CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1923.

PART II. MINERAL FUELS.

CONTINUITY OF SOME OIL-BEARING SANDS OF COLORADO AND WYOMING.

By WILLIS T. LEE.

INTRODUCTION.

As exploration for oil goes forward, Wyoming and neighboring States are found to contain a great number of sands that are productive in one region or another. Nearly every important sandstone in the great Cretaceous system of the West seems to contain oil at some locality, but the exact number of these sands, the region in which each is productive, and the identity and stratigraphic position of the sands containing oil in some particular areas have not been determined, on account of the incompleteness of the geologic and paleontologic work in the areas concerned. Examination of the sequence and mutual relations or correlation of the strata, by tracing from place to place where possible and by the study of fossils where tracing is not possible, is particularly desirable. Such an examination was undertaken by the writer in the summer of 1921 and continued the following season. Special attention was given to the determination of the stratigraphic position of the oil-bearing sands, to the characteristics necessary for their recognition, and to the correlation of these sands along the foothills from Colorado Springs, Colo., to the Big Horn Basin, Wyo. J. B. Reeside, jr., was associated with the writer in the field. Quentin D. Singewald and Harold S. Cave acted as field assistants.

NATURE OF THE AREA EXAMINED.

The area examined extends from Perry Park, Colo., 35 miles due south of Denver, northward along the foothills east of the Rocky Mountains to Douglas, Wyo., thence westward north of the Laramie

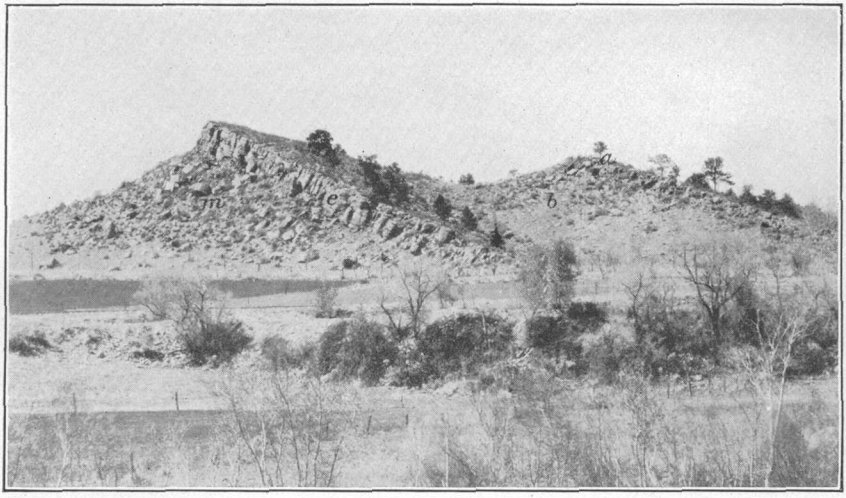
Mountains and their westward extension to a point several miles west of Casper. The mountains were then crossed in a southwesterly direction to Lost Soldier and Rawlins. East of Rawlins the work was in the nature of inspection, in order to correlate the new results with those obtained by other observers, some of which have been published and some, chiefly those of Prof. S. H. Knight, are in the form of unpublished notes.

It was found that in order to make proper use of certain formation names and the correlations implied by these names, observations were necessary in places beyond the area outlined. For this reason some time was spent in the vicinity of Lander, Wyo., and in the southern and eastern parts of the Big Horn Basin. The localities where sections were measured are indicated on the sketch map (Fig. 1).

In northern Colorado the formations described are steeply upturned, and the hard layers of rock form ridges, commonly called hogbacks, such as those shown in Plate IV, *A*. The mountain streams have cut passageways through these hogbacks at short intervals, making good exposures of the rocks in many places (Pl. I, *A*). These streams are used for irrigation, and fresh exposures are found in many places where cuts have been made for irrigation ditches (Pls. II, *A*, and III, *A*). The tilting of the beds was accompanied by slip faulting, and some of the softer beds seem to have been sheared in some places to so great an extent that they are absent in whole or in part. In other places the formations here described are obscured for considerable distances by later deposits, and in still others they have been removed by erosion. The longest stretch in which no exposures were found is between Iron Mountain and Douglas, Wyo., where for nearly 70 miles the older sedimentary rocks are covered with deposits of Tertiary age.

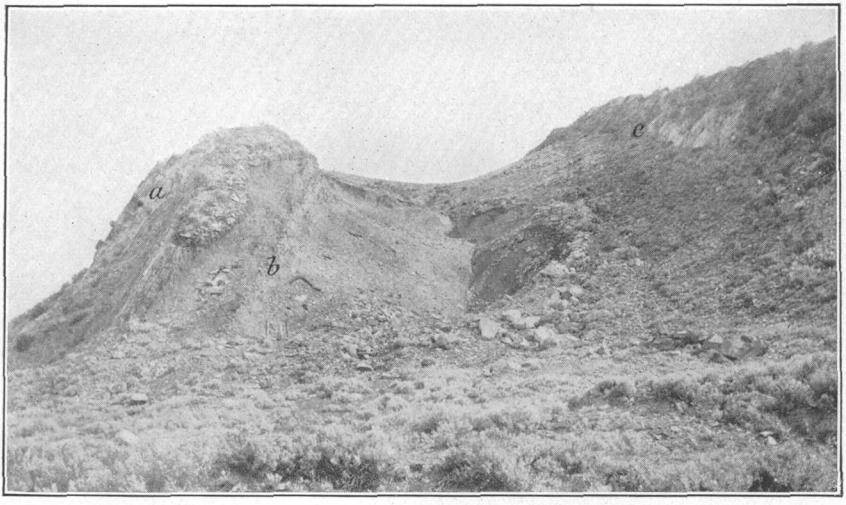
West of Douglas the rocks of the foothills are folded, faulted, and generally disturbed, so that the representation of their outcrops forms intricate patterns on a map. West of the Laramie Mountains also the strata were intricately folded and faulted, and after the folding the rocks were deeply eroded and in some places covered with younger sediments. For these reasons the formations can not be traced continuously from place to place. Nevertheless the sequence of beds as they appear at short intervals is the same, and the strata differ so little in thickness and lithologic character that there is no reasonable doubt that they were once continuous over the whole area.

West of Casper, Wyo., the folding is relatively mild and the older and more resistant rocks are deeply buried. These old rocks, however, are brought up again west and north of the highlands near Casper, in the Wind River Mountains west of Lander, and in the



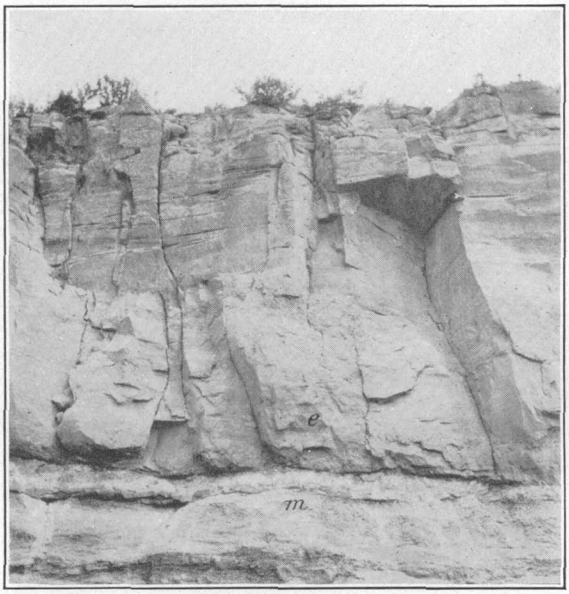
A. DAKOTA RIDGES IN THOMPSON CANYON WEST OF LOVELAND, COLO.

Showing the lower conglomerate (*c*) of the Dakota group above a boulder-covered slope of Morrison shale (*m*); also the middle shale (*b*) and the upper sandstone (*a*). The lower shale and middle sandstone of the group are not exposed.



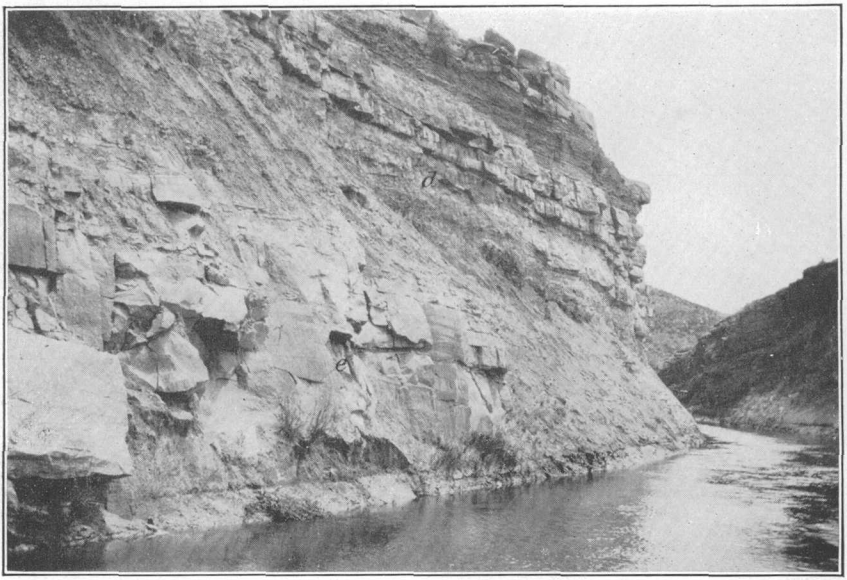
B. RIDGE NEAR IRON MOUNTAIN, WYO., WHERE CHUGWATER CREEK CUTS THE DAKOTA HOGBACK.

