
UNIVERSITY OF WYOMING.

Agricultural College Department.

WYOMING EXPERIMENT STATION,
LARAMIE, WYOMING.

BULLETIN NO. 45.

JUNE, 1900.

A PRELIMINARY REPORT

... ON THE ...

ARTESIAN BASINS OF WYOMING.

WILBUR C. KNIGHT.

Bulletins will be sent free upon request. Address: Director Experiment Station, Laramie, Wyo.

Wyoming Agricultural Experiment Station.

UNIVERSITY OF WYOMING.

BOARD OF TRUSTEES.

Hon. OTTO GRAMM, President, Laramie.....	1903
GRACE RAYMOND HEBARD, Ph.D., Secretary, Cheyenne.....	1903
HENRY L. STEVENS, B. S., M. D., Laramie.....	1903
Hon. TIMOTHY F. BURKE, LL. B., Vice President, Cheyenne..	1901
Hon. JOHN C. DAVIS, Treasurer, Rawlins.....	1901
Hon. NATHAN S. BRISTOL, Casper.....	1901
Hon. MELVILLE C. BROWN, Laramie.....	1905
Hon. JOHN A. RINER, Cheyenne.....	1905
Hon. S. CONANT PARKS, Ph. D., Lander.....	1905
Hon. THOMAS T. TYNAN, State Supt. Public Instruction..	Ex-Officio
President ELMER E. SMILEY, B. A., D. D.,.....	Ex-Officio

AGRICULTURAL COMMITTEE OF THE BOARD OF TRUSTEES.

H. L. STEVENS, Chairman.....	Laramie
OTTO GRAMM	Laramie
M. C. BROWN	Laramie
ELMER E. SMILEY	Laramie

PRESIDENT OF THE UNIVERSITY OF WYOMING.

ELMER E. SMILEY, B. A., D. D.

STATION COUNCIL.

E. E. SMILEY, B. A., D. D.....	Director
B. C. BUFFUM, M. S., Vice Director, Agriculturist and Horticulturist	
A. NELSON, M. S., M. A.....	Botanist
E. E. SLOSSON, M. S.....	Chemist
W. C. KNIGHT, M. A.....	Geologist
C. B. RIDGAWAY, M. A.....	Physicist and Meteorologist
G. R. HEBARD, Ph. D.....	Secretary

W. H. FAIRFIELD, M. S....Wyoming University Experiment Farm
The Horticulturist in Charge,

Wyoming University Experiment Grounds

A PRELIMINARY REPORT
... ON THE ...
ARTESIAN BASINS OF WYOMING.

W. C. KNIGHT.

Introduction.

The object of this bulletin is to place before the citizens of Wyoming a preliminary treatise on the artesian basins of this state and show how this information is available for the agriculturist, stockmen and communities in general. In order to do this it has been found necessary to introduce in a very brief manner a resume of Wyoming geology. This is of necessity technical, since there are no common names to be substituted for scientific ones. I realize fully how difficult it is to popularize a subject of this kind and at the same time make it comprehensive without writing page upon page of explanation that would increase the bulletin beyond a reasonable limit. If I can present the scientific information in such a manner that the citizens of this state can understand the essential features of our artesian basins and be able to locate artesian wells, I will feel that I have fully accomplished my purpose.

Without a scientific treatise relating to the artesian basins there would be no means of discussing the basins, locating them, or referring to the water-bearing zones. Scientific terms in connection with the geology will, as a rule, be defined, so that those who are unfamiliar with the history of our earth can read intelligently. To aid the explanations many

illustrations are used and an accompanying map will aid materially in showing the distribution of the many formations.

The question of securing good artesian water in any part of Wyoming is a very important one. Already, nearly all of the available water from our streams has been appropriated, and the springs and tiny brooks are being fenced up, so that in a few more years not many natural watering places will remain open for stock of any kind. Unless wells are drilled large tracts of land in our state, such as the Red desert, the desert north of the Rattlesnake mountains and country north of Casper will remain as they are today—winter sheep ranges—winter ranges because the flockmaster depends on snow to water his herd. If wells are to be drilled the artesian well is the most desirable. Unless the supply of water can be greatly increased large tracts of valuable land must remain as grazing land only—of little value to the owner since it produces so little, and an obstacle to the state because it cannot be taxed for hay or agricultural land in place of grazing. The Powder River country, which is as a rule low and fertile land, has not sufficient water to irrigate 10 per cent of the vast area. On the south side of the Ferris and Seminoe mountains agriculture is an impossibility under existing conditions, since there are no streams of any consequence along these ranges. North of the Shirley mountains conditions are similar, as they are in numerous other places in the state. Imagine what would happen if all of the country east of the Laramie mountains could be irrigated.

How far artesian wells will solve any of these problems remains for experiment to prove; but without question they will be found beneficial in many instances, and when a system of deep well drilling has been inaugurated the water supply will be sufficient to carry on irrigation on a large scale. One has to go only to Dakota to realize the possibilities of irrigation by means of artesian water. Artesian basins are numer-

ous in Wyoming and some of them are very large and especially well located. So far but little attention has been given to this subject. A few shallow wells have been drilled in several counties, but none of them have gone to a sufficient depth to secure a large flow. Few, if any, have thus far contemplated sinking deep wells with a view of obtaining more than a slight flow. To those who wish to increase their present water supply I refer to the artesian wells of Dakota, where in a few instances water has poured forth under a pressure of 150 pounds per square inch and has been used as a water power as well as to irrigate with. The Dakota artesian basin depends largely upon the Black Hills for its water supply; possibly this may be augmented by the waters from the Big Horn mountains, but this is not probable. Judging from the source of the water in many of the Wyoming basins, the artesian wells in this state should equal any that have been drilled in South Dakota. The high mountains, clothed with pine and spruce forests, and the peaks of perpetual snow, furnish day by day a constant water supply which sinks down between the strata and may be tapped with a drill a thousand or more feet lower than the source.

The data employed in this bulletin have been collected by me during the last four summers. Occasional references are made to some of the early reconnaissance surveys; but all of the structural features have been worked out from field notes. The geological map embodies all that is known of the geology of Wyoming up to date. All of the early maps have been examined and their data used so far as it harmonizes with recent investigations. This map can only be considered reconnaissance work; hence an allowance will have to be made for variations in boundaries between eras and in a few places for structure. For example, the county east of Laramie peak and at the head of the Wind river are not well known and more than likely the geology of all of Uinta county north

of the Oregon Short Line railroad needs careful revision. There are numerous small areas all along the east side of the Laramie mountains that have not been examined. There are in fact numerous places all over the state where greater detail can only be worked out by careful examination. The map has been constructed to illustrate the distribution of the various formations in the state and to act as a key to structural geology. For these purposes it will be found very reliable, and those interested in securing artesian wells will find it a valuable aid. No attempt has been made to show the topographical features, since only a very small portion of the state has been surveyed. Accompanying the bulletin there are numerous geological sections which will be found to be indispensable in considering the structure of the various artesian basins.

Judging from what has been done in the past, it will be many years before the citizens of this state will attempt to increase the water supply by means of artesian wells and it may be possible that the state may have to lend aid to this very commendable enterprise. It will be well for our next legislature to consider the advisability of drilling test wells in the artesian basins where water is most needed, and in this way encourage ranchmen to drill for themselves. In case test wells are put down by the state, the location should be carefully selected and only deep wells drilled. Otherwise many would be discouraged on account of slight flows.

I take this opportunity to thank the United States Geological Survey for electrotypes of the Fort Benton and Niobrara fossils, used in this bulletin; also to thank Prof. Charles Fulton for assisting me in drawing the map and sections, and Mr. Frank Bond for producing such excellent drawings of fossils, which add so much to the bulletin.

A Geological Sketch.

In the following pages will be found a very brief description of the geological formations known in Wyoming. An attempt has been made to describe the various formations so that people residing in any part of the state can work out for themselves the geology of their region and conclude whether or not they wish to attempt drilling for artesian water. Prior to describing the formations I have introduced a scheme showing the names and subdivisions of geological time as applied to Wyoming geology. The top of the scale represents the latest formation and the bottom the oldest.

CENOZOIC	}	Pleistocene	{	Recent. Champlain. Glacial.			
		}	Tertiary	{	Pliocene ? Miocene. Oligocene. Eocene		
	}		{ Bridger. Green River. Wasatch.				
			{ Fort Union? Lower Laramie.				
MESOZOIC	}	}	Cretaceous	{	Montana	{	Fox Hill. Fort Pierre.
			}	}	Colorado	{	Niobrara. Fort Benton.
					Bear River. Dakota.	{	
	}	}	Jurassic	{	Como. Shirley.		
			Triassic.	{			
PALEOZOIC	}	Permian.	{				
		Carboniferous	{	Upper. Lower.			
		Devonian.	{				
		Silurian (absent)	{				
		Ordovician.	{				
}	}	Cambrian	{	Upper. Middle.			
			{				
PROTEROZOIC (Eozoic)	}	Algonkian	{	Not subdivided.			
AZOIC	}	Archæan	{	No natural subdivisions.			

Before taking up the geological discussion it must be understood that nearly all of the stratified rocks have been deposited in seas or fresh water lakes. The name stratified rocks includes limestones, sandstones, shales, slates, conglomerates, as well as most of the clays and marls. During the geological history of our earth all, or nearly all, of the land has been covered with water, and usually many times. If there were no seas or lakes, no rocks were deposited, and the formation is absent. One can form a better idea of geological time if he will consider that there have been constant changes in both sea bottom and land surfaces. The period in which a sea bottom was gradually settling means that there was deposited a very thick band of rocks. If the sea was deep and water clear, limestones were made. If clear, limestones were also made in shallow water. Along coast lines, where sand was produced, sandstones were formed, together with other strata as conglomerates and breccias. In gulfs and bays where there were large rivers emptying, fine sediment and mud accumulated, which were later compressed into shale. If a formation is present in Wyoming, it means that a sea or lake existed during that period; if absent, it means that the state, or that part of the state in which the strata are absent, was dry land. In the same way we can judge of the duration of a geological period by considering the thickness of the rocks deposited. For example, the Paleozoic rocks in Wyoming are not to exceed 3,000 or 4,000 feet thick, while in Pennsylvania they are over ten times that thickness. From this we gather that Wyoming was dry land for the greater part of the Paleozoic era.

Azoic Era.

This represents geological time prior to the appearance of life on earth. The rocks are chiefly granite, and none of the metamorphosed sediments are included.

THE ARCHAËAN PERIOD.

The name Archæan applies to the oldest rocks that we know anything about on our earth. Usually they are granite, gneisses and schists, with granite predominating. Originally the Archæan not only included the above rocks, but also very thick bands of metamorphosed sediment, which have recently been separated from the Archæan by the United States Geological Survey and called the Algonkian. In accordance with the Canadian geologists, the Archean is divided into the Laurentian and Huronian, the Huronian being largely metamorphosed sediment. Under the more recent classification the Huronian belongs with other formations to the Algonkian. The name Archæan restricted as given above, has in it no evidence of life or anything pertaining to life. The rocks were in all probability of eruptive origin and represent the so-called crust of our earth prior to the deposition of any sediment. Other views are held as to the origin of these rocks; but the question of origin cannot be discussed here. The Archæan, then, is the fundamental or primary formation that formed at one time the entire sea bottom and the entire land masses—a formation universal. All of the sedimentary depositions have tended to bury these oldest rocks and in consequence there are only occasional areas exposed, and the most of these in Wyoming occur along the crests of the mountain ranges; when huge folds elevated them while they were covered with many thousand feet of sedimentary rock. The sedimentary rocks have since been removed by erosion. In the Sweetwater

valley there are numerous peaks of granite that appear to have been constantly above the sea since the beginning of the Archæan era. There was in all probability a large Archæan land mass in this region that remained above the sea from Archæan time up to nearly the close of the Tertiary, when it was depressed and covered with a few hundred feet of Tertiary strata. Typical Archæan exposures can be seen at Sherman, Laramie peak, east of Whalen canon, along the Big Horn, Wind River, Gros Ventre, Medicine Bow, Ferris, Seminole and Owl Creek ranges, along the Sweetwater river, a few miles northwest of Rawlins, and north of Clark's Fork, in Big Horn county. These rocks are usually mineral-bearing and when cut with dikes of porphyry make the conditions ideal for the occurrence of all of the precious metals.

The only way that this, the oldest of formations, can affect the artesian basin, is that it forms the highest mountain ranges, where vast quantities of snow accumulate during the winter to feed the basin with water during the summer months, and also forms a bed rock in many localities on which rests the lowest and the greatest water zones in the state. The term bed-rock as used in connection with this bulletin, means the Archæan granite. Springs are quite numerous in this formation, but since the rocks are not stratified there are no water-bearing zones that can be traced. Wells of the very best water can be found in the granite rocks and occasionally the water will rise to the surface and flow in a small stream. Usually wells put down in these rocks have to be provided with some means to elevate the water.

Proterozoic Era.

(EOZOIC.)

This marks the first era of sedimentation; also the introduction of life on earth. The rocks are usually sedimentaries that have undergone extensive metamorphism, and are schists, marbles and quartzites, together with intrusive bands of eruptive rock. They are also acutely folded and nearly all of the evidence of fossil remains has been obliterated. The Proterozoic also marks the first great mountain-making period of our earth. These rocks are found unconformable with the Archæan.

ALGONKIAN.

Up to the present time the Algonkian rocks of Wyoming have been referred to the pre-Cambrian and have not been separated from the Archæan. They form important bands in numerous localities and have in this bulletin, so far as the data have warranted, been separated from the Archæan. The formation is composed of schists in great profusion, marbles, quartzites and these cut with dikes of eruptive rocks. The strike of the entire formation varies from north to northeast, and the dip of the strata is seldom less than 65 or 75 degrees. It is unconformable with the Archæan and is found in great granite basins. The thickness of the entire series has not been absolutely measured, but including the eruptive band, which does not form an important part, the maximum thickness in Wyoming is about 20,000 feet. Typical areas have been found in the Black Hills in Wyoming, and occasional outcrops to the southwest from that place to the Hartville hills—one exposure being east of Lusk, another at Rawhide Butte, and a large one in Whalen canon. They also occur at Halleck canon, Plumbago canon, in the Medicine Bow mountains, nearly all

of the Sierra Madre mountains, in the Seminoe mountains and in the Sweetwater mining district of the Wind River range. None of these localities have been examined in detail; but sufficient work has been done to prove that these rocks were at one time sedimentary and that they have been changed by metamorphism to schists. In the Sweetwater districts the rocks are chiefly schists; but there are many bands of eruptive rock that form dikes which follow the strike of the formation.

We have every reason for believing that life was born on earth during the Algonkian period; in fact a few fossils have been reported from rocks supposed to belong to this formation. At the close of this period in Wyoming there is evidence that great mountain ranges were formed. A very prominent one extended from the Laramie mountains north and east to the Black Hills, the remnants of which are still visible. A second prominent range extended from South Pass northeast to an unknown distance. After the mountains were formed they remained dry land a sufficient length of time to have these ranges reduced to mere hills, and in many places to almost plains, and upon their upturned edges was deposited the Cambrian strata.* On account of the strata being highly inclined and there being no basins in which water could accumulate under much head, none of this series can be seriously considered as valuable artesian basins. However, a small flow of artesian water may be found in several of these areas.

*In Michigan, the Algonkian rocks contain very extensive deposits of both iron and copper and usually they are mineralized wherever found. In Wyoming mines of gold, copper, silver, lead and iron occur, in the camps at South Pass, Encampment, Seminoe and the Black Hills.

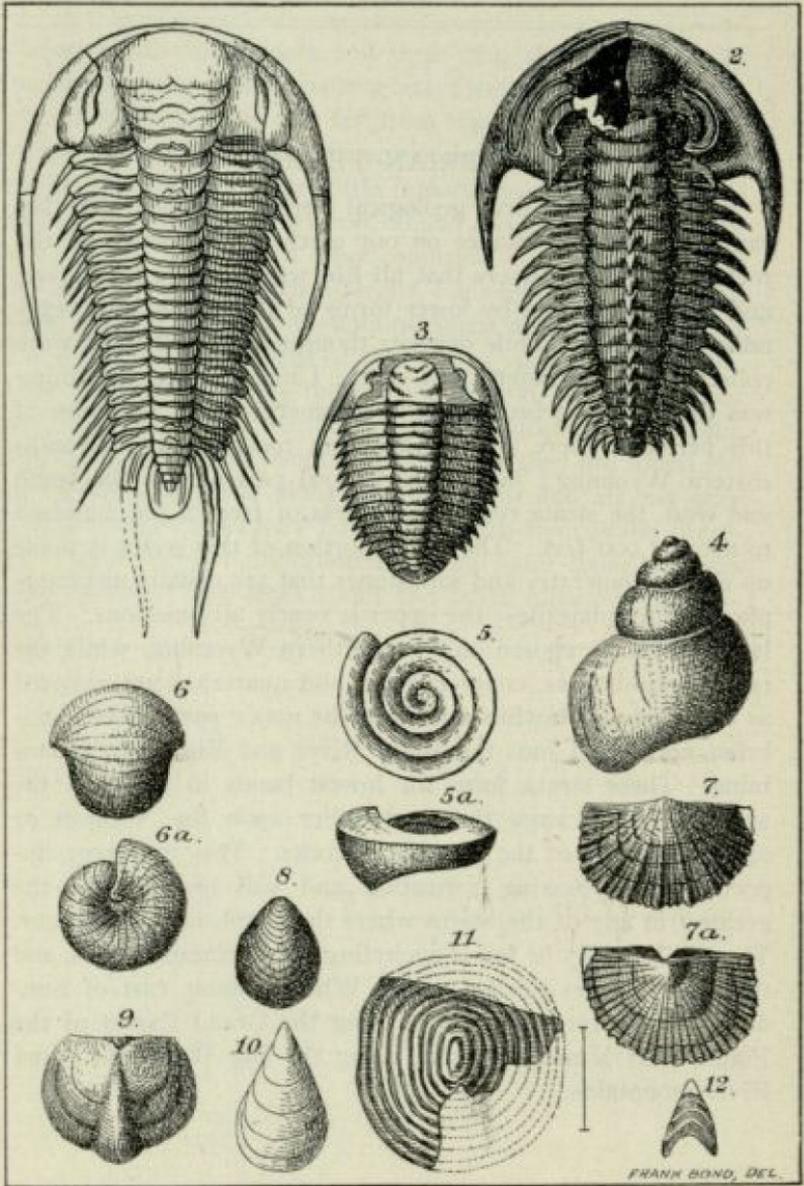
The Paleozoic Era.

The Paleozoic rocks in Wyoming rest unconformably upon the Archean and Algonkian, and vary in thickness from 1,000 to 4,000 feet. Along the Appalachian mountains rocks of the same era have a thickness of 40,000 or 50,000 feet. In Wyoming the Paleozoic rocks are nearly all limestones, with a few bands of calcareous sandstone, some sandstone, quartzites and conglomerates. These occur along the mountain sides, dipping at various angles and sometimes reaching elevations of 9,000 or 10,000 feet. Along the western flank of the Big Horn and the eastern flank of the Wind River range these rocks extend from the granite to the base and practically cover the mountain slopes. Upon reaching the foot of the ranges the Paleozoic rocks dip beneath later formations. From a life standpoint the Paleozoic era was the first important period in the world's history. Life had existed for some time prior to the advent of this era; but it was represented so far as we know only by a few inferior sea animals and the impressions of these have been largely obliterated through the metamorphism of the strata. Conditions changed at the commencement of the Paleozoic and for the first time in the world's history the seas were teeming with invertebrate life. Associated with these were numerous kinds of sea weeds. The life was very simple to start with, but as geological time went on it became more and more complicated. The sea life changed from invertebrates to vertebrates (fishes). Some of the invertebrates of the sea developed into land animals (insects), so that from the beginning to the close the era is one of great biological progress. From the fishes, amphibians developed, and from the amphibians reptiles, which represented the highest type of animal life known at the close of the Paleozoic. The plant life also developed in a similar way. The sea weeds

developed into land plants and these into shrubs and finally into large trees, which made great forests, but the highest form of vegetable life was far from representing the deciduous trees of today. From an economic standpoint the Paleozoic in Wyoming is of but little importance, the building material and the production of iron, oil and gas being the only products. In the east and in other countries, it was in the Paleozoic that the great Carboniferous coal fields were formed. Along the Appalachian mountains there are great fields of oil and gas, as well as beds of salt, clay, gypsum and iron ore. In the Mississippi valley these rocks contain vast deposits of lead and zinc. In Wyoming, this series, although very thin, must be considered as essential bands, since they are found extending to high points along the mountains and act not only as large storage reservoirs but also furnish hydrostatic pressure. Again they are important since the water found in them is usually quite free from alkali and other injurious ingredients.

CAMBRIAN PERIOD.

This was the first geological period in which life became of much importance on our earth. The records of the rocks prove conclusively that all life was confined to the sea, and was represented by lower forms of the animal and vegetable kingdoms. While deposits thousands of feet thick were collecting in the eastern part of the United States, Wyoming was dry land, but became partly submerged near the close of this period. There are no Cambrian rocks known in southeastern Wyoming; but in the central part and in the north and west, the strata reach a thickness of from a few hundred to about 1,000 feet. The lower portion of this series is made up of conglomerates and sandstones that are usually metamorphosed into quartzites; the upper is nearly all limestone. The later beds are exposed only in northern Wyoming, while the reddish sandstones, conglomerates and quartzites are exposed as far south as Rawlins and form the major part of the Cambrian northward into the Wind River and Big Horn mountains. These strata form the lowest bands in many of the artesian basins, since they rest either upon the Archean or upturned edges of the Algonkian rocks. This is a very important water-bearing formation and will probably be the greatest in any of the basins where the Cambrian rocks occur. They will usually be found encircling the Archæan masses, and typical exposures can be seen at Whalen canon, east of Sundance, northwest of Rawlins, along the Grand Canon of the Platte, near Miner's Delight, along the Big Horn and Wind River mountains.



SOME CAMBRIAN FOSSILS SELECTED FROM VARIOUS SOURCES.

[Explanation of Plate I.]

- No. 1—*Paradoxides bohemicus*, Barr.
No. 2—*Olenellus kjerulfi*.
No. 3—*Olenus truncatus*, Brissn.
No. 4—*Holopea sweeti*, Whitfield.
No. 5—*Ophileta primordialis*, Whitfield.
5a—Side view of No. 5.
No. 6—*Bellerophon antiquatus*, Whitfield.
No. 7—*Orthis (Protorthis) billingsi*, Walcott.
No. 8—*Linnarssonina transversa*, Walcott.
No. 9—*Triplesia (Camarella) primordialis*, Walcott.
No. 10—*Lingulepis antiqua*, Hall.
No. 11—*Stenotheca arcadia*, Walcott.
No. 12—*Matheria variabilis*, Walcott.

THE ORDOVICIAN PERIOD.

(LOWER SILURIAN).

At the close of the Cambrian all of Wyoming was elevated above the sea and remained so for long periods of time; but the northern half of the state was submerged near the close of the Ordovician period, which allowed strata to accumulate to a thickness of from 600 to 900 feet. These rocks are light colored, thick bedded limestones and sandstones, but contain very little fossil life. The Ordovician period was one of great importance in geological history. Prior to this time the life was represented by sea life only and the highest types were invertebrates. During this period insects made their first appearance on the land and fishes in the sea. It was also marked by the general advancement of invertebrate life, and trilobites reached their maximum of development. Rocks of this period are found along the Wind River and Big Horn mountains, where they extend to points of considerable elevation. The strata, being sandstones and limestones, are of great importance in the vicinities where they occur, and are practically as valuable for artesian wells as the Cambrian. The supply of water will usually be large and will flow under great pressure. Good exposures of Ordovician can be seen two or three miles northeast of Miner's Delight, along Beaver creek, near the head of Warm Spring creek, a few miles above Dayton, and eight or ten miles west of Hartville. In Wyoming nothing of commercial importance has been found associating within these rocks except building material. In Ohio the Ordovician produces natural gas and petroleum.

SILURIAN PERIOD.

(UPPER SILURIAN).

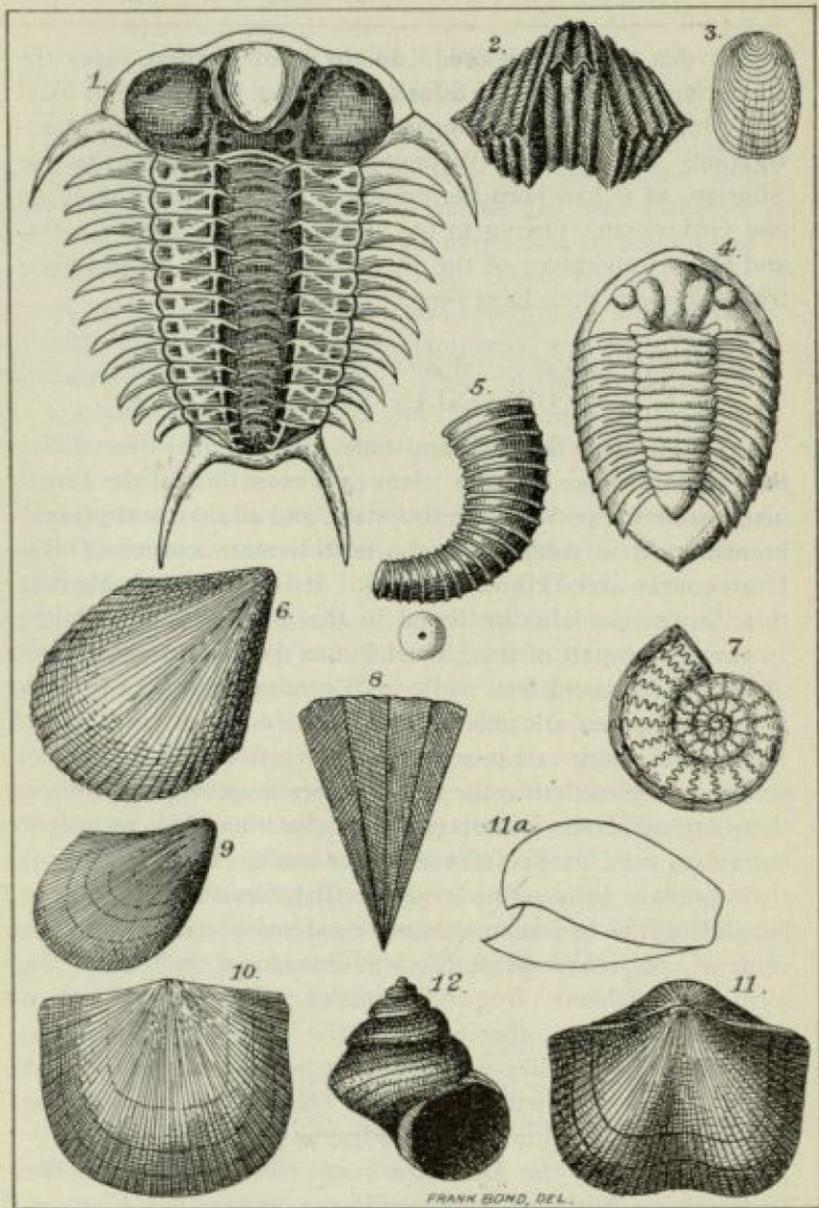
So far as known there are no Silurian rocks in Wyoming. Many geologists have reported the Silurian, and in the reports

of Hayden the term is used. In the most of these cases the Cambrian was considered Silurian, together with the thin band of Ordovician or Lower Silurian. So far as our present investigations have proven, Wyoming was dry land during the Silurian, as it had been the greater portions of the Cambrian and Ordovician. Owing to the absence of the Silurian rocks, and slight importance of the Devonian, plates of fossils illustrating these periods have been omitted.

