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Preliminary Notes on the Revision of the Geological Map of Eastern Colorado

By
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GEOLOGICAL BOARD

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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, October, 1924.

Governor William E. Sweet, Chairman, and Members of the Advisory Board of the State Geological Survey.

Gentlemen: I have the honor to transmit herewith Bulletin of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

PRELIMINARY NOTES ON THE REVISION OF THE GEOLOGICAL MAP OF EASTERN COLORADO

INTRODUCTION

During the past year there has arisen a great need and demand for a revision of the present geologic map of Colorado. Because of this it has seemed advisable to place in bulletin form a brief synopsis of new information at hand, and to place before the interested public a preliminary map of the eastern part of the state where experience has shown considerable revision to be necessary.

The data upon which the present report and map are based have been derived from many sources. The major portion of the information has been derived from field work done under the supervision of the Colorado Geological Survey. Publications of the United States Geological Survey have been consulted freely and where the areal geology is known to be essentially correct, the results have been incorporated in the present work.

FIELD WORK

The field work of the Colorado Survey has been spread over a considerable period and has been supervised by several workers. The area included between the 103d and 104th meridians and the 37th and 38th parallels was mapped by a party in charge of J. T. Duce. In 1921 a party consisting of A. J. Tieje, J. C. Myers, and A. N. Murray covered an area included in T. 24, 25 and 26 S., R. 53 and 54 W. The remainder of an area included between T. 21 and 26 S., R. 53 and 57 W. was mapped in 1922 by Dr. Horace B. Patton and party. In 1923 a party under the direction of the writer completed the mapping of Crowley and western Otero counties. During the past field season two parties were employed in making a rather rapid study of the areas where revision has been shown to be urgent. One party, under the direction of Mr. J. W. Vanderwilt, covered a considerable area in Baca County, the region from southern Cheyenne County (east of R. 50 W.) north to the state line and from the parallel 40° 30′ to the state line west to the foothills. The second party, under the direction of the writer, mapped the territory from the southern boundary of Lincoln County to the northern line of Morgan County and from R. 50 W. to approximately R. 68 W. A considerable portion of the latter territory, included roughly between the tracks of the Union Pacific and the Chicago, Rock Island and Pacific Railroads, was mapped a number of years ago by G. B. Richardson of the United States Geological Survey and has not been studied again. As noted below, however, some additional study of an area east of the town of Kiowa is contemplated in an effort to determine the existence of beds of Raton age.

GEOLOGY

In the course of the work outlined above, the following formations have been studied in more or less detail:

Tertiary:		
Miocene-Pliocene ?	Arikaree, Ogallala, Nussbaum, Mapped as a unit	125 feet
Oligocene	White River	0-140 feet
Eocene	Arapahoe?	?
Cretaceous:		
	Laramie	0-400 feet
Montana group	Fox Hills	400-700 feet
	Pierre	2000-5000 feet
Colorado group	Niobrara	700 feet
	Benton	390 feet
Dakota group	Dakota	100 feet
	Purgatoire	160 feet
Jurassic:		
Morrison formation		150-270 feet
Permian-Pennsylvanian	"Red Beds"	365 feet

Only a brief summary of the lithologic character of the beds can be given in this paper, the detailed description being reserved for a later and more complete publication. For more detailed descriptions of the formations of the foothills of north central Colorado and the Cretaceous of the northeastern part of the state, the reader is referred to Bulletin 19 of the Colorado Geological Survey by Prof. J. Henderson.

DESCRIPTION OF FORMATIONS

PALEOZOIC

Permian-Pennsylvanian: The oldest formations exposed in eastern Colorado outcrop along the Purgatoire River and Chaquaqua Creek in T. 28, 29, 30 S., R. 56, 57 and 58 W., and consist almost exclusively of red beds. J. T. Duce in an unpublished manuscript described two distinct members at the junction of Chaquaqua Creek with the Purgatoire River, the Chaquaqua member below and the Red Canyon member above. The Chaquaqua is described as being 122 feet in thickness and consisting of brick red to purplish sandstone and red to maroon colored sandy shale and shale. The Red Canyon member consists of 240 feet of maroon sandstone, oolitic in structure and probably of eolian origin. Above this member Duce describes 60-65 feet of gypsum, gypsiferous clays, and grey sandy shale transitional to the Morrison. Part of this zone should perhaps be included in the Morrison formation.

JURASSIC?

Morrison formation: Following the past practice of the Colorado Geological Survey, the Morrison is here considered as Jurassic, though there is as good evidence for placing it in the Cretaceous. The formation occurs at the surface, east of the foothills, only in the valleys and canyons of the upper portions of the Purgatoire River and Rule Creek drainage systems in southeastern Otero, northeastern Las Animas, and southwestern Bent Counties. Lithologically, the Morrison is an extremely variable formation, sections from nearby areas often showing few to no similarities either in character of beds or color. In the outcrop area in southern Colorado, the formation consists chiefly of rather brightly colored shales and sandstones with intercalated thin limestones and a basal conglomerate. Greens, reds, purples, and chocolate brown are the predominant colors. The sands are, in general, but poorly indurated. Gypsum is found near the base in most places and, according to Duce, is always overlain by beds containing abundant chalcedony nodules. Bones of dinosaurs are usually present. Though least important in the makeup of the formation, the limestones are the most resistant members and give origin to most of the topographic features in the region of outcrop. In thickness, the Morrison is said to vary from 150 to 270 feet.

CRETACEOUS SYSTEM

DAKOTA GROUP

The Dakota group, consisting of the Purgatoire formation and Dakota sandstone, occurs at the surface in eastern Colorado in an area south and slightly north of the Arkansas River and in the foothills region. In the latter, the Dakota group is not generally separated into distinct units with separate names, but the same tri-partite arrangement as described below has been recognized in most places.

Purgatoire formation: The lower member of the Dakota group is composed of 160 feet or more of white and yellow sandstone with some 15 to 30 feet of grey shale and flaggy quartzitic sandstone at the top. The lower 100 feet consists of massive, coarse grained, rather soft white sandstone. This is overlain by 30 to 40 feet of yellowish sandstone grading up into the shale and quartzite series noted above. Marine fossils are reported in limited numbers from the yellow sandstone and from the shale series. The shale member here undoubtedly corresponds to that which separates the two sands in the Dakota formation in the foothills, and is probably to be correlated with the Fuson shale of the Black Hills region.