Showing the upper sandstone (*a*); the middle shale (*b*), which is fossiliferous near the top; and the middle sandstone (*c*).



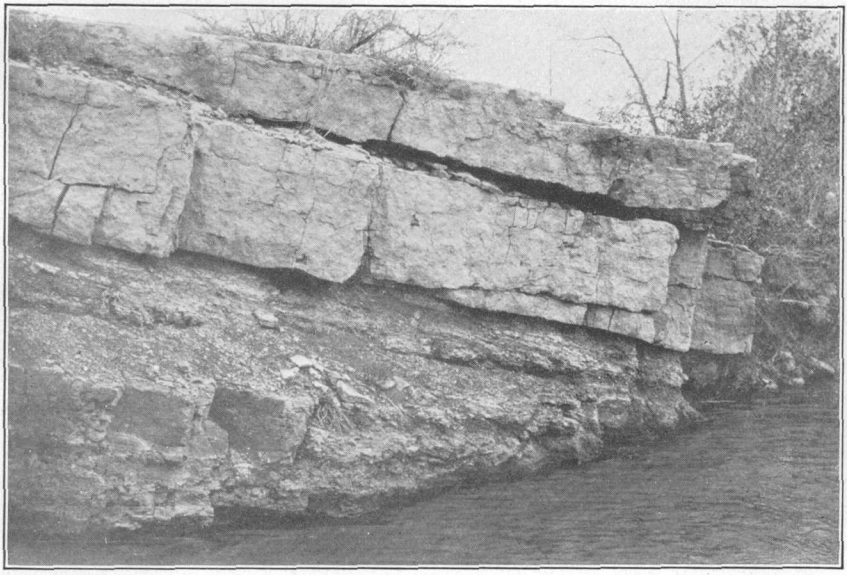
A. LOWER SANDSTONE (*e*) OF THE DAKOTA GROUP 2 MILES NORTH OF BELLVUE, COLO., RESTING UNCONFORMABLY ON MORRISON SHALE (*m*).

The lower part of the sandstone is conglomeratic, and the pebble beds fill hollows in the variegated beds of the Morrison formation.



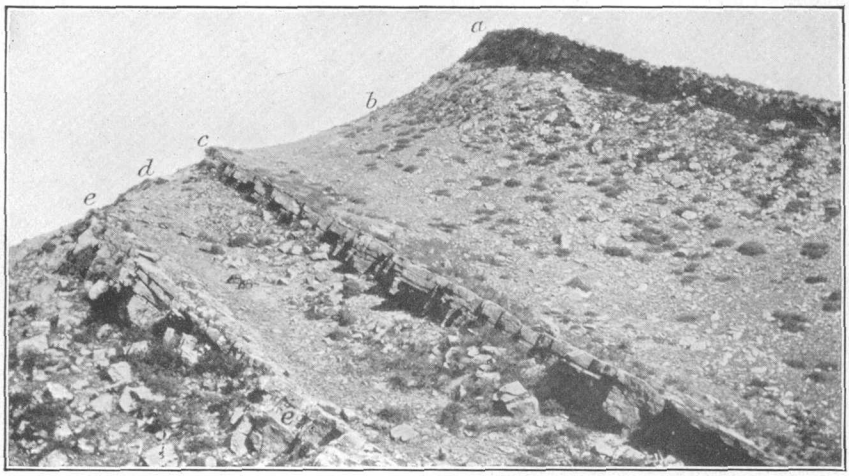
B. LOWER SHALE OF THE DAKOTA GROUP 2 MILES NORTH OF BELLVUE, COLO.

The massive rocks (*e*) are the lower sandstone of the Dakota group, and the shale and thin sandstones (*d*) above are the variegated lower shale, here capped inconspicuously by the middle sandstone.



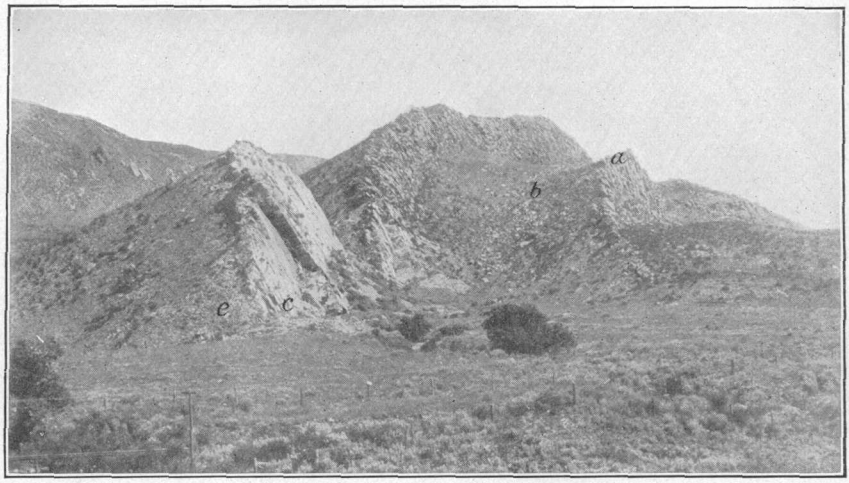
A. DETAILS OF THE UPPER SANDSTONE OF THE DAKOTA GROUP NEAR LYONS, COLO.

Showing a quartzose layer resting on carbonaceous shaly sandstone full of small fragments of carbonized wood, impressions of twigs, and a variety of plant débris.



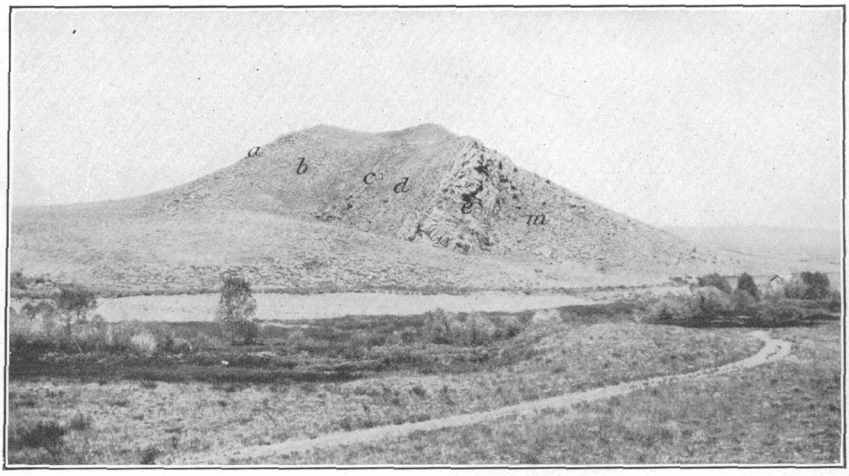
B. NORTH WALL OF SOLDIER CANYON NEAR LOVELAND, COLO.

Showing the lower sandstone (*e*), 36 feet thick; the variegated lower shale (*d*), 32 feet thick (for scale note the horses on the slope); the middle sandstone (*c*), 12 feet thick; the middle shale (*b*), 234 feet thick, fossiliferous in middle part; and the upper sandstone (*a*), 41 feet thick.



A. DAKOTA HOGBACKS NEAR IRON MOUNTAIN, WYO.

Showing the ridges north of Chugwater Creek. The main ridge is faced with the hard platy middle sandstone (*c*), and the conglomeratic lower sandstone (*e*) crops out in the covered slope. The upper sandstone (*a*) forms the smaller ridge, and the middle shale (*b*) the débris-covered slope.



B. DAKOTA RIDGE NEAR POISON LAKE, SOUTH OF DOUGLAS, WYO.

Showing the lower sandstone (*e*), a débris-covered slope of Morrison shale (*m*), a relatively smooth slope of the lower shale of the Dakota (*d*), a central ridge of the middle sandstone (*c*), a second smooth slope of the middle shale (*b*), and another ridge of the upper sandstone (*a*).

