COLORADO GEOLOGICAL SURVEY

BOULDER

R. D. GEORGE, State Geologist

BULLETIN 27

PART I

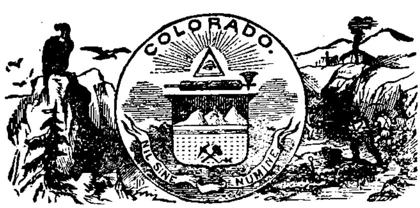
UNDERGROUND WATER POSSIBILITIES
LA JUNTA AREA, COLORADO

PART II

UNDERGROUND WATER RESOURCES OF PARTS OF CROWLEY AND OTERO COUNTIES

PART III

GEOLOGY OF PARTS OF LAS ANIMAS, OTERO, AND BENT COUNTIES



BOULDER, COLORADO
1924

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PART I

UNDERGROUND WATER POSSIBILITIES FOR STOCK AND DOMESTIC PURPOSES IN THE LA JUNTA AREA, COLORADO

BY
HORACE B. PATTON
1923

BOULDER, COLORADO
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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

State Geological Survey,

University of Colorado, Nov. 29, 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 27 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,

State Geologist.

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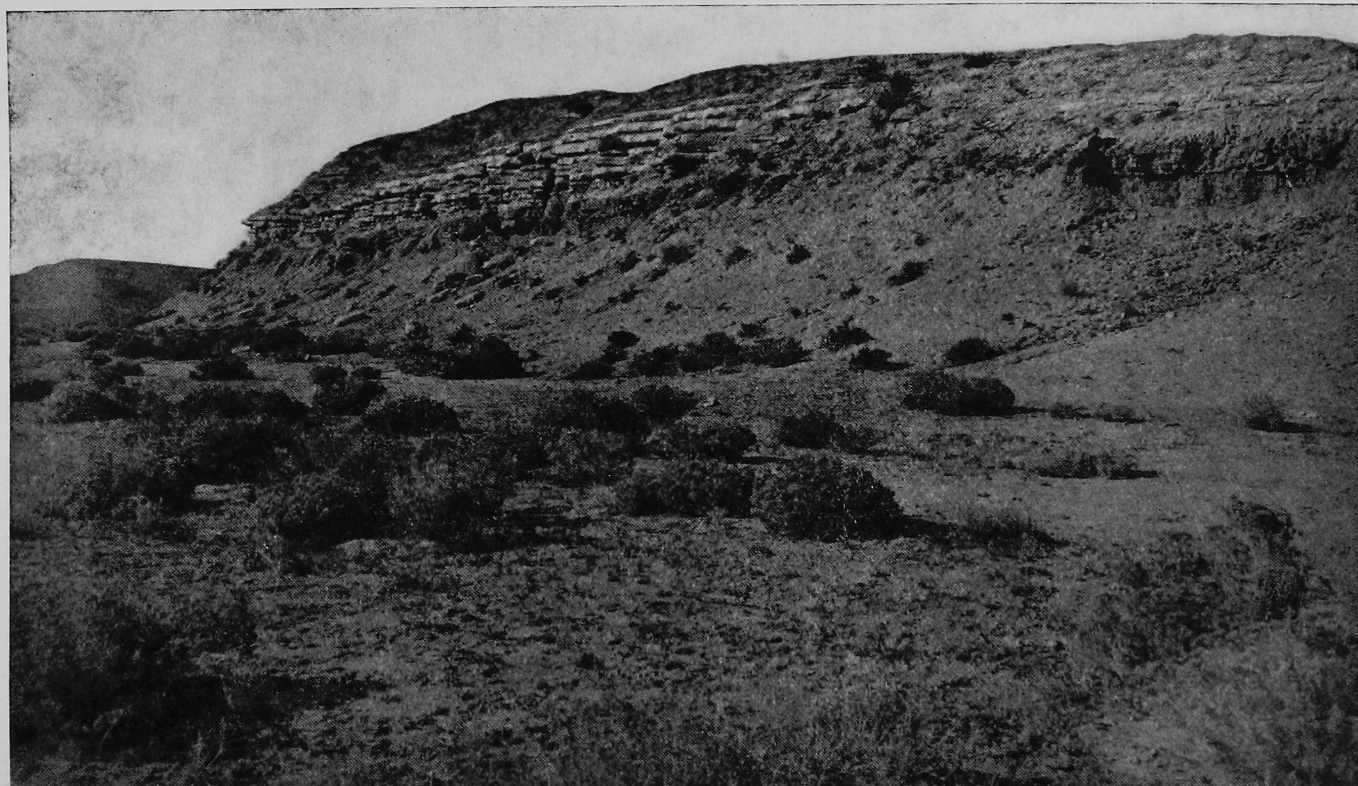

Plate II. Timpas limestone bluff showing Timpas-Carlile contact, two miles northwest of La Junta.

UNDERGROUND WATER POSSIBILITIES FOR STOCK AND DOMESTIC PURPOSES IN THE LA JUNTA AREA, COLORADO

INTRODUCTORY

PURPOSE AND SCOPE OF INVESTIGATION

Quite aside from the use of water for irrigation, the question of a water supply for domestic purposes or for watering of stock is a very vital matter to thousands of farmers and others who have taken up homesteads or have purchased lands in eastern Colorado.

The actual acreage now under irrigation or likely ever to be brought under irrigation is relatively small compared with the acreage suitable for stock raising or for dry farming in this part of the state. Very many farmers on these dry lands are obliged to haul water long distances for drinking and other domestic purposes and often also for stock. Naturally such a condition is very discouraging to the would-be farmer and accounts for the many abandoned homesteads and farms in some sections.

It is well known that a good supply of soft water can be found by sinking comparatively shallow wells within certain portions of the "dry belts" in eastern Colorado; and locally, good "artesian" water may be obtained by deep drilling. But in other parts of the territory in question the water obtained by sinking shallow and, sometimes, deep wells has been of very poor quality or even unusable. In numerous other cases no water whatever could be found.

This investigation has been undertaken with a view to furnishing as definite information as possible to those looking for water for domestic and stock purposes. No attempt has been made to investigate further sources of water for irrigation.

TERRITORY COVERED.

The present report covers only a small part of the large area in southeastern Colorado in which the scarcity of good water is very pronounced. It represents the results of surveys carried on during the working seasons of 1921 and 1922, and embraces a total of 1,048 square miles or nearly thirty townships. The townships involved are 21, 22, 23, 24, 25, and 26 South, in Ranges 53, 54, 55, 56 and 57 West.

The town of La Junta lies in almost the geographical center of this area which includes also the towns of Rocky Ford, Ordway, Sugar City, Timpas and Cheraw.

PERSONNEL.

The field work of 1921 was conducted by Arthur J. Tieje, John C. Myers and Albert N. Murray, who covered 166 square miles, embracing Townships 25 and 26 South, in Range 54 West; Sections 13 to 36 in Township 24 South, Range 54 West; Sections 15 to 22 and 27 to 34 in Township 24 South, Range 53 West; and Sections 3 to 10, 15 to 22, and 27 to 34 in Townships 25 and 26 South, Range 53 West. The balance of the territory, about 888 square miles, was covered by the writer during the summer and fall of 1922. In this work he was assisted at different times by Messers. Frank C. Adams, James W. Hunter and Earl G. Smith.

DEGREE OF ACCURACY.

The field work has been carried on without the aid of a reliable base map and without any map showing contour lines of sufficient accuracy to be of real service. Under these conditions really accurate mapping of the geology or of other features shown on the map accompanying this report was out of the question. Efforts to make use of plane-table surveying in locating formation contacts and prminent topographic features proved to be unsatisfactory owing to the impossibility of making such a survey harmonize with the section lines as described in the Government's official field notes, or as actually laid out and generally recognized by the property owners.

Fortunately the territory covered by this survey has not only been laid out in sections but has been largely fenced along section and quarter section lines, and many county and private roads have been constructed or opened along these lines. For the most part, therefore, the section lines as generally recognized by the community and as marked by roads and fences were accepted as substantially correct, and the sections in most cases were considered to be of uniform mile-square dimensions. The exceptions to this rule are to be seen on the map at the 4th and 5th correction lines South. The sections on the south side of the 4th correction line South measure from north to south nearly a mile and a half; the sections on the south side of the 5th correction line South measure about a mile and a quarter in the same direction.

A further deviation from regularity is to be seen along the north line of Township 26 S., Range 57 W. The original government survey notes on this township contain gross errors of fact that make it impossible to map in accordance with the official description. Along the north side of this township lies a triangular strip or "No Man's Land" about a quarter of a mile long on the east end of the township and tapering to nothing at the west end. This strip, if one follows the official government survey description, cannot be placed in either T. 25 or T. 26; and does not, in fact, legally exist. In preparing the map, however, it becomes necessary to insert this strip where it actually belongs and to draw an arbitrary line between townships 25 and 26. This brings unavoidable confusion in the mapping of this portion of the district. For instance, the town of Timpas is shown on the map as lying considerably further from the north line of Township 26 than actual measurement on the ground would justify.

In mapping the roads an attempt has been made to distinguish between primary and secondary roads. This distinction, however, is rather arbitrary and is not based on whether a road be a county road or not. The distinction is based upon the importance of a road as a used highway or on its present condition. As a matter of fact many private roads are often used in preference to those officially recognized by the county and are in better condition. In such cases the roads have usually been mapped as primary.

In preparing the map of this area, however, it was not the intention to make a complete map, so far as cultural features are concerned. For this reason many secondary roads that do not follow section lines will not be found on the map. Those that do appear are mostly roads that could readily be mapped in connection with working out the geogoly. Many secondary roads, for instance, will be found in the southern and southeastern portion of the map.

SOURCES OF INFORMATION.

The paper by N. H. Darton published by the United States Geological Survey as Professional Paper No. 52, and entitled Geology and Underground Waters of the Arkansas Valley in Eastern Colorado, furnishes much valuable information bearing on the subject of this report, and free use has been made of this information. Wherever possible, information as to wells dug or drilled has been gathered from well drillers and from farmers on whose property wells have been located. Such information is not always as reliable as might be wished, as memories are often faulty and definite well-logs have, in most cases, never been made, or have been lost. Information from these sources in so far as it may bear upon the geological formation passed through has, wherever possible, been checked by field observations on the local geology. Much more reliable information has often been obtained from railroad companies and from large industrial enterprises on whose properties artesian wells have been drilled.

ACKNOWLEDGMENTS.

It is a pleasure to acknowledge the hearty co-operation of the many hundreds of property owners, without whose generous assistance most of the information collected as to wells, would not have been available. The writer has been put under special obligation to the officials of the Fort Lyon Canal Company for valuable maps furnished; to the American Beet Sugar Company at Rocky Ford for maps and well-logs; to the Atchison, Topeka and Santa Fe Railway for numerous well-logs, and other valuable information; to Mr. Charles McVay for helpful information based upon a very extensive experience in well drilling in the district under investigation, and to the International Filter Company, the Permutit Company, and the Graver Corporation, for chemical analyses of shallow well waters carried out in their laboratories.

TOPOGRAPHY

The general elevation of this district is somewhat over four thousand feet, the low and high points being about 3,900 feet in the Arkansas River bottom on the east edge of the mapped area, and 4,900 feet on the high table land capped with Timpas limestone, some twelve or fifteen miles to the south and southwest of La Junta.

The Arkansas River runs in a general easterly direction through the territory and the valley is marked by a flat alluvial plain, varying from a mile to two or more miles in width. This alluvial plain is for much of its course bounded rather abruptly by a more or less pronounced escarpment formed by the Timpas limestone or by the Greenhorn limestone, as, for instance, the very pronounced escarpment running for several miles along the Arkansas River, opposite La Junta.

In the southeast portion of the territory the Purgatory River forms a pronounced canyon cut deep into the Dakota and Purgatoire sandstone formations. It flows into the Arkansas River east of Las Animas at a point some six miles beyond the eastern boundary of the area under investigation.

On the south side of the Arkansas River the Timpas Creek forms the most considerable tributary. It flows in a fairly open valley and contains water most of the time. Other tributaries on the south side of the river are Crooked, Anderson and King arroyos, which, as the name suggests, are deep-cut gulches and afford excellent rock exposures.

Much of the territory south of the Arkansas River, especially that part lying between Timpas Creek and the Purgatory River, consists of high table lands deeply dissected by arroyos and marked by numerous flat-topped buttes and nearly vertical escarpments.

Except for the escarpment facing the Arkansas River, the territory north of the river is mostly devoid of pronounced buttes and deep-cut arroyos. The land lies either flat or gently undulating and the drainage is very little marked with the exception of Horse Creek in the central portion and Adobe Creek on the east edge of the territory. Over a considerable area are to be found large flat depressions, produced by wind-driven sand and silt, and forming natural reservoir sites, or, in some cases, natural lakes and ponds.

A considerable portion of the the territory investigated is under irrigation, especially west of La Junta, and surrounding Rocky Ford, Ordway and Sugar City.

GEOLOGY

GENERAL DESCRIPTION.

The rocks of this district are all of sedimentary origin. The older formations of the Paleozoic era from the Cambrian up to the "Red Bed" series presumably underlie the entire area, but they are nowhere exposed on the surface. The presence of the "Red Beds" has, however, been demonstrated by a few deep wells.

The beds exposed on the surface are mainly of Cretaceous age, and run from the Purgatoire up to the Pierre. Considerable areas are covered with unconsolidated Quaternary sediments. There is also a very little Tertiary in the shape of a few small gravel caps of Nussbaum gravels. Finally, the Morrison formation is exposed in a narrow strip along the Purgatoire River bottom.

The succession of formations here involved, together with their general character and thickness, is shown in the following table:

TABLE OF GEOLOGIC FORMATIONS

Age	Formations	Character	Feet
Quaternary	Dune sands	Fine, unstratified, wind-driven sand	0-60 or more
	Alluvium	Sand, gravel, silt and loam of the Arkansas River bottom	20-25
	Lower terrace gravels	Sand, gravel, loam, some clay	30
	Higher terrace gravels	Sand, gravel, loam, some clay	30
Tertiary	Nussbaum	Sand, gravel	20
Cretaceons	Pierre (lower part)	Dark gray to blue gray shale	400 or more
	Apishapa } Niobrara group	Dark to light gray shale and sandy shale, some impure limestone	500
	Timpas } Niobrara group	Limestone and gray limy shale	200
	Carlile } Benton group	Dark shale with large concretions, brown ferruginous limestone on top	130 or more
	Greenhorn } Benton group	Alternating thin beds limestone and dark gray shale	60
	Graneros } Benton group	Dark shale with 3-foot stratum of Bentonite ("talc")	190
	Dakota } "Dakota sandstone"	Gray, hard standstone, shale or shaly sandstone in lower part	100
	Purgatoire } "Dakota sandstone"	Rather soft, gray or white standstone	165
Jurassic	Morrison	Gray, green and red shales, limestone and standstone layers	200

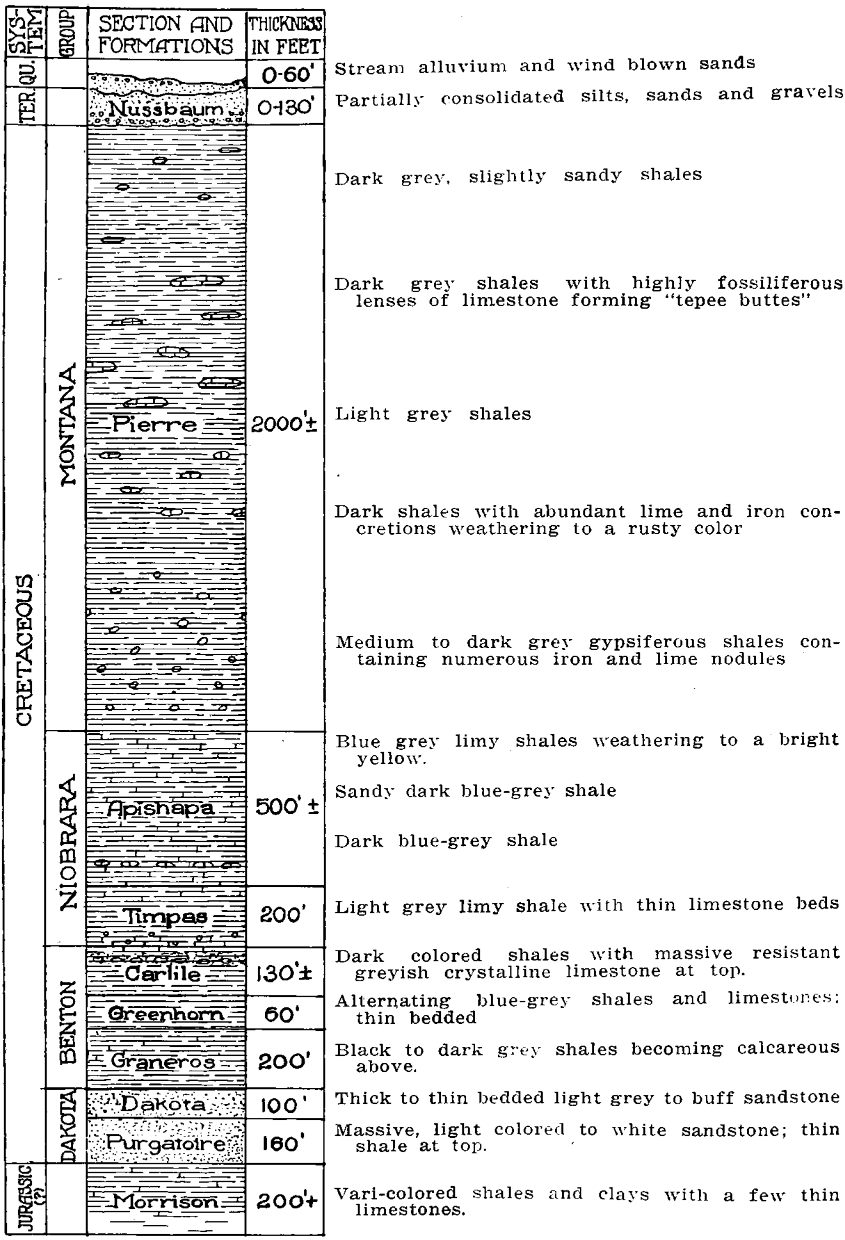

Figure I. General section showing character and thickness of strata.

DESCRIPTION OF FORMATIONS

JURASSIC SYSTEM

MORRISON FORMATION. The Morrison formation which, until recent years has generally been considered as Jurassic, is now by many geologists placed in the Cretaceous system. However, as there is still good authority, for retaining this formation in the Jurassic, it has been thought best to follow the practice of the Colorado Geological Survey which heretofore has so classified it.

This formation is supposed to be about 200 feet thick in this part of the state, but as only the upper part is exposed the full thickness has not been determined. It occurs only in a comparatively narrow strip in the bottom of the Purgatory River canyon in the southeastern part of the area under consideration.

The portion exposed consists of light gray clays, passing into or alternating with clays of greenish or purplish or maroon color, and containing also layers of light gray, compact limestone and of grayish of whitish sandstone. Its chief characteristic is the rapidity with which it changes the character and the color of its beds.

CRETACEOUS SYSTEM

THE DAKOTA-PURGATOIRE SANDSTONE. These two formations comprise what is commonly called the "Dakota Sandstone," a term well known throughout eastern Colorado as this sandstone is the source of nearly all the artesian water suitable for domestic purposes found in this portion of the state. There are in fact two horizons, an upper and a lower, in which artesian water is to be expected. These two are commonly designated by well drillers as the "first sand" and the "second sand" of the Dakota formation. They correspond respectively to the Dakota proper and to the Purgatoire. They are both essentially sandstones and are separated by a relatively thin bed of shale. The "first sand" or the Dakota proper has a thickness of about 100 feet; the "second sand" or Purgatoire of about 160 feet. These thicknesses are subject to local variation. The variation in thickness, especially of the Dakota proper, is perhaps in most cases more apparent than real, in that well logs often record as shale what should more properly be called sandstone. This is due to the great fluctuation between sandstone, shaly sandstone, and shale in the lower half of the formation.

The shale that divides the two sandstones may be nearly pure shale or hard clay (fire clay) of 5 or 6 feet thickness or even less. But more commonly it is a sandy shale or a shaly sandstone, and, in that case, may pass insensibly into the overlying or underlying sandstone. It is difficult to draw the line between the upper sandstone and the shale because the sandstone is inclined to contain irregular shaly streaks, especially in the lower part.

This accounts for the fact that well logs frequently give the thickness of the shale as 50 feet or more, and that the overlying sandstone is given as correspondingly less. The presence of a little shaly matter in a sandstone apparently affects the drillings to such an extent as to make them appear as shale.

The "first sand" or Dakota proper is usually quite hard and is thick-to thin-bedded. Its color is usually light gray to buff, but may locally be nearly white. It may also be locally much darker colored and weather to a yellow or rusty brown color.

The thickness as measured in Purgatory Canyon, including the underlying shale, is as follows:

Sec. 32, T. 25, R. 53, 95 feet.
Sec. 17, T. 26, R. 54, 100 feet.

The Purgatoire or "second sand" is upon the whole a more massive sandstone than is the Dakota proper. It is also softer, of coarser grain and of lighter color. In places it becomes very white. It weathers to a pitted or cavernous surface. In Purgatory Canyon the upper bed of five or six feet is somewhat harder and resisting and weathers to a dark brown color. This dark color and the tendency to form a more or less pronounced bench enables one to recognize readily the top of the Purgatoire.

The thickness was measured in several places in Purgatory Canyon as follows:

Sec. 25, T. 26, R. 54, 165 feet (100 feet of white sandstone at base).
Sec. 29, T. 26, R. 53, 90 feet (very little white sandstone at base).
Sec. 21, T. 26, R. 54, 155 feet.
Sec. 29, T. 26, R. 54, 160 feet.

The thickness of ninety feet in one case would appear to be quite exceptional and is due to the absence of the greater part of the white, coarse grained sandstone that appears at the base of the Purgatoire in most places along the Canyon.

The Dakota-Purgatoire formation underlies the entire territory under consideration, but appears on the surface only in the southeastern portion, covering together with the Morrison formation, altogether a total of about three townships. The sandstones resist erosion greatly and form nearly vertical canyon walls along the Purgatory river and along its tributaries. Sometimes the lower and sometimes the upper sandstone forms the most conspicuous canyon wall.

At the top of the Dakota several feet of alternating sandstones and shales furnish a transition to the overlying Graneros shale.

GRANEROUS SHALE. The so-called Benton Group, lying immediately above and conformable with the Dakota consists of three members, a lower shale member called the Graneros shale, an intermediate limestone, the Greenhorn Limestone, and an upper shale member, the Carlile shale. In southeastern Colorado these three members of the Benton Group are easily distinguished and may, therefore, be treated separately.

The Graneros shale is composed almost entirely of shale and has a thickness of approximately two hundred feet. The central portion has a dark gray to nearly black color. The upper and lower portions are of a much lighter gray. Some forty to fifty feet below the top of the formation occur several thin platy beds of gray, sandy limestone that weather into plates and flakes. The thickest and highest of these limestone beds attains a thickness of about a foot. About 85 feet above the bottom is a nearly white three-foot bed of clay-like material that is known as Bentonite. This bed appears frequently in well logs under the name of "talc." It was not observed on the surface within the territory surveyed, but an outcrop was noticed about a mile east of the area boundary and two or three miles southwest of Las Animas. The Graneros shale is comparatively hard, but weathers easily to thin scales or flakes and ultimtely to a gray clay. Transparent gypsum or selenite crystals are common near the base of the formation.

Owing to its slight resisting power this shale does not often appear in outcrops except on the slopes of escarpments formed by a protecting cap of Greenhorn limestone. In this case the thin limy beds, forty to fifty feet below the top of the formation, often form a distinct secondary bench. Its surface distribution is limited to the Arkansas River valley at the extreme eastern edge of the mapped area and to a strip some one to two miles wide, starting at the southwest corner of T. 26, R. 55, and running northeast to the edge of the territory. It is well exposed in the bluff that faces the river bottom on the south side of the valley.

GREENHORN LIMESTONE. Overlying the Graneros shale occurs a series of alternating bluish gray limestones and darker gray shales having a total thickness of fifty to sixty feet. The limestone layers measure from three to twelve inches in thickness and the intervening shales somewhat more than this. Probably about two-thirds of the formation is composed of shale. Yet because of its resisting power the limestone is much more in evidence than the shale. It often forms benches the slopes of which are strewn with limestone, leaving the impression that the entire formation is composed of this rock. The exact limits of this formation are often difficult to determine because of a gradual transition into the underlying and overlying shales. The limestone is fairly hard and the layers are often characterized by a strong tendency to develop thickly crowded vertical joints which cause the limestone to split into angular blocks or into small plates. This vertical jointing is in marked contrast to the horizontal jointing everywhere characteristic of the higher lying Timpas limestone.

Both the limestone and the shale contain abundant fossils of which the most striking is a large oval-shaped shell having concentric ribs and measuring several inches in diameter.

In southeastern Colorado the Greenhorn limestone has generally been assigned a thickness of 30 to 50 feet. In the territory under consideration, the only place well adapted to determining the thickness was near the center of the north line of Sec. 19, T. 23, R. 53, where this formation measures 60 feet. As it is not certain that the highest beds are present owing to possible erosion it may be that the real thickness is somewhat more than this.

The largest area of outcropping Greenhorn is to be found on the south side of the Arkansas River from just below La Junta to the east line of the mapped territory. A much narrower strip also occurs on the north side of the valley. A further narrow strip runs parallel to the outcropping Graneros shale in the southeastern part of the territory, and a small area is to be seen southwest of Timpas.

In spite of the prominence of this limestone and the appreciable thickness of the formation, well logs very rarely show anything but shale at this horizon. That the limestone is not recognized by well drillers is doubt-

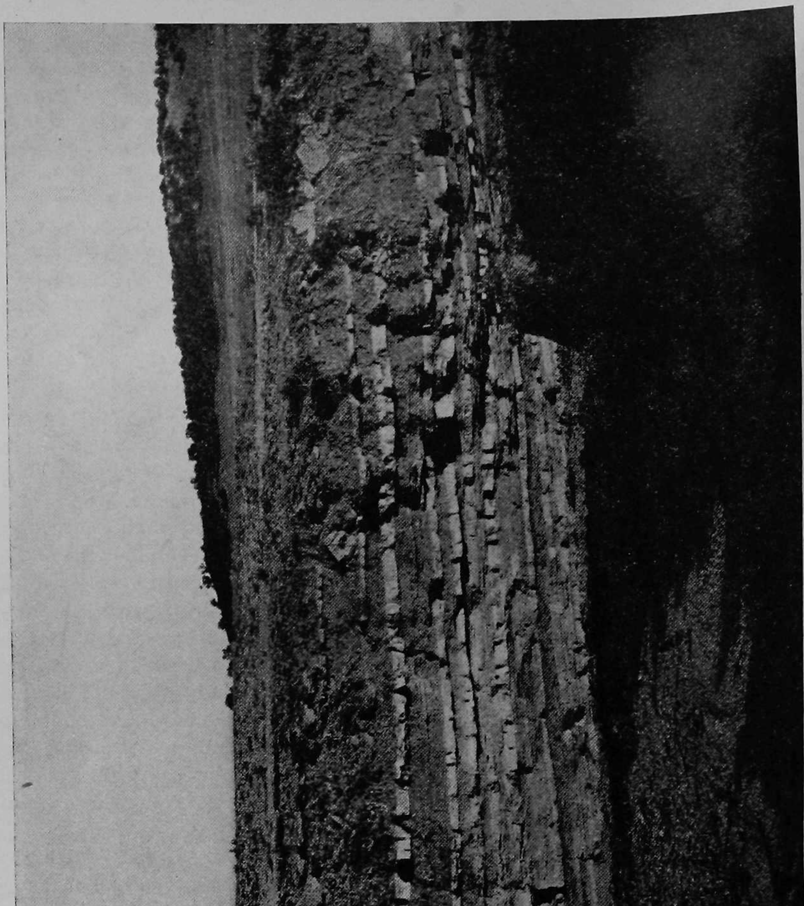

Figure II. Greenhorn limestone near Thatcher.

less due to the fact that limestone and shale are ground together to form a dark gray sludge similar in appearance to the sludge from shale lying above and below the Greenhorn limestone.

CARLILE SHALE. The Carlile shale, which is the third or upper division of the Benton group, has a thickness of 130 feet and consists essentially of shales of medium gray color in the upper and lower portions and of a grayish black color in the center. The thickness was determined by a number of measurements taken on favorably located ground in Sec. 24, T. 24, R. 54. The shales are not quite so firm as are the Graneros shales and in weathering they do not produce quite so sharply defined flakes.

At about 20 to 30 feet from the top of the formation the shale usually becomes slightly sandy and contains large roundish concretions that measure from two to five or six feet in diameter, and that furnished a ready means of identifying the horizon in which they lie. Locally they may be thickly crowded together, the distance between the concretions being not much more than their diameter. They not infrequently protect the shale from erosion and may cause the development of low benches. These concretions are of the type called septaria in that they contain in their interior numerous gapping shrinkage cracks or irregular cavities. The concretions are gray within and brownish towards the outside. The cavities are lined with calcite crystals of two periods of deposition. Next to the cavity wall the calcite of the first period has a brownish or a wine-yellow color, and the crystals consist of sharp-pointed rhombohedrons that measure about ¼ of an inch in diameter. The second deposit of calcite consists of white, flat-rhombohedral crystals from a quarter to a half inch or more in diameter. These large concretions break into fragments under the influence of the weather, so that entire concretions are comparatively rare except in excavations or fresh exposures.

At the top of the Carlile shale is a very characteristic rock, entirely different from the rest of this formation. This is a grayish, crystalline limestone that weathers to a rusty brown color, and that measures from two and a half to three and a half feet in thickness. It is very fossiliferous, the fossils consisting largely of small oyster shells (*Ostrea lugubris*) with which occur not infrequently thin, flat fish scales of black or brown color, and small sharks teeth; also occasionally the casts or impressions of coiled, strangely ribbed ammonite shells (*Prionocyclus wyomingensis*). This top limestone of the Carlile shale resists weathering more strongly than does any other rock in the La Junta area. Consequently it forms very pronounced and continuous outcrops around the edges of all the elevated areas capped by Timpas limestone. It likewise often forms the caps of isolated buttes or of extensive benches from which the higher Timpas limestone has been removed by erosion. This horizon is very easy to recognize, so that there is usually no difficulty in locating the Timpas-Carlile contact.