DEVONIAN PERIOD.

This is the "Old Red Sandstone" period. By others it has been called the age of fishes. It is only recently that the Devonian has been reported from this state, and all that is at present known of it is confined to the northwestern corner of Big Horn county and Yellowstone park. It is highly probable that thin bands may also be found in the Big Horn mountains. In the eastern part of the United States they attain a thickness of several thousand feet, while in Wyoming they are only 250 feet. The strata are chiefly limestones in which there are a few typical species of invertebrates. No fishes have been reported. In considering the many phases in geological history, there are numerous important events that should be recorded; but only a very brief reference will be made. Prior to this period we have little or no evidence that forests ever existed; but during the Devonian they were extensive enough to form veins of coal. Vertebrate life was introduced on land in the form of amphibians (frog-like animals). The seas were filled with fishes. At no other period in the world's history did so many fishes live. They were not like the most of the fish that we are acquainted with today, but belonged to an old type which is represented in our rivers by the sturgeon.

In Wyoming the Devonian rests conformably upon the Ordovician. Nothing of economic importance has been re-



SOME ORDOVICIAN FOSSILS.

[Explanation of Plate II.]

- No. 1—*Ceraurus pleurexanthemus*, Walcott.
An Ordovician Trilobite.
- No. 2—*Orthis (Platystrophia) biforata*, Hall.
- No. 3—*Lingula quadrata*, Hall.
- No. 4—*Lichas trentonensis*, Meek.
- No. 5—*Crytoceras subanunlatum*, D'Orb.
- No. 6—*Ambonychia radiata*, Hall.
- No. 7—*Crytolites compressus*, Hall.
- No. 8—*Conularia trentonensis*, Hall.
- No. 9—*Ambonychia bellistrata*, Hall.
- No. 10—*Rafinesquina alternata*, Meek.
- No. 11—*Orthis occidentalis*, Hall.
- No. 11a—*Orthis occidentalis*, Hall. Side view.
- No. 12—*Cyclonema bilix*, Conrad.

ported from these strata; but in the east they supply both oil and gas, and in England they contain thin beds of coal. On account of the very limited occurrence these rocks enter into the structure of the Big Horn artesian basin only, and in this, in the northwestern corner, where the formations are nearly vertical along most of the outcrops. Consequently they deserve little or no attention. They will be found to be water-bearing and possibly there may be some tunnel propositions, where they may yield considerable water. Their high inclination practically bars them from furnishing wells.

CARBONIFEROUS PERIOD.

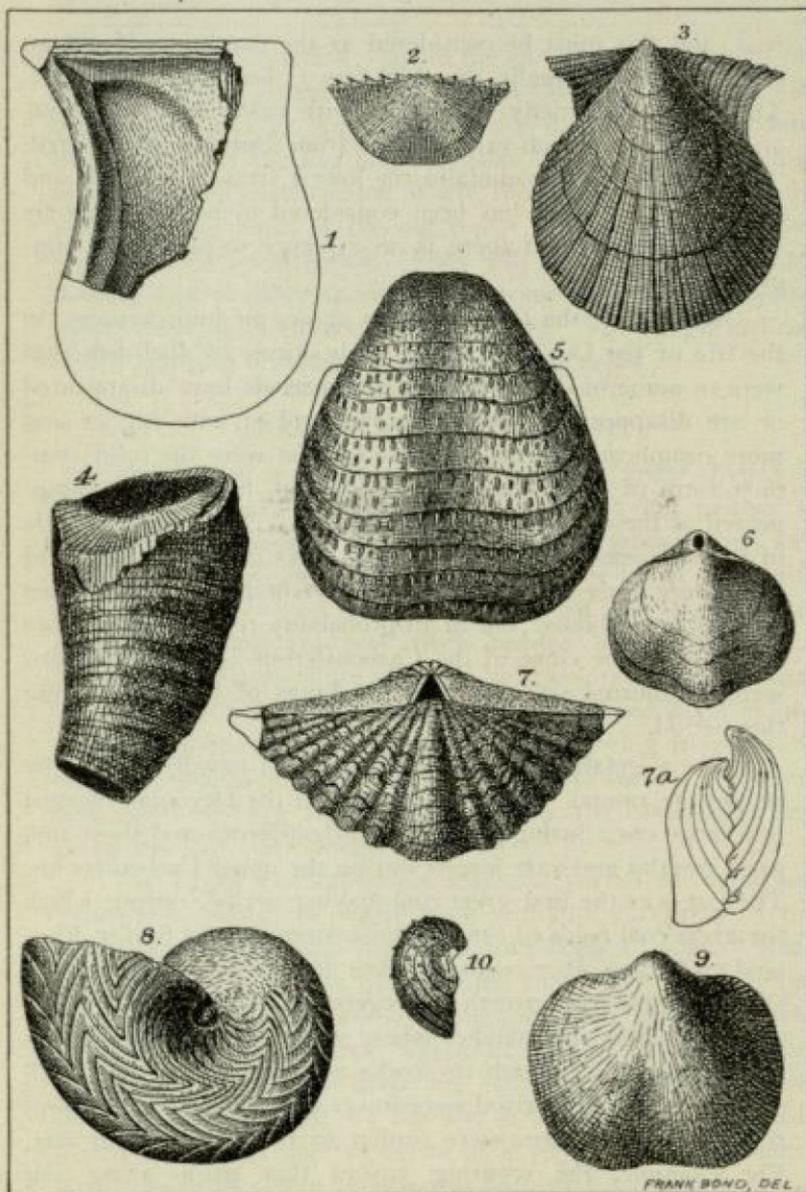
This period is separated into upper and lower divisions, both of which are represented in Wyoming; but neither is of much importance as compared with the Carboniferous formations of the Appalachian mountains. The lower Carboniferous series is formed only in the northern part of the state, where the strata are very thick bedded limestones. Near Miner's Delight there are strata of light colored limestone that are upwards of 50 feet in thickness. In the Wind River mountains this series of rocks has a thickness varying from 400 to 600 feet, but seem to thicken to the northward. The same series of beds have also been observed in the Black Hills and along the Big Horn range.

The upper Carboniferous marks a period in Wyoming geology in which the entire state with the exception of the Sweetwater valley was depressed and became a sea. Even the southeastern corner of the state, that had remained constant land since the close of the Archæan era, was submerged. This subsidence was quite late in the upper Carboniferous period and there are only thin bands of representative rocks, which are the first strata that are universally distributed in the artesian basins of Wyoming. In no instance have these rocks been reported to be over 2,200 feet in thick-

ness, and this must be considered as the maximum if not an over-estimate. Usually the thickness is less than 1,000 feet. The strata are chiefly limestones with calcareous sandstone, and sandstones which vary in color from drab to pink and red. Along the Laramie mountains the lowest stratum is a grit and conglomerate, which has been considered to be Cambrian by some geologists; but there is no evidence to prove this suggestion.

The life of the Carboniferous shows an improvement on the life of the Devonian. The early forms of shell-fish that were so numerous in early Paleozoic periods have disappeared or are disappearing, and their places filled with higher and more complicated forms. Trilobites, that were the most common form of life during the Ordovician, have nearly disappeared at the close of the Carboniferous. The vertebrate life of the seas was made up of several types of fishes. Many of these were large sharks. The land vertebrates that are known were all amphibians; but in all probability reptiles sprang into existence at the close of the Carboniferous. The amphibians were of unusual size and were the kings of land life during this period.

The vegetable kingdom had advanced equally as rapidly as had the animal. The small forests of the Devonian merged into large ones during the lower Carboniferous and these into great jungles and vast forests during the upper Carboniferous. The last was the first great coal-making period, during which the great coal fields of central and eastern United States, England and many other countries were deposited. Conditions favored the rankest growth of vegetation at that time, which accumulated in the marshes where it had grown and was afterwards buried beneath the rocks and changed to coal. All of the trees of this period were lower types than the deciduous trees; many of them were similar to the ferns of our day. For example, the scouring rushes that grow along our



SOME CARBONIFEROUS FOSSILS.

[Explanation of Plate III.]

- No. 1—*Myalina subquadrata*, Shumard.
No. 2—*Chonetes granulifera*, Owen.
No. 3—*Aviculopectin occidentalis*, Shumard.
No. 4—*Zaphrentis stanburyi*, Hall. One-half natural size.
No. 5—*Productus nevadensis*, Meek.
No. 6—*Seminula argentia*, Hall.
No. 7—*Spiriferia pulchra*, Meek.
No. 7a—Side view of No. 7.
No. 8—*Goniatites goniolobus*, Meek.
No. 9—*Orthis resupinata*, Martin.
No. 10—*Productus longispinus*, Sowerby.

streams and are seldom over 18 inches or 2 feet in length, and a quarter of an inch in diameter, were large trees during the Carboniferous coal period. Besides the great accumulation of coal in the Carboniferous, there were beds of iron ore, fire clay as well as other clays, gypsum, salt, petroleum and gas. Petroleum is never found associated with coal veins. There are also deposits of lead and zinc ores in the lower Carboniferous of the Mississippi valley. In Wyoming the Carboniferous rocks in no way compare to the series in the east. They do not contain any coal, clay, salt beds, gypsum, lead or zinc, nor do they contain either oil or gas. The only valuable economic products thus far discovered have been iron and copper ore, together with building material. The great iron deposits at Rawlins and Hartville are found in these rocks, as are oxidized copper ores in the same regions. In a few localities there are beds of marble and marble onyx.

Since these rocks occur in every artesian basin in Wyoming and are thicker than any of the preceding formations, they are worthy of special consideration. In southeastern Wyoming the best wells will be found in these strata, and to the northward they will always be found to contain very valuable water bands. As a general rule water will be found at less depth than in the earlier formations. Especially is this true in localities where wells are to be drilled near the foot of the mountain, in the Triassic red sandstones. The supply of water will vary greatly with the localities; but as a rule it will be found very satisfactorily, and will also be excellent water for all purposes. Generally speaking, these rocks, with the Permian, form the lower slopes of nearly all of our mountain ranges.

THE PERMIAN PERIOD.

The Permian terrane is not well represented in America, and until recent years many have objected to referring any of

the strata to this period. It was a usual thing for the geologists employed by Hayden to refer the highest bands of the Paleozoic of Wyoming to the Permian; but in no case did they offer any evidence for so doing. Later, no one considered any of these strata as Permian. Only a year ago I discovered along the flank of the Laramie mountains a formation, not over 200 feet in thickness, that contains a fauna almost the same as has been reported from the Kansas and Nebraska Permian. There seems little reason to doubt that these rocks are widely distributed and are to be found in the Big Horn and Wind River ranges, as well as in the southeastern corner of the state. The strata along the Laramie mountains are composed of light colored limestones, pink calcareous sandstones, light red sandstones and a bed of pure white sand that has been utilized for glass-making. It is possible that the rocks that have been assigned to the Upper Coal Measures may prove to be Permian. The presence of copper in the bands points that way.

During the Permian period of the world, the life resembled the Carboniferous. There were many lingering Coal Measure genera and a few species. There were also fossils that took on Mesozoic characteristics. The vertebrate life was not only represented by fishes and amphibians, but also by the introduction of reptiles.

The close of the Paleozoic was a mountain-making period and the Appalachian and many foreign ranges were made. In Wyoming there was no change or folding of the strata, and the great Paleozoic era passed into the Mesozoic era as uninterrupted as in many other instances one stage passed into another. Where Permian rocks are definitely known in Wyoming they all form the lower slopes of the mountain ranges and occasionally extend well up to the Archæan. Of the Paleozoic, these beds are of the least importance in the artesian basins. They are, however, superior to any of the Mesozoic.

Usually it will be possible to start a well in the Dakota sandstones, and pass through the Jurassic and Triassic and secure water in the Permian.

The Mesozoic Era.

Wyoming was a land mass during the greater portion of the Paleozoic era, and this accounts for the extremely thin beds of rock belonging to that grand division of geological time. At the close of the Paleozoic era, in the eastern part of the United States, the Appalachian mountains were made; but in Wyoming the Paleozoic seas merged into the Mesozoic without any interruptions, which causes the Mesozoic to rest upon the Paleozoic apparently conformably. It is very thick, from 20,000 to 30,000 feet. They differ from the older rocks in being less compact, and also in containing numerous bands of shale and clay. Although very thick, there are only a few bands containing limestone. Conditions had so changed that the seas were shallow and in some instances fresh water lakes covered vast areas. The changes in life were very important. In the early Mesozoic the vertebrate life had so advanced on earth that huge reptiles occupied both land and sea. The swimming saurians are known as *Plesiosaurs* and *Ichthyosaurs*; the land reptiles as *Dinosaurs*. Mammalian life was also introduced about this time; but the animals were about the size of a mouse and belonged to the lowest type. Our modern fishes also appeared during the early Mesozoic. Toward the middle of the Mesozoic, flying Saurians appeared, and also birds. It was about this time that the *Dinosaurs* reached their maximum development. Vegetable life was also advancing and in the upper portion of the era the first deciduous trees appeared on earth. At the close all of the

Plesiosaurs, *Ichthyosaurs*, as well as many other kinds of swimming Saurians, together with the *Dinosaurs* and *Pterosaurs* (or flying Saurians), became extinct. These rocks at one time covered nearly all of the state, and although great mountains have been made and hundreds of square miles of rock have been carried away by erosion, they cover or underlie three-fourths of Wyoming at the present time. They are found as the base of the mountains and occupying the valleys and forming the plateaus. They play an important part in the artesian basins of the state, since they are associated with all of them. At the close of the Mesozoic, the Rocky mountains were made and the mountain system that practically extends from Tierra del Fuego to Alaska came into existence.

THE TRIASSIC PERIOD.

This series has been called by other names than Trias, or Triassic. In the old world they are known as the "New Red Sandstone" and in Wyoming they have been called the "Red Beds." Of all the geological formations in Wyoming, this is the most conspicuous. It has numerous beds of dark red sandstone, with some red shales and thick beds of gypsum near the base. These bands can be seen at the foot of nearly all of the mountain ranges, either forming precipitous bluffs that rise a hundred or more feet, facing the range, or in dark red bands, following its trend. In some localities they have been nearly leveled by erosion, but can be seen cropping out at the crossing of every stream and in the red soil caused by their decomposition. They often color a wide band reddish that winds about the foot of the mountain like a great snake. Quite frequently these rocks are wind worn and cut into the most fantastic forms and are not easily surpassed for natural artistic beauty. In other regions there are deep circular depressions caused by caves in the Permian rocks below. This makes circular caves which are often one hundred feet in diameter and sometimes a

hundred or more feet deep. These depressions are common in Crook county, east of Sundance, and near Spring creek, Big Horn county. Forming as this period does the base of the Mesozoic, they can easily be separated from the light colored sand and limestones of the Permian below, and the dark colored fossiliferous bands of the Jurassic above. No fossils have been recognized as in other sections, and the entire series is barren or nearly so, for not a single species of fossil of any kind has been reported from them. In other parts of the United States, and in Europe, they are rich in both plant and animal life and are especially marked by the introduction of swimming Saurians and mammals. The mammals were very small, probably not larger than a good-sized mouse. Good, and frequently bad, water will be found in the Triassic sandstones. The usual impurity is gypsum, which makes the water extremely hard and slightly bitter. While it is usually called poor water, it is nevertheless valuable for irrigation purposes. These sandstones will always furnish water in all of the artesian basins, but no one should expect to find a supply such as might be obtained in the Paleozoic rocks.

THE JURASSIC PERIOD.

Formerly the Jurassic and Triassic terranes were united for the Rocky mountains under the head Jura-Trias. They are, however, so different in their general characteristics that a novice can easily draw the line of demarkation, and there is no reason why they should not be discussed as they are here, under different heads.

The Jurassic rocks are everywhere found resting upon the Triassic red sandstone, and are widely distributed throughout Wyoming. Of this series there are two distinct stages, the Shirley representing the marine and the Como the fresh water or upper division.

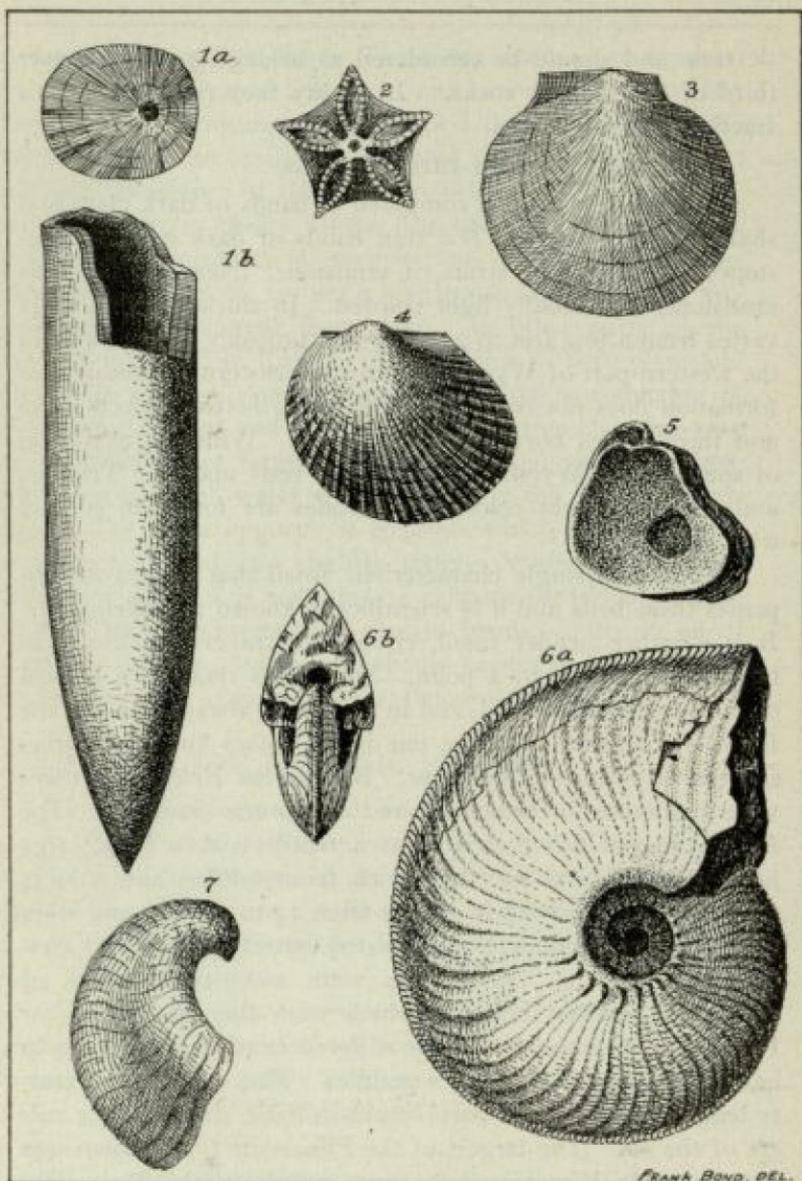
These stages represent a very small portion of the Juras-

sic time and should be considered as belonging to the upper third of the Jurassic rocks. In reality they represent only a fraction of this division.

THE SHIRLEY STAGE.

The Shirley stage is composed of bands of dark clays and shales, together with a few thin bands of dark colored limestones and numerous strata of sandstone. Near the base the sandstones are usually light colored. In thickness this stage varies from a few feet to 250 feet and probably exceeds this in the western part of Wyoming. In southeastern Wyoming this formation does not occur, the limit being between twenty-five and thirty miles northwest of Laramie. With the exception of southeastern Wyoming, the Shirley rests upon the Triassic, and often the light colored sandstones are found in contact with the red.

There is a single characteristic fossil that always accompanies these beds and it is scientifically known as a *Belemnite*. It is a rather slender fossil, circular in traverse section, and tapering gradually to a point. Sometimes there is a conical opening at the broad end, and in fact there always is when the fossil is complete. A large one is six inches long and three-fourths of an inch in diameter. Besides the *Belemnites* there were numerous invertebrates and swimming Saurians. The *Ichthyosaur* or fish Saurian was a reptile with a long, large head, no neck, a round body with four paddles, and a long, slim tail. They varied in length from 12 to 40 feet and were very ferocious animals, that subsisted entirely upon flesh. Associated with the *Ichthyosaurs* were many other types of swimming reptiles, chief of which were the *Plesiosaurs*, or Plesiosaur-like animals. These differed from the foregoing in having long necks and larger paddles. They attained a greater length and were also carnivorous in habit, and absolute rulers of the sea. The largest of the Plesiosaur type known was discovered in Wyoming. A front paddle in the University



FRANK BOND, DEL.

SOME JURASSIC FOSSILS FROM THE SHIRLEY STAGE.

[Explanation of Plate IV.]

- No. 1a—*Belemnites densus*, Meek. Side view.
No. 1b—Transverse section of No. 1a.
No. 2—*Pentacrinus asteriscus*, Meek. Enlarged.
No. 3—*Camptonectes bellistriata*, Meek. One-half natural size.
No. 4—*Pseudomonotis curta*, Hall.
No. 5—*Ostrea strigilecula*, White.
No. 6a—*Cordioceras cordiformis*, M. & H. Much reduced. Side view.
No. 6b—*Cordioceras cordiformis*, M. & H. Much reduced. Profile view.
No. 7—*Gryphaea calceola*, var. *nebrascensis*, M. & H. One-half natural size.

collection is nearly eight feet in length, and other parts in proportion. Associated with the land life, which was largely *Dinosaurs*, were numerous *Pterosaurs*, or flying reptiles, and a few birds that were provided with teeth. None of these have been found in Wyoming, but are associated with Jurassic rocks in other regions. In these seas there were also numerous fishes and turtles, and along the rivers many crocodiles.

THE COMO STAGE.

The Como stage at one time covered the entire state with one possible exception, and persists at the present, except in localities where mountain-making and folding have caused excessive erosion. These strata differ from the Shirley in being of fresh water origin, and hence they do not contain any marine life. This character alone will aid any one in separating them from the lower beds. The formation is from 150 to 250 feet in thickness, and above it there is nearly always a band of either Dakota conglomerate or sandstone, of the Cretaceous. It is a common thing to see the slopes of the Como, which are often quite precipitous, piled up with blocks of Dakota conglomerate, which range from a few feet to cubes 20 feet in diameter. The strata are largely marls and clays of different colors, with yellow, brown, red and drab predominating. These are separated by a few thin bands of sandstone and limestone.

The Como stage is the great *Dinosaur* horizon from which the many curious and huge animals have been collected. *Dinosaurs* represent the largest land animals that have ever lived, as well as very small ones. Wyoming is justly celebrated for these remains, since there is not another spot on earth where so many have been found. The largest of these animals were 80 to 90 feet in length and stood 20 to 25 feet high. A thigh bone in the University collection measures 69 inches high and the shaft is 33 inches in circumference.

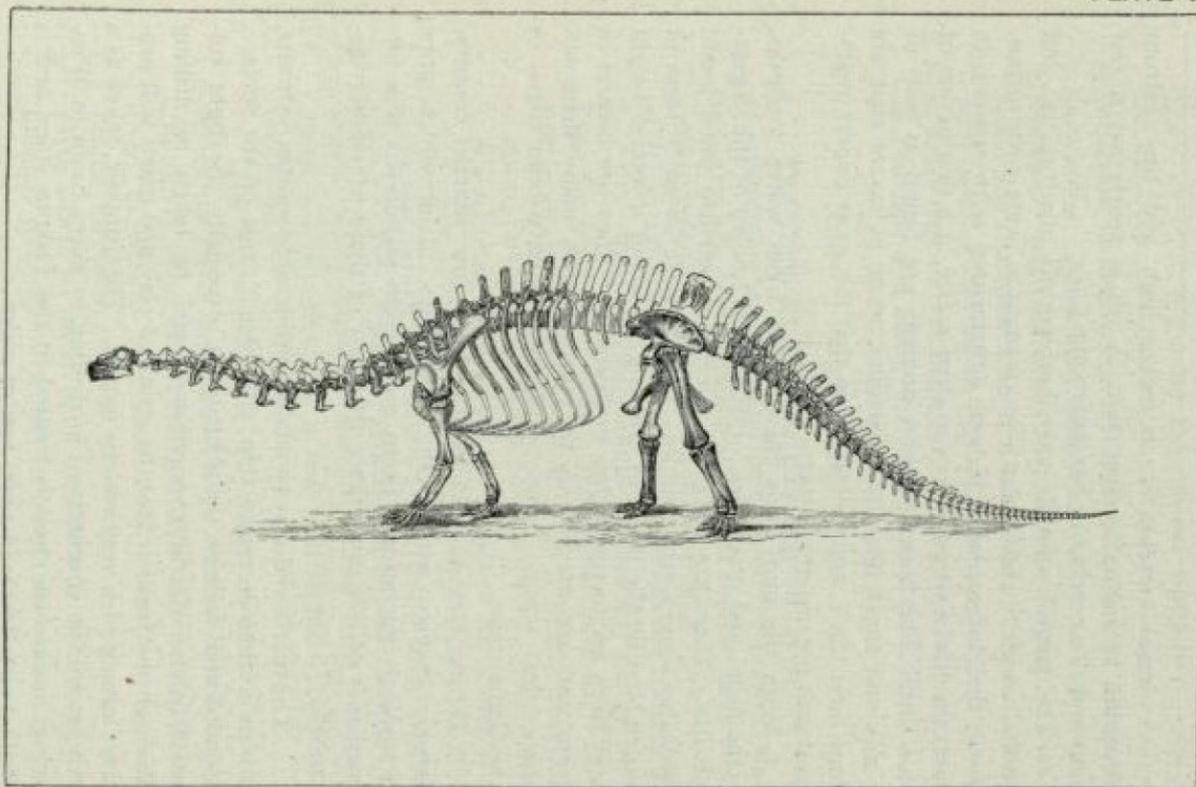
A dorsal vertebra is 40 inches high and the centrum measures 12 inches in diameter. A rib is nearly seven feet long and is 14 inches in circumference.

