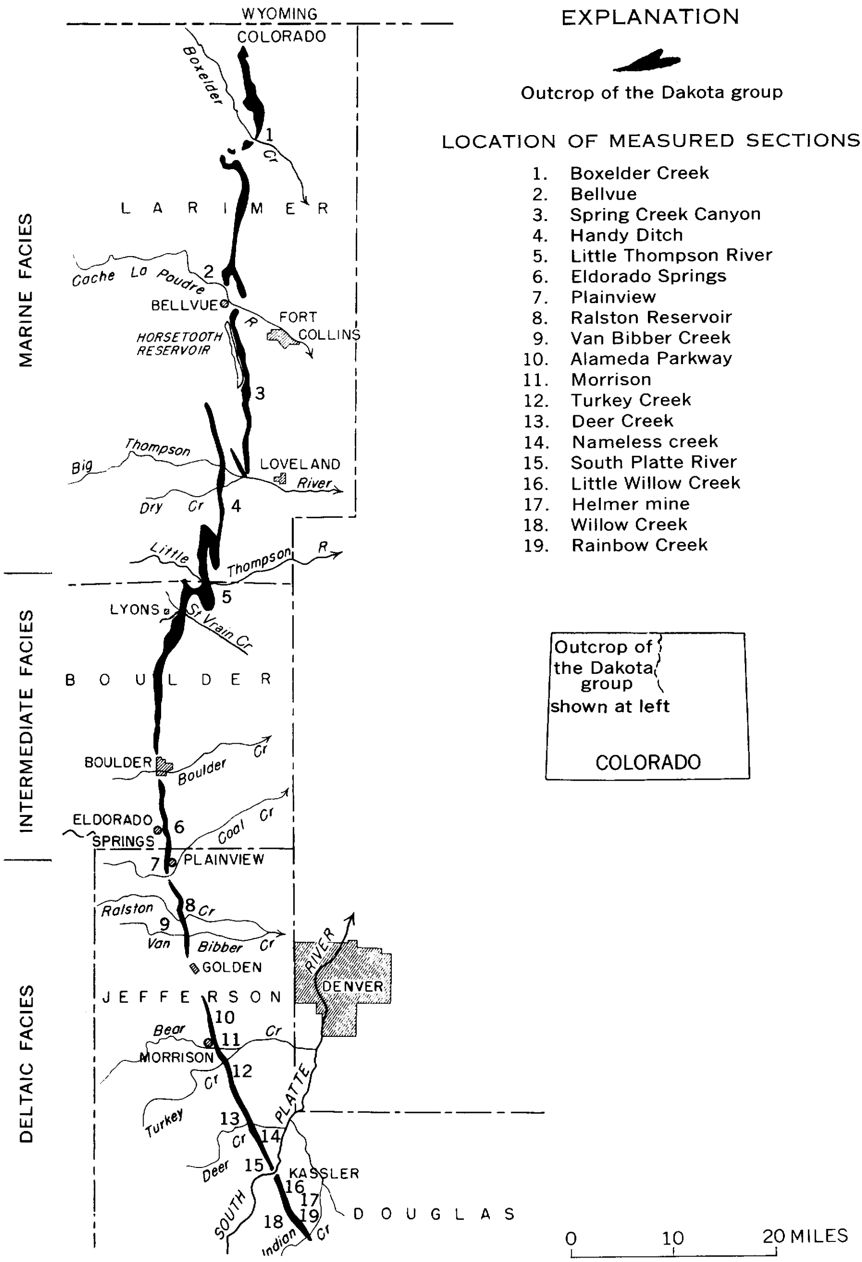

FIGURE 1.—Outcrop pattern of the Dakota group in the foothills of the northern Front Range. (Modified from Waagé, 1955, fig. 4.)

TERMS APPLIED TO CLAYROCKS

In view of the lack of a standardized nomenclature for fine-grained sedimentary rocks, the terms here applied to dominantly clayey rocks are defined below. To a considerable extent these terms follow those proposed by Ingram (1953, p. 870) but some of his definitions have been qualified.

Clayrock—a fine-grained sedimentary rock with clay dominant over silt. The term has no connotation as to breaking characteristics or to the presence or absence of bedding structures; it includes claystone and clay shale.

Claystone—massive clayrock that breaks with blocky, subconchoidal or conchoidal fracture and possesses no bedding structure.

Clay shale—clayrock possessing obvious or inherent bedding structure; commonly fissile but may also have blocky to conchoidal break in fresh samples.

Refractory clayrock, *claystone*, or *clay shale*—clayrock, claystone or clay shale possessing refractoriness; high-grade refractory clayrock fuses at or above 1,650° C. (cone 29 and higher) : semirefractory-grade clayrock fuses between 1,605° C. and 1,650° C. (cones 27 to 29), and low-grade refractory clayrock fuses between 1,530° C. and 1,605° C. (cones 20 to 26). The property of refractoriness depends primarily on the chemical composition of the clayrock. Most fine-textured clayrocks containing a high percent of Al_2O_3 and a very low percent of fusible impurities are refractory. Among the clay mineral groups commonly found in clayrocks only the aluminum silicates of the kaolinite group have the chemical composition requisite for refractoriness.

Whereas Ingram's distinction between claystone and clay shale is made on breaking characteristics, the distinction here is made on the absence or presence of bedding structure. Ordinarily fissility is a superficial expression of bedding structure, but some refractory clayrock, although finely laminated, has a subconchoidal break when fresh and on weathering may yield blocky rather than flaky fragments. Bedding structure is certainly the more significant feature for describing such exceptions, inasmuch as it is a valuable clue to the conditions under which the clayey sediment was deposited. Examples of refractory claystone and clay shale are shown in plate 3.

The amount of silt-size particles in the clayrocks described in this report was not accurately measured and can be expressed only qualitatively. In general, the unqualified use of the terms claystone and clay shale indicates rocks in which the quantity of silt does not exceed, and is commonly well under, 20 percent. Silty claystone and silty clay shale indicate rocks with about 20 to 50 percent silt;

the use of these terms implies sufficient silt impurity to affect the quality of the refractory clayrocks. Clayey siltstone refers to siltstone with about 25 percent or more clay. Most siltstone beds in the Dakota group are massive or flaggy. The clayey siltstone are predominantly massive. The siltstone associated with the clay shale most commonly occurs as thin beds and laminae.

STRATIGRAPHY OF CLAYROCKS OF THE DAKOTA GROUP

SUBDIVISIONS OF THE DAKOTA GROUP

The study of the Dakota group made in the course of the work on its refractory clayrock deposits revealed that none of the various systems of nomenclature previously applied to the Dakota were adequate to express the stratigraphic relationships. Consequently the subdivision and terminology of the group in the foothills of the northern Front Range was revised (Waagé, 1955). The relation of the revised terminology to previous terminologies employed in the northern foothills of Colorado and to current Dakota nomenclature in adjacent areas is shown in figure 2. In the following paragraphs, the principal features of local Dakota stratigraphy are briefly summarized. Inasmuch as the present report treats chiefly those aspects of the stratigraphy that relate to the distribution of refractory clayrock, the reader is referred to Waagé (1955) for a more comprehensive account of the Dakota succession and its stratigraphic features.

The Dakota group in the northern foothills of the Front Range includes the dominantly sandy sequence of beds between the Morrison formation and the Benton shale. This sequence contains lithogenetically distinct lower and upper parts that are called, respectively, the Lytle and South Platte formations. The Lytle formation consists of irregular lenses of light-gray to white sandstone and conglomeratic sandstone interbedded with variegated claystone, similar to that in the underlying Morrison formation. The Lytle is characterized by the lenticularity of its sandstone bodies and by the lack of persistent subdivisions. The overlying South Platte formation consists of alternating subunits of brown-weathering sandstone and dark-gray to black clay shale and siltstone. In marked contrast with the discontinuous beds in the underlying Lytle formation the South Platte subunits are persistent, and their variations are chiefly gradual lateral changes of facies.

The distinct twofold lithic division of the Dakota group into the Lytle and South Platte formations records a change from flood-plain deposition to deposition in the varied fresh-, brackish-, and salt-

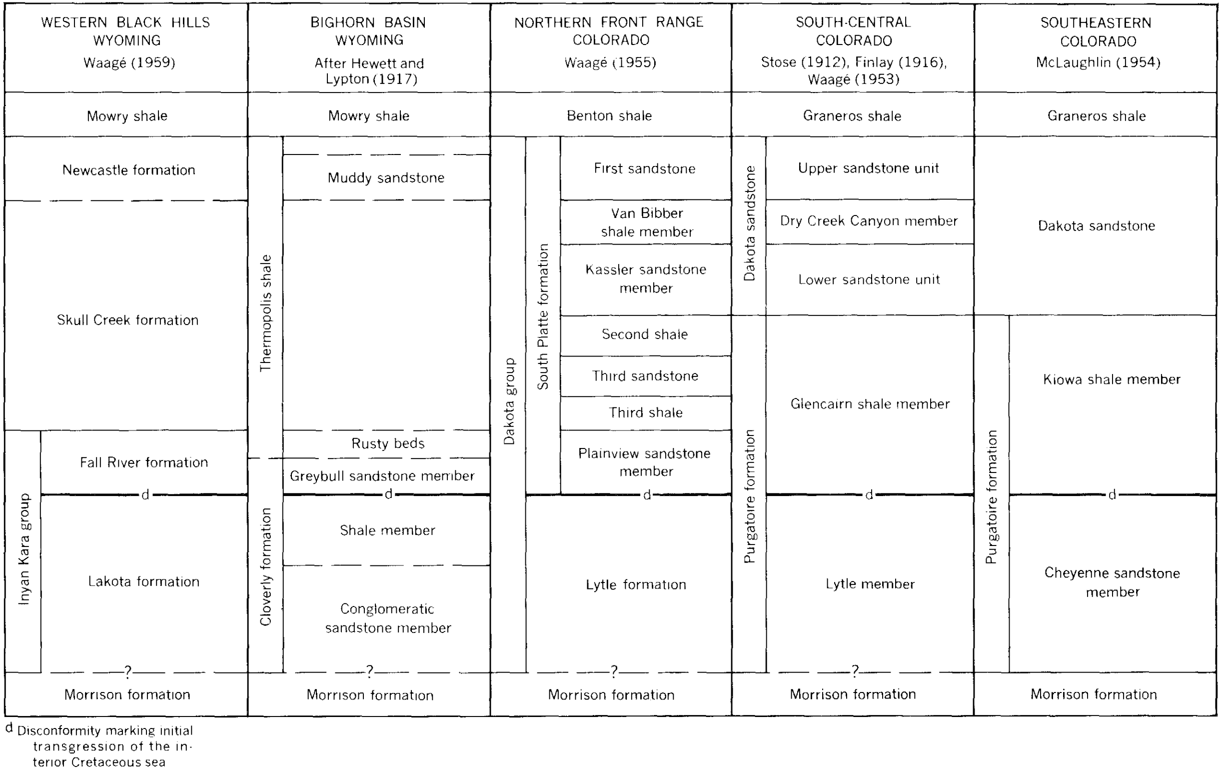

FIGURE 2.—Nomenclature and probable equivalency of outcropping pre-Benton Cretaceous strata in eastern Colorado and adjacent areas.

water environment marginal to the encroaching Cretaceous sea. This change is marked by a sharp, persistent disconformity between the two formations.

Throughout the northern foothills of the Front Range the Lytle varies little in character, and its lateral changes are largely restricted to local variations of thickness and local differences in the relative abundance of clayey and sandy rocks. The South Platte formation, on the other hand, changes from a sequence of dominantly sandy deltaic strata in the southern part of the foothills to a sequence of dominantly shaly marine strata in the northern part of the foothills. The marine facies of the South Platte formation contains a meager shallow-water fauna characterized by the Early Cretaceous, Albian, guide fossil *Inoceramus comancheanus* Cragin. The Lytle has not yielded diagnostic fossils in the northern foothills but it is equivalent to that part of the Cloverly formation of Wyoming that contains Early Cretaceous nonmarine fossils.

LYTLE FORMATION AND ITS CLAYROCKS

Throughout the northern foothills the Lytle formation is between 50 and 100 feet thick. Massive cross-laminated lenses of sandstone that are friable and nonresistant in most places commonly make up at least 60 to 80 percent of the formation. The sandstone beds range in grain size from fine to coarse and locally contain granules and pebbles of chert and quartzite. Conglomeratic lenses are distributed erratically and commonly are absent. No persistent conglomeratic layer marks the base of the Lytle, although the basal sandstone lens of the formation is more commonly conglomeratic than are the lenses above. The Lytle sandstone lenses are the principal aquifers in the Dakota group and have been referred to collectively as the "white Dakota" by well drillers.

The clayrocks interbedded with the sandstone lenses consist of variegated claystone with a subconchoidal to blocky fracture. Most of the claystone contains varying amounts of silt or sand and is semihard to semiplastic. The colors are chiefly different shades of red and green with some maroon, lavender, and yellow. Where claystone immediately underlies the disconformity at the top of the Lytle it is commonly light colored, ranging from white to yellowish white, light green and pink. The pink stain is derived from local concentrations of iron oxide in intercalated silty or sandy lenses.

The sandstone and clayrock lenses have no fixed pattern of succession within the Lytle of the northern foothills. Locally, individual sandstone lenses, or a succession of several lenses, can be traced for as much as 10 miles along the strike, but this is the exception rather than the rule. The base of the formation appears persistently sandy, but it is not persistently conglomeratic. At many places the base of the Lytle cannot be distinguished with certainty from similar sandy beds in the upper part of the underlying Morrison formation. Throughout the southern part of the northern foothills the uppermost beds of the Lytle are claystone in some places and sandstone in others, but in Larimer County the uppermost 5 to 15 feet of the formation is commonly claystone.

Most variegated claystone in the Lytle formation is too inferior in grade even to be used as a source material for common brick. Exceptions to this are the bodies of light-colored claystone which locally underlie the disconformity at the top of the formation; some of these are of refractory grade. This distinctive light-colored claystone is likely to occur wherever the uppermost beds of the Lytle are claystone, although at a very few places, such as in Handy Ditch (section 4, unit 5), the claystone beneath the disconformity is the dominantly red and green variegated color typical of the formation as a whole.

The light-colored claystone bodies commonly occupy the entire interval between the disconformity at the top of the Lytle and the top of the uppermost sandstone lens. However, where the claystone approaches its approximate maximum thickness of 15 feet the color changes gradually downward to light red and light green. In most bodies of light-colored claystone, the clay and silt, or sand, fractions are poorly sorted and silty claystone grades vertically and laterally into clayey siltstone in irregular fashion. Silt-free claystone is exceedingly rare.

The refractoriness of the light-colored claystone decreases downward from the disconformity. The upper 5 to 10 inches commonly has a fusion point of cone 32½. Beneath this zone the cone of fusion decreases abruptly, in most places dropping under cone 29 from 3 to 6 feet below the disconformity. At the Alameda Parkway exposure (section 10), units 7 and 6 at the top of the Lytle constitute a 6.7-foot zone of yellowish silty claystone. The upper 3.7 feet (unit 7, sample 34) has an average fusion value of cone 30½ and the lower 3 feet (unit 6, sample 35) an average fusion value of cone 29½, indicating a decrease in fusibility within the zone as a whole from cone 31 at the top to cone 29 at the base.

The location of the light-colored claystone bodies directly beneath a regional disconformity and the decrease in grade of the claystone downward suggest that they constitute a weathered zone formed before the deposition of the overlying South Platte formation. Local concentrations of iron oxide within the light-colored claystone, or at its base, are also suggestive of a weathered zone; at some places,

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thin, discontinuous silt and sand beds with red ferruginous cement resemble hardpan. Where the claystone zone is relatively thin the upper several inches of the underlying sandstone lens commonly is impregnated with iron oxide that forms a hard red or brown cap.

Iron oxide also occurs as tiny spherical specks scattered in the upper part of the claystone just beneath the contact with the overlying South Platte formation. These ferruginous specks, which are formed by the weathering of authigenic spherulites of siderite, are common in equivalent strata elsewhere in the northern interior region. They appear to be a diagnostic feature of the beds immediately underlying the widespread transgressive disconformity that marks the base of the South Platte formation and its equivalents (see fig. 2). Spherulitic siderite is known from other horizons in interior Cretaceous strata and from sedimentary rocks of different ages throughout the world. According to Deans (1934), who discusses in detail its origin in the English Coal Measures, spherulitic siderite forms when iron in solution is carried down to a zone of stagnation and reduction during the formation of underclays by subaerial leaching and oxidation by ground water.

The presence of refractory-grade claystone in a weathered zone is generally indicative of thorough leaching. There is some indication that the clayrock in the Lytle was dominantly kaolinitic and therefore would readily yield a high-alumna claystone on weathering. Keller (1953, p. 93) determined the most abundant clay mineral in samples collected from the new type section of the Morrison along Alameda Parkway (Waldschmidt and Leroy, 1944), using the lithic units described by Waldschmidt and Leroy as a guide in collecting. He found that the clayrock in the uppermost 77 feet of the new type section of the Morrison, the "Sandstone and Shale unit" of Waldschmidt and Leroy, is dominantly kaolinitic (Keller, 1953, p. 98). Although the exposures in the Alameda Parkway cut are complete, the contact of the Morrison and Lytle is indefinite because of the local lack of a conglomeratic basal lens in the Lytle. A large part, if not all, of the "Sandstone and Shale unit" belongs in the Lytle rather than in the Morrison formation (Waagé, 1955, p. 25). Additional work on the Lytle clay minerals, particularly in areas where the contact with the Morrison is obvious, is necessary to establish the dominant kaolinitic nature of the Lytle suggested by Keller's work and the few tests made for the present report. Conceivably, determinations of clay minerals may provide the best criteria for separating the Morrison and Lytle formations in areas where the contact is indefinite, as the bulk of the Morrison below the "Sandstone and Shale unit" is dominantly illitic or montmorillonitic (Keller, 1953, p. 98).

The light-colored claystone at the top of the Lytle occurs from place to place throughout the foothills of the northern Front Range. The refractory quality of this claystone was first recognized by Butler (1914, p. 132) who described the bed as follows:

> It has been generally believed that there is no true fire-clay north of Boulder, but this investigation has proven this idea incorrect, since six miles northwest of Fort Collins there is a 7-foot bed that is fully as refractory as the material found farther south; and equally promising clays occur from the Wyoming line to a point six miles therefrom, and possibly farther. There the bed varies from 2 to 6 feet in thickness. All these refractory samples came from the lower zone and are much like the southern material in their deficient plasticity, tensile strength, and cohesion. They differ decidedly, however, in color from the southern fire-clays, being white, white and pinkish, or light bluish green. All are massive clays rather than shales, and are sandy.

The locations of Butler's samples of refractory grade claystone from Larimer County (Butler, 1914, p. 233–253, samples 344, 366, and 372) were checked in the field; all are in the weathered zone at the top of the Lytle. This zone is conspicuous in Larimer County where the upper 5 to 15 feet of the Lytle is generally claystone. To the south, claystone bodies of comparable thickness are limited to local lenses between which the claystone is either very thin or the beds are sandstone.

Large bodies of claystone in the Lytle doubtless occur at several places in the northern foothills, but the bed has not been exploited for several reasons. In most places claystone crops out on the west-facing scarp of hogbacks, and, to be mined in quantity, it would have to be reached by tunnel or slope from the east or west foot of the hogback and stoped, as are the clayrocks in the overlying South Platte formation. Operations of this kind are warranted only where the claystone is relatively constant in thickness and quality. Consequently, the great variability in thickness and sand content, which make it impossible to predict the value and continuity of claystone in the Lytle away from the outcrop, are the chief deterrents to its use. Moreover, as the larger and more continuous claystone bodies in northern Larimer County lie far to the north of the refractory-products industry centered in the Denver-Golden area, there is also a geographic reason for the lack of interest in claystone of the Lytle formation.

The possibility of strip mining the claystone of the Lytle is ruled out for most of the southern part of the northern foothills because the outcrop is on the steep scarp face of the hogback and is overlain by most or all of the 200 to 350 feet of sandstone and shale that make up the South Platte formation. At a few places in this area, chiefly adjacent to water gaps, the Plainview sandstone member of the South Platte formation, which directly overlies the Lytle, forms a small subsidiary hogback west of the main hogback. At such places the claystone in the Lytle, if present, is readily accessible and small quantities of it can be stripped or quarried from the narrow lip of outcrop. The only place where the Lytle of the northern foothills has been mined is in a small stripping of this type at the open pits of the Robinson Brick and Tile Co. on the south side of Turkey Creek gap in Jefferson County. The Lytle might also be quarried where the beds in the hogback are vertical.

In parts of Boulder and all of Larimer County the Dakota group commonly makes a double hogback. The outer, or eastern, ridge is formed by sandstone beds at the top of the South Platte formation, the inner ridge is formed by the Plainview sandstone member. Here the claystone in the Lytle crops out at or near the crest of the inner hogback. The overlying Plainview member, which consists almost entirely of hard even-bedded brown-weathering sandstone about 30 feet thick, prevents large-scale strip mining. Nevertheless the outcrop of claystone is more easily accessible for minor amounts of stripping and quarrying than in the southern part of the northern foothills.

The claystone in the Lytle is difficult to evaluate. It is relatively unknown to the clay-working industry in Colorado and other than the tests given in this report (table 2, samples 34, 35, and 36) and by Butler (1914, p. 332–335) there is no published record of its characteristics. Although sizeable bodies of minable grade and thickness may occur locally, the claystone in most places is too variable in character and thickness and too difficult to mine in quantity to be a possible important source of refractory-grade claystone. As a possible minor source of high-grade claystone the Lytle merits much more thorough prospecting than it has received.

SOUTH PLATTE FORMATION

GENERAL FEATURES

The South Platte formation ranges from 200 to 350 feet in thickness within the northern foothills of the Front Range. Its most prominent lithic constituents are fine-grained, brown-weathering sandstone subunits that commonly form one or two hogbacks. Gray to black clay shale occurs in persistent bodies between the sandstone subunits and in local lenses within them.

In northern Douglas and Jefferson Counties the South Platte formation is dominantly deltaic and sandy; in Boulder and Larimer Counties it is dominantly marine and shaly. One persistent marine zone and several thin beds of altered volcanic ash permit a fairly close correlation of subunits between the deltaic and marine facies of the formation. The greatest number of subunits occur in the southern deltaic facies where sandstone subunits alternate with thinner bodies of clay shale. Northward the sandstone subunits in the middle of the formation grade laterally into marine clay shale and siltstone so that the northern marine facies consists of a thick body of marine clay shale and siltstone with sandstone subunits at the top and base.

The term deltaic, as used in this report, deserves further explanation. In the preceding report on the Front Range Dakota sequence (Waagé, 1955) the term nonmarine was used in the same sense that the word deltaic is used here. Nonmarine, however, is employed mostly as a synonym for continental and brings to mind sedimentation of the type common in the western Cenozoic rocks, or in formations like the Morrison and Lytle. No general term, comparable to marine and nonmarine, is in wide use for the varied deposits intermediate between these two realms. Some authors refer to these as marginal or transitional deposits. Outstanding, and seemingly contradictory, features of these marginal deposits are their regularity of succession over wide areas—a "marine" characteristic, and their general lack of marine faunas—a "nonmarine" characteristic. Seaward they grade into marine deposits, landward into strictly nonmarine deposits. Dominantly sandy marginal deposits like those in the South Platte formation from Boulder County southward, show all gradations from intertidal "worm"-worked sand to estuarine, flood-plain and swamp deposits. This diverse association of marginal environments is typical of deltaic deposits, and the word deltaic aptly describes the southern phase of the South Platte formation. A single delta is not implied, rather the formation is largely a succession of several coalesced deltaic deposits that shifted geographically.

The succession of subunits in the deltaic facies of the South Platte formation, shown in figure 3, has been described (Waagé, 1955, p. 28–36). The principal refractory clay shale occurs in the upper part of the formation above the Kassler sandstone member. Here the Van Bibber shale member contains beds that have furnished the bulk of the refractory clay shale in the Denver-Golden area; clay-shale lenses in the overlying first sandstone also have been mined locally. Beneath the Kassler member the clay shale in the South Platte formation is at best only semirefractory and in most places it is too impure to be used.

REFRACTORY CLAYROCK DISTRIBUTION

In the foothills of the northern Front Range refractory clay shale has been mined from the South Platte formation as far north as

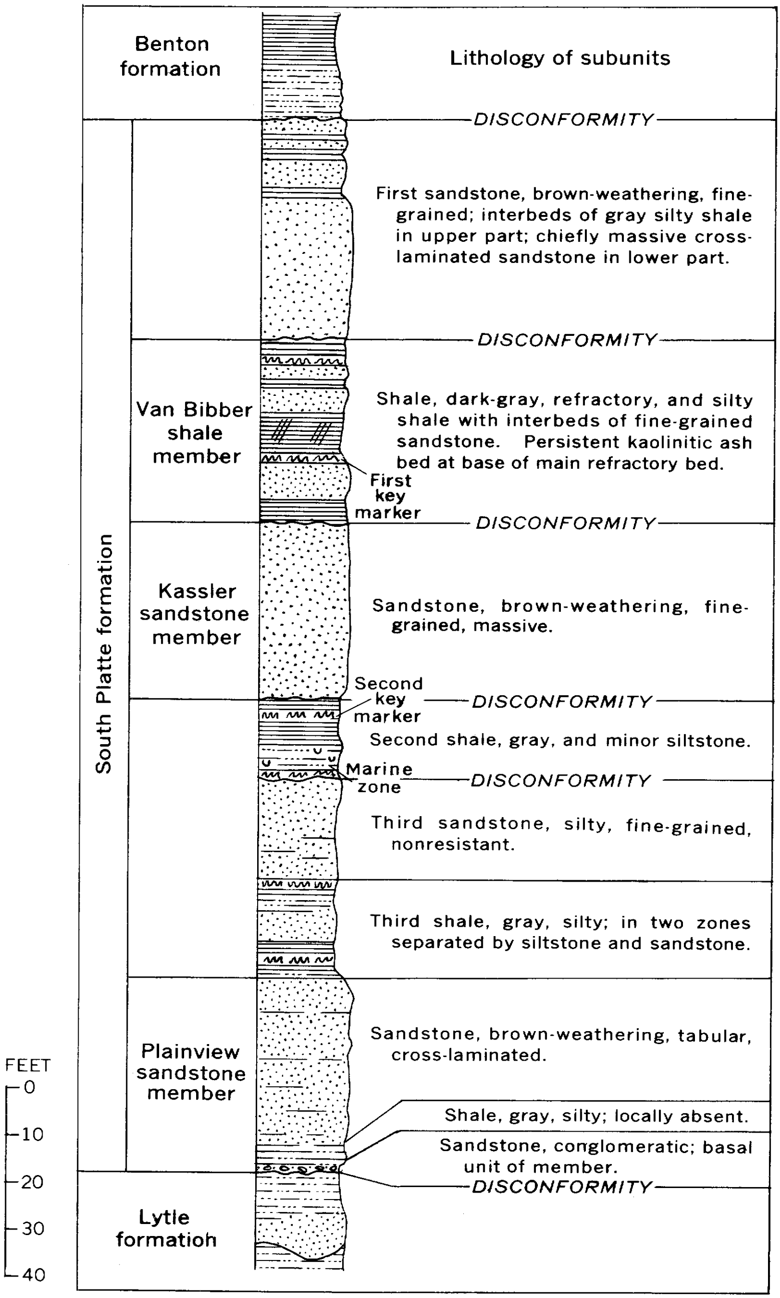

Figure 3.—Subdivisions of the South Platte formation in the deltaic facies. (Modified from Waage, 1955, fig. 10.)

Coal Creek in northern Jefferson County; northward it has not been found in commercial quantity. This abrupt termination of the producing beds of the Golden area has been known since the early stages of their development, and the belief is widespread that no refractory clay shale occurs north of Boulder. Clay workers who do not agree with this belief maintain that the refractory clay shale bodies have yet to be discovered. They point out that north of Boulder the clay shale beds are thicker, more heavily mantled with slope wash and in general poorly exposed and difficult to prospect. Butler's study (1914) revealed the locally refractory claystone at the top of the Lytle in Larimer County, but he recognized that this claystone, which he distinguished as the lower of two shale zones, was not equivalent to the refractory clay shale at Golden. Nevertheless he states ambiguously (Butler, 1914, p. 132) that, "The two shale zones north of Boulder are, outside of their possibly decidedly refractory nature, very promising, since not a single sample taken failed to make good bricks . . ." None of Butler's samples from his upper zone north of Boulder—the zone equivalent to the Golden refractory clay shale—are refractory, and his indirect reference to the possible refractory nature of the upper zone is misleading.

The change from refractory to nonrefractory clay shale northward coincides with, and is a part of, the change of facies of the South Platte formation from dominantly deltaic to dominantly marine. High-alumina clay shale does not occur in the marine beds, consequently the formation can be eliminated as a possible source of refractory material throughout the area of the marine facies. Conceivable exceptions to this would be local nonmarine lenses within the predominantly marine sequence. This is a remote possibility and would apply to the uppermost beds in the formation where such lenses, if present, would most likely be too small to be of commercial value.

CONTROL BY FACIES CHANGE

NATURE OF THE CHANGE

Corroboration, by stratigraphic evidence, of the belief that refractory clayrock does not exist in commercial quantities in the South Platte formation north of Boulder does not necessarily mean that the northernmost limit of refractory clay shale can be pinpointed on a map. The northernmost commercial production of high-grade refractory clay shale has been from the mines at Fireclay siding just south of Coal Creek in the Ralston Buttes quadrangle, Jefferson County. Coal Creek marks the approximate northern end of the dominantly deltaic facies of the South Platte formation. North of Coal Creek abrupt changes, some local in extent, give the formation an appreciably different aspect throughout Boulder County; this is an intermediate facies of the formation (Waagé, 1955, p. 36). A short distance north of the Boulder County line in Larimer County additional changes occur as the formation takes on the features of a dominantly marine facies that characterize it throughout Larimer County. Refractory-grade clay shale disappears northward within the southern part of the intermediate facies. The nature of the change in the South Platte formation that eliminates the refractory clay shale beds and precludes their occurrence to the north along the Front Range is summarized graphically in figure 4.

The major changes that take place northward from the dominantly deltaic facies include the following:

1. Northward thinning and gradation of the Kassler sandstone member and the third sandstone into clayey siltsone, clay shale, and calcareous clay shale with interbedded platy impure limestone.
2. Change of the clayrocks from kaolinitic to illitic and montmorillonitic clays.
3. Change of ash beds from kaolinitic porcellanite to montmorillonitic bentonite.
4. Increase in the stratigraphic range of marine fossils from the single thin zone near the base of the second shale to include most of the strata between the Plainview sandstone member and the uppermost sandstone of the formation.

Changes in the sandstone subunits within the South Platte formation are reflected in the topographic expression of the formation and each facies is characterized by a particular outcrop pattern. In the deltaic facies either the Kassler sandstone member, the first sandstone, or the two combined, most commonly form the crest of the prominent single Dakota hogback of northern Douglas and Jefferson Counties, although there are local exceptions. In the southern part of the intermediate facies, around Eldorado Springs, the single Dakota hogback is supported by the combined Plainview sandstone member and a locally resistant lens of the third sandstone. At Boulder and for a short distance north a thin sandstone at the top of the formation forms a lower hogback east of the Plainview ridge, but northward the Plainview sandstone member alone forms a hogback. Throughout the intermediate facies the dominantly clayey, greatly thickened, parts of the South Platte formation above the Plainview member lie obscured by slopewash on the dipslope of the hogback with only an intermittent low ridge of quartzite, capping the first sandstone, to mark the top of the formation. In Larimer County the first sandstone thickens to form the outer ridge of a double Dakota hogback characteristic of the marine facies; the inner ridge is formed by the persistent sandstone in the Plainview member,

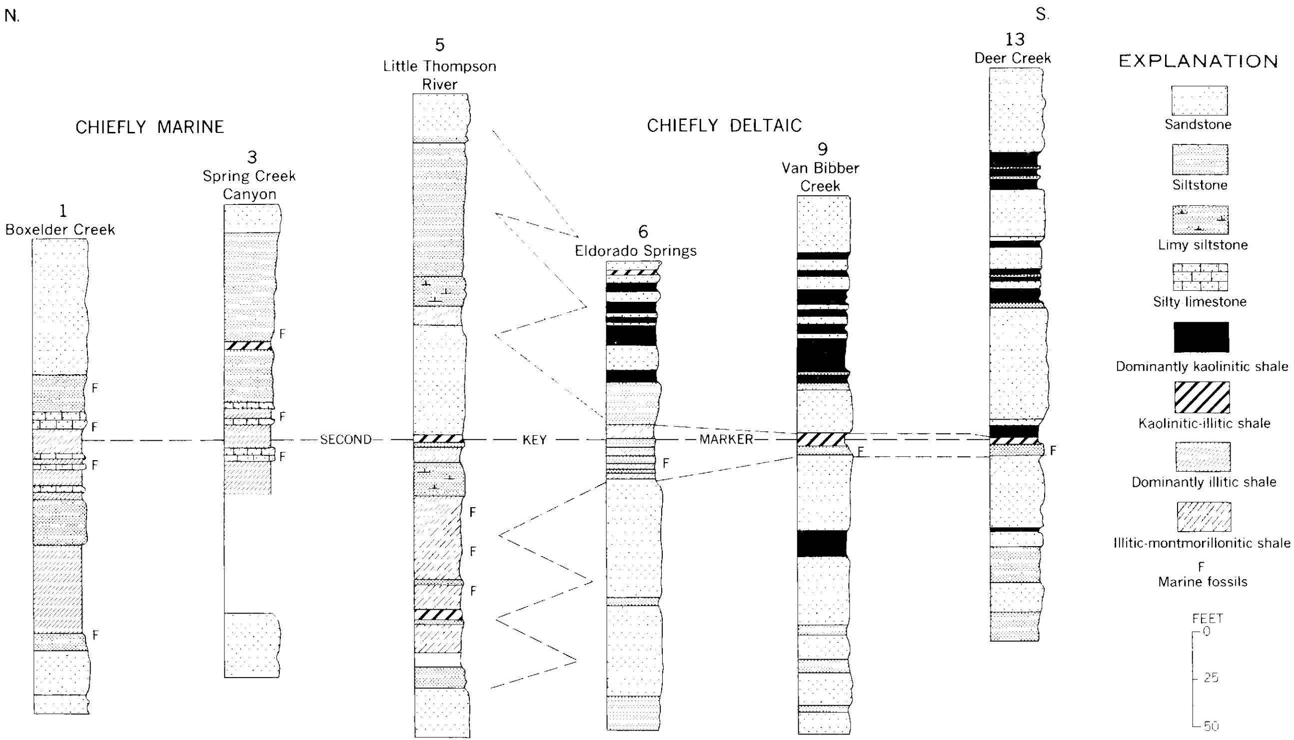

FIGURE 4.—Change of facies in the South Platte formation in the foothills of the northern Front Range, Colo. For location of sections see figure 1.

and the swale between the ridges is eroded in the zone of marine clay shale, siltstone and limestone that makes up the middle part of the formation.

CHANGES IN THE REFRACTORY CLAYROCK BEDS

In figure 4, the second key marker is used as the datum because it is the most persistent and easily identified key bed. It also serves to divide the South Platte formation into two parts for convenient description of its lateral changes. That part of the formation above this datum contains the principal refractory clayrocks.

In the northern part of the deltaic facies, north of Golden in Jefferson County, that part of the South Platte formation above the clay shale containing the second key marker consists of three well-defined subunits that are in ascending order the Kassler sandstone member, Van Bibber shale member, and first sandstone. Here refractory clay shale of commercial grade and thickness is chiefly in the Van Bibber member. Although the two sandstone subunits gradually thin northward from the southern part of the deltaic facies they are sufficiently thick to form prominent, resistant ledges that alternate in forming the crest of the Dakota hogback. Approximately 2 miles south of Coal Creek these two sandstone subunits and the intervening Van Bibber shale recede from the crest position and crop out on the dip slope of a hogback formed by the Plainview sandstone member. From Fireclay siding, about a mile south of Coal Creek, to Plainview, faulting interrupts the normally continuous outcrop of the Dakota group, and in the vicinity of the creek the group is either eliminated by faulting or masked by surficial material. Between Plainview and Eldorado Springs the three subunits in the upper part of the South Platte formation lie in the slope east of the hogback formed by the Plainview member and are not exposed well enough to trace in detail.

In the complete exposures at Eldorado Springs (section 6) the Kassler sandstone member is represented by about 13 feet of siltstone (unit 31) and the first sandstone by three thin beds of sandstone separated by clay shale and clayey siltstone (units 47–52). The intervening Van Bibber member has a normal sequence of beds and its thickness exceeds the combined thickness of the other two subunits. Thermal analyses of the clay shale in this member indicate that it is dominantly kaolinitic throughout and fusion tests (table 2, samples 1, 14, 15, and 16) indicate that much of it is of refractory grade. However, none of the individual clay shale beds exceed 6 feet in thickness and all contain many thin beds and laminae of siltstone.

Between Eldorado Springs and the outcrop on Little Thompson River (section 5), near the north line of Boulder County, the exposures of the beds above the Plainview member are scarce and of limited stratigraphic extent. A brown-weathering, quartzitic sandstone bed, from 2 to 15 feet thick, crops out intermittently in a low ridge along the Boulder-Lyons road. This bed is at the top of the South Platte formation on Little Thompson River (unit 41); to the south it may correspond, at least in part, with the uppermost quartzitic sandstone (unit 52) of the Eldorado Springs section. All exposures of beds directly beneath the quartzitic sandstone in the intermediate facies are characterized by a predominance of clayey siltstone. A composite section generalized from several exposures along Colorado State Route 7, within 6 miles south of St. Vrain Creek is given below.

	Thickness (feet)
Benton shale (obscured).	
South Platte formation:	
11. Quartzite, fine-grained, tabular, brown-weathering; interbedded sandy siltstone in lower part	1–15
10. Shale, silty, gray; contains thin beds of hard siltstone and sandy siltstone, chiefly in middle part, and thin layers of bentonite at top and base	7–8
9. Siltstone and fine-grained sandstone, gray to light-gray; forms rounded brown-weathering ledge locally; some shaly beds in upper part	3–7
8. Siltstone, argillaceous, dark-gray, crumbly to soft; some silty claystone in lower part; irregularly laminated	7.5
7. Sandstone, fine-grained, massive; contains irregular carbonaceous laminae, grades to siltstone above and below; weathers brown, locally hard enough to form rounded ledge	6–8
6. Siltstone, massive, gray; contains irregular dark-gray laminae and partings; becomes increasingly argillaceous downward; weathers, with blocky fracture, to crumbly slopes; some sandy layers in upper 6 or 8 ft	30–35
5. Bentonite	.2
4. Siltstone, hard, argillaceous, calcareous; locally contains calcareous brown-weathering concretions	3–5
3. Bentonite	.2
2. Siltstone, shaly to irregularly thin bedded; calcareous in lower 3 to 5 ft; contains harder interbedded calcareous siltstone and some concretionary, rusty brown-weathering layers about 1 ft thick	12–14
1. Siltstone, partially obscured, irregularly thin bedded to cross-bedded weathers slabby with some shale partings; locally calcareous	6–8

In this section the shale in unit 10 is a mixture of illitic and kaolinitic clays, and units 1, 2 and 4 are calcareous. No clear-cut correlation with the Eldorado Springs section is possible, but equivalents of both the first sandstone and the Van Bibber member are no doubt present. Perhaps the two thin bentonite units (3 and 5) indicate the horizon of the first key marker within the Van Bibber member.

The nearly complete section of the South Platte formation on Little Thompson River (section 5), about 5 miles northeast of where St. Vrain Creek crosses the South Platte outcrop, is also difficult to relate to the Eldorado Springs section and to outcrops of the formation to the north in the marine facies as well. Both the unusually great thickness of the South Platte formation and the predominance of siltstone and shale at the exposures on Little Thompson River make it difficult to recognize any of the three subdivisions in the upper part of the formation. Presumably this part of the South Platte formation in most of the area of poor outcrop in Boulder County is similar to that in the Little Thompson River section. Originally (Waagé, 1955, p. 38) the two bentonitelike clay beds high in the Little Thompson River section (units 31 and 33) were considered equivalent to the second key marker, but subsequent work indicates that the next lower bentonitelike clay (unit 22) is most likely the second key marker. If this is so, units 28 through 35, at least, are probably lateral equivalents of the Van Bibber member. Of these, unit 28 is dominantly illitic shale, and unit 29 above contains marine fossils.

Throughout the intermediate facies north of Boulder, beds equivalent to the Kassler sandstone member are characteristically massive gray clayey siltstone with some sandy siltstone in the upper part. These beds weather to crumbly ledges in road cuts, but in natural outcrop generally do not form ledges in the slope west of the quartzite ridge. In the Little Thompson River section the beds equivalent to the Kassler sandstone member are most likely units 24, 25, 26, and 27, consisting of siltstone and sandy siltstone becoming calcareous near the base and totalling 58 feet in thickness.

North of Little Thompson River the beds equivalent to the Kassler member thin abruptly, whereas the beds above it in the upper part of the formation gradually increase in thickness and, throughout much of the marine facies in Larimer County, contain prominent, hogback-forming sandstone capped by a quartzite bed. This suggests that additional sandstone was deposited in this area prior to the formation of the quartzitic bed which is presumed to be the equivalent of that in the intermediate facies. However, such a correlation is unwarranted on the strength of the quartzitic nature of the bed alone, as a quartzitic cap, locally with "worm" borings, is a common feature of sandstone directly succeeded by marine shale in a transgressive relationship. Similar caps occur on the Dakota in south-central Colorado and in formations of other ages, for example the "*Scolithus*" sandstone beds of the Cambrian.

In the marine facies the interval occupied by beds equivalent to the Kassler and Van Bibber members is chiefly siltstone and clayey siltstone, much of it changing northward from massive beds to alternating thin beds of siltstone and silty clay shale. Many of the thin siltstone beds become progressively more calcareous and grade into silty limestone. All the beds contain scattered marine fossils of the Early Cretaceous *Inoceramus comancheanus* fauna. The thickness of these platy siltstone beds varies from place to place as they have been locally thinned by channeling prior to the deposition of the overlying sandstone. This disconformable relationship is identical to that between the first sandstone and Van Bibber shale member in the deltaic facies.

All clay shale beds in the upper part of the South Platte formation are silty and none attain a thickness of more than a few inches before they are interrupted by a siltstone or silty limestone bed. Thermal analyses of shale from the Spring Creek Canyon section (see fig. 4) show a dominance of illitic clay except in the uppermost sample, which is a mixture of illite and kaolinite.

In summary, four principal changes render the refractory clay shale zone of the South Platte formation worthless north of Boulder; (1) thinning of individual clay shale beds; (2) increase in silt content of the clay shale beds, both by mixing and intercalation of siltstone layers; (3) change from dominantly kaolinitic to dominantly illitic material; and (4) appearance of impurities, such as $CaCO_3$, associated with marine origin. The change begins in the southern part of the intermediate phase with the inception of conditions 1 and 2 above. Although refractory-grade clay shale is present at Eldorado Springs the beds are not of commercial value by present standards because they are too thin and too silty. Moreover their topographic position near the base of the dip slope of the hogback is unfavorable for mining by simple methods and would necessitate shafts to get sufficiently far down dip from the outcrop to stope the beds. This combination of factors will probably discourage any large-scale mining of the clay shale north of Coal Creek, even though beds of refractory grade may persist as far north as Boulder, or a short distance beyond.

CHANGES IN THE LOWER BEDS

That part of the South Platte formation below the second key marker consists largely of sandstone and siltstone in the deltaic facies. Intercalated clay shale beds are silty and, with the exception of the second shale, dominantly kaolinitic. The presence of a thin marine zone in the second shale probably accounts for its being in part illitic throughout most of the deltaic facies.