According to Duce, the Purgatoire thickens westward into the Apishapa quadrangle, where 220 feet are reported by Stose in the Apishapa Folio of the United States Geological Survey. Patton, in his work on the Otero County sections, found the top of the Purgatoire sandstone to be marked by a distinct ledge formed by a bed, five to six feet thick, more resistant than the underlying sands.

Dakota sandstone: The true Dakota in southern Colorado is made up of approximately 100 feet of hard, thick to thin bedded, light grey to buff, locally white, quartzitic sandstone. It is usually finer in grain and much more firmly cemeted than the underlying Purgatoire. Locally the color may

become dark brown. Duce reports that the Dakota yields considerable fossil wood and imperfect leaves in places, whereas only marine invertebrates occur in the lower member. In the foothills region, marine fossils have been found in the formation in several places.

The two formations in the Dakota group are the most important members of the geologic column from an economic standpoint. In the Arkansas Valley and elsewhere in eastern Colorado, the group is the source of artesian water. Both members yield water, the Purgatoire being the "second Dakota", the Dakota the "first Dakota sand" of well drillers. In north central Colorado, the Dakota group forms the reservoir for the oil and gas in the Ft. Collins region. It is the opinion of the writer, Prof. Henderson, and others that the the so-called Muddy sand of the oil geologist is the true Dakota as described in the type area in South Dakota and that the lower member of the group is the equivalent of the Purgatoire of the Arkansas Valley and the Lakota-Fuson of the Black Hills region in Wyoming and South Dakota.

COLORADO GROUP

Benton Subgroup: The Benton formation is divided into three members, the Graneros shale below, the Greenhorn limestone and the Carlile shale above. Because of the limited areas covered by the thinner members, and the difficulty in showing each separately on a small scale map, the three units are mapped together here. The following description, however, gives the chief characteristics of each member.

Graneros shale: The Graneros shale is a body of 200 to 210 feet of medium to dark grey bluish shale. The central portion is dark grey to black, the lower and upper portions are distinctly lighter in color. Some forty feet below the top occur several thin beds of grey, platy, sandy limestone, the thickest bed being about a foot thick. Some 85 feet above the base is a three-foot bed of Bentonite. Crystals of selenite gypsum are common near the base. The Graneros weathers easily and except when protected by the overlying Greenhorn limestone, does not often appear in outcrops. Because of the limited areas where the shale has been mapped separately, its surface distribution is included with that of the entire group on the accompanying map. In general it occurs only in the Arkansas Valley and its tributaries to the south in Otero, Bent and Prowers counties.

Greenhorn limestone: Overlying the Graneros is a series of alternating bluish grey limestones and darker grey shales, fifty to sixty feet thick. The limestone layers vary from three to twelve inches in thickness and comprise about one-third of the total thickness of the formation. They are fairly hard and break into angular blocks as a result of thickly crowded vertical joints. The limy layers are much more resistant than the intervening shales and tend to form benches along valley sides.

The exact limits of the formation are often difficult to determine because of the gradation into the overlying and underlying shales. The largest outcrop areas occur on the south side of the Arkansas River from just south of La Junta eastward to Las Animas, in Bent County. A narrower strip occurs north of the river along most of the area of Benton outcrop and also on the valley sides of the tributaries to the Arkansas from the south in Bent and Prowers Counties.

Carlile shale: The upper division of the Benton group consists of 125 to 225 feet of shales, medium grey in color in the upper and lower portions and greyish black in the middle. About 20 to 30 feet below the top the shale becomes slightly sandy and contains numerous large roundish concretions measuring from two to five or six feet in diameter. The top of the Carlile in the Arkansas Valley is a greyish crystalline limestone weathering to a rusty brown color and measuring from two to fifteen feet in thickness. It is very fossiliferous, the fossils consisting mainly of small oyster shells, (*Ostrea lugubris*), and casts or impressions of strongly ribbed, coiled ammonites, (*Prionocyclus wyomingensis*). This top limestone is, perhaps, the most resistant rock in the Arkansas Valley from Apishapa Creek eastward and it forms most of the pronounced buttes, benches, and escarpments in the region south of the Arkansas River.

This member has been described as a sandstone by Darton, Fisher and Stose in the region embraced in the Nepesta and Apishapa Quadrangles. Patton and the writer, however, have found it to be a distinct limestone in Otero and Bent counties, and the writer finds that the limy nature continues for some distance west into the Apishapa Quadrangle. Sand is introduced even in the region south of La Junta, but at no place studied as far west as R. 61 W. can the rock be called a sandstone. There is little doubt that the rock becomes more sandy and thicker westward and in the foothills region north into Wyoming, the top of the Carlile is distinctly a sandstone.

The Carlile appears at the surface in eastern Colorado chiefly south of the Arkansas River from the foothills to the state line. The larger streams, as the Purgatoire and Rule Creek, have cut through it and removed the formation from a large area north of the Mesa de Maya in Las Animas, southeastern Otero and southwestern Bent counties. From the Apishapa River east, the Carlile forms the bottom of valleys and arroyos and the lower portion of escarpments capped by the Timpas limestone. The formation occurs on the flats of the Arkansas Valley about La Junta where it extends slightly north of the river along Horse and Adobe Creeks.

Niobrara subgroup: The Niobrara consists of two distinct members in eastern Colorado, the Timpas limestone, averaging 200 feet thick, and the Apishapa shale, 500 feet thick above. The two members are mapped as a unit, since separate mapping has been completed only over rather limited areas. The formation occurs at the surface in southern Colorado over a broad area south of the Arkansas River east into Otero County, whence it swings north in a broad band through northern Otero, southern Crowley, most of Kiowa and most of eastern Cheyenne Counties. In the latter two counties, the Tertiary covers large areas and hides the Niobrara. In Kiowa County, it seems probable that most of the surface before Tertiary times had Niobrara as the chief exposed rock. A small area occurs on Black Wolf Creek in Yuma County south of Wray.