The largest animals were herbivorous quadrupeds; but others, which hopped about like a kangaroo, were carnivorous. Some had huge plates of bone ornamented with spikes; in fact, the life was too varied to even notice in a description of this sort. The bones of these animals are found in beds of marls and sandstones and sometimes occur in layers that are four feet thick, and so mixed up that the most expert anatomist can not assemble them again.

With the marl beds there occur fresh water mollusks, some fishes and crocodiles. But little is known of the vegetable life. There are numerous species of petrified wood found and also some Cycad trunks. Cycads were an early form of vegetable life, the trunk of which grew about a foot in height and from six to ten inches in diameter. They are conical in form and are marked in the surface with many diamond-shaped leaf scars. Some twenty species have been found in the Como stage.

During this stage Wyoming was a low, marshy country, largely covered with fresh water lakes, about which grew a tropical vegetation. From an artesian standpoint this formation is of less importance than any of those previously discussed.

The marls and clays contain considerable sodium sulphate, which is often seen as a thin, efflorescent crust on the surface. Good water follows the sandstones, especially the light colored bands. Great precaution should be taken in drilling through the Jurassic, for the strata of clay and marls will produce caving of a very serious nature. The Jurassic, taken as a whole, will be encountered in drilling in every basin in Wyoming in case the well is located in the Dakota stage and is drilled to a depth of 1,000 feet or more.



Brontosaurus excelsus, after Marsh. This animal, when alive, was 80 or 90 feet in length and lived in Wyoming during the Como stage of the Jurassic.

THE CRETACEOUS PERIOD.

The Cretaceous rocks of Wyoming belong to the upper half of the period, with the possible exception of some thin bands found in northern Wyoming, which may be lower Cretaceous. This is the greatest system of rocks of the state, for they cover or underlie over 50,000 square miles of territory. Taken as a whole, the stages are chiefly made up of sandstone, shales and clays, which reach the enormous thickness of from 20,000 to 25,000 feet. The Cretaceous is to Wyoming what the Carboniferous is to Pennsylvania, if considered from an economical standpoint, for these rocks contain all of the coal known in the state and nearly all of the petroleum and natural gas.

Hayden studied the western Cretaceous along the Missouri river nearly half a century ago and made the following divisions:

	Thickness given.
Fox Hills.....	500 feet
Fort Pierre.....	700 "
Niobrara.....	200 "
Fort Benton.....	800 "
Dakota.....	400 "

Since these names were adopted there have been many changes in the meaning of some of them, and the introduction of new terms to take their places. For example, some of the geologists have included the Niobrara, Fort Pierre and Fox Hills under the name Fox Hills. Others have used Fort Pierre to represent the same band. The United States Geological survey have included the Fox Hills and Fort Pierre under the name Montana and the Fort Benton and Niobrara under the name Colorado, but retaining the original names given by Hayden, for lesser divisions. Following the work of Hayden along the Missouri river was the mountain investigation, and the Laramie stage was discovered. At present the Cretaceous divisions are as follows:

		Estimated Thickness, Maximum, in feet.
Laramie...	{ Fort Union?	2,000
	{ Laramie	5,000
Montana...	{ Fox Hills	6,000
	{ Fort Pierre	7,000
Colorado...	{ Niobrara	2,000
	{ Fort Benton	2,000
Bear River	{	3,500
Dakota...	{	1,000?

These stages, so far as known, are conformable with each other.

The geological history of the accumulation of this great series of rocks is intensely interesting, but can not be given in this connection.

Following the Jurassic, when the greatest Saurians lived, we find Saurians, and especially *Dinosaurs*, up to the close of the Laramie. The swimming Saurians, *Plesiosaurs* and *Mososaurs*, were also common; but disappeared from the face of the earth prior to the close of the Cretaceous. Birds that were introduced in the Jurassic became quite numerous in the Cretaceous; but the mammals made no advance. Plant life was very abundant, as the many bands of sandstone and shale containing impressions of leaves, as well as the numerous coal veins, demonstrate.

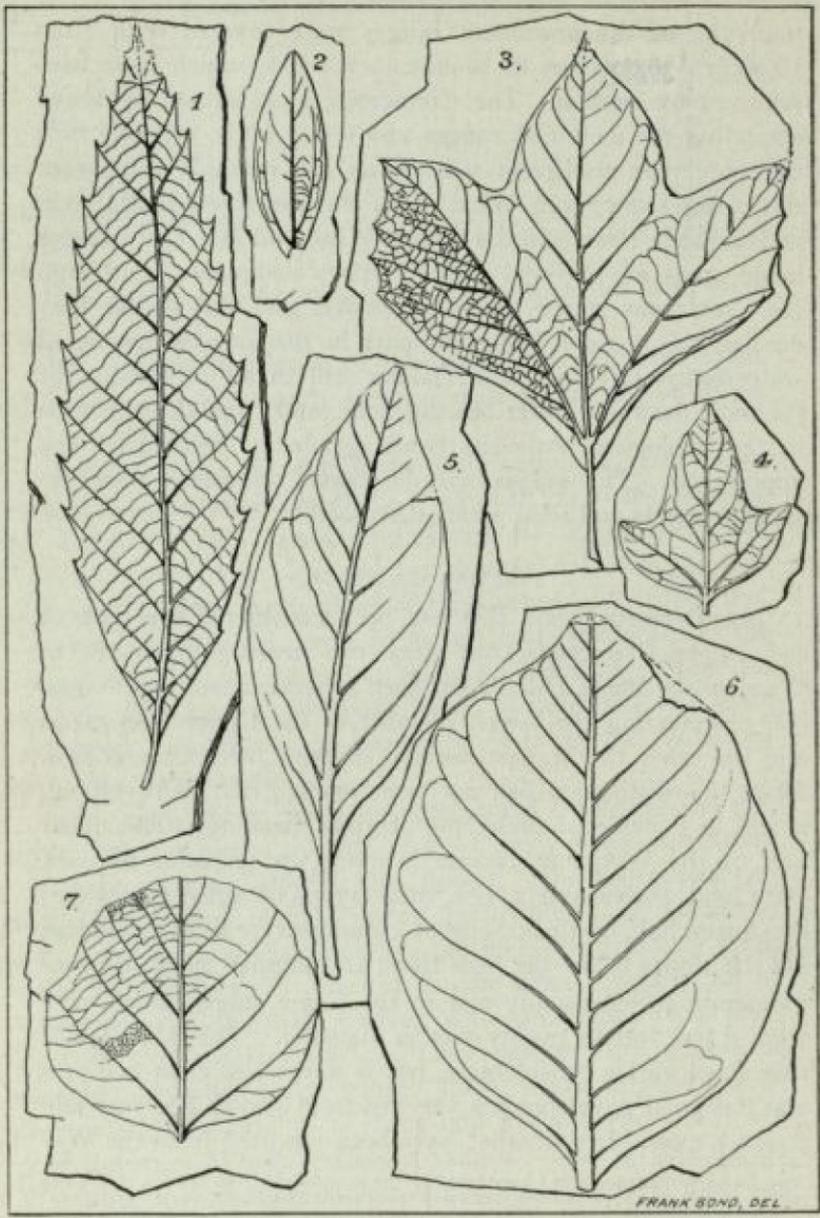
The invertebrate life was represented by numerous species which resembled the shell fish of today much more than the fauna of the Carboniferous period. The Cretaceous period of Wyoming opened under fresh-water lake conditions and closed in a similar manner, the lake being mostly fresh water but occasionally brackish at the close. Nearly all of Wyoming was originally covered with Cretaceous rocks during the coal-making period. Then dawned the period of mountain-making, which caused these strata, together with the underlying ones, to be bent into great folds, which are now the axes of our mountain ranges. During this period Wyoming was changed from a nearly level country, that was about sea level, to one of great mountains and valleys. Orig-

inally all of the prominent ranges were covered with from 10,000 to 30,000 feet of sedimentary rocks, which have been removed by erosion. The Cretaceous rocks are to be found encircling the mountain ranges and lesser folds. At one time they occupied the great valleys, as for example the Green river, Big Horn river, Wind river, Powder river, Platte river and Laramie river. In the Green, Wind and Big Horn basins large areas are covered with Tertiary sediment. Although the Cretaceous strata are so extensive, and very thick, they do not play a very important part in the artesian basins as water-bearing rocks. The Dakota will in all probability be the most desirable water-bearing zone, and from this upwards in the geological scale the bands gradually become of less importance. The stages will be taken up under their respective heads and their strata discussed.

THE DAKOTA STAGE.

Until recent years this has been considered the base of the Upper Cretaceous, but since the investigations of Dr. Ward in the Black Hills it has been separated into two stages, one representing the lowest member of the Upper Cretaceous and the other the highest horizon of the Lower Cretaceous. Since this distinction has not been worked out in Wyoming, it will be considered under the original meaning. The upper half of the Wyoming Dakota is made up of bands of dark clays and shales and a few thin layers of gray sandstone; the lower half of thick beds of conglomerate and sandstone. On the slopes below the beds there are angular blocks of conglomerate which usually rest in the Como stage, which vary from a few feet to twenty feet in diameter. The thickness of this stage varies considerable, but is never less than 200 feet and has local developments varying from 500 to 800 feet and possibly more. Few fossils* have been reported from the Wy-

*Since writing the above I have found in the sandstones of the Dakota, in Johnson county, a small pelecypod, probably belonging to the genus *Nucula*.



FRANK BOND, DEL.

CRETACEOUS.

SOME LARAMIE FOSSIL PLANTS.

[Explanation of Plate VI.]

- No. 1—*Quercus primoidalis*, Lesqx.
No. 2—*Cinnamomum scheuchzeri*, Heer. One-half natural size.
No. 3—*Sassafras cretaceum*, Lesqx.
No. 4—*Sassafras mudgei*, Lesqx. One-half natural size.
No. 5—*Platanus recurvata*, Lesqx.
No. 6—*Juglans debeyana*, Lesqx.
No. 7—*Populites cyclophilla*, Heer? One-half natural size.

oming rocks and these have been found about the Black Hills in Wyoming, and are all plants. In these rocks are found the first evidence of deciduous trees in Wyoming. The formation can best be determined by its lithological character and its position in reference to the Como stage of the Jurassic and the overlying Fort Benton shales. This is the great water bearing horizon of the Dakota artesian basins and is also a conspicuous water horizon throughout Wyoming. Springs of excellent water are of common occurrence in these rocks along the mountains. Some attention should be paid to the fact that this is the second great petroleum horizon in Wyoming and that it also contains valuable veins of coal in Weston, Crook and Big Horn counties, and probably in many others. Along the Rattlensake, Powder River, Dutton, Belle Fourche, Bonanza and Beaver oil basins the Dakota will contain inferior water unless it is found in some of the upper sandstones above the oil. The rocks of this stage were deposited in fresh or brackish water.

BEAR RIVER STAGE.

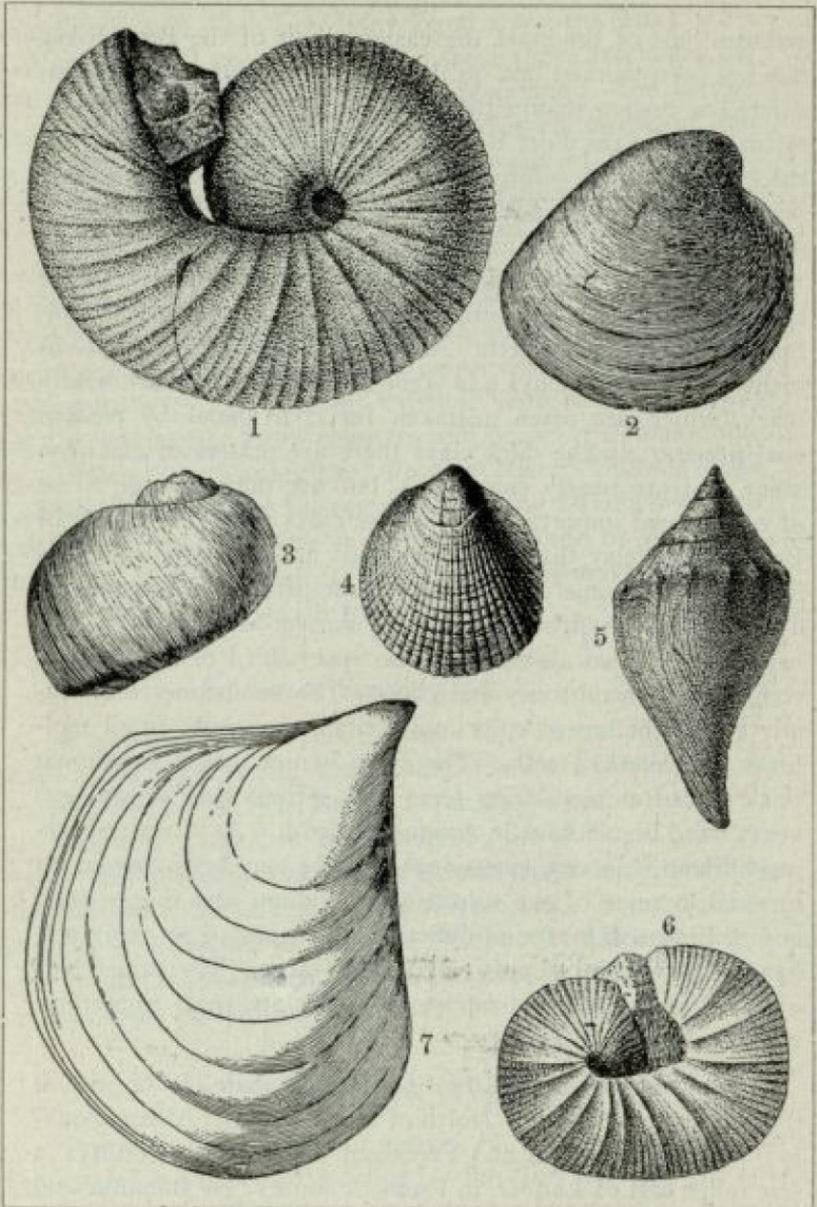
In southwestern Wyoming there is a formation that appears to be between the Dakota and the Fort Benton. It is characterized by an independent fauna and is coal bearing. It has been named the Bear River stage by the U. S. G. S. and it seems very probable that it is a distinct stage and should be included with the others of the Cretaceous. Some authors consider it a division of the Fort Benton. It has been found only in the southwestern part of the state and does not play an important part in our geology.

FORT BENTON STAGE.

Resting conformably, or nearly so, upon the Dakota of the eastern portion of Wyoming, is the Fort Benton. In the

western half of the state the eastern limit of the Bear River has not been worked out, so that the Fort Benton can be considered as resting upon either the Dakota or Bear River stage. At the base of the Fort Benton there is always formed a very thick band of dark colored fissile shales, which weather nearly white. These shale beds are usually 200 feet in thickness, and if they are highly inclined the slopes are always covered with fragments of the shale bands. Associated with these beds there are numerous impressions of fish scales, a few mollusks, and a few fish teeth. Above the shales there are prominent beds of dark clays and some shale bands that are nearly black, which are often mistaken for coal shales by eastern coal miners. In the dark clays there are masses of clay-iron stone that are nearly continuous, but not thick enough to be of commercial importance. In these clays are a few bands of Bentonite (a clay that has been called natural soap) which is destined to become a very important article of commerce. This clay is a hydrous, non-plastic variety which has an unusual power as an absorbent. The upper third of this stage is composed of sandstones and clays. The sandstones are usually of a light brown color and contain numerous fossil mollusks and sharks' teeth. The Fort Benton has a maximum thickness of at least 2,000 feet. Oil springs and natural gas vents have been found in several localities. As a water-bearing horizon it is very questionable. The clay beds contain an unusual amount of the sulphates of sodium and magnesium, and drilling will be found difficult on account of so many soft bands. The water supply will not be large. The upper half of the stage, when the sandstone bands are most numerous, will furnish the best water.

Typical exposures of the Fort Benton shale can be seen at the following localities: North of Hutton's lake, Albany county; at Brown's canon and Freezeout hills, Carbon county; a few miles east of Lander, in Fremont county; at Bonanza and



CRETACEOUS.
FORT BENTON FOSSILS.

[Explanation of Plate VII.]

These fossils are conditionally placed under the Fort Benton stage; realizing that the line between the Fort Benton and the Niobrara has not been finally fixed, and until this has been done we cannot say definitely what are Fort Benton and what are Niobrara fossils.

- No. 1—*Scaphites ventricosus*, M. & H.
- No. 2—*Cyrena securis*, Meek.
- No. 3—*Gyrodes depressa*, Meek.
- No. 4—*Cardium pauperculum*, Meek.
- No. 5—*Fasciolaria (Crytorhyhis) utahensis*, Meek.
- No. 6—*Scaphites warreni*, M. & H.
- No. 7—*Inoceramus fragilis*, H. & M.

two miles west of Cody, Big Horn county; southwest of Dayton a mile or so, in Sheridan county; at the Belle Fourche oil field, in Crook county; at Newcastle, in Weston county; along the north side of the Laramie mountains, in Natrona and Converse counties, and along the east side of the same range in Laramie county.

THE NIOBRARA STAGE.

We know less of the rocks of this stage than any other one of prominence in Wyoming. This is due to the nature of the strata, which in the southeastern part of the state have near their base a thick bed of yellowish-white chalk. This has yielded so readily to erosion that it is seldom seen outcropping. For miles along the foot of a mountain range the chalk beds have been entirely covered with soil. The thickness of this stage approximates 2,000 feet. When the chalk beds are exposed it can be considered sufficient evidence of the stage, for there are no other beds of chalk known in Wyoming. In the Tertiaries there are whitish, soft bands that have been called chalk, such as the many chalk bluffs, hills and mountains; but none of these are chalk and some of them do not contain any carbonate of lime. Above the chalk beds the strata are clays and shales chiefly, with a few bands of sandstone. None of these bands contain many fossils, and all that have been reported are invertebrates. In Kansas they contain great swimming Saurians (*Plesiosaurs* and *Mososaurs*) and also early birds that were provided with teeth. So far, in the development of the mineral resources of the state, nothing of economic importance has been discovered in the Niobrara. There are a few beds of oil sand, and these together with the clays, shales and chalk beds, will prove to be of value in the future.

This stage is on a par with the Fort Benton, so far as artesian wells are concerned. Good water will be found in the sandstones and chalks, but the clays and shales contain a

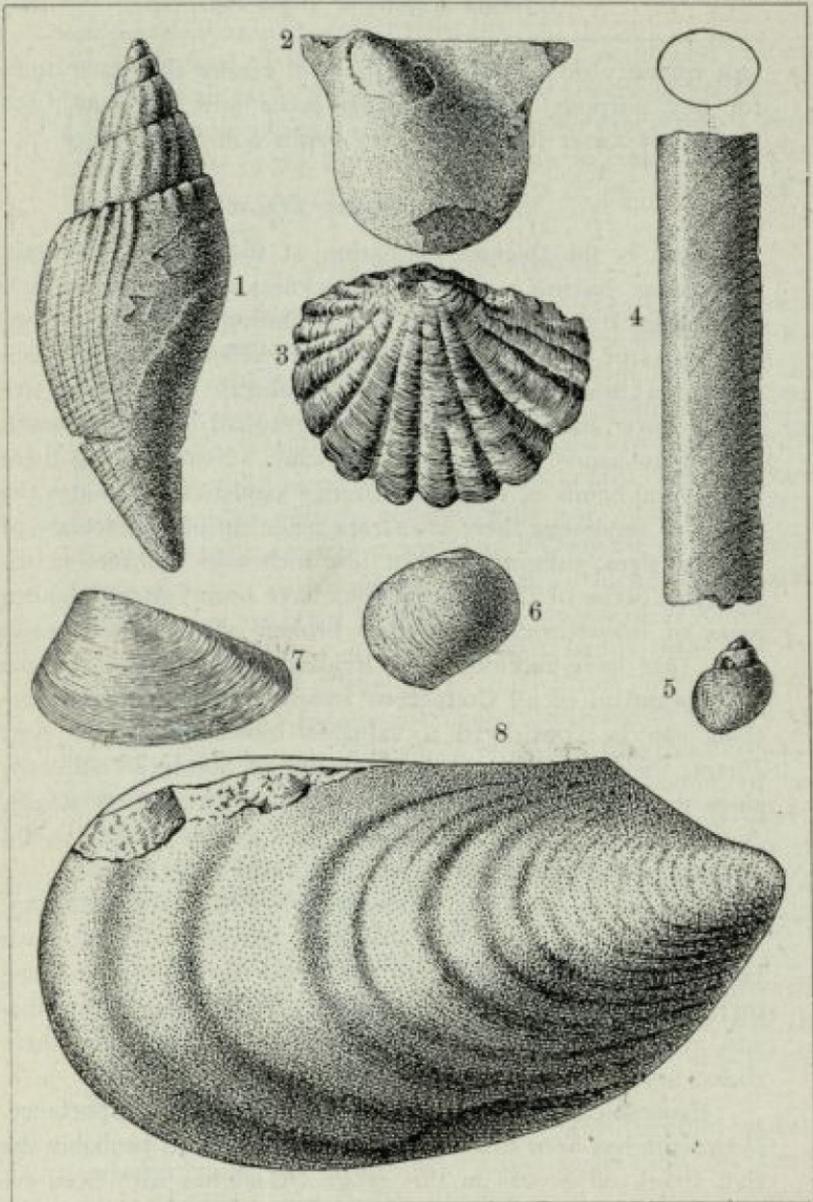
vast quantity of soluble salts that will render the water unfit for any purpose. While flowing wells will be found, the amount of water from any of the bands will not be large.

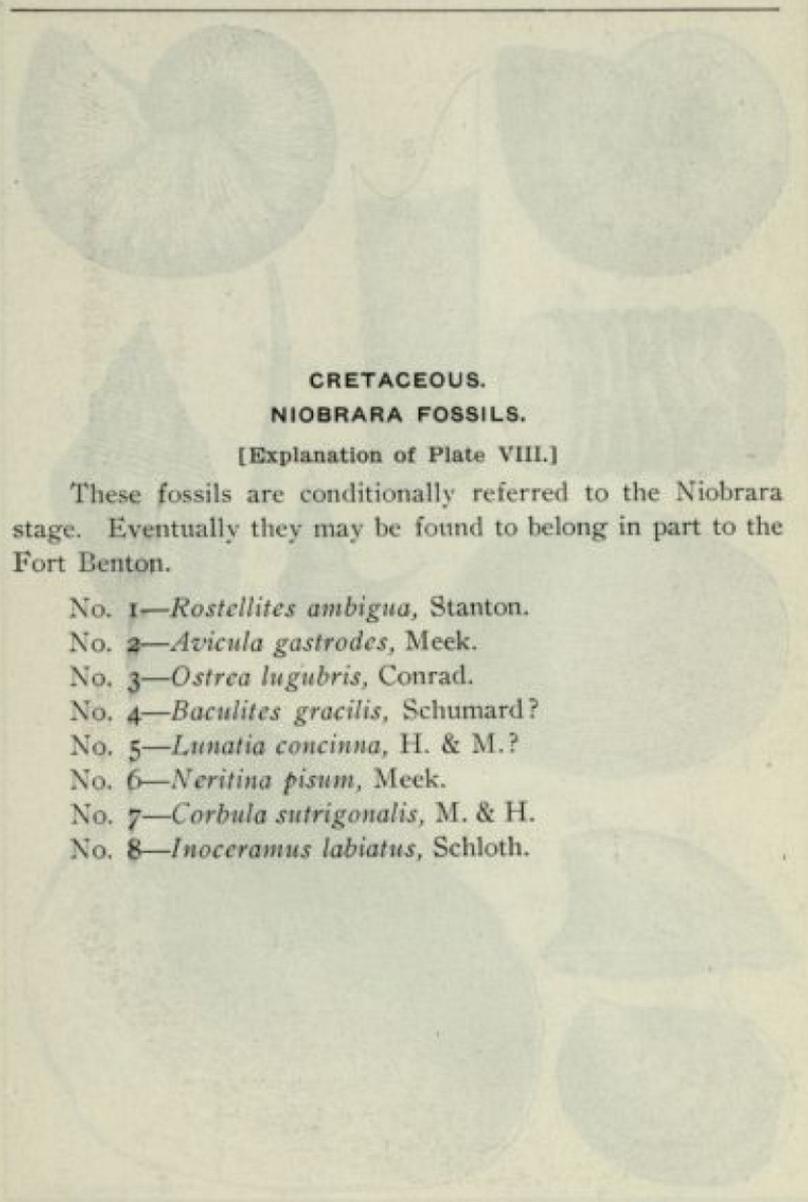
THE FORT PIERRE STAGE.

This is the thickest formation of the Rocky Mountain Cretaceous, having a maximum thickness of over 7,000 feet. It has been found along all of the Wyoming mountain ranges. The rocks of this stage are chiefly dark colored shales, which contain a few fossils, especially *Baculites*. The shales are in the lower half of the series and gradually change toward the top to bands of sandstone and clay. Near the top there are several bands of very fossiliferous sandstone. Besides the bands of sandstone there are strata made up of concretions of various sizes, ranging from a few inches to ten feet in diameter. Some of these concretions have been formed about a mass of invertebrates and when broken open contain specimens that have retained their iridescent luster and are the most beautiful of all Cretaceous fossils. While these concretions can be considered a valuable indication of the Fort Pierre, their presence can not be taken as absolute testimony, since there are concretions found in other Cretaceous stages. A few typical fossils associated with the concretions would furnish ample means for determining this stage.

The fossils associated with the Fort Pierre are numerous. There were many vertebrate animals, but few of these have been found in Wyoming. In the upper bands of sandstone there are many species of fossil plants. The invertebrate fossils, which are of greatest importance in identifying these rocks, are species of *Baculites*, *Inoceramus*.