In the intermediate facies of the formation a marked change takes place in the beds of the South Platte formation below the second key marker. Beginning near Plainview, just south of the Boulder County line, the third sandstone rapidly thickens northward at the expense of the third shale, reaching a maximum thickness of 65 feet at Eldorado Springs. In this area the third sandstone is similar to the Plainview sandstone member, being hard, fine grained, tabular, cross laminated, and brown weathering.

The Plainview member also thickens in the vicinity of Eldorado Springs, but the thick wedge of hard sandstone formed by it and the third sandstone in this area is a local feature; both subunits regain their normal lithic character a short distance to the north in the vicinity of Boulder. The thickness of the lower part of the South Platte formation as a whole does not decrease with the disappearance of the thick wedge of sandstone; instead it continues to increase slightly northward from Boulder. Apparently this is due both to lateral expansion of the second and third shale and to lateral gradation of the expanded third sandstone into clayey siltstone.

Exposures between Boulder and the latitude of Lyons are very poor because of the local thickening of nonresistant units like the Kassler equivalent and the beds beneath it, and because of the concommitant thinning of resistant units in the upper part of the formation. Consequently the exact nature of the change is not known. At Little Thompson River (section 5) the individual subunits cannot be distinguished between the bentonitelike clay taken as the second key marker and the top of the persistent Plainview sandstone member. This interval consists of 128 feet of siltstone and shale and has marine fossils of the *Inoceramus comancheanus* fauna scattered sparsely throughout its upper 75 feet. The corresponding interval at Eldorado Springs (section 6) is 86 feet thick; the lower 62 feet of this interval is sandstone. The topographic expression of the South Platte formation throughout most of Boulder County indicates that its stratigraphy is generally similar to that shown in the Little Thompson River exposure.

In the marine facies of the South Platte formation, which appears within a distance of 9 miles north along the strike from Little Thompson River, the second key marker is thicker, commonly consisting of two or more thin bentonite layers. The beds between it and the Plainview sandstone member are dominantly clay shale and silty clay shale, with minor amounts of clayey siltstone. A persistent zone of fossiliferous platy calcareous siltstone and silty limestone lies a short distance beneath the second key marker in the position occupied by the fossiliferous platy siltstone of the deltaic facies. Silty beds occur locally at the same relative position as the third sandstone of the deltaic facies, but as a whole the beds of the lower part of the marine facies are uniform in character and the subunits of the deltaic facies, other than the Plainview member, cannot be recognized.

In both the intermediate and marine facies the clay shale beds that dominate the lower part of the South Platte formation are for the most part illitic or a mixture of illitic and montmorillonitic clays. Calcareous clay shale occurs chiefly in beds corresponding to the second shale. The platy marine siltstone beds, typical of this subunit in the deltaic and intermediate facies, change northward to impure, petroliferous limestone in the marine facies. Marine macrofossils found in the formation below the second key marker are largely limited to these limestone beds. They include the same fauna as the corresponding siltstone beds of the deltaic facies (see pl. 4) but the fossils are more abundant and more varied. Foraminifera and plesiosaur bones found in the beds equivalent to the third shale in the Boxelder Creek exposures (section 1) indicate that the entire clay shale part of the formation is marine in the northern part of the marine facies. The composition of these clay shale beds obviously precludes the possibility that any part of them is of refractory grade.

ASH BEDS

Thin light-colored beds of clayrock, presumed to be ash beds, are interbedded with clay shale in all three facies of the South Platte formation. Some individual beds, such as the key markers, can be traced from one facies to another. In the marine facies most of these beds have all the macroscopic characteristics of bentonite, being soft, soapy, yellow-green clay that swells on immersion in water. In the nonmarine facies the beds are harder, do not swell, and are commonly light yellow or cream colored; many are gray-white porcellanite. Most are partly laminated, indicating some sorting.

Thermal analyses show that in the deltaic facies these beds are dominantly kaolinitic, whereas in the intermediate and marine facies they vary from mixtures of kaolinitic, illitic, and montmorillonitic clays to dominantly montmorillonitic clay. A few samples were tested by X-ray defractometer to check the thermal analyses; the records of two samples of the same bed, the second key marker, from different phases are compared in figure 5. Peaks on the diagram clearly indicate a dominantly montmorillonitic clay in the sample from the marine facies and a dominantly kaolinitic clay in the sample from the deltaic facies.

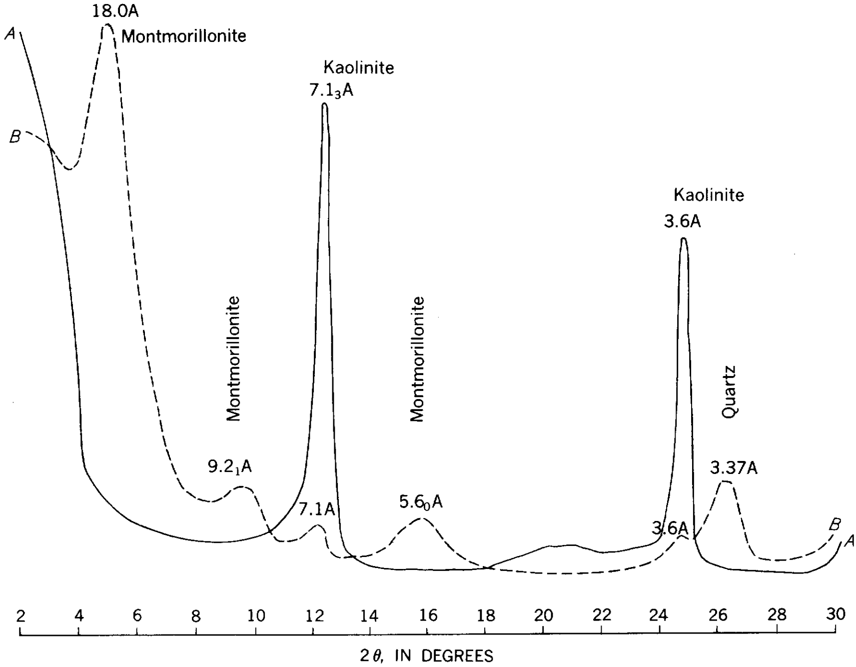

FIGURE 5.—X-ray defractometer traces (smoothed) of two specimens from the second key marker. *A*, kaolinitic clay from Alameda Parkway road cut (sample 32) in the deltaic facies, and, *B*, montmorillonitic clay from Boxelder Creek section, Larimer County, in the marine facies. CuKα, = 1.540 A.

REFRACTORY CLAYROCKS OF THE VAN BIBBER SHALE MEMBER

SUBDIVISION AND TERMINOLOGY

The Van Bibber shale member, the principal source of refractory clayrock in the foothills of the northern Front Range, includes a dominantly clayey sequence of beds lying between the top of the Kassler sandstone member and the base of the first sandstone of the South Platte formation (Waagé, 1955, p. 31). The basal contact with the Kassler is locally sharp and disconformable, but in at least one place the two units appear to intertongue. The contact with the overlying first sandstone is disconformable and the thickness of the Van Bibber member is at least partly dependent on the depth of erosion prior to the deposition of the first sandstone. Throughout most of the central part of the deltaic facies this erosion was sufficiently deep to remove most or all of the member, restricting its principal outcrop to two widely separated areas: the Golden area in Jefferson County, and a smaller, southern area, here called the Douglas County area, extending south from the South Platte River in Douglas County.

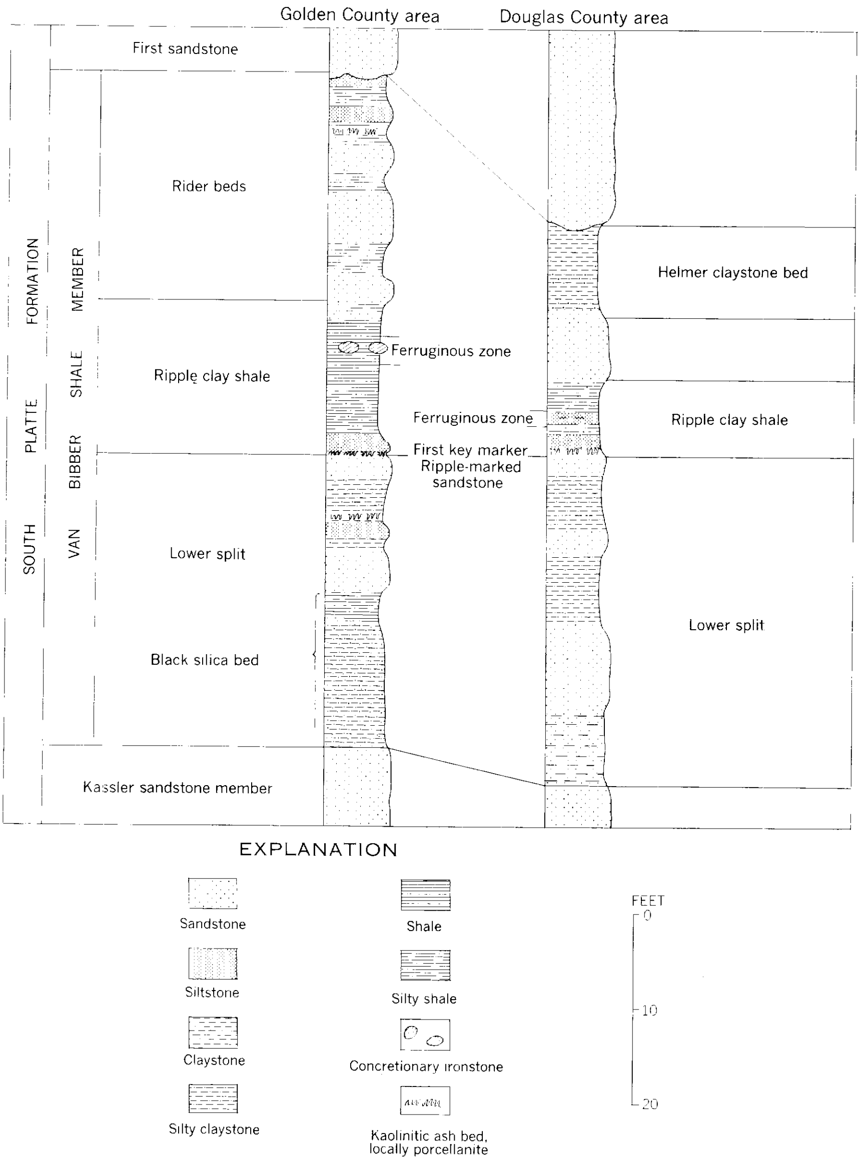

FIGURE 6.—Composite sections of the Van Bibber shale member of the South Platte formation in the Golden, *A*, and Douglas County, *B*, areas.

Although each of the two areas is characterized by certain lithologic features of the Van Bibber member or by distinctive patterns of its sequence, the member as a whole shows a marked persistence of stratigraphic detail throughout its extent. The principal subdivisions are shown on representative sections from the two areas in figure 6. Details of these subdivisions are given for both areas in section on local details beginning on page 33.

The informal names used in figure 6 and in the following discussion of the different beds within the Van Bibber member were coined to facilitate description. Local names were adopted where possible, but because usage is rarely consistent, adoption of most of the names used by clay workers for the different clayrock beds would lead to confusion. Clay shale and claystone within the lower split has been called the "black silica vein" and also the "ribbon clay" in the Golden area, but in the same area the name "black silica vein" has also been applied to other local clay shale lenses elsewhere in the member. The terms "ribbon clay," or "blue ribbon clay," have been used more commonly in reference to the principal producing bed, here called the ripple clay shale. The name "ripple vein" is consistently applied to this same bed in mines in the Douglas County area where it was so named for the characteristic ripple-marked surface of the footwall. As this is characteristic of the principal producing bed in the Golden area as well, the name "ripple clay shale" can be used without ambiguity. The name "ripple-marked sandstone" can be used for the footwall bed. Another common local name, "blue shale," has been used by one company in the Golden area for one or more of the clayrock zones in the rider beds, and by another company in the same area for the second shale, which underlies the Kassler sandstone member. With the exception of the unique Helmer claystone bed, found in the Helmer mine in Douglas County, none of the clayrock beds above the ripple clay shale is given a separate name.

LOWER SPLIT

The lower split comprises those parts of the Van Bibber member lying below the first key marker. Commonly the beds in this interval consist of interbedded clay shale, claystone, siltstone, and sandstone that vary greatly in lithic character and thickness along the strike. At some places, particularly in parts of the Douglas County area, most of the lower split is absent and its uppermost bed, the ripple-marked sandstone, rests directly on the Kassler member. Elsewhere in the Douglas County area the lower split is as much as 35 feet. In the Golden area it is commonly between 5 and 10 feet thick but locally is as much as 40 feet thick. As many as two thin kaolinitic ash beds may be present in the lower split in those areas where it is thick and shaly, but these beds have very local distribution.

Refractory clayrock occurs sparingly in rare local lenses within the lower split in both the Golden and Douglas County areas. At many places the clayrock lenses are more like claystone than clay shale; little of the clayrock has visible bedding structure but some weathers to flakes rather than to blocks or the shardlike chips typical of claystone. In tests on samples from both areas the clay shale fused between cone 32 and 33 (table 2, samples 11, 12, and 13). The lenses are limited in extent and contain both more silt and more carbonaceous matter than the shale in the ripple clay shale bed above. Commercial production from the lower split has been of minor importance; in the Golden area a bed known locally as the "black silica vein," and here called the black silica bed, has been used as a crucible clay.

It is difficult to interpret the relationship between the lower split of the Van Bibber shale member and the Kassler sandstone member in the southern part of the Golden area, between U.S. Highway 40 and the Alameda Parkway. Here the black, silty claystone of the black silica bed lies between two thick bodies of sandstone. The lowest sandstone is undoubtedly part of the Kassler member inasmuch as it overlies the unmistakable second shale. Details of the local stratigraphy (figs. 10 and 11) indicate that the upper body of sandstone is a tongue of the Kassler and that the shale in question lenses out to the south within the Kassler. If this is so the beds assigned to the lower split in the Golden area include beds equivalent to the upper part of the Kassler member in the area to the south.

RIPPLE-MARKED SANDSTONE

Capping the beds of the lower split and directly underlying the ripple clay shale is a thin bed of brown-weathering fine-grained sandstone, locally containing interbedded siltstone. The term "ripple-marked sandstone" is applied to this bed because it is characterized by a persistently ripple-marked upper surface. Mining of the overlying clay shale bed generally stops at this surface, consequently the ripple marks are spectacularly exposed over great expanses in the mines and quarries. The ripple-marked surface is exposed in both the Golden and Douglas County areas and at most places in the intervening area where the lower part of the Van Bibber member is preserved; presumably it extended throughout the deltaic facies, about 40 miles along the present strike, prior to the interval of erosion that followed the deposition of the Van Bibber member. The ripple marks themselves are dominantly symmetrical, and most wave lengths range from 3 to 5 inches. The principal strike of the ripple marks is to the northwest, but local variation in strike is great.

RIPPLE CLAY SHALE

The principal source bed for refractory clay shale in the Golden area is the ripple clay shale. The bed also is mined in the Douglas County area where it is thinner and more silty and is a secondary source in mines whose principal production is from clay shale and claystone in the rider beds and in the first sandstone. In both areas the basal few inches generally consist of a light-colored kaolinitic ash bed, locally a porcellanite, to which the term "first key marker" is applied. The first key marker is in turn overlain by a thin zone of silty clay shale or platy siltstone. At some places the siltstone becomes sandy and thickens to as much as 5 feet; at other places it is absent and the first key marker is directly succeeded by refractory clay shale.

The clay shale above the basal ash and siltstone beds commonly is the most silt free part of the ripple clay shale and consequently the most desirable commercially. The thickness of this clay shale varies with the local abundance of intercalated thin siltstone layers and laminae that characterize the upper part of the ripple clay shale. At many places the siltstone beds and laminae are distributed throughout the ripple clay shale, but even in these places the thicker clay shale layers are in the lower part of the bed. Relatively silt free clay shale bodies as much as 14 feet thick have been mined.

The refractory clay shale is finely laminated (see pl. 3). Fresh clay shale is dark gray to black in color and has a blocky to subconchoidal fracture, but it weathers to light-bluish-gray shaly fragments and is locally quite fissile on the outcrop. Pyrite is the chief fluxible impurity; other unidentified iron compounds are locally present. Carbonaceous matter is abundant but finely disseminated. A number of tests of the ripple clay shale are given in table 2; in general the clay shale ranges in fusion point from cone 32 to cone 34 and, rarely, cone 35.

RIDER BEDS

The term "rider beds" is applied to the alternating beds of refractory clayrock and sandstone or massive siltstone that comprise the upper part of the Van Bibber member succeeding the ripple clay shale. The rider beds are arbitrarily separated from the underlying ripple clay shale at the base of the first sandstone layer sufficiently thick to limit the mining of the ripple clay shale. At some places this horizon probably shifts from one sandstone layer to another, but locally the basal sandstone of the rider beds is a persistent layer. Sandstone layers in the rider beds rarely exceed 5 feet in thickness.

The rider beds are largely limited to the Golden area where they commonly include three or four beds of dark-gray clay shale. One of these clay shale beds contains a thin kaolinitic ash bed that is useful in tracing the individual beds from place to place (fig. 6). The clay shale of the rider beds in the Golden area is commonly refractory, but locally, successively higher beds show a progressive decrease in fusion point. Tests on samples from the beds at several localities (table 2, samples 14, 15, and 16) range from cone 26 to cone 34. At most places the individual beds are not thick enough to mine.

Where the first sandstone is broken by many clay shale lenses it is locally difficult to determine the top of the Van Bibber member. The alternating clay shale and sandstone beds of the rider beds usually are thinner than those of the overlying first sandstone. Moreover, the basal sandstone bed of the first sandstone is commonly thicker than the adjacent sandstone beds and lateral tracing of its base should reveal crosscutting of the underlying beds of the Van Bibber member. Nevertheless in limited exposures, such as those within mine entries, the contact may be obscure.

In the Douglas County area clayrock beds between the ripple clay shale and the base of the first sandstone are rare. An exception is the Helmer claystone bed, a dove-gray claystone which fuses between cone 33 and 34 in its relatively silt free parts. This is the only commercial bed of refractory claystone (the others are shale) in the South Platte formation; it resembles flint clay but is somewhat softer (see pl. 3). The Helmer bed is probably a unique local deposit unrelated to the clay shale in the rider beds of the Golden area.

CLAYROCKS IN THE FIRST SANDSTONE

Unlike the Van Bibber shale member and other parts of the South Platte formation, the first sandstone has no persistent pattern of its parts and lacks key beds. Refractory clay shale occurs in local lenses in both the Golden and Douglas County areas but only in the latter area are the lenses commonly large enough to be commercial.

As a general rule, the lower a clay shale bed lies within the first sandstone, the more refractory it is. The best clay shale beds in the first sandstone are equal in grade to those of the ripple clay shale, but they are much less abundant and much more erratic in their distribution. In appearance they resemble the ripple clay shale in fresh and weathered color, but they commonly lack the pronounced lamination characteristic of that bed. Also they contain at many places entire fossil leaves, some so perfectly preserved that the leaf substance remains as a fragile film and can be peeled free of the rock. Successively higher beds are lighter in color and generally more silty. The uppermost lenses, some within a few feet of the top of the formation, are generally semirefractory at best.

Because of their random distribution further description of the clay shale lenses in the first sandstone is left for the discussion of local details. The lenses are relatively unimportant source beds in the Golden area, but, together with the Helmer claystone bed, they are the chief source of refractory clayrock in the Douglas County area.

OTHER ZONES OF CLAYROCK

Most clay shale beds in the South Platte formation have served to some extent as sources of clay. Other than the zones of clay shale previously mentioned, few contain material of refractory, or even semirefractory, grade and none have been extensively worked. A brief review of the nature of these beds is included to complete the survey of clayrocks in the deltaic facies of the South Platte formation.

PLAINVIEW SANDSTONE MEMBER

The shale locally present in the lower part of the Plainview sandstone member is consistently too high in silt content to be considered as a source of commercial clayrock. The silt occurs both in thin beds and laminae of siltstone and as silt particles dispersed through the clay shale. Locally, burrowing organisms succeeded in mixing the clay shale and silt laminae, so that the bed is chiefly a clayey siltstone. Thermal analyses of a few clay shale beds in the type section of the member at Plainview, in the intermediate facies, show a dominance of kaolinite in most parts of the bed and a dominance of illitic and montmorillonitic clays in the other parts. It is not known whether this mixture of clays persists into the deltaic facies.

THIRD SHALE

The clay shale in the third shale is highly silty, like that in the Plainview member with the difference that the silt is chiefly dispersed through the clay shale. Much, perhaps most, of the third shale is clayey siltstone rather than silty clay shale. In thermal analyses of relatively silt free clay shale samples from the Van Bibber Creek section, kaolinite is the only clay discernible. Fairly sharp exothermic reaction between 400° and 520° C. suggests considerable pyrite and organic matter. Pyrite is observable in hand specimens, and weathered outcrops of the silty clay shale commonly show much ferruginous stain. It is unlikely that clay shale of refractory grade occurs in this zone anywhere in the northern foothills.

SECOND SHALE

The clay shale of the second shale, which includes the second key marker and, in its lower part, the persistent marine zone of platy fossiliferous siltstone, has a mixture of illitic and kaolinitic clays throughout most of the deltaic facies. As far south as the Alameda Parkway illitic clay shale is either dominant or as common a constituent as kaolinitic clay shale, but south of that point kaolinitic clay shale appears to be more common. A zonation of the second shale into an upper kaolinitic part and a lower dominantly illitic part is indicated by tests on samples from one locality between Alameda Parkway and Morrison. Elsewhere in the deltaic facies the second shale was not sampled in sufficient detail to show this zonation, but it is likely that the clay shale in the lower part of the second shale, adjacent to the marine siltstone, is illitic as far south as the marine beds extend. Marine fossils persist in the siltstone at least as far as 6 miles south of the South Platte River in Douglas County.

Locally in the Golden area the second shale does not contain appreciable amounts of silt in its upper part and is thick enough to mine, but the relatively high illite content of the clay shale generally renders most of the bed nonrefractory. Tests by the Golden Fire Brick Co. on clay shale from what is probably the second shale (locally called the blue vein) give fusion points of 21–22 on the raw clay shale and 28–29 on calcined clay shale from the same bed.

In the Douglas County area erosion prior to the deposition of the thick Kassler sandstone member has removed most of the clay shale of the second shale above the platy siltstone beds.

KASSLER SANDSTONE MEMBER

Very small bodies of silty clay shale occur rarely in the Kassler member, but nowhere in the deltaic facies are these scattered shale lenses sufficiently thick and refractory to make the member a commercial source bed. The one possible exception to this is the black silica bed of the southern part of the Golden area, here described as part of the lower split of the Van Bibber shale member.

LOCAL DETAILS OF STRATIGRAPHY AND DISTRIBUTION OF REFRACTORY CLAYROCK

GENERAL FEATURES

Approximately the southern third of the outcrop area of the Dakota group in the foothills of the northern Front Range consists of the deltaic facies of the South Platte formation and its local deposits of refractory clayrock. This area of outcrop, which extends from Indian Creek in northern Douglas County to about Eldorado Springs in southern Boulder County (see fig. 1), is divisible into four parts, differing from one another in the stratigraphic details of the Dakota group and in the distribution and quantity of the refractory clayrock it contains. The southernmost part, here called the Douglas County area, lies between Indian Creek and the South Platte River in the Kassler quadrangle, northern Douglas County. Here the first sandstone and the Van Bibber member of the South Platte formation contain deposits of commercial clayrock, most of which have been mined.

From the South Platte River northward in Jefferson County, through the Littleton, Indian Hills, and much of the Morrison quadrangles, deposits of refractory clayrock in the South Platte formation are few and small. This relatively barren area, here called the southern Jefferson County area, extends for more than a mile north of the Alameda Parkway road cut through the Dakota hogback, but for convenience in description this road cut is taken as its northern limit. Between Alameda Parkway and Coal Creek in northern Jefferson County lies the Golden area, source area for the famous Golden refractory clay shale and chief producing area of refractory clayrock in the northern foothills. The deposits, most of which have been extensively mined, are chiefly in the ripple clay shale of the Van Bibber member. Except for a gap of about 3 miles along the strike in the vicinity of Golden, where the Dakota group is eliminated by faulting, the ripple clay shale is almost continuously of commercial thickness.

North of Coal Creek the lithic character of the South Platte formation changes appreciably as the intermediate facies is approached. Some refractory clay shale occurs in the South Platte formation between Coal Creek and Eldorado Springs, but the beds are poorly exposed and those accessible are thin and silty. This marginal area of the deltaic facies will be referred to as the Plainview area, for the settlement of that name just north of Coal Creek.

With a few exceptions the South Platte formation is exposed at the crest and on the dip slope of the Dakota hogback throughout the deltaic facies. The underlying Lytle formation generally crops out in the upper part of the scarp face. However, at a few places where the Lytle contains thick conglomeratic sandstone lenses, it forms the ridge crest. Local changes in thickness and character of the different subunits within the South Platte formation are also reflected in its outcrop pattern, consequently the crest-forming sandstone of the formation is not everywhere the same. Within the deltaic facies each of the sandstone subunits in the South Platte formation locally forms the crest, but most commonly this position is held either by the Kassler sandstone member or by the first sandstone.

The shift of the crest-forming sandstone from one subunit in the South Platte formation to another has misled workers who assumed that the crest of the hogback was everywhere the same bed and who used it to locate themselves in the section. The most easily identified horizons for locating oneself within the deltaic facies of the South Platte formation are the contact of the Lytle and South Platte formations and the contact of the second shale and Kassler sandstone member. Of these persistent horizons, the first is marked by the pronounced lithologic change between the two formations, and the leached zone at the top of the Lytle. The second is marked by the base of the massive, ledge-forming Kassler sandstone member, and the characteristic second key marker and platy, locally fossiliferous siltstone beds in the second shale. The contact of the South Platte formation and Benton shale is also an obvious horizon, but working downward through the highly variable first sandstone is likely to be confusing. The first key marker lying between the ripple-marked sandstone and ripple clay shale is unmistakable and affords an excellent stratigraphic marker in the Golden and Douglas County areas where the Van Bibber member is extensively preserved; elsewhere the marker is too infrequently present to be useful.

In the description of local details which follows, the Lytle stratigraphy is briefly included in order to give a rounded account of the Dakota group as a whole. Geologic maps of the narrow hogback in the Douglas County area (pl. 1) and the Golden area (pl. 2) show the distribution of the Lytle and South Platte formations, and the approximate outcrop of the ripple clay shale of the Van Bibber member. The contact of the Lytle and South Platte formations serves as a guide locally for prospecting the refractory claystone in the weathered zone at the top of the Lytle. The ripple clay shale outcrop serves as a key for orientation within the refractory clayrock zones of the upper part of the South Platte formation.

DOUGLAS COUNTY AREA

EXPOSURES OF THE DAKOTA GROUP

In the Douglas County area the Dakota hogback is a relatively low, locally flat topped ridge that extends southeastward from the South Platte River across the Kassler quadrangle and terminates abruptly on Indian Creek in the NW¼ sec. 32, T. 7 S., R. 68 W. Here the Dakota strata abut the Pierre shale along a major strike fault—called by Glenn R. Scott (written communication) the Jarre

Creek fault—which marks the southern limit of the northern foothills as defined in this report. The Dakota group is not present between the fault and Perry Park in the Castle Rock quadrangle, about 9 miles south along the mountain front.

From Indian Creek northward for 3 miles the formations in the Dakota hogback strike approximately N. 40° W. to the gap of a tributary of Willow Creek in the SE¼ SW¼ sec. 13, T. 7 S., R. 69 W. From this point north the strike changes to about N. 20° W. and the formations continue in this trend to the South Platte River. The change in strike divides the Douglas County area conveniently into northern and southern parts which differ in certain respects. Throughout the hogback the Kassler member of the South Platte formation is the dominant crest-forming unit although in the northern part it locally shares the crest with the basal sandstone of the first sandstone. The southern part of the hogback tends to be relatively flat topped on the divides between the water gaps, and between Willow and Rainbow Creeks it largely disappears under remnants of the Roxborough Park pediment (G. R. Scott, written communication) which truncates the Dakota strata. In this area, where no well-defined crest is present, the highest elevations are on local thick chertified conglomerate lenses in the Lytle formation. The northern part of the hogback has the characteristic hogback form and stands out as a prominent ridge but it is considerably lower than is normal for the Dakota hogback throughout the deltaic facies to the north in Jefferson County. The height of the hogback, measured between the crest elevation and the elevation of the contact of the Dakota and Benton at the foot of the dip slope, rarely exceeds 250 feet in the Douglas area, whereas to the north the height is commonly between 400 and 500 feet.

Five water gaps, not counting those of Indian Creek and the South Platte River, are cut in the hogback and expose part or all of the Dakota. The gaps of Rainbow Creek (section 19) and Little Willow Creek (section 16) afford complete sections of the Dakota group. Other gaps, mine entries, pits, and outcrops on the scarp face of the hogback afford partial sections, the most complete of which are on Willow Creek (section 18) and at the Helmar mine (section 17). A partial section of the Dakota group exposed at the north end of the hogback just south of the South Platte River, is nearly identical with the type section of the South Platte formation (section 15) 1 mile northwest across the river. Exposures in the southern part of the Douglas County area are relatively poor because of the pediment remnants and the abundant vegetation supported by the soil cover on the flat-topped ridges. Moreover, this part of the hogback is relatively inaccessible by road, and, except for an old abandoned stone quarry, it lacks manmade outcrops.

In the Douglas County area the sandstone subunits in the Dakota group reach their greatest aggregate thickness for the northern foothills. The Dakota group as a whole ranges from 320 to 385 feet in thickness; much of this variation is accounted for by the thickening of the Lytle formation southward from the South Platte River. In spite of the thickening of the sandstone subunits, the South Platte formation locally contains refractory clayrock of minable thickness; and the northern part of the Douglas County area has been the only other commercial source of clay from the Dakota in the northern foothills of the Front Range outside of the Golden area.

LYTLE FORMATION

Throughout most of the hogback in the Douglas County area the Lytle formation lies in the lower part of the west-facing scarp and is largely obscured by slope wash. Four complete sections measured in sand pits and water gaps fairly evenly spaced along the hogback are shown graphically in figure 7. In the northern part of the hogback the Lytle gradually thickens southward from 55 feet near the South Platte River to about 80 feet at Little Willow Creek gap. South of here the formation is generally from 85 to 95 feet thick. However, in the few places where the formation is composed entirely of conglomeratic sandstone, such as at the Willow Creek exposure, it is somewhat thinner.

The Lytle of the Douglas County area is dominantly sandy and consistently conglomeratic. Lenses of red and brown chertified conglomeratic sandstone are a conspicuous feature in the southern part of the hogback, which is the only area in the foothills of the Front Range where this supposedly typical basal Dakota rock type is common. Silicified coniferous wood is a constituent of these chertified Lytle lenses. In the northern part of the Douglas County area, as in most places in the northern foothills, the sandstone and conglomeratic sandstone lenses of the Lytle are relatively friable and nonresistant.

In the few exposures that show the basal Lytle and uppermost Morrison strata the contact between the two units is generally clear-cut inasmuch as the base of the Lytle is conglomeratic. The dominantly red, variegated claystone zone at the top of the Morrison appears to vary greatly in thickness although exposures are few and the distribution of red slope wash may be misleading. Local conglomeratic lenses at the base of the upper third of the Morrison crop out only in the vicinity of Willow Creek.

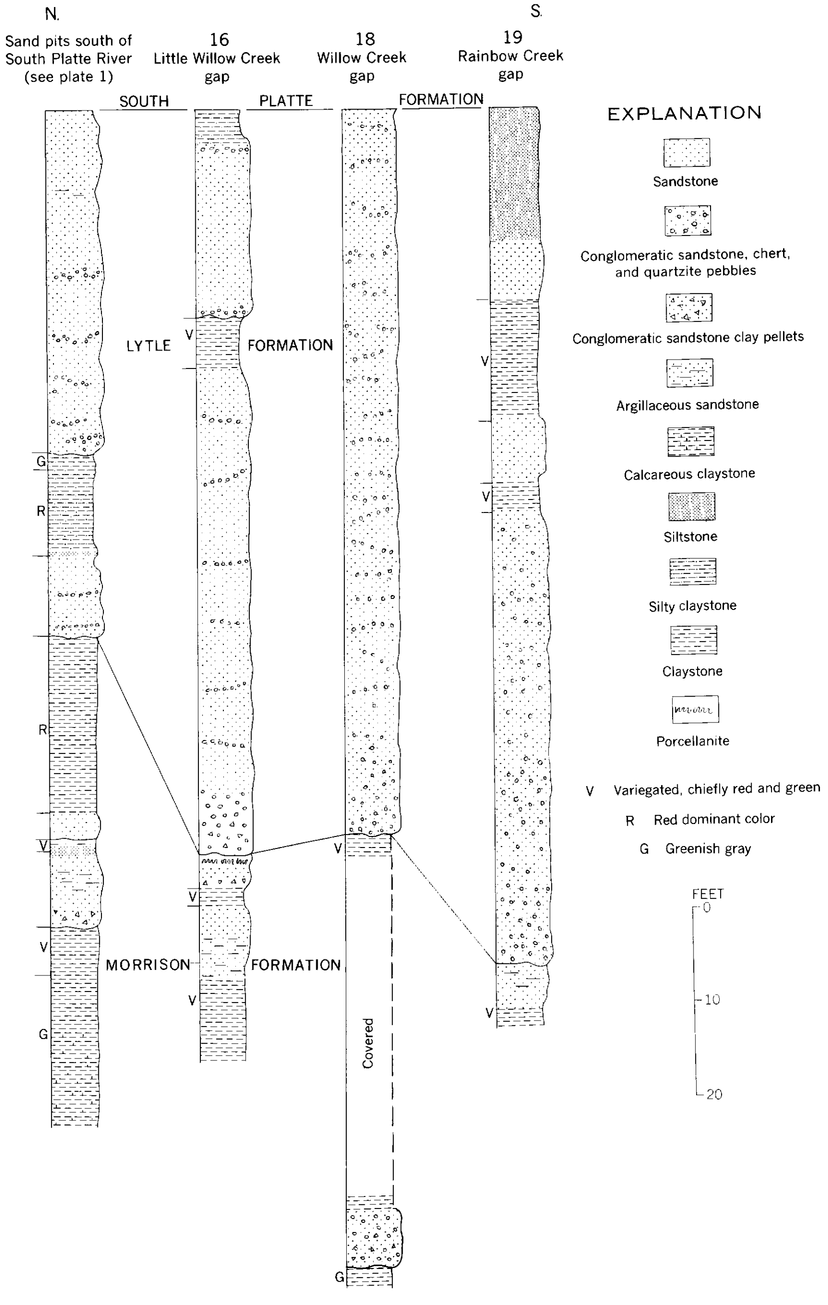

FIGURE 7.—Representative sections of the Lytle formation in the Douglas County area.

Variegated beds make up, at the most, no more than about 35 percent of the Lytle. The beds consist chiefly of silty to sandy claystone and clayey siltstone. Within the formation there is no fixed sequence in the distribution of the variegated beds along the strike. North of Willow Creek, in the NE¼ NW¼ sec. 24, T. 7 S., R. 69 W., about 15 feet of pinkish-white and light-gray claystone and siltstone crop out at the top of the Lytle. These beds lie within the supposed leached zone beneath the contact of the Lytle and South Platte formations; they pinch out abruptly south of Willow Creek. Similar pink and white claystone beds occur in the upper part of the Lytle in the vicinity of Rainbow Creek gap. No tests were made of the clays at either of these localities, but they can be expected to be similar in fusion point and characteristics to clays from the top of the Lytle elsewhere in the northern foothills of the Front Range.

SOUTH PLATTE FORMATION

Between its type section on the north side of the South Platte River gap and the end of the hogback on Indian Creek, the South Platte formation ranges in thickness from 275 to 300 feet. Differences in thickness within this range are local rather than progressive. The formation is dominantly sandy and both the Kassler member and basal sandstone of the Plainview member contain scattered chert and quartzite pebbles. The sand-clayrock ratio is from 4:1 to 5:1; most of this range results from the abrupt lensing in and out of clayrock bodies within the first sandstone.

THE LOWER SUBDIVISIONS

The Plainview sandstone member, lowest of the lower divisions of the South Platte formation, is continuous throughout the Douglas County area, but exposures of its basal contact with the Lytle formation are few. The basal massive, conglomeratic sandstone bed of the Plainview from 0.5 to 3 feet thick, commonly rests on a thin zone of soft clayey siltstone, or a thicker zone of variegated claystone, at the top of the Lytle. In the northern part of the Douglas County area, clay shale beds overlie this basal conglomeratic bed and it, as well as the contact beneath it, lies obscured by wash in a narrow slope between the distinctive ledge of sandstone in the upper part of the Plainview member and the uppermost sandstone of the Lytle. Throughout much of the northern part of the hogback both the Lytle and the Plainview are wash covered and the contact is completely obscured. In the southern part of the hogback where both the Plainview member and the Lytle are thicker and more resistant, exposures of the contact are fairly common, except in the areas of pediment remnants.

The Plainview member ranges from 10 to 60 feet in thickness within the Douglas County area. In the southern part of the hogback it forms a prominent ledge in and adjacent to the water gaps. Between Indian and Rainbow Creek it is 55 to 60 feet thick and consists of sandstone. Here the rusty brown fine-grained tabular sandstone characteristic of the Plainview member is limited chiefly to about the upper 20 feet (see section 19); between this and the 1- or 2-foot basal conglomeratic bed, the sandstone is massive and medium grained. Northward from Rainbow Creek the member thins gradually to 46 feet at the Willow Creek section (section 18) and is mainly tabular in structure.

Within a quarter of a mile north of the Willow Creek section the Plainview member thins to about 30 feet and continues to thin more gradually, northward, until it becomes a narrow, shelving ledge of rusty brown, irregularly bedded to platy, fine-grained sandstone with intercalated clay shale beds just above the basal conglomeratic layer. At Little Willow Creek gap (section 16) the member, partly obscured, is at most 15 feet thick. From this place the characteristic rusty brown sandstone beds, which are only 7 feet thick, can be traced northward for about a mile but then are mantled by slope wash as far as the sand pits just south of the South Platte River gap. Presumably the member gradually thickens northward under this cover for at the sand pits it is 46 feet thick and consists of the following units:

Plainview sandstone of South Platte formation above sand pit in S½ NW¼ NW¼ SW¼ sec. 35, T. 6 S., R. 69 W., Kassler quadrangle

	Thickness (feet)
Plainview sandstone member:	
6. Sandstone, fine-grained, even-bedded, cross-laminated to cross-bedded; weathers yellow-brown; 3-ft friable zone 2.5 ft above base	21.5
5. Sandstone; similar to unit 6 but friable; weathers light gray with rusty brown bands	4
4. Siltstone, clayey and silty clay shale, gray, partly obscured	6.7
3. Sandstone; similar to unit 5	7
2. Siltstone, clayey; grading downward to siltstone	3.8
1. Sandstone, fine-grained, massive, cross-laminated; conglomeratic near base with clay pellets, chert, and quartzite granules	3
Total thickness	46
Disconformity.	
Lytle formation.	

The beds between the Plainview and Kassler members are notably constant in character and total thickness throughout the Douglas County area. Complete sections at four localities (sections 15, 16, 18, 19) are between 63 and 64 feet thick. The third shale, which is between 23 and 30 feet thick, is dominantly siltstone throughout the hogback although the characteristic threefold division into two silty clay shale zones and an intervening sandy zone is obvious. The clay shale zones are composed chiefly of clayey siltstone with thin beds of siltstone; sandy beds are common in the upper zone and the lower zone is clayey. Beds of silty clay shale, rarely more than 2 feet thick, occur locally in both zones. The kaolinitic ash beds, one characteristic of each clay shale zone, occur at a few places but are not persistent. The middle sandy zone consists of interbedded friable sandstone and siltstone that is massive to irregularly bedded with few, if any, resistant layers. It weathers gray with rusty brown bands and splotches.

The upper clay shale part of the third shale grades upward into the third sandstone. The latter is chiefly a friable, irregularly bedded, fine-grained sandstone, from 20 to 30 feet thick, which is silty in its basal part. On weathered surfaces the sandstone varies from gray to rusty brown and tends to show irregular banding of the brown on the gray. The third sandstone commonly is capped by a thin resistant ledge of iron-impregnated sandstone from 1 to 2 feet thick. This is a fairly conspicuous feature on slopes between the Kassler and Plainview members. At some places the surface of this indurated ferruginous cap has broad symmetrical ripple marks as much as 1.1 feet in wave length and about 4 inches in amplitude. These are particularly well exposed in the hogback west of the Helmer mine (see pl. 5).

The second shale rests with sharp contact on the third sandstone. Its thickness ranges from 9 to 20 feet depending on the amount removed by erosion prior to the deposition of the overlaying Kassler member. At a very few localities enough of the second shale remains beneath the Kassler member to show that its characteristic sequence of beds (see fig. 3) persists throughout most of the Douglas County area. In these exceptional exposures the upper clay shale zone is 4 to 5 feet thick and has the persistent second key marker within the upper foot; the underlying platy silstone and sandstone beds and basal clay shale zone are approximately 15 feet thick. Most commonly all but the lower 9 to 12 feet of the second shale is absent and the base of the Kassler member rests on or near the top of the lower bench of platy sandstone and siltstone. The upper clay shale zone is nowhere present in bodies large enough to warrant testing; the largest remnant found was about 5 feet at its thickest part and 10 feet in length along the strike. Marine fossils, chiefly fragments of *Inoceramus*, were found in the lower platy beds as far south along the hogback as Little Willow Creek gap but they are not common. The fossils may possibly be found, with more intensive search, even farther to the south inasmuch as the platy beds containing them can be traced all the way to the fault on Indian Creek.

The Kassler member is commonly between 70 and 80 feet thick south of the South Platte River. From the Helmer mine north to Little Willow Creek gap it appears to thicken gradually to 104 feet. Inasmuch as its upper contact with the Van Bibber member is indefinite at the Little Willow Creek locality, the Kassler measurement may possibly include the sandy basal part of the Van Bibber member. If so, the 93-foot sequence of undoubted Kassler beds in the hogback behind the Helmer mine is the greatest thickness of the sandstone that was measured in the Douglas County area.

Although the Kassler has within it no sharply defined, persistent lithic zones, the upper part is generally fine to medium grained, resistant, and weathers brown, whereas the lower part is friable, coarser in grain, and weathers to light shades of buff, gray, and yellow gray. In the southern part of the hogback the lower, friable portion of the member resembles the Lytle formation in the poor sorting, the yellow- to pink-weathering crumbly outcrop, and the lenticularity of its sandstone bodies. At a few places small lenses of silty dark-gray clay shale occur in the Kassler member but they are rare and not characteristic of the member as a whole.

A distinctive feature of the Kassler member in the Douglas County area, and for some distance northward, is the pellets of silty clay shale and clayey siltstone that occur scattered, or concentrated in lenses, within the lower half to two-thirds of the member. These inclusions are light gray and range from granules to pellets as much as 4 or 5 inches in length. Their shape varies from rounded to angular but the rounded ones are more common. Chert and quartzite granules and pebbles are also scattered throughout much of the lower half of the member and a persistent ferruginous conglomeratic layer, from 0.2 to 1-foot thick, forms its base.

VAN BIBBER SHALE MEMBER

Throughout much of the Douglas County area both the Van Bibber member and the first sandstone contain bodies of refractory and semirefractory clay shale and claystone. Except for the ripple clay shale of the Van Bibber member the clayrock bodies are not persistent but occur as lenses of varying lateral extent. In contrast with the Golden area, the clayrock of these scattered lenses in the upper Van Bibber member and first sandstone, rather than the clayrock in the ripple clay shale, are the chief source of clayrock for the mines in the Douglas County area. Sections of the clayrock-bearing subunits in this area are shown graphically in figure 8.