This limestone horizon at the top of the Carlile shale has heretofore been identified as a sandstone and is so named by Darton, who says: "the top sandstone averages 10 to 20 feet in thickness west of longitude 104". Likewise, Fisher finds this to be a sandstone in the Nepesta Quadrangle, not far to the west; and Stose, in the Apishapa Quadrangle. Darton also gives on Plate XV, opposite page 32 (reproduced in Frontispiece in this report) a photograph illustrative of this supposed sandstone, taken at a point on the north side of the Arkansas River two miles northwest of La Junta.

It is doubtless true that this rock is a standstone as it occurs further to the west, where also it has greater thickness, but, so far as the writer has observed in the territory under consideration, it is nowhere a sandstone. It does locally develop slightly sandy streaks, but not sufficienly so to justify calling the rock a sandstone. A typical sample of this rock, taken on Sec. 15, T. 26, R. 55, was dissolved in hydrochloric acid with the result that less than one per cent of insoluble matter was found. The rock effervesces with great readiness in dilute hydrochloric acid, and would appear to be a neary pure limestone. It is evident, therefore, that this characteristic rock, marking the top of the Carlile shale, changes from a sandstone to a limestone on passing eastward.

A further change in the character of this rock is noted on approaching the eastern edge of the territory mapped. The rock loses its nearly uniform brownish color and becomes mottled brown and white. The irregular brown spots appear almost like inclosed fragments in the prevailing grayish white mass, but the frayed character of the boundary of these brown spots shows that they are due to local oxidation of the iron contents or to staining. At the same time the stratum loses its sharply defined upper edge. Usually there is a sharp line of demarcation between the overlying Timpas limestone and this brown-stained bed, but with the coming in of the mottled color this sharp contact line disappears and it is impossible to draw a line of contact between the two rocks. The upper Carlile limestone bed is to all appearance part of the overlying Timpas limestone.

The above characteristics are well shown at the base of the cliff on the south side of Horse Creek, in the northeast quarter of Sec. 30, T. 22, R. 53, and the same characteristics continue to the eastern edge of the mapped territory.

The Carlile shale forms the bottom of many gulches and arroyos where streams have cut through the Timpas limestone and the lower portions of escarpment slopes, the upper part of which are due to the strongly resisting Timpas limestone, together with top limestone bed of the Carlile formation. Its distribution on the surface is confined mostly to the region south of the Arkansas River. North of the river it runs a considerable distance up the valleys of Adobe Creek and Horse Creek.

Figure III. Contact of Timpas limestone and Carlile shale, Anderson Arroyo.

The thickness of the Carlile shale as given by Stose for the northern part of the Apishapa Quadrangle is 226 feet. In the Nepesta Quadrangle, which lies immediately north of the Apishapa Quadrangle, the thickness as determined by Fisher varies from 210 to 225 feet. The thickness as given above for the territory under consideration is 130 feet. The point where this thickness of 130 feet was determined, lies about 34 miles east of the eastern line of the Apishapa Quadrangle. A thinning of this shale, therefore, amounting to 80 to 95 feet occurs within this distance. It is to be presumed that the thinning from west to east is gradual, so that the thickness of the Carlile shale in the western part of the area may be presumed to be considerably over 130 feet, not improbably 170 to 180 feet.

Darton, N. H., Geology and Underground Waters of the Arkansas Valley in Eastern Colorado, Professional Paper No. 52, U. S. Geol. Survey, p. 28, 1906.
Fisher, C. A., Geologic Atlas U. S., folio 135, U. S. Geol. Survey, 1906.
Stose, George W., Geologic Atlas U. S., folio 186, U. S. Geol. Survey, 1912.

TIMPAS LIMESTONE. The Timpas limestone is the lower member of the Niobrara Group, the upper member being the Apishapa shale. While the name Timpas limestone is applied to the entire formation only the lower fifty feet can properly be designated as a limestone, the upper portion, constituting nearly three quarters of the formation, being essentially a limy shale. The thickness of this formation could not be determined by measurement in the field nor do well logs give any information as the thickness of the upper shaly part. That the formation has a thickness of from 175 to 200 feet is based upon the fact that these thicknesses are given respectively for the Apishapa and Nepesta Quadrangles.

The fifty feet at the base of this formation consist of a soft, light weight, whitish limestone of compact texture and chalk-like appearance. It occurs in layers that are from a few inches to two or more feet in thickness and are separated from each other by a thin film or at most by one or two inches of gray shale. The average thickness of these limestone layers is about one foot. This limestone weathers into rough plates and chips with the cleavage cracks lying parallel to the bedding. In this respect it is markedly different from the lower lying Greenhorn limestone where the joint cracks are at right angles to the bedding. Ultimately this limestone breaks up into small angular, flattish fragments one-half inch to two inches in diameter, that strew the surface or that are washed as gravel into the gulches.

This limestone occasionally contains individual bivalve shells measuring up to five or six inches in diameter (*Inoceramus deformis*). The surface of these fossil shells is usually covered thickly with very small oyster shells (*Ostrea congesta*). In the lower portion of the basal limestone occurs in many places a great abundance of spherical, oval and cylindrical concretions measuring up to one inch or more in length. These concretions have a dark brown color and a rough surface due to pyrite crystals of which they were originally composed, and which have now usually been altered to limonite, a hydrous oxide of iron. They weather out from the limestone and may be seen scattered thickly over the surface.

This basal limestone passes insensibly upward into a limy shale of prevailing light gray color. In places this shale may assume a dark gray color and near the top becomes almost black. With it occur at different horizons thin beds of limestone similar to the basal limestone, usually whitish but occasionally yellowish in color. These intercallated limestone beds are often very thin and occur in repeated alternation with shale. Locally they may thicken considerably and form minor benches or escarpments. At the top of the formation similar limestone beds occur of greater thickness and abundance and having a characteristic yellowish or pinkish yellow color. These limestone beds in the upper part of the formation, especially those at the top, readily split into very thin layers and leaves with smooth parallel surfaces. The shales mostly weather into thin papery leaves and scales. Similar fossils to those noted in the basal limestone also occur in the higher limestone layers of the formation.

The Timpas limestone has a wide distribution within the territory surveyed. Usually the basal limestone member forms the capping rock of the mesas and buttes. This limestone together with the very resistant limestone

Figure IV. Timpas limestone quarry southeast of La Junta.

at the top of the Carlile shale makes very prominent escarpments or vertical cliffs overhanging the soft underlying Carlile shales. Almost everywhere the Timpas-Carlile contact is very irregular and ragged and the topography caused thereby is correspondingly rugged and precipitous. A glance at the map will show the contrast between this ragged contact that marks the base of the Timpas and the comparatively smooth contact line at the top of that formation. The Timpas limestone crosses the mapped area in a broad belt from the southwest to the northeast, covering approximately one-half of the area. Streams have cut through the limestone in many places and brought to light the underlying Carlile shale.

Attention has been called above to the merging of the bottom of the Timpas limestone with the upper limestone bed of the underlying Carlile shale near the eastern edge of the mapped area. In line with this observation is the discovery of a supposedly characteristic Benton group fossil in the basal limestone of the Timpas. Near the center of the east half of Sec. 27, T. 22, R. 53, a specimen of *Inoceramus* was collected near the bottom of the Timpas limestone. This has been identified by Professor Junius Henderson as *Inoceramus labiatus*. This locality is only a little more than two miles from the eastern edge of the investigated area. So far as the writer is informed this fossil has not heretofore been reported as occuring above the Benton Group. We have, then, in this case not only the merging of the upper Carlile limestone, which further west thickens up and passes into a sandstone, into the basal limestone of the Timpas, but a characteristic Benton fossil is found to occur also in the overlying Niobrara.

APISHAPA SHALE. Overlying the Timpas limestone and comformable therewith occurs a series of laminated and somewhat calcareous shales called the Apishapa shale. As in the case of the Timpas it has not been possible to determine on the ground the thickness of these shales. It is presumed that they have approximately the thickness given for the Apishapa and Nepesta quadrangles to the west where this formation has a thickness of from 450 to 500 feet.

The lower portion of these shales for a distance of fifty or seventy-five feet is of a dark, bluish gray color. This is followed by shales of similar color that break up under the influence of the weather into papery flakes. The central portion is distinctly more sandy and much lighter in color; the upper part is dark colored. These shales develop locally and at different horizons impure limestone beds that measure several inches or a foot or more in thickness. Such a limestone bed marked by a distinct bench occurs between the two Nussbaum-capped buttes in the southern half of section 29, T. 23, R. 57. Several similar limestone beds are supposed to occur at the top of this formation, but the upper contact of the Apishapa shale is everywhere covered with loam or sand, and is, therefore, invisible.

The Apishapa shale on exposure weathers to a very pronounced light yellow color that often suffices to identify the formation. This shale is also characterized by the presence of minute, whitish specks that in appearance are suggestive of kaolin flakes. They are easily seen by the aid of a pocket lens, and usually are plainly visible to the unaided eye. They occur throughout the formation from top to bottom, both in the dark gray to black unoxydized shale in the extremely weathered, superficial portions where through oxydization the color has been changed to a light yellow. These light colored specks are sometimes thickly crowded, and sometimes sparsely scattered. In some lamellae they may be apparently missing, but this is not true for any appreciable thickness. With dilute hydrochloric acid the shale effervesces with great readiness and the whitish specks disappear. They would appear, therefore, to be calcite, and this determination is corroborated by an examination of a thin section under the microcsope.

Except for these light colored calcite specks the Apishapa shale near the top of the formation bears a close resemblance to the very dark shales near the bottom of the overlying Pierre formation, and their presence or absence may be taken as a means for distinguishing between the two shale formations. This is quite an important distinguishing mark for this shale as with their aid a few small flakes of the shale brought up by burrowing animals or in connection with well digging and boring may often suffice to identify the formation.

Approximately one hundred feet above the base of the Apishapa shale there are locally to be seen numerous well developed, gray colored concretions from one to three or four feet in diameter. These concretions contain cracks in the interior within which occur calcite and white barite crystals. The concretions are well developed near the center of the eastern half of Sec. 21, T. 22, R. 57, where, by their resistance to erosion, they cause the formation of a distinct bench. At this point the barite crystals attain a diameter of three or four inches. There fragments are to be seen abundantly strewn over the surface. Gypsum is very common in the Apishapa shale. It occurs usually in thin plates along the cleavage planes of the shale or in irregular cracks.

The Apishapa formation occupies about one-third of the area under consideration, and lies almost entirely to the northeast of the diagonal line drawn from the southwest to the northeast corners of the map. Actual exposures of the shale are very infrequent owing to the softness of the material. Over a large portion of the shale area the formation is deeply buried beneath a covering of sand or of loam. As above stated the Apishapa-Pierre contact is nowhere exposed. Its position could be determined only approximately.

PIERRE SHALE. The Pierre shale which probably has a thickness of over two thousand feet in this part of the state is represented within this area by only the lower 400 or 500 feet of soft, bluish black shales that weather on exposure to a buff color. They appear to be entirely free from fossils. This shale is very sparingly exposed. It is confined to the northwestern corner of the area.

As already stated the contact between the Pierre and the Apishapa is not exposed. The indefinite line marking the supposed contact as shown on the map was determined largely with the aid of a few well logs. Judging from the depth of the Dakota sandstone as shown in the well logs of Sugar City and of Ordway it is necessary to locate the Pierre-Apishapa contact somewhere to the south of these towns. The location as shown on the map may, however, be far from correct.

TERTIARY SYSTEM

NUSSBAUM FORMATION. The only member of the Tertiary System represented in this area is the Nussbaum formation. This formation which has extensive development to the north and to the southeast is reduced here to a few very small outlying remnants of what was doubtless once a continuous deposit. These small exposures occur as caps to conspicuous buttes. One of these buttes lies three miles north of La Junta and is a little over a mile in length. Another butte of about equal size occurs in Sections 32 and 33, T. 23, R. 57, about six miles southwest of Rocky Ford. Close to this last butte are to be found several additional small buttes measuring less than a hundred yards across.

Only the lowest beds of this formation which elsewhere may attain a thickness of 200 feet are represented. They consist of unconsolidated gravel, sand, and silt with a slight admixture of clay. The gravel may be locally consolidated into a hard conglomerate. It is usually only a few feet, at most, perhaps, 15 or 20 feet thick. The boulders and pebbles that make up the coarser part of the deposit may reach dimensions of six or eight inches or more in diameter. They consist of a great variety of hard, crystalline, metamorphic and igneous rocks such as compose the rocks of the mountains far to the west. The butte near La Junta serves as a local source of gravel and sand.

The Nussbaum lies unconformably on the Apishapa shales.

QUATERNARY SYSTEM

HIGHER TERRACE GRAVELS. Bordering both sides of the Arkansas River, and running back several miles from it, there are to be found many flat-topped benches or mesas that slope gently toward the river, and that usually terminate suddenly on the lower side in a gravel-covered cliff or steep slope. These gently sloping mesas are remnants of what were at one time continuous benches deposited by the river at a time (Pleistocene) when it flowed at a much higher level than at present. There were two such benches formed, a higher bench, or terrace, deposited on the sides of the valley, and either brought down by the river at flood time or washed down into the valley by tributary streams; and a lower terrace deposited similarly by the river and its tributaries at a later period, and at a time when the general level of the river valley had been materially lowered. The higher terrace is the older as it was laid down first; the lower terrace is the younger. They are described and mapped under the names Higher Terrace Gravels and Lower Terrace Gravels. These two terrace gravels are practically identical in the character of the materials that compose them. They are, in fact closely similar to gravels of the Nussbaum formation. They consist of coarse and fine gravels, sand, silt, and locally deposited clay. The materials were doubtless in part derived from the erosion of the Nussbaum. They vary considerably in thickness but were not observed to have a thickness greater than twenty to thirty feet. Gravel beds almost invariably occur at the bottom, followed by sandy layers and then by finer silts, or by silt and clay or loam. The flat-topped surface of these terraces often shows no sign of gravel. In fact, some of the most fertile tracts surrounding Rocky Ford and elsewhere in irrigated districts, are located on these terraces. The distinction between the two terraces is based entirely on their relative positions and elevations. The higher terrace has an elevation at various points of about thirty feet above the lower terrace. It is not, however, always easy or possible sharply to define the two terraces as the lower terrace may run up into and apparently coalesce with the higher.

The higher terrace gravels are most extensively developed south and southwest of Rocky Ford where they form several rather extensive, irregular shaped terraces that measure from two to four miles in greatest extent. They also occur in small, gravel-capped buttes and ridges on the north side of the river north of La Junta, and on the south side of the river several miles to the east of the city. The higher terrace gravels are very commonly consolidated at the base by calcareous cement into a very hard and resisting conglomerate.

LOWER TERRACE GRAVELS. As already stated the lower terrace gravels are to be distinguished from the higher terrace gravels only by their topographic position. That is, they occur at a relatively lower level. On the south side of the Arkansas River these terraces are extensively developed south and west of Rocky Ford and extend down to the city limits. They lie between the higher terrace gravels and the river. Also to the east of La Junta is to be found one large lower terrace and several smaller buttes capped with the same gravels. On the north side of the river is a narrow strip of these gravels on the west edge of the mapped area. It is impossible to tell how far from the river these gravels go at this place, as the gravel is covered by a sand deposit belonging apparently to the dune sands. Further east, on the south side of the river, they occur northeast and east of La Junta, and extend interruptedly down the valley nearly to the eastern limits of the area. In most cases the upper limit of these lower terrace gravels cannot be determined as they are covered with a deep fertile soil. Like the upper terrace gravels, these gravels may also be cemented to a hard conglomerate at the bottom, but this is not so common.

ALLUVIUM. The alluvium is a river deposit and forms the low, flat lands of the Arkansas River. No attempt to map similar deposits in tributary streams has been made. The material consists mostly of gravel or of gravel and sand at the bottom, and of finer sands, silt and loam at the top, and has a varying thickness up to 25 feet or more. It extends the whole length of the river valley and has a fairly uniform width of one to one and a half or two miles. It is a relatively recent deposit and represents the deposits of the river at flood level.

DUNE SANDS. The so-called dune sands are fine, uniform, whitish or yellowish sand deposits resulting from wind action. Sand dunes, when typically developed, occur in great irregular and often elongated sand billows, separated by hollows and depressions. The surface topography is in such cases very hummocky and there is no established drainage system. The sands are often shifting, being cut away by the winds in one place and deposited in another. Where sands are thus subject to constant movement, there may be little or no vegetation present. More usually vegetation gets a hold and hinders or prevents extensive wind erosion and removal. Sand dunes of this nature characterize the extensive area shown south of the river in T. 23, R. 53, and in two smaller areas further west. This sand strip, two miles wide, stretches not only across this township but also well across the township to the east. The sand in this case is very possibly derived in part from the river bottom. A similar area of sand dunes, but one more heavily covered with vegetation, is a strip a mile or two wide, north of the river, stretching across the southern portion of T. 22, R. 56.

This area of sand does not have definite, recognizable boundaries on the north and west but passes insensibly into a dune sand area to be described below.

Not all the area mapped as dune sand territory is characterized by conspicuous sand billows and intervening depressions, or by visible barren sand deposits. There is a very large area covering much of T. 22, R. 65, and extending over most of T. 22, R. 57, and six or seven square miles in the southwest part of T. 21, R. 57, that is level or gently undulating and that is covered by a fine fertile loam. Over all this area, however, wells disclose a thick deposit of very fine yellow sand that reaches a depth of fifty to sixty feet. This sand deposit is well disclosed in the outlet ditch from Lake Meredith which, for a distance of two or three miles, has been cut into the sand deposit to a depth of from twenty to forty feet. The sand is extremely uniform and apparently without stratification. This sand deposit is not of very recent origin and probably dates back to the Pleistocene age. It was probably deposited along with or subsequent to the lower terrace gravel upon which, as already noted, it lies.

It was not possible to determine how extensive this sand deposit is. The limits of the formation as shown on the map are largely conjectural, based upon very inadequate well-logs. It is very probable that other large areas further east are covered with similar dune sand deposits. This is all the more likely as much of the land investigated, lying north of the Arkansas River, has no well established drainage system and embraces large undrained depressions now occupied by lakes or reservoirs. Such natural depressions are presumably formed as the result of wind action. Probably in most cases the wind-driven material of the area embracing these natural depressions is silt and loam. In other cases it undoubtedly will be found to be sand.

GEOLOGIC STRUCTURE

With the exception of the extreme southwestern portion the area under consideration lies on the northwestern flank of a marked anticline or arch. The axis of this arch crosses the Arkansas valley several miles east of Las Animas and runs in a general way northeast-southwest. It pitches distinctly to the northeast. The beds have in general a northwest dip. This dip is very irregular both in direction and in amount, and may locally be interrupted for short distances by dips in the opposite direction. The average dip in the prevailing direction amounts to between 25 and 30 feet to the mile.

Fluctuations in strike and in dip are often very abrupt and very erratic so that one cannot safely assume that the prevailing northwesterly dip will continue for any given distance. Dips of one or two degrees are very common and occasionally dips of five or six degrees may be noted. The township lying south of Timpas, T. 26, R. 57, lies somewhat outside of the area covered by the above mentioned anticline and has been subjected to a much greater disturbance. The prevailing dip over much of this township is to the northeast and the variations in strike and dip are much more pronounced than elsewhere. At one locality in the southwest quarter of Sec. 17 a northerly dip as great as 36° was observed.

FAULTS AND VEINS

The geologic disturbances that have resulted in the development of the above described anticline and, more particularly, the stresses that have caused the sometimes very sharp local fluctuations in dip and strike, have very frequently resulted in the actual rupture of the rock strata and in the development of faults.

The fault planes appear to be vertical or nearly vertical, but not always so. The vertical displacement, that is, the vertical distance which one side or the other has been moved up or down with reference to the other side, is never very great. Usually it is only a few feet, and never, apparently more than 30 to 40 feet. The faulting is usually associated with an increase of the amount of dip on one side of the fault. In several cases the fault plane runs parallel to and not far from the axis of a synclinal fold or trough. Some of the faults may be traced for a mile or more. They may often be observed to fade out gradually into a more or less sharp fold of the strata.

With one exception all the faults found are associated with fault-veins of white calcite. The calcite vein is invariably slickensided on one or both sides and in at least one instance the vein contains fragments of slickensided calcite which has been again slickensided by a later fault movement. It is evident, therefore, that the fault fissures have been subjected to movement in part, at least, subsequent to the deposition of calcite. The calcite is distinctly and unusually coarsely crystalline. In one case mentioned below (Sec. 17, T. 26, R. 57) cleavable calcite individuals measuring six or eight inches in diameter were observed. With the aid of "float," composed of granular, slickensided calcite, fault planes may often be traced for some distance where otherwise visible evidence of a fault would be lacking. While the slickensiding is always very pronounced its intensity does not appear to be at all dependent on the amount of fault displacement, as it is just as marked where the movement has been only a few inches as where it has been thirty feet.

Most of the faults have a fairly uniform strike of S. 50° to 55° E., which is not far from the prevaling strike of the strata. There are other faults, however, whose strike varies considerably from this and a few that strike nearly at right angles to it. The downthrow side of the northeast striking faults is sometimes on one side, sometimes on the other, but prevailingly on the northwest side of the fault.

From a glance at the map it will appear that the faults are restricted to a belt running from near the southwest corner of the map northeast to within four miles of the eastern boundary. This belt practically coincides with the area within which occurs the irregular contact line between the Timpas limestone and the Carlile shale. In fact the faults as shown are entirely confined to these two formations. That they do not appear in the extended Timpas areas north of this line of contact may perhaps be due to the fact that it is difficult to trace these faults except where escarpments are present. The same may be said to be true for the soft and yielding formations above the Timpas, and this may account for their apparent absence. However, it should be noted that one such fault was indicated by the presence of the characteristic fault-vein calcite high up in the Apishapa shale just north of the area mapped, namely in Sec. 35, T. 20, R. 55. It should also be noted that no case of faulting was observed in the region of Dakota outcrops in the southeastern portion of the territory. As this region is characterized by almost continuous outcropping strata along canyon walls, it should offer a good opportunity for recognizing the faults in case any are present. The absence of such evidence, together with the comparatively slight displacement shown by the faults observed, indicates that the faults do not extend far below the lower Timpas contact, certainly not into the Dakota. They probably also do not extend down below the Carlile shale into the Greenhorn limestone. There are a good many places where this limestone is exposed in escarpments or cliffs, especially along the south side of the Arkansas River valley in T. 23, R. 53. But nowhere have faults been observed cutting this formation.

An itemized list of the faults observed is given below.

FAULT DATA

No. 1, S. W. ¼ Sec. 7, T. 24, R. 53. Strike N. 15° W., changing to N. 5° W. Downthrow 35′ on east side.

No. 2, E. ½ Sec. 8, T. 24, R. 53. Strike N. 60° W. Downthrow 11′ on S. W. side.

No. 3, Sec. 12-13. T. 24, R. 54. Strike N. 12° W., changing to N. 40° W.

Downthrow 30′ on west side, bringing Timpas limestone down to the level of the concretion layer in the Carlile shale.

No. 4, S. ½ Sec. 20, T. 24, R. 54. Strike N. 73° E. Downthrow 20′ to 30′ on south side.

No. 5, N. E. ¼ Sec. 30, T. 24, R. 54. Strike N. 69° E. Downthrow 20′ to 30′ on south side. Beds dip 10° to N. on south side.

No. 6, S. W. ¼ Sec. 31, T. 24, R. 54. Strike N. 63° E. Downthrow 8′ on S. E. side.

No. 7, N. W. corner of Sec. 5, extending into Sec. 6, T. 25, R. 54. Strike N. 42° E. Occurs along axis of syncline. Beds dipping towards fault 2° on S. E. side, 5° on N. W. side. Downthrow 20′ to 30′ on N. W. side at Timpas contact in Sec. 6, 5′ at same contact in Sec. 5.

No. 8, S. W. ¼ Sec. 5, T. 25, R. 54. Strike N. 43° E. Occurs along axis of syncline. Beds dip towards fault 3° on S. E., 7° to 10° on N. W. Downthrow 20′ to 30′ on N. W. side. Fault apparently continues to southwest into Sec. 7, and to northeast to east line of Sec. 5.

No. 9. Near southern line, Sec. 6, T. 25, R. 54, East-west fault. Occurs along synclinal axis. On north side beds dip 5° to 10° S., this is, towards fault. On south side almost level. Downthrow 30′ on north side.

No. 10. Sec. 6-7, T. 25, R. 54. (N. W. ¼ of Sec. 7) Strike N. 53° E. Occurs along synclinal axis. Beds dip towards fault steeply on N. W., nearly flat on S. E. side. Downthrow on N. W. side 7′ in Sec. 6, much more at west line of Sec. 7.

No. 11. S. W. ¼ Sec. 7, T. 25, R. 54. Strike N. 54° E. Occurs along synclinal axis. Beds on N. W. side of fault dip 5° S. E.

No. 12. N. E. ¼ Sec. 35, T. 23, R. 55. Two faults. (1) Strike N. 40° E. Downthrow 10′ to 20′ on S. E. side. (2) Strike N. 69° E. Downthrow 10′ to 20′ on S. E. side. The second fault is apparently cut off by the first.

No. 13. N. E. corner Sec. 24, T. 24, R. 55. Strike N. 12° E. Dip of fault plane 50° E. Downthrow 20′ to 30′ on east side. Timpas limestone is slickensided but there is no calcite fault-vein present.

No. 14. N. W. ¼ Sec. 9, T. 25, R. 55. Strike N. 48° E. Downthrow 11′ on N. W. side.

No. 15. Sec. 4-5, T. 26, R. 55. Strike N. 56° E. Downthrow 20′ to 30′ on N. W. side.

No. 16. Sec. 11, T. 26, R. 56. Strike N. 65° E. Downthrow on N. W., amount 15′ or 20′ or more.

No. 17. Sec. 28, T. 26, R. 56. Strike N. 30° E. Downthrow on S. E. side. Amount uncertain, probably 20′ or more.

No. 18. Sec. 13-14. Two parallel-running faults 100′ to 150′ apart. Strike N. 58° E. Downthrow in each case on N. W. Amount uncertain but the two combined considerable.

No. 19. Sec. 15, T. 26, R. 57. No. (1) Strike N. 78° E. Downthrow at least 20′ on N. W. side.

No. 20. Sec. 15, T. 26, R. 57. No. (2) Strike N. 34° E. Downthrow 5′ on S. E. side. Sudden change in strike and dip of strata on the two sides of fault. On S. E. side, strike N. 85° E., dip 5 N.; on N. W. side, strike N. 73° E., dip 15° N.

No. 21. Sec. 15, T. 26, R. 57. No. (3) Strike N. 54° E., changing to N. 34° E. Downthrow on N. W. side at least 30′.

No. 22. Sec. 15, T. 26, R. 57. No. (4) Strike N. 80° W. Downthrow on north side 30′ or more. Is apparently cut off by fault No. (3).

No. 23. S. E. ¼ Sec. 17, T. 26, R. 57. Strike N. 54° E. Downthrow uncertain, probably on S. E. side. Fault-vein well exposed in road. Contains cleavage calcite individuals 6 inches in diameter.

No. 24. N. W. ¼ Sec. 25, T. 26, R. 57. Strike N. 29° W. Downthrow on S. W. side, amount uncertain. Fault follows an anticlinal fold.

No. 25. Center of North ½ Sec. 32, T. 26, R. 57. Strike N. 75° W. Downthrow on north side, 10′ to 30′.

No. 26. Center of east ½ Sec. 32, T. 26, R. 57. Strike N. 46° W., changing to N. 30° W. Downthrow 30′ on north side.

WATER SUPPLY

GENERAL DESCRIPTION AND CLASSIFICATION.

Practically all underground waters have their origin in rain and snow. This is true of water obtained from shallow and from deep wells and from springs. Only a portion of the water that falls as rain or that is derived from melting snow runs off on the surface into streams. Much of it, and in case of sand or loose soils, almost all of it sinks into the ground. The same is true to a less extent of water that falls on relatively porous rocks, such as sandstone or porous limestone. Ultimately all such water finds its way back to the surface at lower levels through springs or seepage, or it is brought again to the surface by growing vegetation and by capillary attraction and is evaporated into the air.

Ordinarily water works its way to lower levels by seepage through the more or less porous material of the subsoil or through superficial deposits of sand, silt and loam. This seepage is usually a slow process, especially where the materials are very fine and the spaces between the particles of sand and silt are very minute. Where rainfall is abundant, therefore, seepage cannot carry off the water much faster than it is supplied, so that a few feet beneath the surface the soil remains permanently saturated. In regions of lessening rain fall or in periods of unusual dryness, the saturated zone is to be found at correspondingly greater depth. This upper surface of saturation is known as the "water table." It is not a level plane but slopes downward with the ground surface, although not quite so rapidly. However deep it may be far back from a stream, it usually comes to the surface in the valley bottom where the water often emerges as springs.

SHALLOW WELLS.

A pit sunk into the so-called ground water, that is below the water table, will gradually fill with water up to the level of the water table. The water level in the well will rise or sink with the rising and sinking of the water table, that is, with the fluctuations in rainfall. Many shallow wells derive their water from this source. They are dependent on the rain fall in the vicinity of the well, and are likely to go dry in dry years or in the dry season. Other shallow wells sunk in valley bottoms or gulches have a much more permanent water supply. Seepage from the river or creek keeps the flat-bottom land constantly saturated as long as the stream contains water; and long after a stream has become dry on the surface a slow underflow continues beneath the surface and is often sufficient to keep the valley-bottom wells supplied with water during long dry spells. Such water is, of course, also dependent on rainfall, but not so much upon the rain-fall of the immediate vicinity.

DEEP WELLS.

Deep wells are usually dependent upon a water supply from a remote source, especially those that have to be drilled to a depth of several hundred feet. In such cases the water is derived not from unconsolidated surface deposits but from more or less consolidated rock formations. Waters found at such depths not infrequently are under considerable pressure, sufficient in fact to cause them to flow freely at the surface. Such wells are designated as artesian wells. The name, however, is also used for wells that have once flowed and have ceased to do so, or it may even be applied to deep wells in which the water rises considerably higher than the point at which it was struck.

Artesian water may be struck at points many miles, even several hun dred miles distant from their place of origin. No rocks are absolutely impervious to water. Some are nearly so; others are extremely porous and readily receive and hold large quantities of water. Some coarse sand stones, for instance, are capable of holding water to the extent of 30 or 35 per cent of their volume. Wherever such strata come to the surface, especially where their upturned edges outcrop or are covered with a deposit of loose soil, water will readily penetrate. This is true of falling rain or melting snow. It is also true of large and small streams, like the streams that emerge from the Colorado Front range and flow out onto the plains. Such streams, when small, very often vanish, being absorbed by the outcropping porous rocks; and larger streams naturally lose part of their waters in this way. When porous rocks are protected above by a bed of impervious rock, waters thus absorbed will by force of gravity follow the rock strata indefinitely to lower levels, where they may ultimately find their way to the surface in the form of springs, or where they may be tapped by a drilled well and thus reach the surface by artificial inducement.