Economically these strata are of considerable importance. Petroleum has been found in a few instances and probably the Salt Creek oil occurs in this stage. Coal has also been reported, but it is not definitely known that there are workable



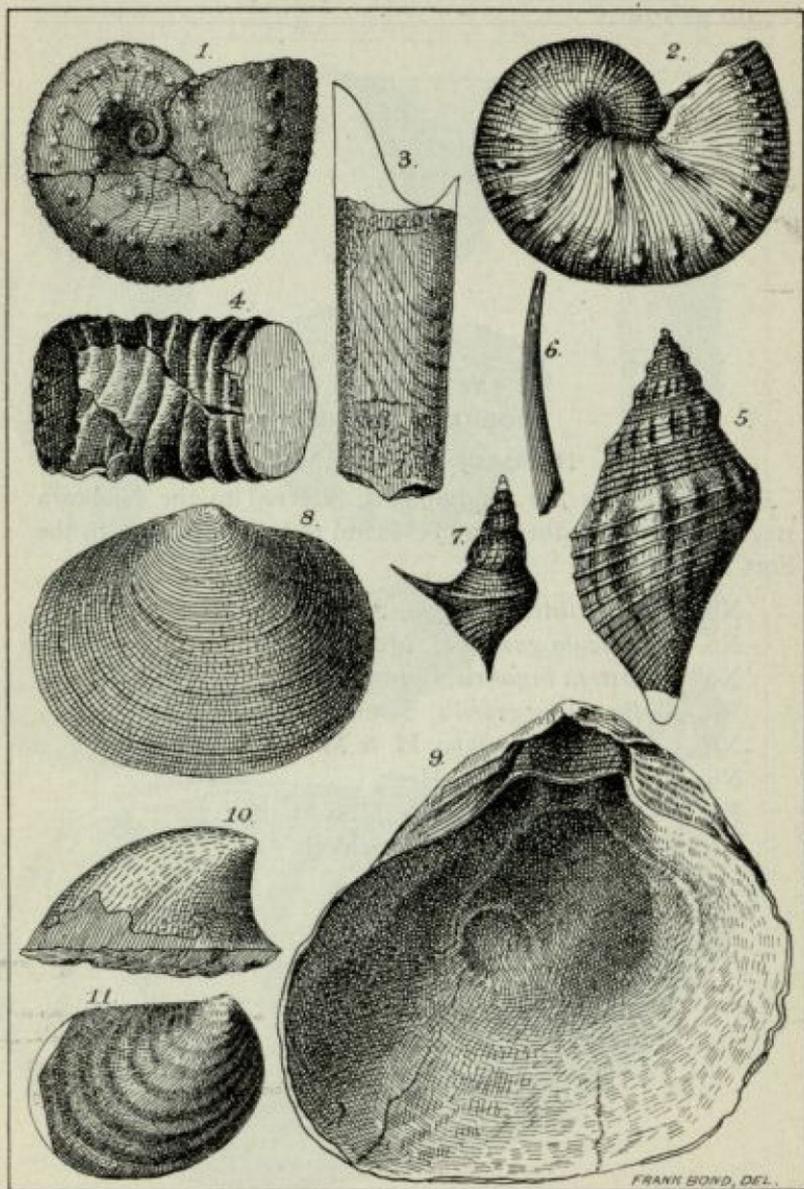


CRETACEOUS.
NIOBRARA FOSSILS.

[Explanation of Plate VIII.]

These fossils are conditionally referred to the Niobrara stage. Eventually they may be found to belong in part to the Fort Benton.

- No. 1—*Rostellites ambigua*, Stanton.
- No. 2—*Avicula gastrodes*, Meek.
- No. 3—*Ostrea lugubris*, Conrad.
- No. 4—*Baculites gracilis*, Schumard?
- No. 5—*Lunatia concinna*, H. & M.?
- No. 6—*Neritina pisum*, Meek.
- No. 7—*Corbula sutrigonalis*, M. & H.
- No. 8—*Inoceramus labiatus*, Schloth.



CRETACEOUS.
SOME FORT PIERRE FOSSILS.

[Explanation of Plate IX.]

- No. 1—*Placenticeras placenta*, var. *mercularis*, M. & H.
One-fourth natural size.
- No. 2—*Scaphites nodosus*, var. *brevis*, M. & H. One-half natural size.
- No. 3—*Baculites ovatus*, Say. Much reduced.
- No. 4—*Heteroceras angulatum*, M. & H. From a fragment. One-half natural size.
- No. 5—*Pyrifusus intertextus*, M. & H.
- No. 6—*Dentalium gracile*, M. & H.
- No. 7—*Anchuria nebrascensis*, E. & S.
- No. 8—*Lucina occidentalis*, Morton.
- No. 9—*Ostrea patina*, M. & H.
- No. 10—*Anisomyon borealis*, M. & H.
- No. 11—*Inoceramus cripsi*, var. *barabini*, Morton.

veins. Clay beds are very numerous, and all grades of clay are found, varying from that used for common brick to the best fire-brick clays.

On account of the enormous thickness of these strata, the formation is usually found in broad bands at the foot of the mountains. The sandstone strata alternating with bands of clay make the artesian conditions ideal, but the pressure will usually be found to be very slight. For this reason the Fort Pierre can not be considered as an important artesian well horizon. Again, the quality of the water is questionable. The shales contain vast quantities of soluble salts which in many instances make the water unfit for any use. Good water usually accompanies the sandstone unless found in the vicinity of coal and oil.

Typical Fort Pierre exposures can be seen north of Harpers, in Albany county; where the Cheyenne and Northern railroad crosses Horse creek, Laramie county; a few miles north of Ervay, Natrona county; west and south of Lander, west of Bonanza, and between Sheridan and the Big Horn mountains.

THE FOX HILL STAGE.

The Fox Hill and Fort Pierre stages are often combined under the name of Montana, but since these stages combined have a thickness of at least 12,000 feet, the terms Fox Hills and Fort Pierre include too great a thickness for a single stage and as soon as they are thoroughly known they will be further subdivided. The Fox Hills in Wyoming has a thickness of 5,000 feet, and probably there are local developments that will reach 6,000 feet. The strata resemble the upper portion of the Fort Pierre and are mostly bands of brown sandstone, alternating with dark clays and shales. Usually there are a few hundred feet of light colored sandstones near the base, and a very thick band of brown sandstone capping the formation. The sandstones are very fossiliferous and con-

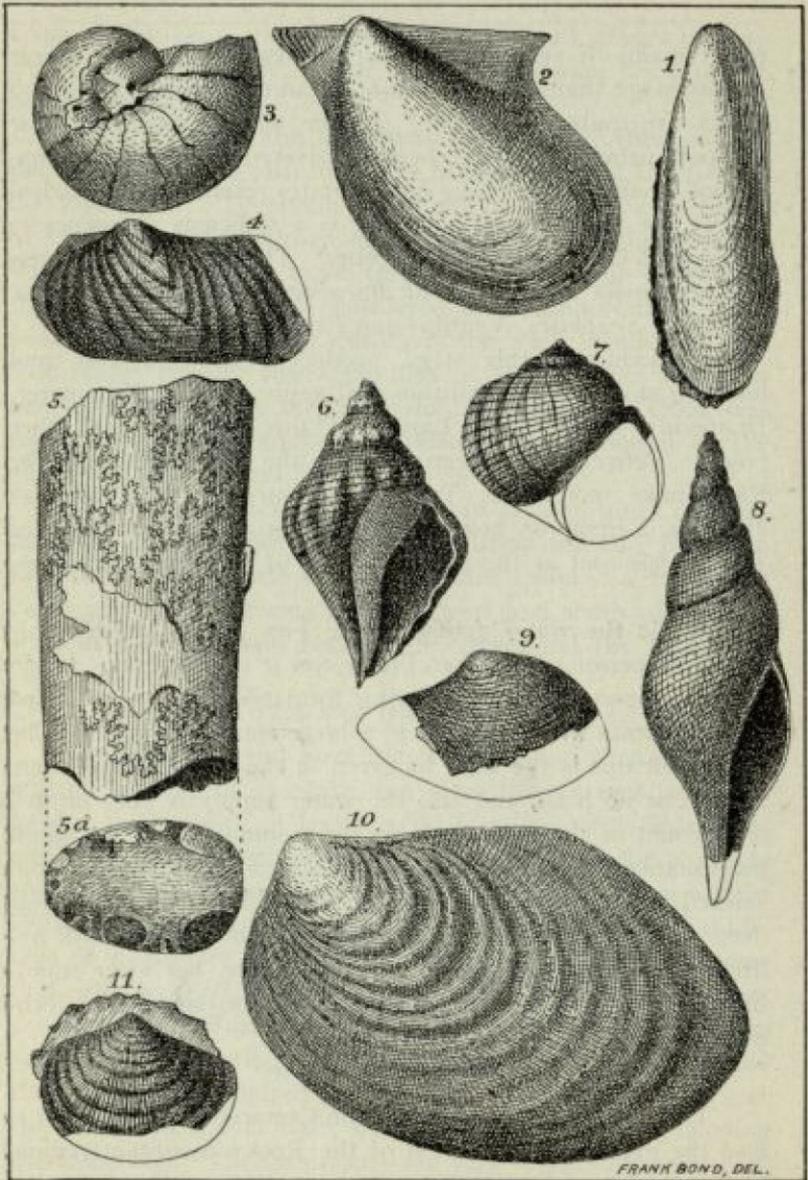
tain remains of vertebrates, invertebrates and plants. It was in this stage that the *Plesiosaurs* became extinct. The fossil leaves are quite remarkable. In the white sandstones near Harpers palm leaves have been discovered that have a diameter of twenty inches. The invertebrates resemble to a marked degree the Fort Pierre, but there is a sufficient difference to distinguish one stage from the other. The most common vertebrate fossils are species of *Baculites*, *Inoceramus*, *Ostrea*, *Anchuria*, *Scaphites*, *Nautilus* and *Pectunculus*.

Economically this stage produces coal, oil, clay and building stone. Very valuable coal veins occur at Kemmerer, Diamondville and on the Laramie Plains and at several other points. Petroleum has been found in the Fox Hills along the Rattlesnake mountains. Typical exposures can be seen at Harpers, Kemmerer, below Bonanza, above Dayton, south of Fort Steele and at the southern base of the Seminoe mountains.

While the water found in the Fox Hills sandstones is usually superior to the Fort Pierre, yet it is not ideal. It can be relied upon as a water-bearing formation, but wells drilled in these strata will seldom yield a large supply of water. The reason for this is the same as given in the Fort Pierre—there is little or no head, and also the water supply is very limited on account of the distance from the mountains and the slight precipitation. Wells drilled in coal and oil belts may be considered as almost worthless. At Almond a well 1,000 feet deep produces water highly charged with sulphuretted hydrogen. When first drawn it is unbearable, but after standing it is used for domestic purposes and also largely for locomotive work.

THE LARAMIE STAGE.

This is the closing stage of the Cretaceous period, and is also the great coal formation of the Rocky mountain region. Owing to its wide distribution, and variations lithologically,



CRETACEOUS.

SOME FOX HILLS FOSSILS.

[Explanation of Plate X.]

- No. 1—*Volsella attenuata*, M. & H.
- No. 2—*Pteria linguiformis*, var. *subgibbosa*, M. & H.
- No. 3—*Nautilus dekayi*, Morton.
- No. 4—*Goniomya americana*, M. & H.
- No. 5—*Baculites ovatus*, Say. Much reduced.
- No. 6—*Cinuli concinanna*, H. & M.
- No. 7—*Vanikoropsis tuomeyana*, M. & H.
- No. 8—*Fasciolaria culbertsoni*, M. & H.
- No. 9—*Tancredia americana*, M. & H.
- No. 10—*Inoceramus cripsii*, var. *subcompressus*, M. & H.
- No. 11—*Liopistha (Cymella) undata*, M. & H.

this vast accumulation of sediment, which is about one mile in thickness, has not been satisfactorily subdivided into lesser divisions. This will be done when the stage has been thoroughly worked over. At present it will be sufficient to suggest that there are upper and lower divisions, the upper, probably equivalent to the Fort Union* stage of early writers, containing the lignite coal veins, and the lower containing bituminous coal, as can be seen at the coal mines at Rock Springs and elsewhere. The strata of the entire stage are made up of sandstones, clays, shales and coal. The sandstones are usually friable, often thick bedded, and vary in color from light gray to dark brown. The clays are in great variety and are usually of a drab color. The shales are soft and friable.

Coal seams are numerous, and in some localities there are not less than 100 veins which vary in thickness from a few inches to 10, 20 and 40 feet. At Ham's Fork, Uinta county, there is a vein of coal 86 feet thick without a parting. Usually there are from six to ten workable veins in a field.

These rocks were deposited in fresh and brackish water and contain an abundance of fossils. Usually there are bands of shale or shaley sandstone associated with the coal veins that contain vast numbers of fossil deciduous leaves. There are also strata that are from six to twelve feet in thickness that are made up of oyster shells. There are also many other invertebrate fossils, especially many species of *Unio* (the common fresh water clam). With this life there are many species of land vertebrates. Chief among these were some large

*Many geologists will object to my placing the Fort Union beds in the Laramie. They were so considered by many of the early geologists, who have had an opportunity to study the Fort Union formation in the field as well as to study the fossil remains. The paleobotanists have practically agreed that this formation is Eocene. I should like to see a consensus of opinions from all branches of paleontology, before this formation is finally considered to belong to the Cenozoic era. One point worthy of consideration in connection with this problem is the fact that, thus far in the study of this formation, no one has reported a mammalian fauna. It would seem that if such exists there has already been sufficient field work done to discover it. If it ever existed during the deposition of the Fort Union sediments, there is no reason why some of the remains should not be present, for these beds are as favorable to the preservation of fossil remains as any other formation in the west. The presence of both plant and invertebrate remains is ample evidence on this point. Without the presence of a mammalian fauna, I would prefer to consider the Fort Union the highest member of the Cretaceous.

Dinosaurs. The largest one was much larger than an elephant and had a large head provided with three horns. These horns were located above the eyes and on the end of the nose. The remains of this huge creature have been found in great abundance in Converse county. There were also several other kinds of *Dinosaurs* living at this time, but they all became extinct at the close of the Laramie. There were also many species of very small mammals.

The Laramie formation is found in every county in Wyoming. The towns of Sheridan, Buffalo, Douglas, Glenrock, Carbon, Hanna, Black Buttes, Rock Springs and Meeteetse are located on these rocks. From Douglas one can go north to the Montana line and walk all the way on the Laramie coal measures. They cover nearly all of the Powder River valley, extending westward to the Big Horn mountains. The most of the coal mined in Wyoming comes from the Laramie rocks; in fact, they cover or extend beneath one-half of this state. At the close of this stage the Rocky mountains were made. Prior to this period Wyoming had been either a sea or a low land mass for geological ages; now these rocks were folded by lateral pressure and the folds soon emerged into long ranges like the Big Horn, Wind River and Medicine Bow mountains. The mountain-making caused many changes. The low swamps of the Laramie were converted into broad valleys and high mountain ranges. This change was sufficient to cause the disappearance of nearly all of the forms of life that inhabited Wyoming during the Laramie stage. It also caused a marked change in the climate, which affected the life and formed such basins as the Green River and Big Horn, which were cut off from the sea and which were, in the following stage, large fresh water lakes. The Laramie not only marks the closing of the Cretaceous system but also of the Mesozoic era.

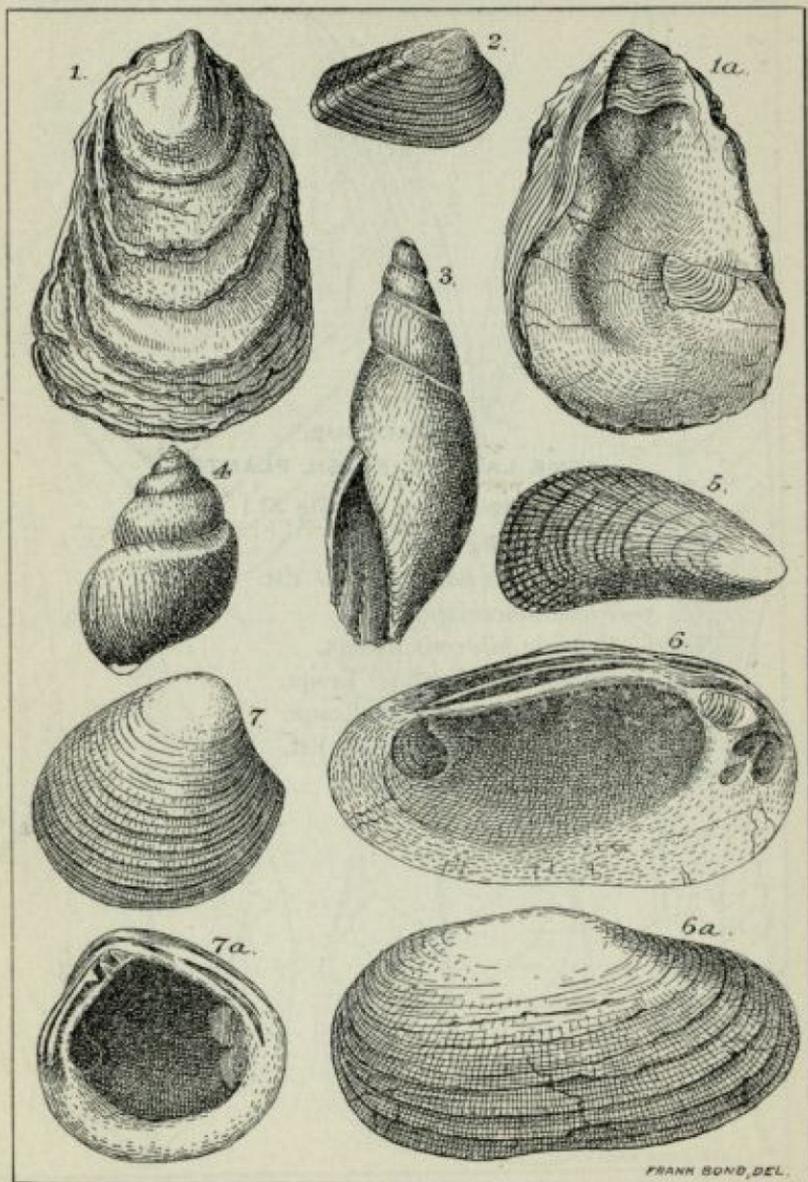
This formation is also the last one in the ascending geo-



CRETACEOUS.
SOME LARAMIE FOSSIL PLANTS.

[Explanation of Plate XI.]

- No. 1—*Quercus drymeja*, Ung.
No. 2—*Eucalyptus haeringiana*,? Ett.
No. 3—*Ficus lanceolata*, Heer.
No. 4—*Sequoia biformis*, Lesqx.
No. 5—*Cinnamomum affine*, Lesqx.
No. 6—*Apeibopsis discolor*, Lesqx.
No. 7—*Cillicoma microphylla*,? Ett.
No. 8—*Salix angusta*, Al. Br.



SOME TYPICAL FOSSILS FROM THE LARAMIE STAGE.

[Explanation of Plate XII.]

- No. 1—*Ostrea glabra*, M. & H.
- No. 1a—*Ostrea glabra*, interior view.
- No. 2—*Corbula subtrigonalis*, M. & H.
- No. 3—*Bulinus atavus*, White.
- No. 4—*Viviparus cousi*, White.
- No. 5—*Volsella regularis*, White.
- No. 6—*Unio danae*, M. & H.
- No. 7—*Corbula cleburni*, White.
- No. 7a—*Corbula cleburni*, interior view.

Note.—No. 4 on the opposite plate is in all probability a species of fresh water mollusk that belongs to the Bear River stage, but has often been referred to the Laramie. It was a mistake in placing it with the typical Laramie fossils, and should be eliminated.

logical scale in which artesian wells may be looked for, and in this the conditions are not favorable for important wells or for good water. Generally speaking, the base of the Laramie strata is a considerable distance from the mountains and the water supply is very limited. The dip of the formation along most of the ranges is slight, and there is not sufficient elevation of the lower bands to produce very much pressure. On account of the coal, all of the water coming in contact with coal veins is very poor. It is unfit for man or beast and is very often so charged with salts of soda and magnesium as to render it unfit for irrigation. Small flowing wells will be found about nearly all of the basins. Already wells have been drilled in the Laramie at numerous places and there are flowing wells at Rock Springs and Buffalo. The water at Buffalo is very good and at Rock Springs very poor.

Cenozoic Era.

After the completion of the Rocky Mountain uplift, and when the ranges were covered with sedimentary rock to a thickness varying from 10,000 to 25,000 feet, the Cenozoic era dawned. The changes wrought since the commencement of mountain making were so vast that neither land nor sea corresponded in any way to the previous condition. The life also changed so as to form a great break in its development. This break has not been, and possibly may never be, accounted for. The Mesozoic was the age of reptiles, but there are comparatively few found in the Cenozoic, and mammals replace them. The largest mammal known in the Cretaceous was not larger than a rat, but in the Cenozoic basins, at the very bottom of the strata, are found large mammals, and in the Eocene period

they are found of elephantine size. The Cenozoic has been, and probably always will be, known as the age of mammals. In these strata are found the ancestral types of our modern animals, such as the horse, wolves, camels, cats, deer, rhinoceros and monkeys, together with a wonderful fauna that has long been extinct. In Wyoming, the early Cenozoic formations are confined to the basins that were made by the great folds which produced the mountains, such as the Big Horn, Wind River and Owl Creek ranges. Later these become dry and the Cenozoic fresh water lakes extend from the Laramie mountains eastward into Nebraska and Dakota. The sediment deposited was largely clay, sand and shale, which seldom formed a hard rock. Since these beds were deposited after the mountain making, they are unconformable with the Mesozoic, the Mesozoic usually dipping from 10 to 80 degrees and the Cenozoic lying nearly horizontal upon the upturned edges. This great unconformability is the only very marked one in the Rocky Mountain geology above the great unconformability between the Algonkian and Cambrian, and in all cases will serve as a guide to separate the rocks of the Cenozoic and Mesozoic eras.

Another characteristic feature is the almost universal "bad land" topography, typical examples of which can be seen in Goshen Hole, Bates Hole, Big Horn Basin, Green River Basin and north of the Rattlesnake range. The "bad lands" are usually sections almost devoid of vegetation, with narrow, deep gulches, which are often small canons, bounded by great walls that are nearly vertical, and culminating in tower and castle-like formations. Now and then these castellated terraces merge into imaginary crumbling cities and villages and make some of the most fascinating scenery in the state. There are also many places where the water has burst forth from the base of a high bluff and caused a great cavern leading backwards and upwards to open into the soft rock to the sur-

face. These caverns are sometimes two or three hundred feet in length and are large enough to admit a man. They are caused by the water settling on the surface and coming in contact with the sandy formation, causing it to flow like a stream of very soft mud.

Following the Tertiary period of the Cenozoic was the Pleistocene, in which great changes were wrought. The climate of North America, as well as of the Orient, suddenly changed, and great ice sheets commenced to accumulate in the north and move southward. This was the glacial period, and the ice sheet extended as far south in the eastern part of the United States, as the Ohio river, but not nearly so far in the west. These conditions changed everything. The animal life that could not or did not migrate became extinct. The flora and fauna disappeared. Following this period of devastation was one of the retreat of the glaciers and the establishment of modern conditions.

The Cenozoic formations do not enter into any of the artesian basins of the state as important factors; but slight flows of water may be found in them. In many instances Tertiary rocks have completely covered thousands of square miles of earlier strata, which otherwise would have been productive territory. In a few places it will be found advisable to pierce the Tertiary where it is thin and secure artesian water in the earlier rocks. For example, along the south side of the Big Horn range, near Lost Cabin, near Oregon Buttes and in Goshen Hole.

THE TERTIARY PERIOD.

CLASSIFICATION OF WYOMING TERTIARY.

		Thickness of stages in feet.	
TERTIARY.	{	Pliocene?	
		Miocene ..	Long Fork 500
		Oligocene .	White River 1500?
			Bridger 1500?
		Eocene . . .	Green River 1000
			Wasatch 1000

The Eocene formations of Wyoming are confined chiefly to the Green River, the Wind River and Big Horn basins, which were fresh water lakes during the early and middle Eocene stages. While these lakes were in existence there were Tertiary Eocene seas in which sediments were being deposited, along the southeastern coast of the United States and also along the Pacific Coast region, as well as at numerous other places in the world. The earliest stage of the Eocene which occurs, so far as known, has been found only in New Mexico, and is called the Puerco.

THE WASATCH STAGE.

In Wyoming the Wasatch is the earliest representative of the Eocene and is composed of variegated beds of clay and sand with occasional bands of sandstone. The clays are of a dark red, shading into pink, and in places yellow and brown. The sands are light colored and so soft that a rain storm will cause them to run like a stream of water. This is the lowest Tertiary formation of both the Green River and Big Horn basins, and has a thickness of about 1,000 feet. Estimates have been made that placed the thickness of the Wasatch at from 3,000 to 4,000 feet, but I have been unable to confirm these. This stage is characterized by the remains of many turtles, crocodiles and mammals. Some of the latter were very large, almost of elephantine size, but a description

in a brief way would draw out this section to an unreasonable length, since mammals were the dominant life.

THE GREEN RIVER STAGE.

The Green River rocks differ entirely from the Wasatch, and they also differ in the kinds of fossils found. A typical section of the Green River stage is exposed at Green River, on the Union Pacific railroad. The rocks are shales or shaley sandstones capped with a thick band of brown sandstone. The shales are mostly bituminous, and there are bands that contain as high as 45 per cent of gas and oil. In many localities the shales are found in very thin layers, and the bedding has been so perfect that they separate into large plates that are from a quarter of an inch to an inch in thickness. The surfaces of these plates are so smooth that they may some day be of commercial importance. The thickness of this series has also been greatly overestimated by early geologists, and it is more than likely that it does not attain a thickness at any place of over 1,000 feet. Besides being made up of shales, they also have many other peculiarities that will aid in identifying them. These shale beds contain many petrified fish, which are so perfect and remarkable that they are known the world over. The fish are closely related to the modern forms and vary in size from a few inches in length to five and a half feet, and when taken out and properly cleaned, the remains are a mahogany color set upon a slab of creamy white shale. Besides the fish there are found insects, birds, leaves and crocodiles.

It is worthy of special note that no mammalian remains have ever been discovered in this formation.

THE BRIDGER STAGE.