The Van Bibber shale member crops out, at least in part, throughout much of the northern part of the Douglas County area along the crest of the hogback or on the upper half of the dip slope east

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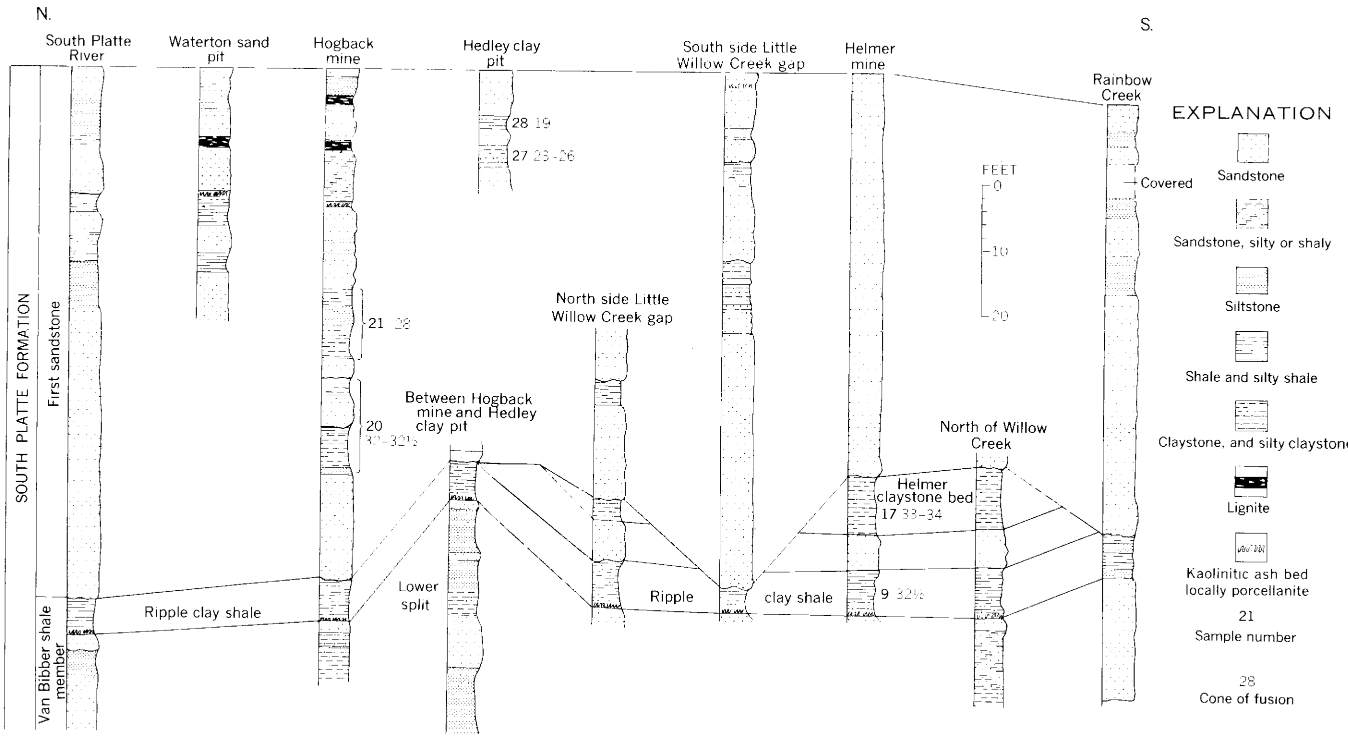

FIGURE 8.—Stratigraphy of refractory clayrocks in the Douglas County area.

of the crest. In the southern part of the hogback outcrops are poor, but part of the member appears wherever the interval is exposed. At a few places the Van Bibber member is absent and the basal sandstone of the first sandstone rests on the Kassler member. Elsewhere the Van Bibber member reaches a maximum thickness of 43 feet.

The sequence of beds within the Van Bibber member, shown in composite section in figure 6, includes the lower split, which is highly variable in thickness and lithic character, and the ripple clay shale. The dark-gray clay shale of the rider beds that occur above the ripple clay shale in the type area of the member are absent. Throughout much of the hogback in the Douglas County area the basal sandstone of the first sandstone rests on the ripple clay shale, but locally the Van Bibber member includes at its top a bed of dove-gray claystone, here called the Helmer claystone bed, which is separated from the ripple clay shale by about 5 feet of sandstone. The Helmer claystone bed and the sandstone that separates it from the ripple clay shale are equivalent in stratigraphic position to the rider beds in the Golden area, but the clay is strikingly different from the clay shale of the typical rider beds.

The ripple clay shale is the most persistent, as well as the most distinctive, part of the Van Bibber member. It generally consists of 4 to 7 feet of dark-gray refractory clay shale containing many thin beds and laminae of light-gray siltstone. At its base is the 1- to 2-inch bed of kaolinitic ash of the first key marker. An exposure of the ripple clay shale near the Helmer mine is shown in plate 6; units 9 through 13 of the section measured in the Helmer mine (section 17) are typical of this part of the Van Bibber member in the Douglas County area. Clay shale from units 11 and 13 of this section (table 2, sample 9) has a fusion point of 32½. The sequence of beds within the ripple clay shale remains virtually unchanged throughout the northern part of the hogback, as a comparison of the Helmer mine section and the following section near the north end of the hogback indicates.

Ripple clay shale of the Van Bibber shale member in the Hogback mine, SE¼ NW¼ SW¼ sec. 35, T. 6 S., R. 69 W., Douglas County

Basal sandstone of first sandstone.

Unconformity.

	Thickness (feet)
Van Bibber shale member:	
Clay shale, gray to dark-gray; siltstone laminae; silty in upper part	2.5
Siltstone, platy; interbedded with gray silty clay shale	1.3
Clay shale, dark-gray to black, silty; contains scattered thin laminae of siltstone	1.7
Siltstone, clayey, light-gray; contains beds of platy siltstone	1
Kaolinitic claystone (first key marker)	.1

Sandstone with ripple-marked upper surface.

Both the high content of silt and the relatively slight thickness are characteristic of the ripple clay shale in the Douglas County area. Parts of the clay shale relatively free from siltstone layers consistently fuse between cones 31 and 32½. Inasmuch as these parts of the ripple clay shale rarely exceed 2.5 feet in thickness the bed is not of commercial value by itself, but is mined locally along with adjacent clayrock beds. The ripple clay shale with its basal kaolinitic ash bed and the persistently ripple-marked surface on the sandstone beneath, afford an excellent key in prospecting for clayrock in the Douglas County area. With one exception, the possible source beds for refractory clayrock lie between the ripple clay shale and the Benton shale; the exception is the lower split of the Van Bibber member, which lies stratigraphically just below the ripple clay shale.

The lower split of the Van Bibber member is dominantly silty or sandy but locally contains lenses of clayrock. Both the thickness and the sequence of beds in the lower split differ from place to place along the hogback and only the 1- to 6-foot ledge of ripple-marked sandstone at the top is persistent. The lower split is rarely less than 4 feet thick and locally is as much as 36 feet thick. It is thickest in that part of the hogback just south of the South Platte River in SW¼ sec. 35, T. 6 S., R. 69 W., and NW¼ sec. 2, T. 7 S., R. 69 W. Here the lower split contains as many as three clayrock zones which, in the thickest section measured, have the following distribution:

Lower split of the Van Bibber shale member measured at north end of swale in the center S½ S½ SW¼ sec. 35, T. 6 S., R. 69 W., Kassler quadrangle

	Thickness (feet)
Claystone, kaolinitic:	
7. First key marker.	
Lower split:	
6. Sandstone, fine-grained, massive; ripple-marked upper surface	1.3
5. Siltstone, clayey, and silty claystone; some thin lenses of fine-grained clayey sandstone in middle part	7
4. Sandstone, fine-grained	1
3. Siltstone, clayey, and silty claystone, sandy in basal 2 ft	8.2
2. Sandstone, fine-grained, massive, cross-laminated, friable	8.5
1. Siltstone, clayey; silty gray shale in upper part	10
Total thickness of lower split	36
disconformity?	
Kassler sandstone member.	

Although considerable variation in this sequence is found even in nearby exposures, the lower split appears to maintain an overall pattern consisting of an upper zone of blocky to subconchoidally fracturing silty claystone, siltstone and sandstone (units 3 through 5), a middle zone of massive, soft sandstone (unit 2), and a basal zone of gray to dark-gray silty clay shale (unit 1). The claystone beds in the upper part are consistently silty and it is doubtful that they are of commercial grade anywhere south of the South Platte River. The basal clay shale, though commonly not present, is locally of refractory grade. A thick lens of it crops out in a small swale on the crest of the hogback about 1,170 feet south along the ridge from the Hedley mine. Clay shale from this bed (sample 13, table 2) fuses between cones 32½ and 33. The basal clay shale of the lower split is probably limited in its distribution to depressions in the surface of the underlying Kassler sandstone member. The shale bodies are few and of short extent along the strike. They probably take the irregularly elongate form of channel fills, which are most likely oriented obliquely across the strike in a northeasterly direction. Swales along the crest of the northern part of the hogback in the Douglas County area commonly are localized on thick lenses of the lower split and serve as guides for locating these beds.

The Helmer claystone is an informal name for a local bed in the Van Bibber member; this bed is not known outside the Douglas County area. Within the hogback it appears to be intermittent as far north as the north side of Little Willow Creek gap and at least as far south as the southwest corner of sec. 19, T. 7 S., R 68 W. It is of commercial grade and thickness in and adjacent to the Helmer mine (section 17, unit 15), for which it is named, and probably as far south as Willow Creek gap. Northward from the Helmer mine it disappears on the east flank of the hogback as the basal sandstone of the first sandstone descends in the section to, and into, the ripple clay shale. It is absent in the exposures on the south side of Little Willow Creek gap but appears for a short distance north of the gap as a 3- to 4-foot bed of gray claystone separated from the underlying ripple clay shale by about 6 feet of massive sandstone.

The Helmer claystone bed is distinctive in its dove-gray color and subconchoidal to blocky fracture (3 pl.). It varies from a silty claystone to a flint clay, a clay type very rare in the Dakota group of the northern foothills of the Front Range. A sample (no. 17) of relatively silt free claystone from the Helmer mine fused between cones 33 and 34, the highest fusion point of any clays tested in the Douglas County area.

FIRST SANDSTONE

Irregular lateral distribution of sandstone and clay shale lenses is as typical of the first sandstone in the Douglas County area as it is elsewhere along the Front Range. Measured sections in the Helmer and Hogback mines, shown graphically in figure 8, serve as approximate limits for its local range in character and thickness. In the Helmer mine it consists of a single body of sandstone 64 feet thick; in the Hogback mine it consists of many alternating sandstone and clay shale beds aggregating 81 feet in thickness. Most commonly the lower third to half of the first sandstone is massive sandstone and the remainder contains the clay shale beds (section 16, units 24 through 33). Throughout much of the Douglas County area the disconformity at the base of the first sandstone is not incised deeply enough to eliminate the ripple clay shale of the Van Bibber member. In some places the base of the first sandstone rests on the lower split of the Van Bibber member and along the hogback in much of the NE¼ sec. 11 and the SW¼ SE¼ sec. 2, T. 7 S., R. 69 W., it is in contact with the Kassler member.

Part of the apparent variability of succession within the first sandstone may result from its generally poor exposure on the dip slope of the hogback, a situation which prevents detailed tracing of beds along the strike. Even with the few exposures available a certain gross uniformity of sequence can be recognized. The basal sandstone is the thickest; in most places it is probably several coalesced lenses rather than a single bed, and locally, as at the Helmer mine, it constitutes practically the entire subunit.

The clay shale lenses, though irregular in distribution because of the variation in thickness of the confining sandstone beds, have different characteristics at different stratigraphic levels within the subunit. The lowermost clay shale beds, which commonly lie 15 to 30 feet above the base of the first sandstone, are dense, dark gray to bluish black, and locally contain leaf imprints. Clay shale beds successively higher in the sequence are progressively lighter shades of gray. These color changes refer to fresh samples; weathering produces additional changes. The dark-gray clay shale beds weather a light bluish gray, show no tendency to slake or become plastic but break into small blocky, flaky, or shardlike fragments. The lighter colored clay shale beds all weather about the same light-gray to gray-white color but become plastic and break down on the outcrop. These changes in the character of the clay shale beds are accompanied by a change in fusibility. The lower dark-colored nonplastic clay shale beds are refractory; the lighter colored plastic clay shale beds are at best semirefractory but are commonly below semirefractory grade. Fusion tests of samples from the mines and pits in the Douglas County area are given with the graphic sections in figure 8, and serve to indicate the magnitude of the progressive decrease in grade upward through the sequence of clay shale beds.

Inasmuch as the upward change in the clay shale beds of the first sandstone does not take place in clear-cut stages within a succession of persistent beds but is only a trend reflected in a variable sequence of lenticular beds, no definite guides to prospecting are warranted. In general, clayrocks in the uppermost 15 feet of the subunit are usually plastic low-grade refractory to nonrefractory clay shale; clayrocks from 15 to 40 feet below the top of the subunit commonly are plastic to semiplastic, semirefractory clay shale; and dark-colored clay shale below this is commonly nonplastic and refractory. At all levels the local intercalation of siltstone or sandstone beds and laminae, or a visible increase in silt content, measurably affect the grade of the clay shale. In the light-colored upper beds thin layers of lignitic shale and lignite locally affect the grade of the clay shale.

REFRACTORY CLAYROCK DEPOSITS

THE WORKED DEPOSITS

Most of the clayrock horizons in the Van Bibber member and first sandstone in the Douglas County area have been tested by mining at one time or another. Clay shale beds in the first sandstone and the Helmer claystone of the Van Bibber member have been the chief producing beds. In addition the ripple clay shale has been mined along with these beds to some extent.

All the mining has been in two limited areas at opposite ends of the northern part of the hogback (pl. 1). The clayrocks in the southern part of the hogback have not been exploited. Mining in the north end of the hogback has been in sec. 35, T. 6 S., R. 69 W., and the N½ NE¼ NW¼ sec. 2, T. 7 S., R. 69 W. Here the Hogback mine of the Robinson Brick and Tile Co. has long been the principal producer. The extensive workings of this mine, which was opened in 1903, have tapped the lower split, the ripple clay shale, and three shale beds in the first sandstone (see fig. 8). In recent years production has been largely from the latter three beds.

In 1952 William Hedley began two operations, about 0.4 mile southeast along the hogback from the Hogback mine, on sublease from the Waterton Sand and Clay Co. One of these, the Hedley mine, was opened in the ripple clay shale and was being driven through to the lower split; the other, the Hedley pit, was an open pit in two clay shale beds in the top of the first sandstone (see fig. 8). In addition to these operating mines and pits there are abandoned workings including an old mine at the north end of the hogback, which was in either the ripple clay shale, lower split, or both, and a small mine in clay shale of the first sandstone on the east side of the north end of the hogback adjacent to the Waterton Sand and Clay Co. sand pit. The Hogback mine also has an abandoned entry near the one now being used.

One mine, the Helmer mine, is producing claystone from the ripple clay shale and Helmer claystone bed (fig. 8) just north of the gap of a tributary to Willow Creek in the SW¼ NE¼ SW¼ sec. 13, T. 7 S., R. 69 W. About 0.1 mile south of the Helmer mine is an abandoned entry in the ripple clay shale (pl. 6). Elsewhere in the northern part of the Douglas County area there are only some abandoned clay shale pits on the south side of Little Willow Creek gap, and a few prospect pits scattered along the hogback.

NORTHERN PART OF THE HOGBACK

Outside those areas of the northern part of the hogback exploited by the Hogback and Helmer mines there is little surface indication of clayrock bodies of commercial grade and thickness. Lack of outcrop is a fair indication that the clayrock beds of the Van Bibber member are very thin or absent, inasmuch as the member tends to crop out at or very near the crest of the hogback and is little obscured by slope wash. On the other hand the clay shale beds in the first sandstone, which crop out low on the dip slope, are likely to be masked by slope wash so that lack of exposure does not necessarily mean they are absent. Nevertheless, a clayrock bed more than 5 feet thick generally will cause a slight bench or break in the dip slope that is noticeable even though it is partly mantled by wash and overgrown with vegetation. Consequently beds of commercial thickness are likely to be hidden only in areas where the slope wash is heavy enough to mask irregularities in bedrock surface.

No clayrock of value remains between the Hogback mine and the north end of the hogback. Southward, the refractory clay shale beds of the first sandstone in the Hogback mine appear to lens out in sec. 35, T. 6 S., R. 69 W., for in the vicinity of the Hedley mine and pit, only low-grade refractory clay shale (samples 27 and 28, table 2) at the very top of the first sandstone is in minable quantity. From the Hedley mine south to the wind gap a quarter of a mile northwest of Little Willow Creek gap the steep, rock-strewn dip slope of the hogback is on the sandstone at the base of the first sandstone. This sandstone thickens abruptly south of the Hogback mine with the disappearance of the beds of refractory and semirefractory clay shale; the lack of any break in the slope formed by the sandstone indicates that none of these clay shale beds reappear at least as far south as the wind gap. The rocky dip slope does break near its base and one or two beds of clay shale crop out intermittently along the strike within about 10 or 15 feet, stratigraphically, of the contact with the Benton shale. These appear to be the same low-grade clay shale as those in the Hedley pit; the best exposures are: down slope from the stone quarry in the SE¼ sec. 2, T. 7 S., R.

69 W.; where the hogback crosses the south line of sec. 2; and starting about 400 feet north of the wind gap. Between the wind gap and Little Willow Creek gap a clay shale lens of limited extent appears in the first sandstone at about the same horizon as the lower refractory clay shale in the Hogback mine (see fig. 8), but it is silty and does not exceed 4 feet in thickness. On the south side of Little Willow Creek gap, clay shale beds in the upper half of the first sandstone, locally exposed in an old quarry, are highly silty. From the quarry southward to the water gap south of the Helmer mine the first sandstone appears to be composed entirely of sandstone and contains no clay shale beds.

Of the other clayrock horizons in the northern part of the hogback, the Helmer claystone bed appears to be limited to the vicinity of the Helmer mine except for a thin, silty lens that is present locally on the north side of Little Willow Creek gap (see fig. 8). The ripple clay shale is distributed along the hogback as shown in plate 1. In two places, one in the southeast corner of sec. 2, and northeast corner of sec. 11, and the other in the NW¼ sec. 13, T. 7 S., R. 69 W., the ripple clay shale is absent for considerable distances along the strike. Elsewhere, except for some local channel-like cutouts, it is consistently between 5 and 8 feet thick, and consistently too silty to be worth mining except with other clayrock beds.

The clayrock beds of the lower split contain the only potentially commercial deposit of unmined refractory clay shale exposed in the northern part of the Douglas County area. This is located at a swale in the hogback crest approximately on the east-west center line of the NW¼ sec. 2, T. 7 S., R. 69 W. Here the refractory clay shale bed (sample 13, table 2) described on page 46, lies at the base of the lower split and extends along the strike for at least the breadth of the swale. At this same locality the ripple clay shale is about 8 feet thick, its maximum thickness for this part of the hogback. Additional tracing and sampling are required to determine whether or not the refractory clay shale at this locality is extensive enough to mine. Five hundred feet south of this locality, the lower split as a whole thins to about 10 feet and the refractory clay shale bed lenses out. To the north, where the lower split is continuously thick all the way to the Hogback mine, the extent of the refractory clay shale bed is obscured and trenching would be necessary to trace it beyond the swale. Outside this area the clayey beds of the lower split are generally silty and sandy and unlikely to contain lenses of refractory grade clay shale or claystone.

SOUTHERN PART OF THE HOGBACK

Exposures of the clayrock-bearing units in the southern part of the hogback are limited chiefly to the water gaps inasmuch as the area lacks any mines or prospect pits. In addition the east-facing dip slope carries a heavier cover of vegetation than it does in the northern part of the hogback and gravel veneer on pediment remnants locally obscures most of the bedrock. Nevertheless, exposures in the Willow Creek area, which lies between the gap made by the first tributary north of Willow Creek and the gap of its south tributary in the southeast corner of sec. 24, T. 7 S., R. 69 W., indicate that clayrock deposits of commercial value may be present. Between the Willow Creek area and Rainbow Creek the Dakota hogback preserves a remnant of the Roxborough Park pediment; here soil and gravel obscure most of the beds and little is known about them. From Rainbow Creek to Indian Creek there is no indication of valuable clayrock deposits along the hogback.

At the north end of the Willow Creek area the Helmer claystone bed and ripple clay shale are exposed at the end of the hogback south of the gap (fig. 8). Here both beds are slightly thicker than they are in the Helmer mine across the gap to the north. The Helmer claystone bed is somewhat silty and weathers with a pink and yellow cast. From here south to Willow Creek gap the beds are obscured by slope wash and vegetation. The exposures in the gap are poor, but there are indications of three clayey beds between the Kassler member and the base of the first sandstone; one of these is the ripple clay shale but the identity of the others is in question. Their proximity to the ripple clay shale suggests that they are the Helmer bed and a clay shale in the lower split but trenching would be necessary to confirm this interpretation.

South of Willow Creek gap these clayrock beds are completely obscured for more than a quarter of a mile along the strike, but where the hogback begins to disappear under the Roxborough Park pediment the beds are partly exposed in two ravines. The southernmost of these, in NE¼ SE¼ SE¼ sec. 24, T. 7 S., R. 69 W., is the south tributary to Willow Creek and marks the south end of the Willow Creek area. In its north wall an exceptionally large number of clay shale beds are partly exposed. Two clay shale beds, each about 6 feet thick, lie within 20 feet of the Benton contact. Beneath these is a sandstone ledge and a number of clay shale beds, presumably in the lower part of the first sandstone. The basal sandstone of the first sandstone is so thinned or broken by clay shale beds that it is not possible to be certain of the position of its contact with the Van Bibber member; consequently the pattern of clayrock beds above the ripple clay shale in the latter member is not known. About 5 feet of the ripple clay shale is present, underlain by two clayrock beds 10 to 12 feet thick containing silty gray plastic claystone. It would take extensive trenching to reveal the thickness, character, and relationships of the clayrock beds at this place, but even in its present partly obscured condition it is without doubt the best prospecting site in the Douglas County area. In the second ravine, about 1,200 feet to the north, the same sequence of clayrock beds appears, but here the exposures are even poorer. This locality also deserves testing.

Between the exposures at the north and south ends of the Willow Creek area the Helmer claystone bed appears to thin southward whereas the clay shale in the first sandstone lenses out northward. As far as the few outcrops indicate the ripple clay shale remains about the same throughout the area ranging in thickness from 5 to 8 feet. Little is known of the lower split, which is between 10 and 15 feet thick at the north and south ends of the area. Both ends of the Willow Creek area are potential sites of commercial clay production, the north end for the Helmer claystone bed and ripple clay shale, the same beds mined in the nearby Helmer mine, and the south end primarily for clay shale in the first sandstone.

Within the area of the Roxborough Park pediment, south of the Willow Creek area, the first sandstone is exposed in an old stone quarry just east of the center NW¼ sec. 30, T. 7 S., R. 68 W. Here the basal sandstone is about 40 feet thick and rests within 18 inches of the base of the ripple clay shale. The thickest clay shale zones in the subunit are two beds of silty clay shale, each about 4 feet thick, which lie near the Benton contact. These exposures in the stone quarry, which reveal the thickening of the basal sandstone of the first sandstone at the expense of the clay shale beds above and below, lie one-half mile southeast along the strike from the many clay shale beds in the ravine at the south end of the Willow Creek area. The possibility that the clay shale beds extend southward from the Willow Creek area for a considerable part of this distance is good enough to warrant prospecting. The formations lie near enough to the surface so that relatively shallow trenches would suffice to expose the clay shale beds.

South of the stone quarry there is little possibility of commercial deposits of refractory-grade clayrock. At Rainbow Creek (section 19) the first sandstone is similar to that in the stone quarry and its clay shale beds are thin and silty. The Van Bibber member contains only a thin bed of highly silty clay shale. This pattern of beds in the clayrock-bearing subunits is repeated just north of Indian Creek, and although the beds in question are completely obscured throughout most of the intervening distance there is no reason to suspect a change in the pattern.

SOUTHERN JEFFERSON COUNTY AREA

EXPOSURES OF THE DAKOTA GROUP

Nowhere along the Colorado Front Range is the hogback formed by the Dakota group a more conspicuous topographic feature than in the southern half of Jefferson County. Northward from the South Platte River it extends unbroken, except by narrow water gaps, for 17 miles along the gently curving strike, terminating about 2.2 miles south of Golden where U.S. Highway 40 turns sharply south around its end. Throughout this distance the hogback is a sharp-crested ridge locally rising as high as 700 feet above the base of its scrub-covered slope but generally between 400 and 500 feet high over most of the distance. The success of the Dakota group as a ridge-forming unit in this area can be attributed largely to the local dominance of sandstone in the upper part of the South Platte formation. Most of the 17 miles of Dakota outcrop lacks a large part or all of the Van Bibber shale member of the South Platte formation and the first sandstone is commonly in contact with the Kassler sandstone member. With few exceptions one or the other of these sandstone bodies is the crestforming subunit.

Absence of most or all of the Van Bibber shale member generally leaves the Dakota group barren of commercial refractory clayrock deposits; so it is with most of the 17-mile stretch of the hogback lying between the South Platte River and U.S. Highway 40. But not quite all of this hogback can be classed as a barren area inasmuch as the Van Bibber member reappears about 2 miles south of U.S. 40 and has been mined extensively from this point northward. For convenience, the Alameda Parkway road cut across the hogback, 3 miles south of U.S. Highway 40, is chosen as a boundary between the southern Jefferson County area and the Golden area to the north. A sketch map of the area is given in figure 9.

Exposures of the Dakota group in the southern Jefferson County area are rarely good enough to afford complete sections of the group or of the included formations. In general the Kassler sandstone member, which commonly forms a ledge starting at the crest of the hogback, and much of the lower part of the South Platte formation beneath it, are the best exposed because they lie in the steep upper part of the scarp face. Locally much of the Lytle formation is also exposed, but outcrops of the Morrison formation are relatively scarce. Beds above the Kassler member, unless they also lie on the scarp side of the crest, are covered by the vegetation on the dip slope. Most of the dip slope is on sandstone, which supports

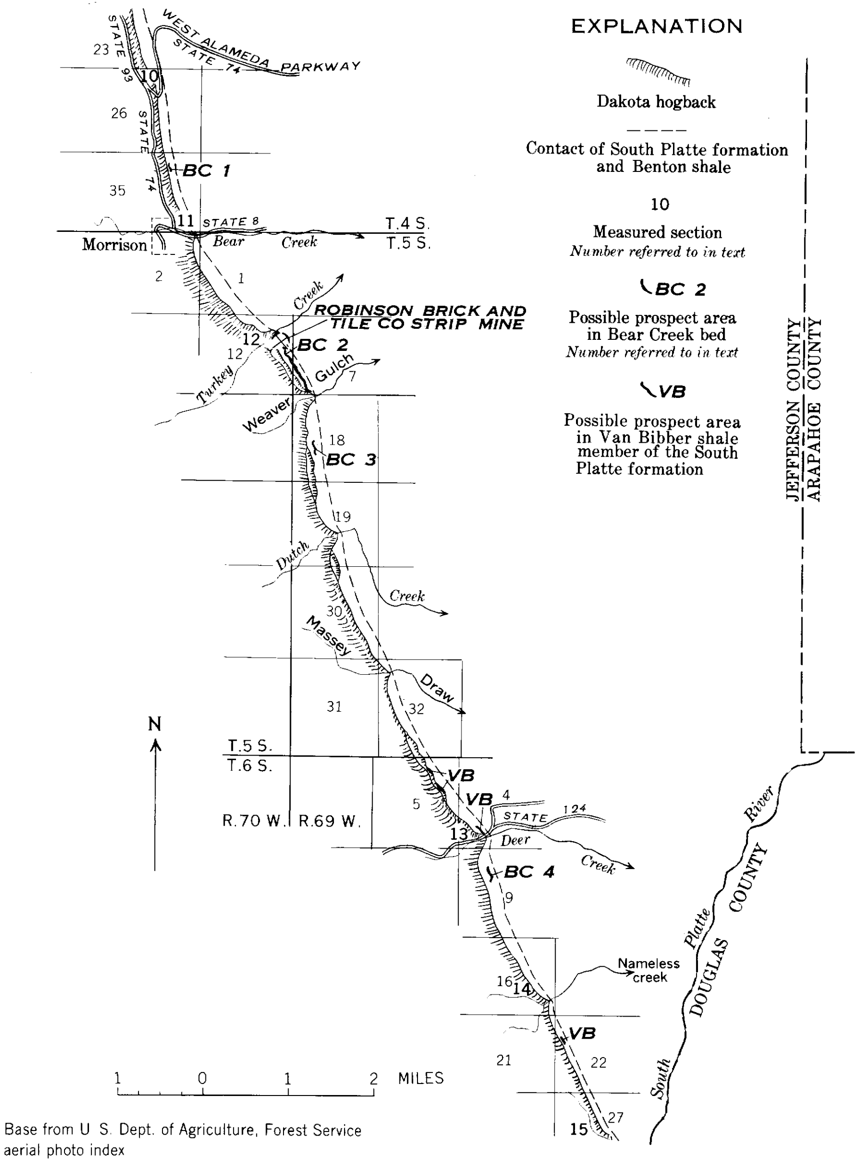

FIGURE 9.—Sketch map of the southern Jefferson County area.

scrub oak, pine, and a variety of bushes. Beds of soft sandstone, siltstone, or clayrock form slight benches on the uniformly dipping slope. Inasmuch as the trees and shrubs grow only on the sandy areas, grass-covered benches indicate the presence of a clayrock bed. Locally successive grassy benches form conspicuous patterns visible from several miles away. Commonly slope wash of sand mantles the narrower clayrock benches and supports a growth of shrubs. As a rule clayrock beds of commercial thickness and purity which crop out on the dip slope give rise either to a grassy bench or local bare patches where the crop line bends downslope around local drainage courses.

Exposures good enough to permit piecing together of relatively complete sections of the Dakota group include the end of the hogback north of the South Platte River gap (section 15 on p. 134), the north side of the gap of a nameless creek in the SE corner, sec. 16, T. 6 S., R. 69 W., Littleton quadrangle (section 14 on p. 133), the hogback north of Deer Creek gap (section 13 on p. 130), Turkey Creek gap (section 12 on p. 128), the north side of the Bear Creek gap at Morrison (section 11 on p. 126) and the roadcut along the Alameda Parkway (section 10 on p. 124).

LYTLE FORMATION

Within the southern Jefferson County area the Lytle formation varies too much in the details of its stratigraphy to permit meaningful generalities. Moreover, except for the upper half to third of the formation, it is not well exposed. Complete sections of the Lytle, measured in the area, range in thickness from 60 to about 100 feet. Except for local variations, the formation thickens progressively northward, reaching its greatest thickness in the vicinity of Morrison. North of Morrison it thins again, abruptly, and at the Alameda Parkway cut it is, at the most, about 60 feet thick.

Sandstone predominates in most Lytle exposures and at most localities examined, conglomeratic lenses occur at one or more horizons. Lenses of conglomerate at the presumed base of the Lytle are discontinuous and where they are absent the position of the Morrison contact is in doubt. It is particularly vexing that the Lytle lacks basal conglomeratic lenses both at Morrison and at the Alameda Parkway cut, respectively the type locality (Eldridge, 1896b) and redefined type locality (Waldschmidt and Leroy, 1944) of the Morrison formation. At these two places, where the sandstone lenses in the Lytle are relatively thin and nonconglomeratic, or sparsely so, and the interbedded variegated claystone lenses are numerous, the Lytle and upper Morrison are lithologically similar and no appreciable lithic break is apparent. About halfway between these two localities a 47-foot lens of conglomeratic sandstone at the base of the Lytle clearly defines the contact with the underlying Morrison. Here the Lytle is about 98 feet thick.

Thin lenses of variegated silty claystone are common in the Lytle of the southern Jefferson County area. Most of these occur in the lower half to two thirds of the formation. A few polished chert and quartzite pebbles occur in these claystone beds, but such pebbles are far less common in the Lytle formation than they are in equivalent beds (Cloverly, Lakota) in Wyoming.

Rarely does more than a foot or two of claystone underlie the contact of the Lytle and South Platte formation and at many localities the South Platte rests directly on sandstone or conglomeratic sandstone of the Lytle. Consequently appreciable bodies of refractory grade clayrock are not likely to exist at the top of the Lytle in this area. A thin bed of sandy claystone at the top of the Lytle has been strip mined at the property of the Robinson Brick and Tile Co. just south of Turkey Creek gap, the only place in the area where clay from this horizon has been mined. At this locality the claystone was economic only because it lay in an accessible topographic position between working pits in other beds of clayrock in the South Platte and Morrison formations. The thin bed afforded limited tonnage where its outcrop turns downslope into Turkey Creek gap from the scarp of the hogback. It was not mined southward along the hogback although it thickens in this direction, reaching a maximum thickness of 10 feet about 800 feet south of the stripped area. Here the claystone bed has a narrow lip of outcrop in a steep bluff just under the crest of the hogback, and is capped by 4 to 7 feet of quartzitic sandstone at the base of the Plainview member. North of the strip mine the claystone at the top of the Lytle grades into argillaceous siltstone. The contact of the Lytle and South Platte formations exposed on the south side of Turkey Creek gap is between this light-colored argillaceous siltstone and gray silty shale and siltstone at the base of the overlying Plainview member.

Tests of silty clayrock in the weathered zone at the top of the Lytle were made on samples taken from the outcrop approximately 100 yards north along the strike from the slump-obscured outcrop of these beds in the Alameda Parkway road cut. Details of this exposure and the tests run on the clays are given on page 11. The only other test of uppermost clayrock of the Lytle in the southern Jefferson County area was made to substantiate the selection of the contact of the Lytle and South Platte formations; it is described in the two paragraphs that follow. In spite of the satisfactory grade indicated by these few spot tests, the top of the Lytle is not a clayrock horizon of potential importance in the southern Jefferson County area. Clayrock is rarely present in appreciable thickness at this horizon and where it is, the difficulty of mining it is too great to make it worth while.

The contact of the Lytle and South Platte formation is clear cut throughout most of the southern Jefferson County area, but at scattered localities along the hogback in the vicinity of Deer Creek its position within a 10-foot interval is obscure. The following section across the contact is generalized from several exposures within a mile north and south of Deer Creek gap.

	Thickness (feet)
South Platte formation:	
Plainview sandstone member (basal part only):	
8. Sandstone, fine-grained, laminated, orange-brown; weathers platy	2
7. Shale, black, silty; scattered thin beds of iron-stained siltstone increase in number upward	8
6. Sandstone, shaly, ferruginous; contains scattered chert and quartz granules locally	.1+
Lytle formation:	
5. Claystone; generally silty, light-gray to greenish-gray with pink stain	.3–2
4. Sandstone, fine-grained, massive, light-gray, ferruginous	1
3. Claystone, gray to dark-gray	1
2. Sandstone, fine- to medium-grained, massive to tabular, cross-laminated; weathers brown	3–6
1. Sandstone, fine- to coarse-grained and conglomeratic, massive, light-gray	10–20

Units 2 and 3 are the confusing beds inasmuch as they resemble Plainview rocks more than Lytle rocks. The thin bed of claystone in unit 5 is commonly obscured and unit 6 is present only locally, consequently the Lytle contact appears to be between the two sandstone beds of units 1 and 2. However, careful lateral tracing shows that units 2 and 3 disappear laterally, apparently lensing out between the light-gray sandstone beds of units 1 and 4. The choice of contact indicated in the section above is further substantiated by a test on a sample of the claystone in unit 5 (sample 36, table 2) from an exposure about 1.2 miles south of Deer Creek at the south end of a local swale in the hogback crest. The claystone is refractory, fusing at cone 32½, and most likely represents the leached zone at the top of the Lytle.

SOUTH PLATTE FORMATION

Dominance of sandstone and abrupt lateral changes in the thickness of its sandy subunits characterize the South Platte formation in the southern Jefferson County area. From the South Platte River northward to the vicinity of Dutch Creek (fig. 9) the formation ranges from 250 to 300 feet in thickness, with few local exceptions. Within this part of the area, differences in thickness are chiefly the result of local variations in the thickness of the Plainview member; although a gradual northward thinning of the Kassler member also influences the total thickness slightly. North of

Dutch Creek abrupt and drastic thinning of the beds above the second shale and thinning of the Plainview member combine to reduce appreciably the total thickness of the South Platte formation—a trend compensated only slightly by concomitant thickening of the third sandstone and the third shale. From the vicinity of Weaver Gulch north to Morrison the South Platte formation is generally less than 200 feet thick; at Turkey Creek, the thinnest measured section of the formation, it is 180 feet thick. Just south of Turkey Creek at Weaver Gulch it is probably even thinner, but a complete section is not exposed. Northward from Morrison, where it is 195 feet thick, the formation thickens to an approximate thickness of 235 feet in the vicinity of the Alameda Parkway road cut.

BEDS BELOW THE KASSLER SANDSTONE MEMBER

The beds of the South Platte formation below the Kassler sandstone member are exposed intermittently along the scarp face of the hogback below the ledge formed by the Kassler sandstone. Except for its obscurity in the vicinity of Deer Creek, described in the preceding section on the Lytle formation, the basal contact of the South Platte is easily recognized on the outcrop in spite of lithologic changes above and below the disconformity. Conglomeratic sandstone, sandstone, siltstone, or claystone are locally at the top of the Lytle, though the first two rocks predominate. Conglomeratic sandstone, sandstone, and dark-gray to black silty shale commonly occur in the base of the Plainview member. Plainview sandstone and conglomerate beds are generally stained rusty brown in sharp contrast with the light color of similar rocks in the underlying Lytle. Locally, the basal sandstone bed of the Plainview is as much as 10 feet thick; at other places it is completely absent and black silty shale rests on the disconformity. Chert and quartzite granules and pebbles are distributed erratically in the basal sandstone bed. At some places the basal sandstone is studded with pebbles, some as much as 4 inches in diameter (pl. 7), whereas at other places it has a few scattered granules or is nonconglomeratic.

Abrupt local increase in the thickness of the Plainview member takes place at Deer Creek gap. Approximately one quarter of a mile north of the gap the member is 25 feet thick. In the north wall of the gap grossly crossbedded lenses of platy sandstone interrupt the more common tabular bedding as the member doubles in thickness. A quarter of a mile south of the gap the Plainview member is 70 feet thick; details of its stratigraphy are given in the following section.

Section of beds in the South Platte formation below the Kassler sandstone member

[Approximately ¼ mile south of Deer Creek in southeast corner NW¼ NW¼ sec. 9, T. 6 S., R. 69 W.]

	Thickness (feet)
South Platte formation:	
Base of Kassler sandstone member.	
Second shale:	
18. Shale, silty, dark-gray; 4-in bed of porcellanite at base	3.5
17. Shale, silty, gray; contains thin beds of light-gray shaly siltstone, carbonaceous fragments, and few fish scales	3.5
16. Siltstone, platy, gray, and platy fine-grained sandstone; weathers to shelving ledge stained brown or orange brown	1.5
15. Siltstone, platy; with beds of gray silty shale	2.2
14. Sandstone, fine-grained; thinly interbedded with siltstone; weathers to shelving ledge with ferruginous stain; contains fish scales and bones, plant fragments, and *Inoceramus comancheanus* Cragin	1.8
13. Shale, silty, dark-gray to black	7.5
Third sandstone:	
12. Siltstone and fine-grained sandstone, friable; weathers light gray to gray white with some ferruginous stain; locally underlies slope; appears massive but has obscure lamination or thin bedding of grain sizes	22
11. Partly obscured by slope wash; float of gray, shaly siltstone, basal foot locally ledgy	4.5
Third shale:	
10. Obscured; gray shale chips in soil	4
9. Sandstone, fine-grained, gray, carbonaceous, irregularly bedded	.7
8. Partly obscured; siltstone thinly interbedded with gray shale	10
Plainview sandstone member:	
7. Sandstone, fine-grained, tabular to even-bedded, cross-laminated. Weathers brown, ledge forming	29
6. Partly obscured by slope wash, thin beds of fine-grained, brown-weathering sandstone protrude	11
5. Sandstone, fine- to medium-grained, even-bedded, cross-laminated, to crossbedded. Thin zones with scattered clay pellets	7
4. Sandstone, as in 5 above but with soft argillaceous zones composed largely of clay pellets	6.5
3. Partly obscured, chiefly silty black shale with siltstone beds	10.5
2. Sandstone, fine- to medium-grained, massive, cross-laminated. Weathers reddish brown	6
Lytle formation (in part):	
1. Sandstone, fine-grained to conglomeratic, massive, cross-laminated, light gray to white, locally argillaceous	33–?

From this locality south to the South Platte River the Plainview member is 50 to 70 feet thick. From the locality a quarter of a mile north of Deer Creek, it ranges from 20 to 30 feet in thickness as far north as Morrison. Between Morrison and the Alameda Parkway the member begins to thicken gradually, and in the vicinity of the Parkway it is 35 to 40 feet thick.

The beds between the Plainview and Kassler members also vary in thickness, but neither as greatly nor as abruptly as does the Plainview member. Locally there is some correlation between thickening of the Plainview and thinning of the beds between it and the Kassler member, but this does not hold true in general. The upper contact of the Plainview is gradational into the siltstone and shale of the third shale and some of the thickening and thinning of the Plainview can doubtless be attributed to lateral intertonguing between these subunits. However, for the southern Jefferson County area as a whole, the combined third shale, third sandstone, and second shale gradually thicken northward from the South Platte River, where they total 64 feet, to Morrison where they total 98 feet. North of Morrison they are thinner and in the Alameda Parkway cut they total 50 feet.

Throughout most of the area the three subunits between the Plainview and Kassler members are fairly easily distinguished from one another. The third shale consists chiefly of silty shale with interbedded siltstone. Between Deer Creek and the Alameda Parkway, where the third shale ranges between 17 and 48 feet in thickness, it contains a thin sandstone lens in the middle part, a fairly persistent thin porcellanite bed in the shale above this sandstone and a nonpersistent thin porcellanite in the shale below. South of Deer Creek the threefold division is not evident and the third shale as a whole thins to as little as 7 feet. This thinning may be due to the coalescing of the middle sandstone bed with the overlying third sandstone. The contact of the third shale and third sandstone is gradational and is arbitrarily taken at that place in the section where the rock type changes from interbedded siltstone and shale to interbedded siltstone and sandstone. No shale of commercial value is present in the third shale; though kaolinitic, it is consistently silty and commonly is interbedded with hard siltstone.

The third sandstone ranges between 20 and 40 feet in thickness. It is consistently a friable, laminated mixture of siltstone and fine-grained sandstone with minor shale partings and some carbonaceous matter. It underlies slopes or weathers to massive rounded outcrops with considerable ferruginous stain. Locally it is made ledgy by indurated ferruginous layers. The contact with the overlying second shale commonly is sharp; with the shale resting on a relatively flat, locally ripple marked, surface of the sandstone. The upper 0.5 to 2 feet of the sandstone is generally a resistant, iron-impregnated cap.

The second shale has its usual subdivisions throughout much of the area, but south of the nameless creek—and at a few places elsewhere in the area—the upper shaly part containing the second key marker, was removed by erosion prior to the deposition of the Kassler member. Marine fossils are found locally throughout the area in the platy beds beneath the shale. The shale bed in the upper part of the second shale is not refractory; the lower, illitic portion of the shale bed fuses under cone 20 and the upper, dominantly kaolinitic part, fuses at about cone 20.