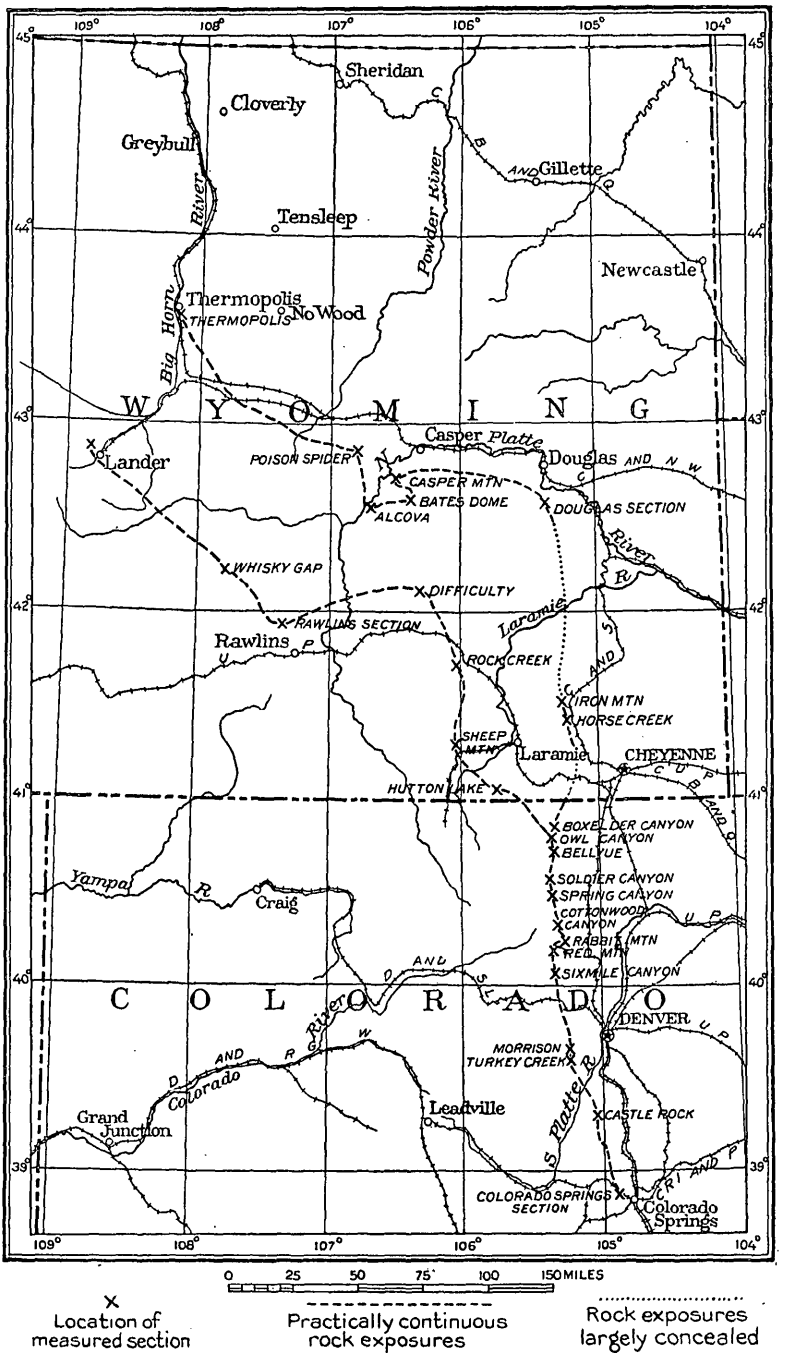


FIGURE 1.—Sketch map of parts of Colorado and Wyoming showing approximate location of sections described.

Owl Creek, Bridger, and Big Horn mountains, which inclose the Big Horn Basin. There are many excellent exposures of the sedimentary rocks in these ranges, and the correlation of the formations with those south and east of Casper, which were examined in greater detail, seems well established. Nevertheless it is desirable that these correlations be tested by observations in the intervening areas.

ROCKS DESCRIBED.

This preliminary report deals only with rocks which in the Rocky Mountain region have long been known as Dakota. In the foothills of the southern Rockies, particularly in northern Colorado east of the mountains, they form a well-defined group, which has generally been regarded as the base of the Upper Cretaceous series. These rocks, on close inspection, are found to consist of several distinct stratigraphic units, which doubtless will be known as formations when they are mapped in detail, hence the term group rather than formation is applied to them. Fossil plants of the Dakota flora have been found at several horizons in these rocks, and fossil invertebrates in many places, notably in the shale in the middle of the group. The best collection of these invertebrates was obtained about 2 miles north of Bellvue, where the rocks are well exposed. The section measured here may be regarded as the type section of the group, although some of its formations are better developed at near-by localities. Near Bellvue the group consists of five formations. At the base is a 40-foot conglomeratic sandstone which rests unconformably on the variegated shale of the Morrison formation (Pl. II, *A*). This is here called the lower sandstone of the Dakota. Above it are several layers of thin sandstone separated by red, green, and blue shale, the whole 40 feet in thickness (Pl. II, *B*). These beds constitute the lower or variegated shale of the group. Above them is a 10-foot sandstone, hard, flaggy, and ripple-marked, which will be referred to as the middle sandstone. Above this sandstone is a shale about 200 feet thick with layers of sandy limestone and concretions that contain marine invertebrates. This is here called the middle shale. Above it is a sandstone about 35 feet thick which the writer calls the upper sandstone.

The five formations of the Dakota group appear to be in conformable sequence throughout the area examined. The rocks pass from coarse conglomeratic sandstone at the base through alternating beds of sand and shale, some of which contain marine fossils regarded by some observers as Upper Cretaceous and by others as Lower Cretaceous. Some of the beds contain thin seams of coal and fossil plants of the Dakota flora. These beds merge upward into the purely marine Benton shale. Physically the group constitutes the base of a series

of closely related beds called the Upper Cretaceous series. However, when the Dakota group is traced laterally the lower formations appear to be equivalent to beds in other areas included in the Lower Cretaceous series, as the Purgatoire of southeastern Colorado, the Lakota and Fuson formations of the Black Hills, and parts of the Kootenai of Montana.

This group as a whole is readily recognized because of the sharp-crested ridges or hogbacks formed by the sandstone where the beds are upturned in the foothills. Owing to the character and stratigraphic sequence of the rocks they are readily recognized and constitute valuable key rocks by means of which less easily recognized horizons may be determined. These key rocks were observed consecutively from place to place, and sections were measured with stadia at short intervals, as shown in the accompanying plate of sections. Except in the wide covered areas the points of observation are so close together that the formations were virtually traced. The present paper embodies the principal conclusions reached that may be of help to the oil geologist and driller concerning the continuity, sequence, and thickness of these beds.

NOMENCLATURE.

The use of any names hitherto employed for the formations of the Dakota group as it is here defined would do violence to local usage in one place or another and would lead to misinterpretation and confusion. Yet it is necessary to name formations in order conveniently to discuss their relations. In order to avoid multiplicity of names and at the same time to hold clearly in view the established relations it has been decided to designate the different shales and sandstones of this group according to their relative position in the group, as upper, middle, or lower, rather than to give each division a formation name. Some of these units are typical formations in the sense that they are lithologic units and seem to extend far beyond the area described in this paper. The term Dakota as it was originally applied in the Rocky Mountain region is retained except that the rocks so named are called a group rather than a formation.

GENERAL CONCLUSIONS.

It is to be emphasized at the outset that the so-called Dakota sandstone of some writers is not so uniform in character and distribution as might be inferred from the general use of the name. In place of a single sandstone there is a group of sandstones and shales, some of which have already been given distinctive names. Among them are a sandstone to which the name Dakota has been applied in a restricted sense, the Purgatoire sandstone and shale, beds to which the name Cloverly has been applied, beds that have been classified as a

part of the Graneros or a part of the Benton, and the Muddy sand of the drillers.

There is no single, definite, persistent, and easily recognized sandstone such as was formerly supposed to exist and was termed the Dakota sandstone. In its place there is a group of intimately related beds, probably even more complicated than the correlation lines of Figure 2 indicate. Doubtless there are many overlapping lenses that differ slightly in age. The group as a whole is interpreted as the result of accumulation of sediments near the strand line of the advancing Cretaceous sea, and as such it differs in age from place to place by the length of time consumed by the advance of the strand line across the intervening distance. Whether this advance marks the beginning of Upper Cretaceous time remains to be determined.

The sequence, character, thickness, and correlation from place to place of the formations which the writer includes in the Dakota group are summarized in the accompanying charts (Figs. 2 and 3).

FORMATIONS OF THE DAKOTA GROUP.

Lower sandstone.—The lower sandstone of the Dakota group is a gray, massive, coarse-grained, usually cross-bedded and conglomeratic sandstone, variable in thickness but everywhere present and readily identified. It rests with obvious unconformity on the variegated shale of the Morrison formation. (See Pl. II, *A*.)

Lower shale.—The variegated shale that overlies the lower sandstone is made up of extremely variable beds of sandy shale and thin layers of hard sandstone. It is usually but not invariably highly colored in many hues of red, purple, green, blue, and other colors. It is recognizable in most good exposures in Wyoming and northern Colorado, where it is definite enough to be considered a separate formation. In Wyoming this shale has been called the middle member of the Cloverly formation. It may prove to be the age equivalent of the Fuson formation of the Black Hills and is probably included in the Kootenai of Montana.

Middle sandstone.—The middle sandstone of the group is gray, hard, quartzose, evenly bedded, and strongly ripple marked at many localities. It is variable in thickness, and where the variegated shale below it is absent or not distinctive it has not been differentiated from the lower sandstone. This sandstone has been called upper Cloverly, true Dakota, and second Muddy and probably is included in the Purgatoire formation by different observers.