Water travelling underground in this way usually moves very slowly, as the pores between the rock grains are not large enough to allow of free flowing. But however slow the motion may be, if there be no chance of escape at lower levels, the water will stand at any given point under a pressure equal to a water column as high as the point of intake. Such conditions, however, can never be, for no rocks are absolutely impervious, and leakage must inevitably take place, especially when the pressure is great. Artesian water, therefore, will never rise quite to the level of the source, and, when leakage is great, it may not rise to the level of the surface, even when such surface is much below the source. For a similar reason, numerous artesian wells all tapping the same water-holding rock stratum must lower the water level and cause a lessening outflow at the surface, or cause a well to cease to flow.

QUALITY OF WATER.

Water has been described as nature's universial solvent. Almost every solid substance can be dissolved to some extent in water, given time enough. Of course many components of rocks and of soils are so very slightly soluble that no appreciable amounts can be taken into solution under ordinary conditions. There are, however, many other components of both soil and rock that are readily taken into solution by underground waters. This is particularly true of the soil which immediately yields up certain constituents to descending rain waters. These dissolved constituents are carried along wherever the water goes, and are found in well water, in springs and in streams fed by springs. Where rainfall is abundant, the more soluble constituents of soils are kept pretty well washed out, so that rain water that runs off the surface is unable to carry away in solution much mineral matter. The case is quite different in relatively dry regions. Soluble salts are formed in the soils faster than they can be carried off by water that penetrates the soil. Also excessive drying of the surface causes the salts to be drawn up to the surface by capillary attraction and to form crusts or "alkali." Such surface crusts are very soluble, so that large quantities of the surface salts are carried off by heavy rains into the streams.

It therefore happens that the Arkansas River and most of its tributaries that traverse this area, carry much solid matter in solution, especially when the first heavy spring or summer rains wash from the surface the fall and winter accumulations of alkaline salts. The same it true of most of the wells that are sunk in the lowlands of the river and tributary streams, and that draw their water supply from these streams. Such wells are often found to be "hard" or "alkaline."

In a similar way, but to a much less extent, the more consolidated rock formations through which under-ground waters may percolate yield up to the water certain of their constituents. Where the rocks contain little readily soluble material, as is the case with many standstones, but little material can be taken into solution, and the water remains soft. In other cases where the rock contains soluble materials, such as shales, or where the rock itself is soluble, as in limestones, the water that comes from the formations may be expected to be "hard."

EFFECT OF DISSOLVED MINERAL MATTER

It is a matter of general knowledge that natural waters vary greatly in character in accordance with the amount and nature of mineral held in solution. This is indicated by the popular use of such terms as "hard" and "soft" water, "alkali" water, "gyp" water and "salty" water. These terms may be and often are used in a very loose way, so that it is difficult to know how much weight to give to information as to the quality of well waters obtained from the property owners. It may not be out of place, therefore, to give a brief description of the more common elements and chemical compounds that are found in well waters and the effects that they have on the quality of the water.

It has been the custom of chemists in making water analyses to report the various chemical constituents found as occurring in the shape of certain definite salts, such as the sulphate of sodium (soda), of the carbonate, bicarbonate, or chloride of sodium or of calcium (lime) etc. It may be noted, however, that of later years it is becoming customary to report separately the metals or the bases and the acids with which they are supposed to be combined. This is done for the reason that it is not possible with our present knowledge to determine just how a number of metals and acids found in a given water may be combined.

Several waters contain a very large number of elements in solution, but in ordinary well water only a few may be expected in appreciable quantity. These are as follows: (1) metals—calcium (Ca) which is popularly known as lime, magnesium (Mg), sodium (Na), potassium (K), and iron (Fe); (2) acids—carbonic (CO_3), sulphuric (SO_4), hydrochloric reported in the form of chlorine (Cl), and nitric (NO_3). Compounds formed by the union of one or more metals with these acids are known as sulphates if combined with sulphuric acid; carbonates or bicarbonates if combined with carbonic acid; chlorides with hydrochloric acid; nitrates with nitric acid. The metals potassium and sodium, or, more correctly, the oxides of these metals (potash and soda) are known as the alkalies; and the oxides of calcium (lime) and of magnesium as alkaline earths.

HARD WATER. So-called "hard" water is caused by the presence of the salts of the alkaline earths, that is, of calcium (lime) and magnesium. These metals may be combined as carbonates, bicarbonates, sulphates or chlorides. "Soft" water is water that is free or nearly free of all salts, or that may contain salts of the alkalies, that is, of sodium and potassium. To a considerable extent salts of the alkalies and of the alkaline earths tend to neutralize each other, so that a water with a considerable amount of the salts of the alkaline earths may be fairly soft provided it contains a sufficient quantity of a salt of the alkalies. This is shown by the experience of the housekeeper who adds a washing powder (usually composed of carbonate of soda) to "cut" the water and to make it soft.

Water is rendered hard by calcium and by magnesium for the reason that these elements have the property of destroying or consuming soap. That is, these salts unite with the soap to form an insoluble, white, curdy salt that appears as soon as soap is added to the water. If sufficient soap is used all the calcium or magnesium present will thus unite with the soap to form this insoluble salt, and be removed from the water, and the water will become soft. This is, however, an expensive and inconvenient way to soften water. It is easier and cheaper to add a washing powder.

"Hardness" in water is of two kinds—temporary and permanent. Temporary hardness is caused by the presence of the carbonates of the alkaline earths. These carbonates are not very soluble in pure water but are soluble in water containing carbonic acid gas (CO_2) in solution. By boiling the water this gas is driven off and the carbonate salt is rendered insoluble and is precipitated. The formation of a crust or scale in the bottom and on the sides of a tea kettle is a familiar illustration of this action. Temporary hardness, may be mostly but not entirely removed in this way. There is always some of the calcium or magnesium salt left in solution after boiling.

Permanent hardness is due to the presence of sulphates, chlorides and nitrates of calcium and magnesium. It cannot be removed by boiling but may be partially removed by the addition of certain chemicals.

Wells that secure their water from limestone rocks or from the underflow of streams that drain limestone areas, usually yield "temporary" hard water. The same may be true of the stream itself especially at low water. The "permanent" hard waters of this area are derived mainly from formations that contain gypsum, a sulphate of calcium. Gypsum is commonly found in the shales of the Graneros, Apishapa, and Pierre formations, also in some of the soils of the La Junta area. It is somewhat soluble in water and, therefore, readily furnishes sulphate of calcium to the groundwaters. Such waters are commonly called "gyp" water. On account of the wide development of gypsum-bearing rocks they are very common. Sulphate of calcium (lime) is also found in the water of the Arkansas River, which drains extensive areas of gypsum-bearing rocks. For this reason many wells that derive their water from the underflow of this river yield water that is permanently hard.

Another source of sulphate of calcium in the wells and streams is to be found in the presence of pyrite—a sulphide of iron—in limestone and especially in alternating limestone and shale formations. Through the oxidation of the pyrite sulphuric acid is formed which thereupon attacks the limestone and forms a sulphide of calcium. This is probably the source of some of the very hard waters that may be struck in the Timpas limestone, especially in the upper part of the formation.

ALKALINE WATER. The chemical constituents that cause what are commonly called "alkaline" waters are the alkalies (sodium and potassium) and alkaline earths (calcium, and magnesium). They are the materials that form white crusts on the surface of the ground caused by evaporation of water held in the soil or by the drying up of temporary ponds. These elements are usually chemically combined as carbonates or sulphates, less commonly in agricultural regions as chlorides. Strong alkaline waters, especially those that have an alkaline taste, are due to the presence of the carbonate or sulphate of sodium (soda), rarely of potassium (potash). Weaker alkaline waters may be caused by the presence of the carbonates and sulphates of calcium and magnesium. Very commonly both alkalies and alkaline earths are present in alkaline waters. Alkaline waters are soft if they contain no salts of the alkaline earths. They are hard if they contain only the alkaline earths or these salts in excess.

EFFECTS OF OTHER COMPOUNDS. Iron is not ordinarily found in natural waters in great amount. It may, however, be very abundant in certain mine waters. In some mineral springs the iron present gives a special medicinal value to the water, but ordinarily it is not desirable. If water contain 4 or 5 parts of iron (Fe) in a million it is not fit to drink. Half of that amount used in laundrying will probably cause the clothes to be stained. One part or even one-half part in a million is sufficient to give the water an iron taste. Such small amounts in drinking water are harmless, and a slight taste of iron is often preferred by many people after they have become accustomed to it. Many of the artesian wells of this area that derive their water from the Dakota sands contain small amounts of iron, but not usually in sufficient amount to render them unfit for drinking purposes.

A very few wells in the district have struck salty water, that is, water containing common salt, or chloride of sodium. This salt is usually not much in evidence, however, in the streams and shallow wells.

Nitrates are seldom found in measurable quantities in natural waters. The presence of this acid is usually taken as evidence of water pollution. It is derived from decaying organic matter.

Acid waters are those that contain free acids, such as sulphuric or hydrocholric acid. These acids are not usually present in ordinary waters, but are to be found in many mine waters and in waters coming from coal seams. They also frequently are run into streams as waste products from chemical and other manufacturing plants.

WATER IN INDIVIDUAL FORMATIONS

MORRISON FORMATION

The Morrison formation in this area is almost entirely confined to the low lands bordering the Purgatory River and one or two of its tributaries. Under these conditions water would naturally be sought in the sand, silt and loam deposits close to the streams, and little occasion would be found to sink a well into the Morrison. Apparently, however, where such efforts have been made, the water found has been of very poor quality. A well was dug in this formation just back of the schoolhouse on Sec. 28, T. 26, R. 54. The water was unfit even for stock. Deep wells drilled to the Morrison formation at other points distant from the area within which the formation appears on the surface give little or no hope of finding water suitable for domestic purposes or for stock.

DAKOTA SANDSTONE

The two Dakota sands representing, respectively the Dakota proper and the Purgatoire formations are the source of nearly all the soft artesian waters found in this area. The same is true for a very much wider territory covering the southeastern part of the state. According to their relations to the general geologic structure the outcropping strata of these sandstones may be a source of intake for artesian waters tapped in lower lying portions of the plains, or they may yield water to the canyon streams through springs and seepage. As there are a number of permanent springs issuing from these sandstones along the sides of the canyon of the Purgatory River and of its tributary streams, it is reasonable to assume that upon the whole the Dakota yields water rather than absorbs it in this area. We may expect, therefore, that good water may be found in the Dakota sands in places where this formation is comparatively close to the surface. As a case in point, near the south line of Sec. 31, T. 25, R. 53, where the Dakota is at the surface, covered only by 6 feet of soil, water was struck at 207 feet in the second sand. It would not be advisable, however, to drill too close to a canyon along whose walls the sandstone is exposed in which water is sought. If only the upper Dakota sandstone is exposed in a canyon water in quantity could not reasonably be expected close to the canyon wall in this particular sandstone, but it might be found in the lower sandstone. It would also be inadvisable to drill for water in a comparatively limited area between two deep-cut canyons, unless one expects to go below the exposed strata. In such a case most of the water in the formation would probably find its way to the canyon bottom along the most easy course.

QUALITY OF WATER. The water obtained in the Dakota sandstones either in artesian wells or in springs is usually good soft water, suitable for drinking and other domestic purposes and for boilers. But the quality is not uniform, and it may even be very hard. It usually contains enough iron to give it a distinct flavor. While this is distasteful to many people, one can quickly become accustomed to it, and there are those who claim that they prefer it to iron-free water. The presence of iron is manifested by the brownish stain it imparts to water tanks. A little sulphur (presumably in the form of sulphuretted hydrogen, (H_2S,) is likely to accompany the iron. The fluctuation in iron content may be very marked even within short distances, as shown by the water analyses from La Junta, given on page 53-54. This may be due to the fact that variations in density of the sandstone cause the seeping underground water to pursue devious and different courses and thus be brought in contact with varying chemical constitutents. It may also be explained by an unequal distribution of the iron (probably originally in the form of iron sulphide) in the Dakota sandstone.

In the vicinity of Timpas the artesian water is poor in both of the Dakota sands: The water is extremely hard on account of the presence of large quantities of sulphates of calcium and magnesium. It was found unsuitable for boilers.

Chemical analyses representatives of the artesian waters derived from the Dakota sandstones in this area are found in the following table. They are taken from Professional Paper No. 52 of the U. S. Geological Survey.

Additional information as to quality as well as quantity of water is presented in the table containing data on Dakota wells to be found on page 35.

QUANTITY OF WATER. As to quantity the water obtainable from the Dakota varies greatly from place to place. This is due to variations in pressure and in porosity of the rock. As a general thing the water that flows from a given artesian well or that may be pumped therefrom is very constant. But when a large number of wells have been drilled within a limited area, necessarily drawing on the same source, the head is lowered for the reason that water is withdrawn faster than it can be replaced by slow seepage through a more or less dense rock formation. This lowering of the head is progressive as the number of driven wells increases. In case of flowing wells, the flowage at first lessens, then ceases altogether and pumping must be resorted to. Then the pumps have to be lowered to greater depths so as to secure a greater head. When artesian wells were first sunk in this area, most of the wells flowed freely. Now many of them do not flow. The entire water table has been lowered so that flowing wells are the exception. The elevation to which water will rise in a well is the elevation of the water table in that immediate vicinity. Usually a greater supply may be obtained by lowering the pump cylinder, but, of course, this means increased expense for pumping.

Illustrative of the above is a well recently drilled by the American Beet Sugar Company at Rocky Ford. Before pumping, the water level stood at 87 feet from surface. With the cylinder at 260 feet below the surface the well tested 14 gallons per minute. With the cylinder at 411 feet the well tested 42 gallons per minute.

City well No. 7 of Rocky Ford, on Home Place, flowed 15 gallons, but when furnished with air jet yielded 230 gallons per minute and the water was lowered 93 feet.

Another well of the American Beet Sugar Company, drilled on their farm No. 2 on the N. E. ¼ of Sec. 22, T. 23, R. 56, four miles southeast of the sugar factory, in 1920, flows naturally 6 gal. per minute at the surface, and 2 gal. per minute 20 feet above the surface. With two exceptions

CHEMICAL ANALYSES OF "DAKOTA" WATERS FROM ARTESIAN WELLS

Parts per million

Locality	Depth Feet	Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Sulphuric acid SO_4	Chlorine Cl	Carbonic acid CO_3	Silica SiO_2	Iron Oxide Aluminum Oxide Fe_2O_3 Al_2O_3	Organic and volatile	Other constituents	Total Solids	Year	Analyst
Las Animas	340	380	......	14	7.2	440	18	244	......	......	40	......	1,114	1899	W. A. Powers
La Junta	439	360	6.4	74	20	676	54	170	16	1.71	......	0.17	1,378	1895	W. F. Hillebrand
La Junta	420	415	......	16	7.4	578	58	171	20	......	96	......	1,362	1898	W. A. Powers
La Junta	420	358	......	5.5	4.4	520	24	140	17	......	39	......	1,108	1898	W. A. Powers
La Junta	425	524	......	14	18	695	33	286	12	7.3	37	6.0	1,627	......	
Rock Ford	?	259	7.0	15	12	454	28	96	12	4.0	(a)	2.2	888	1895	W. F. Hillebrand
Timpas	554	630	......	84	39	1,180	70	247	15	125	......	......	2,390	......	W. A. Powers
Timpas	580	255	......	90	54	775	31	91	16	......	104	......	1,416	......	W. A. Powers
Timpas	620	260	......	118	72	905	21	108	......	......	140	......	1,624	1898	W. A. Powers
Timpas	755	312	......	264	42	1,190	24	141	......	......	215	......	2,198	1899	W. A. Powers

all the flowing wells given in the table on page____ are confined to a relatively small area covering parts of T. 23, R. 56, and T. 24, R. 56.

In the vicinity of Rocky Ford wells have furnished a greater volume of water than at any other portion of the area. Originally wells here flowed 100 or more gallons a minute, while at La Junta only 15 to 35 gallons were obtained by natural flowage.

The amount of water that a well will yield depends not only upon the water head but upon the porosity of the rock and the surface exposed in the well. If the rock is very loose and coarse grained water can flow rapidly into the well to replace that removed by pumping. In such a case pumping does not greatly or rapidly lower the water level. But in a fine grained rock the supply may be quickly exhausted by pumping, and time must be allowed for the well to refill. This may in part be remedied by drilling a larger well or by increasing the surface exposed by blasting. This difference in porosity is very marked at different localities and often at points not far removed from each other. It may be due to variations in size of grain, but more likely to differing degrees of cementation of the rock. By excessive cementation, whereby the pores of the rock are filled and the rock rendered more or less impervious to water circulation, the natural course of underground water movement may be diverted and certain limited areas receive a very scanty supply. This would account for the very limited amount of water that may be obtained in certain wells. If a well be driven at a point where the water-bearing rock is rendered impervious by local cementation little or no water may be found. This will account for the fact that occasionally a well driven down through the two Dakota sands may be dry.

Both of the Dakota sands are subject to variations in density, but they need not both be dense at the same locality. As a general rule the lower sand yields more water than the upper. This is due to the greater looseness of the Purgatoire sandstone. In some cases, however, the situation is exactly reversed. While the second sand is apt to yield a greater supply than the upper, most of the wells in this area derive their water from the first sand. Presumably this is due to the fact that it is cheaper to drill to the first sand.

WELL LOGS. The following well logs of representative Dakota wells will give a fair idea of water conditions and of the formations passed through. A few of these wells have been drilled below the Dakota into the underlying "Red Beds."

LA JUNTA

Well No. 5, Atchison, Topeka and Santa Fe Railway Company, drilled in 1907.

	Feet Thickness	Feet Depth
Sand and gravel	32	32
Shale (Carlile, Greenhorn, Graneros) shale water at 53 and 153 feet	303	335
Sandstone (1st Dakota) water at 400 feet, rose to 100 feet surface	293	428
Shale	142	570
Shale	50	620
Sand	15	635
Shale	3	638
Sand	7	645
Shale, bottom of hole	8	653

SEC. 13, T. 21 S., R. 54 W.*

	Feet Thickness	Feet Depth
Sand and clay	40	40
Blue shale (Apishapa	140	180
Sandstone (Apishapa)	7	187
Gray shale (Apishapa)	40	227
Limestone (basal Timpas)	40	267
Brown shale (Benton group)	5	372
Limestone (Benton group)	5	377
Sandy shale (Benton group)	55	432
Slate (Benton group)	45	477
Brown shale (Benton group)	107	584
Slate (Benton group)	10	594
Black sandy shale	94	688
Gray sandstone (1st Dakota)	15	703
Water-bearing standstone	12	715

This well is located 18 miles due east of Ordway. Water did not flow. Rose to 60 feet from surface. Pumped 20 gallons.

*—From U. S. Geol. Survey Professional Paper No. 52.

LA JUNTA*

	Feet Thickness	Feet Depth
Surface materials	37	37
Gravel	11	48
Shale (Carlile, Greenhorn and Graneros)	182	230
"Talc"	5	235
Shale and light shale (Graneros and Dakota?)	105	340
"Dakota" sandstone, soft water	53	423
Black shale	28	451
Gray standstone (2nd Dakota, Purgatoire.)	94	545
Black shale	10	555
Sandstone, soft water, flows (2nd Dakota)	55	605
Shale (Morrison)	345	950
Sandstone, water, no flow	100	1050
Red and variegated shale	100	1150

"This well was plugged at 700 feet and obtains its principal supply of water from the second sandstone in the 'Dakota' formation at 550 to 605 feet. The original flow at 420 feet was 35 gallons a minute, but vigorous pumping has lowered the water level many feet and the water is now (in 1906) forced out by air lift."

*—From U. S. Geol. Survey Professional Paper No. 52.

TWO AND ONE-HALF MILES SOUTH OF LA JUNTA*

	Feet Thickness	Feet Depth
Soft gray limestone	50	50
Rusty limestone at base of Niobrara	10	60
Dark shales of Benton group	380	440
Soft sandstone with artesian flow, 1st "Dakota"	64	504
Shales	80	584
Soft sandstone, artesian flow, 2nd "Dakota"	116	700
Gray and greenish gray shales with water at 820 to 120 and 860 to 100 feet (Morrison formation)	280	980
"Red Beds" with water at intervals which rose to within 200 feet of the surface	723	1703

Drilled in 1902 for oil or gas, but unsuccessfully.

*—From U. S. Geol. Survey Professional Paper No. 52.

AMERICAN BEET SUGAR COMPANY

Sec. 14, T. 22 S., R. 65 W. Drilled by Charles L. McVey.

	Feet Thickness	Feet Depth
Loam (sand and clay)	78	78
Limy shale (Apishapa and Timpas)	502	580
Limestone (basal Timpas)	60	640
Black shale (Benton group)	380	1020
"Dakota" sand, 1st	105	1125

ROCKY FORD

East well of Atchison, Topeka and Santa Fe Railway Company. Drilled in 1911 by Charles McVey.

	Feet Thickness	Feet Depth
Sand and gravel	31	31
Shale, shale water at 105 feet	223	254
Limestone (Basal Timpas)	41	295
Shale (Carlile, Greenhorn, Graneros)	305	600
Talc vein	5	605
Shales (Graneros)	75	680
Brown sandy shale (1st Dakota)	104	784
Shale	96	880
Sandstone (2nd Dakota)	60	940
Shale	16	956
Red rock	10	965
White sand	50	1015
Red rock	45	1060
White shale and lime shells	127	1187
Gray sand	33	1220
Red sand	14	1234
White clay	11	1245
Red pocked sand	20	1265
White sand, water at 1325 feet rose to 1279 feet	65	1330
Running sand	16	1346

The Morrison formation probably extends from 956 feet to 1187 feet; below this the "Red Rocks." Hole filled up to 960 feet and plugged.

ROCKY FORD

American Beet Sugar Company.

	Feet Thickness	Feet Depth
Surface soil and sand	30	30
Clay	10	40
Blue shale (Apishapa)	215	265
Gray limestone (basal Timpas) water at 280 feet	50	315
Blue shale (Benton group)	383	698
"Dakota" sandstone, soft water	112	710

Before pumping water stood at 87 feet from surface. With the cylinder at 260 feet below the surface tested 14 gallons per minute; with cylinder lowered to 411 feet tested 42 gallons per minute.

ROCKY FORD*

	Feet Thickness	Feet Depth
Surface materials	40	40
Shale	210	250
Limestone with salty water on top	40	290
Shale	315	605
"Talc" vein	3	608
Shale	82	690
Sandstone, with flow of water (1st Dakota)	100	790

Flowed 100 gallons per minute.

*—From U. S. Geol. Survey Professional Paper No. 52.

AMERICAN BEET SUGAR COMPANY FARM NO. 2

Sec. 22, T. 23 S., R. 56 W.

	Feet Thickness	Feet Depth
Soil	10	10
Sand with water	40	50
Blue limestone (basal Timpas)	50	100
Blue shale (Benson group)	395	495
Sandstone (1st Dakota)	135	630
Blue shale	80	710
Sandstone in broken layers (2nd Dakota)	39	749

At 100 feet (base of Timpas) 90 feet of water; at 630 feet flowed 5 gallons per minute; at 749 feet flowed 6 gallons per minute, and 2 gallons per minute at 20 feet above surface. Drilled in 1920.

SWINK, CITY WELL (NEW)

	Feet Thickness	Feet Depth
Soil, limestone and shale (Timpas and Benton)	457	457
Sandstone (1st Dakota), water at 495 feet	90	547
Shale	8	555

Flowed a little at first. The old city well is said to flow 58 gallons per minute after 12 years.

D. S. WEAVER

S. E. Corner Sec. 36, T. 23 S., R. 56 W.

	Feet Thickness	Depth
Clay, sand and gravel	20	20
Shale and lime shells	15	35
Limestone (basal Timpas), water at 40 feet	40	75
Black shale (Benton group), water at 380 feet	395	460
Sandstone (1st Dakota), water at 500 feet, flowed	100	560
Sandy shale and clay	110	670
Sandstone (2nd Dakota)	68	738
Variegated shale (Morrison)	25	763

Flows 1½ to 2 gallons per minute from the two sands, good soft water.

A. N. STOTESBERRY

S. E. ¼ Sec. 22, T. 24 S., R. 56 W.

	Feet Thickness	Depth
Surface materials	40	40
Limestone, with water (Timpas)	80	120
Gray shale	15	135
Shale	195	330
Talc	5	335
Shale (Benton group)	155	490
Talc	10	500
Shale	15	515
Sandstone (1st Dakota)	70	585

Well flows about 10 gallons per minute.

W. C. BEAL

N. E. Corner Sec. 24, T. 25 S., R. 56 W.

	Feet Thickness	Depth
Surface material	16	16
Limestone (Timpas)	64	80
Shale (Benton group)	380	460
Sandstone (1st Dakota)	30	490
Sandstone and shale (1st Dakota)	70	560

ORDWAY*

	Feet Thickness	Depth
Surface materials	42	42
Black shale	18	60
Blue and gray shale	30	90
Shale and shells	26	116
Blue shale	29	145
Black shale	40	185
Sandstone	60	245
Black shale	25	270
Gray shale	75	345
Limestone, soft	65	410
Gray shale, some limestone	63	473
Gray shale, darker below	107	580
Black shale	70	650
Gray shale	50	700
Shale with shells	10	710
Shale	55	765
Brown shale	20	785
Light-gray shale	15	800
Brown shale	25	825
Shale with limestone layers	20	845
Black shale	10	855
Shale with limestone layers	70	925
Limestone and shale	35	960
Limestone (basal Timpas)	50	1010
Black shale	315	1325
"Talc" (Benton group)	2	1327
Black shale	83	1410
Sandstone containing some water (1st Dakota)	90	1500

Well started in the Pierre some 200 or more feet above the bottom. Well did not flow. Water rose to 80 or 90 feet below surface.

*—From U. S. Geol. Survey Professional Paper No. 52.

TIMPAS

Well of Atchison, Topeka and Santa Fe Railway Company. Drilled in 1898.

	Feet Thickness	Depth
Loam	30	30
Dry gravel	4	34
Shale	51	85
Limestone	52	137
Shale	303	440
Talc vein	3	443
Shale	95	538
Sandstone (1st Dakota), poor water at 544 feet	42	580
Shale	25	605
Sandstone (2nd Dakota), poor water	45	650
Shale	97	657
Sandstone (2nd Dakota), poor water flowed at 755 feet	33	790
Red shale (Morrison)	5	795

Well abandoned because of high mineralization.

DATA ON DAKOTA WELLS

Location	Depth to Dakota	Sand Containing Water	Quality of Water	Remarks
N. W. corner Sec. 6-23-52	200 ft.?	1st	good contains sodium	Rises to 210 feet from surface.
S. E. ¼ Sec 26-22-23	295 ft.	1st	good	Abundant, 15 feet in sand.
S. W. ¼ Sec. 32-22-53	300 ft.?		good	School well.
Marlman Sec. 33-22-53	320 ft.?	2nd	good	A little water in 1st.
S. E. ¼ Sec. 34-22-53	240 ft.	1st	good	Abundant, flowed at first, now pumped.
N. E. corner Sec. 36-22-53	210 ft.?	1st	good	Abundant.
S. E. ¼ Sec. 36-22-53	220 ft.?	1st	good	Hard water at 185 feet, rises nearly to top.
S. E. ¼ Sec. 33-23-53	280 ft.?	1st	good	Abundant, rises to 160 feet from surface.
S. E. ¼ Sec. 34-23-53	245 ft.	1st	good	Two flows 35 feet apart, upper may be in Graneros.
S. E. ¼ Sec. 3-24-53	245 ft.?			Contains iron.
S. E. ¼ Sec. 9-24-53	330 ft.?	2nd	good	Abundant, rises to 100 feet from surface.
Center Sec. 20-24-53	239 ft.	1st	good	Rises to 66 feet from surface.
N. E. corner Sec. 28-24-53	159 ft.?	1st	good	Rises to 96 feet from surface.
Center E. line Sec. 28-24-53	170 ft.?	1st	good	
S. W. corner Sec. 6-25-53	249 ft.	1st	good	Contains iron.
Center S. ½ Sec. 31-25-53	0 ft.?	2nd	good	Starts about top of Dakota, a little water bottom 1st sand.
Sec. 13-21-54	688 ft.	1st		
N. W. ¼ Sec. 8-23-54	450 ft.?	1st	good	Rises to 60 feet from surface. pumped 20 gal. per minute.
N. E. corner Sec. 12-23-54	320 ft.?	1st	good	Flows slightly.
S. E. ¼ Sec. 16-23-54	370 ft.?	2nd	good	Contains iron.
N. E. ¼ Sec. 2-24-54	300 ft.?	1st	good	Abundant, rises to 85 feet from surface.
S. E. ¼ Sec. 4-24-54	330 ft.?	1st	good	Abundant, rises to 60 feet from surface.
Center S. ½ Sec. 4-26-54	132 ft.	1st	good	Contains iron.
Center E. ½ Sec. 25-22-55	550 ft.?	2nd	good	Cheraw well, rises to 50 feet from surface, 30 gallons per minute.
S. W. ¼ Sec. 2-24-55	340 ft.	2nd	good	Originally flowed, not now.
N. W. ¼ Sec. 10-24-55	303 ft.	1st	good	Henry Bechtold, 40 gallons per minute.