In the Morrison-Turkey Creek area exposures of the second shale and the third sandstone lack the characteristic succession of beds. None of the subdivisions of the second shale are distinguishable; hence it is possible that all the beds between the Kassler member and the third shale belong to the third sandstone, although this grouping makes the latter unusually thick. Lack of outcrop prevents lateral tracing into adjacent areas with a more characteristic succession. At Morrison (section 11 on p. 126) the beds in question are units 42 through 46; in Turkey Creek gap, they are (section 12 on p. 128) units 30 through 32.

KASSLER SANDSTONE MEMBER

The principal crest-forming sandstone of the Dakota hogback in the southern Jefferson County area is the Kassler member, which commonly crops out in a prominent ledge. Northward from the South Platte River, where the Kassler member is 72 feet thick, it thins, with minor fluctuations, to about 45 feet at Morrison. Between Morrison and the Alameda Parkway it is difficult to distinguish the upper contact of the member. The possibility that the Kassler cannot be distinguished from the first sandstone in the Turkey Creek-Morrison area is discussed in the section on the latter subunit. To the north, in the Golden area, the lower split of the Van Bibber member is thick and contains a bed of refractory clayrock, locally called the black silica bed; this bed is separated from the overlying ripple clay shale by a sandstone. Figure 10 offers an interpretation of the relationships of these clayrock beds in the Golden area. Note that at the south end of this area, from U.S. Highway 40 to the Alameda Parkway, the sandstone between the two clayrock beds thickens greatly. In the Alameda Parkway road cut (section 10) the 15 feet of sandstone of unit 34 is interpreted as the sandstone between the clayrock beds; and units 32 and 33 as the equivalent of the black silica bed. The Kassler member at the road cut is thus restricted to the 30 feet of sandstone in unit 31.

Lack of continuous exposures and lensing in and out of the ripple clay shale and its diagnostic basal kaolinitic ash bed—the first key marker—prevent tracing the black silica bed and its overlying sandstone southward from the Alameda Parkway. About 0.4 mile south of the Parkway road cut the first key marker lies directly on cross-

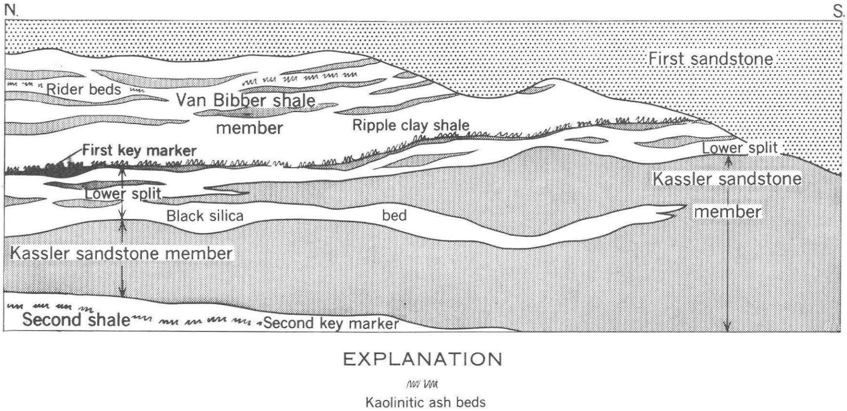

FIGURE 10.—Inferred relationships between the Kassler sandstone member and Van Bibber shale member of the South Platte formation in the southern part of the Golden area. Sandstone beds are stippled.

bedded, platy sandstone which is about 45 feet thick and contains a soft zone of shaly siltstone 10 feet from the top. Beneath this cross-bedded sandstone the second shale, containing the second key marker bed, crops out. Apparently the black silica bed grades laterally into the soft zone of shaly siltstone thereby connecting the overlying sandstone with the Kassler. If this is so, the sandstone overlying the black silica bed is a northward-thinning tongue of the Kassler.

In several parts of the southern Jefferson County area, but particularly in the southern half, stratigraphic relationships between the Van Bibber member and the Kassler member suggest that local erosion along the top of the Kassler member was an important factor in determining the present distribution of remnants of the Van Bibber member. The best example of this relationship is exposed in the north wall of Deer Creek gap, where both the Van Bibber member and the overlying first sandstone are clay bearing very locally. Here the surface of the Kassler member is obviously channeled, the channel becoming deeper down the slope into the gap. At the lowermost exposure in the gap, the ripple clay shale is about 6 feet thick and rests directly on the channel surface of the Kassler member; locally it has silty beds and the first key marker at its base. Above the ripple clay shale are the rider beds, separated from it and from one another by ledges of sandstone. As the exposure is followed up the side of the gap north along the strike, the surface of the Kassler member rises in the section and the ripple clay shale thins. Cover of scrub eventually obscures the outcrop but where it passes from sight the ripple clay shale has all but pinched out between the Kassler member and the basal sandstone in the rider beds.

The local channeling of the surface of the Kassler sandstone member at Deer Creek appears to have resulted in the deposition of a thicker, more complete, sequence of Van Bibber sediment, suggesting that, locally, the thickness of the Kassler member influenced to some extent the distribution of the succeeding Van Bibber member. But this generalization does not seem warranted in view of the more continuous preservation of the Van Bibber member in the Douglas County area to the south, where the Kassler member is thickest. A more complex explanation such as differential settling, or differential local depression of the basin of deposition during, or after, the deposition of the Kassler sandstone member is indicated.

BEDS ABOVE THE KASSLER SANDSTONE MEMBER

Throughout the southern Jefferson County area the beds above the Kassler sandstone member are dominantly sandy. The Van Bibber shale member is only locally and partly preserved; nevertheless parts of it are recognizable from place to place along the hogback. Where none of its diagnostic beds, such as the first key marker, are preserved it is difficult, if not impossible, to separate the Van Bibber member from the overlying first sandstone.

The first sandstone commonly consists of a lower sandstone bed, a variable middle part with lenses of dark-gray to black shale, and an upper sandstone bed. Locally there are shale lenses in both the middle and upper parts.

The distribution of the Van Bibber member appears to have been limited both by local configuration on the top of the Kassler member and by erosion prior to the deposition of the basal sandstone bed of the overlying first sandstone. Nowhere in the southern Jefferson County area is a complete succession of the Van Bibber member preserved. The thickest section, that at Deer Creek (section 13, units 45 through 60), is 35 feet, but the lower split is missing.

Along parts of the hogback the Van Bibber member is absent and the base of the first sandstone rests on the Kassler member (pl. 8). This relationship persists throughout most of the hogback between Massey Draw and Dutch Creek. At Massey Draw the combined sandstone subunits total about 100 feet in thickness and at Dutch Creek, about 75 feet. In some parts of the hogback the basal beds of the Van Bibber member, including the first key marker, are preserved as discontinuous remnants between the deep channels cut into the Kassler member. More complete sequences of the Van Bibber member are less common and are found chiefly in the Deer Creek gap area and in the hogback between Deer Creek and Massey Draw. In this area both the ripple clay shale and some of the rider shale beds are preserved locally. But preservation of these beds does not necessarily mean that they are of economic value inasmuch as the Van Bibber member in the southern Jefferson County area appears to have persistently thin rider beds and the ripple clay shale is siltier than in the Golden area, though not as thoroughly interbedded with siltstone as in the Douglas County area.

Only at four places in the area does the ripple clay shale contain clayrock of minable grade and thickness (over 4 feet). These are labeled VB on the sketch map, figure 9. One of these places is the Deer Creek exposure; the other three are of similar, or more limited, extent. One is along the crest of the hogback slightly over half a mile south of the nameless creek; here a bed of gray silty shale, between 4 and 5 feet thick, is partly exposed for less than 200 feet along the strike. The other two are within a quarter of a mile of each other in a swale along the hogback crest 0.75 and 1 mile north of Deer Creek. At both of these localities the clay bed ranges between 4.5 and 6 feet in thickness. At the southern of the two localities the bed thins abruptly north and south of the limited exposure. At the northern locality it appears to be somewhat more extensive, but the exposure, which is about 200 feet long, lies well down on the dip slope and its lateral extension is obscured by slopewash and vegetation.

The lower split of the Van Bibber member is exposed locally at a number of places in the area. Generally it contains a thin and sandy clayrock bed, between 2 and 4 feet beneath the ripple clay shale. At a few places the lower split contains a highly carbonaceous, silty claystone as much as 3 feet thick. Nowhere does it contain clayrock of economic value.

Above the ripple clay shale it is impossible to distinguish specific clay beds consistently along the strike. In general the first thick sandstone above the ripple clay shale is the basal bed of the first sandstone, but this does not hold true throughout all the area. Local thickening of one of the sandstone beds in the rider beds of the Van Bibber member can, if it is coincident with local thinning of the basal sandstone of the overlying subunit, change the entire aspect of the succession. In such a section the thickened sandstone in the rider beds would be taken as the basal sandstone of the first sandstone and the associated clay beds correspondingly misidentified. In the north end of the area this type of lateral variation is common.

In the southern part of the area, south of Dutch Creek, the lowest sandstone bed of the first sandstone generally is consistently thick. In this part of the hogback clayrock beds belonging in the Van Bibber member are easily identified. Here no clay beds of minable thickness were found in the rider beds. The thickest sequence of rider beds is exposed at the Deer Creek locality (section 13).

Generally, there are clayrock lenses in the first sandstone subunit. These crop out only in water gaps or small gullies; they underlie wash-covered, grassy benches on the dip slope of the hogback. A good grade of refractory clay is exposed in one of these lenses at the Deer Creek gap locality. The trace of this bed dies out a short distance to the north, but southward from Deer Creek gap a grassy bench at approximately the same stratigraphic position can be followed for about half a mile to an exposure of 5 feet of gray silty shale grading downward into platy siltstone. From this place south to the South Platte River one or two narrow benches mark clayrock beds, but there is no indication that these beds contain anything better than the silty clay and siltstone revealed at approximately the same horizons in the gap of the nameless creek (section 14) and the end of the hogback north of the river (section 15).

From Deer Creek north to Dutch Creek, similar traces of clayrock beds are common along the dip slope of the hogback. South of Massey Draw they are narrow and discontinuous, but between Massey Draw and Dutch Creek two grassy benches separated by a narrow ledge of sandstone about 3 feet thick are fairly continuous. None of these beds is exposed.

In that part of the southern Jefferson County area between Dutch Creek and a point on the Dakota hogback about half a mile north of Bear Creek gap—a distance along the outcrop of approximately 5 miles—the South Platte formation as a whole is appreciably thinner than in any other part of the northern foothills of the Front Range. Most of this thinning takes place within the beds above the base of the Kassler member. The magnitude of the thinning can be judged by comparing the 185 feet of beds above the base of the Kassler member on Deer Creek (section 13) with the 76- and 78-foot sections of the same interval at Turkey Creek and Morrison, respectively (section 12 and 11).

Combined with this decrease in thickness, the pronounced changes in the normal succession of beds above the base of the Kassler member rule out the possibility of a simple local thinning of individual subunits. Local change in relationship of the upper South Platte formation to overlying beds along the Benton contact can also be ruled out. The characteristic zone of platy siltstone and siliceous, silty shale at the base of the Benton is continuous without interruption along the foot of the dipslope of the hogback, consequently the first sandstone of the South Platte does not interfinger with the Benton shale. Moreover no angular unconformity and truncation of beds is evident at this contact, inasmuch as a ledge of massive, brown-weathering sandstone from 2 to 12 feet thick can be traced along just beneath the contact throughout the area in question.

Deposition of the first sandstone on an erosion surface cut deeply into the Kassler member would explain both the thinning of the upper part of the South Platte formation and the absence of a normal succession of beds. It is difficult to muster direct evidence for this because much of the critical part of the succession crops out on the dip slope of the hogback where the beds are obscured by scrub oak and other vegetation. Presence of the first key marker and underlying ripple-marked sandstone, diagnostic of the Van Bibber shale member, would rule out deep channeling in the Kassler member; but no undoubted outcrop of these diagnostic beds was found along the hogback between a point 0.4 miles north of Bear Creek and exposures about one mile south of Dutch Creek.

The strongest evidence in favor of the interpretation that the first sandstone is filling deep incisions in the Kassler member is found at the south end of the hogback just north of Bear Creek, at Morrison. At that point on the hogback 0.4 miles north of Bear Creek, where the first sandstone merges with the Kassler member to pinch out the intervening remnant of the Van Bibber member, a grass-covered swale indicating another clayrock bed (hereafter informally called the Bear Creek bed) can be found about halfway down the dip slope of the hogback. As the grass-covered trace of the Bear Creek bed is followed southward it approaches the hogback rim and near the rim a clay bed, 8 feet thick, crops out; the lower 3 feet are dark-gray silty shale with two thin, flinty, porcellanite layers in the lower part, and the upper 5 feet are chiefly argillaceous siltstone. The Bear Creek bed thins near the rim; it extends across to the scarp face of the hogback, where it forms the prominent shale break (units 48 through 51, section 11) between the cliff-forming sandstone in Bear Creek gap. In this gap the massive sandstone beneath the Bear Creek bed, representing the combined basal sandstone of the first sandstone and the Kassler member, is 45 feet thick.

Thus in the Bear Creek gap area the first sandstone fills a deep channel incised in the Kassler member; the depth is not revealed in the exposures, but it is possible that the Kassler member has been completely removed. It is difficult to determine how far to the south this relationship persists. Beds that unquestionably belong in the Van Bibber member reappear in the sequence about a mile south of Dutch Creek, 5.5 miles south of Bear Creek gap. However, clayrock beds occur locally throughout this distance above the sandstone body that is presumably the combined Kassler member and first sandstone. These clayrock beds resemble the clayrock beds of the Van Bibber in both general type of clayrock and position above a massive sandstone ledge in the stratigraphic position of the Kassler member. They are also similar to the Bear Creek clayrock bed, however, and they lack the familiar sequence of individual beds found in the Van Bibber member both to the north and south of the Bear Creek gap area. For these reasons it is inferred that the Kassler member and the basal sandstone bed of the first sandstone are continuously merged from Bear Creek southward at least as far as Dutch Creek, and possibly as much as a mile farther south. The rough correspondence of this distance along the strike with the area of minimum thickness for the South Platte formation as a whole supports this assumption.

Because of the lithic similarity of the sandstone at the base of the first sandstone and the sandstone in the Kassler member it probably is impossible to determine whether or not the Kassler was entirely removed in the Morrison-Dutch Creek area by the channeling preceding the deposition of the first sandstone. At both Morrison and Turkey Creek the sandstone in question rests directly on beds that are most likely in the third sandstone. Even where it is thickest, the Kassler sandstone member is not elsewhere incised so deeply in the underlying beds as to eliminate the second shale completely. Either the Morrison-Dutch Creek area was the site of a drainage course during the periods of erosion preceding both the deposition of the Kassler member and the deposition of the first sandstone, or the erosion during the latter period was locally deep enough to remove both the Kassler member and the second shale.

In the absence of the Van Bibber member between Bear Creek and Dutch Creek, only the clayrocks in the first sandstone remain as possible sources of refractory clayrock. In general these are thin and very lenticular, as can be seen in the abandoned strip pits of the Robinson Brick and Tile Co. on the dip slope of the hogback just south of Turkey Creek. This is the only place in the southern Jefferson County area where clayrock beds in the first sandstone have been mined. Of these beds, only the Bear Creek bed has the individuality and potentiality to attraction attention. This bed appears to be only a little more extensive laterally than the assumed limits of the deep channeling of the Kassler member. The Bear Creek bed apparently rests directly on the basal sandstone of the first sandstone, and is characterized by one or more thin porcellanite layers. Neither its thickness, nor the kind and succession of its included rocks seem constant. But generalizations about the characteristics of the bed are unwarranted inasmuch as it is exposed at only a few places.

The most easily accessible exposures of the Bear Creek bed are in the gap of Weaver Gulch. On the south side of the gulch the following section is exposed.

	Thickness (feet)
Benton shale.	
South Platte formation—First sandstone:	
13. Sandstone, fine-grained, massive, cross-laminated	2
12. Obscured by wash	3.5
11. Sandstone; similar to unit 13; 0.5 ft silty zone 3.8 ft above base	10
10. Shale, silty, gray; interbedded with platy siltstone	2
9. Sandstone, fine-grained, massive, cross-laminated; some siltstone	2.5
8. Obscured; float of silty shale and siltstone	5
7. Sandstone, fine-grained, friable; some siltstone beds in upper 3 ft; shaly partings at base	3.8
6. Shale, silty, dark-gray; with 0.4 ft bed of hard argillaceous siltstone at base	3.7
5. Siltstone and fine-grained sandstone	2
4. Claystone, silty, hard, black	2
3. Ash bed; locally porcellanitic	.1
2. Shale, silty, dark-brownish-gray	1.7
1. Sandstone, medium-grained, massive, cross-laminated	15–?
Slope wash.	

Units 2 through 6 of this section are probably the Bear Creek bed. The 2-foot bed of claystone in unit 4 (sample 19, table 2) fuses at cone 32½.

On the north side of the gulch, beds that appear to be equivalent to the Bear Creek bed are thicker, but slump obscures their lower contact. From this place northward to the open pits of the Robinson Brick and Tile Co. the Bear Creek bed and higher clayrock beds in the first sandstone underlie a broad grassy swale. An old test trench in the swale reveals that much of the underlying clayrock is thinly interbedded with siltstone. At the pits the Bear Creek bed is probably the 5-foot bed in the highest pit on the slope. North of the pits most of the clayrock beds pinch out between sandstone beds as the latter thicken into Turkey Creek gap. Between Turkey Creek and Bear Creek there is little indication of clayrock in the massive sandstone forming the crest and dip slope of the hogback. In addition to the previously mentioned occurrence of the Bear Creek bed on the north rim of Bear Creek gap, there is a good exposure of what is presumably the same bed on the dip slope of the hogback about 0.9 miles north of Bear Creek. Here 2 to 8 feet of dark-gray to black shale containing two thin layers of porcellanite, some silty beds, and scattered plant fossils, extend about 500 feet along the strike but crop out chiefly at the north end around a small gully draining the dip slope. North of this outcrop the Bear Creek bed could not be identified.

South of Weaver Gulch the Bear Creek bed occurs in scattered outcrops as far south as the center of sec. 19, T. 5 S., R. 69 W., about 0.2 mile north along the strike from Dutch Creek. Here the thin zone of clayrock has a sequence roughly similar to the base of the bed at Weaver Gulch, but consists of refractory flint clay, a rarity in the northern foothills of the Front Range. A section of this bed follows.

	Thickness (feet)
First sandstone (in part):	
4. Claystone, gray to light-gray, flinty	1.7
3. Claystone, dark-gray to blue-black; subconchoidal fracture	.9
2. Porcellanite, yellowish-gray, soapy	.2
1. Claystone, dark-gray to black, carbonaceous; contains highly silty sandstone	.5–1

A composite sample of units 3 and 4 (sample 18, table 2) fused between cones 35 and 36, the highest known fusion point for raw clay in the northern foothills. Just beyond this exposure the enclosing sandstone beds coalesce and the Bear Creek bed cannot be identified with certainty to the south. However, the clay bed just above the basal sandstone of the first sandstone in the Deer Creek exposure (section 13, units 62 to 66) occupies the same stratigraphic position and is similar to other exposures of the Bear Creek bed in which the latter consists chiefly of a plant-bearing black refractory shale.

REFRACTORY CLAYROCK RESOURCES

Refractory clayrock in southern Jefferson County is found locally in scattered remnants of the Van Bibber shale member, and in variable lenticular deposits of clayrock, such as the Bear Creek bed, in the first sandstone of the South Platte formation. It also occurs in the leached zone at the top of the Lytle formation. In all of these rock units refractory clayrock beds are generally too thin, too limited in lateral extent, or too generously interbedded with siltstone to constitute commercial deposits. At a few places it is remotely possible that both the ripple clay shale of the Van Bibber member and one or more beds, chiefly the Bear Creek bed, in the first sandstone would yield small quantities of refractory clayrock. Nowhere in the hogback between the South Platte River and the Alameda Parkway does the distribution of clayrocks on the outcrop indicate even a remote possibility of mining operations comparable in size to those in the Golden and Douglas County areas. Moreover, the general lack of clayrocks on the outcrop is not just a surficial feature; the geologic control of clayrock distribution is sufficiently well-known to predict that the subsurface distribution down dip is as spotty as at the surface.

The few localities that might yield limited quantities of refractory clayrock are described briefly in the following paragraphs.

None has been prospected, but all require thorough prospecting by trenching or drilling before their value can be ascertained.

The only part of the area in which the ripple clay shale of the Van Bibber member is at all promising is in the southern half of the hogback between Massey Draw and Deer Creek. The exposure at Deer Creek gap appears as though it was quarried a very long time ago; although easily accessible, it is limited in extent. The two small exposures, 3/4 mile and 1 mile north of Deer Creek, in which the ripple clay shale is of minable thickness, lie in an area where most of the Van Bibber member has been eroded back from the crest of the ridge and crops out on the dip slope (fig. 9). The variable thickness of the ripple clay shale is most likely determined by irregularities on the surface of the Kassler member. In the vicinity of these isolated outcrops the Van Bibber member is largely obscured by wash and vegetation, but it can be traced northwestward along the strike into the NW1/4 SW1/4 sec. 32, T. 5 S., R. 69 W. The grass-covered bench indicating the greatest thickness of these clayrock beds lies halfway down the dip slope between the crest of the ridge and the Benton contact not more than 500 feet southeastward along the strike from the township line. This is the optimum place to begin prospecting. The area is not promising, but it is the only part of the southern Jefferson County area in which the ripple clay shale is fairly extensive and locally of minable grade and thickness.

The most promising areas of limited clayrock production from the first sandstone are those places along the hogback where the Bear Creek bed is exposed. As is true in the Douglas County area, the best grade of clayrock in the first sandstone is found in the lowest bed, that immediately above the basal sandstone. The Bear Creek bed is in this position; the fusion tests made on its clayrock (samples 18 and 19 and possibly samples 24 and 25, table 2) range from cone 31 to cones 35–36. Black silty, locally plant-bearing shale, which weathers a bluish gray and fuses about cone 32, is characteristic of the Bear Creek bed. Some areas that warrant at least preliminary prospecting are listed below and indicated on figure 9 (labeled BC). Unless otherwise noted these are assumed to be in the Bear Creek bed.

1. The exposures on the dip slope of the hogback about 0.9 mile north of Bear Creek in northwest corner, SE1/4 NW1/4 NE1/4 sec. 35, T. 4 S., R. 70 W.

2. The grass-covered swale on the shale partly exposed in the old road cut on the north side of Weaver Gulch. The swale extends from this cut in the southeast corner, SW1/4 SW1/4 sec. 7, T. 5 S., R. 69 W., northwestward to the Robinson Brick and Tile Co. strip-

ping in about the center of the north line of the NE¼ sec. 12, T. 5 S., R. 70 W.

3. The grass-covered bench, north and south of a small exposure a little more than halfway down the dip slope between the crest and the Benton contact about 0.5 mile south of Weaver Gulch in NW¼ NE¼ SW¼ sec. 18, T. 5 S., R. 69 W. About 4 feet of gray silty shale with flinty (porcellanite?) layers in its upper part, crops out at this exposure. The clay is plastic and breaks down when wet to a muck, which dries to form a hard crust along the outcrop. Locally this clay is in two beds with a thin bed of sandstone between. About a quarter of a mile south of the exposure the generally grass-covered bed is difficult to follow through the scrub oak, but the narrow grassy bench formed on it can be picked up again on the slope above an old stone quarry about half a mile south of the exposure. To the north the bench can be followed almost to Weaver Gulch. The clayrock zone in question is probably the upper clay beds, units 8 and 10, of the section given on page 68, rather than that of the Bear Creek bed, but locally these are so close together that one can not be certain whether one bed or the other, or both underlie the grass-covered bench.

4. Exposure of about 5 feet of silty shale a short distance up slope from the Benton contact in about the center, SE¼ NW¼ sec. 9, T. 6 S., R. 69 W., about 0.5 mile south of Deer Creek. This is a clayrock bed in the upper part of the first sandstone. A grass-covered bench on this bed can be followed a short distance north and south of the exposure.

These four localities are the only places where there is some indication that clayrock deposits in the first sandstone may be of minable grade and thickness. They are listed in geographic order from north to south; by reversing 2 and 3 the list would read in order of their probable potentiality. None of them are encouraging prospects, but it would take only inexpensive trenching to test them and they certainly warrant that much attention.

The southern Jefferson County area is not an area of potential refractory clayrock production. Geologic events have rendered the area barren of extensive bodies of clayrock and it remains to be proven that even the scattered small deposits noted are worth mining.

GOLDEN AREA

In contrast to its unbroken outcrop to the south, the Dakota group in the Golden area is locally affected by faulting and folding. In the vicinity of Golden it is completely eliminated by the Golden fault, the dominant local structural feature. At certain other localities the beds are vertical, overturned, or broken by minor faults. Only as much attention was paid the structural features as was necessary to determine the outcrop patterns of the Dakota subunits.

The Golden area, as here defined, includes that part of the Dakota outcrop which has yielded the bulk of refractory clayrock for the local refractory ware industry. Except at the south end, where the area boundary was extended about a mile to conform to a well-defined landmark, the Alameda Parkway, refractory clayrock deposits of commercial value originally were almost continuous throughout the area of Dakota outcrop. These deposits have been extensively mined and the bulk of the readily accessible clayrock is gone. To extend the productive life of the area, mining of the chief source bed, the ripple clay shale, has been carried as deep as is economically feasible, and other clayrock beds above and below it have been exploited.

EXPOSURES OF THE DAKOTA GROUP

From the Alameda Parkway northward to U.S. Highway 40 at Apex Gulch, the Dakota group forms a continuous prominent hogback, and as far as the wind gap a mile north of the Parkway the dip of the beds is within the normal range of 25° to 35° E. North of this place, however, the dip gradually steepens. In the stopes of the Strainland mine, dips range from 60° to 65° E.; just north of the mine the beds become perpendicular, and about half a mile south of U.S. Highway 40 they are overturned, locally dipping as low as 20° W. At the north end of the hogback, just south of the highway, the beds are slightly offset and dragged along a small transverse fault trending N. 34° E. A long narrow block of Dakota rocks, consisting chiefly of the upper part of the South Platte formation, lies along the east foot of the hogback from U.S. Highway 40 southward about 0.7 mile. This block is separated from the South Platte formation in the hogback by a narrow strip of Benton shale. Because it lies along the trace of the Golden fault it has, in the past, been interpreted as a horse, but Reichert (1954, p. 32, pl. 13) suggested that it represents an old slump block from the hogback lying across the trace of the Golden fault.

North of U.S. Highway 40, the Dakota group underlies low rounded hills for about 0.7 mile along the strike and then crops out in a short, prominent ridge a short distance northwest of Colorado State Route 93. Throughout this distance the Golden fault lies close to the contact of the South Platte formation and the Benton shale and the short ridge is cut by several small transverse faults.

Similar small faults probably cut the Dakota in the low hills south of the ridge, but outcrops here are insufficient for detailed mapping.

At the north end of the short ridge Pierre shale is in contact with basal beds of the Benton shale, presumably along the Golden fault. Small strike faults reduce the thickness of the Morrison-Lytle-South Platte sequence in the north end of the ridge. A little over half mile northwest of here the remnants of the Dakota group terminate against Pierre shale along the Golden fault. A trench dug across the fault on the Colorado School of Mines Surveying field in the southwest corner of sec. 34, T. 3 S., R. 70 W., exposes the upper part of the Pierre shale in contact with beds low in the South Platte formation, probably the third shale. All Dakota rocks are gone 200 to 300 feet north of this trench.

Beds of the Dakota group reappear again north of Golden along the north bank of Tucker Gulch in a complex area of slices in the Golden fault zone. At Tucker Gulch the principal fault turns to the northeast and the Dakota group gradually regains its normal thickness. Reappearance of the typical Dakota hogback just north of the Golden Fire Brick Co. plant in the SE¼ NW¼ NW¼ sec. 21, T. 3 S., R. 70 W., marks the return of the upper half of the South Platte formation to the sequence. Some beds are missing at the very end of the hogback along a strike fault, one of several that appear to be associated with the Golden fault in this area, but within about 1,000 feet north of the end of the hogback the Dakota section is complete.

The hogback continues northwestward, uninterrupted except by water gaps, for about 3.5 miles with eastward dips varying between 40° and 50°. Except for a short distance south of Ralston Reservoir, where the beds underlie an old terrace remnant, the hogback is sharp and prominent. About 0.8 mile north of Ralston Reservoir the hogback makes an S-shaped bend around a narrow anticlinal nose that plunges to the south-southeast away from the foothills. This structure is cut on the southwest limb by a slight normal fault roughly parallel to the fold axis. At least two transverse faults are present on the north limb of the fold; these cut across the Morrison and Dakota and apparently coalesce northward to form a strike fault within the Benton shale. The adit at the Johnson mine crosses a fault, presumably the one in question, about 228 feet in from the portal.

From the north limb of the plunging anticline the Dakota group extends to the north-northwest in a relatively low flat-topped ridge. The change from a sharp hogback is due both to steepening of the dip, which facilitates easy weathering of capping layers, and to the gradual northward thickening of nonresistant shale and siltstone beds at the expense of the sandstone beds. Dips in the Dakota range from about 60° to 75° E., increasing gradually northward. The ridge terminates abruptly about 0.3 mile south of the railroad settlement of Fireclay. The Dakota continues north-northwestward in the slope along the west side of the Denver and Salt Lake Railroad tracks to the valley of Coal Creek. Northward from the end of the ridge to Fireclay the beds steepen to vertical, and from Fireclay they are overturned, dipping 38° W. where they pass beneath the rock flow south of Coal Creek.

The accessibility of the clayrock beds to mining is not much affected by the structural features except in the vicinity of Golden, where the Golden fault has completely eliminated the Dakota group. Only where the Dakota strata are very close to, or cut by, the Golden fault is there appreciable minor faulting, but this has not prevented underground mining of the clayrock.

The Golden fault has commonly been interpreted as a relatively high angle reverse fault, dipping steeply toward the west. Recently there has been a tendency to interpret it as a low-angle thrust fault along its entire length, although at this writing little has appeared in print to support this idea. Reichert (1954, pl. 13), in a diagram showing his interpretation of the relation between the elongate block of Dakota south of U.S. Highway 40 and the Dakota hogback, draws in the Golden fault with a westward dip of about 8°. If the dip is this low the lack of sinuosity of the fault trace over the considerable surface relief is astonishing and should be accounted for. The only sinuous fault trace in the area is around the Ralston dike south of Ralston Creek (Parker, 1938). Here there is indeed evidence of low-angle thrusting, but its limitation to the periphery of the igneous intrusion, which may have served to translate the movement into a local horizontal component, is not likely coincidence.

Considerable attention was paid to the Golden fault during the fieldwork for this report, but the detailed study of the fault zone necessary for an extended statement of its character was not within the scope of the project. The most that can be said is that firsthand acquaintance with the Golden fault (or faults) and its affect on the Dakota outcrop failed to reveal any evidence, in either bedrock exposures or deep mine stopes, suggestive of a low dip on the Golden fault. Although the attitude of the Golden fault remains to be conclusively demonstrated, its explanation as a high-angle reverse fault seems most compatible with the local geology.

LYTLE FORMATION

Complete exposures of the Lytle in the Golden area are rare. The contact of the Morrison and Lytle formations generally is obscured by slope wash except at the scattered localities where conglomerate lenses are present at the base of the Lytle. These lenses are fairly common, though individually none are very continuous, so that the contact can be interpolated along the strike without too much difficulty.

The Lytle ranges between 50 and 90 feet in thickness. At most places the thickness ranges from 60 to 70 feet and any thickness over 75 feet seems to be of very local extent. The presence of fairly numerous conglomeratic lenses at the base of the upper third of the Morrison can be misleading. However, the Morrison conglomeratic lenses in the Golden area lie 40 to 70 feet beneath the base of the Lytle. In addition, the common, but not infallible, difference between the two conglomerates is helpful. The conglomerate of the Morrison is most characteristically argillaceous, with small fragments and interstitial filling of claystone, whereas the basal conglomerate of the Lytle has little or no argillaceous material. The two conglomerates can be seen in the same locality at several places along the hogback. One locality is on the scarp face of the hogback about 500 feet north of the end of the hogback north of the Golden Fire Brick Co. kilns. Here the conglomerate of the Morrison crops out as a crumbly ledge about 60 feet beneath the friable basal conglomerate of the Lytle.

Within the Golden area the Lytle shows its usual lateral lithic variation. In the exposure on the north side of Ralston Reservoir (section 8, units 7 through 20) claystone is interbedded and mixed with thin, nonresistant, nonconglomeratic sandstone. North of Van Bibber Creek (section 9, units 3 and 4) the Lytle is locally a mass of fine- to medium-grained sandstone lenses with only 3 or 4 feet of claystone at the top. South of Fire Clay, at the north end of the Dakota ridge, the lower two-thirds of the Lytle is a massive, white conglomeratic sandstone and the upper third is largely variegated claystone. This lithologic succession might be called a classic type of sequence because of the resemblance to Lee's (1923, p. 6) typical lower sandstone and lower shale units.

Claystone in the weathered zone at the top of the Lytle is fairly common in the southern part of the Golden area, south of U.S. Highway 40. Results of tests on silty claystone from just north of the Alameda Parkway road cut were given on page 11. Farther north along the hogback, at a point about 0.5 mile north of the intersection of the road from Morrison with U.S. Highway 40, an old prospect pit reveals white and red clayrock at the top of the Lytle. At this locality the Lytle contains very little sandstone.

SOUTH PLATTE FORMATION

The principal changes in the South Platte formation in the Golden area are an increase in thickness of the Van Bibber member, a decrease in the thickness of the Kassler sandstone member and, with local exceptions in the southern part of the area, a decrease in thickness of the sandstone bed at the base of the first sandstone. The relationship of the Kassler member to the Van Bibber is complex; it is interpreted herein as intertonguing and is described more fully in the section on the Kassler member.

Throughout the area, the thickness of the South Platte formation ranges between 230 and 270 feet. The contact with the Lytle is sharp and not difficult to locate but the contact with the overlying Benton shale is obscure at places because the upper sandstone beds of the first sandstone have been weakened by intercalation of thin shale beds and partings. On fresh exposures the contact is fairly obvious and at a number of places the familiar layer of conglomerate is present at the top of the uppermost sandstone bed. This can be seen in the adit to the Denver Fire Brick Co. mine north of Golden and in the exposure of the overturned contact north of Fireclay siding in the Denver and Salt Lake Railroad cut.

BEDS BELOW THE KASSLER SANDSTONE MEMBER

The Alameda Parkway road cut contains a nearly complete exposure of beds below the Kassler sandstone member of the South Platte formation (section 10, units 8 through 30). Here, every bed except those just above the Lytle contact can be seen. The characteristic tabular, cross-laminated structure of the Plainview sandstone member, the bedding details of the silty, friable third sandstone and the "worm-worked" silty shale and siltstone of the third shale can be studied in detail. Here also, every known kaolinitic ash bed in this part of the section is represented by at least a very thin layer. The second shale lacks the upper beds of black shale generally found in it throughout most of the Golden area, but it does contain the platy siltstone and sandstone (unit 2) in which the rare marine fossils occur. No fossils have been found in the road cut but fragments of *Inoceramus* have been picked up in the float north and south along the hogback.

The thickness of the beds below the Kassler member is about 50 feet in the Alameda exposure. Northward the thickness increases, reaching a maximum of 146 feet north of Van Bibber Creek (section 9, units 5 through 24). Most of the thickening occurs in the third shale and third sandstone, both of which become increasingly sandy northward. A confusing feature of these increases in thickness is the occurrence of sandstone lenses similar to the Plainview in the third shale that make it difficult to be consistent in picking the contact. This northward increase of the Plainview type of sandstone continues into the Plainview area, ultimately taking over both the interval of the third shale and the third sandstone to form the thick lens in the vicinity of Eldorado Springs.

As far as can be determined the Plainview member in the Golden area ranges from 25 to 45 feet in thickness. The basal part of the member varies in character. Carbonaceous clayrock and even thin layers of lignite and lignitic shale occur locally. In general, black silty shale is not as common in the lower part of the member in the Golden area as it is in the areas to the south and north. The black shale at the south end of the hogback north of Golden is an exception to this; here it has been mined locally along with shale in the overlying third shale subunit. The basal sandstone of the Plainview is commonly 2 to 6 feet thick and at some places, such as north of Van Bibber Creek (section 9, unit 5) it is as much as 12 feet thick. Throughout the Golden area this sandstone is commonly conglomeratic, though the chert and quartzite pebbles and granules may be sparsely scattered.

South of Golden the third shale is between 15 and 20 feet thick and differs little from the sequence exposed in the Alameda road cut. Locally more silty shale is present. In the end of the hogback just north of Golden, at the Golden Fire Brick Co. plant, a bed of silty shale at the base of the third shale and another 15 to 20 feet beneath it in the lower half of the Plainview member were once mined and used in the manufacture of second-grade firebrick. At this locality a strike fault eliminates part of the Kassler member, all of the second shale, and at least part of the third sandstone; consequently the shale beds in question lie much higher in the sequence than usual. The strike fault dies out rapidly to the north, however, and these beds regain their proper position in the sequence. The shale of the Plainview is the thickest, locally ranging from 8 to 15 feet in thickness, and was mined more extensively than the clayrock of the third shale. However it is doubtful that either of these local shale beds would have been of commercial value were it not for their proximity to the refractory ware plant. Neither bed has been mined elsewhere.

Northward from the Golden Firebrick Co. plant the third shale thickens gradually, becoming as much as 60 feet thick north of Van Bibber Creek. Throughout most of the northern part of the Golden area the third shale is poorly exposed, and where this subunit can be seen, it is difficult to recognize a sequence of beds similar to that in the southern part of the area.

The third sandstone shows little variation in the Golden area, other than in its thickness, which ranges from about 25 to 40 feet. At the north end of the hogback between Van Bibber Creek and Ralston Reservoir the uppermost 10 to 15 feet of the third sandstone locally is resistant enough to form a ledge—a rare feature of this sandstone. The contact with the overlying second shale is sharp, and generally is underlain by an indurated bed of ferruginous sandstone as much as 1.5 feet thick. Locally, the upper surface of this ferruginous cap is ripple marked, the wavelength of the ripples ranging from 5 to 8 inches. Ripple marks of similar amplitude also were found at this same horizon in the Douglas County area (pl. 5). Although these ripple marks are rarely exposed, the ferruginous cap of the third sandstone subunit is a persistent feature. At places, as in the Alameda road cut, a thin kaolinitic ash bed rests on it.

The second shale ranges from 5 to 15 feet in thickness. Its characteristic sequence of an upper shaly part containing the second key marker, which is locally several thin porcellanite beds, and a lower part of platy siltstone and sandstone interbedded with shale, is easily recognizable throughout the Golden area. Locally, as in the Alameda cut, the upper shale portion is thin and highly silty, and in general the shale is thinner and siltier than it is in nearby parts of adjacent areas. The platy beds in the lower part of the subunit do not seem to be as fossiliferous as they are in the southern Jefferson County area, but this may be because they are not as continuously exposed. Nevertheless marine fossils, chiefly *Inoceramus comancheanus*, were found along the hogback between the Alameda cut and U.S. Highway 40, and a short distance north of Ralston Reservoir.

KASSLER SANDSTONE MEMBER

In the Golden area the Kassler sandstone member is a unit of variable thickness, rarely exceeding 25 feet. Although it can be traced northward from here through the Plainview area, its recognition as a separate member north of the Golden area is not expedient. The apparent thinning of the Kassler member by intertonguing with the basal part of the Van Bibber member was described briefly on page 61. Figure 10 illustrates this interpretation diagrammatically; details of most of the sections on which this diagram is based are shown in figure 11.

The abrupt decrease in thickness of the Kassler member in the vicinity of the Alameda Parkway is largely a matter of a change of

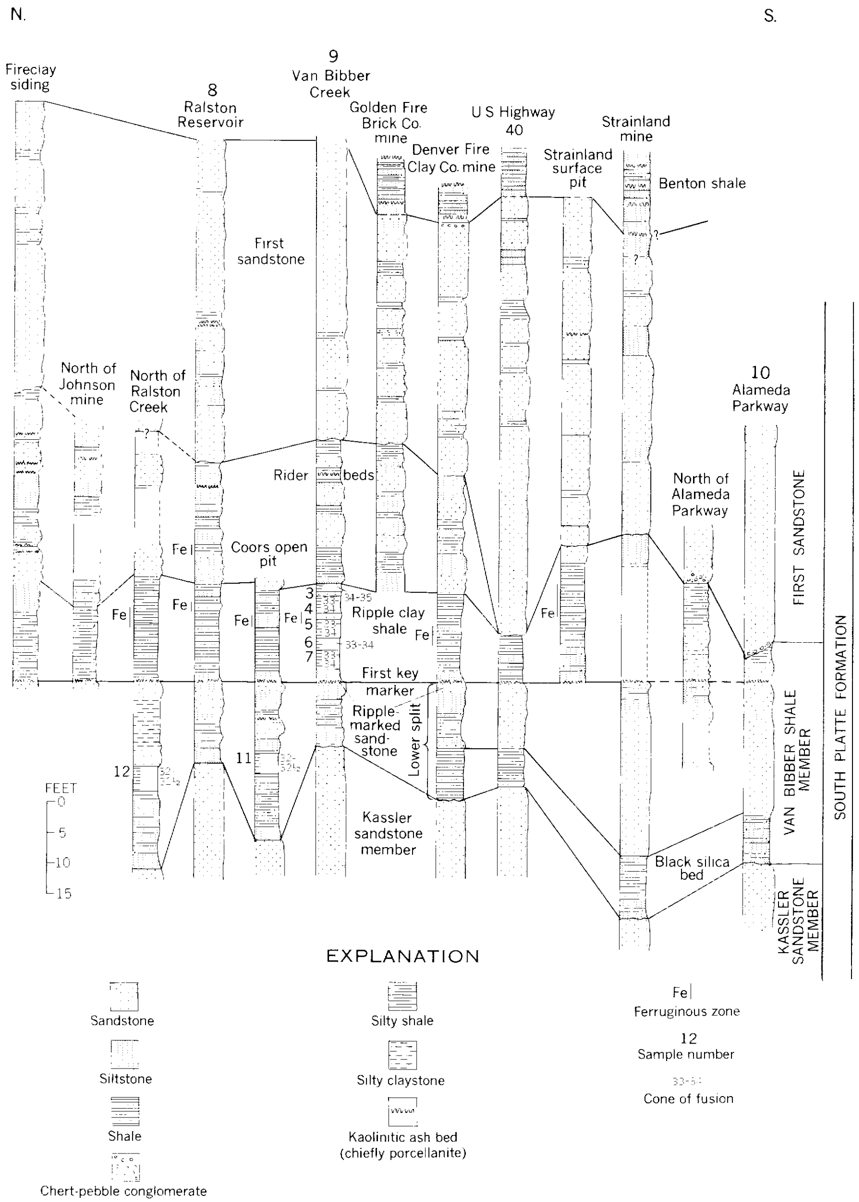

FIGURE 11.—Sections of the refractory clayrock complex in the Golden area, Jefferson County.

nomenclature, for this is the area in which the black silica bed appears. Once this bed of black silty shale breaches the Kassler sandstone member the name Kassler is arbitrarily restricted to the sandstone beneath the black silica bed. Thus the Kassler a short distance south of the Alameda cut is somewhat more than 50 feet thick, whereas in the cut it is 30 feet thick.

The reason for making this arbitrary change becomes evident as the beds in question are traced northward. The black silica bed and the lower split of the Van Bibber shale member converge fairly abruptly northward as the sandstone between them thins. In the hogback north of Golden the intervening sandstone, though possibly represented by one or more of several thin beds, is no longer identifiable and the black silica bed becomes a continuation of the lower split of the Van Bibber member.