The Bridger stage rests upon the Green River shale and the strata are variegated clays, sands and sandstones. The

clays near the base of the stage are a vermilion red and shade into or alternate with lighter colored bands. Toward the top the rocks change into bands of sandstone and clays and often quite thick beds of breccias and conglomerates. It exceeds either of the previous stages in thickness, but absolute measurements are not at hand. The greatest area of Bridger is in southwestern Wyoming, but there are important escarpments in the Wind River basin and Red desert.

The fossils consist of a few fresh-water invertebrates, and monkeys, carnivores, insectivores, ungulates, rodents, birds, turtles, snakes, crocodiles and some large types of mammal life.

The Bridger represents the closing stage of the Eocene in Wyoming, but to the southward and across the Uinta mountains there is yet another stage known as the Uinta, which represents the highest horizon of the Eocene in the mountain region. This group might have covered a portion of southwestern Wyoming during the Miocene and Pliocene times, but was too soft to withstand the great erosion. At the close of the Eocene the basins in which the sediment had been accumulating drained, the Green river draining the southern basin and the Big Horn draining the Big Horn and Wind River basins.

OLIGOCENE STAGE.

There was, however, a great fresh water lake being formed to the eastward of the Laramie mountains and the Black Hills, and in this sediment continued to form.

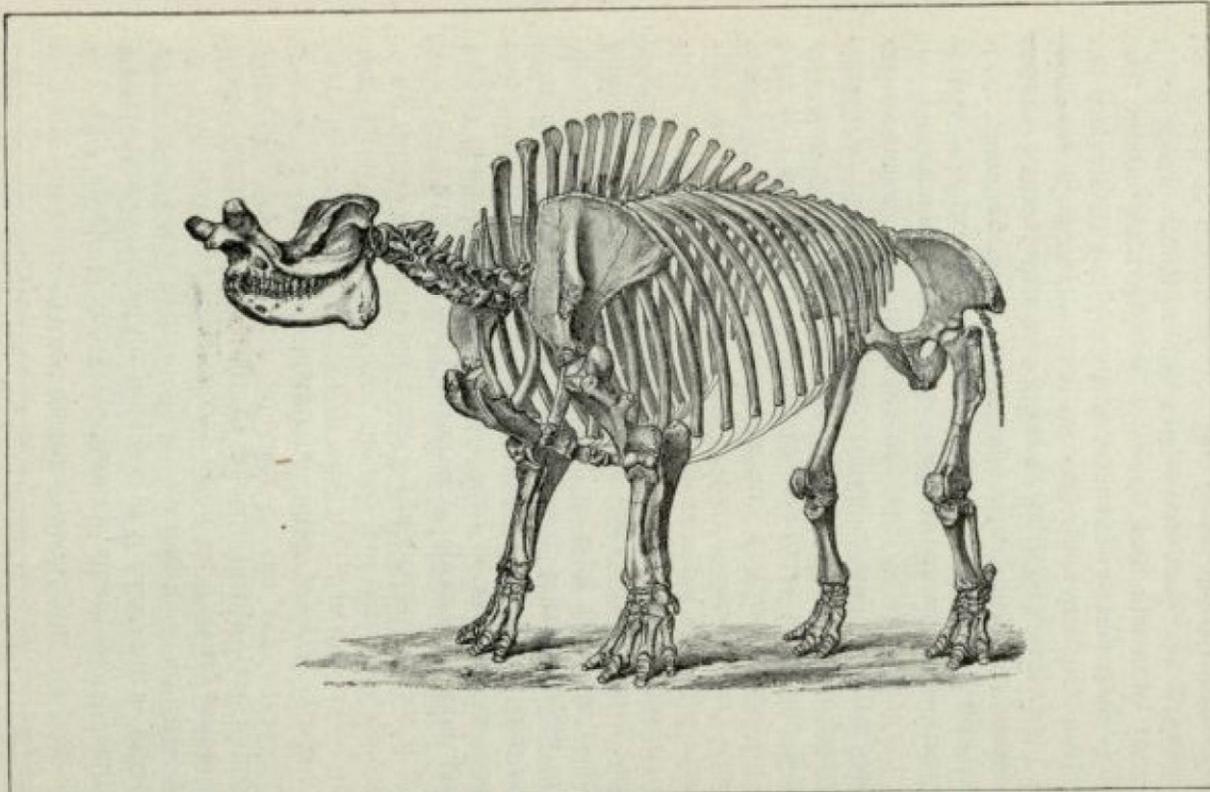
The lowest stage of this lake is known as the Oligocene, and beds are usually called the White River formation. They are largely clays and sands and weather into the typical "bad lands." There are only slight exposures of the Oligocene in Wyoming, since the strata have been covered with Miocene, and unless this covering has been removed the only exposures

are found at the base of the Miocene bluffs, where the Oligocene rests upon the Cretaceous. The best exposures are found in Converse county, along the tributaries of the Cheyenne river, and in Bates Hole. The beds vary in thickness from 300 to 500 or more feet. In other localities there are numerous invertebrate fossils and also a flora, but in Wyoming these are absent. The life found in the Oligocene in this state is chiefly mammalian. There were also numerous turtles and a few crocodiles. Carnivorous animals were numerous and were represented by several types, especially cats. The three-toed horses were common. There were many animals that belong to the rodents (gnawing animals). The largest animal was the huge *Titanotherium*, which was herbivorous and nearly as large as an elephant.

THE MIOCENE STAGE.

The Oligocene and Miocene were practically deposited in the same basin, the Miocene representing the last stage in the history of the great fresh lake. The Miocene rocks are chiefly light colored and in southeastern Wyoming they are capped with a thick bed of conglomerate which extends eastward into Nebraska. The strata are quite soft and easily eroded into picturesque columns and spires, which are so well developed in the "band lands." The Miocene rocks have their greatest development east of the Laramie mountains, where they approximate 1,500 feet in thickness. They are also known in the Yellowstone park and in the Saratoga valley.

Life was very abundant. In the Yellowstone park a large flora has been discovered that is very much like the plants of today. Deciduous trees were numerous. Among the mammals which were very common were wolves and tigers of very ferocious types, camels, horses, mastodons, elephants (primitive), and rhinoceroses, the remains of which are common in the Wyoming formation.



Titanotherium robustum, after Marsh. This was an animal of elephantine size that lived in vast numbers in Wyoming during the Oligocene of the Tertiary.

THE PLIOCENE STAGE.

This epoch is in all probability absent in Wyoming. Early writers referred the beds east of the Laramie mountains to Pliocene, but it is definitely known that these are Miocene.

This was the culminating epoch of the Tertiary and practically introduced the types of animals that we are familiar with today.

THE PLEISTOCENE PERIOD.

The Pleistocene or Quarternary represents recent geological time. Man was probably born on earth at the commencement of this period. The interior fresh water lakes had been drained and elevated during the Pliocene epoch, and Wyoming was no longer composed of high mountain ranges separated by beautiful fresh-water lakes, about which were magnificent forests that were swarming with the greatest variety of mammalian life. Conditions changed when the whole state was elevated some three or four thousand feet, which caused it to become an arid plateau. Our mountain ranges were very different from what they are today, since they were very much higher, probably over 5,000 feet above the present elevations. The valleys were also higher and the great deep canons had not been hewn out of rock.

The commencement of the Pleistocene was marked by the glaciation of the greater part of North America, the great ice sheet extending down to the Ohio river and as far west as eastern Kansas; thence northwest to British America. In Wyoming glaciers existed at the same time, but they were of the Alpine type and did not move down the mountain slopes and fill the large valleys. Glaciers were numerous in the Wind River mountains, the Yellowstone park, the Absaroka, the Shoshone mountains, the Big Horn and Medicine Bow

mountains. Glaciers also reached the Wyoming line from the Uinta mountains, in the southwestern part of the state. At present there are a few small remnants of these glaciers in our highest mountains. The glacial period comprised many intervals in the eastern part of the country, but no divisions have been discovered in Wyoming. The first stage of the Pleistocene was one of grinding down the high mountain ranges, of leveling rough country, and the second of covering the rocks with soil, and later by establishing perfect drainage systems and perfecting climatic conditions, which was preparing it for the use of man. During the first part of this period the hairy mammoth and mastodon lived, and with them horses, bison, bears, wolves, tigers and numerous other animals. Not many of the early Pleistocene animals have been found in Wyoming, but no doubt there are vast fields that will yet reward the persevering scientist. The remains of elephants have already been discovered and in some of the caves numerous animals will probably be found that belong to this very period.

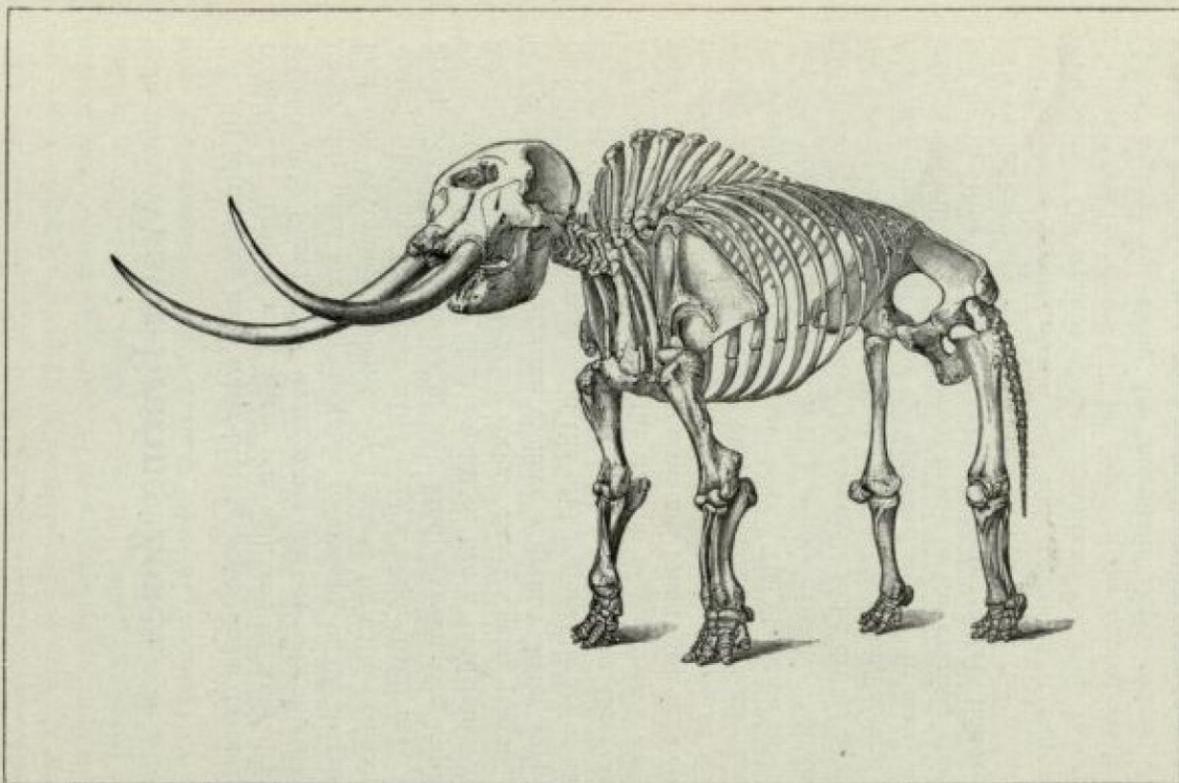
This terminates the geological sketch. It has been exceedingly brief, but it is hoped that enough has been said to enable the citizens of this state to decipher, in part at least, the geology about their own homes and to utilize this information in studying the questions pertaining to artesian basins.

There is one other matter that should be referred to. The lessons taught in the study of geology are indeed many and as a rule they present many interesting phases. In reading or studying geology, consider these few points at least.

This world of ours has not always existed; that it has in some very remote age been created. That originally there was no life on this sphere—that life was born and at the first it was extremely simple; but as geological ages rolled by it became more and more complicated until finally man appeared as the culminating event.

The subject of historical geology deals with the development of life as the records are found in the rocks. In fact, it is the history of the world's development. The history had for its author the Creator and Ruler of this universe—a history written by God Himself, undefiled and undefilable by man.

To those who are interested in the study of geology and wish to perfect themselves in the science, I respectfully refer them to the text-books published by Dana, LeConte and Scott.



Mastodon americanus, Cuvier. The largest mammal that lived during the Pleistocene.
Very common in America.

Water-Bearing Zones.

All formations have water-bearing zones under favorable conditions. Drill a well where one will, and at some depth water will be found. The water zones that are to be discussed under this head are the favorable formations in the artesian basins of Wyoming. Sometimes a whole formation contains water, while on the other hand only a single band may be productive. Porous rocks of any kind between two impervious strata form the ideal condition, hence sandstones are often known as water-bearing rocks. Besides being porous, it is necessary for the stratum to have a greater water supply than the rainfall furnishes, in the arid regions, before it can be worthy of consideration. In an artesian basin there are two principal ways in which the stratum may gather a water supply. The most important sources are found high up along the ranges, where the precipitation is much in excess of that of the valleys, and where the melting snows constantly feed the stratum so long as the snow lasts. The elevation of the stratum not only provides it with a supply of water, but also furnishes hydrostatic pressure for the wells to be drilled along the foot of the mountain or in the valley. A second source is from the streams that cross the upturned strata. In many instances we will find a good-sized brook in the granitic areas, but by the time the stream has passed over a few hundred rods of sedimentary rocks, on edge or nearly so, the volume will be found greatly diminished and sometimes it entirely disappears. On account of these conditions the most favorable water-bearing zones will be found in the formations that extend highest up along the mountain slope, unless the rocks are faulted or so eroded as to allow the water to escape

near the base of the mountain and prevent storage. There are also other considerations to be taken into account that pertain to the water zones. It is not simply water that is needed, but it must be sufficiently pure to be utilized for town, stock and irrigation. In order to meet these requirements it must not contain much mineral and be comparatively free from sulphur and entirely devoid of petroleum. All of these are associated with wells and springs in Wyoming. A well at Green River contains 24 per cent of sal soda; a spring near Beaver oil basin contains 10 per cent of sal soda; a well on Twin creek flows oil and sulphur water, and many wells at ranches all over the state have had to be abandoned on account of the salts of soda and magnesium. There are a few general rules that can be applied to the water-bearing rocks of Wyoming. The Paleozoic* rocks contain the purest water, and it is always good unless found in the regions where petroleum occurs, or occasionally contains a little common salt. The water is usually hard, since it contains considerable lime. The Paleozoic is also the most desirable since it will be found to furnish the largest flows. In the Mesozoic, waters usually carry large percentages of salts, especially sulphates of sodium, calcium and magnesium. Wells drilled at random in these rocks will as a rule contain inferior water and in many cases it will be found unfit for any use. The choicest bands in the Mesozoic are Triassic and the Dakota of the Cretaceous. The Triassic yields poor water for household purposes when the well receives a water supply from a gypsum bed, but it is in no way detrimental for irrigation. Occasionally a flow of salt water is encountered in the Dakota. Above the Dakota the chances to secure good water diminish, and anyone drilling in any of the Cretaceous rocks from the Benton up should consider that the chances to secure poor water are greater than those to secure good. Especially is this applicable to coal regions. There

*Earlier rocks are not considered under this head.

is, however, most excellent water to be found in the thick bedded sandstone strata of all of the stages. None of these zones will, however, compare in importance with the Paleozoic, since the outcrop is usually along the foot of the mountain and in many instances miles away from the range. This not only lessens the pressure of the water-bearing zones, but on account of the slight rainfall the water supply is also very limited. Occasionally the diminution in the water supply may be augmented by some of the streams issuing from the canons. There is a general rule to follow when considering the production of the various water-producing bands. Cambrian can be considered of greatest importance and from these beds the quantity will gradually diminish as one rises in the geologi-

A Table Showing the Chemical Analyses of Water
Analyses by

Name of Well or Spring	Name of County	Name of City if Any	Geological Horizon	Silica SiO ₂	Oxides of Iron and Aluminum Fe ₂ O ₃ and Al ₂ O ₃	Potassium Chloride K Cl	Sodium Sulphate Na ₂ SO ₄
Davis	Albany		Archaean? . . . . .	.420	.087		.974
Pelton	Albany		Triassic	1.409	.082		2.612
Rawlins No. 1.	Carbon	Rawlins	Carboniferous . . . . .	.676	.064	.886	
Rawlins No. 2.	Carbon	Rawlins	Carboniferous . . . . .	.612	.082	.560	5.452
Laramie Springs	Albany	Laramie	Permian . . . . .	.507	.233	.111	.233
University	Albany	Laramie	Permian . . . . .	.950	.047	.210	.373
Filmore		Filmore	Laramie	5.767	.624	1.318	14.124
Experiment Station	Sheridan		Laramie . . . . .	.881		1.726	29.461
Hot Springs	Carbon	Saratoga	Miocene	7.371	.174	2.414	27.117
Hot Springs	Big Horn	Thermopolis	Triassic	4.986	.137	10.249	15.170
Box Springs	Fremont		Laramie	2.461			1.971
Genteeey	Natrona		Dakota . . . . .	.111	.146	.566	48.804
Alkali Spring	Fremont		Eocene	3.324	.111	1.865	.732
Hot Springs	Natrona	Alcova	Carboniferous	2.315	.128	1.464	4.486
Warm Springs	Laramie		Carboniferous	2.245	.333	.618	4.350
Salt Springs	Weston		Dakota	2.052		3.036	
Lithia Water	Albany	Laramie	Dakota	2.293		1.627	79.333
Bitter Creek	Sweetwater	Bitter Creek	Eocene . . . . .	.230			25.050
Red Desert	Sweetwater	Red Desert	Eocene . . . . .	.060			68.250
Carbon	Carbon	Carbon	Laramie?				25.940
Harpers	Albany	Harpers	Fox Hills				49.700
Wamsutter	Sweetwater	Wamsutter	Laramie				54.53
Cherokee Spring	Carbon	Near Rawlins	Archaean?				
Piedmont	Uinta	Piedmont	Eocene				
George	Johnson	Buffalo	Laramie	1.63	.29	1.36	
Experiment Farm	Albany	Laramie	Jurassic	24.64			127.36
Horse Creek	Laramie		Miocene?				

would not be sufficient evidence to warrant anyone in calling it a water-bearing zone. Below the mountain slopes the Triassic red sandstones and the Dakota sandstones usually have springs accompanying them.

The Cenozoic will not be considered under this head, since few if any artesian wells will be found in these rocks. So far as investigation has gone, the Tertiary waters are generally impregnated with sodium carbonate and sulphate, which has been found so plentiful as to render them useless for any purpose unless it be for the manufacture of soda.

The following table will give some information as to the general nature of water that may be found in the various geological horizons:

MIOCENE.—As a rule the water is very good. (In Dakota this formation yields very poor water).

OLIGOCENE.—Water contains soda salts and magnesium generally; but good water is found occasionally.

EOCENE.—Very inferior water, salts of soda being the most common; water often alkaline.

LARAMIE.—Water very poor, but often good for irrigation. Sulphur water common, also salts of soda, lime and magnesium. Occasionally good water in thick bands of sandstone.

FOX HILLS.—Both good and bad water, about equally divided.

FORT PIERRE.—Very poor water as a rule.

NIORARA.—Good water is found in the chalks; otherwise inferior.

FORT BENTON.—Usually inferior water.

DAKOTA.—Excellent water in the sandstones, usually quite soft. Sometimes brackish. In the oil fields usually sulphurous and otherwise disagreeable.

JURASSIC.—Usually very poor; a few bands of sandstone furnish fair water.

TRIASSIC.—Excellent water except in connection with the beds of gypsum.

PERMIAN AND CARBONIFEROUS.—Excellent hard water, except in the oil districts. Brackish water found at Rawlins.

DEVONIAN.—?

ORDOVICIAN.—Excellent hard water.

CAMBRIAN.—Excellent water. Near the base of the beds usually quite soft.

ALGONKIAN.—Very good water except in mineralized districts. Where the water comes from any great depth it contains various salts.

ARCHÆAN.—The purest water found in the state except in mineralized districts.

SECTION I.



Section of an ideal artesian basin in Wyoming, showing the general type and geological position of some of the artesian wells.

Artesian Wells.

The name artesian, as applied to wells today, was derived from the name of French province Artois, where wells of this nature first became famous. In reality, the artesian well is not a modern discovery, for in the old Carthusian convent at Lillers there is a well that has flowed a constant stream since the twelfth century. There are other data which antedates this, and it is probable that flowing wells were known to the Chinese and Egyptians as early as the Christian era.

Originally the word artesian meant flowing wells only; but the meaning has been so broadened in the United States that it includes flowing wells, wells in which the water rises nearly to the surface, and also bore holes that contain water, it matters not how far it is from the surface. Wells that do not flow are not in reality artesian; but much less are those artesian where the water has to be elevated from 50 to 300 feet. The term as used in this bulletin will apply only to flowing wells. In justice to some who have used the word in a broader sense, it may be well to state that wells not flowing have been called negative artesian wells, and those flowing positive artesian wells. The word as used in this bulletin answers the scientific definition of an artesian well, as will be found in all physical geographies and geologies.

In order to secure an artesian well it is necessary that the strata dip and that they extend above the level of the mouth of the well sufficiently high to furnish a water storage and also hydrostatic pressure. Usually the stratum containing the water is quite porous and is confined between two impermeable strata. In nearly every artesian basin there are numerous water-bearing horizons, all of which may become tributary to a single flow; or they may be brought to the surface in individual pipes. It is not an uncommon thing to secure several kinds of water in drilling a deep well. One stratum may

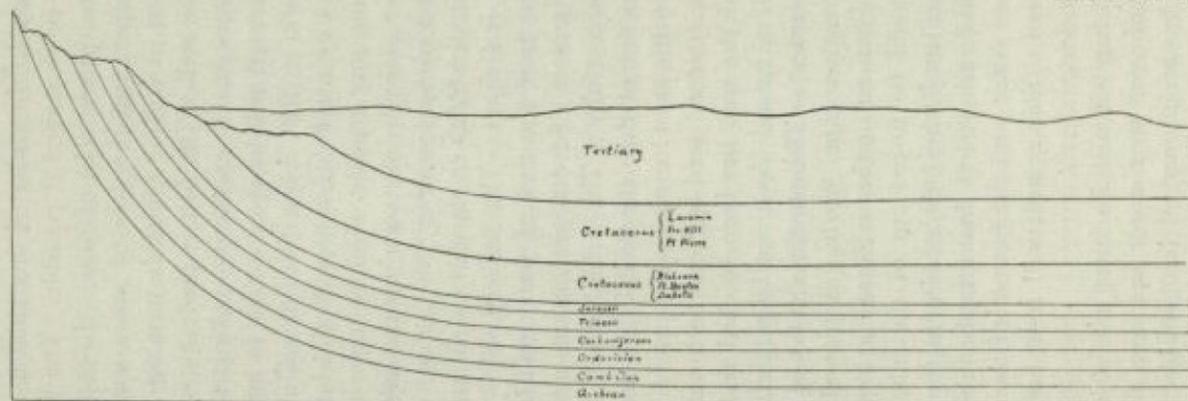
contain an unusual amount of gypsum or sulphuretted hydrogen, which would render it unfit for household use; but would in no way interfere with irrigation. Water of this kind could be brought to the surface in an independent pipe and utilized for irrigation purposes. It often happens that a good flow of hard water is found and just below it a flow of soft water. These can also be separated in the same way. During the last fifty years well drilling has improved in many ways, and especially in sinking deep wells and passing through very soft strata. A century ago a well 500 feet deep was a remarkable one; but at the present time there are wells that are over 6,000 feet deep.

In drilling deep wells a great deal depends upon the nature of the strata.

In Wyoming wells can usually be drilled in the Paleozoic rocks without the use of casing, unless it is put in to shut off a water flow. In the Mesozoic rocks the conditions are entirely different and a driller should be ready to handle a bad cave in any of the formations above the Triassic. In localities where no test wells have been drilled, it will always be advisable to start a large well, if drilling in the Mesozoic strata, so as to allow for casing the caves and to finish with a medium bit. Whenever it is possible, a careful geological section should be made of the strata through which the well is to be drilled. For in this way a driller can locate approximately the soft bands and be prepared to handle caves and also judge of the size of drill to start with to reach a certain zone. In making a section, one should examine the strata in which the well is to be drilled where they are found outcropping along the surface on a mountain slope or in a canyon. In taking measurements for thickness, make due allowance for dip.

It occasionally happens that after a flow has been obtained it suddenly disappears when the drill pierces a porous stratum which does not contain water. Occasionally this may happen when the well is practically finished or that the depth limit

SECTION II.



Section of the type of artesian basins along the eastern flank of the Laramie mountains.

has been reached. In a case of this kind, it is very important that the well be reclaimed if possible. The following suggestions may often prove to be of value. In case the well cannot be drilled deeper, and the flow of water was satisfactory before it was lost, it will be advisable to make a seed bag about the size of the well. The bag is made by sewing up a piece of leather—buckskin is excellent—making a sack that when filled with flaxseed will be about a foot in length. Be sure to make this sack so that when filled it will be small enough to be dropped by means of a rope to the bottom of the well without causing any trouble. Before lowering, have the bag tied, or better, sewed. As soon as the sack is in place it should be packed by lowering the "string of tools" with a cylindrical wooden block in place of a drill and this allowed to fall gently a few times. The flaxseed will swell immediately and in a short time the flow of water will be blocked and it will rise in the well. Several precautions are necessary to do this work successfully. The drill hole in the porous band should not be deeper than the seed bag is long; if deeper, it can be filled with sand or rock. In case a mistake is made with the first a second seed bag can be lowered. As soon as the bottom of the well has been blocked and the water commences to rise a second block can be put in. This should be of Portland cement. The cement should be mixed so that it will pass through a pipe easily. A pipe should be lowered nearly to the bottom of the well—say a foot from it. Then the water should be forced out of the tube by applying air under pressure until the bubbles rise in the well. Then the cement should be allowed to flow into the tube without permitting any air to enter, and the bottom of the well filled to the depth of a foot. This cement will soon harden and make a permanent blocking.

The seed bag will also be found useful in many instances when a flow of very poor water has been found below good water, and it has been found advisable to block the well, rather

than attempt to pack with some of the usual packers now in use.

It often happens that a deep well has to be finished with a very small drill and that it is impossible to ream it out after completion. If the water-bearing zone is a solid sandstone or limestone it will be found advisable to shoot the well with dynamite or a little nitro-glycerine. By an explosion of this kind on the bottom of the well a greater surface will be opened up and the flow materially increased. There is one precaution necessary. If the water-bearing zone has been punctured with the drill, and the stratum below happens to be thin, there is a chance that the floor of the water-bearing zone would be fractured, and cause the water to enter a porous, non-water-bearing zone below and never rise to the surface again.