DATA ON DAKOTA WELLS—Continued

Location	Depth to Dakota	Sand Containing Water	Quality of Water	Remarks
N. E. ¼ Sec. 10-24-55		1st 2nd	good	A. D. Best, 40 gallons per min., rises to 60 feet from surface.
N. W. ¼ Sec. 16-24-55	490 ft.	2nd	good	Abundant, does not flow.
N. E. ¼ Sec. 22-24-55	440 ft.	1st 2nd	good	Deep well, drilled for oil.
S. W. ¼ Sec. 24-25-55	415 ft.?	1st	good	Scanty.
N. E. ¼ Sec. 14-22-56	1020 ft.	1st	good	A. B. S. Co., abundant.
S. W. ¼ Sec. 7-23-56	688 ft.	1st 2nd	good	A. B. S. Co., abundant, rises to 87 feet from surface.
N. W. ¼ Sec. 18-23-56	690 ft.	1st	good	Salty water top of basal Timpas limestone.
N. E. ¼ Sec. 22-23-56	495 ft.	1st 2nd	good	A. B. S. Co., flows 6 gallons.
S. E. ¼ Sec. 25-23-56	457 ft.	1st	good	Swink city well.
Center Sec. 27-23-56			good	Contains sulphur.
S. E. corner Sec. 36-23-56	460 ft.	1st 2nd	good	2 gallons per minute, flows.
N. E. ¼ Sec. 2-24-56	508 ft.	1st	good	Rises to 60 feet from surface.
S. E. corner Sec. 2-24-56	440 ft.	1st 2nd	good	Flows small stream, the 2 Dakotas 300 feet thick.
N. E. corner Sec. 13-24-56	595 ft.?		good	Fairmount school.
S. W. ¼ Sec. 19-24-56			good	School house, flows, contains iron.
N. E. corner Sec. 22-24-56	585 ft.	1st	good	Flowing, 10 gal. per minute.
N. E. ¼ Sec. 23-24-56			poor	Poor quality possibly due to water from above.
N. E. corner Sec. 24-25-56	460 ft.	1st	good	
Sec. 14-21-57	1410 ft.	1st	good	Ordway well, abundance, did not flow, rose to 80 feet from surface.
S. E. ¼ Sec. 21-24-57		2nd	good	Contains iron.
S. E. ¼ Sec. 6-25-57	520 ft.?	2nd	good	Flowing 3 gallons per minute salt water at 158 feet.
N. E. ¼ Sec. 3-26-57	538 ft.	2nd	poor	Timpas, flowed 20 gal. per min. 27 feet above ground, too highly mineralized to be used in boilers.

WATER IN INDIVIDUAL FORMATIONS

GRANEROS SHALE

Depth to Dakota:—from the bottom, 0 feet; from the top about 200 feet.

The Graneros shale is composed almost entirely of shales that are very impervious to water. They are not likely, therefore, to contain water in quantity. Occasionally water may be found in these shales, but apparently it is always of very poor quality. This is probably due mainly to the presence of gypsum which readily dissolves and renders the water very hard. A few instances were noted where good water was found apparently in this formation. But in most cases the wells were sunk in comparatively low ground or in gulches, and penetrated only a short distance into the shale, after passing through gravel or "wash."

As a case in point a well one-half mile north of the Willson house on Sec. 14, T. 25, R. 54, on the south bank of an arroyo, penetrated a foot or two into the Graneros shale, after passing through nearly 20 feet of surface "wash." This well is used for stock, but could be used for domestic purposes if necessary. Again a well belonging to Mrs. Topp, at the center of the south line of Sec. 13, T. 25, R. 54. passes through 30 feet of mixed clay and limestone gravel into the Graneros shale. The water is hard and is used for drinking and for cooking, but not for laundering.

In these instances and others like them, where the well passed through surface gravel and "wash" and only a short distance into the Graneros shale, the water is derived from the wash and not from the shale. There are other cases, however, where water under similar conditions has proved to be very poor. This can be accounted for on the supposition that the water, or part of it, comes from the shale. It is not necessary, however, to make this assumption, as water derived from gravel and other "wash" not infrequently is unsuable.

On the north ½ of Sec. 28, T. 23, R. 54 a well 130 feet deep was drilled through the Greenhorn limestone into the Graneros shale. As the well starts on alluvium overlying the Greenhorn limestone it must penetrate the Graneros shale some distance, probably not less than fifty feet, possibly as much as a hundred feet. This well delivered good soft water, suitable for all domestic purposes. It is the only well known to the writer of which this is true. It is just possible that this water was struck in passing through the Greenhorn limestone.

It would seem from what has been observed that wells in the Graneros shale yield either no water or water that is very seldom fit for domestic purposes or even for stock.

In gulches and arroyos and low ground filled with "wash" water may very often be found just above the shale. If such a well be sunk into the shale the water is liable to be contaminated by shale water and rendered unfit for use.

GREENHORN LIMESTONE

Depth to the Dakota:—from the bottom about 200 feet, from the top about 260 feet.

There is very little information available as to water in the Greenhorn limestone, and this is not very favorable. Limestone is more likely to carry water than is shale. This is due in part to the fact that limestone is soluble and channels are very often formed in limestone by solution. The Greenhorn limestone, however, contains more shale than limestone and the water in the formation may be expected to partake of the quality of the shale water, that is, it will be very hard at best. However, there are several instances of water available for stock, and even for drinking, obtained from wells in this formation. On low ground in gulches this limestone formation is likely to contain water suitable for stock. In such cases the water enters the limestone at some point or points higher up the gulch.

CARLILE SHALE

Depth to the Dakota:—from bottom 270 feet; from top about 390 to 400 feet, probably somewhat over these amounts towards the western part.

The Carlile shale upon the whole is quite unfavorable to a water supply, as the shale is mostly very dense, and, therefore, impermeable to water. There are, however, two horizons within this shale that are likely to carry water. The one is a somewhat sandy shale 20 to 30 feet below the top of the formation, within which occur the very characteristic large concretions. In several cases fairly good water has been obtained within this somewhat sandy portion of this shale. The water here cannot be relied upon as to quality, but it may possibly be usable. The other likely horizon is at the bottom of the three feet of brown-weathering limestone that forms the top stratum of the Carlile shale. Springs are very common either at the contact of this brown limestone with the overlying white Timpas limestone or at the bottom of the same. It may reasonably be assumed that strata that supply spring water will also furnish water for wells.

Water is very commonly found in the "wash" of gulches and arroyos lying over the Carlile shale. The water does not originate in the shale but is the natural underflow of the valley. The density of the shale prevents this underflow-water from penetrating the rock underneath the surface materials and causes it to concentrate at the bottom of the "wash." The quality of this water will depend largely on the nature of the loose surface materials. It may sometimes be very good. For instance, a spring of unusually good water is known as the Chandler spring. It is located in gravel overlying Carlile shale in a gulch on the northwest ¼ of Sec. 2, T. 26, R. 55.

In sinking a well through the surface gravel or other "wash" material to the underlying Carlile shale one should be careful not to penetrate the shale to any appreciable depth. It may be necessary to go a few feet into the shale so as to form a sump for collecting the water. But penetration of the shale for only a few feet may cause the water to become contaminated.

TIMPAS LIMESTONE

Depth to the Dakota:—from the bottom 390 to 400 feet; from the top about 600 feet.

Of the formations that lie in part beneath the surface in this area the Timpas limestone is, next to the Dakota, most likely to have a useful and, perhaps, abundant water supply. This formation, however, should be considered as consisting of two parts. The lower fifty feet consists of nearly continuous limestone and is the part within which usable water is likely to be found. The upper 150 feet consist only in part of limestone, mostly of shale and limy shale. In this upper part water is less likely to be struck, and when struck it is rarely usable.

The lower fifty feet of limestone is frequently referred to in this report and elsewhere as the basal Timpas limestone. There are many wells in the territory that strike good water in this basal limestone, in most cases the water is found only at or not many feet above the bottom of the formation. The following instances, picked almost at randum, will suffice to indicate the nature of the better wells developed.

S. W. ¼ of Sec. 20, T. 23, R. 55. A well 25 feet deep, the lower 10 feet in the basal Timpas limestone. A copious flow of water struck in the limestone at the bottom of well. Good for stock but not for drinking.

S. W. ¾ of Sec. 28, T. 23, R. 55. A well 40 feet deep all in the basal Timpas limestone. Abundant hard water, suitable for stock.

1,400 feet south of the N. W. corner of Sec. 35, T. 24, R. 55. A well

20 feet deep ending the Timpas limestone not far from the bottom contact. Abundance of good water all the year. It is possible in this case that the water is derived by seepage from the arroyo.

Center of north line of Sec. 17, T. 25, R. 55. A. Lozuaway. Well 32 feet deep, all in the basal Timpas limestone. Small amount of good water.

N. E. ¼ of Sec. 4, T. 26, R. 56. L. L. Miller. A well 24 feet deep, all in Timpas limestone. Good, but not abundant water.

N. E. ¼ of Sec. 10, T. 25, R. 57.' Drilled well 190 feet deep, starting near the top of the Timpas and ending at or close to the bottom of same. Water used for stock and laundering but not for drinking.

The above listed wells and others not listed occur sometimes on low ground and sometimes on fairly high ground, or on ground remote from a stream or gulch or other visible source of supply. It is to be noted, however, that on the highest ground, far above the level of adjacent gulches, the basal Timpas limestone is more apt to give only dry or nearly dry wells. On the other hand on low ground, and especially along gulches, this limestone seems pretty certain to yield more or less water, and often water of good quality. This is probably due to the fact that, wherever the strata of this basal limestone outcrop along a water course, water is pretty certain to enter the formation and to follow down the valley under ground, only to re-appear as springs or, perhaps, to furnish water for a well.

With few exceptions the water in the upper 150 feet of shales and limestone layers that overlie the basal Timpas limestone is poor, often useless. To some extent this is also true of the upper part of the basal limestone. In a number of instances the water is reported as salty or as containing sulphur. This is especially true of a number of wells in the western part of T. 25, R. 57 in which salty water is reported as occurring in the following locations, namely, N. E. corner of Sec. 5; S. W. ¼ of Sec. 7, J. H. Murray, (very salty); S. W. ¼ of Sec. 20, Flora Garton; S. E. ¼ of Sec. 30, M. Garton. Sulphur is reported in wells on the N. W. ¼ of Sec. 4, and the N. E. corner of Sec. 17, James Potmesil. A few of the wells in this vicinity are reported as having medicinal properties, more especially the well at Rene, near the center of Sec. 19, in this same township. Most of the water characterized as salty or as containing sulphur is not so highly mineralized but that it has been used for stock.

From what is stated above it will appear that serviceable water is very likely to be found at the base of the Timpas limestone but not more than a few feet above the base, and that this is more apt to be true if the formation lies on relatively low ground. In sinking a well in this formation one should not stop short of the black shale that occurs in the upper part of the underlying Carlile shale.

APISHAPA FORMATION

Depth to the Dakota:—from the bottom about 600 feet; from the top probably 1,100 feet.

The Apishapa formation, consisting of shales, is not likely to hold much water. For this reason wells sunk in this formation are often dry. In the middle portion, however, the shales are usually a little sandy and may be expected to carry more water. Water is also more likely to be found where an occasional limy stratum is developed. A study of wells shows that the water is very seldom available for domestic purposes, and may not be fit even for stock. Some of the water is bitter and, not infrequently, salty.

So far as the writer has observed there are no wells in the Apishapa formation on this area that contain really good water. There are, it is true, a good many fairly good wells on the territory mapped as Apishapa, but these are sunk in the unconsolidated surface material, such as sand, gravel, and salt, and they usually derive their water from the underflow of gulches or from irrigation seepage water.

Unless water can be struck in the soil or "wash" that frequently buries this formation many feet deep, there is not much chance of securing useful water by digging or drilling into the shale itself.

PIERRE SHALE

Only the lower two or three or possibly four hundred feet of this formation are present on this area. This portion of the Pierre shale consists of fine blue or dark gray shales that are quite unsuitable for holding water. Further, the abundant gypsum that characterizes this shale would probably render any water present unfit for use.

The Pierre occupies a comparatively small part of the area and the land is almost entirely uncultivated. No direct information as to water wells in this territory is available.

NUSSBAUM FORMATION

This formation is admirably adapted to absorb superficial waters and is, as a matter of fact, an abundent source of supply for good water over large portions of eastern Colorado. It furnishes, for instance, the water supply of Fowler and of Olney. But only a few very small areas of this formation are to be found in the territory under consideration, and these are far too small to allow the accumulation of water.

TERRACE GRAVELS

Both the higher and the lower terrace gravels are for the most part composed of loose materials, such as gravel, sand, and silt, and are, therefore, well adapted to absorb rain water. Wherever they cover a considerable territory they may very well be an available source for good well water. The water would naturally be found at the bottom of the gravel formation. For the most part the larger terrace gravel areas lie under irrigation, and, as the water derived from irrigation is mostly very hard, wells so located are not apt to produce water suitable for domestic purposes, although they may be and mostly are available for stock purposes.

In T. 23, R. 57 there are several areas of higher terrace gravels that lie above irrigation. It is quite possible that these gravels will yield water at points near the lower boundary of the terraces. Wells so located will probably not furnish a very abundant supply, as the terraces are not large enough to justify this expectation.

ALLUVIUM

The alluvium occurs only in the low-lying river and stream bottoms. No attempt has been made to map this formation except along the Arkansas River. Alluvial deposits occur, however, more or less extensively developed along the larger streams tributary to the Arkansas, more especially along portions of the Purgatory River and Horse, Adobe, and Timpas creeks. Such deposits almost invariably contain water at shallow depth, the water being derived from the adjacent streams. The abundance of the water is in general dependent on the size of the stream, although favorably located wells may secure a very abundant supply in the alluvial deposit of a small stream. The quality of water derived from alluvium will depend mainly on the quality of the river or stream water. As already stated the water in all the streams flowing through this area is hard, and the same is true of the well water in the stream bottoms. Much of this water, however, is of relatively good quality, and is used extensively for domestic purposes in spite of its hardness. It is the source of the city water supply of La Junta.

Wells located on the alluvium of the Arkansas River almost invariably yield abundance of water, and in several cases the water is used for irrigation as well as for domestic purposes. In a good many cases, it may be noted, the water so obtained is much harder than is the natural river water. This is due to the fact that this ground is mostly under irrigation and that irrigation seepage water may furnsh the wells with a local supply. This is more likely to be the case at points remote from the river.

DUNE SANDS

Rain water very readily penetrates the dune sands, especially where fresh sand is exposed on the surface. Under such conditions the sands would absorb practically all the water that falls. These conditions obtain in the large dune area in and adjacent to T. 23, R. 53. It is very likely that water, possibly fairly good water, could be found by sinking a well to the bottom of the sands in this township, especially in the lower lying portions. It would be difficult, however, to tell in advance what positions would be most favorable for well-digging. The sands lie on an uneven surface, but the original irregularities of surface are concealed by the wind-driven sands, so that the highest points on the surface of the dune do not conform with the higher elevations on the ground underneath. The underground water will necessarily seek the lower places of the original surface on which the sands lie. Such places, if one is fortunate enough to find them, would be very likely to furnish considerable water.

The large dune sand area in T. 22, R. 56; T. 21, R. 57; and T. 22, R. 57 shows a considerable extent of clean surface sands along the southern edge of the territory covered, but the greater portion is covered with fine loamy soil. A good many wells have been dug within this dune area and most of them yield water. Undoubtedly conditions are favorable for accumulation of water, but, here again, water might be found only on the low places of the original ground-surface. This probably accounts for the fact that some wells within this area strike water and some are dry. As a general thing the water is inclined to be hard and may be unfit even for stock.

The western part of these last named dune-covered lands is almost everywhere affected by underground seepage coming from the irrigated lands to the north in the vicinity of Ordway and Sugar City. There is a gentle southerly slope from Ordway to the Arkansas River. Practically all the wells sunk within this region obtain water, some fairly good for stock; hardly any of them suitable for domestic use. A few of them cannot be used even for stock. The effect of this irrigation seepage-water is well illustrated by a well belonging to Mr. Case, and located in the center of Sec. 9, T. 22, R. 57. This well is 37 feet deep and was sunk 25 or 30 years ago before irrigation started. It passes through sand and quicksand, but does not reach the underlying Apishapa shale. About 12 years ago, some years after irrigation started further north, the water in the well started to rise, and it has continued to rise until it now stands 7 feet higher than at first. This rising of the water-table is further evidenced by the fact that water is now running in draws that were dry before the days of irrigation. This is true of districts several miles distant from irrigated lands.

As an instance of exceptionally bad water a well may be cited which is located on the property of Mr. H. W. Blaser on the S. W. ¼ of Sec. 7, T. 22, R. 57. Mr. Blaser states that two horses died as the result of drinking water from this well.

This dune sand ground contains locally considerable gypsum. Usually this is disseminated as a cementing material. It may also be in the form of crystals. Sand brought up from the bottom of a 40-foot well in the S. E. ¼ of Sec. 12, T. 22, R. 57 contains small, well defined crystals of gypsum measuring from ¼ to ¾ of an inch in length.

In most of the dune sand territory in T. 21 and 22, R. 57, it is not necessary to go to the bottom of the sand to strike water.

WATER IN GULCHES AND ARROYOS

The character and quality of water obtained from wells dug on low-lying ground along gulches and arroyos vary greatly. Sometimes this variation seems to be most erratic, and cannot be readily explained. In other cases the quality of the water is determined by the character of the rock formation exposed within the drainage area. In general all the shale formations in the La Junta area contain ingredients that render water hard or unusuable. For this reason creeks and gulches that drain shale areas may be expected to yield hard underflow water. This, for instance, is true of Horse Creek and of Adobe Creek that drain extensive areas of Apishapa shale and of Pierre shale, the latter lying mostly beyond the bounds of this area. On the other hand gulches that drain lands covered largely by the Dakota sandstone, or by the Timpas basal limestone, are very apt to furnish a supply of good water. For instance, Anderson, King, and Crooked arroyos drain lands on which the basal limestone of the Timpas forms in the main the surface formation, and these arroyos furnish good water to many wells. In the case of Crooked Arroyo Mr. A. C. O'Conner owns 13 wells located along the west branch between the Sante Fe railroad and the southern edge of T. 25, R. 56, a distance of about four miles, all of which yield very good water.

As the Timpas limestone weathers to small flattish angular fragments that are readily washed down into the gulches to form a gravel bottom, the wells located in such limestone gravel-wash are likely to have an abundant supply of water.

SOFTENING OF WATER FOR DOMESTIC USES

WATER-SOFTENING PROCESSES

The great disadvantage of hard water for drinking and for other domestic purposes is well known to all who live within hard water districts like the La Junta area, and need not be emphasized in these pages. This is attested by the extent to which those living in the country are willing to undergo the expense and trouble of hauling for long distances the artesian waters of the deep Dakota wells, although the Dakota waters are only relatively soft and also contain considerable amounts of hardening salts.

It has been thought desirable, therefore, to make investigation as to the feasibility of applying known processes of water-softening to the shallow-well waters of the La Junta area.

There are numerous processes of softening waters that are widely applied for commercial purposes. These are usually based on chemical reaction between the dissolved salts in the waters and certain other salts, added thereto, whereby the soap-destroying calcium and magnesium salts are precipitated out and removed. The so-called lime-soda ash process is most commonly used and is typical of all such processes. It is often very effective for commercial purposes when applied on a large scale. But it requires considerable skill to handle it, and the process must be varied from time to time in accordance with the variation in the chemical composition of the water to be softened. It also leaves a water that is not palatable, and, therefore, cannot well be used for drinking. For this reason it is not available for domestic uses.

ZEOLITE WATER-SOFTENERS

Within comparatively few years a process of water-softening has been developed to which the name zeolite water-softening is applied. This process is based on passing water through a filter containing a bed of granules composed of zeolite. The zeolite used for this purpose may be a natural mineral or a manufactured product. It is a hydrated silicate of aluminum and sodium. The sodium is very loosely bound and is readily exchanged for calcium and magnesium when water containing these elements is passed through the filter. In this way practically all the calcium and magnesium is removed from the water, provided the percentage of calcium and magnesium salts is not too great, and provided the action is not interfered with by the presence in quantity of certain other ingredients. By this process the amount of sodium in the water is increased, but this does not interfere with the action of soap nor does it usually cause the water to be unpalatable for drinking.

As the amount of sodium that any given zeolite filter may contain is limited, in due time the sodium becomes exhausted and the filter is no longer capable of removing the water-hardening salts. It becomes necessary to regenerate the filter. This is done with great ease and at only a trifling expense by passing through the filter a solution of common salt. The time for this regeneration varies from half an hour to five or six hours according to the type of filter used. Usually this regeneration is done at night, and the process is automatic. These filters require almost no attention and can readily be cared for by a household domestic. They may be attached to any system where water is circulated through pipes, whether the pressure be great or small, and are therefore, adapted to farm houses where water is pumped from the well into a tank.

Manifestly the time a filter will run without regeneration depends on the size of the filter, on the amount of water used, and on the degree of hardness of the water. It is usually desirable to install a filter that requires regeneration only once or twice a week. To determine the hardness of the water a chemical analysis is necessary. Such analysis will be made free of charge by any company that manufactures filters of this kind, provided application is made in good faith by a householder who may contemplate the installing of a water-softening filter. Advice will also be given as to the proper type and size of filter to be installed and as to the cost of same. It will be necessary to furnish information as to the amount of water that will be used. Under ordinary conditions, where water is used for bathing as well as for other household purposes, about 25 to 50 gallons a day per person may be figured on. A list of firms who manufacture and market zeolite water filters for domestic purposes is given below. This list is probably not a complete list of all such firms, but it includes all that have been brought to the attention of the writer.

As already stated, the size of the filter and, therefore, the cost of the same will depend on the character of the water and on the amount to be filtered. In a general way it may be stated here that, for a family of four persons, using 200 gallons of water a day, a filter will cost, laid down in La Junta, from $300 to $600, the cost varying with the character of the water and the length of time the filter will run without regeneration.

LIST OF MANUFACTURERS OF ZEOLITE WATER-SOFTENERS

American Water Softener Co., Lehigh Ave. and Fourth St., Philadelphia, Pa.
Graver Corporation, East Chicago, Ind.
International Filtter Co., 333 West 25th Place, Chicago, Ill.
Oleite Corporation, 110 William St., New York, N. Y.
Paige and Jones Chemical Co., 417 South Dearborn St., Chicago, Ill.
The Permutit Company, 507 Lathrop Building, Kansas City, Mo.
The Refinite Company, Refinite Building, Omaha, Neb.
Wayne Tank and Pump Co., Fort Wayne, Ind.

CHARACTER OF SHALLOW-WELL WATERS OF THE LA JUNTA AREA

As already pointed out in these pages, the waters of the shallow wells of the La Junta area differ very greatly in the amount and character of the salts held in solution, and many of them are extremely hard. Especially in the irrigated areas the well waters show a tendency to great hardness. It is therefore a question as to whether these waters can be treated economically by the zeolite softening process. To determine this point a number of water samples were taken for chemical analysis. So far as practicable these samples were selected so as to be fairly representative of the different types of water in the shallow wells of this area. For instance, samples were taken to represent water from the basal Timpas limestone, from the upper part of the Timpas limestone formation, from the gravelly wash of different arroyos, from the terrace gravels, from the underflow of the Arkansas River, etc.

Arrangements were made with several of the concerns that manufacture zeolite softeners who were glad to co-operate to the extent of making analyses of these samples. As will be seen, most of the analyses that follow were made in the laboratories of these companies.

CHEMICAL ANALYSES

As has already been stated in these pages, there is no universally recognized practice in reporting the results of chemical analyses of waters. Formerly is was customary to give the chemical compounds or salts present or supposed to be present in the water, as, for instance, carbonate of calcium, sulphate of magnesium, etc. The chief objection to this practice is the fact that it is not possible to determine with certainty just how the various elements and radicals are combined in solution, and different chemists will render different interpretations of the analysis of a given water.

Of late years it is becoming customary to give the individual elements or radicals such as Ca, Mg, Na, Cl, So_3, etc., without attempting to indicate how they are combined into salts or other compounds. This is the method adopted in the analyses of the Dakota waters given elsewhere in these pages. But for pratical purposes those who manufacture water-softening devices prefer to abide by the earlier practice of reporting water analyses in accordance with the salts supposed to be present. The water analyses given above, therefore follow this practice.

Again, the quantities of salts or of elements present may be reported as grains per gallon, or as parts per million, or as parts per hundred thousand. It may often be desirable to change from one method to another. This may be done thus:

To convert grains per gallon to parts per million, multiply by 17.12.

To convert grains per gallon to parts per hundred thousand, multiply by 1.712.

To convert parts per million to grains per gallon, multiply by .0584.

To convert parts per hundred thousand to grains per gallon, multiply by .00584.

The hardness of a water is indicated by the total amount of soap-destroying salts, that is, of calcium and magnesium salts expressed in the form of the equivalent amount of calcium carbonate ($CaCO_3$). It is given in the form of grains per gallon, or as parts per million or parts per hundred thousand. Sometimes, again, the term "degree of hardness" is used. By this is usually meant the number of parts of calcium and magnesium salts per hundred thousand. Thus: 1 degree harndess equals 1 part $CaCO_3$ per 100,000, equals .584 grains per U. S. gallon.

WATER ANALYSES OF SHALLOW WELLS AND SPRINGS

MADE IN THE LABORATORY OF THE INTERNATIONAL FILTER COMPANY.

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7		Sample 8		Sample 9		Sample 10	
	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon
Suspended matter	Trace		5.0	.29	10.0	.58	5.0	.29	10.0	.58	Trace		Trace		Trace		5.0	.29	5.0	.29
Total dissolved solids	911.1	53.21	1129.14	65.94	686.1	39.78	964.1	55.30	1031.1	60.22	813.1	47.46	1247.1	72.83	2598.43	151.75	2891.1	168.83	1031.14	60.22
Turbidity	Trace		10.0	.58	20.0	1.16	10.0	.58	10.0	.58	Trace		Trace		Trace		10.0	.58	40.0	2.32
Hardness	600.0	35.04	509.0	29.72	405.	23.65	110.0	6.42	490.	28.62	450.0	26.28	650.0	37.96	1630.0	95.19	1820.0	106.29	290.0	16.94
Alkalinity (total	170.0	9.93	180.0	10.51	100.0	5.84	310.0	18.10	130.	7.59	180.0	10.51	170.0	9.93	80.0	4.67	200.0	11.68	170.0	9.93
Calcium carbonate	170.0	9.93	180.0	10.51	100.0	5.84	50.0	2.92	130.	7.59	180.0	10.51	170.0	9.93	80.0	4.67	200.0	11.68	170.0	9.93
Calcium sulphate	310.0	18.10	300.0	17.52	310.0	18.10			300.0	17.52	230.0	13.43	450.0	26.28	1800.0	105.12	1600.0	93.44	27.0	1.57
Magnesium carbonate							50.0	2.92												
Magnesium sulphate	240.0	14.02	130.0	7.59	95.0	5.55			170.0	9.93	120.0	7.01	180.0	10.51	275.0	16.06	535.0	31.24	120.0	7.00
Magnesium chloride			66.0	3.85																
Iron oxide	.1	.006	.14	.01	.1	.006	.1	.006	.1	.006	.1	.006	.1	.006	.43	.025	.1	.006	.14	.008
Aluminum oxide	5.0	.29	3.0	.18	.4	.23	6.0	.35	5.0	.29	5.0	.29	4.0	.23	82.0	4.79	56.0	3.27	0.0	0.00
Silica	15.0	.87	10.0	.58	10.0	.58	12.0	.70	11.0	.64	8.0	.47	8.0	.46	5.0	.29	10.0	.58	15.0	.87
Suspended matter	Trace		5.0	29.	10.0	.58	5.0	.29	10.0	.58	Trace		Trace		Trace		5.0	.29	5.0	.29
Total incrusting solids	740.1	43.22	694.14	40.53	529.1	30.88	123.1	7.19	626.1	36.56	543.1	31.72	812.1	47.42	2242.43	130.96	2406.1	140.51	337.14	19.668
Sodium sulphate	88.0	5.14	440.0	25.70	150.0	8.76	570.0	33.28	275.0	16.06	220.0	12.85	320.0	18.69	310.0	18.10	360.0	21.02	610.0	35.62
Sodium chloride	83.0	4.85			17.0	.99	66.0	3.85	140.0	8.18	50.0	2.92	115.0	6.72	46.0	2.69	130.0	7.59	89.0	5.04
Sodium carbonate							210.0	12.26												
Total non-incrusting solids	171.0	9.99	440.0	25.70	167.0	9.75	846.0	49.39	415.0	24.24	270.0	15.77	435.0	25.41	356.0	20.79	490.0	28.61	699.0	40.66
Free carbon dioxide	15.0	.88	16.0	.93	13.0	.76	8.0	.47	8.0	.47	19.0	1.11	16.0	.93	10.0	.58	37.0	2.16	10.0	.53

Sample 1. W. E. Fenton. Sec. 2, T. 23 S., R. 55 W. Well 30 feet deep, in lower terrace gravel. On north side of Lake Canal. Sample taken March 5, 1923.

Sample 2. Mr. Smith. Sec. 1, T. 25 S, R. 55 W. Shallow well in basal Timpas limestone in bottom of arroyo. Water in arroyo derived from drainage of basal Timpas limestone and Carlile shale. Sample taken March 7, 1923.

Sample 3. H. Depue. Sec. 13, T. 25 S., R. 53 W. Well 33 feet deep. In gravelly wash overlying Graneros shale. Water derived from drainage of lower Timpas limestone, Carlile, Greenhorn, and Graneros. Samplet taken March 7, 1923.

Sample 4. Chandler spring. Sec. 2, T. 26 S., R. 55 W. Spring in gavelly wash in bottom of arroyo, a little below the Timpas-Carlile contact. Drainage area almost entirely lower Timpas limestone. Sample taken March 7, 1923. Water low.

Sample 5. F. L. Brandham. Sec. 21, T. 25 S., R. 55 W. Well 15 feet deep in bottom of arroyo. Drainage area lower Timpas limestone and Carlile shale. Sample taken March 8, 1923. Water very low.

Sample 6. Mr. Williams. Sec. 5, T. 26 S., R. 55 W. Shallow well in gravelly wash in bottom of arroyo. Drainage area almost entirely basal Timpas limestone. Sample taken March 8, 1923.

Sample 7. W. E. Thomas estate. Sec. 28, T. 22 S., R. 57 W. Well at house 50 feet deep in gravel and sand. Water from underflow of Arkansas River. Sample taken March 9, 1923.

Sample 8. Howard Van Horn. Sec. 30, T. 55 S., R. 57 W. Well 16 feet deep. Water derived from Timpas limestone formation, but not from the basal limestone member. Sample taken March 10, 1923.

Sample 9. H. C. Dick. Sec. 10, T, 23 S., R. 56 W. Well 14 feet deep through wash into the Timpas limestone formation. Water derived from a limestone member near the top of the formation. Sample taken March 12, 1923. Water low.

Sample 10. A. C. O'Connor. Sec. 29, T. 25 S., R. 56 W. Shallow well, bottom of west branch of Crooked Arroyo. Water comes in entirely from basal Timpas limestone. Drainage area basal Timpas limestone. Sample taken in April, 1923.