The Kassler sandstone member, thus restricted, ranges between 5 and 30 feet in thickness. It does not show an appreciable thinning between the north and south ends of the Golden area; rather it is most commonly about 20 feet thick but locally thins or thickens to the limits noted. Where the Kassler thins, the black silica bed commonly thickens. Local thinning of the Kassler at the base of thick bodies of the black silica bed is associated with local channels, cut into Kassler, similar to those described in the Deer Creek outcrop.

North of Ralston Reservoir the Kassler member becomes platy, and locally shaly. At several places in the area the member contains fossil dicotyledonous leaves; these are particularly well preserved at a locality between 250 and 300 feet along the strike north of Ralston Reservoir, where the Kassler is about 7.5 feet thick.

VAN BIBBER SHALE MEMBER

GENERAL FEATURES

Throughout most of the Golden area the Van Bibber member ranges between 25 and 68 feet in thickness. Only the south end of the outcrop of this member and a few scattered localities elsewhere lack clayrock of commercial grade and thickness.

Between the Alameda Parkway road cut and a point 1.7 miles north along the crest, the Van Bibber member is only partly preserved. Remnants of the ripple clay shale underlie massive sandstone at the base of the first sandstone, but they are rarely more than a foot or two thick and nowhere of commercial value. At a few places the ripple clay shale is absent or reduced to little more than the first key marker—its identification tag. Beneath the ripple clay shale and the ripple-marked sandstone the Van Bibber member varies in lithic detail.

Both the upper shale bed and the black silica bed of the lower split are exposed locally with a variable thickness of sandstone between them. Neither bed appears to be of commercial value throughout most of the 1.7 miles along the hogback north of the Alameda Parkway, although the upper shale bed has been prospected at several places and even mined north of the prominent wind gap a mile from the Parkway road cut. In 1937 an adit, the Stranger mine (about the center of the W½ NW¼ NW¼ sec. 23, T. 4 S., R. 70 W.), was driven from the scarp face of the hogback to the clayrock beds in question, probably as an exploratory operation. The upper shale bed of the lower split was followed over a quarter of a mile south along the strike, as a ventilation shaft 250 to 300 feet north of the wind gap attests.

The Stranger mine is about 1,700 feet due south of the point along the ridge crest where the basal sandstone of the first sandstone rises abruptly in the sequence and the ripple clay shale attains a minable thickness. This locality marks the south end of the productive area for refractory clayrock. So sharp a termination to this famous clay mining area is surprising, but the unsuccessful exploration at the Stranger mine supports the outcrop evidence that reveals abrupt channeling of the ripple clay shale. Only the clayrock beds in the lower split remain, and neither of these can be economically mined except in combination with the ripple clay shale.

Northward from the place where the ripple clay shale appears in the succession, a commercially valuable Van Bibber member is continuous, except for structural interruptions and rare local thinning, to the north end of the Golden area at Coal Creek. Because of extensive mining and prospecting, the characteristics of the clayrocks in the member are well known to the industry, consequently relatively few tests were made of Van Bibber clayrocks in the Golden area. Samples tested (see table 2) include numbers 2 to 7, from the ripple clay shale, and numbers 11 and 12 from the black silica bed. Most of these samples are shown in relation to stratigraphic sections in figure 18.

The general nature of the clayrock in the Van Bibber succession described on pages 26 to 31, and illustrated in figure 6A, is based chiefly on exposures in the Golden area so there is no need to repeat the discussion of the succession here. Details of the entire clayrock sequence of the South Platte formation from the Kassler member to the Benton shale in the Golden area are shown in figure 11.

BLACK SILICA BED

The black silica bed is alternately a shaly siltstone and silty shale in the 1.7 miles of hogback between the Alameda Parkway and the south end of the productive area of the Van Bibber member. From this place north to U.S. Highway 40, it is generally a black highly silty shale. In the Strainland mine of the Denver Sewer Pipe and Clay Co., the black silica bed exposed in a crosscut is reported to fuse between cones 27 and 29. It has not been mined in any quantity south of U.S. Highway 40. Between this highway and the termination of the Dakota against the Golden fault, an area in which exposures are generally poor, the bed was not recognized.

In the hogback north of Golden the black silica bed is mined locally along with the ripple clay shale. The sandstone between it and the upper shale bed of the lower split is generally no more than 2 or 3 feet thick so the bed is accessible on a short crosscut. Clayrock mined from the black silica bed by the Denver Fire Clay Co. is reported to have a fusion point of cone 30 to 31. In the south end of the hogback, north of Van Bibber Creek, the Kassler member locally is thick, and the black silica bed is very thin and at best an argillaceous siltstone. North along the hogback, however, the grassy bench on its outcrop indicates that the black silica bed is locally as much as 3 or 4 feet thick. It is exposed in an old open pit of the Adolph Coors Co. just east of the low ridge crest in about the center of the south line SE¼ SW¼ sec. 5, T. 3 S., R. 70 W. The section is shown diagrammatically in figure 11. The black silica bed is located in a scourlike depression in the top of the Kassler. Between 2 and 3 feet of platy siltstone rest on the Kassler, above this is 11.6 feet of silty black shale that becomes progressively more silty downward, grading at its base to argillaceous siltstone. About 2.5 feet of siltstone and shale lie between this bed and the 2-foot sandstone that separates it from the upper shale bed of the lower split. Sample 11 is a channel sample of the upper 3 feet of the 11.6 foot bed; the shale fuses between cones 32 and 32½.

A similar section of the black silica bed is exposed in the hogback about 250 feet north of the old road on the north side of Ralston Reservoir (fig. 11). Here the black silica bed is 16.7 feet thick; all but the upper 4 feet of it is highly silty with thin layers of siltstone. The upper 4 feet (sample 12, table 2) fuses between cones 32 and 32½. North of this locality the sandstone separating the black silica bed from the upper shale bed of the lower split grades into siltstone and it is no longer possible to distinguish between these two beds. The lower split continues northward as a bed of silty shale and claystone ranging between 6 and 15 feet in thickness, and disappears under sandstone talus a short distance south of the point where the outcrop bends sharply eastward into the west limb of the plunging anticlinal fold.

From the anticline north to Coal Creek the beds below the ripple clay shale are not exposed. Locally a bench along the outcrop indicates that soft beds are present in the lower split.

UPPER SHALE BED OF LOWER SPLIT ("RIBBON CLAY")

Except at relatively few places the upper shale of the lower split is too thin or too finely interbedded with siltstone to be commercial. On the ridge directly above (east of) the entry to the Stranger mine it appears to be thicker than anywhere else in the Golden area, however, the wash-covered outcrop is not trenched, so no detailed section is available. A bench on this bed extends northward for at least 1,000 feet along the strike; it has a porcellanite layer near the base, as it does at a few other localities. In this respect the upper shale bed resembles the thin ripple clay shale that lies just down the dip slope from it. No information is available on the nature of the clayrock in the upper shale of the lower split at this locality.

In the Strainland mine the upper shale of the lower split is only 3 feet thick, and silty. Northward along the hogback it thickens locally and, as the old double stopes indicate, it was once mined in parts of the South Golden mine of the Denver Fire Clay Co.

At a very few places north of Golden small pockets of the upper shale have been mined with the ripple clay shale, but in general it is thin and contains many silt layers. Not until the upper shale merges with the black silica bed north of Ralston Reservoir does it appear to be the least bit promising.

RIPPLE CLAY SHALE

By far the greater part of the refractory clayrock mined in the Golden area has come from the ripple clay shale. Where clayrock first appears in commercial quantity, 1.7 miles north of the Alameda Parkway, the ripple clay shale is about 12 feet thick. Just north of this place—in old stopes of the Strainland mine—the details of the bed are as follows.

	Thickness (feet)
Basal sandstone bed of rider beds.	
Ripple clay shale:	
6. Clay shale, semiplastic; laminae of silt; weathers light blue gray	4.8
5. Clay shale; similar to unit 6, but with thin beds ferruginous siltstone, and local concretionary ironstone	7.4
4. Clay shale, silty, semiplastic, with thin layers of siltstone and argillaceous siltstone	1.8
3. Clay shale, silty, thinly interbedded with shaly siltstone and fine-grained sandstone. Bedding surfaces ripple marked	4.2
2. Shale, silty with interbedded shaly siltstone, ripple marked	1
1. Porcellanite, locally a shaly bentonitic clay	.2
Total ripple clay shale	19.4
Sandstone, with ripple-marked upper surface (top of lower split).	

Both the ferruginous zone, unit 5, and the silty nature of the beds beneath it are variable characteristics. In general the ferruginous zone is present consistently in the middle part of the clay shale, but both the amount and nature of the iron varies from place to place. Iron-impregnated siltstone, ironstone concretions, and scattered tiny oolites of an iron mineral in varying concentrations within the shale are the three most common ways the iron occurs. Pyrite is not very common but does occur locally as nodules in the clay or interstitially in siltstone laminae.

The silt and sand content of the clay is highly variable in all parts of the area. At some places it is chiefly above the ferruginous zone, at other places below this zone or in it. The 17-foot bed of ripple clay shale north of Van Bibber Creek (section 9, units 30 through 37, and figure 11) has very little silt or sand, but the ferruginous zone is relatively thick.

Throughout the productive part of the Golden area, the ripple clay shale ranges between 10 and 25 feet in the thickness, except locally where it has been partly removed by channeling. The quality of the clayrock, where not affected by obvious impurities of iron or silt, is fairly uniform. Nevertheless, clayrock from the ripple clay shale south of Golden seems to be slightly higher in silica and slightly lower in iron than the clayrock of the ripple clay shale north of Golden. Representative chemical analyses of the clayrock from the ripple clay share, kindly furnished by Mr. Breitweiser of the Denver Fire Clay Co., are given in the following table.

TABLE 1.—*Chemical analyses of the ripple clay shale from properties of the Denver Fire Clay Co.*

[Published by permission of the Denver Fire Clay Co.]

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on ignition	PCE
1	49.51	33.25	1.30	0.31	0.25	13.82	33
2	45.98	34.00	2.76	.43	.33	14.03	33
3	50.18	32.35	1.26	.33	.23	13.87	32½–33
4	45.49	37.05	1.67	.42	.32	13.69	32½–33
5	55.97	27.95	1.13	.65	.15	11.37	32 –32½

NOTE: Source of samples listed below:
1. North Golden, 200-foot depth, lower part of bed.
2. North Golden, 200-foot depth, upper part of bed.
3. North Golden, 100-foot depth, entire bed.
4. North Golden, run of mine.
5. South Golden, run of mine.

The refractoriness of the ripple clay shale ranges from cone 30 to cone 35. The highest fusion points seem to be those from the clayrock in the Van Bibber Creek section (samples 3 through 7, table 2), which confirms oral reports from several clay workers in the Golden area. A fusion point between cone 32 and 33 would be about average for clayrock from the bed.

In two parts of the Golden area there has been little or no mining of the ripple clay shale. One of these is in the W½ NE¼ sec. 10 and SW¼ SE¼ sec. 3, T. 4 S., R. 70 W., between the end of the hogback at U.S. Highway 40, and the short, faulted ridge southeast of Deadman Gulch. Here the ripple clay shale has been tentatively identified where Colorado State Route 93 crosses the outcrop, and for a short distance southeast of that point. It also appears to be the clayrock in a shallow trench in the hill on the Bachman ranch just north of Apex Gulch. Presumably the clay shale is continuous throughout the area in question, though it appears to be offset locally by a fault. Although the exposure on State Route 93 has a white-weathering kaolinitic ash bed on the west side of the shale bed it is a little presumptive to take this as the first key marker and make positive identification of the ripple clay shale without exposing more of the outcrop to establish the sequence. A similar pattern of outcrop would be given by the second shale if it were overturned. Lack of any prominent ridge-forming sandstone beds in this area is puzzling and could mean that the first sandstone is locally eliminated by a fault. However, it may only be that the local thick channel sand at the base of the first sandstone at the north end of the hogback south of U.S. Highway 40 has thinned out abruptly northward. With so few outcrops for guidance in an area adjacent to the Golden fault, exploratory trenches across the strike are necessary to establish the presence, and continuity, of the ripple clay shale.

The hogback between Van Bibber Creek and the plunging anticline north of Ralston Reservoir contains a minable thickness of the ripple clay shale throughout most of its length. The most extensive mining operation in this area is the Dry Creek mine of the Golden Fire Brick Co. located at the end of the hogback on the north side of Van Bibber Creek. The section of the ripple clay shale, a part of the type section of the Van Bibber member (section 9, units 30 through 37), was measured in a ventilation shaft of this mine.

Between the Dry Creek mine and Ralston Reservoir the ripple clay shale and associated rider beds and lower split form a broad swale on the hogback indicative of a thick clay rock sequence. There are a few abandoned pits and adits at the north end of this area where the hogback gives way to a low ridge, but no extensive mining has been done. Figure 11 gives a composite section of the clays in pits and trenches of the Adolph Coors Co., located about half a mile south of Ralston Reservoir; details of the ripple clay shale at this locality are as follows.

	Thickness (feet)
Basal sandstone of rider beds.	
Ripple clay shale:	
4. Clay shale, dark-gray; locally finely silty; basal 1.5 to 2 ft contains ferruginous shale, ironstone layers, and concretions	6.6
3. Clay shale, dark-gray	8.4
2. Shale, dark-gray to black, silty; contains thin beds of white siltstone up to 0.2 ft thick	1.2
1. Porcellanite (first key marker)	.2
Total ripple clay shale	16.4
Sandstone, ripple-marked (top of lower split).	

Compared with the section at the Dry Creek mine, the ripple clay shale exposed at the Coors mine seems to have a much thinner ferruginous zone. Some clayworkers in the area report that a high iron content, locally high enough to spoil the clayrock, characterizes the ripple clay shale north of Van Bibber Creek. Evidence from the outcrop indicates that the iron content, though generally greater than in the bed south of Golden, is locally a variable feature that can change appreciably within 100 feet along the strike. In the 1.5 miles along the hogback between Coors pits and Van Bibber Creek it is the 0.5 mile just north of Van Bibber Creek that has the greatest concentration of ironstone and ferruginous siltstone on the outcrop, but local concentrations of iron also occur at a few places to the north. An excellent exposure of most of the Van Bibber member in a pinnacle on the south bank of the Ralston Reservoir includes the following section of the ripple clay shale.

	Thickness (feet)
Rider beds:	
9. Shale, black, locally silty; interbedded with lenticular sandstone layers	19.4
Ripple clay shale:	
8. Clay shale, dark-gray, silty; contains thin layers argillaceous siltstone, locally stained yellow-brown	3.3
7. Shale, dark-gray, fissile; finely silty with thin beds white siltstone	2.4
6. Ironstone	.4
5. Clay shale, dark-gray; splintery fracture; finely silty in upper 1 ft; few thin siltstone in laminae	3.2
4. Clay shale, dark-gray, semiplastic	6.6
3. Siltstone, platy, argillaceous, and fine-grained sandstone	.2
2. Shale, dark-gray, silty and shaly siltstone	.3
1. Porcellanite (first key marker)	.2
Total ripple clay shale	16.6
Sandstone, ripple-marked (top of lower split).	

Both this section of the ripple clay shale and the preceding one, taken half a mile to the south, show that the ferruginous zone is limited to the lower part of the more silty upper third of the sequence leaving 8 to 10 feet of shale relatively free of silt and iron beneath. At a few places this lower clay rock contains some of the fine specks, or oolites, of an unidentified iron mineral seen in the Van Bibber Creek section.

North of Ralston Reservoir, the ripple clay shale continues at a minable thickness for approximately 0.6 mile along the hogback. At a quarry on the north side of the reservoir the ripple clay shale is about 16 or 17 feet thick; details of its sequence are given in the Ralston Reservoir section (sections 8, units 39 through 44). To the north the clay shale thickens to as much as 22 feet; but more commonly it is about 18 feet thick with the ferruginous zone lying about 10 feet above the basal kaolinitic ash bed. Locally, small transverse faults offset the bed. About half a mile north of the reservoir the ripple clay shale begins to thin locally to 10 or 13 feet, apparently as a result of channeling associated with erosion before deposition of the rider beds. Farther northward the base of the first sandstone cuts downward across the Van Bibber member, eliminating it on the sharp fold on the southwest flank of the plunging anticline.

Traces of two clayrock beds are visible around the nose of the plunging anticline and one of these can be followed northward to an exposure of the ripple clay shale on the steep hill south of the New Johnson mine of the Denver Sewer Pipe and Clay Co. Here 5.2 feet of clayrock with a thin porcellanite at the base underlies the ridge-forming sandstone at the base of the first sandstone. In the New Johnson mine the ripple clay shale varies in thickness with the configuration of the overlying sandstone that rests on its channeled surface. Commonly the bed is 5 or 6 feet of uniform, tough, semi-plastic, laminated clayrock with as much as 4 inches of laminated porcellanitic clay resting on a beautifully ripple-marked footwall. Presumably the clay bed is continuous southward at approximately the same thickness onto the nose of the anticline, although local thinning or pinching out of the clay bed can be expected there.

North of the New Johnson mine the ripple clay shale has been extensively mined along the outcrop to a point 0.7 mile north of Fireclay, where the clay shale lies within the Denver and Salt Lake Railroad right of way as far as the end of its outcrop south of Coal Creek.

RIDER BEDS

The thin sandstone and shale beds that make up the rider-bed sequence are not commonly present in the Van Bibber member south of the Golden. Locally the basal part of the sequence appears where the base of the overlying first sandstone rises in the section. North of Golden the rider beds are generally continuous except in the vicinity of the plunging anticline, where they are eliminated by deep channeling at the base of the first sandstone.

Nowhere in the area do these beds contain clayrock layers of commercial thickness for any appreciable distance along the strike, although the grade of the thin beds is similar to that of the ripple clay shale. Representative successions of the rider beds are given in sections 8 and 9, at Ralston Reservoir and Van Bibber Creek, respectively.

FIRST SANDSTONE

Beds of clayrock of commercial grade and size are unknown in the first sandstone in the Golden area. The general character of the subunit is illustrated by some of the graphic sections in figure 11. As these sections show, there may be many argillaceous zones in the sequence, but they are thin and generally highly silty.

Where the basal sandstone bed of the first sandstone is comparatively thick, as it is just north of the Alameda Parkway, at U.S. Highway 40, and at the north end of Fire Clay siding, the overall thickness of the first sandstone is greatest, ranging from 45 to 80 feet. Elsewhere, it is consistently less than 55 feet thick and in some places is little more than 25 feet thick.

Although it has local variations of thickness, the first sandstone gradually thins northward as the underlying Van Bibber member thickens. In addition, there are indications of a facies change. Beginning near U.S. Highway 40, "worm" borings appear in the first sandstone. These become increasingly more common northward in the Golden area. They suggest that the beds were deposited locally in waters sufficiently saline to support marine burrowing animals.

EVALUATION OF REFRACTORY CLAYROCK RESERVES

Partly as a consequence of intensive mining since the late 1860's, and partly because certain areas underlain by clayrock are not available for exploitation, the Golden area has little reserve potential other than the clay left in the working mines. In terms of clayrock in the ground, however, the unavailable lands have a considerable potential reserve.

The unmined area lying across Colorado State Route 93 north of U.S. Highway 40 is not promising inasmuch as the clay distribution is poorly known, the proximity of the Golden fault implies structural complexity, and the low-lying terrain precludes easy access for large-scale mining.

The unmined parts of the hogback between Van Bibber Creek and Ralston Reservoir have a continuously thick ripple clay shale. The only adverse feature apparently is the locally high iron content of the clay. In this respect the ripple clay shale is similar to that in the hogback south of Van Bibber Creek where the clayrock was not mined locally because of a high iron content. Thorough testing of the ripple clay shale, preferably by core drilling, is the only way in which the clayrock resources of the area north of Van Bibber Creek can be evaluated.

Although the same can be said for the hogback between Ralston Reservoir and the plunging anticline, less ferruginous material appears on the outcrop of the ripple clay shale. Consequently this seems to be the best of the potential reserve areas.

Present knowledge of the clayrocks in the potential reserve areas is summarized in the preceding section on the Van Bibber member. In none of the areas is it likely that clay could be mined profitably on a large scale from any beds other than the ripple clay shale unless the latter were also mined at the same place. Locally, as in the hogback north of Ralston Reservoir, the lower split is another possible source of valuable clayrock easily accessible from the ripple clay shale.

PLAINVIEW AREA

EXPOSURES OF THE DAKOTA GROUP

In the Plainview area the refractory clayrocks of the South Platte formation become thin and lose their refractoriness as the formation changes northward into a dominantly marine facies. Unfortunately the upper clayrock-bearing part of the formation is so poorly exposed that it could not be mapped or studied in detail comparable with that in the areas to the south.

The area includes the outcrop of the Dakota group between Coal Creek and South Boulder Creek at Eldorado Springs. Complex faulting around the valley of Coal Creek has eliminated the Dakota group in that valley area except for a few small blocks a few hundred feet north of Colorado State Route 72, about half a mile east of the Denver and Salt Lake Railroad trestle. From this locality north to Plainview any Dakota that may be present is covered by slope wash and terrace gravels. From Plainview north to Eldorado Springs the Dakota group crops out in a ridge supported by the Plainview sandstone member of the South Platte formation and similar sandstone beds that appear within the third shale and third sandstone. All higher beds lie in a tree- and grass-covered eastern slope where the beds are exposed at very few places in manmade cuts.

The only complete exposure of the Dakota group in the area is at the north end of the hogback south of Eldorado Springs (section 6). Here most beds of the sequence above the third sandstone are exposed in an abandoned irrigation ditch cut in the slope just above Community Ditch; the sequence from the third sandstone into the

Morrison is exposed higher on the ridge in cuts along the access road to the South Boulder Diversion Canal. The Dakota group at this locality is 336 feet thick: the Lytle formation, 93 feet and the South Platte formation, 243 feet.

LYTLE FORMATION

Two exposures of the Lytle formation at opposite ends of the area yield the bulk of information on the unit. In the Denver and Salt Lake Railroad cut through the Dakota at Plainview, beds below the Lytle-South Platte disconformity (section 7, units 2 through 15) consist of alternating sandstone and variegated claystone lenses aggregating 151 feet in thickness. The lowest unit completely exposed is a chert-pebble conglomerate with much interstitial claystone; beneath this are a few feet of greenish-gray claystone, then slope wash and vegetation obscure the nonresistant beds in the valley west of the Dakota ridge. Between the conglomerate at the base of the section and the disconformity at the base of the South Platte formation are four sandstone lenses of similar lithology. All but the upper lens are weakly conglomeratic, with scattered chert and quartz granules and pebbles. Nowhere else in the foothills of the Colorado Front Range is the indefinite nature of the contact of the Morrison and Lytle formations more clearly shown.

The lithic character of the Lytle north of Plainview affords a clue for the recognition of the basal sandstone of the Lytle in the railroad cut. At Eldorado Springs and southward to within 0.5 mile of the Plainview cut, a thick bed of conglomeratic sandstone with a bed of coarse conglomerate as much as 10 feet thick at the base, marks the base of the Lytle (section 6, unit 6). Nowhere south of Boulder, except in the southern part of the Douglas County area, are thicker and coarser lenses found at the base of the Dakota group. Although the conglomerate disappears north of the Plainview cut, the sandstone, apparently continuous with it, can be traced with reasonable certainty to the second sandstone lens beneath the Lytle-South Platte disconformity in the railroad cut. This makes the Lytle about 72 feet thick and the upper sandy part of the underlying Morrison 79 feet thick. The basal conglomeratic sandstone of the sandy phase of the Morrison (units 2 and 3) is about 61 feet below the Lytle, which corresponds with the position of similar lenses at this horizon in the Golden area.

In the fresh exposures in the Plainview railroad cut there is a conspicuous contrast between the brightly variegated claystone lenses well down in the Lytle and in the upper part of the Morrison, and the whitish to pastel tints of the claystone just beneath the contact of the Lytle and South Platte formations. The weathered zone here is chiefly an argillaceous siltstone, locally a silty claystone, with spotty red-stained concentrations of iron oxide. Nowhere along the Lytle outcrop in the Plainview area is there any indication of a thick claystone in this weathered zone.

SOUTH PLATTE FORMATION

The only formal subdivision of the South Platte formation recognized north of the Golden area is the Plainview sandstone member, whose type section is in the railroad cut at Plainview (section 7, units 16 through 21). Even the Plainview member cannot be mapped separately in the Plainview area because the beds between it and the second shale change laterally to a thick resistant sandstone identical to that in the upper part of the member. This unique sandstone lens in the generally nonresistant part of the South Platte formation was first interpreted as a local thickening of the third sandstone (Waagé, 1955, p. 30), but subsequent study indicates that both the third sandstone and third shale grade laterally into this lens; no evidence of an unconformity at the base of the lens was observed.

The third sandstone and third shale change gradually to tabular, brown-weathering sandstone northward from Plainview. The only shale beds observed in this part of the section are at the east end of the Plainview cut; these are thin, silty, and interbedded with sandstone. In the railroad cut the shale in the lower part of the Plainview member (units 17 and 18) is silty and contains thin beds of siltstone. Shale taken between the siltstone layers in the lower 4 feet of unit 17 (sample 33, table 2) fused between cones 26 and 27.

The South Platte strata above the third sandstone are described in the Eldorado Springs section (section 6, units 20 to 52); as this is the only complete exposure of these beds in the Plainview area, it is shown diagrammatically in figure 12. The beds are partly exposed in the banks of the South Boulder Diversion Canal and in several strip pits north of Plainview. Tests of the least silty shale beds (fig. 12) indicate that clayrocks equivalent to the ripple clay shale of the Van Bibber member are refractory and that those of the rider beds are refractory in the basal part and semirefractory above. In the second shale all clayrocks are dominantly illitic and nonrefractory. The shale beds in the first sandstone are at best low-grade refractory clayrocks.

Sandstone beds are fairly numerous, but they are thin and generally nonresistant. The uppermost bed of the first sandstone is locally quartzite and at some places is riddled with borings showing laminae that are concave upward. The ripple-marked sandstone lies beneath the ripple clay shale, but only siltstone occupies the position

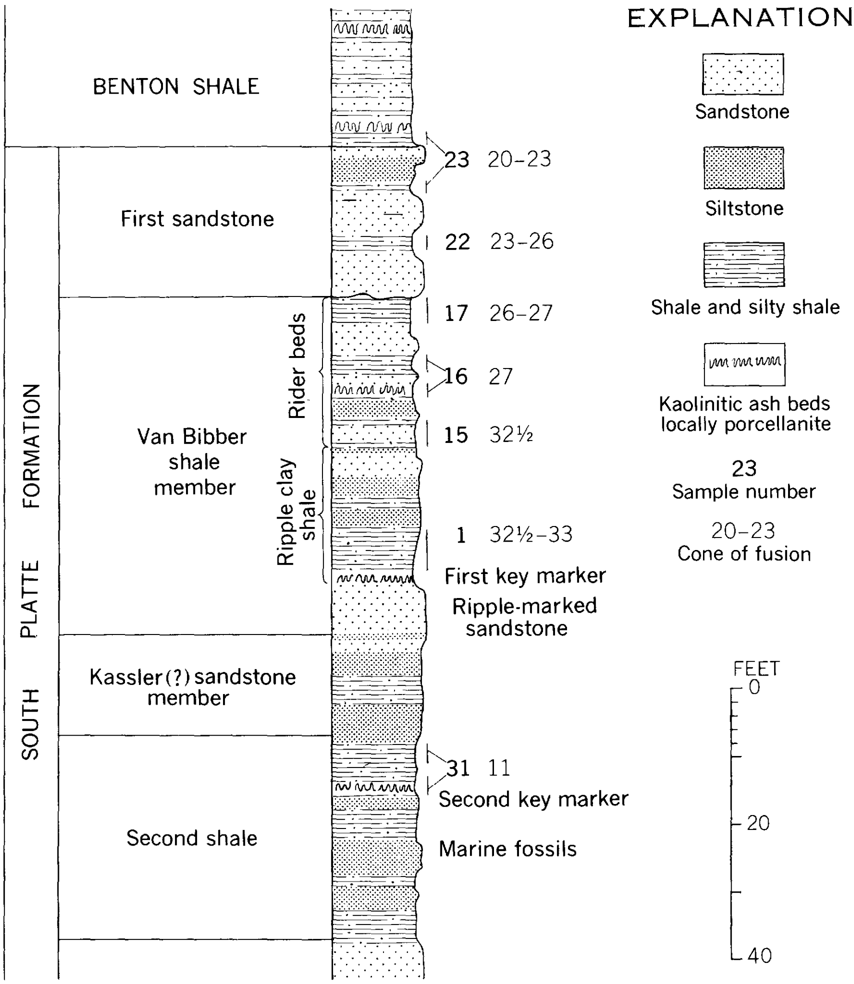

FIGURE 12.—Clayrocks in the upper part of the South Platte formation at Eldorado Springs.

of the Kassler member. The platy siltstone in the second shale is sparingly fossiliferous, yielding fragments of *Inoceranus comancheanus* and *Pteria salinensis*.

Any changes in the upper South Platte formation south of Eldorado Springs are effectively masked by overburden. One or two low sandstone ledges appear east of the main ridge just north of Plainview; one of these may be a last vestige of the Kassler member.

EVALUATION OF REFRACTORY CLAYROCKS

Except for information gained at some exploratory strip pits within a mile north of the railroad cut at Plainview, knowledge of the refractory clayrocks is based on the Eldorado Springs section (fig. 12). Unfortunately, the amount of bedrock exposed in the pits is insufficient to permit positive identifications of the beds; some pits are chiefly, if not entirely, in the Benton shale.

Refractory clayrock is largely restricted to the ripple clay shale that appears continuous throughout the area, judging from the lack of a thick sandstone bed at the base of the first sandstone. The overlying rider beds are semirefractory. None of the clayrock beds in the few exposures exceeds 5 feet in thickness. All of the beds are silty and commonly contain laminae and thin beds of siltstone, reminiscent of the ripple clay shale of the Douglas County area. The tests of clayrocks in the Eldorado Springs section (fig. 12) were made on samples of the shale layers only, and though these samples include dispersed silt and silt laminae, they do not include the thin-bedded siltstone.

Possibly the ripple clay shale and some shale of the rider beds may be worth mining locally but the increase in silt content and the apparent thinness of the shale beds holds no promise for large-scale refractory clayrock production in the Plainview area.

PALEOGEOGRAPHIC RELATIONS OF CLAYROCKS OF THE DAKOTA GROUP

TRANSGRESSIVE-REGRESSIVE PATTERNS IN THE SOUTH PLATTE FORMATION

The dominantly marine facies of the South Platte formation in Larimer County is a relatively simple sedimentary cycle consisting of a basal sandy transgressive part, the Plainview member; a middle part of marine shale and siltstone; and an upper dominantly sandy, regressive part. This simple pattern is complicated southward, beginning in Boulder County, by the appearance of a deltaic facies in which the formation becomes dominantly sandy. In this deltaic facies as many as three transgressive-regressive cycles are discernible. These are shown diagrammatically in figure 13.

To avoid misunderstanding of the terms "transgression" and "regression" as used herein, it is necessary to preview briefly the regional pattern of Lower Cretaceous deposition. The invasion of the interior region by the Cretaceous sea is marked by the transgressive disconformity at the base of the South Platte formation and its genetic equivalents. The sea spread at an irregular rate interrupted by stands. The overall pattern, at least through the deposition of most of the Benton shale and related beds, is transgressive. Regressive phases were principally fluctuations of local extent that left a record along the margins of the seaway. The extent of the fluctuations

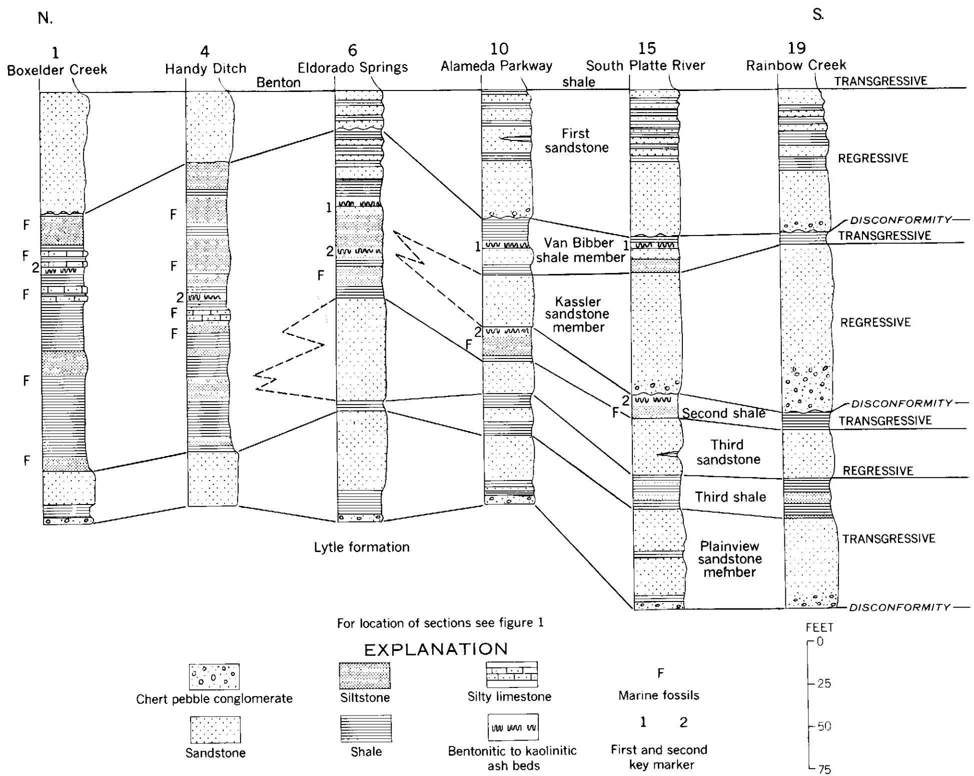

FIGURE 13.—Transgressive-regressive cycles in the South Platte formation.

differed in time and place. Most extensive was the regressive phase marked in the northern Front Range by the first sandstone, whose equivalents extend over much of the interior region. This regressive phase does not mark a complete withdrawal of the sea, but rather a general restriction more pronounced in some areas than in others. Records of other regressive phases are more limited in areal distribution, as parts of the deltaic facies in the Front Range indicate.

The regressive phases may be the result of either one of the commonly accredited methods of shifting the strand line seaward: by eustatic lowering of sea level or by increase in amount of sediment beyond the point where it can be handled by the sea, resulting in the occupation of former areas of seawater by deltas and deltaic plains. Possibly when many more of the details of Dakota stratigraphy are known, an estimate can be made of the relative importance of these two methods. The choice to account for the deltaic deposits in the foothills of the Rocky Mountains of Colorado seems to be between local uplifting in nearby parts of what are now the Front Range and Wet Mountains and derivation of the sediments from areas farther to the west and southwest which were drained by rivers whose outlets to the sea were concentrated in the foothills area. There is no indication of a regional subsidence of sea level.

Within the deltaic facies of the South Platte formation, the conformable sequence of beds including the Plainview member, third shale, and third sandstone constitutes one local transgressive-regressive cycle. Actually very little regression is involved inasmuch as the initial trangression in this area was not followed by deposition of off-shore marine beds. However, "worm" trails and borings are locally found in both the shaly basal part of the Plainview member and in the third shale. The latter subunit in particular locally contains "worm"-worked beds in which the silt and shale laminae were disrupted by burrowing organisms in a manner similar to that described in studies of modern tidal flats (Van Straaten, 1954, pl. 1, A and B). The overlying third sandstone is coarser and generally lacks signs of burrowing. In the Golden area it is commonly laminated, but southward lamination gives way to crossbedding and the subunit as a whole shows no characteristics of intertidal sedimentation.

The abrupt termination of the third sandstone at a relatively plane surface covered, at a number of places, with ripples of exceptionally long wave length, marks the beginning of the second transgressive phase in the deltaic area. Above this surface lie the fossiliferous lower beds of the second shale containing a few members of the *Inoceramus comancheanus* fauna. Remnants of the second shale mark the farthest advance into the deltaic area of waters capable of supporting marine mollusks; even so the fauna probably consisted of individual species that could stand considerable variation of salinity.

The subsequent regression is marked by the deposition of the Kassler member, and the scour that preceded it. The base of the sandstone, though obviously disconformable on the second shale, is not resting on a highly irregular surface with deep channels, instead the surface is a gently undulatory disconformity that is generally somewhat more deeply incised in the direction that the Kassler member thickens and coarsens. The Kassler, even at its edge in the Golden area, shows no evidence of marine deposition; its only fossils are remains of wood and leaves.

The third cycle in the deltaic area begins with the deposition of the Van Bibber member. Relationships between this member and the underlying Kassler member vary from place to place. Except at the margin of the Kassler in the Golden area, however, the Van Bibber strata commonly rest disconformably on locally scoured surfaces on the sandstone. The dominantly kaolinitic shale of the Van Bibber member, and especially its refractoriness—a quality uncommon to clay sediments deposited in saline waters—indicate deposition in brackish or fresh water. The lamination of the shale and silt suggests quiet water, and the uniformity in the sequence of the beds suggests uniformity in conditions of deposition throughout a large area. Extensive swamps, including areas of open water, around the low-lying flats of large deltas, or a delta plain, would fit the conditions indicated. Although not a transgression in the sense of a forceful invasion by marine waters, deposition of the dominantly shaly Van Bibber strata indicates either a rise in sea level sufficient to impound the drainage over parts of the delta plain, or an appreciable decrease in the supply of sediment.

Relative shift of the strandline seaward subsequently permitted removal of much of the Van Bibber sediments by erosion. Locally, deep, broad channels were excavated, such as the one in the Morrison area, which were cut into, if not through, the Kassler sandstone member. On this irregular surface the basal sandstone bed of the first sandstone was deposited. The upper beds in this subunit are lenticular shale and sandstone, with some thin coal beds intercalated in the Douglas County area. Although the sequence of beds shows considerable lateral variation, a partial return to coastal swamp conditions is indicated. The many channel sandstone beds probably mark shifting distributaries between which existed the swamps where the finest sediment was deposited. This stage of sedimentation was brought to a close by an undoubted eustatic rise of sea level which brought the Benton sea over the area.

EXTENT OF THE DELTAIC FACIES

The description of the deltaic facies of the South Platte formation in the Golden, southern Jefferson County, and Douglas County areas alone gives a very limited picture of the distribution of South Platte subdivisions; actually some of the subdivisions have regional extent. A brief review of what has been written previously (Waagé, 1955, p. 42) on this subject can serve as background for discussion of the deltaic facies and its clayrocks in Colorado.

The Plainview sandstone member can be traced northward from Colorado into eastern Wyoming where it is lithogenetically equivalent to the so-called Rusty beds at the top of the Cloverly formation and to the Fall River formation of the Black Hills region. Originally, and more logically, the Rusty beds were included at the base of the marine Thermopolis shale. Some geologists still follow this older practice. Apparently the member is a northern element in the South Platte sequence inasmuch as it cannot be identified for any appreciable distance south of the northern foothills of the Front Range. The third sandstone grades northward into marine facies in the northern foothills and becomes an inconspicuous silty zone in a dominantly shaly sequence to the south in the Colorado Springs area; consequently it appears to be a local subunit. The Kassler sandstone member is a southern element that grades northward into marine silt and shale in the vicinity of Boulder but extends widely southward over south-central and southeastern Colorado. The first sandstone becomes less conspicuous northward but its equivalents, the Muddy sandstone member of the Thermopolis shale and the Newcastle sandstone, are widespread in Wyoming. Southward from the northern foothills the equivalent of the first sandstone is persistently sandy. Throughout the Front Range hogback and southward in the Wet Mountains, and over much of southeastern Colorado, equivalents of the first sandstone and Kassler member are prominent ledge-forming sandstone bodies, commonly coalesced to a single massive unit but locally separated by a sequence of refractory clayrock equivalent to the Van Bibber member. These rocks are the succession to which Stose (1912) restricted the name Dakota. The correlation chart, figure 2, shows the different terminologies applied to the beds in question.

As the foregoing summary indicates, at least part of the deltaic, clayrock-bearing facies of the South Platte formation extends southward and southeastward beyond the area covered in this report. The relation of the South Platte formation to these equivalent strata to the south merits more detailed discussion. Beds equivalent to that part of the South Platte formation beneath the Kassler sandstone member become thinner south of the Douglas County area and in the vicinity of Colorado Springs the third sandstone and Plainview sandstone member cannot be identified. Here the entire section between the base of the Kassler member and the Lytle contact is shale with a few silty zones. Absence of the Dakota outcrop north of Colorado Springs prevents continuous tracing, so it can only be presumed that the third sandstone and Plainview sandstone member have either graded laterally into shale or been overlapped southward. This shale, which Finlay (1916) called the Glencairn shale member of the Purgatoire formation, is marine, though fossils are rare. It locally contains a species of *Lingula* near the base, fish scales scattered throughout, and some agglutinated Foraminifera. Tests of the shale (samples 39 and 40, table 2) show that it is illitic and not refractory.

South of Colorado Springs the Glencairn shale member gradually becomes sandy and in the Canon City embayment area it consists of alternating sandstone and shale subunits that are remarkably similar in distribution to the subunits in the northern foothills, even to the distribution of kaolinitic ash beds and a persistent marine zone. The shale immediately beneath the Kassler equivalent is low-grade refactory to semirefractory and has been extensively mined. Agglutinated Foraminifera were recovered from this shale, and *Inoceramus* was found in interbedded sandstone at its base. Sandstone units corresponding in relative stratigraphic position to the Plainview and third sandstone are chiefly fine grained, tabular, cross laminated and brown weathering similar to the Plainview in general. Whether the entire interval between the Kassler equivalent and the Lytle contact (the Lytle member of the Purgatoire formation) in the Canon City embayment area can be matched unit for unit with the corresponding sequence in the northern foothills remains to be proven; at the present stage of investigation such appears likely. Eastward and southeastward from the Canon City embayment the Glencairn member loses the sandstone subunits, and becomes a silty marine shale in southeastern Colorado.

For the foothills of the Front Range as a whole, that part of the deltaic facies represented by the third sandstone is less extensive than that represented by either the Kassler or first sandstone. The seaward margin of the third sandstone lies athwart the foothills approximately in northern Boulder County, lies east of the foothills south at least as far as Perry Park in Douglas County, and turns westward over the foothills somewhere in northern El Paso County. South of Colorado Springs the seaward margin lies within the Canon City embayment roughly near the east line of Fremont County; at this place it turns eastward on the north side of the Beulah area in

Pueblo County, where there is a local thick sandstone and conglomerate facies in the Dakota and Purgatoire formations similar to that in the Dakota group in the southern part of the Douglas County area. Beyond this it has not been traced.

The upper two regressive sandstone beds in the deltaic facies, the Kassler and first sandstone, extend over the entire outcrop area in south-central Colorado and over most, if not all of southeastern Colorado. The seaward edge of the Kassler sandstone member extends southeastward from its outcrop in the foothills in Boulder County. Together with the first sandstone it must have formed a broad delta plain, lying southwest of the seaway, until the transgression of the Benton sea. During this presumed stillstand of the Cretaceous sea, one widespread episode of coastal swamp formation on the delta plain is recorded by the clay shale and claystone beds of the Van Bibber member of the South Platte formation and its equivalent, the Dry Creek Canyon member of the Dakota sandstone. The bulk of Colorado's refractory clayrock was deposited in these swamp areas. As in the northern foothills, channeling prior to the deposition of beds equivalent to the first sandstone removed most of the clayrock deposits in southcentral Colorado (Waagé, 1953, p. 20–26).