The cost of drilling wells will vary greatly. It has been customary for drillers to charge \$2.00 per foot to drill shallow wells, while in the east the cost of drilling deep wells ranges from 40 cents to \$2.00 per foot. Wells that can be drilled along lines of railroad in Wyoming should be drilled to a depth of 4,000 feet at a cost of not to exceed \$2.00 per foot; understanding that this price does not include casing. When any of the basins in the state become known by drilling wells, the price of drilling will rapidly diminish, for the information obtained by one will in all cases be very beneficial to those who follow, and in the majority of cases the well will not only show the nature of the strata, but also the places where casing is necessary.

There is one danger that will possibly affect more or less the artesian wells in the future. Each basin has a certain capacity and the moment that the tax is greater than the supply all wells securing water from that particular zone in a community will be affected. In some artesian basins in the world the wells have increased in number, until finally none of them would flow at all. Such is the case in the basin near Denver. The question of drilling the proper number of wells in any

basin is one that should be considered; but there is no law that can in any way regulate it, since each land owner would have equal rights in a case of this kind. All will admit, no doubt, that a basin with 200 flowing wells that would irrigate considerable land would be far superior to 500 that would furnish only enough water for ranch use.

Up to this time, none of the ranchmen in Wyoming seem to have considered the advisability of drilling to secure artesian water for irrigation purposes. The question of water storage has been advocated for several years and a number of small reservoirs have been put in, and a few large ones are being constructed. Nature has already arranged an underground storage of water in many places in the state, and these should be considered before vast sums of money are spent in erecting dams to retain water during flood-tide. Irrigation by means of artesian wells is not a new nor untried scheme. It has met with success in numerous instances, especially in California.

Up to the present time very little attention has been paid to artesian well drilling in this state. There are, however, a few flowing wells, many of which were drilled for oil or in search of oil and gas. In the Laramie basin there are a dozen wells ranging from 100 to 1400 feet in depth, but the majority being less than 300 feet in depth. The wells near Laramie have all been drilled in Triassic sandstone and two or three have penetrated the Permian rocks below. While many of these furnish ample water for a large ranch, none of them could be considered as producing enough for irrigating a small tract of land. With depth, the flow of all of these wells could be greatly increased. For example, the greatest flow of water in the Laramie basin will be found at the base of the Carboniferous in a coarse grit or in contact with the granite. To reach this lower zone, the deep wells would have to be drilled from 600 to 800 feet deeper. The flow of water should be at least ten times what it is at present. At Rawlins conditions are

similar. Here the wells are in the Carboniferous and the largest flow will be found in the Cambrian, probably near the granite. The Rawlins wells should be drilled to bed-rock to insure the greatest supply of water. At other places wells have been drilled, but they are usually quite shallow and flow slight streams of water. So long as wells furnish only small supplies of water there will not be any incentive to drill deeper ones. It must be remembered that it will be the deep wells that will furnish large flows, and without these we cannot expect the enthusiasm displayed that would be had a few wells been drilled that would produce a half million or more gallons per day. There is no question in my mind but that the future artesian wells of Wyoming will irrigate large tracts of land and in some instances the pressure will be found sufficient to apply the flow to a water wheel and furnish power to be utilized for any purpose. In South Dakota electric plants and mills are operated by power direct from the wells and the water afterwards utilized for irrigation.

The following table will give a list of the artesian wells that have been drilled in Wyoming, together with such other information that may be of interest:

Name of Well	County	Geological stratum	Depth	Flow in gallons per 24 hours	Kind of Water
S. W. Downey	Albany	Triassic.	2-1	3,927	Good
O. D. Downey	"	"	170	8,640	"
S. W. Downey	Carbon	Fox Hills.	380	Small	Poor
Oxford Ranch	Albany	Permian	540	"	Good
Thomas McHugh	"	?	112	1,080	"
Thomas McHugh, No. 2	"	?	117	831	"
J. Simpson	"	Triassic.	112	864	"
G. Montague	"	"	150	Small	"
Ryan Bros.	"	"	85	840	"
Rawlins No. 1	Carbon	Carboniferous	467	108,000	"
Rawlins No. 2	"	"	496	432,000	Good; brackish
Saratoga	"	Tertiary	55	72,000	Good
University	Albany	Permian	1015	50,000	"
County	"	"	1470	"	"
Judson	"	Fox Hills	540	Small	Sulphur; poor
George	"	Triassic.	140	Quite large	Good

Name of Well	County	City, if any	Geological situation	Depth	Flow, per 24 hours	Kind of Water
Guthery	Johnson . .	Near Buffalo .	Laramie . .	2-1	Small . .	Good
Rock Springs .	Natrona . .	Rock Springs .	Dakota . .	1000	" . .	Sulphur; poor
Bacon	Sweetwater .	Near Frvay . .	Laramie . .	" . .	" . .	Poor
Mullen	Natrona . .	Dallas	Niobrara . .	" . .	Medium . .	" . .
	Albany . . .		Fox Hills . .		" . .	Good
	Fremont . .		Permian ? .	1200	" . .	Oil; sulphur water

INSTRUCTIONS FOR LOCATING ARTESIAN WELLS.

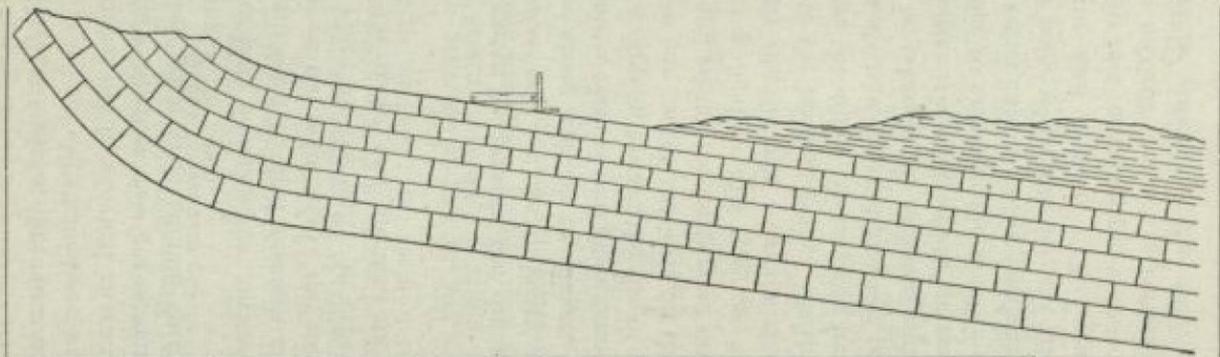
It is not an easy task to locate with assurance an artesian well in a new basin. The many factors entering into work of this kind are so variable that a person may reasonably hesitate in forming an opinion or rendering judgment. Unfortunately it has been the rule to drill regardless of any scientific data that may be at hand. When once an artesian basin has been punctured with a drill and an accurate log kept of the work, those that follow have a comparatively easy task. In advice of this nature it is utterly impossible to make rules that will apply to all cases. It is also impossible to give the necessary information as to the depth of wells and the quantity of water one might reasonably expect.

The location, the geological formation, and the depth of the well all have an important bearing on this subject. A well in one basin 2,000 feet deep might furnish 1,000,000 gallons of water a day, while in another the flow might only be sufficient for one ranch house. Before anyone attempts drilling a well in any of the basins, unless he is fortunate enough to have ample funds to experiment with, let him consider the following essentials:

1. Be sure that you are in an artesian basin and that there are strata above you of sufficient magnitude to warrant a storage of water.

2. Examine the nature of the strata and determine if

SECTION III.



An illustration showing how the dip may be taken with an ordinary level and square.

possible the geological horizon, that you may compare your locality with others, where wells have been drilled. If this cannot be done examine the lithological characters of the strata and satisfy yourself whether they are porous or impermeable and note if at any point you can find springs which would signify an overflow of the basin.

3. Before drilling estimate the thickness of the formations that you will have to drill through and the difference in elevation between the point where the rocks were exposed and the selected place for the well. In order to do this, estimate the dip of the rocks, and use also the thickness in the estimate.

METHOD OF TAKING DIP.

Use a clinometer to measure the dip with, but in case you do not possess one use an ordinary carpenter's level. Select some place along a gulch or canyon where the strata have been worn into a vertical wall and examine carefully until you find the strata dipping toward the site of the well location. At this point place one end of the level on the highest side of a bedding plane and adjust the instrument until it is perfectly level. While being held in this position have an assistant measure accurately the distance from the elevated end of the level downward to the bedding plane. In this way you have data that gives you the dip of the rocks in terms of inches per foot which can easily be converted into feet per mile. Several readings should be taken in an estimate and these averaged. In case the clinometer is used it will be necessary to use trigonometrical formulae to ascertain the number of feet the strata dip per mile. In either case it will be necessary to measure the distance from the point where the dip was taken in a horizontal direction to the well location. This measurement multiplied by the dip in feet or inches per mile will give approximately the depth to drill to reach a certain horizon. From this depth should be subtracted the difference in elevation

between the point on the hill where the estimate for dip and thickness were made, and the well.

A Table Giving the Vertical Depths from the Surface for Each One Hundred Feet Measured Horizontally, for all Degrees of Dip Between 1 and 90.

In using this table, multiply the number of feet you have measured horizontally, by the number of feet placed after the degree of the dip you are working with. For example: if the dip of the formation is 12 degrees, and you wish to find out how deep you would have to drill at a point 4,200 feet away, you would have to multiply the 42, which represents the number of hundreds of feet, by 21.25 feet.

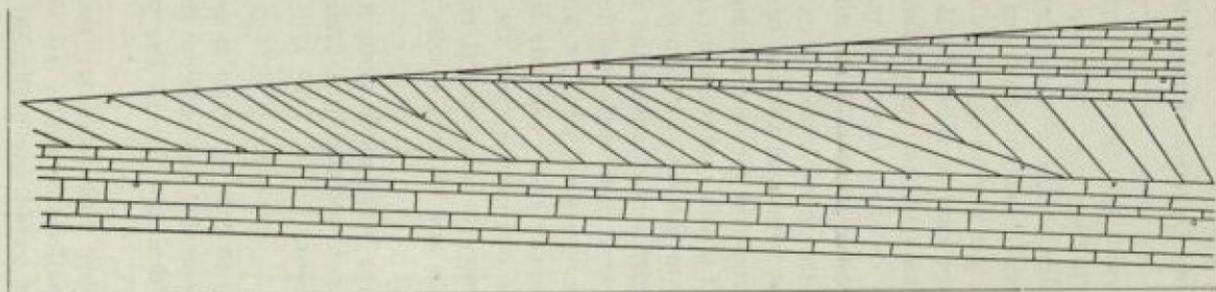
The estimate, made in this way, would be considered as horizontal from the outcropping strata, and from this should be subtracted the difference in elevation.

Degrees of dip	Vertical depth for each 100 feet measured horizontally	Degrees of dip	Vertical depth for each 100 feet measured horizontally
1 degree.....	1.75 feet	18 degrees.....	32.35 feet
2 degrees.....	3.50 feet	19 "	34.50 "
3 "	5.25 "	20 "	36.50 "
4 "	7.00 "	21 "	38.50 "
5 "	8.75 "	22 "	40.00 "
6 "	10.50 "	23 "	42.25 "
7 "	12.50 "	24 "	44.50 "
8 "	14.00 "	25 "	46.75 "
9 "	16.00 "	26 "	47.75 "
10 "	17.50 "	27 "	51.00 "
11 "	19.50 "	28 "	53.25 "
12 "	21.25 "	29 "	55.50 "
13 "	23.25 "	30 "	58.00 "
14 "	25.00 "	31 "	60.25 "
15 "	26.75 "	32 "	62.50 "
16 "	28.50 "	33 "	65.00 "
17 "	30.00 "	34 "	67.50 "

Degrees of dip	Vertical depth for each 100 feet measured horizontally	Degrees of dip	Vertical depth for each 100 feet measured horizontally
35 degrees.....	70.00 feet	63 degrees.....	200.00 feet
36 "	72.50 "	64 "	205.00 "
37 "	75.25 "	65 "	213.00 "
38 "	78.00 "	66 "	224.00 "
39 "	81.25 "	67 "	235.00 "
40 "	84.00 "	68 "	250.00 "
41 "	87.00 "	69 "	260.00 "
42 "	90.00 "	70 "	275.00 "
43 "	93.00 "	71 "	300.00 "
44 "	96.00 "	72 "	308.00 "
45 "	100.00 "	73 "	327.00 "
46 "	104.00 "	74 "	345.00 "
47 "	107.00 "	75 "	370.00 "
48 "	111.00 "	76 "	400.00 "
49 "	115.00 "	77 "	433.00 "
50 "	119.00 "	78 "	476.00 "
51 "	123.00 "	79 "	515.00 "
52 "	128.00 "	80 "	570.00 "
53 "	133.00 "	81 "	633.00 "
54 "	137.00 "	82 "	714.00 "
55 "	143.00 "	83 "	813.00 "
56 "	150.00 "	84 "	1000.00 "
57 "	154.00 "	85 "	1140.00 "
58 "	161.00 "	86 "	1430.00 "
59 "	166.00 "	87 "	1912.00 "
60 "	172.50 "	88 "	2865.00 "
61 "	180.00 "	89 "	5714.00 "
62 "	188.00 "	90 "	—————

In measuring dip greatest care should govern the work and average dip planes considered. In some instances the strata rise and fall in a wave-like structure, which makes an estimate for depth quite uncertain. Special caution should be taken at all times in taking dip, owing to cross-bedding structure of many sandstones, and especially the Triassic. By

SECTION IV.



Ideal illustration of cross-bedding planes. The oblique lines terminating at the letters x are the cross-bedding planes and the less oblique lines marked o are the natural bedding planes.

cross-bedding it is meant that there are apparent bedding planes not conforming to the dip of the strata.

For estimating differences in elevation an aneroid barometer will be found useful; but you must make an allowance for at least twenty-five feet in reading an ordinary instrument. In a case of this kind the reading should be taken at either the top or bottom of the slope and the second one follow as soon as possible, in order to avoid the error that may be caused by a change in the atmospheric pressure. The difference between the two readings gives the approximate difference in elevation.

In case you cannot secure an aneroid barometer, use the same method as recommended for determining the dip of the rocks. Select a place if possible where you can sight from the exposed stratum down to the well location. Arrange a piece of 2x4 on this line, which will represent the average slope of the mountain or hill, and then apply the level and square, which will give you the inches fall per foot, and knowing your horizontal distance you can easily estimate the elevation. It will often happen that one cannot sight the entire distance. Then it will be necessary to take several readings and also horizontal measurements and add the results for entire elevation.

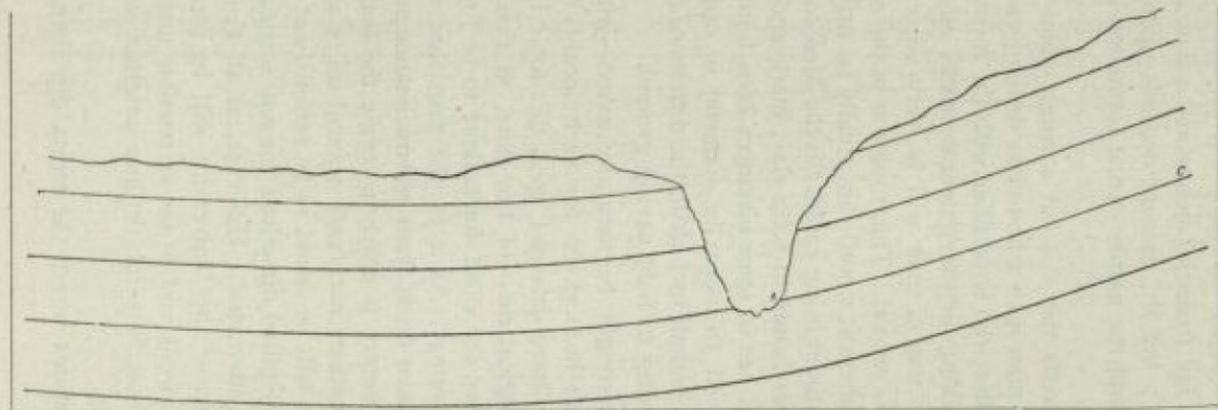
In case a location is being made along a mountain slope be sure that you are not working in a drained area. Such often occur in good basins.

EXAMPLE.

It would be useless to drill for water at any point between A. and C., since the canon that has been cut through the rocks has provided natural drainage for all the strata above the letter A. See Section V.

It will often happen that wells are needed in regions where all of the formations or nearly all are covered with soil, which will almost forbid any preliminary work. However, in case the well is to be drilled in any of the artesian ba-

SECTION V.



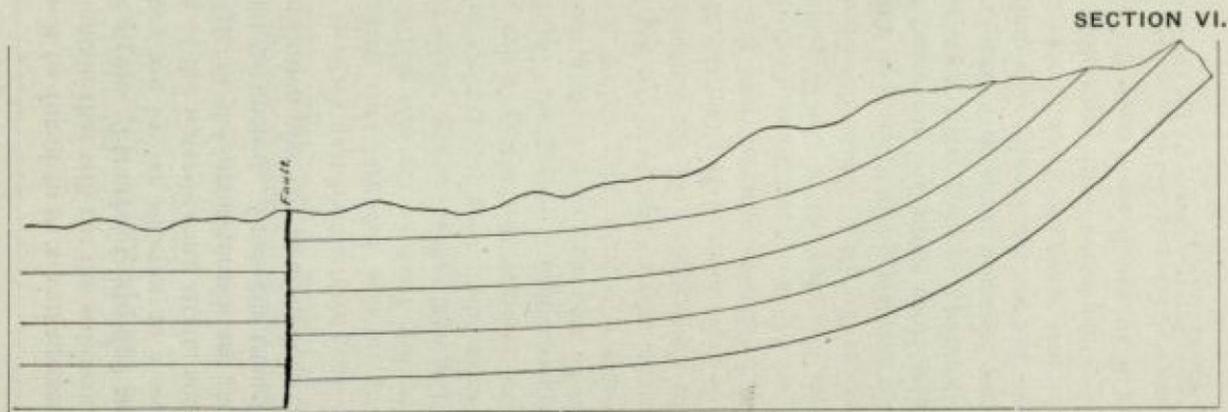
An illustration showing how an area in an artesian basin may be entirely drained by a canon paralleling the strike of the formation. Illustration taken from Canon creek, Big Horn county.

sins, and not too far from the mountains, a flow of water can easily be secured; but the amount depends upon the natural reservoir above, and the nature of the formation in which the well is drilled.

In drilling wells there is but a single point to consider. Hire a first-class man with a first-class drilling outfit. If possible secure a driller who is familiar with the formations. The differences in drilling in the Paleozoic rocks and the Mesozoic are so great that a man will be very successful in the first and fail in the second. The trouble is in the nature of the strata. In the Paleozoic a well can usually be drilled through the formations without being cased. In the Mesozoic the strata are in many places bands of soft clay, marl, and shales that cave easily, and it has in some instances been found necessary to start with a well 18 inches in diameter in order to finish with a three and one-half inch drill, the difference in size being taken up with casing to hold caving ground.

The question might be naturally asked—why have not working directions been given for each locality? It would have been well to have enlarged upon this topic if there was an accurate geological map of the state, so that one would know from the map the exact formations to be found in each township in Wyoming. As it is, the map that accompanies this bulletin has been made from reconnaissance surveys only, and while the structure is nearly accurate the boundary lines between the formations may vary several miles and in some localities the map will be found to be seriously at fault. For these reasons no detailed directions for any section of land in a region will be attempted. However, at all times the geological department of the University will be pleased to aid in the location of wells and so far as possible make examinations and give directions for drilling artesian wells in any locality in the state.

In some localities where the strata dip sharper than 45



An illustration showing how an artesian basin may be partially drained by a fault. Example taken from the Laramie artesian basin.

degrees it will be found to be advantageous to drive a tunnel into the mountain that will cut the sedimentary rocks at right angle to the strike. Tunnels of this kind are not very expensive and they are by far superior to a well. They open a greater area of the water-bearing strata, and by driving drifts at right angle to the main tunnel an immense amount of ground could be opened. Cross-cut tunnels of this kind in mining camps often give rise to a small river.

The Artesian Basins.

THE BIG HORN ARTESIAN BASIN.*

In many respects this is the most promising artesian area in Wyoming; but in this, as in all sections, the most valuable part is covered so deep with sedimentary rocks as to render it unavailable. Being located between two great ranges of mountains, like the Big Horn on the east and the Absaroka and Shoshone on the west, whose highest peaks are above the line of perpetual snow, and whose forest areas are so vast as to store great snow reserves that supply water gradually to these ranges, the water supply is very great. On the south this basin is hemmed in by two cross ranges which meet at the Big Horn river, the western portion being called the Owl Creek range and the eastern, which extends to the Big Horn, is locally known as the Rattlesnake. To the northward this area melts away into the great table lands along the Missouri river in Montana. The formations entering into the structure of these basins are as follows: Cambrian, Ordovician, Devonian, Carboniferous, Permian, all of the Wyoming Mesozoic bands and the Eocene Tertiary. These formations, with the exception of the Eocene, dip gently to the west along the western slope of the Big Horn range and are found resting upon the Archæan at elevations varying from 7,000 to 9,000 feet. As a rule, all of the Mesozoic rocks have been removed from the mountain slopes and are not usually seen until the foot of the mountain is reached, when the Triassic red sandstone usually appears as huge "hog-backs" with precipitous walls facing the range. North of Hyattville some miles the rocks dip at a

*That portion of the Big Horn basin lying north of the Stinkingwater river that has been represented on the map as Tertiary, belongs to the Fort Union beds. No Wasatch was observed north of the Stinkingwater river.

higher angle and for a considerable distance the Mesozoic rocks are found within a few miles of the Archæan granite. These conditions again change on nearing the Montana line, where the Paleozoic rocks dip gently as they bend about the north end of the Big Horn mountains and form many square miles of exposure corresponding to the southern end of the western slope of the range.

In the vicinity of Hyattville there are three local folds. In the one west of Bonanza the exposure is entirely Cretaceous. The one between Bonanza and Hyattville has a Jurassic core and possibly Triassic rocks may be exposed along the axis further to the north. At Hyattville the fold has been nearly obliterated by erosion. All of these folds weaken the head of water stored in the Mesozoic rocks above the Triassic.

Between Hyattville and Red Bank there are numerous springs breaking forth from Carboniferous and Permian limestones, indicating faults, and along Canon creek large areas of Paleozoic rocks have been drained by the deep canons which are parallel to the axis of the Big Horn range in the limestone. North of Shell creek, and extending northwest across the Big Horn river, are two other anticlinal folds, the greater of which has a Carboniferous core and the lesser a Triassic. While these folds have seriously affected the basin along the foot of the Big Horn mountains, they may also be considered as advantageous; for if they are complete arches, that is, not fractured or faulted, they are favorable places to drill and secure flowing wells a considerable distance away from the range. For example, southwest of Bonanza, in the Bonanza oil field, exceptionally large flows may be secured by drilling 2,000 or 3,000 feet. At Hyattville one would not have to drill over 200 feet to reach the same zone in the Triassic sandstone.

Along the eastern side of the Big Horn basin the most desirable territory for well drilling will be found from the

crest of the Triassic sandstones toward the mountains. In case wells are drilled in the Triassic, one should drill not less than 2,000 feet. In case shallower wells are desired it will be better to drill in either Carboniferous or Ordovician strata.

Beyond these disturbances, to the westward, the Mesozoic rocks appear, and especially the Cretaceous, which is capped with the Laramie. Westward from the Laramie the Eocene Tertiary covers the entire central area of the basin and extends nearly to the foothills to the west.

On the western edge of the basin the structural features are not so easily worked out. Following the period of mountain making, after the sedimentary rocks had been tilted and eroded, there was a vast accumulation of volcanic breccia deposited for a distance of sixty or eighty miles along the mountains. This has greatly obscured the geology of this region and also hinders materially in the search for artesian water. This great deposit has a width of from ten to forty miles and a maximum thickness of 5,000 or 6,000 feet. Between this deposit and the Tertiary on the east there are exposures of the upper Cretaceous series; but none of the older rocks are known from the Owl Creek range northward until the Stinkingwater river is reached, where there are slight exposures of Paleozoic rocks which extend northward to the Archæan mass on Clark's fork.

In the vicinity of Cedar mountain conditions are quite complicated. This mountain is an anticlinal fold, with probably a Cambrian core, and with the strata highly inclined on either side. To the westward there is a broad synclinal valley that will undoubtedly prove to be valuable artesian territory. On the eastward the strata, although sharply inclined along the mountain, flatten very rapidly toward Cody, which makes the area along the base of Cedar mountain a very fair artesian proposition. Northward, above Chapman's ranch, the opportunities for wells are excellent, but from Clark's fork

north to the Montana line the Paleozoic rocks are nearly vertical and the productive area is very narrow unless wells are drilled in the Mesozoic. Along the range from Cody north flowing wells will be found in all of the Mesozoic rock. West of Clark, tunnels may prove to be useful in securing water from the nearly vertical strata.

The structure of the southern end of this basin resembles, to a considerable degree, the eastern border, except that the mountains are not so high. The width of the basin at the southern termination is nearly eighty miles, and artesian conditions extend the entire distance. Along the Owl Creek mountains, including the uplift on the east side of the Big Horn river, the Archæan, so far as known, is only exposed along a portion of the distance. For many miles along the axis of these ranges the Carboniferous or Carboniferous and Permian rocks, form a complete arch that has not been fractured. On this account the extreme eastern and western sides along this border are not as favorable for valuable wells as the central section. The strata dip gently northward from the Archæan rocks along the northern side of the range, and there is an area composed of Cambrian, Ordovician, Carboniferous and Triassic stretching across the end of the basin that varies from ten to twenty miles in width. At no point in this area will it be necessary to drill more than 3,000 feet to reach bed-rock, and over the greater portion not over 1,500 feet. The Big Horn river has to some extent drained the strata that lie above the river bed. Near Thermopolis, at the great hot springs, the water rises in numerous places, proving conclusively that there is a very good fountain head. The warm water pouring forth from these springs derives its heat by sinking deep into the earth and coming in contact with heated rocks and being forced to the surface through a fault by means of the pressure derived from the storage of water along the mountains. In this, as in other parts of the basin, artesian

wells can be drilled further away from the range, and no doubt they will flow; but the supply of water would be quite limited unless a well could be drilled to five or six thousand feet.