Timpas limestone: Although the name Timpas limestone has been applied to the entire thickness of the lower member, only the lower fifty feet can be properly designated as limestone. This consists of soft, whitish limestone of very compact texture in layers from a few inches to several feet thick. The layers are separated by thin films or one or two inch

bands of dark grey shales. The rock weathers into thin, rough slabs and chips with the cleavage planes parallel to the bedding. Large individual shells of *Inoceramus deformis* occur in most places. The surface of these shells is usually well covered with the masses of *Ostrea congesta.* The contact of this limestone member with the Carlile is usually sharply defined, but east of La Junta Patton reports it difficult to separate the Timpas and Carlile limestones, due to the fact that the latter becomes lighter in color and seems to grade into the former.

The basal limestone passes gradually into some 150 feet of limy shale, prevailingly light grey in color, but locally dark grey and even almost black at the top. Intercalated with the shales at different horizons are thin beds of limestone similar to that at the base. At the top of the member occur thicker white to yellowish limestones, which split readily into thin layers and leaves. Fossils similar to those in the basal limestone also occur in the higher horizons.

Apishapa shale: Conformably overlying the Timpas are some 500 feet of highly calcareous shales called the Apishapa shale. The lower 50 to 75 feet are dark bluish grey in color. These are followed by shales of similar color that weather into papery flakes. The central portion is much lighter and distinctly more sandy in character; the upper is much darker. Locally, the shales develop into impure limestones a foot or more thick. Upon exposure, the Apishapa weathers into a pronounced light yellow color, which in itself is often enough to identify the formation.

The shale is characterized from top to bottom, both in the unoxidized dark parts and the weathered portions, by an abundance of minute whitish specks. They are usually visible to the unaided eye and are easily seen with a lens in all specimens taken. With dilute hydrochloric acid, the shale effervesces freely and the tiny white spots disappear. They would appear, therefore, to be calcite. This was verified by Patton after an examination of thin sections under the microscope.

Fossils occur sparingly throughout the formation. *Ostrea congesta* upon an undetermined large species of *Inoceramus* is most abundant, but fish scales, shark's teeth, fragmentary skeletons of fish and a few other forms occur.

No sharp line of demarcation between the Pierre and Apishapa has been found. Over most of the Arkansas Valley the contact is covered by recent sands and alluvium and the lines drawn upon the map are only approximately correct.

MONTANA GROUP

Pierre formation: The Pierre shales outcrop over considerable areas in Crowley and Lincoln Counties in the drainage basins of the larger streams, notably in the Horse Creek-Pond Creek basin in Crowley and southern Lincoln Counties, in the Sand Arroyo of Lincoln and Cheyenne Counties and along the Big Sandy Creek from the vicinity of Hugo south and east into Cheyenne County. In these areas, the complete thickness of the formation is exposed, but limited outcrops preclude the possibility of measuring the thickness with any degree of accuracy. In central Morgan, northeastern Adams and western Washington Counties, occur several hundred feet of

beds which are here referred to the upper Pierre or, better, to the so-called "Transition series" between the Pierre and Fox Hills.

In the southern outcrop area noted above, the total thickness of the formation probably does not exceed 2200 feet and may be considerably less in places. An indefinite three-fold division has been noted by several workers, but detailed investigation shows that any attempt to subdivide the formation is fruitless. The lower 400-600 feet consist of dark grey to black shale, with much gypsum and some thin limestone lenses and concretions near the top. The lower beds are practically barren of fossils and contain little calcium carbonate except in concretionary forms. The upper part of this lower series is much stained by iron, and passes into a middle zone with abundant limonite concretions. Because of the abundance of iron concretions, the weathered outcrops of the middle 600 feet present a distinct yellow brown or rusty appearance and this is called the "Rusty Zone" by Darton and others. Lime concretions and fossils are rare in the zone. The remaining portion, some 1000 feet in thickness, is characterized by an abundance of limestone lenses which, because of greater resistance to weathering, give rise to numerous tepee buttes, particularly in the lower few hundred feet of the zone. These buttes contain an abundance of fossils, notably *Lucina occidentalis*, *Baculites ovatus*, *Scaphites nodosus* and *Inoceramus barabini*. The shales of the zone are predominantly dark grey in color, with a few bands of light grey, and others almost black color.

The question of thickness of the Pierre in various places in eastern Colorado could not be settled during the present field work. In the foothills region Henderson, Fenneman and others report thicknesses of from 4000 to 7000 feet at a maximum in sections from near Pueblo north to the Wyoming line. To the east the formation is undoubtedly much thinner, but the amount of thinning is open to question. All lines of evidence from well logs indicate a maximum of from 1800 to 2200 near Ordway, 2000 feet near Akron, about 2000 feet near Sterling, and, according to verbal reports, 2500 feet in western Nebraska near the state line. No additional proof of eastward thinning was secured. There can be no question of the thinning eastward from Pueblo into Crowley and Cheyenne Counties, but similar thinning in the region to the north up to the South Platte Valley is problematical.

Though an attempt has been made to separate the Pierre and Fox Hills in the mapping, the work of the past summer has served only to emphasize to the writer the utter impossibility of establishing a boundary that is not open to severe question. Between the typical upper Pierre shales and the arenaceous shales of the Fox Hills, as recognized in Colorado, are several hundred feet of transitional shales containing a mixture of Pierre and Fox Hills faunas, but which are lithologically inseparable from either formation. It is beds of this nature that are mapped in southern Morgan, northeastern Arapahoe and western Washington Counties as Pierre, but except that *Inoceramus fibrosus* and allied forms occur in abundance there is no basis for the line of contact as shown other than topography. To the writer, the simplest procedure seems to be to limit the use of the term Fox Hills to the upper sandstone, the Milliken, where it is typically developed, and to group the underlying shales and sandy shales with the Pierre under the term Montana Group.

Fox Hills: This upper division of the Montana group occurs at the surface over considerable portions of Elbert, Arapahoe, Adams, and Washington Counties between R. 53 and 58 W., (except that an area of Pierre will be shown from the South Platte south to the middle of T. 3 S. in R. 54, 55, and 56 W.). Outcrops of Fox Hills occur also on both sides of the South Platte from eastern Morgan County west to Greeley. In the valley proper a heavy mantle of dune sand and alluvium hides the formation.