WATER ANALYSIS

(By I. W. Reed)

	Sample 11	
	Parts per Million	Grains per Gallon
Calcium carbonate	298.4	17.40
Calcium sulphate	444.1	25.89
Magnesium sulphate	360.7	21.03
Sodium sulphate	518.5	30.23
Sodium chloride	104.0	6.06
Iron carbonate	11.6	.88
Silica	22.0	1.28
Organic and volatile	127.7	7.44
Totals	1887.0	110.21

Sample 11. D. V. Burrell, Sec. 25, T. 22 S., R. 57 W. Well 18 feet deep in alluvial gravel. Water derived from underflow of Arkansas River. Sample taken

WATER ANALYSES OF SHALLOW WELLS

MADE IN THE LABORATORY OF THE GRAVER CORPORATION

	Sample 12		Sample 13		Sample 14		Sample 15		Sample 16	
	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon
Total solids	1162.7	67.91	1929.7	112.73	3777.3	220.64	4537.9	265.06	1406.5	82.15
Hardness	625.7	36.56	79.76	46.64	1153.9	67.48	116.5	68.12	54.7	32.00
Alkalinity	167.8	9.80	258.5	15.10	155.8	9.10	239.7	14.00	219.1	12.80
Calcium carbonate	167.8	9.80	258.5	15.10	155.8	9.10	239.7	14.00	219.1	12.80
Calcium sulphate	305.1	17.82	386.6	22.58	896.4	52.36	931.3	54.40	200.3	11.70
Magnesium sulphate	280.6	16.39	306.8	17.93	408.5	23.86	290.0	16.94	217.8	12.72
Silica	14.2	.83	22.6	1.32	54.3	3.17	16.4	.96	18.6	1.09
Iron and aluminum oxides	3.6	.21	8.4	.49	8.7	.51	6.1	.36	8.2	.48
Total incrusting solids	771.3	45.05	982.9	57.42	1523.7	89.00	1483.6	86.66	664.1	38.79
Sodium sulphate	325.3	19.00	828.7	48.41	2008.3	117.31	2347.2	137.10	702.3	41.02
Sodium chloride	66.1	3.86	118.1	6.90	245.3	14.33	707.1	41.30	40.1	2.34
Total non-incrusting solids	391.4	22.86	946.8	55.31	2253.6	131.64	3054.3	178.40	742.4	43.36

Sample 12. D. V. Burrell. Sec. 4, T. 23 S., R. 56 W. Well 15 feet deep. One of a battery of several wells in coarse, gravelly sand of the Lower Terrace Gravel on north or upper side of the Holbrook canal. Sample taken March, 1923.

Sample 13. P. Edwards. NE. ¼ Sec. 21, T. 22 S., R. 54 W. Well 22 feet deep, almost entirely in sand (probably dune sand) on irrigated ground. Sample taken March 3, 1923.

Sample 14. T. S. Switzer. Sec. 9, T. 22 S., R. 54 W. Well 18 feet deep, below ditch on partially irrigated ground. Probably in Horse Creek alluvial deposit. Sample taken March 3, 1923.

Sample 15. R. K. Stanton. SW. ¼ Sec. 36, T. 22 S., R. 55 W. Well 30 feet deep. Water derived mostly from the Timpas limestone near the top of the formation. Sample taken March 3, 1923.

Sample 16. W. E. Allison. Center West ½ Sec. 8, T. 25 S., R. 54 W. Well 15 feet deep, in arroyo wash not far below Timpas-Carlile contact. Drainage area almost entirely basal Timpas limestone. Sample taken March 7, 1923.

WATER ANALYSES OF SHALLOW WELLS

MADE IN THE LABORATORY OF THE PERMUTIT COMPANY

		Sample 17		Sample 18		Sample 19		Sample 20	
		Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon
Total hardness	Calculated as $CaCO_3$	1227	71.66	914	53.38	845	49.35	873	50.98
Calcium hardness	Calculated as $CaCO_3$	786	45.90	604	35.27	485	28.32	616	36.07
Magnesium hardness	Calculated as $CaCO_3$	441	25.75	310	18.10	360	21.02	257	14.91
Alkalinity (Methyl Orange)	Calculated as $CaCO_3$	258	15.07	295	17.23	220	12.85	110	6.42
Basicity-Alk. (Phenolphthalein)	Calculated as $CaCO_3$	0	0	0	0	0	0	0	0
Causticity	Calculated as $CaCO_3$	0	0	0	0	0	0	0	0
Free carbon dioxide	Calculated as CO_2	21	.62	15	.88	13	.76	3	.18
Chlorides	Calculated as Cl	87	5.08	60	3.50	126	7.36	22	1.28
Sulphates	Calculated as SO_3	1141	67.63	772	45.08	805	47.01	814	47.54
Iron	Calculated as Fe	0	0	0	0	0.2	.01	0.05	.003
Manganese	Calculated as Mn	0	0	2	.12	0	0	0	0

		Sample 21		Sample 22		Sample 23		Sample 24	
		Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon	Parts per Million	Grains per Gallon
Total hardness	Calculated as $CaCO_3$	749	43.34	335	20.73	1372	80.12	422	24.64
Calcium hardness	Calculated as $CaCO_3$	414	34.18	262	15.30	820	47.69	276	16.14
Magnesium hardness	Calculated as $CaCO_3$	335	19.56	93	5.43	552	32.24	146	8.53
Alkalinity (Methyl Orange)	Calculated as $CaCO_3$	205	11.97	210	12.26	220	12.85	210	12.56
Basicity-Alk. (Phenolphthalein)	Calculated as $CaCO_3$	0	0	0	0	0	0	0	0
Causticity	Calculated as $CaCO_3$	0	0	0	0	0	0	0	0
Free carbon dioxide	Calculated as CO_2	8	.47	12	.70	17	.99	8	.47
Chlorides	Calculated as Cl	46	2.69	27	1.58	128	7.48	46	2.69
Sulphates	Calculated as SO_3	723	42.22	243	14.19	2128	124.28	522	30.48
Iron	Calculated as Fe	0	0	0	0	0	0	0.4	.02
Manganese	Calculated as Mn	0	0	0	0	0	0	0	0

Sample 17. La Junta City water mains. Derived from underflow of Arkansas River. Sample taken March 1, 1923.

Sample 18. D. V. Burrell. SW. ¼ of SE. ¼ of Sec. 25, T. 22 S., R. 57 W. Well 18 feet deep in alluvial gravel. Water derived from underflow of Arkansas River. Sample taken March, 6, 1923. Same well as sample 10.

Sample 19. G. C. Weston. NE. ¼ of Sec. 10, T. 23 S., R. 56 W. Well 25 feet deep in Terrace gravel. On irrigated ground. Sample taken March 6, 1923.

Sample 20. J. O. Pearson. NE. ¼ of Sec. 24, T. 25 S., R. 54 W. Well 33 feet deep in gravelly wash. Drainage area Timpas, Carlile, Greenhorn and Graneros. Sample taken March 7, 1923.

Sample 21. W. H. Wilson. Sec. 29, T. 26 S., R. 54 W. Well at house 25 feet deep, in gravelly wash of Vogel Canon. Drainage area from Basal Timpas limestone down to Morrison. Sample taken March 7, 1923.

Sample 22. Virgil Bosley. SW ¼ of Sec. 8, T. 26 S., R. 56 W. Well 15 feet deep through gravelly wash into Timpas limestone. Drainage area entirely the basal Timpas limestone. Sample taken March 8, 1923.

Sample 23. Frank Mallett Ranch. Sec. 9, T. 22 S., R. 57 W. Well 37 feet deep in sand of Dune sand area. No irrigation, but water influenced by irrigation to the north. Sample taken March 9, 1923.

Sample 24. A. C. O'Connor. Sec. 21, T. 25 S., R. 56 W. Well about 300 feet from Crooked Arroyo, in arroyo wash. No irrigation. Drainage area basal Timpas. Sample taken March 10, 1923.

CONCLUSIONS

With comparatively few exceptions, the chemical analyses of the water samples collected within the La Junta area, as given above, indicate that the waters are susceptible to softening by the zeolite process. It is doubtful, however, whether this can be done economically in case of waters whose total hardness is above 60 grains per gallon. That is, the expense involved in such cases will probably be greater than many people would care to pay. The expense will not be so much in operation as in the original cost, as it will be necessary to install a large filter so as to avoid too frequent regeneration. It is also possible or even probable that in some cases of hardness between fifty and sixty grains per gallon the character and quantity of salts present other than the soap-hardening salts will render successful softening difficult.

As already stated, each case will have to be determined by itself after an analysis has been made. However, the analyses already made indicate that certain geological conditions are more favorable and others less favorable to the successful softening of the shallow well waters. In a general way these varying conditions are indicated below.

TIMPAS LIMESTONE

It has already been stated that a possible or probable source of water for deep wells is to be found at the base of the Timpas limestone. This is also true of shallow wells. Not a few such wells secure their water at some point within the fifty feet of limestone at the base of the Timpas limestone formation. This is more likely to occur at the very bottom of the limestone or at the bottom of the three-foot bed of brown colored limestone that immediately underlies the Timpas limestone, and that is supposed to form the top member of the Carlile shale. In either case the water, whether from shallow or from deep wells, or from springs that emerge at this point, is likely to be suitable for softening by the zeolite process. On the other hand wells that strike water in the Timpas limestone formation above the basal fifty feet will probably contain water very high in salts and quite unsuitable to softening.

CARLILE SHALE

The only position within this shale formation where water capable of softening may be expected has just been mentioned in connection with the Timpas limestone. It is at the base of the upper, three-foot bed of brown limestone. At all other places in this shale the water will probably be very hard and incapable of softening.

DAKOTA SANDSTONE

Probably all water derived from deep or shallow wells or from springs within this formation are susceptible to complete softening. In fact such water is usually soft enough for domestic use without artificial softening, although such softening will greatly improve the character of the water in any case.

OTHER OLDER FORMATIONS

All other formations older than the unconsolidated gravels, sands and silts of the Tertiary and Quaternary are likely to contain only very hard waters that cannot successfully be softened.

TERRACE GRAVELS

There are probably cases where water from irrigated soils that overlie terrace gravels have premeated the gravels so that shallow water wells yield waters too hard to be successfully softened. The water samples analyzed thus far are not numerous enough to throw definite light on this matter. But it would seem that water from wells in the terrace gravels may be expected to be relatively soft, that is, to contain not over fifty grains hardness per gallon, and perhaps much less than this. They should, therefore be available for zeolite-softening.

In this connection it may be well to call attention to the fact that the time available for conducting this survey did not suffice to map the areas covered by terrace gravels with great accuracy. Indeed it would be extremely difficult and perhaps impossible to do so in any case because of the heavy covering of soil that usually obscures these gravel benches. Also some of the larger streams tributary to the Arkanas River probably have developed terrace gravels that do not appear on the map. This is most certainly true of the Timpas Creek. From certain well data it would appear that such a terrace gravel deposit has an extensive development, but is mostly hidden beneath the surface soil. Wells sunk in this gravel deposit will also be likely to furnish water susceptible to softening. Finally it may be taken for granted that wells sunk through the soil into gravels, except, perhaps along the Arkansas River bottom, are likely to yield water suitable for softening.

DUNE SAND DEPOSITS

It is probable that water struck in the more evident dune sand area where the sand is extensively exposed on the surface and where irrigation is not extensive will be available for softening. On the other hand there are very extensive areas of wind-driven sand and silt whose character is difficult to determine except through the digging of wells or other excavations, as the surface is covered by a heavy soil. Only a portion of such areas appears on the map as dune sand. In general it would appear that these very fine sand deposits that may be as much as fifty feet or more in depth contain very hard water that cannot readily be softened, although there are doubtless exceptions. One cannot draw any general conclusions in these cases. Each well will have to be separately tested.

ARKANSAS RIVER ALLUVIUM

The coarse sand and gravel deposits that make up a considerable part of the alluvium of the Arkansas River bottom lands are saturated with water derived mainly from the underflow of the Arkansas River and its tributaries. This underflow is considerably harder than is the surface flow of the river, but like the river it becomes increasingly hard down stream. It is also as a rule harder than the water of the average shallow well of this area. Three of the above given analyses are of waters derived from this underflow. No. 17 from the La Junta city water mains, No. 18 from just above Rocky Ford, and No. 7 from a point about four miles above Rocky Ford illustrate this point. The water from La Junta is very distinctly harder than the water from the two other locations, and the softest of the three is the one taken farthest up stream. Water taken from the river underflow at or below La Junta will be very difficult to soften. Water from the underflow above La Junta will probably be capable of softening.

Many wells located in the river bottom do not penetrate deeply into the alluvial sand and gravel and probably derive much of their water from the surface soil which is largely under irrigation. These wells may be expected to be harder than those which derive their water entirely from the underflow.

ARROYO GRAVELS AND WASH

Most of the arroyos located on the south side of the Arkansas River and some of those on the north side contain more or less extensively developed gravelly wash deposits that occupy the lower parts of the valleys and that sometimes extend some distance back from the stream, or arroyo bottom. The gravel in these cases is composed of more or less flatish half rounded fragments of limestone, derived mainly from the Timpas limestone, in part also from the Greenhorn limestone. Such gravelly wash usually contains water that is much softer than the average well water of this district. This is particularly true of the wash in arroyos that drain areas largely or entirely covered by the basal Timpas limestone. Such well waters may have a hardness of less than 25 grains per gallon, and are well adapted to softening. It is likely that in nearly all cases where wells are sunk in a gravelly arroyo wash, and strike water in the wash, the water can be softened by the zeolite process.

CO-OPERATION BY THE COLORADO GEOLOGICAL SURVEY

It is of course possible for individual farmers, ranch owners or other householders who may contemplate the installing of a water-softening machine in their homes to correspond direct with one or more of the firms that market such water-softeners. In many cases, however, perhaps in most cases, a rough, preliminary test will suffice to show whether a regular chemical analysis is necessary or worth while. This is done by testing the effect a standard soap solution has upon the water, and is called the "soap test." While the Colorado Geological Survey cannot undertake to make a thorough chemical analysis it will be glad to make a soap test of any sample sent in, and to give advice, based on this test, as to likelihood of softening the water in question. The sample need not be over one or two ounces and should be placed in a clean, tightly corked glass bottle. It should be sent accompanied by a letter addressed to the Colorado Geological Survey, Boulder, Colorado. The letter should give as complete information as possible as to the exact location in section and quarter section and as to position with reference to streams, arroyos geological formations, and irrigated or non-irrigated ground, and should state the depth of well and the character of the material that is passed through and that yields the water.

Samples of water should not be sent to manufacturers of water-softeners until instructions have been received from them as to gathering and shipping the sample.

COLORADO GEOLOGICAL SURVEY

BOULDER

R. D. GEORGE, State Geologist

BULLETIN 27

PART II

UNDERGROUND WATER RESOURCES OF PARTS OF CROWLEY AND OTERO COUNTIES.

BY

W. C. TOEPELMAN

BOULDER, COLORADO

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PART II

UNDERGROUND WATER RESOURCES OF PARTS OF CROWLEY AND OTERO COUNTIES

INTRODUCTION

During the summer of 1923, the Colorado Geological Survey conducted additional investigations for possible shallow water supplies for domestic and stock uses in an area lying to the north and west of the region described in Part I of this Bulletin. It was found that the waters were very similar to those in the La Junta area and as a result, no detailed chemical analyses were made. For a general idea of the nature of the impurities in the waters the reader is referred to the tables given by Dr. Patton in Part I.

LOCATION

The area to be described is in T. 18-20 S., R. 55-59 W., and T. 18-26 S., R. 58, and the east half of 59 West, and covers the northern part of Crowley County and the two eastern tiers of townships in Otero County. The most important towns in the area are Manzanola (formerly Catlin), Olney Springs and Crowley. Ordway, the county seat of Crowley County, lies a little south of the region in T. 21 S., R. 57 W.; Fowler is just across the border of the area in T. 22 S., R. 59 W.

FIELD WORK

The field work upon which the report is based was done from June to September, 1923. The investigation was carried on more or less as a reconnaissance, and the surveys of the United States Land Office were used as a basis for the mapping. In many places, the land surveys are very inaccurate and considerable difficulty arose in checking earlier maps of surrounding regions. Wherever several land surveys had been made, the latest results were used in constructing the map. In several places, particularly in T. 18 S., R. 55 W., and west of the village of Ayer in T. 24-26 S., R. 58-59 W., the land surveys are so conflicting that hurried revisions were made, but elsewhere the section and township corners recognized by landowners were used in this work.

In the course of the summer the writer was aided by H. A. Hoffmeister, R. A. Koenig, C. L. Mohr, and W. E. Taylor, assistants on the Survey staff. The area included in T. 22-26 S., R. 58-59 W., was mapped by Mohr and Koenig and finally checked by the writer.

AREAL GEOLOGY

The surface of the area is occupied by sedimentary rocks of Cretaceous, Tertiary and Quaternary age. The oldest formation exposed is the Greenhorn limestone of the Benton Group of the Cretaceous; the youngest is the recent stream alluvium along the Arkansas River and its larger tributaries. The formations from the Greenhorn limestone to the top of the Apishapa Formation are fully described in Patton's report on the La Junta area (pp. 14-22). As no essential differences were discovered in this region, no attempt will be made to repeat the descriptions. The columnar section on page 12, gives the general characteristics of the rocks found in the area.

DESCRIPTION OF FORMATIONS

CRETACEOUS SYSTEM

Benton Group—Niobrara Group: (See pp. 14-22, Part I).

MONTANA GROUP: The Montana Group is represented in the region by the Pierre shale only and outcrops over most of Crowley County. The formation consists almost entirely of dark colored shales with a few thin lenses of limestone near the middle. Three general zones have been recognized in the total thickness of nearly 2,000 feet.

The lower 500 feet consists of medium to dark gray shales with a series of thin yellow brown shale at the base. The beds are practically barren of fossils in all places studied. Near the top of the series occur small iron concretions and a few lime carbonate masses. The latter weather locally to a bright yellow color. Crystals of selenite are abundant everywhere.

Above this lower zone is a series of 400 to 550 feet of dark shales containing an abundance of lime and iron carbonate concretions. These, when freshly broken, are blue gray in color, but when weathered are of a distinct rusty color. This color has given rise to the term "Rusty Zone" for this series of beds[1]. Near the top in eastern Crowley County occur several bands of lime concretions in the form of septaria. These range from one to six feet in diameter and are extremely hard and resistant, but too limited in extent to be of stratigraphic value. In the same vicinity, there are found almost spherical concretions of white gypsum with calcite centers. Flakes of selenite are abundant in the beds.

Following this zone are from 100 to 250 feet of lighter gray shales containing numerous specimens of *Baculites ovatus* and several species of *Inoceramus*. Above this is the "Tepee Butte" zone, extending through several hundred feet of the section and passing into a slightly sandy shale along the north line of Crowley County. The zone is characterized by small conical buttes which occur in groups in places. The buttes consist of small lenses of impure coarse textured gray limestone and range from a few feet to approximately 100 feet in diameter. The limestones are exceedingly fossiliferous, *Lucina occidentalis*, *Inoceramus barabini*, *Baculites ovatus*, and *Scaphites nodosus* being most abundant. The tepee buttes have been described by Gilbert[3] and Fisher[2] as originating from cylindrical masses of limestone in the shale. In the region here described the cores of the buttes are very distinctly lenticular masses of limestone and no evidence of cylinders was found. Usually two or three thin lenses are separated by a few feet of shale in the larger buttes. At present no reasons can be given for the grouping of the buttes nor for the presence of such an abundance of fossils. The surrounding shales contain very few fossils.

LATE TERTIARY

"NUSSBAUM FORMATION:" The Nussbaum beds occupy considerable areas in western Crowley County, and on the stream divides in the eastern part of the county. A small area occurs in the west central part T. 23 S., R. 58 W., south of the Arkansas River.

The formation consists of partially or wholly uncemented gravels, sands and clays ranging from a few to almost 130 feet in thickness. The latter thickness was determined from well logs in the western part of Crowley County and is exceptional for this part of the State. The average thickness is less than 50 feet. The lower beds are in general the coarsest and consist of fine gravels and coarse sands, gray to pink in color, containing an abundance of angular fragments of orthoclase feldspar. Cross bedding is common and points to stream origin. The upper beds are composed of sands and clays of whitish, grayish, and locally yellowish color with a few lenses of unconsolidated gravels. In the gravels, both upper and lower, pebbles in excess of two inches in the longest dimension are rare. This characteristic is of importance in separating the Nussbaum and the Quaternary gravels to be mentioned below.

The age of the deposits can not be definitely determined. Gilbert[3] and others have considered the beds to be of late Tertiary, probably Pliocene, age and there seems to be no good evidence for changing this usage at present. No fossils have been obtained from the formation and its age must be determined from its relation to structural and physiographic features in the regions it covers.

QUATERNARY SYSTEM

The Quatêrnary deposits found in the region consists of terrace gravels, dune sands, and stream alluvium scattered widely over the area. The terrace gravels and some of the dune sands may be of Pleistocene age; the alluvium and some eolian sands are distinctly recent in age and origin.

PLEISTOCENE SERIES

TERRACE GRAVELS: Most of the earlier maps of the Arkansas Valley have shown two rather distinct levels of terrace gravels developed along the streams. In the course of the work upon which this report is based, a third level was found and mapped. The terraces have been called the high, middle and low, the former two corresponding to the High and Low Terrace levels in Patton's report on the La Junta area. The Low Terrace of the present paper was not recognized by Dr. Patton.

HIGH TERRACE GRAVEL (Qht.): The oldest terrace deposits are best developed in the region south of the Arkansas River. They extend back some five or six miles from the present stream course and rise from 125 to 175 feet above it. The lower boundary is rather easily located and mapped. The upper boundary, away from the stream, is difficult to locate due to covering by surface wash in many places. The deposits consist of 20 to 30 feet of coarse gravels at the base followed by finer gravels, sands and silts. The basal gravels contain numerous pebbles of granite and metamorphic rock having diameters of six inches or more. Much of the material in the deposits was undoubtedly derived from the formations near the mountains and from the older Nussbaum formation. The coarser pebbles, however, could not have come from the latter beds since at no place studied in the course of the field work were large pebbles found in the Tertiary.

MIDDLE TERRACE GRAVELS (Qmt): Except that the middle level gravels are some forty feet lower topographically and considerably closer to the present flood plain, there is no essential difference between them and the higher gravels. In but few places is there any difficulty in recognizing the two levels.

LOW TERRACE GRAVELS (Qlt.): The lowest terrace occurs on both sides of the Arkansas River across the area mapped. Its base is some twenty-five or thirty feet above the recent flood plain, the upper surface about fifty feet below the middle terrace. In general, the gravels on the lowest terrace are somewhat finer than those on the higher levels, but the materials included are essentialyy the same. Much o fthe irrigated section is located on the low terrace, but the middle level is also extensively utilized for agriculture.

OTHER PROBABLE TERRACE DEPOSITS (Qt. ?): In the west half of T. 18-19 S., R. 56 W., and through the middle of T. 18 S., R. 57 W. in north-central Crowley County, there exist on the flat stream divides from 20-30 feet of fine gravels, sands, and sandy clays the age of which is open to some question. The base of the formation, in most places, consists of a few inches to several feet of cemented gravel which contains angular bits of pink feldspar very much like that found abundantly in Tertiary beds. The sands and clays also are similar to those of the Nussbaum, but this formation is everywhere from 50 to 100 feet higher topographically and is separated from the terrace deposits by a sharp rise in which Pierre shale is at the surface. In position, therefore, these terrace deposits are similar to the lower Nussbaum terrace noted by Darton[1] in Kiowa County. There can be no doubt that the terrace deposits were derived from the Tertiary sediments to the north. The writer is, however, inclined to consider the deposits of Pleistocene rather than Pliocene age since a considerable time interval must have elapsed between the deposition of the Nussbaum and the laying down of the beds in question upon a rather flat surface developed some sixty feet lower than the Nussbaum deposition plane.

RECENT SERIES

ALLUVIUM: The most extensive areas of alluvium in the district are along the Arkansas River. The thickness is variable from place to place, but probably does not exceed fifty feet anywhere. The materials are chiefly fine sands and silts with a few lenses of gravel and are still being deposited by the stream at flood time.

Other alluvial materials are found in narrow belts along Horse and Pond creeks and Sand Arroyo in Crowley County. Because of the difficulty in separating these deposits from eolian sands and in determining the exact limits, no attempt was made to map the area covered. The deposits are important as water bearers and hence are mentioned here.

DUNE SANDS: Wind blown sands occur extensively over much of the area mapped. North of the Arkansas the Nussbaum formation furnishes the material for extensive areas of sand dunes which spread widely over the Pierre in many places. The alluvium along the larger streams also serves as the source of much sand in Crowley County. The accompanying map shows the location of the most important areas of dune sand. South of the Arkansas the most extensive deposits of wind blown sand occur in T. 24 and 25 S., R. 58 and 59 W. These are probably derived chiefly from alluvium deposited by the Apishapa River and Dry Creek which pass through the district.

These eolian deposits consist of extremely fine grey to yellow sands and silts. In many places the surface is billowed as in typical dune areas, but only locally are the dunes active. The thickness of the deposits is from a few inches to 50 or 60 feet.

IGNEOUS ROCKS

Excepting two small dikes in T. 26 S., R. 58 W., and T. 26 S., R. 59 W., no igneous rocks are known at the surface in the region covered by this report. The dikes are composed of compact dark colored rock very similar to that found by Stose[4] in the Apishapa Quadrangle. The dike found in sections 11, 15 and 16, T. 26 S., R. 59 W., extends into the Apishapa area where it was determined to be vogesite. The second dike in sections 9 and 10, T. 26 S., R. 59 W., is of the same material. The width of the intrusions is from 50 to 60 feet. In many places the only evidence of the existence of the igneous rocks is the presence of a band of weathered boulders.

STRUCTURE

In general, the district lies on the south and southeast flanks of a large synclinal basin having its center near the city of Denver. Through practically all of the area north of the Arkansas River, the Cretaceous beds dip one to two degrees to the north, northeast and northwest. The latter direction is most common and the westerly component becomes more marked toward the eastern part of Crowley County. In a few places slightly higher dips are recorded, but are based upon very doubtful observation on limited outcrops. Immediately northeast of Lake Henry in the southwestern part of T. 20 S., R. 56 W., there is some indication of a minor flexure or fold, but because of the short time available for the water survey, no detailed work was done in the region. The highly weathered condition of the shales would necessitate considerable digging of pits to secure true dips.

South of the Arkansas, especially in the southern parts of T. 25 and 26 S., the beds dip northward at slightly greater angles, (3°-9°), making a step-like fold across the area. On the south edge of the map the beds are again practically flat. In this district the presence of limestone beds in the Benton and Niobrara groups aids materially in determining the true dip. Near the station of Ayer on the Atchison, Topeka and Santa Fe railroad in sections 24 and 25, T. 26 E., R. 58 W., and section 19, T. 26 S., R. 57 W., Koenig and Mohr outlined roughly a small anticlinal fold with an axial trend somewhat north of east. Whether or not the fold is closed was not determined at the time. The information at hand, however, seems to make detailed work advisable. An artesian well is bottomed in the Dakota at 343 feet and yields an abundant supply of water. The crest of the fold is exposed in the bottom of Hoe Creek one-half mile northeast of Ayer.

FAULTS: Several minor faults occur in the region. The most important are in the two townships mentioned above. In section 27, T. 26 S., R. 59 W., a normal fault with a vertical displacement of 75 feet extends for slightly less than a mile in an east-west direction. Laterally the fault passes into a sharp monoclinal fold having a dip of 9° or more to the north. In section 25, T. 26 S., R. 58 W., occurs another normal fault which can be traced for about one-half mile. The displacement is slight. The fault trends northeast, parallel to the crest of the fold noted above.

The only other fault found in the region is in the south half of section 29, T. 20 S., R. 56 W., where it is exposed in the Colorado Irrigation Canal. Its strike and magnitude could not be determined in the time available for structural study.

WATER RESOURCES

The conditions necessary for the existence of ground water supplies have been outlined by Dr. Patton in Part I, and will not be repeated here. In most of the region included in this paper, the available shallow water supply is derived from the rainfall in the immediate vicinity or from nearby regions. Only in the region south of the Arkansas is water encountered in the consolidated rocks and then only in the Dakota group of formations which are not present at the surface within the area mapped.

The following pages outline briefly the water conditions in the formations occurring within the region.

ARTESIAN SUPPLIES: The only source of artesian waters is the Dakota sandstone which underlies the whole area. In the southern part of the region, about Ayer, the Dakota is reached at a depth of about 290 feet. According to Darton[1], the wells when first drilled flowed at the rate of 25 gallons per minute, but the water is heavily charged with sulphate of lime and is very unsatisfactory. Northward the depth to the water bearing sands increases rather rapidly. In the Arkansas Valley, the sand is encountered at 1030 feet at Manzanola, (Catlin), 1374 feet near Fowler, and approximately 1400 feet in various places. The wells in the valley all flowed freely when brought in but the flow has constantly decreased until at present most of them are pumped.

North of the River, but few artesian wells have been drilled. Near Ordway just south of the border of the map, the Dakota was tapped at 1410 feet, but the well did not flow. At the Cudahy Ranch in section 22, T. 20 S., R. 58 W., the sandstone was reached at approximately 1800 feet. An abundance of water is available, but does not flow. Immediately north of the Crowley-Lincoln County line in section 32, T. 17 S., R. 57 W., a test for oil reached the Dakota at 2785 feet. According to settlers of the region, water rose in the casing to within a hundred feet of the top. The Midwest Refining Company has one report that the water flowed but this has not been confirmed.

Analyses of the artesian waters in this region are not available but all evidence indicates that the character of the waters does not vary much from that reported by Patton. In most places the water is rather heavily charged with iron, magnesium and lime and in some wells contains traces of sulphur.

No other artesian horizons are known in the district. The Carlile, which in some areas yields water, contains little or no sand and except in the Midwest well in Lincoln County no water is reported from it. In the Midwest log, hot water is reported at 2330 feet, probably from the Carlile.

SOURCES OF SHALLOW WATERS

In the region south of the Arkansas River, beds of Benton and Niobrara age occupy most of the surface. The formations making up these series are chiefly of shale and limestone and carry but little water. When wells are secured the waters are usually very impure and useless for domestic and even stock purposes. The analyses given by Patton for waters obtained in the formations will serve as a guide to the chemical impurities found in this region. So far as could be discovered in the field, there is no well in the region of outcrop of the Benton and Apishapa groups of formations that is extensively used for human consumption. Most of the wells are utilized for stock, but a few yield water that is distinctly injurious to animals. A well on the ranch of C. J. Doyle in section 2, T. 25 S., R. 58 W., contains water that is reported to have caused the death of mules and cattle. An analysis of the water made for Mr. Doyle by the American Beet Sugar Company shows the following impurities:

Sodium Chloride	96.44 parts per million
Sodium Sulphate	1265.99 parts per million
Magnesium Sulphate	349.86 parts per million
Calcium Sulphate	33.00 parts per million
Calcium Carbonate	167.47 parts per million
Silica (SiO_2)	2.60 parts per million
Iron (Fe_2O_3) & Aluminum (Al_2O_3)	1.30 parts per million
Organic and Volatile Matter	109.04 parts per million
TOTAL IMPURITIES	2025.70 parts per million

In the course of the investigation, practically all wells dug or drilled into the Apishapa and Timpas were tested with soap solution to determine the general nature of the waters. The soap solution test, though very crude at best, serves to show roughly the hardness of waters and very roughly indicates the calcium carbonate content.