Middle shale.—The thickest formation of the group is a shale which, because of its median position, is here called the middle shale. It is a dark-colored bituminous marine shale, evidently an important

source of oil in both Colorado and Wyoming. In many places in northern Colorado between Morrison and Boulder it contains fossil plants which F. H. Knowlton refers to the Dakota flora. North of Boulder it has yielded fossil invertebrates which Reeside tentatively

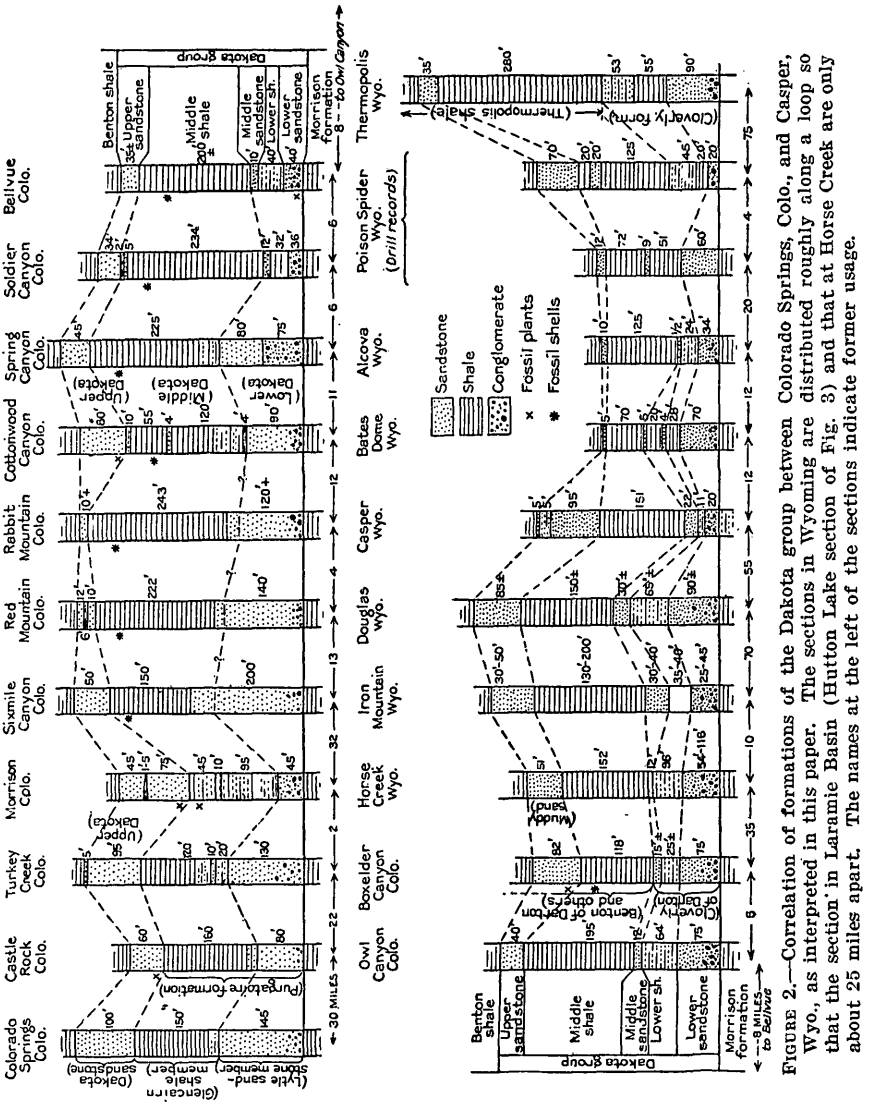


FIGURE 2.—Correlation of formations of the Dakota group between Colorado Springs, Colo., and Casper, Wyo., as interpreted in this paper. The sections in Wyoming are distributed roughly along a loop so that the section in Laramie Basin (Hutton Lake section of Fig. 3) and that at Horse Creek are only about 25 miles apart. The names at the left of the sections indicate former usage.

places in the Kiowa fauna of Kansas and the Purgatoire fauna of southeastern Colorado. Although belonging to species of wide range, these fossils tend to strengthen the contention that the Kiowa and Purgatoire should be classed as Upper Cretaceous.

Near Colorado Springs this shale is called the Glencairn shale member of the Purgatoire formation. In southern Wyoming it has been included in the Graneros shale or the lower part of the Benton. It is equivalent to the lower part of the Thermopolis shale of northern Wyoming.

Upper sandstone.—The upper sandstone is variable in character and thickness and in some places thins out entirely. It contains fossil plants, fragments of charcoal, streaks of coal, and a variety of markings and curious bodies resembling the fillings of worm borings. In many places it is a ridge maker. In others it is soft, granular, and extremely porous. It is a reservoir for oil derived from the bituminous shale below and is one of the oil-producing sandstones of Wyoming.

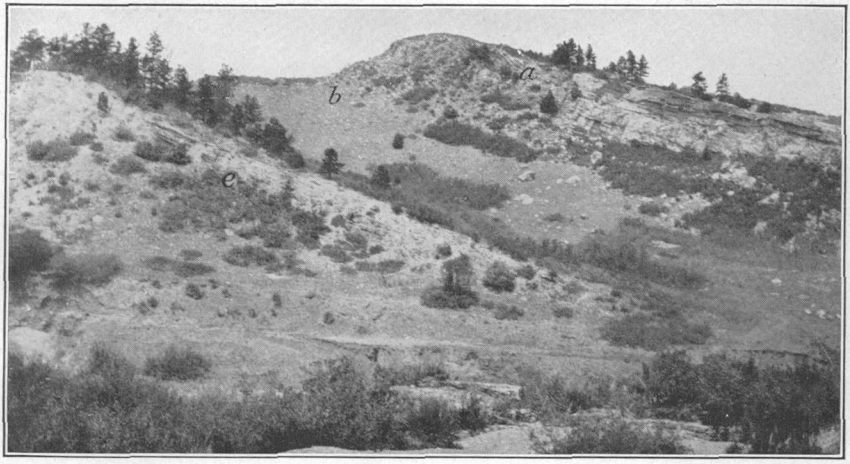
This sandstone is the upper Dakota of northern Colorado but is known to the oil men as the Muddy sand.

LOCAL CRITICAL OR ILLUSTRATIVE DETAILS.

In the following paragraphs are given notes on local details arranged in geographic order from Colorado Springs, Colo., to the Big Horn Basin, Wyo. Sections at most of these localities are shown in Figures 2 and 3.

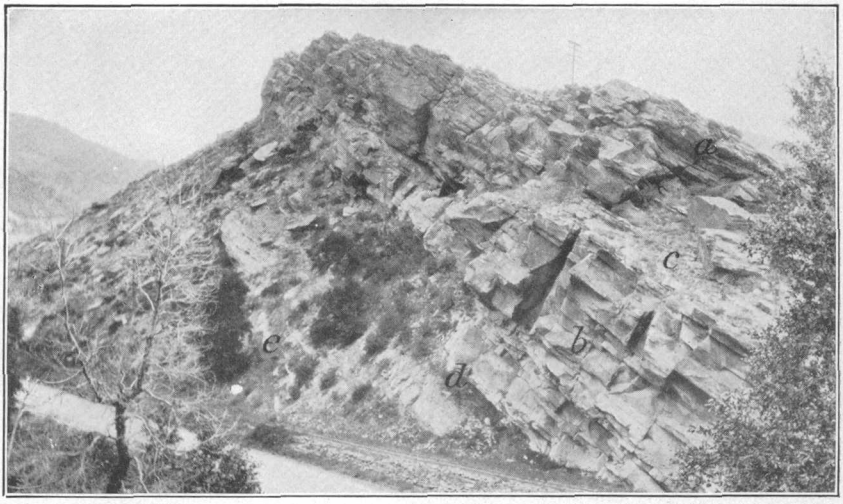
Perry Park, Colo.—The Dakota group in Perry Park, Colo., consists of two heavy sandstones separated by a thick bed of shale in which are thin sandstones and sandy shale. In some places the two main sandstones are both ridge makers (Pl. V, *A*); in others the younger sandstone forms the crest of a ridge in which the older sandstone crops out in the western slope. The lower sandstone is 80 feet thick, the shale 160 feet, and the upper sandstone 60 feet. The lower sandstone and the overlying shale in this district have been provisionally correlated with the Purgatoire formation, which has been referred to the Comanche series. The sandstone—the Lytle sandstone member of the Purgatoire formation of the Colorado Springs quadrangle and probably the basal sandstone of the Purgatoire formation of the Apishapa quadrangle—rests on the variegated shale of the Morrison formation and corresponds to the lower Dakota of localities in northern Colorado, and, to establish uniform nomenclature, it should be known by the same name. The temporary designation lower sandstone of the Dakota group is here offered.

Above the main mass of the lower sandstone in this area is a stratum of friable shaly sandstone a few feet thick, which has the physical character and color of the variegated shale of the middle Cloverly in many localities in Wyoming. It is overlain by a few feet of hard quartzose sandstone, which has the general appearance



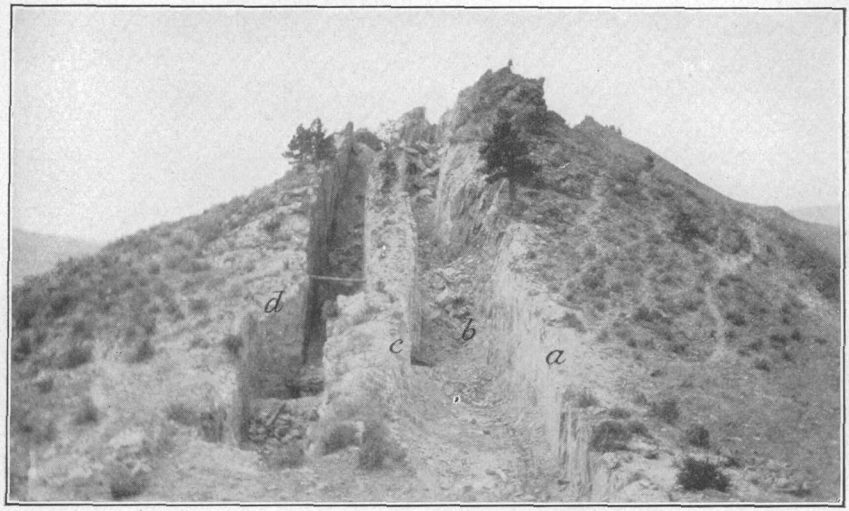
A. DAKOTA HOGBACK IN PERRY PARK, CASTLE ROCK QUADRANGLE, COLO.