SOURCE OF THE CLAY SEDIMENT

The distribution of deltaic bodies along the Front Range and to the south makes it obvious that most of the sediment of the South Platte formation and its correlative beds in southcentral Colorado came from a source either within the present areas of the Front Ranges of the Rocky Mountains or farther to the west and southwest. Direct evidence on the source of the Dakota group sediment is slight. Channel deposits in the beds equivalent to the first sandstone are elongate northeastward in exposures at the northeast corner of the Canon City embayment in northwestern Pueblo County (Waagé 1953, p. 26, pl. 4). Southeast of the embayment, near the settlement of Beulah, the gross directional features of a locally sandy and conglomeratic facies of the Dakota group indicate east to northeast transport of sediment. These inadequate bits of directional data support a western or southwestern source but shed no light on whether it was local or distant.

The possibility of relatively local source areas has been kept alive by many reports of the overlap of the Morrison and older formations by the Dakota group, particularly in the Canon City embayment area (Gilbert, 1897; Hills, 1900; Lovering, 1929, p. 88, among others). Residual kaolinitic mantles in such local source areas were suggested as the source material for the refractory clayrocks in the Dry Creek

Canyon member in south-central Colorado (Waagé, 1953, p. 47). However, a number of the supposed examples of overlap by the beds equivalent to the Dakota group have been investigated as the opportunity arose during the last several years and as yet not one clear-cut example has been found. Instead it appears to be the Morrison that overlaps the older rocks. At some places where the Morrison rests on the Precambrian, as in the vicinity of Parkdale, west of Canon City, it appears to be relatively thin and conceivably the local Dakota equivalents might at one time have overlapped it in areas, now long since eroded, near the center of the ranges. A good argument against this, in the Parkdale area, is the abundance of arkosic sandstone and conglomerate in the Morrison and the lack of it in the Purgatoire and Dakota formations. Even the typical dense Morrison limestone beds locally contain fresh angular fragments of pink feldspar. Although a number of areas of reported Dakota overlap have yet to be checked, there seems to be no good reason to continue to rely blindly on local overlap by the Dakota; source areas other than local ones must be considered.

Whatever the source, clay sediment in the Dakota group appears to have had its mineralogical characteristics determined largely by the locus of its deposition. Although this cannot be proved, it is indicated by the amazing conformity of illitic clays to the marine facies and of kaolinitic clays to the deltaic facies in the South Platte formation (fig. 4). Even the thin marine zone of the second shale has dominantly illitic clays associated with it far into the deltaic facies. Most striking is the record of the ash beds exemplified by the tests on the second key marker. Here the same ash bed is a kaolinitic porcellanite in the deltaic facies and an illitic-montmorillonitic clay to montmorillonitic bentonite in the marine facies. The presence of illite as a minor constituent in many of the dominantly kaolinitic shale samples may indicate that much of the original clay sediment was illitic.

The dominantly kaolinitic nature of the clay in the deltaic facies conforms to the generally accepted conclusion that kaolinite tends to form in an acidic environment of deposition in which there is circulation and renewal of the water. The swamps on the delta plain were open to the sea at the margins of the plain but they extended miles landward. Circulation and renewal of the water would have been accomplished by direct drainage of river waters through the swamp, by overflow and seepage from the distributaries, and by tidal action. The swamp waters, at least those back from the seaward margin, were charged with organic acids. Proximity to salt water may raise some objections about the reliability of so general an explanation for the dominance of kaolinite in the South Platte sediments. The apparent low salinity of the interior Cretaceous sea at this time may have been a factor permitting the formation of kaolinite in coastal areas within the tide range. Direct evidence for a low salinity is found in the peculiar distribution of marine invertebrates described by Reeside (1923); a normal marine bottom fauna is restricted to Kansas and the southeastern corner of Colorado, only an impoverished faunal remnant inhabited the Front Range area. It is not difficult to account for the low salinity for this was the initial encroachment of the Cretaceous sea in this part of the interior region; the sea was probably shallow except at its connection with the open ocean, and it was receiving fresh water from a vast drainage area embracing most of the interior region of the United States. Indeed it is not until well into Benton time that invertebrate faunas begin to show a more normal marine aspect in eastern Colorado.

Much remains to be learned about the genesis of the highly refractory clayrock in the South Platte formation. The stratigraphic approach to clayrock distribution followed in this report has gone about as far as it can in reconstructing the broader outlines of the environment of deposition and paleogeography. With the stratigraphic details in hand, the study of the South Platte clayrock should be a rewarding one for the sedimentologist or clay mineralogist.

DISTRIBUTION AND EXPLOITATION OF REFRACTORY CLAYROCK

The swamp areas whose deposits later became the Van Bibber and Dry Creek Canyon clayrock units were apparently limited to a belt along the deltaic plain. This belt was at least 50 miles wide in south-central Colorado. The inferred extent of the belt of swamp deposits southward from Boulder County, includes all the areas of known and potential refractory clay deposits in eastern Colorado. Such deposits are scattered and restricted in area because of extensive erosion subsequent to their deposition.

Three areas of outcrop include most of the clay-bearing rocks: the area near Denver, described in this report, the area around the Canon City embayment described in an earlier report (Waagé, 1953), and the area in the flat-lying Dakota strata of southeastern Colorado, partly treated in the earlier report. The area around Denver is largely mined out except for the reserves on lands not now available to the local refractories companies. The Canon City embayment area has extensive reserves left in its eastern parts (Pueblo County) and is the nearest source of refractory clayrock for the industry in the Denver area. The more remote and generally inaccessible area in southeastern Colorado has not been thoroughly explored for refractory clayrock; the eastward extent of the clayrock units in this area is unknown.

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MEASURED SECTIONS OF THE DAKOTA GROUP

The sections referred to in the text are described in detail on the following pages. Each section includes an introductory statement giving the location and whatever annotations are necessary. The location of all sections is shown graphically in figure 1.

Section 15 includes the type section for the South Platte formation and for the Kassler sandstone member. Section 9 includes the type section of the Van Bibber shale member and section 7 the type of the Plainview sandstone member.

In the individual sections the word "unconformity" is used as a general term for all stratigraphic discordances whose exact nature could not be determined. All the breaks at the base of sandstone and conglomerate bodies in the Lytle formation and upper part of the Morrison formation are in this category. Although most of these are channeled disconformities, one of them, which is usually unidentifiable, may be slightly angular (Waagé, 1955, p. 25). Until this possibility can be substantiated or disproved a noncommittal designation of the breaks seems the least objectionable.

The breaks in the South Platte sequence are disconformities of two types, the transgressive type in which the surface is relatively flat, and the regressive type in which the surface is channeled locally. The contacts of the Lytle and South Platte formations and of the South Platte and Benton formations are the major transgressive disconformities in the sequence. Channeled disconformities are common at the base of the first sandstone and to a lesser extent at the base of the Kassler sandstone member. In the sections they are noted only at those locations where channels are obvious.

SECTION 1.—*Boxelder Creek*

[Dakota group, complete section pieced from exposures ¼ to ½ mile north of Boxelder Creek in the W½ NE¼, sec. 9, T. 10 N., R. 69 W., Larimer County. The locality is at or very close to that described by Lee (1927, p. 39) "about 2 miles east of the Greenacre ranch" along Boxelder Creek. The outcrops are easily accessible from a point slightly less than 3 miles by road from the end of the Union Pacific Railroad spur at Buckeye.]

	Thickness (feet)
Benton shale: obscured by slope wash.	
South Platte formation:	
37. Sandstone, brown-weathering, fine-grained, quartzitic, hard	9.7
36. Sandstone, light-gray, fine-grained; local rusty-brown stain, in massive beds 0.6 to 2 ft thick, cross-laminated, soft to friable	26
35. Sandstone; similar to unit 36, but hard and resistant; forms hogback	36
Disconformity; channeled surface.	
34. Obscured, partial exposures show crumbly argillaceous siltstone locally capped by lens of hard fine-grained sandstone weathering olive-brown	8.1
33. Sandstone interbedded with siltstone; weathers light olive brown; platy to shaly; locally calcareous; some sandy shale	12.7
32. Siltstone, platy to shaly, calcareous; contains thin beds of silty to sandy, petroliferous, crystalline limestone and partings of silty shale; fossiliferous; contains *Inoceramus comancheanus* Cragin *Ostrea larimerensis* Reeside and fish scale and bones	8.3
31. Shale, gray to dark-gray, silty; with two bentonite layers, 0.2 ft thick, 2.4 ft and 3.2 ft above base	4.1
30. Bentonite (second key marker)	.9
29. Shale, gray, silty with many thin beds and laminae of shaly siltstone; bentonite bed, 0.1 ft thick, 4 ft from top	7.8
28. Limestone, gray, crystalline, petroliferous; weathers tan, silty to sandy, with beds of dark gray to black shale; fossiliferous; contains *Inoceramus comancheanus* Cragin *I. bellvuensis* Reeside *Ostrea larimerensis* Reeside *O. noctuensis* Reeside	2

	Thickness (feet)
South Platte formation—Continued	
27. Shale, dark-gray to black	3
26. Limestone and shale; fossiliferous, as in unit 28 above	2
25. Shale, dark-gray to black, hard; scattered thin layers of siltstone that weather with yellow-brown to red ferruginous stain; bentonite, 0.2 ft thick, 1.2 ft above base	12.4
24. Bentonite	.3
23. Shale, dark-gray to black; contains a few silt laminae	4.5
22. Siltstone, gray, argillaceous, and silty gray shale; irregularly thin-bedded; weathers light gray and brown; zone of large, barren ironstone concretions 9 ft above base	23.5
21. Shale, dark-gray to black, fissile; weathers blue-gray; scattered thin beds and laminae of silt in upper part	4.5
20. Shale, dark-gray to black; weathers fissile; thin zones with interlaminated silt, weathers rusty-brown; argillaceous siltstone 1 ft thick at top	22.8
19. Siltstone, weathers rusty-brown, shaly, ferruginous; has local ironstone concretions	.8
18. Shale, similar to unit 20; contains scattered silt laminae and a thin bed of siltstone 4 ft above base	15.7
17. Ironstone concretionary layer	.6
16. Shale, gray to dark-gray; a few beds of olive-gray siltstone	2.2
15. Siltstone, olive-gray and silty, gray to dark-gray shale; zones of ironstone concretions in lower 1.5 ft and 3 ft above base; Plesiosaur vertebrae in siltstone at top of bed	4.3
14. Siltstone, platy to shaly; weathers buff to dark brown; locally ledge-forming	1.5
13. Siltstone, platy to shaly; weathers light gray and buff, and interbedded silty shale	2.9
Plainview sandstone member:	
12. Sandstone, brown-weathering, fine-grained, medium- to thin-bedded, cross-laminated; contains some thin zones and partings of sandy shale; forms second Dakota hogback; measurement, on dip slope, is approximate	19
11. Obscured, sandy, argillaceous wash	2.7
10. Sandstone, light-gray, fine- to medium-grained, massive, cross-laminated; weathers buff to brown	1
9. Shale, black, carbonaceous, silty	0.5–2
8. Sandstone, similar to unit 10; varies in thickness at expense of containing shale beds	0.5–1.5
7. Shale, gray, sandy	2.5–4
6. Sandstone, similar to unit 10, locally conglomeratic, with pebbles of chert and quartzite	2.8
Disconformity.	
Lytle formation:	
5. Claystone, sandy; contains zones of argillaceous sandstone; partly wash covered; weathers gray-white and light gray mottled pink and yellow; sandstone layers commonly ferruginous and weather brick red	7
4. Sandstone, fine-grained, massive, lenticular, cross-laminated; weathers light gray and yellow; contains local thin lenses of variegated silty claystone	26

	Thickness (feet)
Morrison(?) formation:	
3. Obscured by slope wash; exposed patches show variegated, claystone and argillaceous sandy zones; red color dominant	40
2. Sandstone, weathers gray-white, fine-grained, massive	5
Morrison formation (undoubted):	
1. Claystone, maroon and reddish purple in uppermost 1.5 ft, grading to gray-green downward, finely silty.	

SECTION 2—*Bellvue*

[Dakota group, measured from exposures in the walls of the Poudre Valley and Reservoir Co. ditch on hillside to northeast above the Cache La Poudre River along combined highway U.S. Route 287 and Colorado State Route 14 in the W½SE¼ sec. 13, T. 8 N., R. 70 W., approximately 2 miles north of the town of Bellvue, Larimer County. This exposure was chosen by Lee (1923) as the type section for his Dakota group in northeastern Colorado.]

	Thickness (feet)
Contact with Benton obscured.	
South Platte formation:	
40. Sandstone, brown-weathering, fine-grained, massive to ledgy, cross-laminated; top and base obscured	35±
39. Interval obscured by slope wash; some float of sandy, calcareous siltstone with shell fragments	35–40
38. Siltstone and fine-grained sandstone, calcareous, platy; interbedded with thin beds of sandy limestone and gray calcareous silty shale; fossiliferous, containing *Inoceramus comancheanus* Cragin *Ostrea* sp.	30
37. Shale, dark-gray, silty, calcareous; contains silt laminae	2.5
36. Clay; like bentonite	.4–1
35. Shale, similar to unit 37	2.6
34. Clay; like bentonite (second key marker)	1.1
33. Shale, gray, silty, calcareous; interbedded with platy calcareous siltstone	3.7
32. Shale, gray, finely silty, calcareous; contains some silt laminae	4.7
31. Clay; like bentonite	.1
30. Shale, gray, finely silty	4
29. Interbedded platy calcareous siltstone and fine-grained sandstone; gray, calcareous, gysiferous shale; and thin beds of gray, sandy, petroliferous crystalline limestone. Limestone and siltstone beds fossiliferous containing *Inoceramus comancheanus* Cragin, *I. bellvuensis* Reeside, *Ostrea noctuensis* Reeside, *Pteria salinensis* White fish scales and bones	8.3
28. Shale, dark-gray, silty, gypsiferous	7.4
27. Shale, gray, silty; interbedded with thin beds of siltstone and fine-grained sandstone that weather olive-brown	2.2
26. Shale, silty; weathers olive-brown; grades downward into dark-gray shale	2.5
25. Clay; like bentonite	.3
24. Shale, dark-gray, with scattered thin siltstone beds	4.5
23. Shale, mottled dark- and light-gray, silty; blocky fracture; gypsum in cross fractures	13.5
22. Shale, very silty, and argillaceous shaly siltstone; contains beds and laminae of siltstone	10.7

	Thickness (feet)
South Platte formation—Continued	
21. Shale, dark-gray to black	3.2
20. Shale, dark-gray; silty in lower foot; bed of white-weathering argillaceous siltstone, 0.1–0.3 ft thick at top	6.8
19. Clay; like bentonite	.1
18. Shale, dark-gray, silty; contains laminae and thin beds of siltstone in lower 11.6 ft	14.2
17. Obscured, chiefly dark-gray shale	12.5
16. Sandstone, platy to shaly, fine-grained; weathers with greenish cast	1.5
15. Shale, gray, silty; contains greenish cast, weathers red	1.2
Plainview sandstone member:	
14. Sandstone, brown-weathering, fine-grained, even-bedded, finely laminated; upper 4 or 5 in. shaly sandstone; forms hogback	14.2
13. Sandstone, fine-grained, platy; in beds 0.2–4 ft thick; interbedded with dark-gray shale containing thin beds and laminae of siltstone; trails and worm castings on bedding surfaces; some vertical borings	5.9
12. Shale, dark-gray to black; mottled yellow with iron stain on weathered surfaces, silty; upper foot is argillaceous siltstone	3.1
11. Sandstone, brown-weathering, massive, fine-grained, dense; locally quartzitic where pierced by fine tubular cavities that cut bed at all angles	5.4
10. Shale, dark-gray; contains fine-grained, brown-weathering, sandstone in middle part; latter locally thickens to as much as 2 ft; shales above and below thin to mere partings	1.2
9. Sandstone, massive, fine-grained, dense; weathers brown to reddish brown, grades to shale locally	3.7
8. Shale and claystone, black, silty, carbonaceous; contains beds gray and dark-gray argillaceous siltstone	3.6
7. Sandstone, varies from 4-ft bed dense, fine-grained, similar to unit 9, to 0.3 ft of soft carbonaceous sandstone; locally absent and unit 8 rests directly on disconformity	.3–4
Disconformity.	
Lytle formation:	
6. Clay, claystone, and argillaceous siltstone, variegated; upper third gray-white to yellow gray with orange-brown stain; middle third chiefly light-red-purple claystone with lens green siltstone; lower third light greenish gray to gray white; colors vary laterally; light-gray, chert concretions, as much as 1 ft in diameter in upper gray-white zone; some scattered pyrite concretions; Gypsum in fractures throughout	16
5. Siltstone, argillaceous, and fine-grained sandstone; ledgy, contains beds of silty claystone; variegated, light gray-green, pink, and yellow-gray colors predominate	8
4. Sandstone, fine- to coarse-grained and conglomeratic, massive; weathers yellow-brown with pink cast, made up of intersecting lenses, obscurely cross laminated; contains chert and quartzite pebble conglomerate mostly in lower 15 ft; pebbles at base average 0.5 in. in diameter; contains rare, thin lenses variegated sandy claystone, and fossil stems and logs locally	56

	Thickness (feet)
Lytle formation—Continued	
Unconformity.	
3. Sandstone, fine- to coarse-grained; irregularly interbedded with conglomerate composed of claystone fragments and scattered chert and quartzite pebbles; basal 2 ft is friable sandstone and chert pebble conglomerate with claystone matrix	7
Unconformity.	
Morrison formation:	
2. Claystone, stained pink and orange-brown, silty	4
1. Claystone, gray to green-gray, grading downward to calcareous claystone and marl.	

SECTION 3—*Spring Creek Canyon*

[Dakota group exposed in road cut along Colorado State Route 186 on the south side of the dam across Spring Creek Canyon, Horsetooth Reservoir, in the SE¼ sec. 32, T. 7 N., R. 69 W., Larimer County. About 5.5 miles, airline, southwest of Fort Collins.]

	Thickness (feet)
Benton shale: obscured.	
South Platte formation:	
29. Sandstone, fine- to medium-grained, locally quartzitic; massive; cross laminated with some lenses thinly cross-bedded; weathers buff and brown	15
28. Shale, dark-gray, plastic	.2
27. Sandstone, brown-weathering, fine-grained, crossbedded to massive, cross-laminated; becomes silty and friable downward	13.2
26. Sandstone, gray, fine-grained, silty; locally carbonaceous and pyritic; grades downward into argillaceous gray siltstone and, laterally, sandy shale	25.7
25. Shale, sandy, and thin-bedded argillaceous siltstone and fine-grained sandstone, weathers buff to tan; becomes progressively more shaly downward; laminae and thin layers of gypsum in lower part; contains *Inoceramus comancheanus* Cragin *I. bellvuensis*? Reeside *Ostrea* sp., and fish remains	22
24. Clay, like bentonite	.1
23. Siltstone, argillaceous, and fine-grained sandstone; weathers buff to tan; contains thin cross-laminated lenses and hard beds with few thin beds of sandy shale and partings of gypsum; bentonitelike clay 0.1 ft thick 3.4 ft from top of bed	8
22. Clay, like bentonite (first key marker?)	.3
21. Siltstone, similar to unit 23, becoming more shaly downward; contains *Inoceramus* sp.	18.3
20. Shale, dark-gray to black; contains thin, hard, beds of calcareous, laminated siltstone and fine-grained sandstone, and silt laminae; abundant fossils in lower beds, include *Inoceramus comancheanus* Cragin *Ostrea larimerensis* Reeside *O. noctuensis* Reeside and fish remains	12.2
19. Shale, black, with scattered silt laminae	3.7
18. Bentonite	.5
17. Shale, similar to unit 19, with 0.1 ft of bentonite 0.2 ft from base	2.2
16. Bentonite (second key marker)	.6
15. Shale, similar to unit 19	4.6

	Thickness (feet)
South Platte formation—Continued	
14. Limestone, gray, silty to sandy, petroliferous, crystalline; weathers tan; calcareous siltstone and fine-grained sandstone in hard beds as much as 0.3 ft thick interbedded with dark-gray to black shale; fossils, as in unit 20 abundant in limestone; unit capped by thin fish-bone conglomerate in sandy limestone matrix; lower 3 ft more shaly, grading to dark-gray shale below	6.7
13. Obscured by slope wash in swale between hogbacks; partial exposures show dark-gray to black shale; measurement approximate	70
Plainview sandstone member:	
12. Sandstone, brown-weathering, fine-grained, hard; in massive, cross-laminated beds averaging about 0.8 ft thick, locally thinly crossbedded; platy zone with intercalated shaly siltstone in middle part; forms second Dakota hogback	15.3
11. Sandstone, fine-grained, silty, irregularly bedded, weathers buff and brown, contains partings of argillaceous sandstone	6.4
10. Siltstone and fine-grained sandstone, argillaceous, buff- to brown-weathering; platy to shaly with 1.6-ft bed of fine- to medium-grained, irregularly bedded sandstone 0.6 ft from top	4
9. Sandstone, buff- to brown-weathering, fine-grained, thin-bedded, with irregular beds of argillaceous siltstone common in upper 2 ft	6.5
Disconformity.	
Lytle formation:	
8. Claystone, light-gray, sandy; with pink and yellow stain; grades imperceptibly into unit below	1–3.7
7. Sandstone, fine-grained, massive, cross-laminated; weathers yellowish-gray to buff with pink and light-purple staining locally	23.6
6. Claystone, gray-green, silty; red and yellow stain in upper foot	2.4
5. Sandstone, argillaceous, and sandy claystone; weathers with red, pink and yellow stain	1.4
4. Sandstone, light-gray, fine-grained, cross-laminated; pink to yellow cast, contains thin irregular beds and lenses of green-gray silty claystone; clay-pellet conglomeratic layers throughout, thickest at base	21.8
3. Sandstone; similar to unit 4 but fine- to coarse-grained with a few thin lenses of small chert and quartzite pebbles; few lenses of claystone and a 2.2-ft bed of clay-pellet conglomerate 8 ft from top	13.8
2. Sandstone and conglomerate; upper 3–4 ft are chert and quartzite pebble conglomerate; remainder partially obscured by wash, appears to be lenses massive, cross-laminated, friable sandstone and conglomeratic sandstone	12.9
Unconformity.	
Morrison formation:	
1. Clay and claystone, variegated, silty; upper 2 ft colored yellow, underlain by 4 ft purple-red claystone that grades downward through about 3 ft maroon, and bluish purple to typical green claystones of Morrison	12±

SECTION 4.—*Handy Ditch*

[Dakota group exposed in walls of Handy Ditch where it is cut through the Dakota hogback on the south side of Dry Creek Gap in the center of the S½ sec. 24, T. 5 N., R. 70 W., Larimer County.]

	Thickness (feet)
Benton shale.	
South Platte formation:	
35. Sandstone, brown-weathering, fine-grained, thin-bedded, cross-bedded	13
34. Siltstone, argillaceous, sandy; silty shale in basal foot	3
33. Sandstone, brown- to gray-weathering, fine-grained; upper part hard, massive becoming argillaceous, irregularly bedded downward; lower 4 ft gray, argillaceous, containing plant remains	12.2
32. Siltstone and fine-grained sandstone, gray, argillaceous, soft, irregularly thin-bedded; few hard thin sandstone layers in upper 4 ft; ironstone concretion zone 3 to 4 ft above base	20
31. Obscured; wash shows silty shale and argillaceous sandstone	5.4
30. Shale, gray, silty; contains beds of hard, platy, siltstone in upper part and silt laminae throughout	8.6
29. Siltstone, tan-weathering, argillaceous, hard, platy; contains beds of silty gray shale, fragments of marine fossils	5.8
28. Shale, gray, silty; scattered thin, hard beds of tan siltstone	9.1
27. Siltstone, tan-weathering, argillaceous, platy to shaly; contains beds of black shale and few thin beds hard fine-grained sandstone	11
26. Sandstone, fine-grained, platy; locally silty with shale partings	2
25. Siltstone, tan; thin beds and laminae, interbedded with silty, dark gray to black shale; some thin beds fine-grained sandstone in upper 4 or 5 ft; calcareous concretions in zone 9.8 ft from top and scattered throughout lower 12 ft; fragments of marine fossils	21.9
24. Shale, black	4.1
23. Clay; like bentonite; locally contains calcareous concretions (second key marker)	.4
22. Siltstone, tan, calcareous; in thin beds and laminae interbedded with dark gray shale; worm(?) trails and castings on siltstone bedding surfaces	10.2
21. Limestone, gray; sandy, crystalline, petroliferous; weathers tan; tan, calcareous siltstone in thin beds with partings and beds of black shale; contains *Inoceramus comancheanus* Cragin, *Ostrea* sp., and fish bones and scales	4.8
20. Siltstone, tan; thin beds and laminae, interbedded with dark gray shale; siltstone dominant in upper half, shale in lower half; contains *Inoceramus comancheanus* Cragin	11
19. Shale, dark-gray to black; few beds of siltstone; becoming more silty in lower 4 ft	6.1
18. Shale, dark-gray, silty with ledge of concretionary siltstone 2 ft from top; becomes less silty in lower 6 ft	12.7
17. Clay, like bentonite	.1
16. Shale, dark-gray to black	10.6
15. Shale, silty, dark-gray; contains 1-ft bed of argillaceous siltstone at top	3.3
14. Shale, black, becoming silty in lower 4 feet. Few scattered thin beds of brown-weathering silt	19

	Thickness (feet)
South Platte formation—Continued	
13. Siltstone, gray, argillaceous, interbedded with dark gray to black silty shale. Siltstone predominates in upper 6 feet	10.6
Plainview standstone member:	
12. Siltstone, tan-weathering, platy; with beds of fine-grained sandstone	1.6
11. Sandstone, brown-weathering, fine-grained, laminated and cross-laminated; in beds as much as 1.5 ft thick; shaly partings	4
10. Sandstone, brown-weathering, fine-grained, laminated and cross-laminated; interbedded with argillaceous sandstone and dark-gray shale	5.7
9. Sandstone; similar to unit 11	4.2
8. Sandstone interbedded with shale; similar to unit 10	4.3
7. Sandstone, similar to unit 11, with thin beds of shaly sandstone and siltstone	4.7
6. Shale, dark gray to black, sandy; irregularly interbedded with thin beds of argillaceous sandstone; basal 0.6 ft black sandy shale	3.2
Disconformity.	
Lytle formation:	
5. Claystone, green, sandy; local 1-ft lens light-gray fine-grained, argillaceous sandstone 0.8 ft from top	3.8
4. Sandstone, fine-grained, massive, cross-laminated; weathers buff to brown	25
3. Partly obscured; slope on red and greenish-gray claystone and silty claystone	25
2. Sandstone, light gray, fine-grained to conglomeratic, massive, lenticular; broken by lenses of sandy red, light-gray, and green claystone; sandstone includes lenses chert and quartzite pebble conglomerate; basal 2.8 ft chiefly green-gray claystone	10.8
Morrison formation:	
1. Claystone, purple and red; sandy with lenses fine-grained, argillaceous, purplish red, sandstone in upper 4 ft; grades downward into dark greenish-gray sandy claystone with scattered irregular layers of fine sandstone.	

SECTION 5.—*Little Thompson River*

[Dakota group, composite section. Units 10 to 41 measured on shale slope of west-facing scarp on prominence just south of Little Thompson River in the SW¼NW¼ sec. 2, T. 3 N., R. 70 W., Boulder County. Can be reached by Bureau of Reclamation access road to irrigation tunnel through Rabbit Mountain. Units 1 to 8 measured in cut at east entrance of Bureau of Reclamation tunnel through Rabbit Mountain, west across tributary valley to Little Thompson River from exposure of units 10 to 41. Unit 9 measured in gulch east of tunnel.]

	Thickness (feet)
Benton shale.	
South Platte formation:	
41. Sandstone, brown-weathering, fine- to medium-grained, tabular cross-laminated to cross-bedded, quartzitic; caps prominence above tributary to Little Thompson River; contains fish remains and *Halymenites* sp.	17
40. Sandstone, brown-weathering, platy, irregularly bedded, and gray silty sandstone with beds of shaly siltstone and argillaceous sandstone	6–10

	Thickness (feet)
South Platte formation—Continued	
39. Siltstone, gray, argillaceous, irregularly bedded; local carbonaceous and shaly partings, upper foot fine-grained sandstone	7
38. Siltstone, argillaceous, and dark-gray silty claystone; 0.1 ft of mixed light-brown silt and bentonitelike clay at base	1
37. Sandstone, fine-grained, and argillaceous siltstone; massive to irregularly bedded with shaly carbonaceous partings; weathers to a brownish-gray crumbly, blocky ledge	19
36. Siltstone, gray, argillaceous; becomes sandy in upper 8 ft and grades into unit 37; lower 15 ft contains interbedded shaly siltstone	23
35. Siltstone, argillaceous, and fine-grained sandstone; weathers orange-brown, thin-bedded, locally calcareous; forms ledge	2.4
34. Siltstone, argillaceous, hard, with blocky fracture	2
33. Clay, gray, waxy; like bentonite with 0.1 ft of dark-gray shale at top (first key marker?)	.3
32. Siltstone, similar to unit 34; upper 0.6 ft forms local ledge	5.3
31. Clay, gray, waxy; like bentonite with 0.1 ft of dark-gray shale at top	.2
30. Siltstone, gray, argillaceous, thin-bedded	9.6
29. Sandstone, gray to brownish-gray, fine-grained, thin-bedded, laminated to cross-laminated; interbedded with shaly siltstone and some silty shale; locally calcareous; fossils rare	14.5
28. Shale, dark gray to black; becomes silty in upper part; scattered thin beds siltstone and fine-grained sandstone	9
27. Siltstone and fine-grained sandstone, argillaceous; upper 2 ft ledge-forming	8
26. Sandstone, brownish-gray, silty, irregularly thin-bedded; argillaceous partings contorted as if disturbed when soft; forms crumbly ledge	10
25. Siltstone, gray, argillaceous, soft, massive becoming harder and sandier in upper 10 ft; irregularly bedded, with irregular argillaceous partings in upper part	30
24. Siltstone, gray to brown-weathering, argillaceous; with ledges, hard, thin-bedded, calcareous siltstone in lower 1.9 ft; calcareous concretions weathering orange-brown in zones at top and base of unit	9.5
23. Siltstone, gray, argillaceous, and silty, gray shale	2
22. Clay, greenish-gray (second key marker) like bentonite	.2
21. Siltstone, brown-weathering, in thin, hard beds, slightly calcareous, locally argillaceous	3.5
20. Siltstone, gray, argillaceous, soft, irregularly bedded with thin beds of dark-gray silty shale in upper part	8
19. Sandstone, fine-grained, and siltstone, brown-weathering, even-bedded, laminated to cross-laminated; forms blocky ledges broken by softer intercalated argillaceous siltstone and silty shale; calcareous throughout	16.5
18. Shale, gray, silty, with beds, hard, platy, laminated to cross-laminated, tan-weathering, locally calcareous, siltstone increasing in number upward. Some calcareous concretions in upper part; contains fossils *Inoceramus comancheanus* Cragin, *Ostrea noctuensis* Reeside, *Pteria salinensis* White ammonite fragment	25

	Thickness (feet)
South Platte formation—Continued	
17. Shale, gray, silty; contains thin beds and laminae of argillaceous siltstone; fossils rare	19
16. Siltstone, gray, shaly and thin beds laminated, silty, fine-grained sandstone; contains *Inoceramus* fragments	2.6
15. Shale, dark-gray to black, finely silty; with laminae and thin beds of shaly siltstone in lower half	14
14. Shale, black, hard, fissile, with 0.4 ft bed hard, orange-brown-stained siltstone bed at top	4
13. Siltstone, orange-brown weathering, hard, ferruginous, irregularly thin-bedded, forms ledge	1.6
12. Shale, dark-gray to black, finely silty to very silty; some beds shaly siltstone; upper 3 ft irregularly interbedded carbonaceous shale and siltstone	15.6
11. Obscured by wash, chiefly shale with thin hard beds siltstone	7.1
10. Partially obscured, irregularly bedded gray, argillaceous siltstone and sandstone interbedded with platy, gray, fine-grained sandstone and gray silty shale	11.2
Plainview sandstone member:	
9. Sandstone, brown-weathering, fine-grained, even-bedded, laminated to cross-laminated; in beds rarely more than 1.5 ft thick; vertical borings and worm(?) trails on bedding planes; some shaly partings and thin beds; forms east slope of Rabbit Mountain in vicinity	25±
Disconformity.	
Lytle formation:	
8. Siltstone, yellow-weathering, argillaceous; grades into unit below	2–3
7. Claystone, silty, and light-gray to greenish-gray, argillaceous siltstone; weathers mottled yellow-gray	17
6. Sandstone, light-gray, fine- to medium-grained massive, cross-bedded; brown stain on joint planes; thickens laterally at expense of overlying unit	8
5. Sandstone, gray, fine-grained, interbedded with silty, greenish-gray clay; relative content of sandstone and clay varies laterally	7
4. Sandstone, similar to unit 6 above; locally lenses out into red and green clay and argillaceous siltstone	7
3. Clay, variegated, chiefly red, silty, and argillaceous siltstone	14
2. Clay, purple-red, silty, and siltstone; variegated, with a few thin lenses fine-grained sandstone; abruptly replaced laterally at mouth of tunnel by channel fill of sugary, fine- to coarse-grained, conglomeratic sandstone with chert and quartzite pebbles that may be local abrupt thickening of unit 4 or latter may thicken and coalesce with this unit at tunnel mouth; relationships of sandstone lenses obscure	15–20
Unconformity.	
Morrison(?) formation:	
1. Claystone, purple-gray to greenish-gray, silty.	

SECTION 6.—*Eldorado Springs*

[Dakota group measured from exposures on the north end of the hogback south of Eldorado Springs in W½SW¼ sec. 30, T. 1 S., R. 70 W., Boulder County. Units 1 to 19 exposed continuously along access road to the South Boulder Diversion Canal where it is cut through, and along, the west side of the hogback. Units 20 to 53 were measured along the wall of an abandoned irrigation ditch at the end of the hogback on the slope above Community Ditch.]

	Thickness (feet)
Benton shale (basal part):	
53. Shale, dark-gray, silty, interbedded with thin hard beds of platy to shaly, dark-gray argillaceous siltstone that weathers light bluish gray; contains thin beds of bentonitelike clay; transition zone to South Platte formation	20
Disconformity.	
South Platte formation:	
52. Sandstone, brown-weathering, fine-grained, quartzitic; locally forms thin ledge with conspicuous structure of borings filled with laminae concave upward	1.5±
51. Siltstone, gray, argillaceous; shaly in lower part with carbonaceous fragments on bedding planes	2.1
50. Shale, dark-gray, finely silty	2.7
49. Sandstone, fine-grained; weathers brown to orange-brown; in beds 0.2 to 0.8 ft thick with beds and partings of siltstone	4.7
48. Shale, dark-gray, silty; thin zones of gray, very silty shale	4
47. Sandstone, brown-weathering, fine-grained, hard, dense; contains few silty partings in upper 2 ft	6
(Beds equivalent to Van Bibber shale member):	
46. Shale, dark-gray to black; lower 2 ft plastic, slightly silty; remainder silty, locally carbonaceous with thin beds of siltstone	5.6
45. Siltstone; gray with brown stain, argillaceous	.9
44. Sandstone, brown-weathering, fine-grained, hard; in slabby beds with shaly partings	2
43. Shale, dark-gray, silty	3
42. Sandstone, brown-weathering, fine-grained	1
41. Shale, dark-gray, silty with 0.3 ft of argillaceous siltstone at base	1.2
40. Clayrock, yellowish gray; kaolinitic	0.2
39. Shale, similar to unit 41; 0.2 ft siltstone at top	.8
38. Siltstone; weathers light gray to rusty-brown, platy, in beds as much as 0.6 ft thick, interbedded with dark-gray silty shale; 0.8 ft of fine-grained, laminated sandstone 2 ft from base; thin zone ferruginous concretions 6 ft from top	8.8
37. Sandstone, brown-weathering, fine-grained, massive, dense	2.8
36. Siltstone, gray, argillaceous, soft, and gray silty shale; few irregular, thin beds resistant siltstone 3–4.5 ft from top	10
35. Shale, gray to dark-gray, silty; zones of argillaceous siltstone and 0.2 ft bed argillaceous siltstone at base	5.7
34. Clayrock, yellowish gray, kaolinitic (first key marker)	.2
33. Sandstone, brown-weathering, fine-grained, massive; ripple-marked upper surface	7.6
(Presumed base of beds equivalent to Van Bibber shale member.)	
32. Siltstone, gray, argillaceous and fine-grained, argillaceous sandstone	2

	Thickness (feet)
South Platte formation—Continued	
31. Siltstone, gray to rusty-brown, argillaceous to ferruginous; in thin beds, interbedded with dark-gray silty shale; upper foot chiefly silty shale	12.8
30. Shale, dark-gray, silty; some silt laminae	3.8
29. Shale, dark-gray, silty; thinly interbedded with siltstone	3
28. Clayrock, yellow gray, kaolinitic (second key marker)	.4
27. Shale, similar to unit 29	4.6
26. Shale, dark-gray, finely silty; few thin beds and laminae of silt	4.3
25. Siltstone, gray to brownish-gray; partings and thin beds of dark gray argillaceous siltstone and silty shale; fossiliferous, contains *Pteria* sp. and *Inoceramus comancheanus*	3.7
24. Shale, similar to unit 26	3.6
23. Sandstone, rusty-brown, fine-grained, ferruginous; shaly partings	1.6
22. Shale, similar to unit 26	1.3
21. Clayrock, yellowish gray, kaolinitic	.1
20. Shale, gray to dark-gray, silty; contains beds of argillaceous siltstone increasing in number downward	3.3
19. Sandstone, brown-weathering, fine-grained; in massive beds 0.4–6 ft thick, cross-laminated, locally crossbedded	59
18. Sandstone, as above, in thin beds with partings of shale	2.7
17. Shale, gray, silty to sandy; irregular beds of argillaceous siltstone	1.5
Plainview sandstone member:	
16. Sandstone, brown- to gray-weathering, fine-grained, locally silty and argillaceous with shaly partings	11
15. Sandstone, similar to unit 19	36.8
14. Siltstone, gray to dark-gray, argillaceous, and sandy siltstone, irregularly interbedded	5.5
13. Shale, dark-gray, silty; thin beds of siltstone in upper foot	2
12. Siltstone, gray; locally rusty-brown and sandy; in thin layers interbedded with dark-gray silty shale; chiefly silty shale in lower 3.7 ft	8.7
11. Sandstone, gray with local rusty stain, fine- to coarse-grained, locally conglomeratic with chert and quartzite pebbles; few shale partings	.7–1
Disconformity.	
Lytle formation:	
10. Sandstone, gray-white, fine- to medium-grained, argillaceous, friable; light yellow and pink stain; few thin lenses light-greenish-gray silty claystone	9
9. Claystone, variegated, chiefly light greenish-gray, pink, and yellow-gray, silty to sandy; 0.6 ft lens sandstone (similar to unit 10) 1.3 ft from top	6.9
8. Sandstone, fine-grained, hard, ledge-forming; rusty-brown stain	1.7
7. Claystone, partly obscured, light-red and green mottling, silty	10
6. Sandstone, light-gray, fine- to coarse-grained; weathers buff and brown, locally quartzitic; conglomeratic in lower 25 ft; some thin lenses silty greenish claystone 17–20 ft from top; basal 6 ft locally chert and quartzite pebble conglomerate	65

	Thickness (feet)
Unconformity.	
Morrison (?) formation:	
5. Claystone; chiefly light green, yellow green, and buff; 6-ft maroon zone 6 ft from top, silty	24
4. Siltstone, purple-red, argillaceous; grades laterally into rusty-yellow fine- to coarse-grained sandstone with scattered chert and quartzite granules; locally lenses out	2.6
3. Clay, silty; with beds of light-green, yellow-green, and deep-red silty claystone; basal 16 ft chiefly light green	29.2
2. Siltstone, calcareous, platy, laminated and crosslaminated; weathers orange-brown	5
1. Clay and claystone, green and greenish gray.	

SECTION 7.—*Plainview*

[Lower part of the South Platte formation, the Lytle formation, and top of the Morrison formation, exposed in the railroad cut of the Denver and Salt Lake Railroad (Moffat Tunnel Route) through the Dakota hogback at Plainview in the northeast corner of NE¼ sec. 12, T. 2 S., R. 71 W., Jefferson County.]

	Thickness (feet)
South Platte formation (in part):	
24. Siltstone and fine-grained sandstone; thin beds interbedded with gray silty shale	17
23. Sandstone, fine- to medium-grained; weathers buff and orange-brown, tabular, cross-laminated beds 0.2–4 ft thick, becomes progressively more thin-bedded downward and contains silty shale partings in lower part; bedding surface commonly ripple-marked; grades imperceptibly into unit below	11
22. Sandstone, fine-grained; weathers light gray; and thin-bedded, sandy siltstone, with beds of gray, plastic, silty shale 0.1–0.6 ft thick; bedding surfaces have ripple marks and "worm" castings	5
Plainview sandstone member:	
21. Sandstone, fine to medium-grained; weathers red-brown; tabular cross-laminated to crossbedded; some bedding surfaces ripple-marked; forms ridge	24
20. Sandstone, fine-grained; ferruginous layers weather rusty-brown, argillaceous layers light gray; irregularly thin-bedded, locally crossbedded, in layers as much as 0.3 ft thick; lower 2.2 ft has beds of fissile gray clay shale; worm(?) castings on bedding surfaces	3.2
19. Sandstone, fine- to medium-grained; weathers buff with reddish stain; tabular cross-laminated to crossbedded in upper 2 ft, remainder massive, cross laminated	5.8
18. Siltstone, gray, argillaceous, thin-bedded; contains beds shaly siltstone and one of dark-gray shale, 1.5–2.1 ft from top	3
17. Shale, dark-gray to black, silty; thin beds and laminae of light-gray argillaceous siltstone; local concretionary thin lenses of pyritic silt; basal 0.8 ft ferruginous sandy siltstone; "worm" trails and castings on bedding planes	6.2
16. Sandstone, light-gray, medium- to coarse-grained and conglomeratic; scattered chert and quartzite pebbles as much as 0.4 ft in long diameter	1–4

Disconformity.

Lytle formation: *Thickness (feet)*

15. Siltstone and silty claystone, greenish-gray to gray-white, soft; local reddish stain; contains irregular, thin lenses of red-weathering, ferruginous, fine-grained sandstone ____ 4
14. Sandstone, rusty-brown, fine-grained; irregular lens; pinches out locally ____ 3
13. Siltstone, similar to unit 15 ____ 4
12. Sandstone, gray-white, fine- to medium-grained; buff-weathering with local pinkish cast; few thin coarse-grained massive cross-laminated zones; upper 0.6–1 ft is red-brown iron-impregnated cap; variable in thickness ____ 22±

Unconformity?

11. Clay, silty, and argillaceous siltstone; upper 4 ft greenish and gray with some red mottling; remainder red with some green mottling; few thin lenses of brownish-red fine-grained hard sandstone and one 2.5 ft bed in basal 5 ft ____ 19
10. Sandstone, medium-grained, massive, weathers rusty-brown with local red stain from clay above; contains coarse-grained to conglomeratic zones with chert and quartzite pebbles in lower 8 ft ____ 19.6

Unconformity?

Morrison (?) formation:

9. Silty claystone and lenticular argillaceous siltstone beds; variable interval, upper foot green, remainder chiefly red with green and, locally, yellow mottling; dense, argillaceous siltstone in beds about 1 ft thick; weathers buff to orange-brown ____ 9.5
8. Claystone, red, silty ____ 9
7. Sandstone, siltstone, and silty claystone, irregularly interbedded; fine-grained sandstone, weathers buff to rusty-brown; contains local medium-grained lenses and basal chert pebble conglomerate where unit 6 thins; greenish argillaceous siltstone and silty claystone chiefly in upper 2 ft ____ 8.2

Unconformity?