The character of the Fox Hills is sufficiently well known so that no detailed description need be given here. Near the foothills the transitional beds from the Pierre are overlain by from 800 to 1000 feet of sediments becoming progressively more sandy toward the top which is marked by the Milliken sandstone of Henderson. Overlying the Milliken sandstone near Windsor and Milliken, (Wild Cat Mound), is a thin series of sandy shales transitional to the Laramie which may or may not be part of the Fox Hills.

East of Greeley the nature of the formation is notably different. Except in one or two places north of Weldon, (T. 6 N., R. 59 W.), the Milliken cannot be recognized and the entire thickness consists of alternating greyish, arenaceous shale, yellow brown to white sandstone, usually in thin beds, and sandy purple brown concretionary limestone. The thickness assigned, not more than 400 to 500 feet, depends entirely upon the thickness of the transitional shales included with the Fox Hills at the base, and the plane where the Fox Hills-Laramie contact is placed. The latter, however, can be located within rather narrow limits in most places. The outstanding characteristic of the Fox Hills east of R. 65 W. is the great abundance of purplish brown concretions of limestone and the decidedly lower proportion of sand contained in the formation. In the easternmost exposures studied, in the vicinity of Brush, the formation is distinctly a shale with some sand and suggests the possibility that under the Tertiary to the east the formation would entirely lose its identity and be inseparable from the Pierre except on a strictly faunal basis. Faunal studies are as yet very incomplete, but the faunas also seem to suggest that in eastern Colorado the Fox Hills does not exist as a separate member of the Mountain Group.

LARAMIE

The Laramie coal-bearing formation is exposed over most of the surface west of R. 58 W. from a point a few miles south of the Chicago, Rock Island and Pacific Railroad in Elbert County, north to T. 1 N., whence it swings west along the South Platte Valley. North of the river, the formation again covers a broad area from R. 58 W. to a line of cliffs, extending northwest from a point about six miles north of Greeley through R. 66, 67, 68 W. almost to the Wyoming line.

Lithologically, it is rather difficult in some places to separate the base of the Laramie from the Fox Hills. As indicated above, in the vicinity of Windsor and Wildcat Mound a thin series of shales is transitional from the Milliken sandstone to the basal sandstone of the Laramie. Along the eastern margin of the outcrop, the shale series was not seen and the white sandstone of the Laramie rests directly upon Fox Hills sands and shales. The characteristic white sandstone of the foothills region forms the base of the Laramie in the region here mapped and is overlain by several hundred

feet of dark carbonaceous shales, thin iron stained sands, lignitic shale and discontinuous coal seams, with numerous thin beds made up almost exclusively of shells of *Ostrea glabra* and *Anomia micronema* in some places and various species of *Corbicula* in others. These shell beds occur at no definite horizons and cannot be used for key beds except over very limited areas.

In thickness the beds vary from slightly over 100 feet on Crow Creek to some 300 feet near Briggsdale, in Weld County, and to 400 feet or slightly more in the region south of the South Platte Valley. Thicknesses of 1800 or more are reported in Bijou Creek drainage area by White, but it is wholly probable that there were included in this section a series of beds that are now known to contain an abundance of Raton plants. This region has not been studied in detail as yet, but it is hoped that additional information will soon be available. Suffice to say here that limited collections made by Cockerell and Hubbard of the University of Colorado, and identified by Miss Grace Sandhouse, have brought to light a flora having distinct affinities with the Raton in an area mapped as Laramie.

TERTIARY

Sedimentary beds of Tertiary age cover extensive areas of eastern Colorado. Except that they cover the older formations and serve as a source of domestic and stock waters, the rocks are of little economic importance. But little time was devoted to them except to determine the contact with the earlier horizons. The oldest Tertiary seen in the field is of Eocene age, the latest, the "Nussbaum," is probably Pliocene.

EOCENE

Arapahoe formation: The present geologic map of Colorado shows a broad area of Arapahoe beds in the vicinity of Brighton, in Adams County, and extending northward in a broad tongue to T. 3 N., R. 62 W., in south central Weld County. During the past field season a very hurried reconnaissance of the area was made. Outcrops are exceedingly few and poor, and, as a result, no great change has been made in the mapping. The northern part of the area is heavily mantled with recent dune sand. The limited exposures consist of light ash-grey clays and fine to coarse sands with abundant unidentifiable plant fragments. No trace of conglomerate was discovered in the region studied, but as noted above, only a very hurried trip was made and it is quite probable that future study will show the need of revision in this region.

Denver-Dawson-Raton?: The present map shows a considerable area of Eocene beds south and east of the city of Denver. This area was covered in detail by G. G. Richardson during a study of coal deposits for the United States Geological Survey and it is assumed that the results of his work are essentially correct. No new information has been brought to light except in the Bijou Valley east of Kiowa, where, as noted above in the discussion of the Laramie, it seems probable that a series of beds below the basal conglomerate of the Dawson as generally recognized may be Raton. A detailed study of the question is contemplated in the near future and the final edition of the geologic map will incorporate any changes found necessary.

OLIGOCENE

White River: The White River formation outcrops over rather narrow areas from a point about two miles north of the south line of T. 4 S. and the line between R. 53 and 54 W., north and east through western Washington County and thence northeast through southeastern Logan County to approximately the place where the South Platte leaves the county. Thence it covers an irregular band through northern Logan and Weld counties almost to the foothills. A few outliers, too small to be mapped, occur just north of the Morgan County line and about Briggsdale.

Lithologically, the formation consists chiefly of white and vari-colored clays, marls, sands, with locally a conglomerate at the base. In some places, notably some fifteen miles east and slightly south of Brush, numerous coarse, highly cross-bedded channel sandstones are found in the lower portion. These sandstones are very firmly cemented and resistant, with the result that numerous slight escarpments are capped by them. The major portion of the formation, however, consists of easily eroded partially consolidated clay, sandy clay, and marl, the so-called chalks of the region about Pawnee Buttes and westward. The beds are often highly colored with pinks, reds, and yellows as the dominant shades. Upon erosion, the formation tends to form badlands as in the type region in South Dakota, though upon a much smaller scale. Due to the great unconformity between the White River and older beds, the thickness varies greatly from place to place; the maximum may be as much as 150 feet, the minimum as little as five or ten feet.