Showing the lower sandstone (*c*) and middle shale (*b*) (Purgatoire formation of the Castle Rock folio), and the upper sandstone (*a*) of the Dakota group. The lower shale and middle sandstone were not seen.



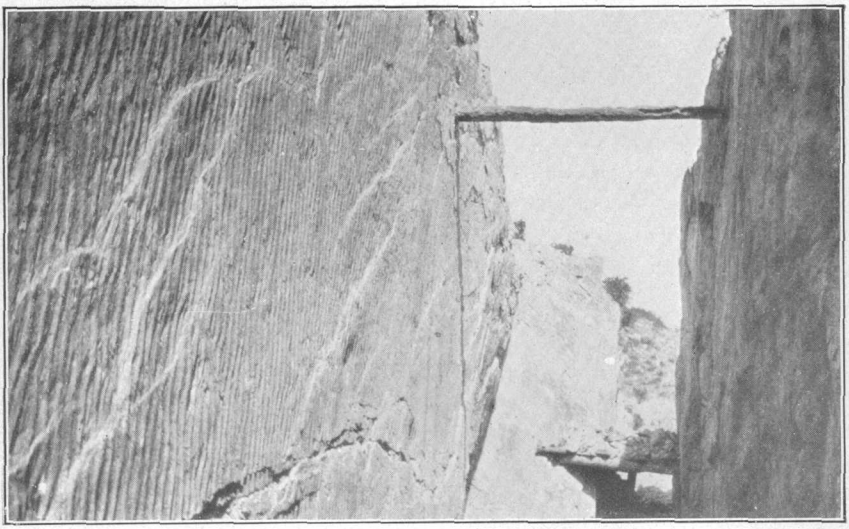
B. NORTH WALL OF GAP AT MORRISON, COLO.

Showing the upper sandstone separated into two members (*a*, *b*) by a thin dark shale (*c*). The base of this sandstone at *d* is marked by a porous layer of sandstone that contains fragments of carbonized wood. Soft shaly sandstone at *e* contains fossil plants of the Dakota flora.



A. DAKOTA HOGBACK ABOUT 3 MILES SOUTH OF GOLDEN, COLO.

Faulting causes an abnormal appearance of the beds. The lower sandstone and lower shale are represented in the slope at the right. The beds exposed in the clay pits (*b*, *c*, *d*) possibly represent the part of the middle shale that yielded fossil plants at Morrison, although they occupy a position that suggests the middle sandstone of the Dakota group. *a*, Sandstone in which no fossil plants were found; *b*, plant-bearing shale, 15 feet thick where quarried; *c*, plant-bearing sandstone, 8 feet thick, offset by a fault; *d*, sandstone in which no plants were found.



B. NEAR VIEW OF THE UPPER SURFACE OF THE MIDDLE DAKOTA OR 8-FOOT SANDSTONE (*c*) SHOWN IN *A*.

Upturned to a vertical position and exposed by removal of the shale, showing the intensely ripple-marked upper face.

of the middle sandstone as that formation is well shown in northern Colorado east of the mountains.

The thick shale between the two heavy sandstones in the writer's opinion corresponds to the Glencairn shale of the Colorado Springs quadrangle and probably to the upper part of the Purgatoire formation of the Apishapa quadrangle, to the middle shale of the Dakota in northern Colorado, and to the basal Benton of the Laramie-Sherman quadrangle and other parts of Wyoming. For the sake of uniformity it is here called middle shale of the Dakota group.

The upper heavy sandstone, about 60 feet thick, is the chief ridge maker in Perry Park, is relatively fine grained and quartzose, and contains fossil wood and leaf impressions of Cretaceous plants. It has previously been classed as the lowest member of the Upper Cretaceous series, but it corresponds to the upper Dakota of northern Colorado, to an unnamed sandstone in the Benton shale of the Laramie and Sherman quadrangles, and to the "first Muddy sand" of the oil men of southern Wyoming. For the sake of uniformity it is here called the upper sandstone of the Dakota group.

Roxbury Park, Colo.—About 10 miles north of Perry Park the upper sandstone of the Dakota group of this region is well exposed, but the lower sandstone and the Morrison formation, although recognized here, are not exposed sufficiently well for satisfactory measurement. The Morrison is succeeded, with an abruptness which suggests unconformity, by a conglomerate at the base of the lower Dakota. This sandstone is white, friable, and relatively soft. Together with the overlying middle shale it crops out in the western slope of the hogback.

The upper sandstone forms the main ridge and is a thick mass of hard cross-bedded quartzose sandstone. Between the massive ridge-making part of this sandstone and the overlying Benton shale there are several thin layers of sandstone and shale, the whole series 57 feet thick. Good exposures of the Benton shale and Niobrara limestone, which were deposited on the upper Dakota, occur here.

Turkey Creek, Colo.—Between Roxbury Park and Turkey Creek, a distance of about 12 miles, the foothill formations are exposed almost continuously and remain practically unchanged. The hogback is prominent, and the crest is formed by the upper sandstone, which occurs here in two massive layers separated by a thin shale. In the canyon of Turkey Creek the rocks are well exposed where the section was measured.

Morrison, Colo.—From Turkey Creek to Bear Creek canyon, about 2 miles farther north, the upper sandstone (Muddy sand) of the Dakota group is perfectly exposed. It forms the crest of the hogback and is the sandstone near Morrison long known as Dakota.

The well-known exposures of the Morrison and Dakota formations along Bear Creek, at the town of Morrison, are often cited by geologists. They were restudied by the writer in 1921, and the thickness was measured with stadia and plane table.

The double sandstone at the crest of the hogback (Muddy sand) is well exposed where Bear Creek cuts it (see Pl. V, *B*), and the two parts are separated by 1 to 5 feet of sandy shale. These sandstones, according to the late Prof. George L. Cannon, of Denver, are the two sandstones that were originally interpreted as the upper and lower sandstones of the Dakota group, and the shale as the fire-clay bed said to separate the two sandstones of the Dakota. His statement has the weight of authority, for he was associated in the field with those who wrote the reports. The writer found that this shale thins out within a short distance north of Morrison, and its position was not recognized farther north. The layer 2 inches thick at the base of the lower of the two sandstones is filled with fragments of carbonized wood and corresponds in position with the carbonaceous sandstone found in many other places just below the upper sandstone of the Dakota group as defined in this paper. This layer, according to Cannon, marks the base of the Dakota in this section as originally described. Numerous fossil leaves have been found in the upper sandstone and below it.

The upper part of the Morrison formation in Bear Canyon as originally interpreted is the middle Dakota of this paper. It consists of soft, friable sandstone and sandy shale. The lower part is variegated like the lower shale of the Dakota of localities farther north. In color it resembles the true Morrison shales, and until recently these variegated beds were included without question in the Morrison formation. The conglomerate below this colored shale is probably the "Saurian conglomerate" of the older descriptions of this section.

Golden to Boulder, Colo.—The shaly sandstone of the middle Dakota, above the variegated beds, yields fossil plants belonging to the Dakota flora and has been traced northward to Golden, where it is richly fossiliferous. South of Golden the upper sandstone is relatively thin and crops out in the eastern face of the hogback ridge, where a lower sandstone forms the crest. The beds between the two sandstones, consisting of shale and shaly sandstone (see Pl. VI), contain great numbers of leaf impressions. The lowest of the leaf-bearing sandstones is the one which near Golden has previously been called lower Dakota, although a still older sandstone (the lower sandstone of this paper), crops out inconspicuously in the west slope of the ridge.

The lower conglomeratic sandstone, the overlying variegated beds, and the Morrison formation, as here restricted, were traced from the town of Morrison northward nearly to Golden, where they crop out stratigraphically below the plant-bearing beds at the clay pits. Unfortunately the rocks have here been so disturbed by faulting and shearing that measurements do not indicate their original thickness, but the order of succession is the same as at Morrison. From this point northward to Boulder, Colo., the rocks of the foothills are so faulted and otherwise disturbed that it is difficult to trace the formations. This area was described at length in the Denver monograph as a region of ancient transverse folds against which the several formations were built and which was finally buried by the sediments of Cretaceous age. This interpretation has been successfully challenged by Victor Ziegler,[1] who discusses the structural relations found near Golden and explains them as due to faulting.

The beds of the Dakota group reappear less than 2 miles north of Golden, where they form the usual hogback. In spite of faulting, warping, and shearing, the general succession is recognizable where the clay has been mined out.