6. Claystone, silty, argillaceous siltstone, and fine-grained, argillaceous sandstone in lower part; variable zone chiefly gray and greenish gray with coarser beds red and yellow ____ 4.5–10
5. Sandstone, buff with ferruginous specks, fine-, medium-, and coarse-grained, massive, friable ____ 7

Unconformity?

4. Claystone; mottled red and green in upper 11 ft, remainder greenish-gray; silty, contains 1 ft concretionary silty zone that weathers rusty-brown at base mottled zone ____ 18
3. Sandstone, fine-grained, argillaceous, weathers brown with pink cast; locally silty; grades into unit below ____ 6
2. Conglomerate and conglomeratic sandstone, chert and quartzite pebbles, and some claystone fragments; matrix of white quartz grains and siliceous(?) claystone, peppered with small red-stained pits that give pink cast to unit on weathered surface ____ 12

Unconformity?

1. Clay and claystone, green, locally silty; only top exposed.

SECTION 8.—*Ralston Reservoir*

[Dakota group exposed along abandoned road and in gullies on the north bank of Ralston Reservoir in the center of the S½NW¼ sec. 5, T. 3 S., R. 70 W., Jefferson County. Units 21 to 63 measured along or just above road, units 1 to 20 measured in gullies down west-facing scarp of hogback just north of road.]

	Thickness (feet)
Benton shale.	
63. Siltstone, light-gray, platy; interbedded with dark-gray shale.	
South Platte formation:	
62. Sandstone, buff to light-gray, fine-grained; silty shale partings near top and base	10.5
61. Sandstone, buff-weathering, fine- to medium-grained, tabular, cross-laminated; thin-bedded in upper 4.6 ft; contains some intraformational conglomerate of silty white claystone and plant fragments in upper part; ripple marks on bedding surfaces	17.6
60. Shale, gray to black, locally carbonaceous; two thin light-gray kaolinitic clayrock beds 2 ft from top and 0.2 ft above base	2.6
59. Sandstone, light-gray, fine-grained, locally argillaceous, thin-bedded; some shaly partings	3.6
58. Shale, gray, sandy	0.4–1
57. Sandstone, light-gray, fine-grained; contains dark-gray silty laminae	3.6
56. Shale, gray, silty, and argillaceous siltstone grading downward into platy siltstone	3.4
55. Sandstone, similar to unit 57	2.6
54. Shale, dark-gray to black, silty; contains laminae and thin beds of siltstone	1.7
53. Sandstone, light-gray, fine-grained, massive, dense	6.5
Van Bibber shale member:	
52. Shale, hard, silty; weathers light blue gray	1
51. Siltstone, dark-gray to black, argillaceous, locally shaly; weathers dark gray with greenish cast	2.4
50. Clayrock, light-gray, kaolinitic	.2
49. Siltstone, similar to unit 51; interbedded with fine-grained sandstone	5
48. Shale, dark-gray to black, fissile	1.9
47. Siltstone and fine-grained sandstone, argillaceous; shaly parting in middle part	2.2
46. Shale, gray, silty, hard; subconchoidal fracture; peppered with white specks; has rusty stain locally	1.6
45. Siltstone, argillaceous, and fine-grained sandstone, gray and light-gray, irregularly interbedded; contains thin beds shale chiefly in upper 1.5 ft	5.2
44. Shale, light-gray, silty, blocky, and argillaceous siltstone	1.6
43. Shale, dark-gray, silty; contains laminae and thin beds of silt	1.8
42. Sandstone, rusty-brown, ferruginous; ironstone concretions	.6–1
41. Shale, dark-gray to black, blocky, refractory; locally finely silty; locally has laminae of fine white specks of unidentified iron mineral	11.7
40. Siltstone, light-gray, platy, argillaceous, and silty shale	.2
39. Clayrock, yellowish gray, kaolinitic; (first key marker)	.3
38. Siltstone, light-gray to buff, platy; upper surface ripple-marked; grades into unit below	1.5

	Thickness (feet)
South Platte formation—Continued	
37. Sandstone, light-gray to buff, fine-grained, massive; thin beds of dark-gray argillaceous siltstone in lower 2 ft	4.4
36. Shale, dark-gray to black, silty, carbonaceous; interbedded with argillaceous siltstone; fine-grained, silty, argillaceous sandstone 2.7–3.5 ft from top	7
Kassler sandstone member:	
35. Sandstone, light-gray, fine-grained, irregularly thin-bedded, cross-bedded; local orange-brown stain, partings and laminae of gray siltstone; plant fragments throughout	24
(Base of Kassler sandstone member.)	
34. Shale, dark-gray to black, silty	.3
33. Clayrock, gray-white, kaolinitic (second key marker, part?)	.3
32. Shale, similar to unit 34	3
31. Clayrock, gray-white, kaolinitic (second key marker, part)	.4
30. Siltstone, platy; weathers light gray to rusty, interbedded with dark-gray silty shale that predominates in upper 4.3 ft; some friable yellowish sandstone in basal 2 ft	6.7
29. Sandstone, medium-grained; cross-laminated beds 0.6–2 ft thick	4.4
28. Sandstone, fine- to medium-grained, locally silty; irregularly bedded in alternating friable and resistant beds; contains thin layers and laminae of argillaceous siltstone; weathers gray with some rusty stain	15
27. Sandstone; similar to unit 28, becomes more silty downward and contains thin beds of gray silty shale	21.2
26. Sandstone, siltstone and silty shale, gray, interbedded; fine- to medium-grained thin-bedded sandstone predominates in lower 12 ft; thin bedded dark-gray argillaceous siltstone and silty shale predominate in upper 21 ft	33
Plainview sandstone member:	
25. Sandstone, buff-weathering, fine- to medium-grained, friable, thin-bedded to massive	3.6
24. Sandstone, gray, fine- to medium-grained, platy; partings and thin beds of silty shale	14
23. Sandstone, buff-weathering, fine- to medium-grained; shaly in upper 1.6 ft; massive below	3.9
22. Shale, dark-gray, silty	.6
21. Sandstone, gray, fine- to coarse-grained, massive, cross-laminated; contains thin layers of chert and quartzite pebble conglomerate	0.4–6.5
Disconformity.	
Lytle formation:	
20. Claystone, greenish-gray, silty to sandy	1–2
19. Sandstone, buff, fine- to medium-grained, friable; upper 0.5 ft argillaceous with greenish cast	3
18. Obscured by slope wash, partial exposure shows red and green silty clay, red at top	5.5
17. Sandstone, fine- to medium-grained, friable; weathers pinkish brown	3.4
16. Sandstone, ferruginous, locally concretionary, rusty to gray, friable, fine- to medium-grained; interbedded with green sandy claystone	16.5
15. Claystone, red, silty	1

	Thickness (feet)
Lytle formation—Continued	
14. Claystone, green, sandy	2.6
13. Sandstone, similar to unit 17 with ferruginous specks	3
12. Claystone, green to gray, silty	2
11. Sandstone, similar to unit 13; lenses out laterally	3
10. Claystone, similar to unit 12	1
9. Sandstone, similar to unit 13; local hard zones with ferruginous cement	5.5
8. Clay, gray, silty; red in lower part	7.8
7. Sandstone, fine- to medium-grained, massive, pitted; peppered with ferruginous blebs; weathers pinkish brown to gray	3.7
Unconformity?	
Morrison(?) formation:	
6. Clay zone; partly obscured by wash; chiefly gray, silty clay with red in middle part; thin, rusty-weathering concretionary zone 6 ft above base	24.7
5. Sandstone, gray, fine-grained, argillaceous, calcareous; contains ferruginous specks	1.3
4. Obscured, chiefly greenish-gray, silty clay with a few thin lenses of sandstone in lower 5 ft	13.5
3. Sandstone, gray, fine-grained, argillaceous	2.5
2. Sandstone, fine- to medium-grained, massive, laminated to cross-laminated, locally thin-bedded; weathers pinkish brown	5.3
1. Clay, greenish-gray, locally silty, with thin beds of dense gray limestone.	

Section 9.—*Van Bibber Creek*

[Pieced from exposures of the Dakota group on the north side of the gap made by Van Bibber Creek in the SE¼ sec. 8, T. 3 S., R. 70 W., Jefferson County. Units 54 to 58 were measured in an abandoned quarry on the east side of the ridge; units 1 to 53 from outcrops on the west-facing scarp of the ridge.]

	Thickness (feet)
Benton shale (basal part):	
58. Shale, dark-gray, fissile; weathers gray; locally silty, argillaceous, laminated siltstone that weathers light blue gray in layers 0.5–0.8 ft thick at top, 3.2–3.8 ft from top and at base	8
57. Clay; like bentonite	.3
56. Shale, dark-gray; weathers light gray; locally silty with local rusty stain	5.7
55. Sandstone and siltstone interbedded with shale; lower 8 ft thin bedded platy, gray, fine-grained, argillaceous sandstone that weathers light gray to bluish gray; beds as much as 0.5 ft thick with partings of dark-gray silty shale and shaly siltstone; upper 7 ft increasingly shaly with sandstone becoming finely laminated and grading to siltstone; siltstone ledge 0.5 ft thick caps unit	15
54. Obscured by slope wash; float shows platy sandstone and dark shale similar to unit 55 above	6
South Platte formation:	
53. Sandstone, medium-grained, tabular, cross-laminated; weathers buff and brown; beds 0.2–0.6 ft thick with ripple marks on bedding surfaces	8.5

	Thickness (feet)
South Platte formation—Continued	
52. Sandstone, fine- to medium-grained, laminated to cross-laminated; weathers buff and brown; thin beds chiefly 0.1 ft thick, with beds and partings of light-gray argillaceous siltstone and silty shale	11
51. Sandstone, buff-weathering, fine-grained, massive, cross-laminated; thickens locally to 10 ft at expense of enclosing units	3
50. Sandstone, buff- to brown-weathering, fine- to medium-grained; beds as much as 2 ft thick	9
49. Claystone, gray to dark-gray; brownish stain, hard siliceous, basal 0.3 ft fissile, brown shale, plant fragments throughout	1
48. Sandstone; weathers light gray with rusty stain, fine-grained, argillaceous and massive in upper part; sandier and thin-bedded with shaly partings in lower part	7.7
47. Shale, dark-gray, silty	1.3
46. Sandstone, buff- to brown-weathering, fine-grained, tabular; beds 0.5–2 ft thick; dense with prominent vertical jointing; local current ripple marks 0.5 ft between crests on basal surface	5–8
Disconformity.	
Van Bibber shale member:	
45. Shale, dark-gray, silty, hard; weathers light blue gray; beds of fine-grained shaly sandstone and platy siltstone in upper foot	3.6
44. Siltstone and fine-grained sandstone, argillaceous; weather rusty-brown	1.2
43. Shale, dark-gray, hard, silty; weathers light blue gray; locally less silty; semiplastic; contains thin kaolinitic, gray-white, bed in middle part	2.5
42. Sandstone, fine-grained, argillaceous, irregularly bedded; weathers light gray with rusty stain upper half with beds of argillaceous siltstone	2.8
41. Shale, dark-gray, finely silty, hard; weathers light blue gray	1.8
40. Sandstone, buff- to brown-weathering, fine-grained, tabular, cross-laminated; beds 0.4–2 ft thick; bedding surfaces ripple-marked	5.5
39. Shale; similar to unit 41; thin bedded siltstone and fine-grained sandstone in lower part	4
38. Sandstone; similar to unit 40; beds as much as 1 ft thick	2
37. Shale, gray, refractory; subconchoidal fracture; silty in lower part	1
36. Sandstone, rusty-brown, fine-grained, locally ferruginous	.3
35. Shale, gray, semiplastic, refractory; subconchoidal fracture; lower 1.5 ft peppered with minute white to yellowish ferruginous oölites that are locally concentrated in bedding laminae	4
34. Shale, gray, stained red and rusty-brown, contains concentration of ferruginous oölites that form concretionary structures locally	.5–1
33. Shale, semiplastic, refractory; gray with rusty stain; scattered ferruginous oölites, oolitic laminae, and local concretions as much as 3 ft in diameter composed largely of the oölites	3
32. Shale, dark-gray, semiplastic, refractory, with scattered silt laminae	6
31. Shale, dark-gray, silty, with beds of rusty-brown-stained siltstone in lower part	1.5
30. Clay, kaolinitic, yellowish-white, first key marker	.1

South Platte formation—Continued Van Bibber shale member—Continued	*Thickness (feet)*
29. Siltstone and fine-grained sandstone; gray weathers light gray with local brown stain; some interbedded silty claystone, sandstone in upper part, top surface locally ripple marked	2.3
28. Shale, dark-gray, silty; contains beds of hard siltstone	4
27. Siltstone, weathers light gray with rusty stain, irregularly thin-bedded with hard sandy and argillaceous layers; locally resistant	3.5
26. Obscured, probably soft argillaceous siltstone	.5
Kassler sandstone member:	
25. Sandstone, gray- to brown-weathering, fine-grained, locally silty; chiefly irregularly thin-bedded to crossbedded, beds 0.3–0.5 ft thick; locally massive, cross-laminated	22
(Base of Kassler member.)	
Disconformity.	
24. Shale, silty; weathers gray with rusty stain	1.1
23. Clayrock, kaolinitic, white, hard (second key marker, part)	.6
22. Shale, dark-gray to brownish-gray; thin layers and laminae of rusty-stained silt	1.7
21. Clayrock, kaolinitic, white, soft (second key marker, part)	.3
20. Shale, dark-gray, soft, finely silty; interbedded with thin beds of rusty-stained, laminated siltstone	3.3
19. Siltstone and fine-grained sandstone, thin-bedded, platy, weathers rusty brown, thin beds and partings silty shale	3.3
18. Sandstone, brown to orange-brown, fine-grained, hard; forms ledges locally; grades into unit below	6
17. Sandstone, gray-white, chiefly fine-grained, massive, laminated; layers that weather rusty brown; some argillaceous, silty layers and laminae, and thin layers of hard ferruginous sandstone; chiefly nonresistant; underlies steep slope, basal 3–4 ft fairly hard, forms ledge locally	34.8
16. Siltstone, dark-gray, argillaceous; interbedded with silty shale; weathers light blue gray with local rusty stain	13.3
15. Sandstone, rusty-brown, medium-grained; thin layer hard ferruginous sandstone at top	.6
14. Siltstone, light-gray, argillaceous, soft	1
13. Sandstone, fine-grained, friable, thin-bedded; stained rusty-brown; peppered with ferruginous specks	2.5
12. Sandstone, buff- to brown-weathering, fine-grained, platy, irregularly bedded, cross-laminated to crossbedded; beds 0.1 to 1 ft thick, forms ledge locally; ferruginous specks throughout	21
11. Shale, sandy, and interbedded gray- to brown-weathering, fine-grained, thin-bedded sandstone, with ferruginous specks	4.5
10. Sandstone; similar to unit 12, with beds as much as 3 feet thick; local ferruginous concretionary zone, 8–9 ft from top; beds above more resistant than those below but unit as whole is soft; lower 2 ft argillaceous, silty; grades to unit below	12.5
9. Shale, silty, and argillaceous siltstone; weathers gray to light gray; local rusty-brown to red stain	6.5
Plainview sandstone member:	
8. Sandstone, fine-grained, tabular, cross-laminated; weathers buff to brown; beds as much as 2 ft thick	9

	Thickness (feet)
South Platte formation—Continued	
Plainview sandstone member—Continued	
7. Sandstone, fine-grained; weathers buff to brown; massive to irregularly bedded with zones of sandy gray shale 1.5–2.8 ft from top and in lower 2 ft; grades into unit 6	8
6. Shale, gray to dark-gray, sandy, and sandy claystone grading to argillaceous sandstone	3–4
5. Sandstone, fine- to coarse-grained, massive, cross-laminated; weathers light gray; some rusty-stained zones; upper 5 ft chiefly fine-grained, friable; lower 7 ft coarser with two layers of chert and quartzite pebbles about 0.5 ft thick 7 and 2 ft above base	12
Disconformity.	
Lytle formation:	
4. Claystone, greenish-brown and yellow gray; weathers pink; silty with irregular, thin layers siltstone and fine-grained sandstone in lower foot	3–4
3. Sandstone, fine- to medium-grained, massive, cross-laminated to crossbedded, only locally resistant; weathers light gray with some brown stain; lower part contains rusty-colored pits where ferruginous concretions have weathered out	60
Unconformity.	
Morrison (?) formation:	
2. Clay, red and greenish-gray, silty	2.5
1. Siltstone, argillaceous; weathers gray	3
Obscured, slope wash on variegated silty clay.	

Leroy (1946, p. 71–72) published a section of the "Dakota," measured at the Alameda Parkway locality, to which the section below can be related by matching units. Unit 41 of the section below includes in its basal part Leroy's unit 17, and units 8 to 40 below are an elaboration of Leroy's units 30 to 18 showing the subdivisions of the South Platte formation and the stratigraphic position of the kaolinitic marker beds. The disconformity between the South Platte and Lytle formations is obscured by wash in the Alameda road cut but is well exposed a short distance north of the road. Leroy's basal unit 31, which is 12 to 15 feet thick (Leroy's thickness of 51 feet is doubtless a typographical error) in the road cut thins to 1 foot (unit 5 in section below) and is a local lens within the Lytle formation.

As none of the sandstone lenses locally exposed in the Lytle and upper Morrison contain chert pebble conglomerate, the usual basis for picking the Lytle-Morrison contact is lacking. The "slightly conglomeratic" zone mentioned by Leroy in the lower 3 feet of his basal Dakota unit 31, is clay-pellet conglomerate and apparently intraformational. A short distance north of the road cut lenses of chert and quartzite pebble conglomerate appear at a position no lower than unit 7 of Leroy's section of the Morrison formation (1946, p. 61) and no higher than his unit 3. As unit 7 is the coarsest of the lenses in the road cut and locally contains chert granules it may well mark the base of the Lytle.

SECTION 10.—*Alameda Parkway*

[Part of Dakota group measured in and adjacent to the Alameda Parkway, Colorado State Route 74, road cut through the Dakota hogback in S½ sec. 23, and N½ sec. 26, T. 4 S., R. 70 . The section begins just above the base of the first sandstone of the South Platte formation; units 10 to 41 were measured in the road cut, units 1 to 9 several hundred feet north of the road along the west-facing scarp of the hogback.]

	Thickness (feet)
South Platte formation (in part):	
41. Sandstone, fine- to medium-grained, massive, cross-laminated; weathers buff to orange-brown; coarse to conglomeratic in lower foot; conglomeratic zone has small chert and quartzite pebbles and clay pellets; thickness varies	35±
Disconformity. Channelled surface.	
Van Bibber shale member:	
40. Shale, gray, silty; beds of siltstone in lower part	1–3.5
39. Sandstone, fine-grained, platy, laminated; ripple marks on bedding planes; weathers gray to buff and brown	2
38. Shale, gray, silty; 0.5-ft bed of locally ferruginous siltstone	1±
37. Clayrock, kaolinitic; varies from 0.2 ft of hard white porcellanite to as much as 1.5 ft soft white clay; latter in local pockets between interference ripple marks on underlying bed. Probably the first key marker	.2–1.5
36. Sandstone, fine-grained; gray- to brown-weathering; in massive beds; upper surface with broad interference ripple marks with intersecting crests as much as 3 ft apart	2.5±
35. Siltstone, gray, platy to shaly, locally sandy	2.8
34. Sandstone, fine-grained, massive to thick-bedded, cross-laminated; locally irregularly bedded; weathers gray to buff	15
3. Shale, black, silty; weathers fissile; thinly interbedded with siltstone	4.3
32. Shale, brown, silty, plastic; grading down to argillaceous brown siltstone	4.3
Kassler sandstone member:	
31. Sandstone, fine-grained, weathers gray to buff; massive to irregularly thin-bedded; cross-laminated	30
(Base Kassler member.)	
Disconformity.	
30. Shale, dark-gray to black, contains silt laminae with ferruginous stain	.9
29. Clayrock, gray-white, kaolinitic (second key marker)	.2
28. Shale, similar to unit 30	.8
27. Siltstone, gray, platy; thinly interbedded with fine-grained sandstone; weathers light brown to orange-brown, with shale partings in upper half and interbeds gray silty shale in lower half	4.4
26. Sandstone, fine-grained, locally silty; weathers light gray; shaly laminae disrupted by borings	1.2
25. Clayrock, yellowish gray, kaolinitic	.1
24. Sandstone; similar to unit 26, locally hard, ferruginous	1.6
23. Clayrock, yellowish gray, kaolinitic	.1–.2
22. Sandstone; similar to unit 26, with thin beds of silty shale and platy siltstone	12.6

	Thickness (feet)
South Platte formation—Continued	
21. Sandstone; similar to unit 22 but with more siltstone than sandstone and more dark-gray argillaceous laminae; local hard ferruginous siltstone layers as much as 0.2 ft thick increasingly common downward	11.8
20. Shale, dark-gray, silty	.5
19. Clayrock, yellowish to grayish-white, kaolinitic	.2
18. Siltstone, dark-gray, argillaceous, carbonaceous; some silty shaly, becoming less argillaceous in lower 5 ft; laminated with laminae disrupted by borings	7.2
17. Siltstone, dark-gray, with interlaminated silty shale; similar to unit 18 with more argillaceous material	4.3
16. Clayrock, gray-white, kaolinitic	.2
15. Siltstone, gray, platy to shaly; some silty shale chiefly in lower foot, laminated, locally disrupted	3.4
Plainview sandstone member:	
14. Sandstone, brown-weathering, fine-grained, tabular; laminated to cross-laminated, silty at top, platy to shaly in lower 1.8 ft	18–25
13. Siltstone, brownish-gray; weathers light gray, massive; contains plant fragments	2.4
12. Clay, brown to black, lignitic, silty; thin kaolinitic clayrock bed in middle part	1.1
11. Clayrock, gray, silty, kaolinitic	.2
10. Sandstone, fine-grained, massive; weathers light gray	2.8
9. Claystone, silty, locally lignitic	2
8. Sandstone, similar to unit 10; thin conglomeratic layer or scattered chert and quartzite pebbles at base; locally silty and carbonaceous	8.3
Disconformity.	
Lytle formation:	
7. Siltstone, argillaceous and silty claystone; weathers yellow, pink and gray	3.7
6. Clay, gray, silty; weathers gray-white, pink stain; minor amounts of argillaceous siltstone; few zones minute ferruginous pellets	3
5. Sandstone, porous, ferruginous; weathers pink to red	1
4. Claystone, gray, silty, grading down to argillaceous, locally sandy, siltstone; weathers light gray; zones of ferruginous red-weathering sandstone	2.3
3. Partly obscured, similar to unit 4	10±
2. Claystone, alternating red and gray, silty, with thin layers of sandstone partially obscured	20±
1. Sandstone, fine-grained, massive; buff with pink cast; basal part covered by slope wash.	

In the following section at Morrison channeling prior to the deposition of the first sandstone, has apparently removed the Van Bibber shale member and part or all of the Kassler sandstone member. The second shale is also missing. This shortening of the South Platte section makes it impossible to identify subdivisions with certainty. Unit 47, here in contact with the third sandstone, is probably the coalesced Kassler member and first sandstone.

SECTION 11.—*Morrison*

[Dakota group and upper part of Morrison formation exposed on the hogback north of Bear Creek gap at Morrison, Morrison quadrangle, Jefferson County. Units 25 to 52 were measured in the gap along the north side of highway routes U.S.285 and Colorado 8, about on the north line of NE¼NE¼ sec. 2, T. 5 S., R. 70 W.; units 1 to 24 measured on west scarp of ridge about in the center S½SE¼ sec. 35, T. 4 S., R. 70 W.]

	Thickness (feet)
South Platte formation:	
52. Sandstone, brown-weathering, fine-grained, massive, cross-laminated to crossbedded	23.3
Disconformity—channeled surface.	
51. Shale, dark gray, silty, and shaly siltstone with thin beds light-gray-weathering, laminated siltstone in upper 1.5 ft	3.3
50. Sandstone, fine-grained, hard; weathers gray with greenish cast; silty laminae	1.6
49. Siltstone, dark-gray to black, argillaceous, hard	1.7
48. Sandstone, fine-grained; weathers light gray at top, buff to brown below; argillaceous in upper 1.5 ft	2.8
47. Sandstone, brown-weathering, fine- to medium-grained; thick-bedded to massive, cross-laminated; locally coarse-grained at base with zones clay-pellet conglomerate in lower 2 ft, many intersecting channel fills	45
Disconformity—channeled surface.	
46. Siltstone and fine-grained sandstone; dark to light-gray with greenish cast; few thin beds silty shale; locally carbonaceous in upper 3.6 ft, chiefly massive, thin-bedded to laminated	11.7
45. Siltstone, argillaceous, and silty claystone, dark gray	2±
44. Sandstone, fine-grained, laminated; weathers light gray; irregularly interbedded with argillaceous siltstone and fine-grained sandstone that weathers light blue gray; some dark-gray silty shale partings at top and in lower 2 ft	9
43. Sandstone, fine-grained, silty, laminated; weathers light gray with yellow to buff stain; similar to unit above but lacks argillaceous partings	13
42. Shale, dark-gray, silty; thin interbeds of siltstone as much as 0.3 ft thick, with orange-brown stain	14
41. Shale, dark-gray, finely silty	5.3
40. Clayrock, light-gray, kaolinitic	.1
39. Shale, similar to unit 41	.8
38. Siltstone; weathers orange-brown to red-brown; in beds as much as 0.2 ft thick; with beds dark-gray silty shale	1.5
37. Shale, dark-gray, silty; thin beds and laminae of siltstone	2.5
36. Siltstone; irregularly interbedded with fine-grained sandstone; weathers gray with buff and brown stain; contains silty shale partings; nonresistant	7.2
35. Shale, similar to unit 37	1.4
34. Shale; similar to unit 36 with sandstone predominating, shaly zone 11 to 17 ft from top; basal 4 ft locally fairly resistant	21
33. Siltstone, argillaceous; weathers blue-gray; and silty, gray clay	2.8
32. Sandstone and siltstone, gray, crumbly, locally argillaceous	2
31. Siltstone, black, shaly; hard with thin beds and laminae of gray-white siltstone	3.5
30. Shale, brown-weathering, silty	.6

	Thickness (feet)
South Platte formation—Continued	
Plainview sandstone member:	
29. Sandstone, fine-grained, tabular, laminated to cross-laminated, locally crossbedded; weathers brown to orange-brown, few shale partings	7.6
28. Shale, dark-gray to black, silty; locally carbonaceous	1.4
27. Sandstone, similar to unit 29	1.5
26. Shale, dark-gray to black, sandy	2
25. Sandstone, gray to light-gray, fine-grained, massive, locally argillaceous; contains pockets of chert and quartzite pebbles and clay pellets at base; plant fragment throughout, and locally a 0.5-ft lens of bituminous, argillaceous silt	6
Disconformity.	
Lytle-Morrison formations (undifferentiated):	
24. Sandstone, fine-grained, light-gray, argillaceous; grades laterally to sandy light-gray claystone; locally stained red, yellow or orange in upper 1.5 ft	3–5
23. Sandstone, light-gray to gray-white, fine- to medium-grained, massive, friable; local red and orange stain, scattered, small ferruginous concretions and claystone blebs; irregular, thin chert lenses common in lower two thirds	10–14
22. Obscured by slope wash; spot trenching shows sandstone similar to unit 23 but more argillaceous; stained light orange-brown	11
21. Partially obscured by slope wash, soft, ferruginous, red-weathering sandstone grading downward to light-gray, sandy claystone	6.5
20. Sandstone, light-gray to buff, fine-grained, locally argillaceous, some silty zones; local zones ferruginous stain, weathers with pitted surface; contains thin zones intraformational clay-pellet conglomerate; lower 6–8 ft with scattered ferruginous blebs	11
Unconformity?	
19. Claystone, red, silty; mottled green and purple in lower 6 ft	15
18. Sandstone, fine-grained, massive, cross-laminated; weathers pitted; weathers buff with pink cast	5.8
Unconformity?	
17. Claystone, red; silty to sandy with zones fine-grained, argillaceous sandstone 2.6–5 ft from top	6.1
16. Sandstone, similar to unit 18	2
Unconformity?	
15. Claystone, red, silty	1
14. Sandstone; weathers light gray to buff, pinkish cast; fine-grained in upper 4 ft; medium- to coarse-grained below; cross-laminated; contains zones fine-grained sandstone and siltstone giving irregular banded appearance; weathers pitted; some zones with ferruginous blebs	10
Unconformity.	
13. Claystone, silty and argillaceous siltstone, red and green	3
12. Sandstone, similar to unit 14	6
Unconformity?	
11. Claystone and silty claystone, green to gray; locally weathers yellow, some red mottling	7.7
10. Sandstone, fine- to coarse-grained, locally conglomeratic, massive, cross-laminated; weathers light gray to buff with local pink cast; conglomeratic layers include chert and quartzite pebbles and some clay pellets, latter locally concentrated in rounded concretions as much as 3 ft in diameter	8

	Thickness (feet)
Unconformity.	
Morrison formation:	
9. Claystone, green, gray, and red, silty, with local thin lenses fine-grained sandstone	1–4
8. Sandstone, fine-grained, massive, cross-laminated; locally weathers pitted, buff with pinkish cast	13–15
7. Claystone; upper 2 ft gray, 3–4 ft maroon, remainder green grading to gray, slightly silty, locally calcareous	19
6. Limestone, gray, argillaceous, hard; conchoidal fracture; weathers light-gray with orange stain	2.5
5. Claystone, dark-gray, calcareous, hard	3.5
4. Sandstone, buff- to brown-weathering, fine-grained, massive, argillaceous in upper part	5.9
3. Claystone, green and greenish-gray, with scattered thin beds gray limestone; partly obscured, measurement approximate	55
2. Siltstone, green and greenish-gray, locally argillaceous, dense; weathers light buff and brown	14
1. Claystone, similar to unit 3.	

SECTION 12.—*Turkey Creek*

[Dakota group exposed in the gap of Turkey Creek, about 1¾ miles southeast of Morrison, in NW¼ sec. 12, T. 4 S., R. 70 W., Morrison quadrangle, Jefferson County. Units 12 to 30 measured along an old trench cut in bedrock on the south side of the gap in W½SE¼NE¼ sec. 12; units 31 to 35 measured in the vicinity of the old exploratory hole on the north side of the gap along Colorado State Route 70 in SW¼NE¼NE¼ sec. 12; and units 1 to 11 measured north of the same road in the E½SW¼NE¼ sec. 12.]

	Thickness (feet)
South Platte formation:	
35. Sandstone, fine-grained, massive, cross-laminated; forms cliff; buff- to brown-weathering	32.6
34. Sandstone; brown- to gray-weathering, locally shaly and platy, forms break in cliff face	1–4
33. Sandstone, similar to unit 35	39.8
Disconformity.	
32. Siltstone, dark-gray, argillaceous, hard; weathers mottled gray and light gray; locally with ferruginous stain; bedding obscure, some lamination	13.6
31. Siltstone, gray, hard, locally sandy; in two thick beds separated by 2 ft of argillaceous siltstone and silty shale	6
30. Siltstone thinly interbedded with fine-grained sandstone and shale; weathers orange-brown; platy; laminated to thin-bedded	26
29. Obscured by slope wash, probably shale	6
28. Siltstone, light-gray; locally argillaceous with thin shaly zone in middle	1.1
27. Shale, dark-gray, silty	.2
26. Clayrock, light-gray, kaolinitic	.2
25. Sandstone, brown-weathering, fine-grained, irregularly bedded; with 0.3 ft bed of silty shale 2 ft from top	5.7
24. Shale, dark-gray, semiplastic, locally silty	2.4
23. Siltstone; irregularly interbedded with fine-grained sandstone, weathers brown to buff with light-gray silty beds	11.4
22. Shale, dark-gray, silty; thin interbeds of siltstone	1.6

	Thickness (feet)
South Platte formation—Continued	
21. Siltstone and some fine-grained sandstone similar to unit 23, with argillaceous layers throughout and shaly siltstone in lower foot	5
20. Shale, gray to dark-gray, silty	2.6
19. Siltstone; weathers gray to brown-gray; platy; in thin irregular layers with shale partings and thin interbeds; middle part contains considerable silty shale; thin bed of sandstone with ferruginous stain at base	6
Plainview sandstone member:	
18. Sandstone, brown-weatherings, fine-grained, massive, cross-laminated to crossbedded	7
17. Sandstone, fine-grained, cross-laminated; weathers brown; interbedded with light-gray-weathering friable argillaceous siltstone; basal 0.5 ft is silty shale	4
16. Sandstone, fine- to medium-grained, massive; weathers light gray to buff; cross-laminated with rare, isolated pebbles of chert and quartzite	6.1
Disconformity.	
Lytle formation:	
15. Siltstone and fine-grained sandstone; weathers gray-white, highly argillaceous; hard but crumbly; some ferruginous stain	9.6
14. Sandstone, fine- to medium-grained; weathers light gray to buff; somewhat argillaceous, zones of intraformational conglomerate of sandstone pellets identical in composition to matrix; poorly resistant, underlies slopes or forms low rounded ledges	30.6
13. Obscured, wash of fine-grained white sand, probably similar to unit 14 but more argillaceous and friable; locally grades laterally into mottled red and green sandy claystone	7.5
12. Sandstone, weathers light gray to buff, with pink cast where topped by red beds; fine-grained at top becoming progressively coarser downward, chiefly medium-grained with many thin lenses of conglomeratic sandstone in lower 20 ft containing chert, quartzite and claystone pebbles; top of bed hard, with red ferruginous stain and pitted surface	40±
Unconformity.	
Morrison formation:	
11. Claystone, red and green, silty	10.8
10. Sandstone, fine-grained, massive to thick bedded, cross-laminated; weathers reddish-brown	7.8
9. Sandstone, argillaceous, and sandy clay, gray to greenish-gray, crumbly; thin beds of sandstone in lower 3.7 ft	9.3
8. Claystone, red, silty	5.7
7. Claystone, gray to greenish-gray, silty; zone of ferruginous concretions at base	9
6. Clay, gray, silty; grades to argillaceous siltstone in lower foot	9.7
5. Sandstone, fine-grained; weathers rusty-brown, irregularly interbedded with greenish-gray argillaceous siltstone; sandstone dominant in lower half, siltstone in upper	16.3
4. Siltstone, light-gray, argillaceous	1
3. Claystone, purplish-red	.5
2. Claystone, green, silty	20
1. Sandstone, light-gray to tan, locally conglomeratic; pebbles gray and minor amounts of red chert and quartzite	8

SECTION 13.—*Deer Creek*

[Dakota group exposed in the hogback north of Deer Creek in SW¼ sec. 4, and E½NE¼SE¼ sec. 5, T. 6 S., R. 69 W., Littleton and Indian Hills quadrangles, Jefferson County. Units 45 through 78 measured on the east side of the ridge about 250 feet north of the road, Colorado State Route 124, through Deer Creek gap; units 1 through 44 measured on the scarp face of the hogback in SE¼NE¼SE¼ sec. 5, where there is continuous exposure from the crest-forming Kassler sandstone member to the Lykins formation (Triassic? and Permian?). Between this locality and Deer Creek gap the Plainview sandstone member thickens abruptly causing considerable local variation in the thickness and appearance of the South Platte formation.]

	Thickness (feet)
South Platte formation:	
78. Sandstone, fine-grained, irregularly bedded, cross-laminated; weathers rusty-brown	6
77. Siltstone interbedded with fine-grained sandstone; weathers light gray, platy to shaly; some beds sandy shale	6
76. Sandstone; weathers brown and gray, fine-grained platy with interbedded siltstone	3
75. Sandstone, fine-grained, massive, cross-laminated; weathers brown	4.6
74. Siltstone, dark-gray, argillaceous, irregularly laminated; minor amounts of fine-grained sandstone	4–6
73. Shale, gray, silty, and shaly siltstone	1
72. Sandstone, light-gray, fine-grained; lower 2 ft irregularly thin-bedded to laminated, worm? borings in upper foot	3
71. Obscured, nonresistant zone	1
70. Sandstone, fine-grained, cross-laminated to cross-bedded, resistant; weathers brown, grades to unit 69	3
69. Sandstone, interbedded with siltstone, gray- and brown-weathering, platy to shaly, nonresistant; minor amounts of silty shale	7.5
68. Sandstone, fine-grained, cross-laminated to crossbedded, ledge-forming; varies in thickness at expense of underlying shale; weathers buff to rusty-brown	2.5–10
Disconformity—channeled surface.	
67. Shale, black to dark-gray and brown, silty; with laminae and thin beds of siltstone; becomes more silty downward	7.5
66. Siltstone; weathers light gray; massive to laminated, locally sandy	1
65. Shale, dark-gray to black; weathers bluish gray, semiplastic, upper 0.4 ft silty and weathers light gray; lower foot contains fossil leaves with original delicate leaf tissues preserved	3.2
64. Siltstone, argillaceous; weathers light blue-gray	.4
63. Shale, dark-gray to black, highly silty, locally carbonaceous, hard	6.4
62. Siltstone, similar to unit 64	.4
61. Sandstone; weathers light buff and gray; fine- to medium-grained with local coarse-grained layers containing white-weathering argillaceous chips	20–30
Disconformity—channeled surface.	
Van Bibber shale member:	
60. Sandstone, fine-grained, platy, hard; weathers light gray with irregular rusty stain; beds 0.6–1 ft thick with partings of argillaceous siltstone	3
59. Shale, dark-gray, silty	1.5
58. Siltstone and fine-grained sandstone interbedded with dark gray silty clay, platy, ripple-marked	1.8

	Thickness (feet)
South Platte formation—Continued	
Van Bibber shale member—Continued	
57. Sandstone, buff-weathering, fine-grained, massive to tabular, cross-laminated	6–9
56. Claystone, gray, sandy, and argillaceous fine-grained sandstone	1.4
55. Sandstone, fine-grained, massive; weathers buff	1
54. Shale, dark-gray, semiplastic in upper 0.8 ft; silty below with argillaceous siltstone at base	1.5
53. Sandstone, similar to unit 55	2
52. Shale, gray, silty	1.5
51. Sandstone, similar to unit 55	2.5
50. Siltstone, gray, argillaceous, thinly interbedded with fine-grained sandstone, grades to unit below	1.3
49. Shale, dark-gray, semiplastic, finely silty; weathers bluish gray	1.7
48. Siltstone, light-gray, argillaceous, sandy	.3
47. Shale, dark-gray, silty, weathers fissile	5.8
46. Siltstone, weathers light gray, argillaceous, minor silty shale	2
45. Kaolinitic clayrock, yellowish gray, locally present in pockets on surface of disconformity (first key marker)	.2±
Disconformity—channeled surface.	
Kassler sandstone member:	
44. Sandstone, massive, cross-laminated to crossbedded; fine- to medium-grained; weathers gray to rusty-brown; basal 5.5 ft coarse-grained; locally conglomeratic with clay pellets, chert and quartzite pebbles; cliff-forming caprock of hogback north and south of Deer Creek gap	58.5
Base of Kassler member.	
Disconformity.	
43. Siltstone, argillaceous; weathers light gray; interbedded gray silty shale containing silt laminae	3
42. Shale, dark-gray, silty, with laminae of silt	4
41. Clayrock, kaolinitic, white, hard, porcellanitic (second key marker, part)	.0–.4
40. Shale, brownish-gray silty	1
39. Clayrock, kaolinitic, gray-white (second key marker, part)	.2
38. Shale, similar to unit 42	3
37. Sandstone, rusty-brown to orange-brown, fine-grained; locally silty	.4
36. Siltstone and fine-grained sandstone; weather light gray and rusty-brown, platy, interbedded with gray to dark-gray silty shale; basal 1.5 ft chiefly hard sandy siltstone ledge with black ferruginous stain; rare fossils of *Inoceramus comancheanus* Cragin and fish scales	5.5
35. Shale, dark-gray, silty; thin beds of siltstone	4
34. Sandstone, fine-grained, silty, hard; weathers rusty-brown	.6
33. Shale, dark-gray, silty; thin beds of siltstone in lower 2 ft	3
32. Sandstone, fine-grained, soft; weathers light gray with local rusty stain, some interlaminated silt. Argillaceous in basal 3 ft	20
31. Sandstone, fine-grained, fairly resistant; weathers light gray and buff	2
30. Sandstone, similar to unit 32, interbedded with argillaceous siltstone and some dark-gray silty shale	8
29. Shale, gray silty	.3

	Thickness (feet)
South Platte formation—Continued	
28. Clayrock, gray-white, kaolinitic	.4
27. Siltstone, rusty-brown, sandy	.2
26. Sandstone, fine- to medium-grained, friable; weathers orange-brown; some partings ferruginous sandy shale	7.5
25. Shale, dark-gray to black, silty; locally a shaly siltstone	3.3
24. Shale, dark-gray, silty; thinly interbedded with gray argillaceous siltstone	7.3
23. Obscured, similar to unit 24 with siltstone predominating	8
Plainview sandstone member:	
22. Sandstone, medium-grained, massive; weathers light gray to buff	3
21. Siltstone, argillaceous; interbedded with silty shale, weathers light blue-gray	4.7
20. Sandstone, medium- to coarse-grained, massive, cross-laminated, hard; weathers buff	2
19. Sandstone, buff- to brown-weathering, fine-grained, laminated, locally cross laminated, platy; with worm? borings	2.4
18. Sandstone, similar to unit 20	1
17. Sandstone, similar to unit 19, becomes silty and grades into unit 16	2
16. Shale, dark-gray to black, silty; scattered thin beds argillaceous siltstone	9
15. Sandstone, gray, variable; locally fine-grained to silty and argillaceous; commonly ferruginous; laterally may thin out or thicken and become conglomeratic with scattered chert and quartzite	.4
Disconformity.	
Lytle formation:	
14. Claystone, sandy; gray with local pink stain, some zones argillaceous sandstone	0.3–1
13. Sandstone, medium- to coarse-grained and conglomeratic, massive, lenticular; weathers light gray and light buff; locally cliff-forming; conglomerate chiefly in lower 10 ft	24
Unconformity.	
12. Siltstone, light gray and greenish-gray; red mottling in lower 5 ft, zones of silty claystone and some argillaceous sandstone	8
11. Sandstone, fine- to medium-grained, massive; weathers orange-brown; ferruginous specks throughout; 0.4-ft zone of argillaceous siltstone 3 ft from top	6.5
10. Claystone, silty, and argillaceous siltstone; chiefly red, some gray and greenish-gray; contains thin bed hard light-gray sandstone 2 ft above base	5
9. Sandstone, light-gray-weathering, fine- to medium-grained; massive; locally silty zones at base and top, varies locally from 4–15 ft thick within 100 ft along strike	12
Unconformity?	
8. Claystone, red, silty; some green mottling at top and base; contains rare polished chert pebbles ("gastroliths") as much as 3 in. in long diameter	6.5
7. Sandstone, medium- to coarse-grained; weathers light gray to buff; some conglomeratic zones of small chert and quartzite pebbles	8.5

	Thickness (feet)
Unconformity.	
Morrison formation:	
6. Claystone, silty with beds of argillaceous siltstone, chiefly green and gray with silty zones weathering yellowish-gray; minor red mottling in lower part	25
5. Siltstone and fine-grained sandstone, red- to green-stained, massive, argillaceous	3
4. Claystone, silty, and argillaceous siltstone; red, locally gray at top	5
3. Siltstone and fine-grained sandstone, yellow-gray, pink and red, massive; grades into unit below	8
2. Sandstone; weathers pink to buff with pink cast; medium-grained in upper 15 ft, remainder medium- to coarse-grained and conglomeratic; basal 5 to 6 ft locally solid lens of conglomerate with chert and quartzite pebbles and greenish claystone fragments, in argillaceous matrix peppered with small cavities coated with rusty stain	36.6
Unconformity.	
1. Claystone, green and gray-green; locally silty; thin beds gray limestone and calcareous concretion.	