Of six wells dug in the Timpas limestone, it was found that the waters are rather uniform in character. The soap test indicates an average content of about 300 parts of calcium carbonate or its equivalent per million, with 256 and 382 parts per million as the extremes. In addition most waters are distinctly alkaline in taste and are used, if at all, for stock purposes only. Wells are much more abundant in the Apishapa formation and show a greater range in hardness, the lime carbonate content ranging from 51 parts to 460 parts per million. Most of the waters range between 250 and 350 parts per million in hardness. None are good for human consumption but a few are used when no good supplies are within easy hauling distance.

In depth the wells in the Niobrara formations range from a few feet to fifty or sixty. Except in the sandy parts of the formations, the amount of water available is small and apparently is derived entirely from seepage from the surface. Considerable areas yield no water, or so little that tests are abandoned. In general, it may be said that the Niobrara group will not yield good water anywhere in the region mapped, and except to supply stock it is useless to attempt to secure wells. In a few limited areas where alkalinity is low, water softeners might give satisfactory results but on the whole even patented softeners would be of no value, since the impurities are such that the processes in use at present will not remove them.

PIERRE SHALE: The Pierre shale outcrops in practically every part of Crowley County north of the Missouri Pacific Railroad and in many places the situation as concerns water supplies is acute. Except where covered with terrace, dune or alluvial deposits, no good water or sources of good water have been discovered. In other districts in Colorado, sandy shales and sandstone beds occur in the formation but none have been found in this region. Homesteaders and ranches have zealously tried to find water in most sections where Pierre is at the surface, but except meager supplies of water for stock, their efforts have been without results away from streams and more recent sand deposits.

During the investigation about fifty wells dug into the Pierre were visited and the waters tested with soap solution. In addition, some data were secured on a number of dry tests in various places. Most of the producing wells are between 15 and 50 feet deep. Several tests have been made to depths of over 100 feet without securing a water supply. Along the smaller creeks and draws fairly abundant supplies of hard, bitter water are obtained. Most of the water from weathered Pierre is exceedingly poor. In calcium carbonate equivalent, it varies from slightly over 100 parts per million to 481 parts. The majority of the waters show between 200 and 300 parts per million of calcium carbonate, but apparently carry many other impurities of which calcium sulphate, or gypsum, is most abundant. No chemical analyses of Pierre waters have been secured for this region but because of the abundance of iron oxide, iron carbonate, and gypsum in the shales it seems logical to expect these materials in quantity. Many of the waters are greenish in color and taste of iron.

So far as could be determined in the field, none of the wells is used for household purposes, though most are used to water stock. In a number of places, it has been reported that cattle were killed or made seriously sick by waters from certain wells, whereas, when placed on water from wells within a short distance no ill effects were shown. However, some difference of opinion occurs as to the direct cause, as veterinarians laid the sickness to fungus growths on the grass. The facts seem to indicate that the water is the chief cause, for, as stated above, when the stock is put on waters from other wells and during wet seasons when water is abundant in waterholes, the stock seems to thrive.

In summary, the Pierre can not be considered as a source of domestic waters in this part of Colorado. Although a few wells may be used for human consumption, there is no assurance that wells even a few hundred yards away will yield the same kind of water. One of the striking features brought out by the field studies is the great variation in wells even in the same quarter section. One well may be fairly soft and without noticeable taste, a neighboring well to the same depth will be exceedinly hard and decidedly bitter. In passing, it would be well to note the most abundant supplies of water are obtained relatively close to the surface in places where the shale is highly weathered to an adobe-like soil. Below 20 or 30 feet from the surface the shale is usually too compact to yield much water and the few tests to depths of 100 feet or more have resulted in dry holes. Along the small creeks and draws water can usually be found within a few feet from the surface and is usually of slightly better quality than that on the divides. The soft, potable waters along Horse, Pond, and Breckenridge creeks are derived from alluvial and windblown Quaternary deposits.

TERTIARY WATERS: The Nussbaum formation of late Tertiary age is the best water bearing horizon in the region. It occupies a large area in the two western tiers of townships in Crowley County, an area from two to three miles wide through T. 18-20 S., R. 55-56 W., a small portion of T. 18 S., R. 55 W., and, south of the Arkansas River, the west central part of T. 23 S., R. 58 W. In all of these districts some water is secured from the formation near the contact with the underlying shale formations. The outcrop in western Crowley County is most prolific of water, but even within it water is not available at all places.

All of the water contained in the Nussbaum comes directly from surface seepage during rainy periods. The downward percolation is stopped when the shale is reached and the water then follows along the contact plane to the outcropping edges of the formation. North of the Arkansas Valley, the surface of the plain upon which the Nussbaum was laid down slopes gradually to the southeast, and, as a result, the waters flow the southeast and come forth as springs at many places along the south and east faces of the so-called Nussbaum plateau. Wherever the basal beds of the formation are coarse sand and gravel, there springs may be expected.

The springs are usually rather steady in volume and are utilized by several towns for municipal supplies. A group of springs in the north part of T. 22 S., R. 59 W. and in T. 21 S., R. 59 W., have been enlarged and supply excellent water to the towns of Fowler, Olney Springs and Ordway. The latter city has a very limited supply at present, but by utilizing other springs to the north, particularly in the Antelope Springs district in sections 32 and 33, T. 19 S., R. 58 W., a sufficient supply for a population considerably in excess of the present could be secured. Many springs in the district have a very small flow, but the writer is confident that the flow could be materially increased by enlarging and cleaning the springs. By combining the flow from the numerous springs and seeps a large quantity of water can be made available.

Back for a short distance from the outcropping edges of the formation and upon the upland proper, good wells can be secured in most places. Farther back, the distribution of water seems to correspond to pre-Nussbaum valleys cut into the Pierre. The existing wells are in north-south belts a mile or two wide with the best wells near the middle of the belt. In most places, the depths are likewise greater near the middle, seeming to bear out the channel theory. The most marked of these belts within the area lies along the center of T. 19-21 S., R. 59 W. A less well defined belt occurs in the west half of the same townships in R. 58 W. Between the belts water is less commonly found and when found is much less abundant.

In this region of western Crowley County the depth of wells varies from a few feet to approximately 130 feet. To secure a constant and copious supply, it is necessary to drill or dig the well into the shale. Throughout the whole region, the quality of the water is very uniform; it is soft and practically tasteless. The soap test indicates considerably less than 100 parts per million of calcium carbonate equivalent in most wells and this seems to be the only marked impurity.

In the outliers of Nussbaum noted above, the water supply is much less abundant because of the limited catchment area. Along the contact of the elongate outlier in T. 18-20 S., R. 55-56 W., a few seeps occur but only in the southern portion does water occur in any abundance. In the south part of T. 19 S. and through most of T. 20 S. water can be secured near the outcrop but on the top of the divide few wells are known. Many failures are reported by homesteaders in the area. In quality the water is essentially like that described above. The smaller outliers mentioned previously are too small to serve as sources of water in any quantity. Seeps occur at the contact in places but no wells were found. It is not improbable, however, that small supplies may be found near the contacts of the Nussbaum and the shales even in these areas.

QUATERNARY WATER BEARING HORIZONS:—HIGH, MIDDLE AND LOW TERRACES: In most places where the high and middle terraces occur the area covered is rather limited and, as a result, the gathering area is too small and the thickness is too slight to accumulate much water. In one or two places in the northwestern part of T. 23 S., R. 58 W., springs occur at the contact between the Apishapa and the high terrace. The water from the springs is of excellent quality, containing about 80 parts of calcium carbonate equivalent per million as the only important impurity. Elsewhere, the wells started in the high and middle terraces penetrate the underlying Apishapa formation and obtain their water from it. The middle terrace is under irrigation in most places and such water as it furnishes is essentially like that contained in the ditches and is therefore useless. The same is true to an even more marked degree in the low terrace which lies entirely in the irrigated section.

QUATERNARY TERRACE (Qt?): The terraces of doubtful age described above from T. 18-19 S., R. 56-57 W., are important water bearing horizons. In R. 56 W., the deposits yield water in most places. It is reported that when the district was first settled, the waters were of excellent quality and abundant. At present, a system of five small reservoirs, the Box Springs Irrigation District, irrigates the area. The wells in the vicinity of the reservoirs have gradually become tainted with alkali and are passing out of use except for supplying stock water. North of the reservoirs, the water obtained is soft and palatable. It is slightly harder than that obtained from the Nussbaum but nevertheless can be used for all purposes.

In R. 57 W., good wells are secured over the entire area covered by the deposits. The water is soft and abundant; the soap test indicates from 120 to 210 parts of impurities per million. There is no noticeable taste and the water is used for all purposes. So far as could be discovered no failures to secure producing wells have resulted in the outcrop area of the terrace.

RECENT WATER HORIZONS—ALLUVIUM: Alluvial deposits of recent age occur along the Arkansas River, Horse Creek, Sand Arroyo, and to a lesser extent along Pond and Breckenridge creeks. The deposits in the Arkansas Valley are in the irrigated section. Though they yield abundant water in most places, it is tainted by the waters from the river and ditches and is valuable only for stock. All wells visited were distinctly alkaline, but contain only limited amounts of calcium carbonate equivalent, (115-180 parts per million). Since most of the area covered by alluvium in the Arkansas Valley is on the flood plain proper, it is not likely that it will ever be thickly settled and the water situation is not likely to be serious.

Along Horse Creek through the middle of T. 18-20 S., R. 56 W., there is a belt of alluvium consisting chiefly of well washed sand and fine gravel that is the source of large supplies of good water. The thickness of the water bearing beds is variable, but most wells strike water within a very few feet of the surface. Even in dry seasons, owners report no decline in flow, a fact which points to a considrable sub-surface flow in the deposits. The width of the belt varies from slightly over 100 yards to nearly a mile. As noted above, the limits are difficult to determine because of the gradation laterally into dune sands in places.

The soap test shows a slight increase in hardness from north to south along the valley. In T. 18 S., R. 56 W., in the Box Springs district, the calcium carbonate equivalent is 115 parts per million. The city of Ordway has contemplated using water from this place for its municipal supply. The amount available is large but the quality is poorer than that of the water in the Antelope Springs district mentioned above. In addition, there is greater danger of contamination in the Horse Creek waters.

Southward from T. 18 S., the waters gradually become harder and tend to have an alkaline taste. In the south part of T. 20 S., tests of several wells show slightly over 200 parts of impurities per million. The waters taste slightly of alkali but are otherwise good for all purposes. The width of the alluvial belt is greatest in this region.

Along Pond and Breckenridge creeks, there are small patches of sand yielding water, but on the whole the alluvium is more of the nature of adobe which contains water essentially like that from the Pierre. Along Sand Arroyo in T. 18 S., R. 55 W., an alluvial belt averaging about one-half mile in width is the source of very good waters much like those along Horse Creek.

DUNE SANDS: The deposits of wind blow sand scattered over the region. because of their porous nature, store up considerable quantities of water in some places. The dune sands on the Tertiary are as a rule unproductive as the water seeps downward into the lower sands and gravels. Those in the region south of the Arkansas River are too thin to store much water and contain too much silt and clay to give pure supplies. The eolian deposits within the irrigated district about Olney Springs contain abundant water but it is thoroughly contaminated by irrigation and is not used for household consumption.

There remain, therefore, only the dune deposits along the Nussbaum outcrop in northwestern Crowley County and small areas immediately east of Horse Creek to serve as sources of water. The former area is extensive in T. 18-19 S., 58-59 W. The thickness of the sand is from ten to twenty feet and when wells are stopped at the underlying shale and adobe, good water may be obtained. The water tests about 120-130 parts per million in hardness but the amount obtained is small, especially in dry seasons. Because of the patchy distribution of the sands, the distribution of wells is irregular. In all places where several square miles are covered with a reasonable thickness of sand, good water may be obtained.

East of Horse Creek in T. 18-19 S., R. 56 W., several patches of dune sand have been mapped but the boundaries of the deposits are exceedingly indefinite. The thickness of the sand is from ten to thirty feet. The sand is very fine and thoroughly mixed with clay. The few wells that have been dug into the sands, yield water in some abundance, but in general the quality is much the same as in the area described above. The tests made show from 115 to 130 parts of calcium carbonate equivalent per million.

BIBLIOGRAPHY

1. Darton, N. H., Geology and Underground Water Resources of the Arkansas Valley in Eastern Colorado: U. S. Geol. Survey Prof. Paper No. 52, 1906.
2. Fisher, C. A., Geol. Atlas U. S., Nepesta fol. No. 135, U. S. Geol. Survey, 1904.
3. Gilbert, G. K., Geol. Atlas U. S., Pueblo fol. No. 36, U. S. Geol. Survey, 1897.
4. Stose, G. W., Geol. Atlas U. S., Apishapa fol. No. 186, U. S. Geol. Survey, 1912.

COLORADO GEOLOGICAL SURVEY
BOULDER
R. D. GEORGE, State Geologist

BULLETIN 27
PART III

GEOLOGY OF PARTS OF LAS ANIMAS OTERO AND BENT COUNTIES

BY
JAS. TERRY DUCE

CONTENTS

GEOLOGY OF PARTS OF LAS ANIMAS, OTERO, AND BENT COUNTIES

PREFARATORY NOTE: The work of H. B. Patton, Part I, of this Bulletin, overlaps the northern part of the area covered in Part III. As the purposes of the two surveys were different the texts are given in full as prepared by the two authors. As the map made by Mr. Duce had to be redrawn to conform to the scale and conventions now used by the Survey, that part of Mr. Duce's map covered by Mr. Patton's map is omitted, in order to save expense, as the findings were essentially the same.

The field work on which this report is based was done in 1916. The results of later studies by the author and by other oil geologists are leading to interpretations of the region which differ widely from one another and from those commonly accepted, but he does not feel justified at this time in presenting even tentative views or interpretations on an area which presents so many difficulties of interpretation and which will doubtless be the subject of much controversy among geologists.

LOCATION AND AREA

The plateau area south of the Arkansas River is unique in its isolation. Although it is situated close to one of the great trans-continental railroads, little is known about it, even by those who live on its very borders. The southern boundary of the area is the thirty-seventh parallel and its northern line the thirty-eighth parallel. The east and west boundaries are meridians 103° and 104°. This territory includes the Timpas, Higbee, Mt. Carrizo, and Mesa de Maya quadrangles of the United States Geological Survey topographic atlas.

ACKNOWLEDGEMENTS

The writer desires to express his thanks for the co-operation of Professor R. D. George in this work. He has been at all times ready to discuss the perplexing stratigraphic questions and has aided in many other ways. Thanks are also due to Mr. Kenneth Willson and Mr. Harold Morley, who worked faithfully under trying conditions, and also to Mr. Harold Flanders, and to many others who aided the party in the field. The writer has drawn freely on the descriptions and maps of Mr. Willis T. Lee and Mr. N. H. Darton of the United States Geological Survey, and has used the stratigraphic data of Mr. T. W. Stanton. Whatever errors appear in this paper are due solely to the writer.

METHODS

The geology of the area was platted on the reconnaissance topographic maps of the U. S. Geological Survey made about 35 years ago. These maps are reasonably accurate only as to the prominent topographic features. (The details of topography, the placing of minor streams, and the cultural features are very unreliable and in many instances could not be recognized at all). Most of the work was done with aneroid barometer and Brunton compass, but where critical points of structural gelogoy were concerned, rapid level lines were run by stadia methods.

The inaccuracies of the base maps doubtless have caused similar inaccuracies in placing the formational boundaries. And it is improbable that this map will register with those of Patton and Toepelman to the north, which were based more largely upon the recent land surveys and data obtained from other reliable sources.

No detailed geological work has been done in this part of southeastern Colorado. The only publications dealing with the area as a whole are those by Gilbert and Darton of the U. S. Geological Survey. (See bibliography). Papers by Lee and Stanton discuss the age of certain formations, and are of local interest and value.

ACCESSIBILITY

The main line of the Atchison, Topeka and Santa Fe Railway passes along the northern and western borders of the area, and brings most of it within thirty miles of rail transportation. A good road passes north from La Junta to the Purgatoire River and another from Las Animas to the head of Muddy Creek. The roads on the prairie are fair, but those in the canons are frequently impassable, while on the upper part of the Purgatoire cattle trails only exist. The only town of importance is La Junta at the junction of the Colorado branch of the Santa Fe with the main line. Scattered postal stations are located along the streams of which the largest is Wilson's Spur on the Colorado and Southern Railroad.

Until within the last few years the only settlers have been along the Purgatoire River and along the line of the Santa Fe Railroad. The settlements on the Purgatoire are very old, however, for it was along the west rim of the Canon that the Old Santa Fe trail was established. Bent's Fort at the junction of the Iron Canyon and the Purgatoire is a land mark of the days when the Santa Fe trail was "twelve wagon tracks wide," and formed the main highway between St. Louis and Spanish America. The population was then chiefly Mexican. Later the higher lands were invaded by the cattle men who, in turn, are now being replaced by the "dry farmer." The open prairie is a thing of the past. In the "Red Rock Country" and among "the cedars," however, the cattle men still hold away. There was a short period in the eighties when a series of settlements such as Troy and Indianapolis were founded, but several dry years discouraged the settlers and they left the state.

CLIMATE AND VEGETATION

Slightly more rain falls on the high lands of the Mesa de Maya than to the north along the Arkansas Valley, but the climate must be classed as semi-arid. The few summer storms are generally violent, and an inch of rain may fall in three hours. July and August are very hot and the temperatures become almost unbearable in the canyons in the Red Beds. The nights are commonly cool and pleasant. The winters are mild.

The vegetation is that typical of the warmer parts of the Great Plains. The bunch grass, sage, scattered cactus and yucca give the rolling surface a monotonous dim color, except after the summer rains when the flowers add their brilliant colors. The rims of the lower canyons are forested with cedars. At higher elevations pinon also appears. In the valleys cottonwood is the commonest tree, but boxelder, elder and scrub-oak are not uncommon. Some of the smaller canyons contain a very dense underbrush and the trees are covered with wild grape. Many of those canyons which extend into the Red Beds are very beautiful, and especially so as one approaches the rims from the glaring slopes of the lower Morrison.

TOPOGRAPHY

Starting southward from the Arkansas Valley the surface rises in a series of slanting step-like plateaus. The first of these extends south from the river terraces above Las Animas to Stage Canon. Its east and west extension is from just east of Clay Creek to a mile west of the Purgatoire River. It is approximately 30 miles wide and rises from an altitude of 4000 feet to 4600 feet, or 20 feet to the mile. The surface formation is the Dakota sandstone. To this bench the writer has given the name Higbee denudation plain. Along its western half this plain is terminated abruptly to the south by a high densely timbered escarpment which is highest to the west and gradually decreases in height eastward to Hackberry Creek where it becomes a line of minor hogbacks which grade imperceptibly into the Higbee plain. This escarpment is due to a rather sharp monocline whose face occasionally dips 12°. The edge of this fold has been dissected into cliffs by intermittent streams. In this report it is called the Black Hills escarpment, as it is developed best at the point locally known as the Black Hills, where it rises five hundred feet above the Higbee Plain in two and one-half miles, or about 200 feet to the mile. The erosion plane which succeeds the Black Hills escarpment stretches back as far as the lava covered Mesa de Maya on the Colorado-New Mexico line. On its northern edge the slope is about ten feet to the mile,—but it gradually increases southward. This plain will be called the Tobe erosion plain from the postoffice of Tobe. The surface is also formed by the Dakota. Its maximum width is 25 miles, and its average slope 33 feet per mile. It is terminated on the south by the rather abrupt escarpment of the Mesa de Maya, a tableland of Cretaceous strata capped by a remnant of the great basalt flow that came from the west and protected the underlying shales. This mesa has a maximum altitude of 6,800 feet, and is the crest of the divide between the Arkansas and the Canadian Rivers. (See north-south section on the right hand side of map in pocket).

Along the western edge of the Timpas and Mesa de Maya quadrangles and paralleling the course of the Purgatoire there is a series of mesas formed by the westward dipping beds of the Greenhorn limestone. In contrast with the Black Hills, this line of mesas has been called the Grey Hills. Westward from these hills in the Timpas quadrangle is the rather gently rolling valley of Timpas Creek excavated in the soft Cretaceous shales, but with occasional low escarpments formed by the Greenhorn limestone such as those about Iron Springs.

Most of the streams have deeply entrenched themselves in canyons which traverse the area either due south or to the east of south as in the case of the Purgatoire River and Timpas Creek. These canons are narrow and are walled in by step-like cliffs of the harder strata except along the Black Hills monocline, where they widen, forming basins strangely resembling the craters of extinct volcanoes. The depressions occur at the crest of the monocline and their northern edges are the hogbacks formed by the steep

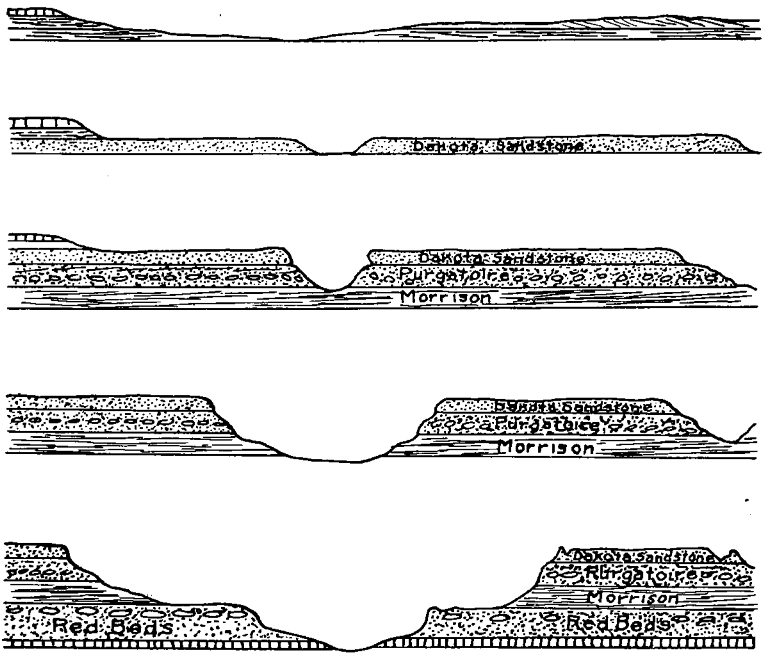

Fig. I. Sections showing stages in the development of canyons and mesas in areas of horizontal strata.

northward dipping beds of the fold. There are three of these depressions; the first and deepest is formed at the junction of the Purgatoire River and Chaquaqua Creek, and is excavated to a depth of 350 feet in the Red Beds. Three series of almost vertical cliffs hedge it about, the lowest that of the Red Beds followed by a sloping terrace of Morrison, then the cliff formed by the Purgatoire sandstone, and at the rim the Dakota cliff about a thousand feet above the River. The second depression is in Smith Canon and the third on Muddy Creek. In these the Red Beds are not cut deep enough to form a cliff.

Throughout the area the canyons are very much alike, and their form is that common to a region where deep erosion of horizontal beds of unequally hard material has taken place. In the earliest stages of the present topography the rivers flowed in broad, shallow valleys across a gently rolling surface of Cretaceous shales and limestones. Gradually the major streams cut vertically walled troughs into the hard Dakota sandstone, and as these were deepened and widened a second escarpment appeared in the somewhat more readily eroded Purgatoire sandstone. When the streams had cut as deep as the Morrison the canyons became considerably wider, but the sides were still steep for the soft shales of the Morrison were eroded away rapidly enough to keep pace with the retreat of the younger formations from the stream. The underlying Red Beds were much harder, however, and in them the vertical walled box canon appears again and is crowned by a terrace gently sloping down from the higher escarpments. The following series of sketches illustrates the evolution of this topography.

The main streams are (from west to east) Timpas Creek, the Purgatoire River and Rule Creek, with their respective tributaries, and to the south, Longs Canon and Carrizo Creek drain into the Cimarron River. With the exception of the Purgatoire River all these streams are intermittent, rarely containing running water more than a few months in the year, and yet they are very treacherous. With the coming of one of the summer thunder showers the dry arroyas may fill with turbulent streams of muddy water in a very few minutes. The writer saw a dry bed of Red Rock Canyon fill to a depth of eleven feet in twenty-five minutes.

The Purgatoire flows a rather small volume of water continuously, but its bed becomes almost dry in September and October. One of its tributaries, Chaquaqua Creek, also flows a little water the year round. Nevertheless, the remaining territory is not altogether waterless, and the traveler will usually find springs of good water to supply his needs. A very notable one, known as Alkali Spring, flows out of some conglomeratic beds on the Johnny Branch. The water is slightly alkaline, but has a volume of about 50 gallons per minute. A great many of the small springs are alkaline, and this is particularly true of those that issue from the base of the Morrison. Gypsum impregnates others. The spring waters found at the base of the Purgatoire are without exception of excellent quality.

Part of the drainage system is inherited from an older period, a fact which has caused the intrenchment of meanders, particularly along Chaquaqua Creek and the Purgatoire River.

STRATIGRAPHY

FORMATIONS OLDER THAN THE "RED BEDS"

In the area which this report covers there are no direct data concerning horizons older than the "Red Beds." Ninety miles to the west, however, Lee[16] described a section from below the "Red Beds" in the Culebra Range containing four hundred feet of shales, limestones and sandstones succeeded by a red grit and finally by granite. These contained many fossils of Pennsylvania age. Nothing older was recognized. Farther north, where more detailed work has been done, the following section has been described by Darton.[5]

Age	Formation	Principal character	Thickness (Feet)
Mississippian	Millsap Limestone	Grey and purplish limestone	20-500
Ordovician	Fremont Limestone	Grey to pinkish dolomite uneven grain	100
	Harding Sandstone	Fine, even grained, grey to pink sandstone, some shale	100
	Manitou Limestone	Reddish dolomite	100-270
Upper Cambrian	Sawatch Sandstone	Reddish sandstone	40-100
Pre-Cambrian	Gneiss and Schist		

These sections are taken across the upturned edges of the beds forming the Rocky Mountain monocline. It is probable that the formations underlying the "Red Beds" of Purgatoire Canyon do not differ vitally from Darton's section. For this reason a short description of each unit is given below.

PRE-CAMBRIAN: This is a series of highly metamorphosed sedimentary and igneous rocks.

SAWATCH SANDSTONE: This formation is upper Cambrian, and consists of two members: the lower, 11 feet of rather coarse, white sandstone with occasional quartz pebbles; the upper, 30 feet of coarse, reddish-brown, calcareous sandstone with green patches of glauconite and occasionally a stratum of limestone.

MANITOU LIMESTONE: Finlay[8] gives the following description:

"The base of the formation consists of 6 feet of clear red limestone overlain by about 50 feet of thin-bedded purplish and reddish-gray limestone, followed in turn by 100 feet of clear-gray massive limestone, in part granular. The top of the formation consists of nearly 100 feet of thick bedded dove-colored limestone, rich in cherty layers half an inch thick. The upper half of the formations contains massive beds of dense bluish limestone, and at the top is a zone of coarsely brecciated rock much stained by limonite and hematite. The highest beds exposed are a foot or more thick, and are drab or in places clear red. The limestone of the formation is at most places magnesian."

Fossils are relatively abundant. The age is lower Ordovician, (Beekmantown).

THE HARDING SANDSTONE: Succeeding the Manitou limestone is a fine-grained sugary sandstone, banded light gray and pink with occasional bands of dark red or purplish sandy shale. Fossils are abundant and show the formation to be upper Ordovician (Trenton) in age.

THE FREMONT LIMESTONE: This is a sandy bluish gray to pinkish dolomite characterized by the coral Halysites catenulatus. It is abundantly fossiliferous and is also of upper Ordovician (Trenton) age.

THE MILLSAP LIMESTONE: The Fremont is succeeded by 200 feet of gray and purple limestone. Shale bands occasionally appear. It is abundantly fossiliferous, and of Mississippian age.

THE "RED BEDS"

The great series of formations which succeeded the Mississippian and underlies the Morrison in eastern Colorado is familiarly known as the "Red Beds." The brilliant colors of these strata, the fantastic shapes into which they weather, and the ruggedness of their outcrops make them easily the most noticeable feature of foothill geology. Despite this, their geologic relationships are but poorly understood for fossils are exceedingly scarce, and lateral variations of strata are common. For these two reasons correlations are fraught with almost insurmountable difficulties. Yet it is very im-

(Note: The term "Red Beds" as used in this paper does not imply any stratigraphic unit, but the series of red strata which vary in age from Pennsylvanian to Triassic. The term is convenient in that it indicates a series of beds which are not likely to carry petroleum in paying quantities).

portant that an approximate estimate of the thickness of these beds be reached, because upon their thickness depends, in no small measure, the possibility of reaching any oil that may exist in southeastern Colorado. For this reason the writer will present rather more stratigraphic data than are usual in a paper of this type.

The "Red Beds" exposed in this area may be divided into two parts: the lower, a series of brick red sandy shales and crinkled purplish limy sandstones; and the upper, a massive, cross-bedded, oolitic, maroon sandstone succeeded by gypsum which may possibly belong to the overlying Morrison. A section taken at the junction of Chaquaqua Creek and the Purgatoire is as follows:

Morrison formation.

Transitional zone.

Gypsum, gypsiferous clays, and gray sandy shale—63 feet.

"Red Beds."

Upper division—Red Canyon member.

Maroon sandstone, oolitic in structure—upper part much cross-bedded and in some parts leached of its coloring matter. Possibly of aeolian origin, 240 feet.

Lower division—Chaquaqua member.

Maroon shales	2 feet
Massive dark red sandstone	21 feet
Maroon shale	5 feet
Brick red sandy shale	36 feet
Purplish limy sandstone (crinkled)	18 feet
Brick red sandstone	30 feet
Purplish limy sandstone	10 feet
	122 feet

The writer tentatively correlates these two divisions with the Lykins of the Colorado Springs and Denver areas, giving to the upper division the name Red Canon member and to the lower, the name Chaquaqua member.