In Van Bibber Canyon, 3 miles north of Golden, the Morrison formation is not well exposed, but the lower sandstone of the Dakota, the shale and plant-bearing sandstones of the middle Dakota, and the upper sandstone or Muddy sand are well exposed. Between this canyon and Eldorado Springs the observed stratigraphic relations indicate that there is probably no change in the character of the formations. At Eldorado Springs, about 5 miles south of Boulder, most of the beds of the Dakota group are exposed in a road cut, where they stand practically vertical. A conglomeratic sandstone above the Morrison shale is obviously the lower sandstone of the Dakota group of this paper, and thick sands above probably represent the upper sandstone. The intermediate shale may have been sheared out here when the strata were upturned, as it has been in other places near Golden and Boulder.

Sixmile Canyon, Colo.—In the vicinity of Boulder, Colo., the rocks are faulted and otherwise disturbed and the Dakota group is not well exposed, but a few miles north of the town good exposures are found. The lower Dakota of the section measured years ago in Sixmile Canyon may include the variegated shale and the middle sandstone. This section has not been examined since these formations were recognized. The other formations of the group are well defined.

Lyons, Colo.—A section from the base of the lower sandstone of the Dakota group to the base of the Benton shale was measured with stadia near Lyons, Colo., about 1 mile southeast of Red Mountain,

[1] Ziegler, Victor, Foothills structure in northern Colorado: Jour. Geology, vol. 25, pp. 715–740, 1917.

and another section on the east slope of Rabbit Mountain, about 3 miles east of Lyons. The lower Dakota forms the chief "Dakota hogback" in this region. South of Lyons the upper Dakota forms a relatively high ridge, but near Rabbit Mountain it is so inconspicuous as to be scarcely recognizable on the plain, and in some places it disappears entirely. A few miles east of Lyons this sandstone is well exposed where cut on a ditch line (Pl. III, *A*) and found to consist chiefly of dark carbonaceous sandy shale. The middle sandstone and lower shale are not exposed and are probably included in the platted sections of the lower sandstone.

Cottonwood Canyon west of Loveland, Colo.—The upper sandstone north of Rabbit Mountain continues thin and inconspicuous for nearly 12 miles, but west of Loveland, Colo., it thickens and again forms a prominent ridge. Here all the strata of the Dakota group are well exposed and were measured with stadia in Cottonwood Canyon (Dry Creek) in a ditch cut. The results are platted on the chart (Fig. 2). The lower shale of the Dakota is represented here by 4 feet of red shale, and the middle sandstone by four thin sandstones separated by shale.

Thompson Canyon, Colo.—Thompson River has cut gorges through the several ridges formed in a great fold by which the upturned rocks are here offset to the east. The lower sandstone is the most prominent ridge maker of the Dakota group, although the upper or Muddy sand in some places makes a ridge of nearly equal prominence, as shown in Plate I, *A*. However, a few miles farther to the north the Muddy sand is so thin and the ridge made by it so inconspicuous that it might easily escape notice.

Spring Canyon and Soldier Canyon, Colo.—The rocks of the Dakota group are well exposed in Spring Canyon, near Fort Collins, Colo., and a few miles farther north in Soldier Canyon, where they were measured with stadia. In this region there is a distinct sandstone between the massive lower sandstone and the fossiliferous middle shale shown in Plate III, *B*. Were it not for the higher sandstone, which forms the main hogback ridge, these lower sands might readily be interpreted as upper Dakota and lower Dakota. A large collection of fossil invertebrates from the middle shale has been used in correlating the formations.

Bellvue, Colo.—The foothill formations have been thrown into a dome near Bellvue, Colo., and this dome was later cut by Cache la Poudre River, so that the formations bowed up in the dome are now exposed in the bluffs of the river. The Morrison formation south of the river is well exposed and contains dinosaur bones. The lower sandstone (see Pl. II, *A*) is unusually conglomeratic and contains petrified logs. About 2 miles north of Bellvue the several formations of the Dakota group are well exposed in a ditch cut, as described in the

introductory paragraphs. The middle shale yielded a good collection of invertebrates, which have been used in establishing the correlations made in this paper. An unconformity at the base of the conglomerate is marked by channel-like hollows in the variegated Morrison shale filled with pebble beds of the overlying lower conglomerate of the Dakota.

Owl Canyon and Boxelder Creek, Colo.—North of Bellvue all the formations of the Dakota group continue uninterruptedly and were measured with stadia on Owl Creek, about 10 miles north of Bellvue, and on Boxelder Creek, 6 miles farther north.

Boxelder, Colo., to Horse Creek, Wyo.—About 7 miles north of Boxelder Creek the formations of Cretaceous age disappear under Tertiary deposits, and for about 25 miles they are covered by these deposits except for small exposures in a few places where streams have cut through the Tertiary beds. In the Laramie and Sherman quadrangles and in southern Wyoming generally the beds here assigned to the lower part of the Dakota group have been called Cloverly by Darton. (See Horse Creek section, Fig. 2.) The middle sandstone is the upper Cloverly of many geologists, the variegated shale is the middle Cloverly, and the lower sandstone of the Dakota group is the lower Cloverly as that name is used in southern Wyoming. The middle shale and the upper sandstone or Muddy sand have been generally included in the Benton shale. A section of the Dakota group about 30 miles north of the Colorado-Wyoming State line, as measured on Horse Creek and on Mill Creek 1½ miles north of Horse Creek, is shown on the chart (Fig. 2).

Iron Mountain, Wyo.—The foothill formations are exposed in many places north of Horse Creek and near Iron Mountain, about 10 miles north of this creek. They are particularly well exposed in the gorge cut through the Dakota hogback by Chugwater Creek (Pl. I, *B*), where quarrying has exposed to view the middle shale of the Dakota, and also in a gulch one-eighth of a mile north of this gap (Pl. IV, *B*).

A few miles farther north, in the canyon of Threemile Creek at the Jordan ranch, the Dakota group is upturned so that the formations are vertical and the sandstones make prominent ridges. The shales between the sandstones are not well exposed here, and few details could be obtained, but the sandstones and the shale intervals were measured with tapeline.

Douglas, Wyo.—North of Iron Mountain the Cretaceous rocks are covered with Tertiary deposits for a distance of nearly 70 miles. The next locality north of Iron Mountain at which satisfactory exposures of the Dakota group were found is near Douglas, Wyo. (Pl. IV, *B*). In many places south of this town the formations of the group are

well exposed and were found to vary greatly from point to point. The strata are thrown into a series of sharp folds and otherwise greatly disturbed, and the variations in thickness may be due to these movements. The Douglas section of the accompanying chart (Fig. 2) is a composite of measurements made at several localities south of Douglas.

Casper, Wyo.—The formations of the Dakota group were observed in several places between Douglas and Casper. The lower formations of the group are exposed on La Prele Creek west of Douglas, where the lower and middle sandstones and the shale separating them were recognized. Barnett[2] gives a section of these formations measured on Boxelder Creek, 17 miles west of Douglas. The same writer in describing the possibilities of oil in the Big Muddy dome gives a section of the "Cloverly" formation 137 feet thick, 20 miles farther west, at the east end of Casper Mountain, where he found two prominent sandstones separated by shale. The present writer verified this observation and recognized also the middle shale of the Dakota and Muddy sand above Barnett's Cloverly. No indication was found of any notable change in the group, and the next point at which detailed observations were made is at the west end of Casper Mountain, where the Dakota formations are well exposed. Measurements made here by Reeside are used in platting the Casper section of Figure 2.

Bates dome, Wyo.—The lower sandstone is variable in thickness around the Casper Mountains, but the lower shale, middle sandstone, and middle shale are readily recognizable. The upper sandstone or Muddy sand is variable. In some places it is so thin that it probably would not be noticed as different from certain sandstone layers within the Benton shale, were it not traced laterally to localities where its character is unmistakable. In the Bates dome, 12 miles south of the place where the Casper section was measured, the Dakota group was penetrated by the drill. The thicknesses used in platting the sections in Figure 2 are taken in part from well records and in part from surface measurements.

Alcova, Wyo.—Farther to the southwest, near Alcova, Wyo., about 12 miles from the Bates dome, the formations of the Dakota group were measured where they crop out in a series of folds. All the formations of this group are present, but the middle sandstone is represented by only 6 inches of pebbly sand. Probably its identity as the middle sandstone of the Dakota would not be suspected except for its position above the conglomeratic lower sandstone. The upper sandstone also changes in character westward. Near Alcova it is distinctly shaly, and in some places it is little more than

[2] Barnett, V. H., The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, p. 61, 1914.

a sandy zone included in dark-colored shale. In some localities the upper and middle sandstones seem to merge into shale toward the west and disappear as recognizable formations.

Poison Spider Creek, Wyo.—West of Casper and about 20 miles north of Alcova the Dakota group has been penetrated by the drill in many places and observed at the outcrop over a considerable area. The records of two wells near Poison Spider Creek, 20 miles west of Casper, have been selected as representative of this part of the country. (See Fig. 2.) The three sandstones of the Dakota group are noted in the well records, but little is known of their character.