SECTION 14.—*Nameless Creek*

[Dakota group pieced from exposures north of the gap of an unnamed creek that cuts through the hogback in the NW¼SE¼SE¼ sec. 16, T. 6 S., R. 69 W., Littleton quadrangle, Jefferson County.]

	Thickness (feet)
Benton shale: Obscured.	
South Platte formation:	
33. Sandstone, brown-weathering, fine-grained, hard	1
32. Siltstone; thinly interbedded with silty shale; weathers gray and light gray, minor amounts of fine-grained sandstone	9
31. Siltstone; weathers light gray	.8
30. Obscured; similar to unit 32	5
29. Sandstone, fine-grained, massive, weathers gray with orange-brown stain; a double bed	4
28. Obscured, interbedded brown-weathering sandstone and silty shale, contains 2.7-ft ledge of sandstone 0.8 ft above base	11
27. Sandstone, similar to unit 29	4.8
26. Obscured, shaly beds	2
25. Sandstone, fine-grained, tabular, ledgy, cross-laminated, locally friable; weathers yellow-brown to gray; basal 4 ft has clay-pellet conglomerate	33.4
Disconformity—channeled surface.	
Van Bibber (?) shale member:	
24. Obscured, soft argillaceous zone	4
23. Sandstone, fine-grained, massive; weathers brown; upper surface ripple-marked	4.6
22. Siltstone; weathers blue-gray, argillaceous with dark-gray silty clay	5.4
Kassler sandstone member:	
21. Sandstone, fine-grained, massive to tabular, cross-laminated; weathers gray and yellowish gray	15.5
20. Obscured; argillaceous siltstone in float	3.5
19. Sandstone, similar to unit 21	13
18. Obscured; float of sandstone, minor amounts of argillaceous siltstone	4

	Thickness (feet)
South Platte formation—Continued	
Kassler sandstone member—Continued	
17. Sandstone, brown-weathering, fine- to medium-grained, massive to tabular, cross-laminated; thin basal zone of chert, quartzite, and clay-pellet conglomerate	34
Base of Kassler member.	
Disconformity.	
16. Shale, dark-gray, silty	1
15. Siltstone and fine-grained sandstone, platy; weathers brown to rusty-brown; contains partings of shaly siltstone and silty shale, and a 1-ft bed 2.5 ft from top	5
14. Obscured, slope wash shows thin, platy siltstone and some shale in lower part	9
13. Sandstone, fine-grained, massive; weathers brown	3.5
12. Partly obscured; slope chiefly on nonresistant, yellowish-gray-weathering, fine-grained sandstone, minor amounts of light-gray siltstone	32.5
11. Siltstone, argillaceous; weathers gray-white to yellow and brown, irregularly bedded	7.5
Plainview sandstone member:	
10. Sandstone, brown-weathering, fine-grained, tabular, cross-laminated to crossbedded; thin silty, argillaceous zones 25 and 30 ft from top	52
9. Obscured by slope wash, float with thin slabs siltstone, some silty shale	15.8
8. Shale, black, silty	1.5
7. Siltstone, gray	.1
Disconformity.	
Lytle formation:	
6. Claystone, light-gray, pink stain, with ferruginous siltstone at base	.4
5. Sandstone, fine- to coarse-grained; weathers light yellow-gray to yellowish brown; conglomeratic in lower 20 ft with chert and quartzite pebbles as much as 0.3 ft in diameter	37
Unconformity.	
4. Partly obscured, slope wash on variegated silty claystone and argillaceous siltstone	20
3. Sandstone, fine-grained, locally silty, massive; weathers yellow to brown; some argillaceous zones, crumbly	9
2. Claystone, red and yellow, silty	2.2
1. Siltstone, light-gray-weathering, massive; irregularly bedded, with sandy zones	3

SECTION 15.—*South Platte River*

[Dakota group exposed on the Verdos Ranch at the south end of the hogback about ½ mile north of the South Platte River at Kassler in the NE¼ NW¼ SE¼ sec. 27, T. 6 S., R. 69 W., Kassler quadrangle, Jefferson County. Units 26 to 39 were measured above the creek bed that cuts around the toe of the ridge, units 1 to 25 were measured on the west-facing scarp of the ridge a short distance to the northwest]

	Thickness (feet)
Benton shale not exposed.	
South Platte formation:	
39. Sandstone, fine-grained, platy; thinly interbedded with siltstone, light gray with sandy ledges stained rusty brown, locally argillaceous	15.2
38. Sandstone, fine-grained, massive; soft; weathers light gray with local rusty stain and some fretwork	5

	Thickness (feet)
South Platte formation—Continued	
37. Shale, brown to gray, silty; grades to light gray argillaceous siltstone	3
36. Sandstone, brown-weathering, fine-grained, massive	3.7
35. Shale, gray and brownish-gray, silty; 1 ft argillaceous siltstone at base	4.2
34. Sandstone, brown-weathering, fine-grained, massive- to thin-bedded, laminated to cross-laminated; interbedded with light-gray friable siltstone	8.2
33. Sandstone, fine- to medium-grained, tabular cross-laminated to crossbedded; weathers gray, basal 3 or 4 ft contain scattered clay pellets	45.7
Disconformity—channeled surface.	
Van Bibber shale member:	
32. Shale, gray, plastic	.4
31. Shale, gray, silty; interbedded with platy to irregularly bedded siltstone and fine-grained sandstone	2.5
30. Shale, gray, plastic; 0.1–0.4 ft of ferruginous clay at top	0.4–0.7
29. Sandstone, fine-grained, platy, weathers light gray with brown stain; locally silty; grades to argillaceous siltstone	1.1
28. Clayrock gray-white; kaolinitic, porcellanitic, locally ferruginous in upper 0.3 ft (first key marker)	.6
27. Sandstone, fine-grained, massive, weathers gray to brown; rusty-brown, ferruginous cap and ripple-marked upper surface	2.5
26. Sandstone, fine-grained, even-bedded; beds 0.1–2 ft thick, locally laminated weathers light gray, contains partings and thin beds of gray, shaly, siltstone chiefly in upper 2 ft	12
Disconformity?	
Kassler sandstone member:	
25. Sandstone, fine- to medium-grained, irregularly thin-bedded, cross-laminated to crossbedded; weathers gray; some zones intraformational, clay-pellet conglomerate in lower part	44
24. Sandstone, medium- to coarse-grained, massive, cross-laminated, friable; weathers gray to light gray; contains many clay pellets and few small chert pebbles throughout	10.6
23. Sandstone, fine- to coarse-grained, thin-bedded, crossbedded; 0.2 ft of chert and quartzite pebble conglomerate at base; weathers gray	17.2
Base of Kassler member.	
Disconformity.	
22. Sandstone, fine-grained, platy, hard; thinly interbedded with argillaceous siltstone; weathers brown; contains some silty gray shale at top	2.8
21. Siltstone, gray, argillaceous, and silty shale	1.9
20. Sandstone: similar to unit 22; basal brown-weathering sandstone bed about 1 ft thick; rarely contains *Inoceramus bellvuensis* Reeside fossils	4.9
19. Shale, dark-gray, silty; beds of argillaceous siltstone; upper 1.5 ft is siltstone	5.4
18. Sandstone, fine-grained; weathers light gray with rusty stain in upper part; irregularly thin-bedded, becoming progessively more friable and silty downward; upper 1–2 ft indurated ferruginous cap	14.8

	Thickness (feet)
South Platte formation—Continued	
17. Sandstone, fine-grained, irregularly bedded, forms ledge locally; weathers light gray	1.5
16. Clayrock, kaolinitic, light-gray to gray-white, locally shaly; silty in lower 0.7 ft; thin layer ferruginous siltstone 0.1 ft from top	1.5
15. Siltstone and fine-grained sandstone, soft, friable, locally argillaceous; top 0.6–0.8 ft is resistant, forms ledge locally	11.4
14. Sandstone, fine-grained, massive, surface pitted; weathers rusty-brown	2.5
13. Siltstone, soft; weathers mottled gray and brown, argillaceous and carbonaceous laminae	8.3
12. Partly obscured; gray to black silty shale with thin beds of rusty-stained silt; basal foot is chiefly siltstone with shale partings	8.7
Plainview sandstone member:	
11. Sandstone, fine-grained, tabular, cross-laminated; weathers light brown with local rusty stain; silty partings in upper 6 ft	17.2
10. Sandstone, fine-grained, irregularly bedded, friable; weathers light gray with rusty brown streaks	6.4
9. Siltstone, gray, argillaceous; shaly in lower part with 1 ft plastic paper shale at base	5.8
8. Sandstone, fine-grained, tabular, cross-laminated to crossbedded; weathers light gray to yellow brown; basal 2 ft contain scattered small clay fragments	20.8
7. Siltstone and fine-grained sandstone, gray, platy to shaly, locally argillaceous; interbedded with silty gray shale	4.7
6. Sandstone, fine- to coarse-grained, massive; weathers light gray; chert, quartzite, and claystone pebbles throughout	.8
Disconformity.	
Lytle formation:	
5. Siltstone; grades downward to fine-grained sandstone, yellow with red stain in sandy part, argillaceous	1.7
4. Sandstone; fine- to coarse-grained, massive, cross-laminated; weathers light gray, locally yellowish, basal part contains thin zones of small chert and quartzite pebbles	6
3. Siltstone and fine-grained sandstone, weathers gray and yellow-gray, blocky, argillaceous	2.4
2. Sandstone, similar to unit 4; chert and quartzite pebbles in lower part	21.8
1. Wash covered slope on red, yellow and green claystone	6.5

SECTION 16.—*Little Willow Creek*

[Dakota group exposed north and south of the gap made by Little Willow Creek in the hogback at Helmer's ranch in the southeast corner NE¼, and northeast corner SE¼, of SE¼, sec. 11, and the southwest corner NW¼, and NW¼SW¼ of SW¼, sec. 12, T. 7 S., R. 69 W., Kassler quadrangle, Douglas County. Units 21 to 35 measured in old clay pits on the east side of the hogback south of the creek. units 1 to 20 measured on the hogback north of the creek and in Helmer's sand pit dug in the Lytle formation.]

	Thickness (feet)
Benton shale (basal part):	
35. Shale, dark-gray to black, locally silty.	
34. Obscured by slope wash, partial exposures show shale similar to unit 35 with thin beds of platy siltstone; transition zone to South Platte formation	7

	Thickness (feet)
Disconformity?	
South Platte formation:	
33. Sandstone, gray, fine-grained, platy	2.2
32. Clayrock, light gray; kaolinitic	.2
31. Sandstone, gray to buff, fine-grained, soft, friable, massive	6.4
30. Shale and clay, brownish-gray, silty, plastic	1.8
29. Sandstone; similar to unit 31	3.5
28. Clay, gray, plastic, locally silty	2–4
27. Sandstone, gray, fine-grained; beds 0.1–1.5 ft thick; cross-laminated, with thin partings of silty shale	3.5
26. Sandstone, gray- to brown-weathering, fine- to medium-grained, massive, cross-laminated; basal beds shattered; may be local fault here	9.3
25. Sandstone, fine-grained, and gray-weathering siltstone; interbedded with gray to black, locally carbonaceous, silty shale; clastic beds 0.1–0.8 ft thick	11.6
24. Sandstone, brown-weathering, fine-grained, massive, thick-bedded, cross-laminated to crossbedded	40
Disconformity—channeled surface.	
Van Bibber shale member:	
23. Shale, dark-gray, silty, with thin beds of siltstone	2.4
22. Siltstone, light-gray, platy; shaly partings	1±
21. Clayrock, yellow to white, kaolinitic (first key marker)	.2

(Unit 24 thins to 15 or 20 ft across gap to north, the Van Bibber shale member beneath it includes the following unit above the kaolinitic first key marker.

	Feet
Clay, gray, silty	3.3
Sandstone, buff, massive	6.3
Shale, dark-gray, with interbedded silt	6.8
Siltstone, platy	.8
Clayrock, yellow-white, kaolinitic	.2)

	Thickness (feet)
20. Sandstone, light-gray, fine-grained, massive to even-bedded, laminated; with rusty stain on ripple-marked upper surface	3±
Disconformity.	
Kassler sandstone member:	
19. Sandstone, chiefly brown-weathering, fine- to coarse-grained, massive to thick-bedded, cross-laminated to crossbedded; conglomeratic at base, chiefly in lower 10 ft, chert and quartzite pebbles	104±
Base of Kassler member.	
Disconformity.	
18. Siltstone, thinly interbedded with fine-grained sandstone; weathers gray; platy, with streaks of rusty-brown stain	6.2
17. Shale, gray, silty; interbedded with shaly sandstone	4.5
16. Sandstone, fine-grained, irregularly bedded, friable; weathers light gray and buff to brown with streaks of rusty-brown stain; silty in lower part	23
15. Siltstone, gray; thinly interbedded with fine-grained sandstone; locally shaly	5
14. Sandstone, light-gray; irregular zones and knobs of rusty-brown, fine-grained, massive sandstone	10
13. Partly obscured; upper half sandy and argillaceous; lower half chiefly very silty gray shale and argillaceous siltstone	14.5

South Platte formation—Continued

	Thickness (feet)
Plainview sandstone member:	
Plainview sandstone member:	
12. Sandstone, fine-grained, platy to tabular, weathers brown to rusty brown, beds 0.1–0.8 ft thick, silty partings at top and base	6.8
11. Shale, silty, and shaly siltstone, weathers light gray	3+
10. Obscured, wash-covered zone hides disconformity that marks formation contact	5
Disconformity.	
Lytle formation:	
9. Claystone, gray-white and argillaceous siltstone with zones and blotches of pink stain	3+
8. Sandstone, light-gray, fine- to coarse-grained, massive, cross-laminated; two thin zones of chert and quartzite-pebbles conglomerate near top and at base	19
Unconformity:	
7. Claystone, chiefly greenish-gray with red zones in upper 1.5 ft, silty; basal foot is red-stained argillaceous siltstone	5.5
6. Sandstone, weathers light gray to buff with local pink cast, fine- to coarse-grained and conglomeratic, basal 8 ft chiefly conglomerate of chert and quartzite pebbles and large fragments of hard claystone	51±
Unconformity.	
Morrison (?) formation:	
5. Sandstone, fine-grained, massive; weathers buff, shaly interbeds and thin lenses, capped by thin, hard, rusty-brown layer with scattered chert and quartzite pebbles; contains silty porcelanitic layer locally in upper foot; base commonly has intraformational clay-pellet conglomerate	3.7
4. Claystone, silty, and fine-grained argillaceous sandstone, weathers light gray; some red-weathering zones	2
3. Sandstone, buff-weathering, fine-grained, massive	1.6
2. Sandstone, fine-grained, argillaceous, and sandy claystone; weathers light gray	5
1. Claystone; green with red zone in upper 0.6 ft, silty	10+
Covered by slope wash.	

SECTION 17.—*Helmer mine*

[Part of the South Platte formation measured in the Helmer clay mine and on the hogback above it in the center of the W½E½SW¼ sec. 13, T. 7 S., R. 69 W., Kassler quadrangle, Douglas County. Units 10 to 21 from the Helmer clay mine, units 1 through 9 on the hogback.]

	Thickness (feet)
Benton shale (basal part):	
21. Shale, gray; scattered thin beds of siltstone.	
20. Bentonite	0.1
19. Shale, gray, plastic, finely silty; thinly interbedded with light gray platy argillaceous siltstone	1.7
18. Shale, gray, plastic, finely silty	3.6
17. Siltstone, gray, platy, argillaceous	1.2
Disconformity?	
South Platte formation:	
16. Sandstone, massive, cross-bedded, friable, fine- to medium-grained, weathers buff to brown; some silty zones in upper 10 ft; underlies lower part of dip slope of hogback	63.8

	Thickness (feet)
South Platte formation—Continued	
Disconformity—channeled surface.	
Van Bibber shale member:	
15. Clay, gray, plastic; locally finely silty; blocky to subconchoidal fracture; interbedded argillaceous silt 4–6 ft from top; some argillaceous siltstone in lower 2 ft (Helmer claystone bed)	8–10
14. Sandstone, gray, fine-grained, platy; weathers brown; interbedded argillaceous siltstone and partings silty claystone	5–7
13. Shale, light-gray; silty with silt laminae	1.6
12. Siltstone, light-gray; thinly interbedded with dark-gray to black shale	1.9
11. Shale, dark-gray, silty; with silt laminae	2.2
10. Siltstone, light-gray, platy	1
9. Clayrock, grayish white, kaolinitic (first key marker)	.3
Disconformity?	
Kassler sandstone member:	
8. Sandstone, massive, lenticular, cross-laminated to crossbedded; brown to buff-weathering; grading from fine- to coarse-grained downward	65±
7. Sandstone; weathers light brown to gray; chiefly coarse grained, with intraformational conglomerate of fine-grained sandstone and argillaceous siltstone fragments	3
6. Sandstone, fine- to coarse-grained with zones of chert and quartzite pebbles throughout	25
Base Kassler member.	
Disconformity.	
5. Sandstone, fine-grained; interbedded with siltstone, weathers light gray, platy with local ferruginous stain; locally some silty gray shale above this unit at disconformity in section	6±
4. Shale, silty, and shaly siltstone; weathers light gray	5
3. Sandstone; weathers gray with irregular zones and knobs of rusty-brown; chiefly fine-grained; some medium-grained sandstone at top; capped by rusty-brown crust of ripple-marked sandstone, ripples as large as 1.1 ft between crests	25
2. Obscured by slope wash, partial exposures show weathered light-gray silty shale with thin beds of siltstone and fine-grained sandstone	11
1. Sandstone, fine-grained, massive to irregularly bedded; weathers rusty-brown; base obscured	3.5±

SECTION 18.—*Willow Creek*

[Part of the Dakota group exposed on the southwest-facing scarp of the hogback about 700 feet southeast along the ridge from Willow Creek gap in about the center of the SW¼NE¼ sec. 24, T. 7 S., R. 69 W., Kassler quadrangle, Douglas County. The section starts at or very near the top of the Kassler sandstone member and extends downward into the Morrison formation.]

	Thickness (feet)
South Platte formation (in part):	
Kassler sandstone member:	
17. Sandstone, fine- to medium-grained; weathers gray, some coarse-grained at base with intraformational conglomerate; tabular, cross-laminated in upper 20 ft; massive, crossbedded below	57
16. Sandstone, medium- to coarse-grained and conglomeratic, massive, crossbedded, friable; weathers yellow-gray with pink and purple stain, basal 0.3 to 0.6 ft is conglomerate with ferruginous stain	18

	Thickness (feet)
South Platte formation (in part)—Continued	
Disconformity.	
15. Siltstone; thinly interbedded with fine-grained sandstone; weathers gray, some rusty stain, platy; few shaly partings in upper 6 ft, common in lower part	9.3
14. Sandstone, weathers rusty-brown, fine-grained, massive, cross-bedded, friable. Upper foot is resistant, ferruginous ledge-forming cap	10
13. Sandstone, fine-grained, silty, argillaceous, weathers gray and light gray, grading to argillaceous siltstone	16
12. Shale, black; silty with laminae and few thin beds of silt	2
11. Siltstone, weathers light gray, locally soft, argillaceous; few platy beds in upper foot	13.5
10. Shale, gray, silty, and shaly siltstone, hard	1
9. Clayrock, kaolinitic bed, light-gray, silty	.1
8. Shale, similar to unit 10	.5
7. Siltstone, mottled gray, argillaceous, massive in upper part, becoming platy to shaly in lower part	11.5
Plainview sandstone member:	
6. Sandstone, gray- to brown-weathering, fine- to medium-grained, tabular, cross-laminated; becomes coarse-grained in basal 3 ft and grades into unit 5	43.6
5. Conglomerate, chert and quartzite pebbles and many white claystone fragments	2.4
Disconformity.	
Lytle formation:	
4. Sandstone, massive, lenticular; weathers gray to brown and reddish-brown; fine- to coarse-grained and conglomeratic with beds of chert and quartzite pebble conglomerate throughout; local zones are quartzitic with chert matrix	77
Unconformity.	
Morrison formation:	
3. Obscured by talus, nonresistant zone; partial exposures along strike to south show variegated claystone	40
2. Conglomerate and conglomeratic sandstone; chert and quartzite pebbles and claystone fragments	6
1. Obscured by talus, slope on greenish claystone.	

SECTION 19.—*Rainbow Creek*

[Dakota group measured from continuous exposures on the north side of the gap made by Rainbow Creek in the Dakota hogback, NW¼SE¼ sec. 30, T. 7 S., R. 68 W., Kassler quadrangle, Douglas County.]

	Thickness (feet)
Benton shale:	
27. Shale, gray, silty; grades upward within 10 ft to black shale.	
26. Siltstone, white-weathering, platy; interbedded with gray silty shale	6.5
Disconformity?	
South Platte formation:	
25. Sandstone, silty, fine-grained, hard, tabular, cross-laminated; weathers white on upper surface	2
24. Sandstone, fine-grained, friable, massive, cross-laminated; weathers orange-brown	2.7

	Thickness (feet)
South Platte formation—Continued	
23. Siltstone, shaly, and silty shale	2.5
22. Sandstone, similar to unit 24; becomes silty in lower part	2.7
21. Shaly zone, obscured by slope wash	5.5
20. Siltstone, platy; interbedded with fine-grained sandstone in beds as thick as 0.5 ft; partings of silty shale	3.3
19. Sandstone, fine-grained, platy to irregularly bedded	6
18. Siltstone, gray, argillaceous; lenses of gray silty clay; basal half shaly siltstone	6.3
17. Sandstone, fine- to medium-grained, tabular, cross-laminated; scattered thin zones of clay pellets; upper 1 ft platy with abundant leaf imprints	36
16. Conglomerate, clay-pellet, claystone and argillaceous siltstone fragments; interbedded with thin beds of silty claystone and fine-grained ripple-marked sandstone	2
Van Bibber shale member (in part):	
15. Shale, dark-gray, silty; with laminae and thin beds of light-gray siltstone	6.7
14. Sandstone, fine- to medium-grained, tabular to irregularly bedded, cross-laminated; weathers light gray to brown	19.3
Disconformity?	
Kassler sandstone member:	
13. Sandstone, medium- to coarse-grained and conglomeratic; chiefly massive, cross-laminated, brown-weathering; lower 20 ft locally friable, pink- to yellow-weathering; clay-pellet zones common; scattered chert pebbles and thin chert-pebble conglomeratic zones at base and 21.5 ft above base	77.5
Base of Kassler member:	
Disconformity.	
12. Sandstone, fine-grained, platy; interbedded with platy to irregularly bedded siltstone; upper 1 ft iron-impregnated; lower 1 ft argillaceous with shale partings	10.5
11. Sandstone, fine-grained; grading downward to siltstone and sandy siltstone in lower few feet	30
10. Obscured by slope wash; rubble indicates some platy siltstone and argillaceous siltstone	23
Plainview sandstone member:	
9. Sandstone, brown-weathering, fine-grained, tabular; cross-laminated in upper part, becomes medium grained, massive, cross-laminated in lower part	43
8. Sandstone, medium- to coarse-grained, massive, cross-laminated	11
7. Conglomerate and conglomeratic sandstone, chert and quartzite pebbles	1
Disconformity.	
Lytle formation:	
6. Siltstone, argillaceous, massive, with variable argillaceous content; weathers light gray and white; pink zone 5 ft above base; capped with 0.8 ft ochrous siltstone	15
5. Sandstone, fine-grained, massive; weather light yellow-gray	4
4. Claystone, variegated, silty, with bed of fine-grained sandstone (as in unit 5) from 4–10 ft above base; claystone obscured by slope wash of red and white clay; upper 5 ft is red zone	24

	Thickness (feet)
Lytle formation—Continued	
3. Sandstone, fine-, medium- and coarse-grained, conglomeratic throughout, massive, cross-laminated. Chert and quartzite pebbles. Upper 2 ft mottled red, purple and yellow, remainder weathers brick red. Local chertified zones in which pebbles and grains are cemented by red chert	48
Unconformity.	
Morrison formation:	
2. Sandstone, fine-grained, argillaceous; mottled red, purple and yellow; grades downward into variegated argillaceous siltstone and silty claystone	4
1. Wash covered slope mostly on variegated claystone; 0.5-ft porcellanite bed at base	48

TESTS OF CLAYROCK SAMPLES

Tests of clayrocks from the Dakota group were made for two purposes: to identify the dominant clay mineral group and to determine fusion points and other firing qualities. Identification of the dominant clay mineral group was used primarily as a prospecting technique. Approximately 150 differential thermal analyses were made; when results were inconclusive or warranted substantiation by more precise methods of identification, X-ray powder patterns, or analysis by X-ray Geiger-counter spectrometer, were used. Detailed listing of these exploratory tests would serve no purpose; the results are summarized in figure 5 and its accompanying discussion.

Forty samples of clayrock were selected for firing tests and submitted to T. A. Klinefelter, supervising minerals technologist for the Industrial Minerals Branch of the U.S. Bureau of Mines. Results of the tests, as reported by Klinefelter, are given in table 2. Samples were selected primarily to gain information for comparing the grade of the clayrock in the different beds, secondarily to test individual deposits. Unless otherwise noted, all samples are channel samples of the thickness of beds indicated.

In the column of table 2 giving the pyrometric cone equivalent (P.C.E.), more than one number is given for some samples, for example sample 1 is 32½–33. T. A. Klinefelter reports (written communication) that

> the first [reference] cone listed [32½] is flat and the second one [33] is about half down—as cone 32½ represents a temperature of 1,725° C and cone 33 a temperature of 1,745° C then the sample cone reached 6 o'clock at about 1,735° C. Where one cone number only is given it means that cone had deformed to 6 o'clock at the same time the sample cone reached 6 o'clock.

Klinefelter's description of the firing tests is paraphrased as follows: A number of briquettes were made from each sample and fired to temperatures between 1,000°C and 1,325°C, or as high as cones 10 to 11. Percent shrinkage, percent absorption, and apparent specific gravities were recorded for the temperatures 1,260°C (2,300°F) or cone 8, and 1,320°C (2,400°F) or about cone 11.

TABLE 2—*Tests of clayrock samples*

Sample No.	PCE	Percent shrinkage at—		Percent absorption at—		Apparent specific gravity		Fired color at—	
		2,300° F	2,400° F	2,300° F	2,400° F	2,300° F	2,400° F	2,300° F	2,400° F
Ripple clay shale									
1	32½–33	7.0	8.0	14.2	12.8	2.65	2.65	Off white	Off white.
2	32½	7.5	10.0	16.3	12.7	2.71	2.71	Gray white	Gray white.
3	34–35	8.0	9.5	11.0	8.7	2.66	2.72	White	White.
4	33–34	9.5	12.5	12.0	7.0	2.63	2.64	do	Do.
5	33–34	10.0	13.0	12.8	7.8	2.58	2.65	Pink	Light gray.
6	33–34	10.0	13.0	12.9	9.1	2.63	2.63	White	White.
7	33–34	9.5	11.0	13.2	10.0	2.71	2.67	do	Do.
8	32–32½	5.0	6.0	19.5	18.2	2.65	2.68	do	Do.
9	32½	7.0	12.0	19.2	13.1	2.66	2.60	Yellow white	Off white.
10	34	9.0	10.0	16.1	14.2	2.71	2.70	Off white	Do.
Black silica bed									
11	32–32½	5.0	7.5	16.1	14.5	2.60	2.61	White	White.
12	32–32½	6.5	8.0	20.3	19.6	2.63	2.64	do	Do.
Lower split									
13	32½–33	9.0	10.0	18.2	14.5	2.65	2.64	Off white	Off white.
Rider beds									
14	32½	9.0	10.0	9.9	8.0	2.59	2.61	Off white	Off white.
15	27	9.0	10.0	11.0	8.5	2.51	2.51	do	Do.
16	26–27	12.0	14.5	6.3	2.0	2.44	2.41	White, brownish.	Light gray.
Helmer claystone bed									
17	33–34	9.0	14.0	16.8	8.5	2.70	2.63	Off white	White.
Bear Creek bed									
18	35–36	10.0	12.0	11.6	8.5	2.62	2.66	Off white	Off white.
19	32½	7.0	9.0	15.4	11.8	2.63	2.63	White	White.
First sandstone									
20	32–32½	6.5	7.0	8.2	16.2	2.63	2.63	White	White.
21	28	9.0	10.0	12.5	9.7	2.51	2.48	do	Do.
22	23–26	12.5	14.5	18.2	1.8	2.44	2.31	White, brownish.	Gray white.
23	20–23	11.0	12.5	7.1	6.3	2.47	2.48	Pale red	Gray.
24	32½	8.0	11.0	18.1	14.7	2.62	2.61	White	White.
25	31–32	6.5	7.0	19.3	18.4	2.63	2.63	do	Do.
26	28–29	7.5	10.0	14.8	9.3	2.59	2.48	do	Do.
27	19	10.0	11.5	13.2	10.1	2.42	2.31	Off white	Off white.
28	23–26	5.0	7.5	14.7	12.6	2.59	2.50	do	Do.
Second shale									
29	16	8.0	12.0	11.5	3.1	2.50	2.26	Pale red	Purple.
30	20	15.0	15.0	4.5	0	2.38	2.22	White, brownish.	Gray.
31	11	10.0 expanded		3.0	19.6	2.16	1.15	Gray, pinkish	Do.
32	34	7.5	10.0	19.9	14.5	2.65	2.63	Off white	Off white.

TABLE 2—*Tests of clayrock samples*—Continued.

Sample No.	PCE	Percent shrinkage at—		Percent absorption at—		Apparent specific gravity		Fired color at—	
		2,300° F	2,400° F	2,300° F	2,400° F	2,300° F	2,400° F	2,300° F	2,400° F
Plainview sandstone member									
33	26–27	5.0	5.5	14.3	12.0	2.54	2.52	Off white	Off white.
Lytle formation									
34	30–31	5.0	5.5	15.0	13.9	2.66	2.65	White, brownish.	White, brownish.
35	29–30	5.0	5.5	13.9	12.8	2.58	2.59	Off white	Off white.
36	32½	7.5	10.0	14.6	12.1	2.63	2.66	Pink	Do.
Benton shale									
37	18–19	7.5	12.0	14.3	5.8	2.45	2.31	Off white	Off white.
38	19–20	14.0	15.0	6.5	1.0	2.39	2.27	White, brownish.	Gray.
Glencairn shale member									
39	13	12.5 Slagging		4.1	3.0	2.02	2.10	Olive gray	Olive gray.
40	12	12.5 Slagging		4.4	4.5	2.04	1.68	Brownish, gray.	Do.

NOTE: Stratigraphic position and location of clay samples.

South Platte formation:

Van Bibber shale member:

Ripple clay shale:

1. Eldorado Springs section 6, units 34 and 35, 6 feet of clay shale including first key marker.
2. New Johnson mine, Golden area. Spot sample of clay shale.
3. Van Bibber Creek section 9, unit 37, 1 foot of clay shale.
4. Van Bibber Creek section 9, unit 35, 4 feet of clay shale.
5. Van Bibber Creek section 9, unit 33, 3 feet of ferroginous clay shale.
6. Van Bibber Creek section 9, unit 32, upper 2 feet.
7. Van Bibber Creek section 9, unit 32, lower 4 feet.
8. Deer Creek section 13, unit 47, 5.8 feet silty shale.
9. Helmer mine section 17, units 11 and 13, 3.8 feet of silty shale.
10. Alameda Parkway section 10, unit 37, spot sample of first key marker.

Black silica bed:

11. Coors quarry south of Ralston Reservoir, upper 3 feet of silty clay shale bed.
12. Outcrop about 250 feet north of Ralston Reservoir, upper 4 feet of silty clay shale bed.

Upper shale of Lower split:

13. Outcrop on scarp face of hogback about 1,200 feet south of Hedley pit, Douglas County area.

Rider beds:

14. Eldorado Springs section 6, upper 6 feet of unit 38, silty shale between siltstone interbeds.
15. Eldorado Springs section 6, units 38, 40, 41, and 43, total of 5 feet of silty clay shale, including thin porcellanite bed.
16. Eldorado Springs section 6, unit 46, 5.6 feet of silty, locally carbonaceous clay shale.

Helmer claystone bed:

17. Helmer mine, Douglas County, spot sample of Helmer claystone.

(Notes continued on p. 145)

To give some idea of how the sampled clays will appear if used for ceramic products, the colors of briquettes fired to 2,300°F and 2,400°F are noted. Of the color terms, white means bone white, "off-white" indicates faint color tint, generally pinkish in the 2,300°F briquettes and grayish in the 2,400°F briquettes.

Samples 3 through 7 illustrate the usefulness of the fired colors. Together, these samples are a complete test of the 14-foot ripple clay shale at the type section of the Van Bibber member. All samples have about the same pyrometric cone equivalent, and all but

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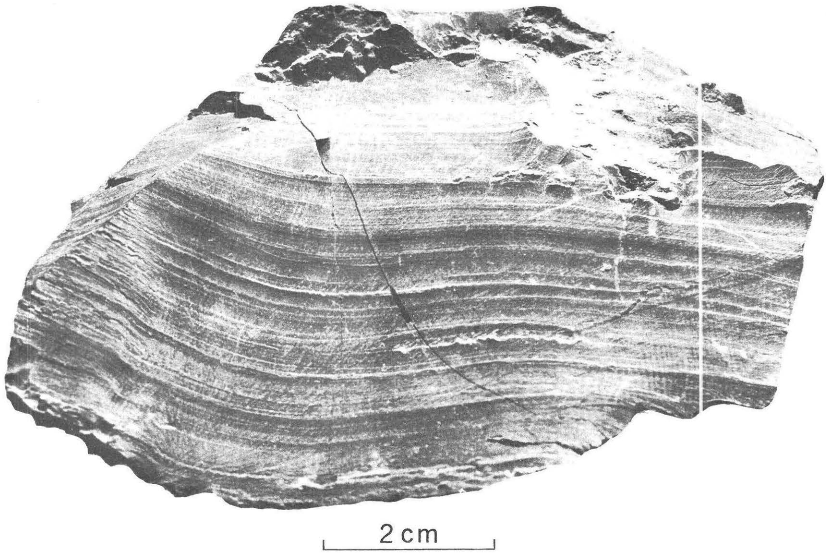
(Notes continued)

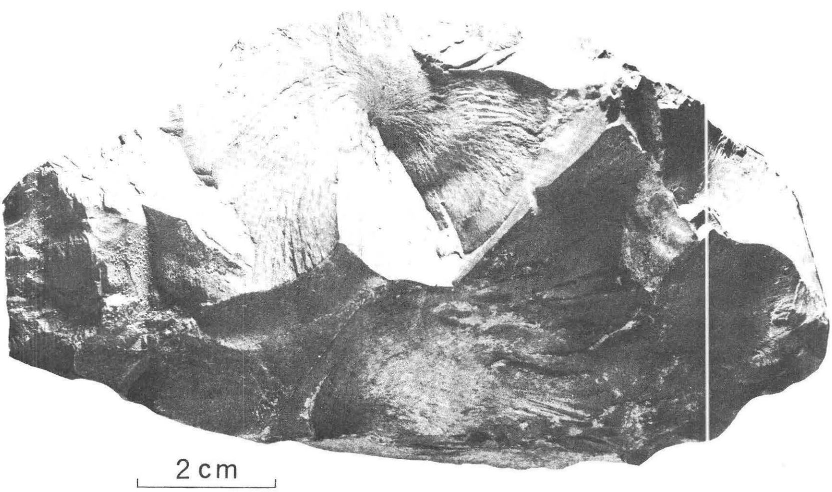
South Platte formation—Continued
First sandstone.
Bear Creek bed:
18. About 1,000 feet northwest along the strike from Dutch Creek, Jefferson County, 2.6 feet of flint clay in what may be Bear Creek bed.
19. South side of Weaver Gulch, Jefferson County, 2 feet of silty clay shale.
Various unnamed beds:
20. Hogback Mine, Douglas County, combined sample of the lower two of four clayrock beds within the lower two-thirds of the subunit; a total of 8 feet of clay shale.
21. Hogback Mine, Douglas County, the upper two of the four clayrock beds; a total of 6.3 feet of clay shale.
22. Eldorado Springs section 6, unit 48, 4 feet of very silty clay shale.
23. Eldorado Springs section 6, combined sample of unit 50, 4–6 feet beneath Benton contact, and about 0.5 foot of clay shale with bentonite bed at base of Benton.
24. Deer Creek section 13, unit 65, 3.2 feet of semiplastic clay shale.
25. Deer Creek section 13, unit 63, 6.4 feet of highly silty clay shale.
26. Hogback mine, Douglas County, 4.6 feet of silty clay shale.
27. Hedley pit, Douglas County, 4.3 feet of soft clay shale.
28. Hedley pit, Douglas County, 2 feet of clay shale.
Second shale:
29. Outcrop slightly more than 0.5 mile northwest along the strike from road cut in Bear Creek gap, Morrison, Jefferson County, lower 4.4 feet of silty clay shale.
30. Same location as sample 29, upper 4.4 feet of same bed.
31. Eldorado Springs section 6, units 28, 29, and 30 exclusive of siltstone interbeds; total of 5.6 feet of silty clay including the kaolinitic second key marker.
32. Alameda Parkway road cut, Jefferson County, spot sample of porcellanite from second key marker.
Plainview sandstone member:
33. Plainview section 7, lower 4 feet of unit 17, very silty clay shale.
Lytle formation:
34. About 700 feet north of Alameda Parkway along the strike from the Lytle-South Platte contact. Outcrop of 3.7 feet of yellowish silty claystone beneath South Platte contact.
35. Same as above, 3.7–6.7 feet beneath the South Platte contact.
36. Outcrop about 1.2 miles south of Deer Creek, Jefferson County; 8 inch bed just beneath South Platte contact.
Benton shale:
37. Rustler mine, Jefferson County, 9.5 feet of shale above basal platy siltstone beds. Approximately 10 to 12 feet above the South Platte contact.
38. Same as above, from 9.5–12 feet above the platy beds.
Purgatoire formation at Colorado Springs, El Paso County.
Glencairn shale member:
39. Road cut north side Bear Creek road, Colorado State Route 338; upper 4 feet of 8 foot bed of clay shale beginning about 6 feet beneath base of Kassler sandstone member equivalent.
40. Same as above, lower 4 feet of the 8 foot bed.

sample 5 burn white. Sample 5 is of the ferruginous zone in the middle of the bed, and the fired color reflects this impurity.

Data on the clay minerals in the samples were omitted from the table because, with four exceptions, the samples are predominantly kaolinitic. The exceptions, samples 29, 31, 39, and 40, are all illitic clayrocks. Except for the most highly refractory clayrocks, those fusing above cone 32, the kaolinitic clay shale and claystone generally contain a minor amount of illite.

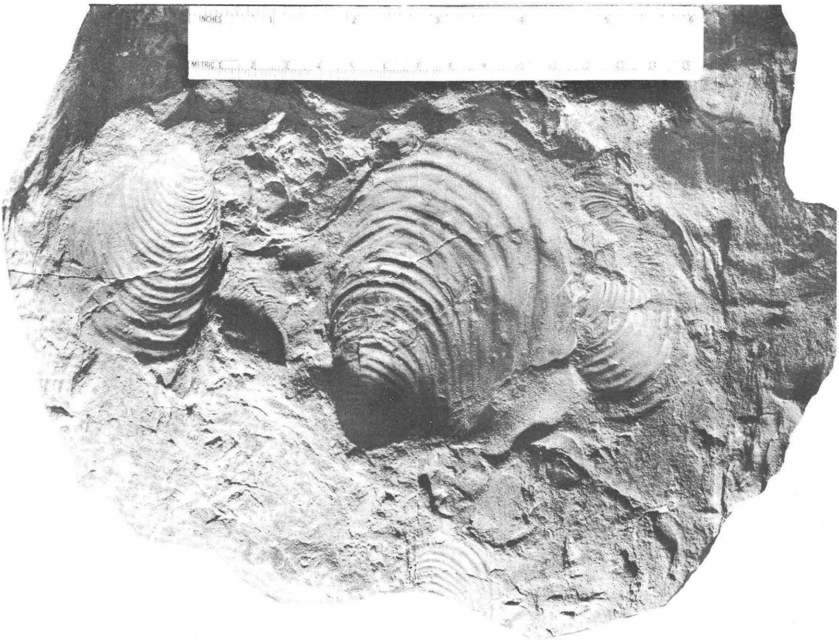


A. REFRACTORY CLAY SHALE FROM THE RIPPLE CLAY SHALE BED

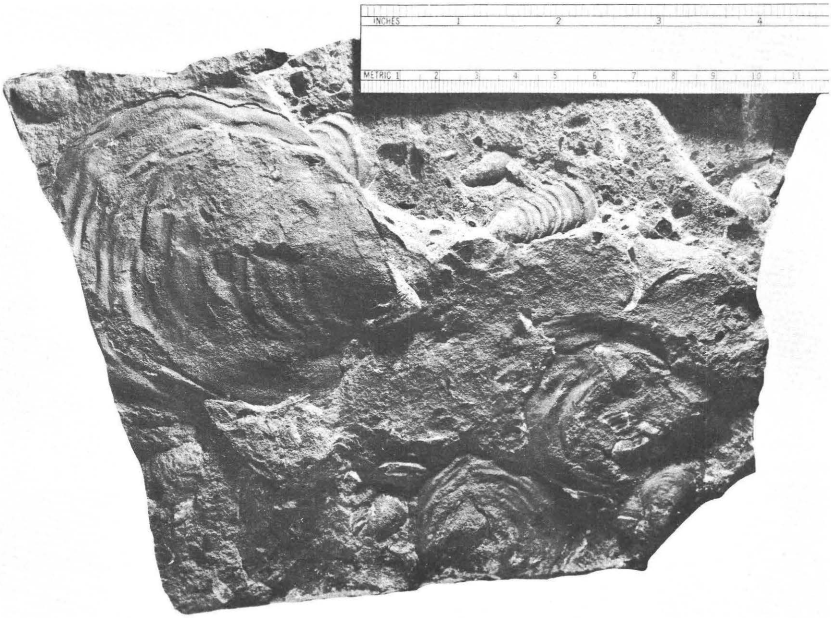


B. REFRACTORY CLAYSTONE FROM THE HELMER CLAYSTONE BED

TWO TYPES OF REFRACTORY CLAYROCK FROM THE VAN BIBBER SHALE MEMBER OF THE SOUTH PLATTE FORMATION



A. PLATY SILTSTONE OF THE SECOND SHALE, INDIAN HILLS QUADRANGLE, JEFFERSON COUNTY



B. EQUIVALENT LIMESTONE BEDS NEAR BELLEVUE, LARIMER COUNTY

FOSSILS, CHIEFLY *INOCERMAUS COMANCHEANUS* AND *I. BELLVUENSIS* IN THE SOUTH PLATTE FORMATION

RIPPLE-MARKED UPPER SURFACE OF THE THIRD SANDSTONE OF THE SOUTH PLATTE FORMATION WEST OF THE HELMER MINE, DOUGLAS COUNTY

RIPPLE CLAY SHALE IN OLD OPENING, ONE-TENTH MILE SOUTH OF THE HELMER MINE, DOUGLAS COUNTY

R, ripple-marked sandstone surface. Note interbedded silt that is typical of this unit in the Douglas County area.

BASAL CONGLOMERATIC SANDSTONE OF SOUTH PLATTE FORMATION

Disconformable on sandstone of the Lytle formation south of Dutch Creek, Jefferson County.

COMBINED KASSLER SANDSTONE MEMBER AND FIRST SANDSTONE OF THE SOUTH PLATTE FORMATION CAPPING THE HOGBACK

View northward from Massey Draw in Jefferson County

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