The maximum thickness of the Chaquaqua shales exposed is 122 feet. At their base is a purplish limy sandstone, mottled and crinkled in a mannner much like that of the crinkled sandstone of northern Colorado. Occasionally this sandstone has been brecciated, and it is commonly ripple marked. It is succeeded by a brick red sandstone, very thin-bedded, the coloring of which is due to ferric oxide that has been deposited about fine grains of pure quartz. In some places this coloring matter has been leached and peculiar circular white spots appear on otherwise red slabs of sandstone. These spots are due to a particle of organic matter from which reducing solutions were derived and spread out into the surrounding sandstone changing the red ferric oxide to the almost colorless ferrous oxide. Purplish spots due to the presence of a little manganic oxide are also found, while flakes of sericite appear on the bedding planes.

Following this is a second band of crinkled sandstone similar to the lower one but thicker. As it resists weathering to a greater extent than the overlying shale, it forms a low terrace along the creeks. Above this comes a second band of brick red sandy shale. It is similar to the lower band but the coloring matter is frequently leached along the joint planes. It is succeeded by a ripple-marked maroon shale about 2 feet thick, containing numerous slip planes due to gliding under the weight of overlying sandstones. Mica is common in this shale and appears on the bedding planes. The next stratum is a massive, ripple-marked, micaceous, maroon sandstone, 21 feet thick, composed of different colored laminae. Unidentifiable plant fragments were found in it and shattered pieces of bone. The wind erosion of this stratum sometimes results in fluted and honey-combed surface of remarkable intricacy. An efflorescence of magnesium sulphate and an alum collects at the base of this bed. The Chaquaqua member ends with two feet of deep maroon shale similar to the lower band.

Above this shale is 240 feet of massive maroon oolitic sandstone. Jointing and bedding planes appear at the top and at the base of this member, but the middle hundred and fifty feet often shows no sign of a crevice or a dividing line of any kind. Sometimes, however, it is cross bedded at high angles, some of them 60 degrees. Ripple marked surfaces occur, and usually at an angle with the true bedding. The oolitic appearance of the sandstone is due to the aggregation of the sand grains into little pellets with a silica cement. The pellets are bound together by a cement of ferric oxide. As a rule the oxide does not penetrate into the grains or into the siliceous cement of the ,pellets. The topmost five feet of this member has been leached of its coloring matter by acid solutions derived from the overlying gypsum. These solutions have followed the joint cracks and have so mottled the sandstone that it has the appearance of a conglomerate.

The strata succeeding this sandstone are very variable. It is succeeded by a mottled limestone (Purgatoire River), a slate-gray sandstone(Chaquaqua Creek), gypsum (many occurrences) and by an interformational conglomerate (Longs Canyon). The overlying beds are almost always gypsiferous, and the gypsum commonly associated with chalcedony, pink chert, barite and celestite (rare). The gypsum occurs in ellipsoids and is of granular texture. Seams of fibrous gypsum are also common and masses resembling septarian nodules are found in a grey joint clay. The total thickness of this gypsiferous zone does not exceed 125 feet and is usually much less, averaging about 50 feet. Its outcrop is very rough where the overlying Morrison has slipped down on account of the solution of the gypsum. Whether these strata should be assigned to the underlying Lykins, or to the overlying Morrison, has been a matter of doubt. From their association with sediments very similar to the Morrison and strikingly unlike the underlying "Red Beds," and from the fact that they quite frequently contain numbers of bone fragments, it appears safe to regard them as Morrison. T. W. Stanton[20] in speaking of this zone says:

"Beneath the Morrison formation, or possibly forming a member of it, there are gypsiferous shales and gypsum varying greatly in thickness in different exposures, the maximum observed being 125 feet."

At another point in the same article he speaks of "the gypsum and gypsiferous shales" resting on the Exeter sandstone which is separated from the "Red Beds" by a marked unconformity.

EXETER

The Exeter sandstone appears as a thin lentil between the Morrison and the Lykins in the southern part of the area. Lee[14] in describing this formation notes that there is marked unconformity between it and the underlying Cimarron. It is described as follows:

"It is a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color. The lower strata are pink, while those above grow progessively lighter colored. It has the appearance of being composed of coarser material from the eroded Red Beds and may be a basal sandstone formed by the encroaching waters from the east or south, which cut away the Red Beds. The sandstone has a maximum thickness of seventy-five feet and extends from a point several miles west of Exeter, where it thins out, eastward to the New Mexico line where it drops beneath the canyon bottom. No fossils of any kind were found in this sandstone."

At a later date Lee[17] reports the finding of vertebrate remains of Triassic age. This sandstone is, therefore, probably the equivalent of the Dockum of North Texas described by Drake[6].

The portion of the "Red Beds" underlying the Lykins in nowhere exposed in the area and no drill holes have pierced it, and so we have no direct data on the problem of its thickness. Indirectly we may arrive at a conclusion by comparing data drawn from places surrounding the area where more or less complete sections are known. There are no exposures of the "Red Beds" to the north or east. To the southeast we have a well section at Gate, Beaver County, Oklahoma. (Aurin[1]). This well passed through 1,700 feet of red strata and then went into limestone with shales and salt which probably are equivalent to the lower Permian, Big Blue, of Prosser[20]. This well did not start at the top of the "Red Beds" and we are justified in the belief that at least three hundred feet of "Red Beds" have been eroded away at the well head. This maks the series at least 2,000 feet thick.

Red sandstone is the chief component of this section but salt shale and sandy limestone also appear.

Along the Cimarron River just south of the Colorado border the thickness of the "Red Beds" is probably at least two thousand feet, although only 900 feet is exposed, for there is a steady thickening of the Red Beds west and northward in Oklahoma.

To the westward along the foothills the first section in which the Red Beds are well exposed is in the Culebra Range where several thousand feet of red arkoses and grits occur between the Morrison and a series of sandstones, limestones and shales containing Pennsylvanian fossils.[16]

On the southern end of the Greenhorn Mountains R. C. Hills[12] described the "Red Beds" as consisting of two hundred feet of conglomerates and sandstones. This small thickness is due to overlap. In the Pueblo Folio Gilbert describes the "Red Beds" as over 2100 feet thick and mainly composed of arkoses, sandstones and clays, but adds "The top of the series is not there seen, but the missing beds are probably thin."

Still further to the north Finlay[8] has described the "Red Beds" as consisting of three members: the upper, the Lykins, 180 feet thick; the middle, the Lyons, 800-850 feet thick; and the lower, the Fountain, 4500 feet thick. These sections are compared graphically on the accompanying sheet.

The first non-red formation below the Red Beds outcropping along the Rocky Mountains foothills is the Millsap of Mississippian age. In western Kansas it is the Big Blue of lower Permain age. The youngest red formation along the foothills is the Lykins of Permo-Carboniferous age, the youngest in the Cimarron Valley is the Exeter which is Triassic and the equivalent of the Dockum of North Texas. This suggests that the conditions which governed the deposition of the "Red Beds" migrated eastward. See Figure.

We can sum up the facts as follows:

1. Wherever a complete section of the "Red Beds" is exposed in the Texas Pan Handle, its total thickness is over two thousand feet.
2. Complete sections along the eastern foothills in southern Colorado give thicknesses of 4000 feet and more.
3. The material deposited becomes coarser and more arkose-like as the formations thicken, but the period of deposition is usually closed by the deposition of fine material (Lykins).
4. Trassic Red Beds (the Exeter) extend as far north as the Cimarron Valley and add to the thickness of the section. These beds are separated from the Permian by an unconformity.
5. While the lower limit of red color is Middle Permian in Kansas it is lower Pennsylvanian in Colorado.
6. While the color line moves upward as one passes eastward there is little or no diminution in the thickness because of the overlap of upper Permian and Triassic "Red Beds" on the older beds.

It appears very probable that the section of the "Red Beds" along the Purgatoire River will be at least 2,500 feet thick.

The age of the "Red Beds" exposed on Chaquaqua Creek and the Purgatoire River is given as Permian by Darton and his conclusion is sustained by the work of Butters[2] on the Lykins of the northern foothills and by the presence of a belodont bone. The presence of the Exeter shows that there is an unconformity of considerable magnitude between the Lykins and the Morrison representing a long period of time and perhaps considerable erosion.

Life seems to have been at a minimum during this period.

THE MORRISON

The series of shales, sandstones and limestones lying directly above the Lykins and below the massive sandtones and conglomerates of the Purgatoire is known as the Morrison. It is extremely variable in character, but is characterized by the presence of dinosaur bones and of brilliantly colored fragments of chert.

The following sections are representative:

SECTION AT RED ROCKS CANYON WILLIS T. LEE.[13]

DAKOTA SANDSTONE

(Purgatoire)

25 ft. Brick-red arenaceous shale, containing bands of hard, fine-grained sandstone.
3-5 ft. Reddish limestone having a conchoidal fracture and very brittle.

30 ft. Soft dark clay shale.
11 ft. Brown clay shale.
6 inches Argillaceous limestone.
7 ft. Brown shale.
1 ft. Concretionary limestone.
7 ft. Variegated clay shale; joint structure.
3 ft. Fine yellow paper shale.
6 inches Argillaceous limestone finely laminated.
18 inches Fine shale.
1 ft. White limestone.
15 ft. Variegated clay shale.
8 inches Argillaceous limestone.
4 ft. Yellow shale.
1 ft. Sandstone containing agate either in concretionary masses half an inch or more in diameter or disseminated generally throughout the mass.
8 ft. Sandstone easily crumbling made up of thin layers.
2 ft. Massive sandstone, poorly indurated.
2 ft. Fine paper shale.
1 ft. Massive sandstone, poorly indurated.
Red Beds.

CHAQUAQUA CREEK. DUCE AND MORLEY.

PUGATOIRE SANDSTONE

1 ft. Green shale.
20 ft. Brown sugary sandstone with occasional chert pebbles up to an inch in diameter.
14 ft. Alternating layers purplish shale and brown argillaceous sandstone containing barite.
9 ft. Brown sandstone—pisolitic.
3 ft. Shale variegated.
4 ft. Jointed limestone containing angular fragments of quartz not exceeding 1-8 inch in length.
21½ ft. Massive brown sandstone containing cavities resembling those left by fossil wood.
5 ft. Joint clay.
22 ft. Alternating grey clays and sandstone containing nodular masses of gypsum.
20 ft. Gypsum with thin grey sandstone selvages.
1 ft. Greenish shale.
2 ft. Sandstone with chalcedony containing pink and green chert.
4 ft. Green shale with gypsum veinlets.
20 ft. Grey sugary sandstone with gypsum nodules and veinlets of fibrous gypsum.
17 ft. White sandy gypsum.
6 ft. Cream colored cherty clay.
"Red Beds."

SMITH CANYON JUST ABOVE JUNCTION WITH PURGATOIRE RIVER

DUCE AND WILLSON

PURGATOIRE SANDSTONE

Purgatoire sandstone.
3½ ft. Brown sandstone with contorted layers. Chert pebbles and occasional particles of bone are present.
62 ft. Green and chocolate shales.
20 ft. Hard, much jointed brown sandstone.
Gypsum nodules in clay.
Canyon bottom.

JOHNNY BRANCH. DUCE AND WILLSON

This section is covered to a great extent.

PURGATOIRE SANDSTONE

24 ft. Brown concretionary sandstone almost pisolitic. Some large ellipsoidal concretions with a great diameter of 3 feet in some cases. Black dendrites are common and the band contains small crystals of pyrite.
2 ft. White saccharoidal sandstone not well indurated.
97 ft. Olive green to chocolate shale with bands of joint clay and limestone. Partially covered.
90 ft. Gypsum, sandy shales, green and chocolate shales traversed by gypsum seams and followed by friable sandstones, shales and joint clay. Partially covered.
"Red Beds."

LONGS CANYON. DUCE AND WILLSON

PURGATOIRE SANDSTONE

Morrison.
45 ft. Clays and shales partially concealed by talus.
1½ ft. Chocolate sandstone; poorly indurated.
14 ft. Greenish argillites.
2 ft. Brown sugary sandstone.
58 ft. Greenish argillites and Greenish to violet shales.
6 ft. Violet shales containing nodules and seams of chalcedony with fragments of dinosaur bones.
6 ft. Sandstone blocky and almost a quartzite.
36 ft. Greenish grey shales with joint clay bands.
43 ft. French grey shales with chalcedony and agate band about half way up.
60 ft. Chocolate shales alternating with thin sandstones.
30½ ft. French grey sandstone with pink gypsum nodules and selenite seams followed by chocolate shales.
Exeter (?)
88½ ft. Friable salmon pink sandstone.
48 ft. Dark red twin cross bedded sandstone grading imperceptibly into maroon sandy shale with white or grey streaks following the bedding planes.
1 ft. Limestone and clay.
2 ft. Coarse conglomerate with pebbles derived from underlying beds.
"Red Beds."

Even a cursory examination of these sections will show that this formation is an extremely variable one. The following general facts are noteworthy, however. First, the colors of its constituent shales are usually bright, greens and chocolates predominating; second, the sandstones that occur are in general but poorly indurated; third, the limestones, while thin, are the most resistant members of the formation; fourth, gypsum is almost always present at the base of the formation; fifth, chalcedony nodules are always found just above the gypsum beds; sixth, dinosaur remains are usually present.

The chalcedony nodules appear to have been deposited on the lake or stream floors in which the Morrison was laid down. The strata about them are not deformed in any way, and pink and green chert fragments are mixed intimately in the body of the chalcedony. Furthermore the nodules are but slightly or not at all abraded and therefore could not have been carried any great distance. The large area over which they are scattered and the thinness of the zone in which they are found lead to the same conclusion.

The thickness of the Morrison does not exceed 270 feet and drops occasionally as low as 150 feet. The determination of its exact thickness is rather difficult because the solution of the gypsum at the base has caused many land slips that produce an apparent thinning or thickening of the series.

The topographic expression of the Morrison is typically a bench which exhibits either bad land topography or the hummocky surface characteristic of land slips.

The age of the Morrison has long been a matter of dispute. By Lee, Darton, Berry, Williston and others it has been considered of lower Cretaceous age, while other authorities regard it as late Jurassic. The evidence in favor of the Cretaceous age seems to be the better at present.

THE PURGATOIRE

The Marine beds directly overlying the Morrison are known as the Purgatoire formation. Typically they consist of a lower massive sandstone succeeded by a series of shales and flaggy sandstones above, containing abundant marine fossils.

The following sections are typical:

MOUTH OF MINNIE CANYON. DUCE

DAKOTA MASSIVE SANDSTONE

25 ft. Grey Purgatoire clay and blocky quartzite, sand lenses with abundant fossils. (See list).
40 ft. Brown sugary sandstone.
110 ft. Massive, sugary brown sandstone much cross bedded and streaked with purple.
Morrison.

SMITH CANYON. DUCE AND WILLSON

DAKOTA

Purgatoire

31 ft. Thin bedded quartzitic sandstone and sandy grey shales.
32 ft. Ochreous brown sandstone with worm holes, fossil wood, etc. Limonite nodules are plentiful.
1 ft. Black shale.
90 ft. Cross bedded white sandstone.
Morrison.

JOHNNY BRANCH. DUCE AND WILLSON

8½ ft. Somewhat sandy black shales, with quartzitic sandstone bands and fossils.
23 ft. Orchreous sandstone with wood fragments and worm borings (?)
85 ft. White saccharoidal sandstone with ochreous bands and concretions.
Morrison.

LONGS CANYON. DUCE AND WILLSON

Dakota.
15 ft. Grey shale and fire clay with quartzite bands. Abundant preserved fossils.
30 ft. Ochreous sandstone with abundant poorly preserved gryphaes.?
95 ft. White sugary sandstone with some concretionary zones.
Morrison.

The three divisions—a shale, a yellow sandstone, and white sandstone—are present everywhere. The shale is usually very sandy and contains numerous imperfect fossils, and very hard quartzitic layers, which are seldom more than 4 inches thick. The surfaces of these bands are often marked by worm tracks (?), mud cracks, and rain prints, and their quartzitic character is very pronounced. The fracture is conchoidal and the rock gives a metallic ring when struck by the hammer. This zone is from 7 to 30 feet thick. Directly below it is found an ochreous sandstone. This is evenly bedded, but little indurated and is usually pierced by circular holes which have been regarded as worm borings. Ordinarily this band is not fossiliferous but at Longs Canyon and in the Two Buttes area it contains abundant Gryphaea shells. It occasionally forms a bench on the canyon wall but where the streams have uncovered the underlying sandstone band it is usually merged into a gradual talus slope underlying the Dakota.

Between this band and the underlying band, dark shales sometimes appear, and Stose[21] has noted them in the adjoining quadrangle. They are absent from the upper Purgatoire Canyon. They are fossiliferous.

The lowermost band is a loose textured white sandstone that weathers into grotesque forms. At the top it is quite hard because of the deposition of limonite between the sand grains. In the middle of this zone there is a conglomeratic band with pebbles of quartz and chert varying from 5-10 to 2 inches in diameter. The conglomeratic layers are of a faint purplish tone. Between this sandstone and the underlying Morrison there is no trace of unconformity. No fossils were found. The band may reach a thickness of 120 feet but is usually about eighty feet thick.

The Purgatoire as a whole seems to thin eastward. To the west in the Apishapa Canyon, Stose (previous citation) found it to be between 210 and 220 feet thick. On the the Purgatoire it was not over 180 feet thick, at Smith Canyon 10 miles east it is not over 160 feet thick and on the Johnny branch 5 miles farther east it is not over 120 feet thick, a decrease of 100 feet in 25 miles.

The fossil forms listed by Stanton[20] as present in the Purgatoire formation are as follows:

Inoceramus comancheanus Cragin.
Triagonia emoryi Conrad?
Cardium kansasense Meek.
Cyprimeria sp.
Pholadomya sancti-sabae Roemer?
Protocardia texana Conrad.
Leptosolen conradi Meek.
Tapes sp.

The writer has also found undeterminable gryphaeas in the same area. This fauna is of Comanche age.

THE DAKOTA

The blocky quartzitic, deep brown sandstones overlying the Purgatoire are known as the Dakota sandstone. The name once covered all the strata underlying the Benton and overlying the Morrison. It was found, however, that the white sandstones of the Purgatoire contained a very different assemblage of fossils from that of the upper brown sandstones which contained abundant fossil leaves, so the name Dakota has been restricted to the upper brown sandstone member of the group.

Typically the Dakota is a hard quartzitic sandstone, breaking into angular blocks of great size, coated on weathered surfaces with the film of deep brown iron oxide known as "desert varnish".

A typical section is as follows:

Benton shales.
Transitional zone of thin sandstones and shale.
10 ft. Thin-bedded, cross-bedded sandstones weathering into fantastic forms.
30 ft. Thick-bedded sandstone coated with "desert varnish."
1½ ft. Shale and shaly sandstone.
40 ft. Thick-bedded sandstone coated with "desert varnish."
Purgatoire.

This is a general section. The Dakota seems to thicken considerably to the south, but no measurements were taken.

The lower band is the one that rims almost all the deeper canyons. It is a fine, even-grained sandstone in which there has been considerable recrystallization of the sand grains. The unweathered rock is white to light grey and on bedding planes has a frosted appearance. There is a very large joint pattern that divides the whole stratum into large rectangular blocks and gives to its cliff faces a serrated edge. Weathered surfaces are almost always covered by a thick coat of "desert varnish." Below this bed and in the reentrant formed by the upper Pugatoire shales alum is found in many places. In one place on the Johnny branch there was a deposit containing several tons of impure kalinite. (See section on economic geololgy.)

The shaly band succeeding this is never over three feet thick. It is a coal black sandy shale that weathers to light blue, and usually forms a reentrant on the Dakota cliff face.

The upper sandstone is similar to the lower in composition but it is much more thinly bedded and usually cross bedded. It contains abundant casts of wood, and charcoal, and imperfect fossil leaves may be found on the bedding planes. The upper portion of this stratum is usually worn back from the cliff face. Where it does appear it is weathered into fantastic forms. Pyrite is common throughout the band and is secondary for it exhibits well marked crystal faces of which striated cubes are the most common.

The Dakota as a rule presents an almost vertical cliff face to the canyon and forms the uppermost rim rock. Its blocky structure and the serrated appearance clearly mark off this cliff from the lower Purgatoire cliff which is rounded and slanting.

The age of the Dakota is upper Cretaceous, probably the lowest horizon, as it contains a well developed flora of the broad leaved type. Its total thickness does not exceed 100 feet and is usually about 90 feet.

The formations younger than the Dakota and older than the Tertiary were not examined by the writer. The following short descriptions are drawn from Stose.[21]

THE BENTON GROUP

"This consists of two shale series separated by a thin limestone named the Greenhorn Limestone. The lower shale is named the Graneros Shale, the upper Carlile Shale."

THE GRANEROS SHALE

"Next above the Dakota is a body of clay shale 200 to 210 feet thick. Its color is bluish gray, ranging from medium to dark, the middle part being darker than the upper and lower. The name Graneros shale for this formation has been in use over 15 years, since Gilbert recognized the threefold division of the Benton and named the lower formation from Graneros Creek, which traverses the formation 25 miles southwest of Pueblo."

GREENHORN LIMESTONE

"The Graneros and Carlile shales are separated by about 30 feet of interbedded thin limestone and shale named the Greenhorn limestone. This name was introduced over 15 years ago for the thin limestone in the midst of the Benton group, and was derived from Greenhorn Creek, a branch of St. Charles River in the Pueblo quadrangle, where good exposures of the limestone are exhibited. The limestone beds are from 3 to 12 inches thick and the intervening shale beds from 10 to 20 inches. Although the shale predominates the limestone resists weathering so strongly that its fragments cover the surface of the outcrop, concealing the shale and giving the impression of a thick sheet of limestone. The limestone is bluish gray, weathering to lighter shades, and is of fine grain. Most of the layers are divided by vertical cracks into rectangular blocks or smooth plates. The shale is bluish gray, darker than the limestone, and is calcareous. There are also some interbedded thin layers of white shale. Both the shale and limestone contain abundant fossil shells, especially the concentrically marked oval Inoceramus labiatus. At the top are 5 to 6 feet of very fossiliferous arenaceous limestone interbedded with shale, forming a transition into the overlying Carlile shale."

CARLISLE SHALE

"The Carlile shale, the uppermost formation of the Benton group, was named by Gilbert after Carlile Spring, on Arkansas River 20 miles above Pueblo, which is located on the shale in the upper part of the Benton. It is from 200 to 232 feet thick and consists chiefly of argillaceous shale. In the lower 50 feet it is medium gray; then comes 25 feet of dark-gray beds, including bands that are nearly black, above which the color is again medium gray. About 60 to 70 feet below the top of the formation the shale is sandy and contains lenses of friable sandstone. In most places yellow sandstone 10 to 20 feet thick occurs at the top. The sandstone is calcareous in fresh exposure, and is generally very fossiliferous in the upper part, its fragments being marked by casts of a large, strongly ribbed coiled ammonite Prionocyclus wyomingensis.

"The sandy shale contains many calcareous concretions, more or less globular in form, which range from a few inches to 4 or 5 feet in diameter. The outer layers have what is called cone-in-cone structure, seeming to be made up of a system of interlocking cones with apices all pointing toward the middle of the concretion. The inner parts are of even, fine texture and gray color. The larger concretions are traversed by ramifying cracks, which are partly or wholly filled by crystalline calcite, and are called septaria. The first-formed calcite, adjacent to the walls of the cracks, is usually of a rich dark brownish color, but the last formed is white or transparent, and in some specimens large flat rhombohedrons or "nailhead" crystals of this calcite stand in relief on the botryoidal surface of the wine-colored interior. There is also present with the calcite some translucent to chalk-white crystalline barite. Although the cleaved fragments of the barite closely resemble the calcite in color and form, it may be readily detected by its greater weight."

TERTIARY

NUSSBAUM FORMATION

The unconsolidated sands and conglomerates that overlie the Cretaceous beds unconformably in this region have been grouped by Gilbert as the Nussbaum formation. They are composed of clayey sands, coarse conglomerates and an occasional limy stratum. The conglomerates are composed of rounded cobbles of igneous rock, while the sandstones are very yellow and crumble at the touch. Locally they are cemented by calcium carbonate, whence comes the name "mortar beds." About fifty feet of this formation caps the Dakota sandstone in the central east portion of the area. The age of this series is suppoedly Pliocene.

QUATERNARY

GRAVELS

Gravels apparently younger than the Pliocene occur in the basin of Johnny Branch at Alkali Spring. These are masses of partially consolidated gravel filling the stream bottom. They are composed mostly of pebbles originally derived from the pre-Cambrian rocks of the mountains. From them issues the largest spring in the Rule Creek basin.

Similar gravels are known on West Carrizo Creek where they are capped by one of the younger lava flows. (See section on Geologic History.)

RECENT

Along the floors of the larger canyons there is usually a veneer of alluvium sometimes over twenty feet in thickness. It strongly resembles loess in its tendency to stand in high straight walls, but contains boulders of considerable size. In the main, however, it is fine grained. In some places, (along Chaquaqua canyon for instance), mollusc shells are rather abundant. Professor Junius Henderson, of the University of Colorado, has identified the following species.

Fresh Water and Land Molluscs from the Alluvium of Chaquaqua Creek, 5 miles from junction with the Purgatoire River.

Sphaerium sp.	Vallonia gracilicosta, Reinh.
Physa sp.	Pupilla Glandia, Morse
Lymnaea sp.	Bifidaria armifera (Say).
Succurea avara (Say).	Planorbis sp.

This alluvium forms a rich soil, but in the deeper canyons it is being rapidly eroded. The writer[7] has elsewhere attributed this erosion to the influence of cattle.

Along the Arkansas Valley there is also a wide alluvial plain which is modified by the floods of the Arkansas from year to year. On some of the higher prairies yellow loams somewhat resembling loess appear. They are a product of wind work and weathering.

IGNEOUS ROCKS

The igneous rocks of the area are all dense basalts. The great caps of the Mesa de Maya, Mount Carrizo and Volcanic Mound are members of a series of flows each about fifty feet thick which extend westward as far as Trinidad. The total thickness of the flows reaches 500 feet but they thin eastward. All the formations from the Laramie to the Dakota are overlapped by these rocks. Hills describes these basalts as follows in the Elmore Folio:

"The extrusive basalts are grayish or dark colored, occasionally reddish brown. All are at times vesicular. Notwithstanding that the rocks of the individual flows differ from one another in outward appearance, they are much alike in texture and mineral constitution. The groundmass is usually a fine-grained aggregation of minute crystals of lime-soda feldspar, augite, and magnetite, and rarely some glass. Of the porphyritic crystals (phenocrysts), olivine largely predominates over augite. Chlorite, serpentine, and biotite appear as products of the alteration of olivine and augite, and calcite is often abundant in the cavities."

The basalt is of two distinct periods, the first Eocene and the second of Pleistocene age, the latest lavas being those to the east.

In Van Bremer arroyo a wide dyke of a basic, rock follows the stream course and outcrops as a series of small mounds. A plug about 100 feet in diameter occurs just south of the station of Watervale in the Graneros shale. These are part of the Spanish Peaks dike system.

AREAL GEOLOGY

On examining a geologic map of this area the most noticeable fact is the relatively wide distribution of Dakota outcrops. The Dakota forms two-thirds of the surface exposures. It extends over a triangle which has its apex at Las Animas and its base on the Colorado-New Mexico border. Where the streams have crossed this triangle they have excavated deep canyons along whose sides are found in succession the Purgatoire, the Morrison and the Lykins. In the northern part of the area, the dip of these beds is slightly greater than the gradient of the streams, so that as we pass southward (upstream) the formations that occupy the canyon bottoms are progerssively older and older. The rather abrupt fold at the Black Hills on the Purgatoire brings up the Lykins, and this has been trenched to a depth of 400 feet so that it forms a staple shaped outcrop along the canyons of the Purgatoire and Chaquaqua Creek. This outcrop is all in the canyons and covers about fifty square miles. A similar area of about twenty square miles is found on the Johnny Branch. Surrounding these and extending along the canyon walls are narrow outcrops of Morrison. Small patches of this formation are also exposed where Two Butte and Freezeout Creeks have cut across local folds, and rather large exposures outcrop in the Muddy Creek Basin and Smith Canyon.

Passing southward the dip of the formations lessens slightly while the grade of the streams steepens, until they finally emerge from their canyons on to the Dakota surface and play out against the abrupt escarpment of the Mesa de Maya.

Here flows of basalt have protected from erosion the soft shales of the Cretaceous, and the edges of the basalt cliffs are fringed by outcrops of the Benton and Niobrara. Southward from the Mesa de Maya, the northern tributaries of the Cimarron have excavated deep gorges which expose the formations from the Dakota to the Lykins.

Along the northwestern half of the Timpas Quadrangle, along the edges of the Timpas Creek syncline, the three divisions of the Benton outcrop in long, parallel northeast to southwest strips and are followed by a wide area of Timpas limestone. This is broken at Ayer and just west of Bloom where local uplifts have brought to the surface the Graneros and the Dakota.

The high ground between Rule and the Purgatoire is also occupied by a lozenge shaped patch of Graneros.

Tertiary gravels cap the hills just south of Mount Carrizo in the southeastern part of the area and also the ridge between Patterson Creek and the Purgatoire in the northwest corner of the Timpas quadrangle.

STRUCTURAL GEOLOGY

The area covered by this report was at one time below sea upon whose floor sedimentary rocks were laid down in rather even layers. At the close of Cretaceous time these strata were uplifted from five to seven thousand feet by the forces which caused the Rocky Mountain uplift.

The structure of this uplift seems at first glance astonishingly simple, —an abruptly folded monocline of sedimentary rocks against a granite core. This comparatively simple structure has, however, been faulted and folded to an amazing extent. The folds are of the echelon type while the faults are largely strike faults. A typical section along the Rocky Mountain front would reveal a series of these folds associated with strike faults extending southeast to northwest. They are arranged en echelon and plunge to the southeast where they gradually merge into the flat lying strata of the plains. We can compare these folds to a plaited sheet of leather nailed at one edge to a sloping stick. The central stick represents the main range, the gently curving plaits the echelon folds. The most persistent of these folds is an irregular faulted and folded zone that extends southeast and east from the Beulah-Chandler fault system, at the end of the Wet Mountain salient. This zone has been called the Apishapa acticline. It extends eastward to the Purgatoire River where it intersects the Mesa de Maya dome and forms the Black Hills uplift.