MIOCENE PLIOCENE?

The most extensive exposures of Tertiary deposits in eastern Colorado are those variously called Nussbaum, Arikaree, and Ogallala and assigned with some doubt to the Miocene and Pliocene epochs. No good basis for the separation of the units has been found and the same symbol is here used for the entire series. The term Nussbaum should probably be limited to the beds in the area between the Arkansas River and Big Sandy Creek; the Arikaree to the deposits along the Arikaree River; and the Ogallala to the more northerly exposures. On the whole, the Nussbaum is perhaps the coarsest in texture, but texture is at best a most unsafe guide in separating the several units.

The Miocene-Pliocene deposits cover the major portion of the surface east of a line trending in general in a northeasterly direction from almost the Arkansas River some 10 miles east of Pueblo to the Nebraska line in the center of R. 45 W. near Julesburg. Big Sandy Creek has cut entirely through the Tertiary along its whole course and exposed Cretaceous beds. The larger creeks flowing into the Arkansas from the north have also cut their valleys through the Tertiary for long distances. North of the Big Sandy valley only the larger streams have succeeded in cutting valleys to the Cretaceous, and these only near the eastern border of the state. Outliers occur at widely scattered places over much of the eastern part of the state.

The Nussbaum-Ogallala-Arikaree consist essentially of sands, sandy clays and conglomerates all partially or entirely uncemented. The coarser beds are as a rule near the base and are characterized by a great abundance of

undecomposed pink orthoclase feldspar debris, varying in size from minute fragments to bits nearly an inch long. Associated are well rounded to angular pebbles of quartz and igneous materials often several inches in diameter. The sands are much finer and usually are very poorly cemented, so that enormous quantities are easily dislodged and scattered widely by winds. Because of incomplete sections no general thickness can be assigned, but it is known to vary from practically nothing, near the contacts with older formations, to several hundred feet in the vicinity of the Arikaree River. It is probable that sudden variations in thickness occur because of the great unconformity below, and because of the manner of deposition as stream debris. There seems to be little reason to doubt that most of the material was laid down by running water, as evidenced by its heterogeneity of material and its peculiar bedding from place to place.

QUATERNARY

Though no attempt has been made to map as separate units the Pleistocene and Recent sediments, it would be well to outline in a general way the distribution of the more important areas covered by the deposits.

Alluvium: Along the Arkansas and South Platte Rivers extensive deposits of stream alluvium cover all earlier beds. These vary in width from a few hundred yards to several miles and serve as a source for many of the sands to be noted below. Other less important alluvial deposits occur along the smaller streams, particularly Big Sandy, Rush and Horse Creeks, tributary to the Arkansas.

Eolian sands: Eolian sands cover large areas about the two major streams and also near the boundaries of the Miocene-Pliocene formations. The most extensive areas of sand dunes occur north of the 40th Parallel to approximately 40° 30′ north and from R. 52 W. to the vicinity of Brighton and Greeley. Though these sands are not continuous, they commonly hide the bed rock in critical areas and many of the indefinite contacts in the South Platte basin are due to sand cover. The thickness of the cover varies from a few inches to fifty feet or more. Typical sand dune topography is developed in most of this region.

Other less extensive deposits of eolian sands occur between Rush and Big Sandy Creeks in eastern Lincoln and western Cheyenne Counties. These are probably derived chiefly from Tertiary beds and hide the contact between the Tertiary and Pierre. Sands of similar origin occur in patches in southern Lincoln and Crowley Counties on and near the Nussbaum. Between the Missouri Pacific R. R. and the Arkansas River in southwestern Crowley County a large sandy area, without dunes, covers the Pierre-Niobrara contact. South of the Arkansas, though sands occur, they are less important.

Terrace deposits: Several levels of terrace gravels occur along both the Platte and the Arkansas Rivers. These are mentioned only because some of the higher deposits have previously been confused with Tertiary formations. They are, on the whole, distinctly coarser than the Tertiary gravels and less widespread in distribution.

Consolidated gravels: At widely separated places in northern and eastern Colorado, there exist thoroughly consolidated gravels and conglom-

erates, whose age is the subject of considerable discussion. These contain many small boulders of igneous and metamorphic rock, some pebbles of sediments found in the foothills region, and in most places large masses of silicified wood. The best known exposures on the plains are on an escarpment in T. 9-10 N., R. 67 W., at the top of Wild Cat Mound, in T. 4 N., R. 67 W., and at Point of Rocks, T. 6 N., R. 62 W. Others of similar appearance occur near the Morgan County line in Weld and Morgan Counties to the east. The preponderance of evidence to date indicates Pleistocene age for these deposits, but additional data is needed to settle the question.

AREAL DISTRIBUTION

The accompanying map incorporates all of the information that has come to light in the past decade concerning the areal distribution of the sedimentary rocks of eastern Colorado. In some places, notably south of the Arkansas River, recent field studies have shown the present edition of the Geologic Map of Colorado to be essentially correct. Such areas will be discussed only in a most general way in the following pages. Where numerous changes have been made, more detailed discussions will be given.

Upon the map, suitable letters have been used to differentiate the several formations. As noted at the beginning of the report, the map is not to be regarded in any way as a finished product, and some slight revisions of small areas may still be necessary before the final complete revision of the whole state map is issued.

PALEOZOIC

Pennsylvanian-Permian: The red beds of late Paleozoic age occur at the surface at several places in southern Colorado. The area shown about the Chaquaqua Reservoir, in Las Animas County, on the present map has been found to be approximately correct, though a trifle too large. The limits of the formation are found in the southern half of T. 28 S., R. 55 and 56 W., T. 29 S., R. 54 to 57 W., T. 30 S., R. 55 to 57 W., in the north central part of T. 31 S., R. 56 W. and the northeast corner of T. 31 S., R. 58 W. Except near the junction of Chaquaqua Creek with the Purgatoire River, the formation occurs only in narrow outcrops along the stream bottoms. A second outcrop covers a small area in T. 34 and 35 S., R. 55 and 56 W. Another small area of red beds is found in T. 35 S., R. 50 W.