Throughout the central portion of the basin no one will be warranted in drilling wells expecting to secure artesian water. The Eocene formation is usually quite thick and on account of its sandy and clayey texture would foil the most expert well driller before he had reached 1,000 feet.

The most valuable portion of the entire basin extends from Red Bank north to Shell creek; valuable because wells can be drilled to reasonable depths and secure an abundance of very good water.

See Section VII for geological structure of Big Horn artesian basin.

THE SHOSHONE ARTESIAN BASIN.

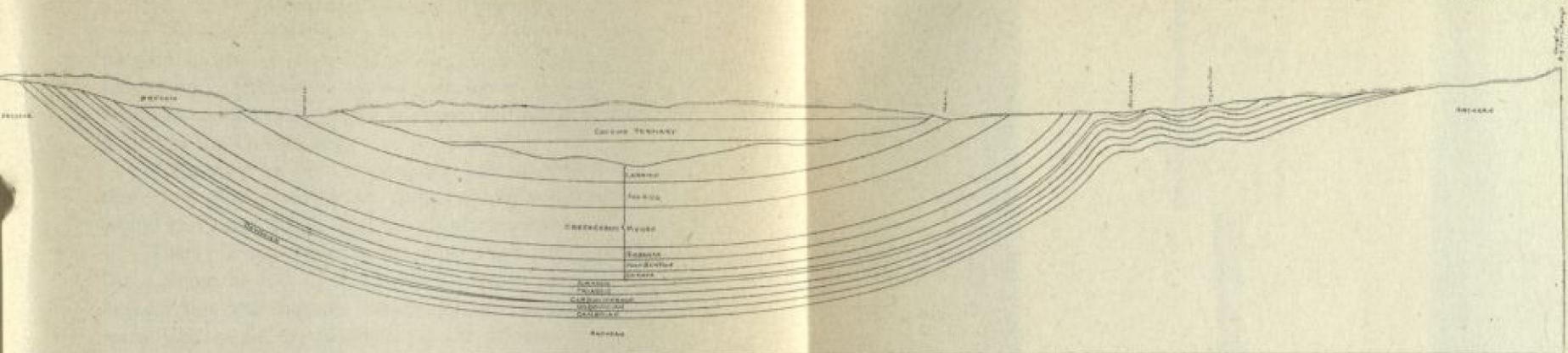
The basin is bounded on the north by the Owl Creek and Big Horn mountains; on the east by the Powder River basin; on the south by the Rattlesnake range and the high bluff of Tertiary extending from the Rattlesnake westward to Beaver creek and the Wind River mountains; on the west by the converging Wind River and Owl Creek ranges. As the limits are given, this basin emerges into the Powder River on the east, and at several intervals along the southern border there are no barriers that would prevent it from extending further southward. The remaining exteriors are, however, valuable territory and will be discussed under separate headings.

The northern border skirts the Owl Creek and the western extension of the Big Horn mountains. This range is continuous and has different names on opposite sides of the Big Horn river, which cuts it in two. These slopes have not been studied and the present observations are based on information secured in crossing these ranges. In the main uplift in the

vicinity of the Big Horn river there is a narrow Archæan mass that extends from east to west to an unknown distance, and as plotted on the map is largely guess-work, Mr. J. B. Okie of Lost Cabin having informed me that there was granite north of his place and that it extends westward to the known mass at the Big Horn seems reasonable. The forces producing this great fold that hems in the Big Horn basin on the south operated from the north and caused the sedimentary rocks to dip sharply to the south. This dip gradually decreases to the eastward and westward, to the respective boundaries. South of the Archæan uplift the exposed formations are Cambrian, Ordovician, Carboniferous and Permian(?); south of this all of the Mesozoic rocks are covered with Tertiary. Eastward the Triassic sandstones appear at a distance and will more than likely be found along this uplift. The supply of water will not be large, since this region is wholly dependent upon the precipitation for storage unless it may be possible for some of the porous strata from the Wind River range to augment this supply.

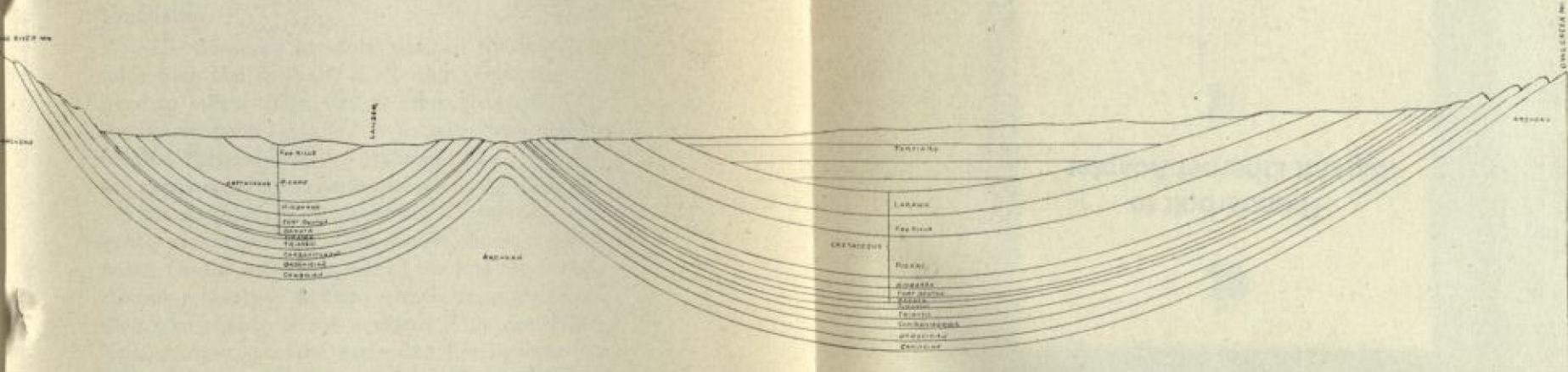
The crest of the Owl Creek range west of the Big Horn river a few miles, with the exception of a few small exposures of Archæan, is all Carboniferous or Permian. Similar conditions exist in the lower Big Horn range east of Lost Cabin. This arch of limestone is very detrimental to the storage of water in the Paleozoic, and unless it is fractured in numerous places, wells drilled to this horizon either eastward or westward from a line extending southward from the termination of the Archæan will be found to be unsatisfactory. Opposite the Archæan, to the south, the Paleozoic rocks are so highly inclined as to make the productive area very narrow, and deep wells will be necessary to reach a flow. About Lost Cabin the Triassic red sandstone seems the most desirable band to penetrate with a drill, though possibly the upper band of the Carboniferous will be found equally valuable. The same can

SECTION VII.



Geological section from the Absaroka mountains eastward to the crest of the Big Horn mountains. This section crosses the Big Horn artesian basin, through Meeteetse, Alamo, Bonanza, and Hyattville. [Drawn to Scale.]

SECTION VIII.



Geological section from the Wind River mountains northeastward to the Owl Creek mountains. This section crosses the Shoshone basin in the vicinity of Lander. [Drawn to Scale.]

be said of the western end of the flank of the Owl Creek mountains. Cretaceous strata, whenever exposed, will be found to contain many water horizons, and the best may be expected in the Dakota stage.

Wells may be drilled along the base of this range when there is a thin covering of Tertiary, but a few miles away would carry one beyond the bounds of reasonable well drilling.

There is no question but that there is quite a large basin along the foot of this range for ten or twelve miles, and beyond this the Jurassic rocks appear. Probably there are some Cretaceous exposures along the streams flowing south and west, where the Tertiary capping has been removed. Westward from the river the entire complement of the Mesozoic appears rather suddenly, since it occupies an elevation above the level of the Tertiary.

Since the western boundary of this basin is formed by the convergence of the Wind River and Owl Creek ranges, it will be discussed in connection with the northern and southern boundaries.

The Shoshone anticlinal parallels the Wind River mountains from Hailey nearly to the Big Wind river, a distance of over 50 miles. This fold is some distance from the range, the nearest point being five or six miles from the foot and double that distance from the Archæan rocks. The Triassic strata are exposed nearly the entire length along the axis of this fold. On the northeast the Jurassic and Cretaceous rocks dip away gently and only a few miles distant obtain considerable thickness. On the southwest side of the fold the Jurassic and Cretaceous rocks have suffered greatly from erosion and are seldom seen above the soil surface. This condition produces a long, narrow synclinal basin that lies between the anticlinal fold and the mountains. This can be considered as a small artesian basin. It is to some extent separated from the great basin along the northeast side of the anticlinal. This narrow

basin, which gradually widens to the northwest, should be seriously considered by the people who live along this range, as sometimes there is a shortage of water. The possibilities are unsurpassed for large capacity wells, and the Mesozoic rocks are so thin near the range and often in the valleys that wells need not be drilled to great depths. The reasons for this being a specially favorable location are that Paleozoic rocks rise along the flank of the mountains two and three thousand feet above the valley and that the Archæan peaks rise far above the snow line and furnish a constant supply of water during the summer. Above Lander, on the forks of the Popo Agie river, there are places where it will be advisable to tunnel for water. When a tunnel has been completed from the base of the mountain to granite it will be found the bed of a good-sized stream. Excellent places to drill for water are along Red canon, at the experiment farm, and to the north and west along the outcropping Triassic rocks. At Lander and Fort Washakie wells could be obtained, but the depth would be very great. In cases of this kind it would be more advantageous to drill nearer the range and pipe the water to lower horizons.

Along the anticlinal axis wells may also be obtained. Already there is an artesian well near the mouth of Twin creek. This well was drilled to a depth of 1,200 feet. The formations lying beneath the axis of the fold are the Permian, Carboniferous, Ordovician and Cambrian, all of which are supplied with water from the range, and if not exhausted at this point will furnish a supply of water for the country lying beyond the fold to the northeastward. Well drilling to the northeast of the Shoshone anticlinal will have to be confined to a very narrow belt on account of the rapid thickening of the Cretaceous rocks. Beyond these limits no one should drill for the Paleozoic rocks. Wells may be drilled in the Cretaceous strata, but no one should expect more than a slight flow. Those who drill along the anticlinal must always consider that water found

will usually be contaminated with oil and sulphur. While it may be possible to utilize such water for irrigation purposes, it would first be necessary to contrive a method to store the oil and allow the water to escape.

From the fold eastward the first distributed rocks are found at the Beaver oil basin, where the Cretaceous rocks stand nearly on edge and there are no associated Paleozoic rocks, since Tertiary has obscured them. Artesian wells can be secured, but the flow will be slight and the water unfit for irrigation, stock or ranch use on account of its contamination with sulphur, oil and alkali.

Eastward from the Beaver basin some five or six miles is the Connant anticlinal, which has a Carboniferous core and the Triassic and Jurassic rocks on either flank. About the base of this uplift the lower beds of the Cretaceous are exposed and wells drilled along these outcroppings will furnish a small supply of water which is very desirable in this very arid region. Here, as at Beaver, one should be prepared to encounter water containing sulphur or petroleum. Petroleum has not been found in this vicinity, but it does occur on both sides, and those drilling must choose well their location, for oil springs are numerous all along the ranges, and wells associated with petroleum would not furnish good water; the oil not being the only drawback, but the presence of an abundance of sodium sulphate being even more serious. Petroleum along the range is wholly confined to the Cretaceous rocks, but ranges from the Dakota to the Fox Hills.

From the Connant anticlinal eastward there is a nearly continuous precipitous wall of Miocene Tertiary that rises several hundred feet from the desert country and practically connects this section with the Rattlesnake mountains. Along the foot of this huge bluff are numerous small springs which have their source in the Tertiary rocks, but there are no conditions warranting well drilling.

Within eight or ten miles of the Rattlesnake mountains there is simply the termination of the Dutton anticlinal, known as the Dutton oil basin. In this V shaped area the Triassic rocks are the oldest exposed, and the tilted bands along the anticlinals are so low that there is little or no opportunity for water storage. Along both sides of the fold there are a few small springs, some of which contain very poor water; others are associated with natural gas escapes and a few with petroleum. The conditions in this section are anything but favorable for a large supply of water, and yet I know of no region where water would be of greater benefit.

The Rattlesnake mountains form a peculiar range that is some 40 or 50 miles long and have probably been elevated by a huge fault that extended along the southwestern base. It is not definitely known that there are Archæan* rocks along the southern slope, but there is a complete series of rocks as known in central Wyoming, commencing with the Cambrian and terminating with the Tertiary, along the northern slopes. These rocks dip from 28 to 35 degrees and form great ridges paralleling the range which are occasionally cut by small streams. This range is one of the celebrated oil districts of the state and wells drilled in any of the Cretaceous bands may furnish water that is charged with sodium sulphate, sulfuretted hydrogen, and tainted with oil, since the petroleum ranges from the base of the Dakota stage to the crest of the Fox Hills.

On account of this drawback wells should be commenced in the Triassic and the flow looked for in the lower Triassic or Permian, and possibly in older bands. Along the range from Garfield peak eastward and westward for a distance of from 6 to 10 miles tunneling may be resorted to. Although this range is not high, there is every evidence that wells drilled or tunnels run will afford considerable water. This basin has al-

*Only recently, while investigating the Rattlesnake mountains, I found that the Archæan was exposed, and that it is chiefly a hornblende granite.

ready been proven, by companies drilling for oil, and at present there are one or two wells flowing very poor water.

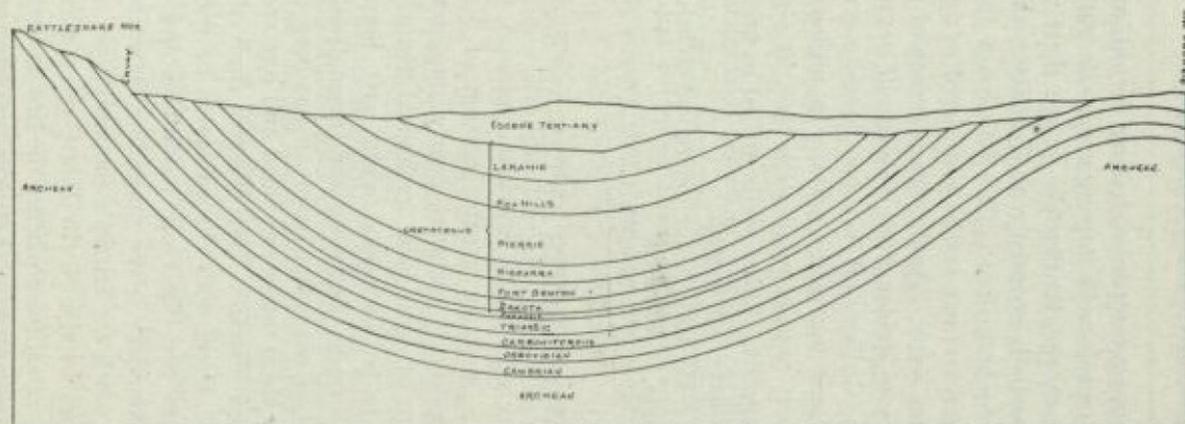
Eastward from the Rattlesnake range there is a broad synclinal valley partially covered with Tertiary rocks, and just beyond the Oil mountain fold. This fold has a Jurassic axis and is badly faulted and can not be considered as an important source for artesian water. Again, the presence of oil impairs its value. On Poison Spider creek, only a mile or two north of Oil mountain, the Guthery oil well has flowed a small stream of sulphurous water for many years. In regions like this, where water is very scarce, small wells like the Guthery may be found advantageous. Other wells drilled to greater depths but further away have not flowed.

See Sections VIII and IX for geological structure of Shoshone artesian basin.

THE POWDER RIVER ARTESIAN BASIN.

This basin includes all of Sheridan, Johnson, Crook, and Weston counties; also the greater portion of Natrona and Converse. In reality it includes nearly one-fourth of the state. On account of some local geological disturbances this, the largest area to be discussed, might have been separated into several small ones; but since the lesser divisions would not be considered as important basins, it has been deemed advisable to include them under one head and pay special attention to the isolated districts. The western limit of this basin is the Big Horn range, with the exception of the depressed area lying between the Big Horn mountains and Oil mountain, where the boundary is the range line between ranges 82 and 83. On the south the Laramie mountains act as a barrier from the big bend of the North Platte river eastward to a point south of Douglas, from whence the line extends eastward to the stae line, over an area that does not offer any artesian

SECTION IX.



Geological section from the Rattlesnake mountains northeast to the Big Horn mountains, across the Shoshone artesian basin.

[Drawn to Scale.]

advantages. The eastern limit can be considered the Wyoming line between Nebraska and South Dakota, but since natural law knows no artificial boundaries, the basin from Newcastle south to the southern boundary extends for an unknown distance eastward. From Newcastle northward, the Black Hills uplift forms a natural barrier that contributes to the water supply of Wyoming. On the north, this great basin extends into Montana, but since the Black Hills uplift terminates south of the Montana line, and the Big Horn range practically terminates in Wyoming, that portion north of the Wyoming line is not worthy of consideration, since it is too far removed from the mountain ranges to furnish a water supply, unless wells could be drilled to very great depths, say 10,000 or more feet.

The western side of the basin presents many peculiar conditions, hence it will be necessary to discuss several localities along the range in order to properly understand the possibilities as well as the probabilities of this region. Along the range opposite Sheridan and northward and westward to the termination of the Big Horn range, the strata flanking the mountains gradually decrease in dip. They dip at a high angle at Piney creek and very gently opposite Pass. The formations flanking the range are the same as occur in the Big Horn basin, except that the Devonian is not known, but may be found in very thin bands. As on the western side of these mountains, the strata lie high up along slopes and attain an elevation of from 4,000 to 6,000 feet above Sheridan. This provides for unsurpassed storage, as well as pressure, and makes this section an ideal one for artesian wells. The most desirable locations will be found near the base of the range and extending toward the plains as far as the top of the Triassic sandstone, though at this distance it will often be found impracticable to drill deep enough to reach bed-rock. There are, however, numerous zones between bed-rock and the Triassic that will fur-

nish large flows of water. Beyond the Triassic sandstones artesian flows can be secured almost any place in the valley lands or along the table lands; but the source of the water is in the Cretaceous rocks, and with the exception of the Dakota sandstone the chances are that very inferior water will be obtained. For example, a well a thousand feet deep at Sheridan would in all probability flow; but the water coming from rocks associated with coal is never good. Occasionally water in a coal formation, where there is a heavy band of sandstone between two bands of clay, is excellent. Wells drilled at Sheridan should not be expected to produce much water, since the strata that carry the water beneath the city crop to the surface between Sheridan and the mountains, and in consequence have a very limited water supply. Were it possible to drill deep enough at Sheridan, say 10,000 or 15,000 feet, the supply of water thus obtained would surprise the world.

From Piney creek southeast and south the dip of the strata increases very rapidly until at a point opposite Buffalo they are nearly vertical; but southward they again decrease in inclination and at Crazy Woman creek the dip is only 15 or 20 degrees. West of Buffalo nearly all of the sedimentary rocks have been obscured by the detritus from the mountains, which along Clear creek is a very thick band of conglomerate. On account of the strata being nearly in a vertical position it will be impossible for anyone with modern appliances to drill and pierce any of the Paleozoic bands, and it is questionable if any of the lower Mesozoic rocks could be reached. South of Buffalo, as the dip decreases the opportunities for wells increase, and only ten or twelve miles south of Clear creek the territory in which the best wells can be secured has increased sufficiently to warrant large expenditures in drilling. Buffalo is located on the Laramie beds, which dip very slightly to the east. These beds will be found to furnish artesian water, but there will be the same drawbacks to consider as at Sheridan.

Already shallow wells have been drilled at Buffalo that produce small streams of very good water. Deeper wells will furnish more, but the chances are that the water would contain too much mineral matter to be used for domestic purposes or irrigation. From Muddy creek, south of Buffalo, to the southern termination of the Big Horn range, the strata gradually decrease in dip, which widens the Paleozoic outcrops along the range. Along the Big Horn mountains, nearly opposite Mayoworth postoffice, the Archaean rocks no longer appear on the surface, but are covered with a great arch of the Paleozoic, and the Carboniferous rocks form the crest of the range southward to the great bend in the range, and from thence westward. Along the mountain slopes the Triassic rocks are occasionally seen, but as a rule they outcrop at the foot of the range. In this portion of the range conditions are the same as cited in the southern end of the Big Horn basin, which is just across the mountains. Because the granite is covered with Cambrian, Ordovician and Carboniferous bands the storage has been greatly decreased. In case these rocks have been faulted or fractured the water supply would correspond favorably to that portion of the range at Muddy creek. On the other hand, the Triassic sandstone would be the leading horizon and the Dakota sandstone a second one below, but in neither place would the supply be large.

Along the southern boundary of the Powder river basin the Laramie mountains act as a barrier and along these the strata are tilted to the north at various angles depending upon the locality. Here the formations change. The Paleozoic rocks are very much thinner, the Ordovician series have not been detected, and the Cambrian, which has been found along the western arm of the Laramie mountains, thins very rapidly to the eastward. The remaining bands are the same as seen at Buffalo or Sheridan. The Laramie range practically terminates before reaching the North Platte river, which has

cut its way across the northern extension through Triassic sandstone. In this vicinity there is a large spring in the Triassic sandstone that acts as an overflow for this section. Eastward along the range the Paleozoic rocks gradually decrease in dip, for many miles. There are in all probability some changes in geological structure along this range that have not been discovered. Between Douglas and Laramie peak there is a small secondary fold with a Triassic core, but with this exception nothing is known out of the regular anticlinal structure. The range is quite low, Laramie peak being only 10,000 feet and the rest of the granite peaks to the westward varying between 8,000 and 9,000 feet. Owing to the precipitous slope along the range opposite Casper, the Paleozoic rocks offer only a very narrow band in which to drill. South of Glenrock the conditions are more favorable, and opposite Douglas the productive area has so increased in width that the artesian possibilities are very promising.

Wells can also be secured by drilling in Mesozoic rocks, but the chance to secure large flows of water decrease very rapidly as one leaves the foot of the mountains. Flows may be secured at Casper, Glenrock and Douglas, but wells are not recommended for these cities: First, since the flow would not be important, and secondly, because the source of the water would probably render it too impure for ordinary uses.

The southeastern corner of the Powder River basin cannot be considered as of importance for artesian well drilling, not that the basin does not exist, but that it is by far too deep to drill and reach the valuable zones. Wells can no doubt be found eastward from Douglas, but the water will seldom if ever rise to the surface. This is largely due to the Tertiary beds of the Miocene period which cover this section and are in nearly horizontal strata. These strata vary from 1,000 to 1,500 feet in thickness. This thickness would have to be drilled through before the Mesozoic rocks that flank the Laramie

range on the eastern slopes could be reached. North of Lusk and along the slopes of the Cheyenne river there is a small area of Fort Pierre shales and in this section wells may be drilled deep enough to reach the Dakota sandstone, which would furnish an ample water supply. Further to the northward the Laramie rocks appear and there is little opportunity to drill wells. At Newcastle and northward to Cambria and thence north and northwest, the country favors well drilling and a reasonable water supply may be looked for. This brings us to the region affected by the Black Hills uplift and some lesser folds. While the Black Hills are usually known as belonging to South Dakota, the Wyoming-Dakota line passes over some very prominent peaks of Algonkian schists, in the tin-bearing regions, which leaves a small area in Wyoming. On the western slopes of the Black Hills the Cambrian strata dip very gently westward, and above the Cambrian are the Ordovician, Carboniferous and probably Permian. These are found in rather wide beds, the Permian extending westward to within ten miles of Sundance. From this point westward to Sundance the Triassic red sandstone covers the entire valley, extending to the northward and southward many miles, while the Paleozoic rocks bend to the eastward as they encircle the main uplift. Throughout this area artesian wells can be secured, and although the bands of rock do not reach high up along the hills, one can expect a large supply of water, since the precipitation in this section of the state is almost double that of central Wyoming. North and east of Sundance the conditions are very favorable. The Bear Lodge mountains traverse considerable country north and south. They have a core of Cambrian rocks and the Ordovician, Carboniferous and Permian flank either side. The elevation of the highest peak is 6,750 feet. These rocks furnish water for the western side of the basin, that is supplied from the east by the Black Hills. At Sundance good wells will be secured

if drilled to a depth of 1,000 or 2,000 feet. On the west side of the Bear Lodge range is also a second area that will be found productive. Westward on the Belle Fourche river there is an anticlinal fold in Cretaceous rocks, in the Belle Fourche oil field, but this is of little importance for artesian water, on account of a slight production and the contamination with petroleum.

Having dealt with the exterior of this, the largest artesian basin in Wyoming, some may inquire what is to be done with the central region, where streams are scarce and water is so badly needed. Very unfortunately the best water-bearing zones are buried so deep with upper Mesozoic rocks that any attempt to pierce them with a drill would prove futile. In reality this is the most valuable portion of the basin if it were possible to drill and reach the Dakota sandstone or the Paleozoic rocks, but unless there are new inventions that will aid us in drilling, no one need for a moment consider drilling a well deeper than 5,000 or 6,000 feet, and since a well here would have to be from 10,000 to 20,000 feet deep to reach the great water zones, it makes the question hinge on impossibilities. Even in the central regions slight flows may be found near the surface that would repay many times the expense of drilling. In the Salt Creek oil fields artesian water bands have been found, but the water was so saturated with sodium sulphate as to render it useless for any purpose. Along the fold of the Powder River oil basin wells may be found, but if associated with the oil sands they will not be useful. On account of the Dakota sandstones cropping to the surface in this section, there is an excellent opportunity to drill along the axis of the anticlinal fold and secure a large supply of water that would come from the Big Horn mountains. The Oil Mountain oil field should also be included as a possible place for securing a flow. In fact the Guthery well, which is drilled on Poison Spider creek, has furnished a small flow of sulphur water for several

years. Wells drilled nearer the axis of the fold should produce more water.

See Section X for geological structure of Powder River artesian basin.

THE GREEN RIVER ARTESIAN BASIN.