The Mesa de Maya dome is a low fold of very large area and has its highest point just to the south of the Mesa de Maya where the Dakota sandstone reaches an altitude of 6000 feet. The western slope of this dome is rather abrupt for the Dakota reaches an altitude of 4000 feet at Trinidad forty miles to the west. To the north and east the slope is very much more gentle for the 4000 foot line is eighty miles to the north and about the same distance east. The southern slope has not been explored so far, but judging from the mapped outcrops in northern New Mexico it should be gentle.

LOCAL STRUCTURES

AYER FLEXURE: This is a small monoclinal fold with its axis just east of Ayer. It can best be described as an unclosed dome. The open side of this dome is to the southwest. It has no effect on the topography and on the geologic map it appears as an inlier of Greenhorn surrounded by Carlile shale.

BLACK HILLS DOME: This structure is a monocline upon which a small dome is imposed. If one goes eastward from the A., T. and S. F. R. R. siding at Bloom he passes along a somewhat gentle escarpment which grows steeper and steeper as he approaches the Purgatoire River. The dips are all northward and in places reach 15°. To the east of the Chaquaqua Creek this escarpment swings to the south and finally disappears along the western edge of Smith Canyon. The total displacement is about four hundred feet. Most of the fold is truly monoclinal, but at the junction of Chaquaqua Creek and the Purgatoire it appears as a dome, whose apex lies in the high mesa just south of the junction of two streams. The closure of this dome is small to the south for it does not exceed forty feet.

The abrupt north face of this fold is visible for a long distance down the Purgatoire River as a high cedar covered escarpment and its abruptness is accentuated by the dissection of its slope by east or west flowing streams. The picturesque "Red Rocks" country is due to the outcrop of the Lykins where the canyons of the Purgatoire and Chaquaqua cross this fold. (See also page----).

THE MUDDY CREEK MONOCLINE: This fold is very similar to the Black Hills monocline but presents a more abrupt western face. The dips are west along Smith Canyon, north across Rule Creek, and east along Hackberry Creek. The maximum dip observed was 3°. No southern dips were found. The top of this fold is exceedingly flat and covers the area known as Muddy Creek Basin. It is possible that level lines along the Johnny Branch might establish a small dip to the south, but the writer could not detect any such dip. The following sections show its nature.

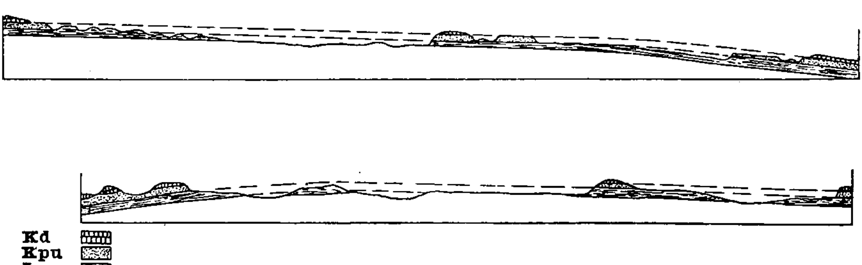

Fig. II. Upper. Left to right is a south to north section across Muddy Basin. Lower. Left to right is a west to east section across Muddy Basin. Kd, Dakota, Kpu, Purgatoire, Jm, Morrison.

Topographically this fold is expressed by a series of slightly tilted hogbacks that surround the Muddy Creek Basin on three sides. Erosion of the fold has exposed the Red Beds along the Johnny Branch.

MUSTANG CREEK DOME: This is a small dome on Two Butte Creek just below its junction with Mustang Creek. Here an inlier of Morrison is surrounded by escarpments of Purgatoire. There is a small closure. It was not examined in detail.

FREEZEOUT CREEK DOME: This dome is similar to the Mustang Creek dome but rather smaller in area. It was not examined in detail.

HISTORICAL GEOLOGY

PRE-PALEOZOIC TIME: Without doubt the great series of igneous and metamorphic rocks exposed along the axes of the Rocky Mountains underlies the sedimentary formations in eastern Colorado. These rocks as now exposed were brought to their present condition at considerable depths below the surface of the earth, and during pre-Cambrian time the area was uplifted and, in time, reduced by the agents of erosion until at the opening of the Cambrian they formed a rolling plain which covered all the southern part of the Great Plains area.

PALEOZOIC TIME: A gentle downwarping of this plain allowed the sea to invade the Rocky Mountains and sands and limy muds were deposited on the sea bottom. Gentle oscillations of the region took place until Pennsylvanian time and periods and deposition and erosion alternated so that a series of sandstones, limestones and shales was formed. As the shore line of the seas advanced, the sea flowed most readily into flow troughs such as that at Canon City, and it is in these troughs or bays that we find the older sediments best preserved. Along the main part of the mountain front they have been eroded or covered by the overlap of younger formations.

The latter part of the Paleozoic is marked by the upwarping of a mountain range in the Rocky Mountains, and the streams flowing from it poured coarse sediments into a shallow sea. The climate became arid and areas of the sea cut off from the main body deposited gypsum and salt as their waters were evaporated. As the mountains were reduced more nearly to a base level the material brought down to the sea was finer and finer grained. The most rapid deposition took place against the new mountain front and resulted first in the formation of the coarse sediments characteristic of the Fountain. The occurrence of gypsum and limestones with the arkoses and conglomerates is due to the formation of lagoons by deltas and bars. The coarser sediments did not extend far to the east, for conglomerates in the "Red Beds" are much rarer to the eastward, and in Kansas and Nebraska shales and fine grained sandstones deposited in tranquil seas represent Pennsylvanian time. The succeeding Lyons is a well washed beach sand over which the clays and clayey sandstones of the Lykins were laid down. These three formations represent strikingly three stages in the erosion of the land that contributed the sediments; First, a high upland with torrential streams that brought down large volumes of coarse debris and dumped them along the shore line, forming the

Fountain in which occur sub-angular pebbles and relatively fresh feldspar, proving a short, rapid journey to the sea. Second, a period of medium relief during which the streams remained fairly swift but weathering decomposed such minerals as the feldspars and shore currents removed the resulting fine grained material leaving pure quartz sand—the Lyons. Finally the lands were eroded almost to a peneplain, the rivers became sluggish and muds with a little sand were laid down. Towards the close of the Lykins in the Purgatoire area the sea had retreated and the wind deposited two hundred feet of crossbedded oolitic sands while red colored marine sediments were being deposited in Kansas and Oklahoma.

MESOZOIC: The opening of the Mesozoic was marked by wide spread emergence of land from the Permian sea. This was due probably to progressive in-filling of the sea taking place in very much the same way as city water fronts are filled in by the loose material washed from further back on the land by hydraulic giants. This filling did not take place so rapidly to the southward and the Exeter and Dockum formations of Triassic age are evidences of the slow retreat of the sea in that direction. It seems quite probable that this is the reason for the absence of any trace of Triassic sediments north of the New Mexico line and west of Two Buttes. The climate remained arid until the opening of the Morrison, which appears to represent not a change produced by orographic movements but a climatic change which transformed a parched, wind swept plain dotted with playa lakes into a forested swampy area. Gypsum was deposited at the opening of the Morrison but this seems to have been derived from the Red Beds and its intermingling with clays and sands and its occurrence in fissures suggest that it may have resulted from spring waters derived from the underlying formations. Succeeding the gypsiferous layers, sandstones, limestones and shales were deposited in thin beds. Though plant fossils are few, the presence of such animals as Brontosaurus, a herbiverous dinosaur 70 feet long, suggests abundant vegetation. Mook[18] has characterized the deposition of this formation as follows: " * * * the Morrison was deposited on a wide spread plain of low relief, and probably of low altitude. It is the result of alternating deposition and erosion, there being no place, probably, where deposition went on continuously from the time when the first beds were laid down until the uppermost beds were deposited."

At the conclusion of the Morrison the sea again invaded the area and the sands of the Purgatoire were deposited. Abundant marine life was present in the shallow seas. At the close of the Purgatoire the sea again retreated and sands of great uniformity were deposited. These contain leaves and some fragmentary fresh water shells. From the Dakota to the Laramie a sinking sea floor was slowly covered with very fine silts and limy muds to a depth of 4000 feet when with the opening of the Laramie an upward movement started. This was at first slow and the sands of the Fox Hills and Laramie were deposited in lagoons and swamps of the retreating sea. Then this movement became more abrupt and at the close of the Cretaceous the lineaments of the present Rocky Mountains had appeared.

CENOZOIC: The great upthrust at the close of the Mesozoic produced three phenomena at the opening of the Cenozoic: first, a very rapid erosion of the uplifted strata; second, a series of minor disturbances such as settling and faulting about the thrust block; and third, pronounced volcanic activity.

In the Purgatoire area the conglomerates of the Nussbaum give evidence of the vast sheet of debris brought down by the streams and deposited on the plains. This gravel also indicated a very different drainage system from that of the present day for it contains pebbles derived from the Archean rocks of the mountain areas even though it occurs along drainage systems whose source is far removed from the Archean areas of today, as for example the conglomerates on Two Butte Creek which heads to the east of the Purgatoire drainage.

The main Rocky Mountain uplift while steepening the gradient of the streams, overloaded them and as a consequence they formed an aggraded peneplain in early Tertiary time. This has been gradually removed as the mountain erosion became less and the streams were more competent to deal with the load thrown into them by their upper tributaries. The comparative youth of the canons of the Purgatoire is due to this phenomenon.

The folds described under structural geology give evidence of the settling after the Rocky Mountain uplift. Partially at least these folds may be of recent origin as the deeply intrenched meanders on Chaquaqua Creek indicate a revival of the cutting power of that stream at a comparatively recent time.

The volcanic activity is attested by the flows of the Mesa de Maya some of which appear to overly the Nussbaum. However, most of them are older than this and belong to the Spanish Peaks Group of eruptions which are of Eocene age.

ECONOMIC GEOLOGY

PETROLEUM

The growing importance of the oil industry has led to a feverish wildcatting all along the eastern front of the Rocky Mountains. Wyoming experience and Oklahoma experience have been applied unintelligently to Colorado problems and wells have been located because a certain district "looked like the Cushing field" or like "the Salt Creek dome." Conditions are very different in southeastern Colorado. Almost all the formations younger than the Dakota have been eroded from the possible oil structures, and the Pennsylvanian and pre-Pennsylvanian strata which yield oil in Oklahoma are here buried under two thousand feet of "Red Beds."

Three questions must be answered in regard to southeastern Colorado:

1st. In what formations may petroleum be found?

2nd. Do geologic structures occur which justify the belief that commercial accumulations of petroleum have been formed in these strata?

3rd. At what depth may these strata be reached on such structures?

OIL SANDS: Above the Dakota, oil has been found mainly in the Benton and the Pierre. Of these, the Benton has been much more important. The Florence oil occurs in sandy lenses and lenses of joint clays in the shale. Both the Benton and the Pierre have been eroded from this area.

Recent developments have brought the Dakota into prominence as an oil producer. In this region it is a loosely cemented sandstone with some shale. It contains abundant fossils and in many places oil seeps from it in considerable quantities as at Iron Canyon and on Mustang Creek. Everywhere it is bituminous. It is the most favorable sand above the "Red Beds" in southeastern Colorado. It is, however, very deeply eroded in the quadrangles under discussion and only under very unusual structural conditions could oil be expected, for it would have leaked away ages ago along the outcrops in the various canyons.

THE MORRISON: The extremely fine grain of the Morrison sands, the abundance of clay and its fresh water origin would not justify the expectation of any considerable amount of oil in this formation. It has also been deeply eroded, and leakage would have dissipated oil which might have been stored in it.

THE "RED BEDS:" This series of strata is notably deficient in organic matter. The arid climate which prevailed during its deposition prevented the existence of much life and favored the rapid destruction of animal and vegetable tissue. Besides this the enormously thick sandstones that occur would to some extent dissipate in their pore space whatever petroleum was formed. There is little likelihood that oil will be derived from this series.

STRATA BELOW THE "RED BEDS: The exact lower limit of the red color in this area is not known. As has been noted before the color which extends down to the Mississippian in Colorado does not extend below middle Permian in Kansas so that the time represented by the red Lykins is represented by non-red Permian oil bearing formations in Kansas. If, as may be the case, the base of the "Red Beds" is higher in this region than it is along the Front Range highly fossiliferous strata of Pennsylvanian age such as those in the Sangre de Christo Range may exist between the Millsap and the "Red Beds." If. as the writer believes, the Fountain is a littoral (shore) phase of the oil bearing Pennsylvanian strata exposed in Oklahoma this condition may be expected for the effect of arid land conditions does not extend into the sea beyond the above zone. This possibility should be held constantly in mind in the interpretation of well logs. Non-red Pennsylvanian strata would contain organic matter and are very promising as a source of petroleum.

Below these Pennsylvanian rocks the following strata are promising:

The Millsap—A cavernous limestone and sandstone, which might be a source of oil and might store oil.

The Fremont—A sandy limestone. A possible source of oil.

The Harding—A fossiliferous sandstone which is worthy of consideration.

The Manitou—A limestone, possibly petroliferous.

The Sawatch—A sandstone containing little organic material and therefore probably not petroliferous.

STRUCTURES

The structural conditions existing within these four quadrangles are in at least three cases such as would suggest the occurrence of petroleum. The most prominent and best defined of these structures lies in the junction of Chaquaqua Creek and the Purgatoire River (Black Hills monocline). This is a typical dome imposed on a very large anticline that extends into the Arkansas Valley to the north, to western Kansas on the east to New Mexico on the south, and to the Trinidad syncline on the west. The smaller fold has a very large area of strata tributary to it that are not broken by faults or folds. The most favorable place for drilling this structure is in the Canyon of the Purgatoire 4,800 yards above the junction of that stream with Chaquaqua Creek. A well drilled at this point would be but a short distance from the apex of the structure.

A second structure is that of Muddy Creek Basin. It is not a dome, but the bench formed by the rather abrupt monocline might yield oil. The most favorable place for testing this structure is on the Johnny Branch 4,000 yards below Alkali Spring.

The structures on Freezeout Creek and Mustang Creek were not examined. They are, however, closed domes and are favorable.

The structures along Timpas Creek are not attractive as there is approximately one thousand feet of sediment to pass through that has been eroded on the other structures.

DEPTH OF STRATA

The depth of the formations given below is tentative.

It is based on the distance from base of the Dakota, the larger figures are the most probable.

	Maximum thickness in feet	Minimum thickness in feet	Depth from Dakota
Dakota	----	----	--------
Purgatoire	190	123	123- 190
Morrison	270	125	248- 460
Red Beds	3500 (?)	2500 (?)	2960-3750
Millsap	500	25	2985-4250
Fremont	100	100	3085-4350
Harding	100	100	3185-4450
Manitou	270	100	3285-4720
Sawatch	100	40	3325-4820

This would make the depth to the base of the Sawatch at the Black Hills dome on the Purgatoire River between 2600 feet and 4100 and probably more nearly the latter figure. On the Muddy Creek structure it would be between 3000 and 4500 and on the Mustang and Freezeout Creek structures between 3200 and 4700. Obviously the first test should be made on the Black Hills dome. No well should be started which is not designed to go four thousand feet and no reasonable effort should be spared to reach that depth if a thorough test of these structures is desired.

DEVELOPMENTS

Wells have been started by the Mustang Oil Company on Mustang Creek and by the Red Rock Canyon Oil Company on the Purgatoire. The well on Mustang Creek penetrated the Red Beds to a depth of 1700 feet where an enormous flow of carbon dioxide and salt water caused the abandonment of the well. The well on the Purgatoire has not at the time of writing reached any great depth. It is well located and should test the Black Hills dome.

BUILDING STONE AND CLAY

The best building stone in the area is the quartzitic Dakota sandstone. This stone is very durable, dresses easily but is likely to stain badly when exposed to the weather as it contains pyrite. Other sandstones are available in the Purgatoire and the Lykins but they contain appreciable admixtures of clay and effloresce when exposed to the weather so are not as desirable as the Dakota. Mesa de Maya basalts are also available. All these stones are avilble in unlimited quantities.

The clays of this area are mainly those of the upper Cretaceous. Thin beds of fire clay occur at the base of the Dakota but are not developed in great enough quantities to justify exploitation.

GYPSUM

The gypsiferous beds of the lower Morrison contain large amounts of impure gypsum. The pure material is in such small amount, however, that it will never compete with that of Oklahoma and Kansas.

ALUM

At the base of the Dakota sandstone in the re-entrant angle above the Purgatoire accumulations of alum form from the decomposition of the pyrite in the overlying sandstone. They occur as crusts and fibrous masses. A specimen from a deposit east of the Johnny Branch upon analysis gave 6.06 per cent potassium oxide. It is probably kalinite. The amount of this material is small, but it is probable that the present high price of potash would justify the collection of this material in a small way.

WATER SUPPLY

DEEP WELLS: Along the Arkansas Valley and along Timpas Creek the Purgatoire formation has yielded water in considerable quantities. It is of excellent quality although containing iron salts. Deep wells in the "Red Beds" always encounter water but it is usually of poor quality as it contains sulphates of the alkalis and alkaline earths. Good water is found at some horizons, however, particularly at the base of the Red Rock Canyon member of the Lykins about two hundred feet from the top of that formation. Soft water springs occur at several points at this horizon and drilled wells would undoubtedly encounter water there. The supply is small, however, and would not yield enough for irrigation. There is little chance of a good supply of water being found south of the Arkansas Valley by deep boring.

SHALLOW WELLS: The favorable locations for shallow wells are as follows:

1. In the dry streams beds in canyon bottoms.
2. In the bottom of shallow gullies in the Dakota.
3. Where the Dakota is the surface formation wells driven to the fire clay band of the Purgatoire will yield water.
4. In the gravels of the Nussbaum.

All these locations will yield water sufficient for domestic use.

BIBLIOGRAPHY

1. Aurin, Fritz, Geology of the red beds of Oklahoma: Oklahoma Geol. Survey Bull. 30, pp. 25, 41, 61, 1917.
2. Butters, R. M., Permian or "Permo-Carboniferous" of the eastern foothills of the Rocky Mountains in Colorado; Colorado Geol. Survey Bull. 5, part 2, 1912.
3. Darton, N. H., Preliminary report on the geology and underground water resources of the central great plains; U. S. Geol. Survey, P. P. 32, 1905.
4. Darton, N. H., Geology and underground waters of the Arkansas valley in eastern Colorado: U. S. Geol. Survey, P. P. 52, 1906.
5. Darton, N. H., The structure of parts of the central great plains; U. S. Geol. Survey Bull. 691-A, 1918.
6. Drake, N. F., Stratigraphy of the Triassic formation in northwest Texas: Texas Geol. Survey, Third Ann. Rept., pp. 227-259, 1891.
7. Duce, Jas. T., The effect of cattle on the erosion of canyon bottoms: Science, new ser., vol. 47, pp. 450-452, 1918.
8. Finlay, G. I., Geol. Atlas of U. S., Colorado Springs fol. No. 203, U. S. Geol. Survey, 1916.
9. Gilbert, G. K. Underground waters of the Arkansas valley in eastern Colorado: U. S. Geol. Survey, Seventh Ann. Rept., pt. 2, pp. 553-601, 1896.
10. Gould, Chas. N., Geology and water resources of Oklahoma: Water-supply and irrigation paper No. 148, pp. 28-77, 1905.
11. Gould, Chas. N., Geology and water resources of the western portion of the panhandle of Texas: Water-supply and irrigation paper No. 191, pp. 12-39, 1907.
12. Hills, R. C., Geol. Atlas of U. S., Walsenburg fol. No. 68, U. S. Geol. Survey, 1900.
13. Lee, W. T., The Morrison formation of southeastern Colorado: Jour. Geology, vol. 9, pp. 343-352, 1901.
14. Lee, W. T., The Morrison shales of southern Colorado and northern New Mexico; Jour. Geology, vol. 10, pp. 36-58, 1902.
15. Lee, W. T., Canyons of southeastern Colorado: Jour. Geography, vol. 1, pp. 357-370, 1902.
16. Lee, W. T., Note on the Carboniferous of the Sangre de Christo range, Colorado: Jour. Geology, vol. 10, pp. 393-396, 1902.
17. Lee, W. T., Red Beds of the Rio Grande region in central New Mexico: Jour. Geology, vol. 15, pp. 52-58, 1907.
18. Mook, C. C., Origin and distribution of the Morrison formation: Geol. Soc. America Bull., vol. 26, pp. 315-322, 1915.
19. Prosser, Chas. S., Revised classifications of the Upper Paleozoic formations of Kansas: Jour. Geology, vol. 10, pp. 703-737, 1902.

20. Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, pp. 657-669, 1905.
21. Stose, G. W., Geol. Atlas of U. S., Apishapa fol. No. 186, U. S. Geol. Survey, 1912.

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PUBLICATIONS OF THE SURVEY.

* FIRST REPORT, 1908:	Out of print.
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BULLETIN 2, 1910:	Geology of Grayback Mining Dist., Costilla Co.
BULLETIN 3, 1912:	Geology and Ore Deposits of Alma Dist., Park Co.
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BULLETIN 5, 1912:	Part I, Geology, Rabbit Ears Region, Grand, Jackson, and Routt Counties; Part II, Permian or Permo-Carboniferous of Eastern Foothills of Rocky Mts. in Colorado.
* BULLETIN 6, 1912:	Common Minerals and Rocks, Their Occurrence and Uses.
BULLETIN 7, 1914:	Bibliography Colorado Geology and Mining Literature.
BULLETIN 8, 1915:	Clays of Eastern Colorado.
BULLETIN 9, 1915:	Bonanza District, Saguache County.
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BULLETIN 12, 1917:	Common Rocks and Minerals, Their Occurrence and Uses. 50 cents; $1.00 to non-residents.
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* BULLETIN 23, 1920:	Some Anticlines of Routt County, Inc. with 24.
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BULLETIN 26, 1921:	Preliminary Report, Underground Waters, S. E. Colorado.
BULLETIN 27, 1923:	Part I, Underground Waters of La Junta Area; Part II, Underground Waters of Parts of Crowley and Otero Counties; Part III, Geology of Parts of Las Animas, Otero and Bent Counties.
BULLETIN 28, 1923:	Oil and Water Resources, Parts of Delta and Mesa Co.
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Boulder, Colorado

GEOLOGIC MAP OF PART OF THE CATLIN QUADRANGLE AND ADJOINING AREAS

Colorado State Geological Survey
R. D. George State Geologist

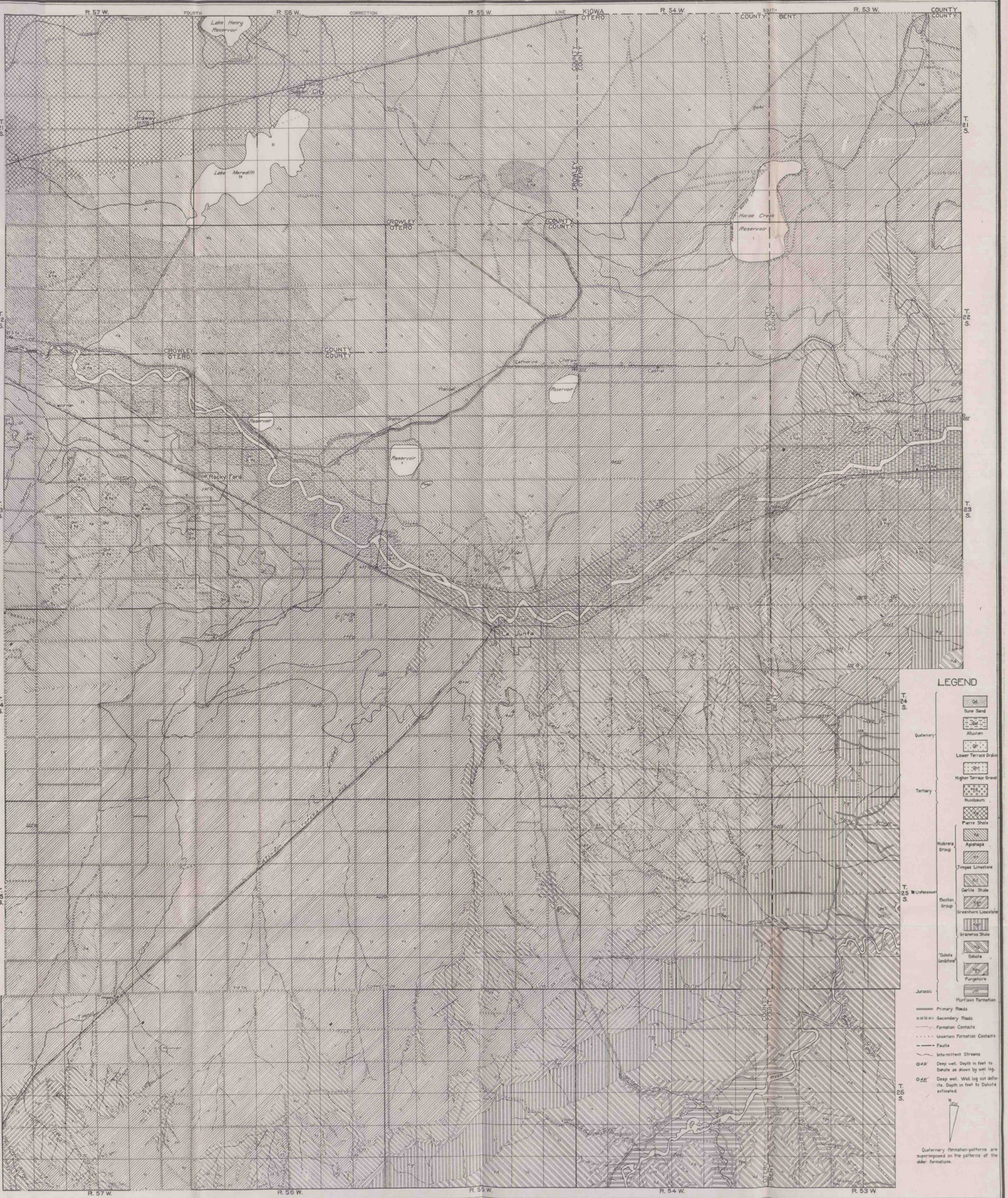
Surveyed by W. C. Toepelman assisted by W. E. Taylor, Ralph A. Koenig, C. L. Mohr, and H. A. Hoffmeister 1923

Scale of Miles

Colorado State Geological Survey
R. D. George, State Geologist.

GEOLOGIC MAP OF
THE LA JUNTA AREA
COLORADO

Bulletin 27 Plate I.

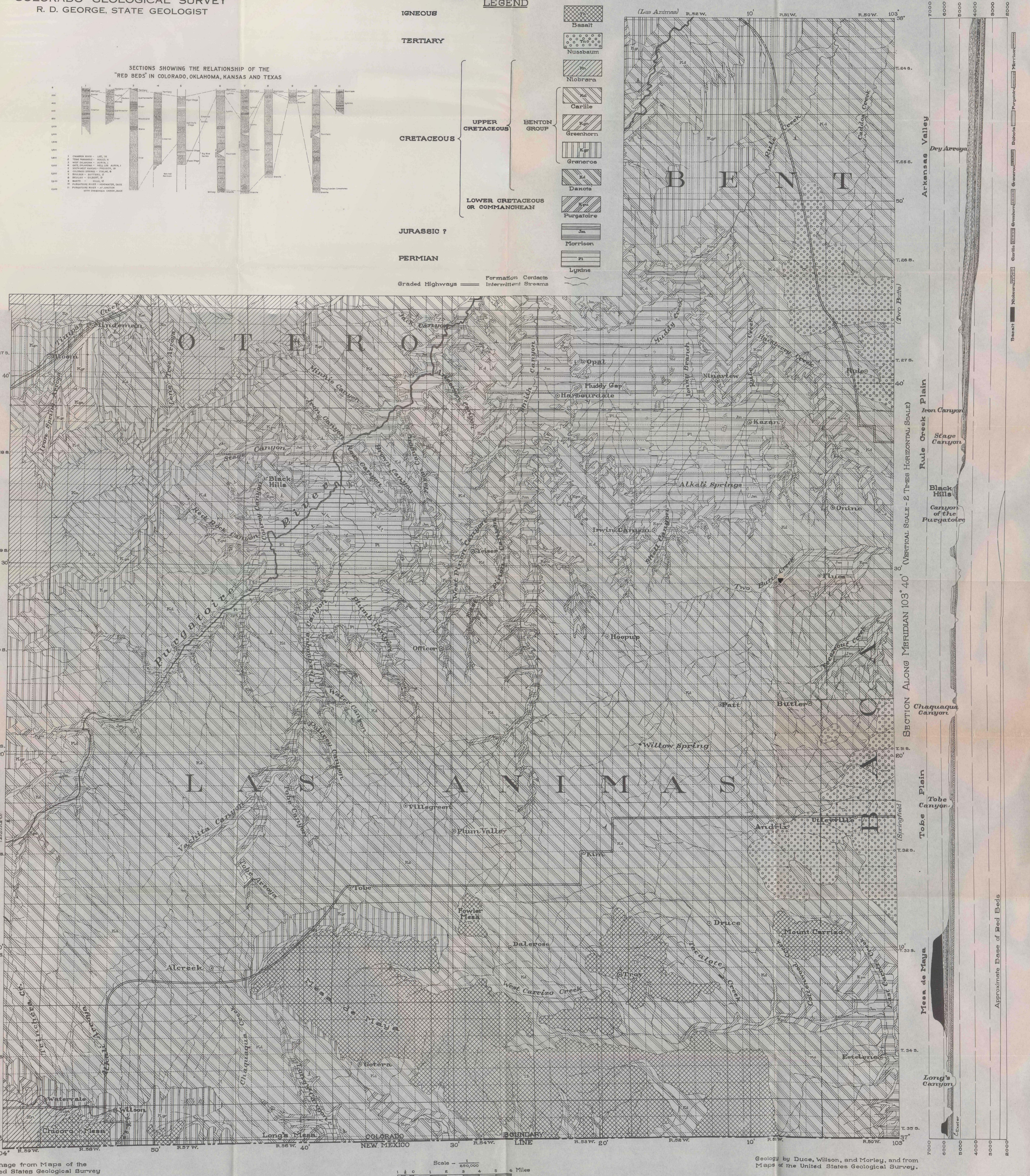


Surveyed by Horace B. Patton
and in part by Arthur J. Tieje
and John C. Meyers. 1921-1922

Scale ½ inch = 1 mile

Drafted by C. L. Mohr

COLORADO GEOLOGICAL SURVEY
R. D. GEORGE, STATE GEOLOGIST



Drainage from Maps of the United States Geological Survey

Geology by Duce, Wilson, and Morley, and from Maps of the United States Geological Survey.

GEOLOGIC MAP OF PARTS OF LAS ANIMAS, OTERO AND BENT COUNTIES