The area of red beds shown in T. 28 S., R. 52 W., on the existing map was not found by Duce and is omitted here.

JURASSIC? SYSTEM

Morrison formation: As was the case with the red beds outcrops but little revision of the distribution of the Morrison has been found necessary. Such changes as have been made are of minor importance and need not be discussed in detail. The formation outcrops broadly about the headwaters of Rule Creek and the lower portion of Chaquaqua Creek in T. 26 S., R. 52 to 54 W., T. 28 S., R. 51 to 56 W., T. 29 S., R. 51 to 54 W. In T. 29 to 32 S., R. 55 to 58 W., the outcrops are confined to narrow bands below younger formation along the stream courses. In T. 33, 34, 35 S., R. 50 W., Duce has described a small area of Morrison, not shown on previous maps.

CRETACEOUS SYSTEM

DAKOTA GROUP

The lower formation of the Dakota group, the Purgatoire, occurs as a narrow band all around the Morrison outcrop area as outlined above. In but few places is the band as much as a mile wide and then only for short distances. In actual surface area covered, the Purgatoire is the least important formation to be discussed in this paper. On the accompanying map, the Purgatoire is included with the Dakota because of the fact that its outcrop area is too limited to be shown separately on such a small scale. The final edition will, however, map the formation as a separate unit.

The Dakota sandstone comes to the surface over extensive areas in southeastern Colorado from the Arkansas Valley south to the state line. It is probably present below the Tertiary over most of Baca County.

Between the 103d and 104th meridians and from T. 30 S. to the New Mexico line, the Dakota is at the surface in all places not mentioned in the descriptions given above, except where it is covered by Tertiary basalt in parts of T. 33 to 35 S., R. 51 to 56 W., and by the Nussbaum sediments in parts of T. 33 and 32 S., R. 50 and 51 W. North of T. 30 S. the surface has been more thoroughly dissected by streams and the outcrops are less continuous. Likewise the regional dip is in a northerly direction and younger formations begin to cover the Dakota near the Arkansas River. West of the Purgatoire River, the formation is at the surface in an irregular band from the north line of T. 33 S., R. 60 W., northeast to T. 26 S., R. 53 W., from which place it occurs on both sides of the stream to the city of Las Animas. A rather large inlier occurs in T. 27 and 28 S., R. 57 and 58 W. East of the Purgatoire, Dakota sandstone outcrops broadly to the 103d meridian from T. 27 S., to the south side of T. 22 S. just north of the city of Las Animas and thence east to a point a few miles east of Lamar. This represents the most northerly exposure of the formation in the plains region of the state. Between the Purgatoire and Rule Creek, a large outlier of Benton covers the divide in T. 23 to 25 S., R. 51 to 52 W. Outliers of Dakota, separated only slightly from the main outcrops, occur in T. 27 to 29 S., R. 54 to 55 W., and in the northwestern part of T. 28 S., R. 51 W.

East of meridian 103° west, no recent studies of the geology have been made north of Baca County. In the latter, Vanderwilt reports that only slight changes are required in the distribution of the Dakota. The chief change has been to make the outcrops along Horse and Bear Creeks and Sand Arroyo much narrower than on the 1913 map.

COLORADO GROUP

Benton subgroup: As was the case with the preceding formations, the Benton group of the Cretaceous is exposed only in southeastern Colorado. From T. 29 S., R. 58 W., northeast to Las Animas, the formations are found west of the Purgatoire, paralleling the stream as a band varying from three to perhaps ten miles wide. The contact with the Dakota on the east is a fairly regular line, that with Niobrara on the west is exceedingly irregular and sinuous. Isolated patches of Niobrara cover the Benton formations in several places. From about five miles west of La Junta to the 103d meridian, Benton occurs on both sides of the Arkansas. The northern boundary

swings northeast along the river to T. 22 S., R. 53 W., whence it continues east along the north line of the township. The southern boundary is again irregular, the formation usually occurring below the Timpas limestone in stream valleys only. Directly south of La Junta it is found as a strip a mile or more wide through the center of R. 55 W. south into T. 26 S. Another small strip is found along the north edge of the Tertiary basalt in T. 33 and 34 S., R. 54 to 56 W. On the whole, however, no serious errors have been found in the contacts as shown on the existing map.

Niobrara subgroup: Because of the great difficulty in definitely establishing the contact between the two members of the Niobrara group, the Timpas limestone and Apishapa shale are mapped together. In general it may be said that the Timpas outcrops over less territory and is found south and east of the Apishapa. New data on the distribution of Niobrara is confined to a region between the east boundaries of the Apishapa and Nepesta quandrangles in Otero and Crowley Counties and the 103rd meridian in Bent and Kiowa Counties. It is known that considerable revision of the Geologic Map is needed in Cheyenne, Kiowa, Bent and Prowers Counties but no opportunity for field study has yet occurred.

The Niobrara-Benton contact enters the accompanying map in the north part of T. 26 S., R. 60 W., continues southeast to the north half of T. 27 S., R. 59 W., crosses the Santa Fe tracks on the west line of T. 26 S., R. 57 W., thence swings south to T. 28 S. in the same range and then northeast roughly parallel to the Santa Fe Railroad to the middle of the east line of T. 24 S., R. 54 W. From this point, the location of the contact is outlined above in the discussion of the Benton formation. The contact with the Pierre as it is shown here is open to some question, as it lies almost entirely in the irrigated section north of the Arkansas River. It enters the map just south of the Arkansas River in the middle of T. 22 S., R. 59 W., and trends slightly north of east to the Crowley-Kiowa County line in T. 20 S., R. 55 W. Here the boundary turns rather abruptly north through the west half of R. 54 W. to the middle of T. 18 N.; thence it again turns east and south to the Missouri Pacific right of way in R. 52 W. Over the whole extent of this northern boundary, no outcrop showing the actual contact has been found. In the irrigated area east and west of Ordway, a heavy mantle of recent dune sand covers all bed rock and the position of the boundary has been computed from dips measured in two or three places. It is the writer's belief, however, that the contact is as nearly correct as it is possible to make it without reliable sub-surface data.