Oil fields northwest of Casper, Wyo.—Hares [3] describes a conglomerate of general occurrence which he regards as Lower Cretaceous, resting on Morrison shale. This conglomerate is the lower sandstone of the Dakota of the present paper. Above the conglomerate is Hares's Lower Cretaceous shale, which corresponds to the writer's middle shale of the Dakota. Apparently Hares did not distinguish the middle sandstone and lower shale of the Dakota group as separate units. His Dakota sandstone is correlated with Woodruff's Dakota of the Lander field, which is the upper Dakota of this paper and the Muddy sand of local geologists. But in his correlation table he seems to regard this sandstone as that which in certain places is here determined as the middle sandstone. On the whole it is obvious from Hares's descriptions that in the area between Casper and Thermopolis there is no notable change in the Dakota group.

Thermopolis, Wyo.—Although the formations of the Dakota group in the Big Horn Basin have been described by many geologists, there still remains uncertainty as to the exact interformational lines and the correlation with formations at localities outside of this basin. In order to compare the formations directly with those observed between Colorado Springs, Colo., and Casper, Wyo., the writer visited the Big Horn Basin and made observations at several localities. He is satisfied that the Morrison formation as recognized by all observers in this basin is the same as the Morrison of other localities described in this paper. The Mowry shale marks an upper horizon that is easily recognized and is believed to be constant over wide areas. Between the Morrison and the Mowry are the beds in question. Resting on the Morrison unconformably in some if not in all places is a conglomeratic sandstone, the lower member of the Cloverly formation. It is obviously the lower Dakota sandstone of this paper. Above this conglomerate is the variegated sandy shale, called middle Cloverly by some writers, Fuson formation by others, and a part of the Kootenai formation by still others. It is the lower

[3] Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey Bull. 641, pp. 233–279, 1917.

shale of the Dakota of this paper. Above it is another sandstone, the middle sandstone of this paper, which is equivalent to the Greybull, upper Cloverly, or Dakota of various writers. Still higher is the Thermopolis shale, 400 to 800 feet thick, including at the base 100 feet or more of "rusty beds," overlain by dark-colored shale included in the middle shale of the Dakota of this paper, and near the middle a sandstone termed by the drillers the Muddy sand.

A section of these beds was measured about 3½ miles north of Thermopolis, the middle shale by pacing across the strike, the other formations by direct tape measurement. The upper sandstone (Muddy sand) was measured in a nearly vertical cliff, and the lower formations of the group in the railroad cut northeast of the town. The lower part of the beds here included in the lower Dakota is quite different from the upper part. It consists of dark-colored masses of loosely cemented conglomerate about 10 feet thick and of about 10 feet of carbonaceous shale, so black that prospect entries have been driven into it in search of coal. The conglomerate and shale are different from the other parts of the Dakota group and may represent a distinct formation. The lower pebble beds and black shale are still more prominent east of the river, but in many other places they are not represented. Darton included these beds in the Morrison formation, but they are different from any beds which the writer has seen elsewhere in that formation.

The occurrence of carbonaceous shale below the conglomerate of the lower Dakota recalls Fisher's description[4] of a coal bed on Nowood Creek "beneath the lowest prominent sandstone" of the Cloverly, where he found fossil plants of the Kootenai flora. Wegemann notes a similar occurrence in the Powder River oil field east of the Big Horn Mountains. Fisher also describes a section near Frannie, Wyo., in the northern part of the Big Horn Basin, in which 50 feet of leaf-bearing sandstone occurs beneath the lower conglomeratic sandstone of his Cloverly formation. These occurrences suggest that the isolated remnants of coal-bearing strata may represent the lower or coal-bearing part of the Kootenai formation of Montana.

Tensleep, Wyo.—At the exposure near Tensleep illustrated by Hewett and Lupton[5] the writer recognized all the formations of the Dakota group and found dinosaur bones in the Morrison shale 50 feet below the base of the lower conglomeratic sandstone of the Dakota. The Dakota group here differs in no essential from that near Thermopolis described above, except that no dark-colored conglomerate or black shale was found between the Morrison shale and the white conglomerate of the lower Dakota.

---

[4] Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geology, vol. 3, p. 85, 1908.

[5] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Big Horn Basin, Wyo.: U. S. Geol. Survey Bull. 656, pl. 4, *A*, 1917.

Greybull, Wyo.—It has been stated frequently that the Cloverly formation is equivalent in whole or in part to the Dakota. The type area of the Cloverly is in the northeastern part of the Big Horn Basin, where Darton measured a section 1½ miles west of Cloverly, Wyo. His description leaves no room for doubt that the same beds are exposed near Greybull, where they were examined hastily in the anticline north of Sheldon's ranch and at the south end of Sheep Mountain, a few miles northeast of Greybull. At both of these localities the sandstones are relatively soft and friable and are colored like those of the Morrison formation. Because of this color some geologists have included the lower sandstone and lower shale of the Dakota in the Morrison formation. Therefore, it is not certain that the interformational boundaries of different observers are drawn in the same place. The writer holds the opinion that all five formations of the Dakota group are represented here, but measure-

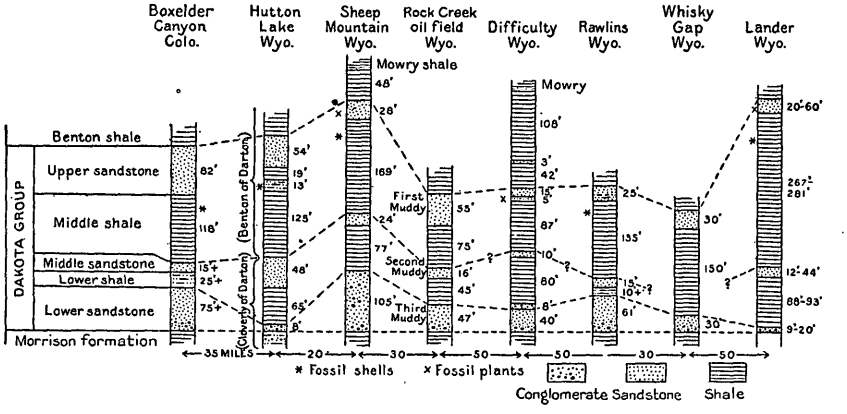


FIGURE 3.—Sections of the Dakota group west of the Laramie Mountains, Wyo.

ments comparable with those made at more southerly localities were not obtained.

Sections west of the Laramie Mountains, Wyo.—In northern Colorado the sedimentary formations occupy a reentrant in the mountains where they are separated from those of the Laramie Basin by a low ridge a few miles wide from which the sedimentary rocks have been eroded. The Boxelder section is situated in this reentrant and serves to show the relation of the formations of the eastern foothills to those west of the mountains. Sections of the Dakota group measured by Prof. S. H. Knight in the Laramie Basin are shown in the second and third columns of Figure 3. Professor Knight has examined the outcrops at practically all exposures in this basin, and his observations and conclusions were verified in many places by the writer.

Laramie Basin and Hutton Lake, Wyo.—The Cloverly in the vicinity of Laramie, Wyo., has been described by Darton in the

Laramie-Sherman folio [6] as consisting of two sandstones and a shale. Above the Cloverly—that is, in the lower part of the Benton of this folio—is a shale that corresponds to the middle shale of the present paper and a sandstone that is obviously the upper sandstone or Muddy sand. A section of these beds published in this folio was measured years ago near Hutton Lake, 12 miles southwest of Laramie. Later an irrigation ditch was cut through the upturned beds. Professor Knight's section (see Fig. 3) was measured in this cut. He assigns only 8 feet to the lower Dakota, whereas Darton assigns 75 feet to it. The writer, in company with Professor Knight, observed here below the 8-foot layer a considerable thickness of conglomeratic sandstone which, because of the highly colored shale interbedded with it, is included in the underlying Morrison formation. Doubtless in weathered exposures the conglomerates would appear to belong together, and if in spite of the interbedding of colored shale they are included in the lower Dakota, the thickness would approach the 75 feet formerly assigned to it.

West flank of Sheep Mountain, Wyo.—Another section of the Dakota group was measured by Professor Knight in the Laramie Basin on the west slope of Sheep Mountain, 20 miles northwest of Hutton Lake. Here the basal conglomerate is unusually thick and rests with conspicuous contact on soft Morrison shale. The lower shale of the Dakota group is highly colored—pink, orange, red, and black. The middle sandstone is brown, flaggy, and ridge making. The middle shale is dark colored and contains near the base ironstone concretions that give it a rusty aspect and near the top thin warped layers of sandy limestone that yielded fossils characteristic of the middle shale of the Dakota. Above the brown cross-bedded upper sandstone is black to greenish-gray shale 48 feet thick, with bentonite, and above this in turn is the Mowry shale.

Rock Creek oil field, Wyo.—In the Rock Creek oil field, about 30 miles north of Sheep Mountain, many wells have penetrated the Dakota group. Some of these wells are on the side of the Rock Creek dome and penetrate diagonally through the beds of this group. However, several are so near the crest of the dome that they penetrate the formations at right angles to the bedding planes and therefore their records show true thicknesses. In six of these wells the three sandstones of the Dakota group, here called first Muddy, second Muddy, and third Muddy, seem to be clearly recognizable, and the figures used in the platted section (Fig. 3) indicate average thicknesses as shown by the well logs.

[6] U. S. Geol. Survey Geol. Atlas, Folio 173, 1910.