Beds of Niobrara age have recently been reported by several workers in the central part of T. 2 S., R. 43 W., south of Wray, in Yuma County. The outlines of the outcrops have not been definitely determined, but it is unlikely that the area of Niobrara exposed is more than a few square miles. A narrow band is also found immediately above the Benton and below Tertiary basalt in T. 33 and 34 S., R. 55 and 56 W., in southern Las Animas County.

MONTANA GROUP

Because of the practical impossibility of definitely establishing a dividing plane between the Pierre and Fox Hills members of the Montana group, the letters Kp (Pierre) and Kf (Fox Hills) are inserted in areas where

it is reasonably certain that faunas show the presence of the formation indicated, but the contacts are only approximate. The writer wishes again to call attention to the desirability of discarding the use of the term Fox Hills in the plains region of Colorado. Neither lithology nor faunas warrant a separation of the Montana group, and as indicated by Hayden and many others, had the beds been studied first in the mountain region, it is highly probable no distinction between Pierre and Fox Hills would have been made.

Pierre shale: Except in the vicinity of Colorado Springs, and in Cheyenne County east of R. 50 W., the boundaries of the Pierre exposures have been revised over all of eastern Colorado. The location of the contact with the Niobrara has been discussed above. The location of the boundary between the Pierre and overlying formations has been changed considerably from previous maps in many places and Pierre shale has been found exposed in places where older maps indicated younger formations.

In practically all of Crowley and Lincoln Counties, the Pierre is limited above by the Tertiary Nussbaum formation. The contact enters the map about the middle of the south line of T. 21 S., R. 59 W., where the Nussbaum forms a sharp cliff along the Missouri Pacific Railroad. It swings almost immediately north through the east half of the range and except for a few minor changes conforms to the old geologic map. In Crowley County, the only alterations found necessary are in T. 19 S., R. 58 W., and T. 17, 18, 19, 20 S., R. 56 and 55 W. In the former location, it is found that the Nussbaum occurs only in the township mentioned, whereas the former map shows the formation to extend into T. 18 S., R. 58 W. In the second area mentioned, it is found that the long arm of Tertiary extending south from the main outcrop area is much narrower than formerly shown, and instead of being an arm is really an elongate outlier occupying the divide between Horse Creek and Sand Arroyo. A smaller outlier occurs in the east half of T. 18 S., R. 55 W. The Pierre, therefore, extends somewhat farther north in this area than previously mapped.

In western Lincoln County, (T. 12 to 17 S., R. 55 to 59 W.), Pierre shale occurs only in the deeper valleys of Horse and Rush Creeks and their tributaries. The chief revision found necessary was to extend the Pierre from one to ten miles farther up stream along some of the tributary valleys. In eastern Lincoln County, the distribution of the Pierre is very different from that indicated on the 1913 edition of the geologic map. South of T. 15 S., only a few minor corrections have been noted and these can be neglected here. Beginning at about the middle of the east line of T. 14 S., R. 54 W., the Pierre-Nussbaum contact extends through the east half of the range to about Section 25, T. 12 S., thence southeast to the south third of T. 13 S., R. 53 W., and again north and west parallel to and some two to three miles west of the Big Sandy Creek to the southwest corner of T. 10 S., R. 55 W., where the Pierre gives way to Fox Hills. East of this line and south of the Big Sandy, Pierre is found over all the surface to R. 50 W., except for an area in the south half of T. 14 S., R. 51 and 52 W., and the north half of T. 15 S., R. 51 W., where it is covered by Tertiary beds. A large portion of this area is covered by dune sand, but sufficient outcrops occur to allow the location of contacts with reasonable exactness.

North of the Big Sandy, the Pierre has been found to extend considerably farther north and east than previously thought. From about the middle of T. 9 S., R. 55 W., the Pierre-Nussbaum contact extends west and south into T. 10 S., R. 52 W., and then northeast to the middle of the east line of T. 8 S., R. 50 W., northeast of Flagler, where it crosses the South Fork of the Republican and trends back on the south side of the stream to the west side of T. 11 S., R. 52 W. From this point, the contact trends southeast to the southeast corner of T. 13 S., R. 51 W. Three small outliers referred, with some question, to the Nussbaum occur in T. 13 S., R. 52 W. North of the south line of Kit Carson County and east of R. 52 W., no Pierre occurs at the surface, except narrow bands in the valley of the Arikaree River in T. 3 S., R. 43 W., and T. 1 and 2 S., R. 41 and 42 W., and on both sides of the Chicago, Burlington and Quincy Railroad immediately east of Wray in T. 1 and 2 N., R. 41 and 42 W. The formation is also reported from several localities on the South Fork of the Republican River in southeastern Yuma and northeastern Kit Carson counties.

During the past summer, an hitherto unmapped area of Pierre shale was found in southeastern Morgan, northeastern Adams and southwestern Washington Counties. Only the upper few hundred feet of the formation are exposed and, because there is a complete gradation faunally and lithologically into the Fox Hills as recognized in Colorado, no boundary line could be determined. Upon the accompanying map, the writer has shown by a broken line the probable extent of the Pierre in the region. Similar beds are reported by Vanderwilt along Pawnee and Clear Creeks in Logan County. Outcrops in all places are few and unsatisfactory, and it is probable that considerable change will be found necessary as more detailed work is done. Because of this uncertainty, no effort to discuss the boundaries will be made here.

Fox Hills formation: Beds of Fox Hills age outcrop much more extensively over eastern Colorado than indicated on previous maps. The most southern exposures studied in recent field work occur below the Nussbaum on the headwaters of Horse Creek in T. 13 S., R. 58 and 59 W., in southwestern Lincoln County. About Limon the Fox Hills occurs in the valley of Big Sandy Creek in T. 8, 9, 10 S., R. 55 to 58 W. It is covered by Tertiary beds both on the north and south. North from T. 7 S. the formation covers a broad triangular area from the divide between the Bijou and Badger Creek drainage basins in R. 58 W. to the Tertiary-Fox Hills boundary discussed in the following paragraph.