Hanna Basin, Wyo.—In his report on the geology of Hanna Basin, Wyo., which is about 30 miles northwest of Rock River, Bowen[7] assigns 231 feet of strata to the Cloverly formation, which he describes as consisting of an upper sandstone, a middle shale, and a lower conglomeratic sandstone. This thickness leads to the suspicion that Bowen's upper sandstone is the upper sandstone (Muddy sand) of this paper rather than the upper part of the Cloverly. It also raises a question as to Bowen's Thermopolis shale, which lies between his Cloverly and the Mowry shale. If the Thermopolis of the Hanna Basin is equivalent to the Thermopolis of the Big Horn Basin, the Muddy sand should be within it rather than below it. The Thermopolis of the Hanna Basin may be the dark shale which the writer has observed generally in Wyoming between the upper sandstone of the Dakota and the overlying Mowry shale.

Professor Knight measured a section on Difficulty Creek in the north rim of this basin (sec. 21, T. 24 N., R. 80 W.), which is platted in the accompanying Figure 3. He found here no colored shale above the basal conglomerate. The shaly beds between it and the sandstone assigned to the upper Dakota are all dark colored, "of Benton type." Hence it is not certain that the 10-foot sandstone near the middle is properly correlated with the middle sandstone of the Dakota. The uppermost sandstone of the group contains fossil plants, and above it is black shale—the upper part of the Thermopolis and the Mowry shale.

Rawlins, Wyo.—About 50 miles west of Difficulty Creek a section was measured about 12 miles northwest of Rawlins, Wyo., where the formations of the Dakota group are all plainly recognizable. However, no place was found where the lower Dakota is well enough exposed for exact measurement. Its thickness in some places is greater than the 10 feet assigned to it, but its character, where seen in isolated exposures, does not differ from that of other localities where more extended observations were possible. The middle shale is sparingly fossiliferous and otherwise like the lower Thermopolis, but the upper sandstone of the Dakota is here shaly and forms an inconspicuous ridge.

Whisky Gap, Wyo.—The Dakota group was examined about 30 miles northwest of the Rawlins section, near Whisky Gap, north of Lost Soldier. The section for this locality shown in Figure 3 was measured by A. E. Fath during his examination of the Lost Soldier oil field. This locality is about 50 miles southwest of Alcova, on the opposite side of the granite area that represents the western extension of the Laramie Mountains. The Cretaceous strata on the two sides of this mountain range are so similar that it seems certain that

[7] Bowen, C. F., Stratigraphy of the Hanna Basin, Wyo.: U. S. Geol. Survey Prof. Paper 108, pp. 227–241, 1918.

they originally extended without interruption across the area where these mountains now stand. Mr. Fath did not note the presence of the middle sandstone or of the variegated lower shale, which is not well exposed here. On the other hand, the writer found at a locality south of Whisky Gap the lower sandstones separated by shaly beds. Fath noted 30 feet of upper sandstone, but at the locality examined by the writer, although the Mowry shale is well exposed, no sandstone was found below it at the horizon of the upper sandstone of the Dakota. Doubtless here, as in many other places, the Muddy sand is not perfectly continuous.

Lander, Wyo.—Between the Lost Soldier oil field and the exposures at the south end of the Wind River Mountains, a distance of nearly 50 miles, the surface is occupied generally by Tertiary rocks, and there is little opportunity of observing the older formations. But in the foothills of the Wind River Mountains all the formations of the Dakota group were recognized. The subdivisions described by Woodruff[8] in 1911 were reviewed in the field by the writer in 1922 for the purpose of correlating them with the sections used in the present paper. Woodruff describes a massive gray coarse-grained cross-bedded conglomeratic sandstone 9 feet thick on Twin Creek south of Lander and 20 feet thick on Sage Creek northwest of Lander, which rests on the Morrison shale and which he assigns to the base of his "Lower Cretaceous rocks." This sandstone is obviously the lower sandstone of the Dakota of the present paper. Above this conglomeratic sandstone are soft sandy shales of varied color, 88 feet thick on Twin Creek and 93 feet thick on Sage Creek, which correspond to the lower shale of the writer. The middle sandstone is represented by a sandstone in Woodruff's Lower Cretaceous, 12 to 44 feet thick, containing fresh-water shells and plants. On this sandstone lies shale 267 to 281 feet thick, which includes layers of rusty sandstone and black carbonaceous shale and near the top limy layers containing fossils similar to those found in many places near the top of the shale here called the middle shale of the Dakota. Above this shale is a sandstone 20 to 60 feet thick, according to Woodruff, which has yielded fossil plants of the Dakota flora. The writer has no hesitancy in correlating this sandstone with his upper sandstone (Muddy sand) of the Dakota group. It has the same stratigraphic position as the Muddy sand of other localities—above dark rusty fossiliferous shale and below Mowry shale—and like the Muddy sand it is locally absent near Lander.

CONCLUSIONS AS TO OIL SANDS.

The sections platted in this report tend to confirm the opinion, previously advanced by the writer, that the Dakota group in north-

[8] Woodruff, E. G., The Lander oil field, Fremont County, Wyo.: U. S. Geol. Survey Bull. 452, p. 18, 1911.

eastern Colorado is not divisible on physical grounds into Lower Cretaceous and Upper Cretaceous, as these subdivisions are generally understood, but is a single group of variable beds formed near the margin of the transgressing Cretaceous sea and as such constitutes the basal portion of an indivisible Cretaceous series. When the group is traced laterally for long distances, however, difficulties are met in making this assignment. The lower beds of the group seem to be identical with beds in southern Colorado and Kansas that have been assigned by paleontologists to the Comanche series. These beds have been called Lower Cretaceous[9] by some geologists and Upper Cretaceous by others. The question of their geologic age has been discussed by the writer,[10] who concludes that the beds in question belong to the Upper Cretaceous series. Tracing the group northward from Colorado Springs,[11] where these beds have been called Lower Cretaceous, discloses changes whose significance is not fully understood. But there is little room for doubt that the lower conglomeratic sandstone, called Purgatoire in some places, lower Dakota in others, and lower Cloverly in still others, is a continuous formation. It should be noted further in this connection that in some places in northern Wyoming beds that contain fossil plants of Kootenai age separate this conglomerate from the underlying Morrison. The colored lower shale thickens northward and has been correlated by some geologists with the Kootenai formation of Montana and by others with the Fuson formation of the Black Hills. The middle sandstone is known under several different names—upper Cloverly, "true Dakota," and Greybull. The middle shale, in the writer's opinion, is the Glencairn of Colorado Springs, the lower part of the Benton shale of southern Wyoming, and the lower part of the Thermopolis shale of the Big Horn Basin. The upper sandstone (Muddy sand) occurs near the middle of the Thermopolis shale and is probably the same as the Newcastle sandstone of eastern Wyoming.

Whether the strata of this group are wholly of Upper Cretaceous age or in part Upper Cretaceous and in part Lower Cretaceous may be only an academic question, of no practical importance. But the facts underlying the stratigraphic relations implied in those names are of prime importance economically. If the lower part of the group is Lower Cretaceous in one place and Upper Cretaceous in another place, the continuity of the beds as shown by the correlated sections can not be correct, and in its place there must be certain physical relations that have not yet been discovered. The writer's work in the field tends to show that the formations

[9] Stose, G. W., U. S. Geol. Survey Geol. Atlas, Apishapa folio (No. 186), p. 4, 1912.

[10] Lee, W. T., Type section of the Morrison formation: Am. Jour. Sci., 4th ser., vol. 49, p. 188, 1920.

[11] Finlay, G. I., U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), p. 7, 1916.

are essentially continuous from place to place, so far as his examinations have extended, and belong to a single series of rocks. It warrants a question as to the propriety of assigning the lower conglomerate and shale to a separate series—the Lower Cretaceous.

Several economic applications of this work are immediately apparent. Perhaps the most important is the knowledge that the upper sandstone or Muddy sand is present along the east front of the Rocky Mountains from points in northern Wyoming to Colorado Springs, Colo., and that almost everywhere it is underlain by a body of dark bituminous shale. The character of this sandstone and shale makes them important contributors of oil in Wyoming and possibly also in Colorado.

The knowledge that a sandstone known as the Dakota in some regions is in fact the Muddy sand and that below it are two other sandstones which may be oil bearing is also of primary importance. Barrenness of one or even of two of these sands need not mean that all three are barren. These three sandstones of the Dakota group have been tested comparatively little in southern Wyoming and northern Colorado, and many of the wells put down have terminated in the Muddy sand. But although normally there are three sandstones, one or another is so thin in some places that it would scarcely be recognized in drilling.

The attention which this work draws to the presence of colored or variegated beds above the lower sandstone of the Dakota group is also timely. Ordinarily colored shales below the somber beds of the Benton have been interpreted as Morrison, and it has been reasoned that the chances of oil production from these or lower beds were negligible, whereas in many places the lower sandstone would be reached if the variegated beds were penetrated for a depth of 20 to 100 feet. Although the lower sandstone of the Dakota is not of great promise as an oil-bearing sand, it should unquestionably be tested where a test can be made without prohibitive expense.

The persistently conglomeratic nature of the lower sandstone should also be emphasized. Some of the overlying beds are slightly conglomeratic, but the lower sandstone is persistently so. This characteristic may not permit certain recognition of this sandstone, but lack of conglomeratic material in drill cuttings may justify the conclusion that the lower sand has not been reached.