Tertiary-Fox Hills boundary: This boundary marks the eastern limit of Fox Hills exposures in the state and differs only in details from the Laramie-Tertiary contact shown on the existing map. Beginning at the southwest corner of T. 7 S., R. 57 W., the Miocene beds (Nussbaum-Arikaree) overlie the Fox Hills east of a line trending northeast to the southeastern part of T. 4 S., R. 54 W., where the White River formation of Oligocene age is introduced below the younger Tertiary. From this place on, the contact trends north in R. 54 W. to T. 2 N. and then slightly northeast to the south line of T. 11 N., R. 48 W., in Logan County. The contact parallels the South Platte in a southwesterly direction to the middle of T. 9 N., R. 52 W., and thence turns northwest through the east half of T. 11 N.,

R. 55 W. From the latter point the formation occurs only in the bottoms of the valleys of Horse Tail Creek and its tributaries in T. 9 and 10 N., R. 53, 54, 55 W. Beginning at approximately the northeast corner of T. 8 N., R. 53 W., the Fox Hills-White River boundary trends in general to the west but is very irregular about the headwaters of the tributaries of Pawnee Creek in T. 8, 9, 10 N., R. 53 to 58 W. From the middle of the north line of T. 8 N., R. 57 W., the line extends through the north half of the township to the west corner of R. 58 W., where the Fox Hills gives way to the non-marine Laramie formation.

Outliers of White River rest upon Fox Hills beds in the north half of T. 8 N., R. 53 W., in a small area in the east half of T. 10 N., R. 54 W., and in a large mass only slightly separated from the main outcrop body in T. 7 and 8 N., R. 55 to 58 W. Numerous patches of what may be White River, but too small to map, occur near the north line of Morgan County. Included here are several outcrops of consolidated gravel, the age of which is doubtful.

Laramie-Fox Hills boundary: It has long been known that the Laramie was much less extensive than shown on early maps of eastern Colorado. The contact between it and the Fox Hills first emerges from below Nussbaum beds in the middle of T. 10 S., R. 58 W., and continues in a northerly direction through the Range to T. 1 N., where it begins to turn west. In Range 58 West the contact is practically on the crest of the Bijou-Badger Creek divide. Coal beds occur in the western half of the range throughout the entire extent noted above, but except in parts of T. 8 and 9 S., the eastern half is some 200 feet lower topographically and outcrops yield marine Fox Hills-Pierre fossils in most places.

From the 40th parallel in R. 58 W. the contact is covered by dune sand. The boundary as here located is quite indefinite and has been determined largely on the basis of topography and a few scattered outcrops. As drawn the contact runs northwest into T. 5 N., R. 54 W., and thence southwest to the edge of the map in the middle of T. 2 N., R. 68 W.

North of the South Platte River, the Laramie is likewise much less extensive as the surface rock than formerly thought. The contact with the Fox Hills enters the present map on the south side of T. 11 N., R. 68 W., and continues smoothly southeast to the south side of T. 6 N., R. 64 W., some three miles north of Greeley. From this point to the middle of the east line of T. 6 N., R. 62 W., the surface is again heavily mantled with sand and alluvium and the boundary has been placed on the basis of topography. From the latter point the contact is exposed irregularly in the north half of T. 6 N. through R. 59, 60, and 61 W. From the southeast corner of T. 5 N., R. 58 W., the contact is again hidden over considerable distances but is known to extend northeast until it disappears below the White River in T. 8 N., R. 58 W. Northeast the Laramie is found only in the valleys of the major streams in T. 9 and 10 N., R. 58 W. Outliers of Laramie occur in T. 5 and 6 N., R. 61 W., and west of Greeley in T. 5 N., R. 66 and 67 W.

Laramie-Tertiary boundary: Except an area east of Brighton where it is thought beds of Arapahoe age exist, the Laramie comes into contact with the Tertiary only in Weld County, and for short distances in eastern Elbert

County. In the latter region the contact has been traced only from the middle of T. 10 S., R. 58 W. to west line of T. 11 S., R. 59 W. A small finger of Tertiary projects over the Laramie for a short distance in the southwest corner of T. 7 S., R. 57 W. In Weld County the Laramie first appears in contact with the White River in the northwest corner of T. 8 N., R. 5 W. Thence it trends westward through the north half of the township to the middle of R. 61 W., where it turns slightly northwest to the northwest corner of T. 11 N., R. 66 W., and then west to the border of the map. Small outliers of White River rest upon the Laramie in the middle of T. 7 N., R. 59 W., in the north half of T. 8 N., R. 62 W., on the line between R. 62 and 63 in T. 9 N., and in the southeast quarter of T. 9 N., R. 63 W.

Outcrops of the Laramie reported north and east of Sterling in Logan County were not seen in the course of the past season's field work and are not included on the map.

EOCENE

Arapahoe formation: The Arapahoe area in southern Weld and northern Adams Counties is left approximately as on the 1913 map. No data were found to justify any but minor alterations.

OLIGOGENE-MIOCENE-PLIOCENE?

The contacts between the later Teritary deposits and the Cretaceous formations have been sufficiently discussed above. There remains, therefore, only to mention the White River-Miocene-Pliocene (?) contact. The White River first appears below what are probably Arikaree sands in T. 4 S., R. 54 W. The contact then follows in almost the same direction as the Fox Hills-White River boundary northeast through western Washington County, southeastern Logan County, and on into Sedgwick County to T. 11 N., R. 45 W., where it crosses the South Platte and continues north to the state line in T. 12 N. The latest Tertiary beds almost immediately again reenter the state in the east half of T. 12 N., R. 46 W. and the contact between them and the White River trends in general westerly direction through T. 12 N. to the middle of R. 48 W. It then drops down in T. 11 N. and continues through it, chiefly in the north half, to the west line of R. 53 W., where it again enters T. 12 N. to R. 56 W. Thence the contact turns north through the west half of the range to the Wyoming line. The boundary once more enters Colorado just west of the east line of T. 12 N., 64 W., continues west in the south half of T. 12 N. and the north third of T. 11 N. to R. 68 W., where it leaves the map. Outliers, too small to map separately, occur in various places all along the contact as outlined above.

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Bull. 19, Colorado Geological Survey.

Apishapa Folio No. 186—U. S. G. S.

Nepesta Folio No. 135—U. S. G. S.

Prof. Papers No. 32 and 52—U. S. G. S.