The area of this basin is very great, but the boundary lines cannot be surely fixed, since there are no mountain ranges that act as barriers, and also because the Tertiary rocks have obscured the greater portion of the Mesozoic and Paleozoic terranes. The Rawlins uplift marks the eastern limit, but as this only extends a few miles, it only establishes a portion of the boundary. From the Rawlins uplift the line extends south to the western flank of the Sierra Madre range, thence south to the Colorado line. To the northward it extends to Green mountain. The northern boundary extends from Green mountain northwest to South Pass, thence north and west to the great bend of the Green River and thence southwest along the Gros Ventre mountains. The western border is formed by the Gros Ventre mountains and lesser folds that extend southward outcropping occasionally between Lead creek and at a point just west of Opal, thence due south to the Colorado line; but all, or nearly all, of the older sedimentary rocks are buried beneath the Tertiary. The southern boundary is in reality in Colorado, where the Uinta mountains form a higher barrier, with the Paleozoic and Mesozoic rocks dipping toward Wyoming. Conditions about the basin are different from any described. There are some high mountains but the strata do not as a general thing extend high up along the ranges. For miles none of the Mesozoic and Paleozoic rocks are exposed and if they ever did flank the range they have been completely buried by more recent sediment. At Rawlins there is an Archean exposure, but the sedimentary rocks reach a higher elevation than the granites. To the west of the Archean the Paleozoic

rocks, which are Cambrian, Carboniferous and probably Permian dip to the westward at a higher inclination and also gradually decrease in elevation toward the Red desert. The Mesozoic rocks, apparently conformable, dip at a less angle and at a distance of ten or fifteen miles, the Laramie rocks dip only a few degrees to the west. South of Rawlins the dip of the strata gradually flattens, and only the Cretaceous series appear on the surface. Along the Sierra Madre the Cretaceous rocks rest upon the Algonkian schists. The drainage from this range may enter the Cretaceous at various intervals, or it may follow the unconformability to a great depth. North of the Rawlins uplift artesian conditions disappear. The Cretaceous rocks are folded, but form a rough and broken country that is bordered on the west with Eocene Tertiary rocks, and the north by an elevated region known as Green mountain, the structure of which is not definitely known. Possibly Green mountain may act as a storage reservoir, but with this exception there are no elevations to produce hydrostatic pressure. To the west of the Rawlins uplift slight flows may be looked for, and these may be secured many miles west of Rawlins: but large wells should never be expected. Along the Sierra Madre mountains, the question of artesian water cannot be settled without drilling. Surface conditions do not warrant an opinion.

The northern boundary of this basin, from Crook's gap westward, is a broad Tertiary plateau, which practically forms the northern boundary of the Red desert. To the southward the plateau terminates in precipitous bluffs which rise from 500 to 1,000 feet above the desert, and reach in almost an unbroken line from just west of Crook's gap nearly to Pacific Springs. Throughout this entire distance there is no evidence of any rocks older than the horizontal Tertiary strata, that alike covers the table land and the desert. Mesozoic rocks are below; but how deep one would have to drill to reach them no

one can tell. Prior to the deposition of the Tertiary, the Cretaceous rocks flanked the Wind River range. These rocks seem to have suffered greatly from erosion along the southern and western slopes and later their upturned edges were entirely buried by the Tertiary. At the foot of the escarpments along the desert it may be possible to drill and reach some of the Cretaceous bands. At present there are no indications to follow, since there are only a few small springs known that have their origin in the Tertiary. From Pacific Springs north and west conditions are similar until within a few miles of the great bend of the Green river, where both Mesozoic and Paleozoic outcrop. These escarpments are very small, however, and give but little promise of important water supplies. West of the Green river, along the southern and eastern slopes of the Gros Ventre mountains, the sedimentary rocks lie high up on the range and offer similar inducements for drilling as have been cited along several of the other important mountain ranges. Conditions are not exactly the same, since the Tertiary strata obscures the most of the Cretaceous and will make it necessary to drill in the lower Mesozoic bands and in the Paleozoic. Along this range the rocks exposed are the same as formed along the eastern slope of the Wind River mountains.

From the Gros Ventre mountains southward to the state line there is an anticlinal fold along which the lowest exposed rocks belong to the Carboniferous. This exposure is not continuous, for the Tertiary rocks have in many instances covered the entire fold. It is especially prominent northward from Opal on the Oregon Short Line railroad. Between the Gros Ventre range and Opal there are no high mountains, and the Carboniferous rocks must be considered the lowest zone in which to look for artesian water, and in this only small flows can be expected. On account of the Tertiary covering most of the Mesozoic the most desirable locations for drilling will

be found along a narrow band paralleling the Carboniferous exposure. South of Opal the entire fold is covered with Tertiary, which debars it from artesian possibilities.

The southern boundary of the basin is in reality the Uinta mountains. In Wyoming there is a narrow belt of the uppermost Cretaceous bands that extend from Black's Fork nearly to Dixon. While flowing wells may be found in this region, the locality is unfavorable, on account of coal veins and poor water. Further, the supply would be quite small and if good water could be found the production would not warrant the expense.

Some mention should be made of the central part of this basin. At Salt Wells and to the south there is a broad anticlinal fold which causes the rocks to dip westward to Rock Springs and eastward to Black Buttes. To the east the surface gradually rises so that very little depth is gained. Toward Rock Springs the surface falls rapidly but does not equal the dip. On this account flowing wells can be obtained in the vicinity of Rock Springs and to the north and south some distance. They can be found by drilling at Green River city. None of these localities are recommended: First, on account of the numerous coal veins, which always produce bad water; and second, on account of the abundance of soda salts found in this region. Wells drilled at Green River in which the water rose to the surface and at times flowed, have contained as high as 24 per cent of sal soda or sal soda mixed with other soda salts. Artesian wells have been drilled at Rock Springs, and a small flow obtained; but the water was anything but desirable.

See Section XI for geological structure of Green River artesian basin.

THE SWEETWATER VALLEY.

Since the structure of this valley is very questionable and thus far has not been entirely satisfactorily explained, it can not be called an artesian basin. The valley extends from the North Platte river westward between the Seminoe, Ferris and Green mountains on the south and the Rattlesnake mountains on the north, nearly to Lewiston. All of this area is covered with Tertiary (probably Miocene) except the low round granite masses that have been called the Sweetwater mountains. The largest granite areas extend along the northern side of the Sweetwater river from below Devil's Gate westward nearly to Rongis. The highest peaks are not over 1,000 feet above the valley. The masses are irregular in outline, with numerous low and long narrow ridges extending out into the valley. The slopes are smooth and contain little or no soil, but there are occasional grass patches or a few scrubby pine trees. The peaks are dome shaped and are worn so smooth that it is usually very difficult to scale them. In all cases the Tertiary rocks are found lying upon or against the granite. Besides the large masses of granite there are numerous outliers and these are often very small, only a few acres in extent. These outlying exposures are widely scattered and are to be found not only in the center of the valley but also along the Rattlesnake and Ferris mountains. So far as investigation has proven, there are no Paleozoic or Mesozoic rocks exposed in this region. Along the Ferris mountains the Tertiary was found resting upon the Archæan and across the valley the Rattlesnake mountains so far as known present the same features. Along the Ferris range the Paleozoic dips at high angle to the southward while along the Rattlesnake these rocks dip to the northward. At first one is inclined to consider this valley the axis of a great anticlinal, with the ranges on either side representing what was at one time the base of a broad and high range. On a second thought it seems more likely that this valley was an Archæan

land mass and that it continued to be an island from the beginning of the Archæan up to the close of the Eocene Tertiary. Following this period the granite highland was depressed and covered by a Miocene sea, but the peaks and highest ranges protruded above the lake surface. Prior to this valley becoming a Tertiary sea the Ferris and also the Rattlesnake mountains were in all probability elevated by means of enormous faults which paralleled the valley. In case this solution is true the granite peaks of the Sweetwater valley represent the only portions of Wyoming that have been constantly above sea since the beginning of geological time. Again, if this solution is true, the Sweetwater valley is not an artesian basin, and while wells may be found by drilling, no one should expect a flow.

See Section XII for geological structure of the Sweetwater valley.

THE LARAMIE ARTESIAN BASIN.

This ideal basin lies between the Laramie and Medicine Bow mountains, being limited in its southern extension by the union of the Laramie and Medicine Bow mountains and on the north by the westward bend of the Laramie mountains, which forms the eastern boundary, and on the west by the Carbon and Shirley artesian basins, which boundary is a north and south line passing just west of the western termination of the Como anticlinal. In the northern half of the Laramie basin there is a local anticlinal fold extending from the old Miser siding north and east nearly to the Big Laramie river, and a second one north of Rock Creek which has the same strike as the Miser and is several miles in length. West and north of these is the Como anticlinal and a portion of the anticlinal north of Medicine Bow, which influences the strata as much as either of those previously mentioned.

The rocks forming this basin include all of the periods known in the Rocky mountain geology from the Carboniferous

to the Fox Hills inclusive. Along the Laramie mountains the Carboniferous and Permian lie high up along the range, often reaching an elevation of from 1,000 to 1,500 feet above the valley and dipping gently, about 12 degrees, to the westward. In reality these rocks form the western slopes of the range and on this account there is not a single stream that forms from springs along the mountain side that reaches the Laramie river, on account of the water following the bedding planes and supplying the artesian basin. The conditions along the southern end of the basin cannot be as clearly shown, since the rocks are badly distorted, faulted, and in many places they dip at a high angle northward and are largely covered with soil. Along the Medicine Bow mountains the dip of the rocks is very sharp, often reaching 60 degrees, and on account of the soil and talus washed from the range they are as a rule buried. In the Centennial valley, which lies between Sheep mountain and the main range, there is a small area in which the rocks are not very thick, since they have suffered exceptional erosion and not less than 10,000 feet of sedimentary rocks have been removed. In consequence the entire strata in this region are not over 4,000 feet thick in the center of the valley and the rocks dip gently from both the east and the west and likewise from the south. North along the Medicine Bow range the Carboniferous rocks seem to rest upon the Archæan or Algonkian and can be seen occasionally where the streams issue from the mountains. Sometimes they are found higher up than along the Laramie range. The greatest difference between the eastern and western sides of this basin is that on the east the rocks dip gently and the oldest sedimentary rocks extend a long distance from the crest of the range, while along the western side the rocks approach the vertical and are only seen in narrow bands. (For illustration, see geological section of the Laramie basin.)

Along the northern end of the basin the Carboniferous

rocks are gently inclined to the south and form a broad band that disappears beneath the Tertiary on nearing Sheep creek. Above the Carboniferous there is a broad band of Triassic sandstone. These gently dipping strata will furnish a considerable amount of water. For this section, the Laramie mountains must be considered as the primary source for the water, which is slightly augmented by the flow from Freezeout hills. The slight uplifts near Miser, Rock Creek, Como and Medicine Bow also affect this whole region. Along the anticlinals the axes have been eroded down to the Triassic and in the one north of Medicine Bow to the Permian or Carboniferous. Between these folds are slight synclinal basins which may prove valuable for small wells. There are a few springs that act as overflows for this section. One is at Como, another at Seven Mile spring, north of Rock Creek, and a third at Boswell springs. These folds have been beneficial to a certain degree, for they have caused the Cretaceous bands to be removed and made it possible to reach the Carboniferous and the Archæan a long distance from the Laramie mountains.

The mountains on three sides of this basin furnish the water supply for this basin. On the plains the average rainfall is about 12 or 14 inches, but in the Medicine Bow mountains it is double if not treble that amount. A considerable portion of this snow, which melting, gradually follows the strata on their downward course and this basin is filled to the overflowing, the overflows being springs in various places along the ranges. Along the foot of the Laramie mountains there are the Laramie, Soldier Creek, Simpson, Red Buttes and Sportsman lake springs, all of which appear to come from a slight fault. The large springs in the Centennial valley are also vents.

The most important water-bearing horizons are the Carboniferous, Permian, Triassic, and Dakota Cretaceous. Above these bands good wells may be secured in which the water will be questionable. Along the western boundary of the basin the

above formation cannot be seriously considered, since as a rule they are found high up along the range where water is not needed. Below, along the valley, the depth will be too great to penetrate with a drill. The Centennial valley is an exception to the above, for at any point in the valley it will be possible to drill to the granite. Artesian wells, however, will be found by drilling in the Cretaceous rocks along the Medicine Bow mountains. The chances for securing good water are about equal to the chances for securing poor.

Along the eastern side of the basin conditions are exceptionally favorable for well drilling to secure water in the Carboniferous, Permian and Triassic rocks. There is a belt varying from three to six miles in width the entire length of the basin, where wells drilled from 200 to 3,000 feet can secure good flows of excellent water, the deep wells having preference and producing the largest volume of water.

At the present time numerous experiments have been tried in the Laramie basin and they have usually been successful. Quite a number of wells have been drilled in and about Laramie. These vary in depth from 200 to 1,500 feet and the water has usually been found, but the flow only moderate. It is only fair to remark that had they used larger tools the production of each well would have been increased. So far as known, the wells drilled at Laramie have all been in Triassic sandstone and but a few of them have been drilled deep enough to reach the Permian or Carboniferous rocks, where the best wells will be found. I would suggest that the most valuable water-bearing horizon lies near the granite, where there is a coarse sandstone. At Laramie a well would have to be drilled about 2,000 feet to reach this zone, which in all probability will furnish a surprising water supply. Along the western edge of the basin four wells have been drilled, three of which flow, and in the fourth water would rise to within 18 inches of the surface. The water of two of these

wells was excellent. The others were sulphurous and contained considerable sodium sulphate. The good wells secured their flow in the Fox Hills sandstones. The water supply of the Laramie plains can be greatly augmented by drilling artesian wells. The basin is large, has a vast area tributary to supply water which can not only be utilized for ranch and municipal purposes, but to a considerable extent for irrigation. What is most needed today is a deep well that should be drilled a good distance west of the Laramie range and deep enough to reach bed-rock.

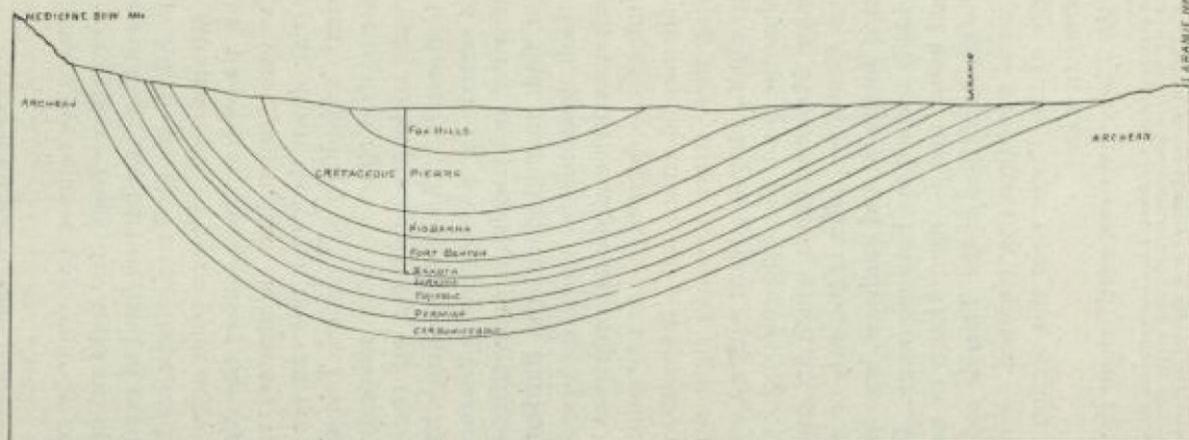
How many wells this basin will support and give to them all a reasonable supply can not be estimated. However, the area is large and the water supply is more than ordinary. By drilling wells the pressure must of necessity be decreased, but this will not be apparent until the demand exceeds the supply.

See Section XIII for geological structure of the Laramie artesian basin.

THE SHIRLEY ARTESIAN BASIN.

Lying east of the North Platte river and north of the Shirley mountains there is a depression that has been known for years as Shirley basin, but this must not be confused with the Shirley artesian basin, which is very much larger. The artesian basin includes all of the territory lying between the Laramie mountains on the north and the Shirley mountains and Freezeout hills on the south. There are no natural barriers hemming in this basin on the east or west. The North Platte river can be considered the western boundary and a line extending north from the eastern termination of the Freezeout hills the eastern. Along the Laramie mountains the Tertiary strata have covered nearly all of the earlier sedimentary rocks. Near the Platte river, where the waters have cut a broad val-

SECTION XIII.



A geological section of the Laramie artesian basin, extending from the Laramie mountains westward through Laramie to the Medicine Bow mountains.

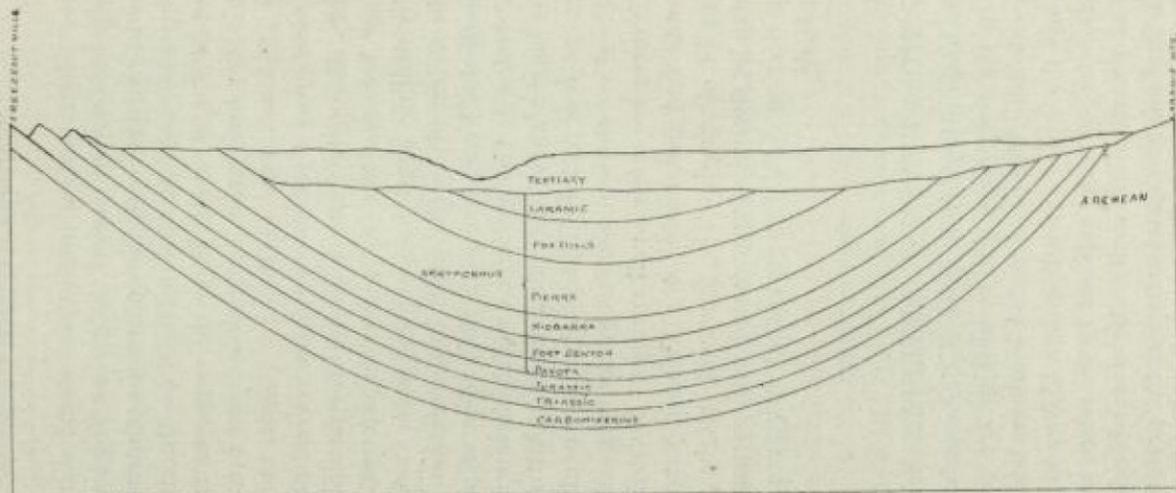
[Drawn to Scale.]

ley, the Tertiary rocks have been entirely removed and exposed the formations from the Archæan upwards. Hence along the river there is a narrow band of exposures which are bordered on either side by Tertiary beds, and which will produce some artesian wells. From a point a few miles below the mouth of the Sweetwater river, where the Platte river surges through the great canon, the sedimentary rocks dip to the north. Passing down the canon one can see along the walls the Cambrian, Carboniferous, Permian, Triassic, Jurassic, and the very base of the Cretaceous, when suddenly the Carboniferous or Permian rocks are duplicated and rise at least 400 feet above the Cretaceous. This sudden change has been due to a fault which extends for a considerable distance on either side of the Platte river and possibly is the southeastern termination of the great fault that produced the Rattlesnake mountains. From this fault flows several warm springs which have been credited with remarkable medicinal properties. The water has a temperature of 140 degrees F. At any point above the fault artesian wells may be drilled and a flow obtained. The Platte river crossing these strata at nearly right angle as it passes through the canon, furnishes them with an unusual supply of water. Below the fault, the Paleozoic rocks are covered with gently dipping Mesozoic bands which are capped with Laramie. Below Alcova ten miles is the axis of a synclinal basin which extends northwest and southeast, beyond which the strata rise gradually toward the Laramie range. On either side of the synclinal basin, that is, near Alcova or near the Laramie range, wells can be drilled in the Triassic and possibly in the Fort Benton and a medium flow obtained. Were it not for the water supply of the Platte river this section would be of no value for artesian water.

From the Platte river eastward* along the range there are

*Since the geological map was drawn I have investigated Bates Hole and found that the central portion of this area has been eroded down to the Cretaceous. The Cretaceous exposure along the Platte river should extend in a narrow belt some thirty miles east and south.

SECTION XIV.



Geological section from the Freezefoot hills northeast to the Laramie mountains, across the Shirley artesian basin.

[Drawn to Scale.]

no places where surface indications would warrant anyone in searching for artesian water. Along the Shirley mountains the Tertiary has also covered the upturned sedimentary rocks from the Platte river eastward to the head of Muddy creek. From the head of Muddy creek along the range as far as Freezeout hills, the Paleozoic strata are exposed and are nearly vertical, dipping slightly to the northeast. Below, in the valley, are the Mesozoic rocks, which extend for several miles northward, when they disappear beneath a high Tertiary bluff. All along the range between the last points mentioned, wells may be found by drilling near the mountain base. A better method would be to tunnel for the water in the section.

Along the Freezeout hills the oldest exposed rocks are either Permian or Carboniferous which do not rise to any considerable height above the valley lands. All of the Mesozoic rocks are present and the Dakota band forms the slopes of the hills. These are cut in numerous places by gulches and ravines in which there are a few small springs. By drilling in the Dakota bands and penetrating the Triassic sandstones flowing wells can be obtained. The flow will not be strong and the water may be strongly impregnated with gypsum.

See Section XIV for geological structure of the Shirley artesian basin.

THE CHEYENNE ARTESIAN BASIN.

This basin differs from most of the artesian basins of the state. In the first place, the mountains are found along the western side only, the eastern and southern borders having no barrier and the strata extending into Colorado and Nebraska. The Carboniferous rocks exposed to the westward of Cheyenne outcrop at Omaha. Secondly, the water-bearing rocks were originally and are to a great extent at the present time covered with Miocene Tertiary. Nevertheless there are artesian possi-

bilities in the Cheyenne basin, which is bounded on the north by the Powder river basin, on the west by the Laramie mountains, and extending on the south into Colorado and the east into Nebraska. Along the Laramie mountains the Paleozoic rocks, which are composed of simply the Carboniferous or Carboniferous and Permian, stand in nearly a vertical position, except at Table mountain, where a large block of limestone has been carried up by the granite and is an isolated area nearly level. To the northward of Table mountain, along Pole creek, Horse creek and Chugwater, the Carboniferous can be seen as huge hog-backs paralleling the range. Similar exposures are seen south of Table mountain. Occasionally there are exposures of the Triassic sandstone accompanying the Carboniferous and in a few instances the Tertiary has been removed in the valleys, laying bare the Cretaceous rocks as high as the Fort Pierre shales. In localities where the Mesozoic and Paleozoic rocks are exposed and the strata are not vertical, artesian wells may be found, but the water supply will be small, since these strata depend upon the rainfall for their water.

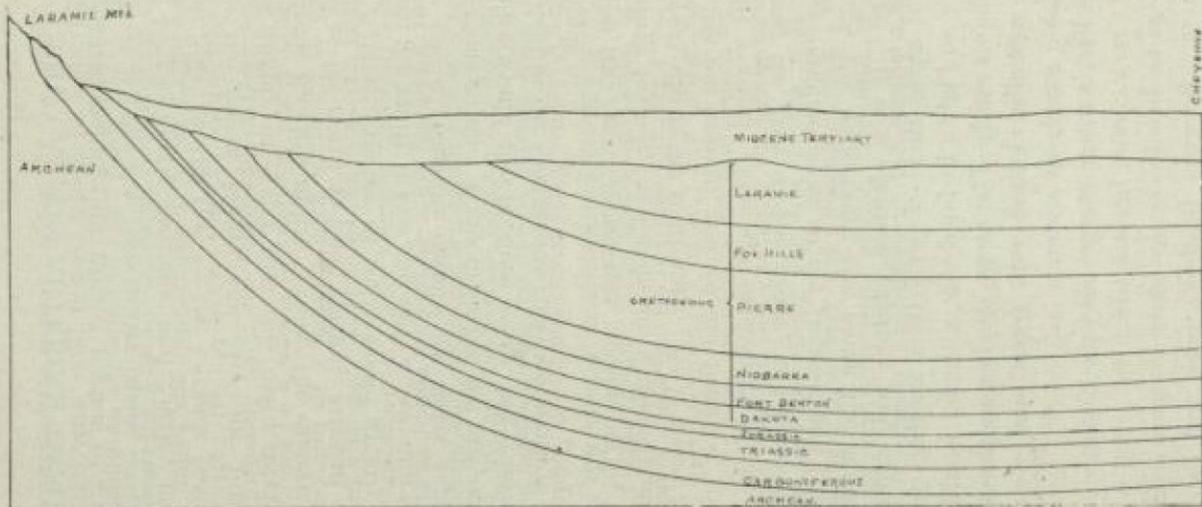
In Goshen hole the Tertiary rocks have been removed from quite large areas, and the Laramie sandstones exposed. Artesian water will be found in this depression, but on account of the coal the water may be very impure. Again, the supply of water from wells drilled in this region will never be very great. North of the Big Laramie river, and especially along the Platte river and extending eastward to the Hartville hills, the geology is entirely different from the southern half of the basin. Here not only the Tertiary rocks have been removed, but also the Mesozoic, leaving the Carboniferous exposures. To the westward of the canon of the Platte there is a synclinal basin, in which there are some Cretaceous rocks. Representing the oldest strata along the Laramie mountains are the Carboniferous and Cambrian rocks extending high up along the mountain slopes. This produces a basin of considerable import-

ance, and wells drilled in the Dakota or lower will unquestionably find an abundance of excellent water. All of the limestone area between the Cheyenne and Northern railroad and Hartville can be considered as artesian territory. Wells will not have to be drilled deep and the flow will not be large. Eastward from Hartville conditions are unfavorable for well drilling. The Tertiary country lying east of Whalen canon will probably never have a flowing well. The rocks to be encountered below the Tertiary are the Laramie, which are quite liable to furnish very inferior water. In case an artesian well is contemplated at Cheyenne in the future they should arrange to drill not less than 4,000 feet. But in any case it is very questionable if a well would ever pay the necessary expense. In this connection it is well to recall some of the wells that have been drilled in the Tertiary that do flow small streams of good water. One of these is south of Cheyenne. In the Tertiary there are lenses of clay that are impermeable layers, and these confine a small quantity of water that is taken up by the ground and carried to lower levels. The Tertiary dip slightly to the eastward, which accounts for the artesian pressure. Small wells may be found near the surface, but since the clay bands are local well drilling will be mere guess-work.

In the Cheyenne basin the conditions are such that in the future it may be found advisable to drill wells near the mountains, where they would not be so deep, and pipe the water to lower levels. The great springs at Granite Canon reveal the fact that there is quite a large water storage along the Laramie mountains west of Cheyenne, and that this spring acts as the overflow for the basin.

See Section XV for geological structure of the Cheyenne artesian basin.

SECTION XV.



Geological section from the Laramie mountains eastward through the Cheyenne artesian basin to Cheyenne.

[Drawn to Scale.]

THE CARBON ARTESIAN BASIN.

This basin includes the greater portion of Carbon county. On the west it joins the Sweetwater basin; on the north it is bounded by the Ferris, Seminoe and Shirley mountains and Freezeout hills; on the east by the Laramie basin and on the south by the Sierra Madre and Medicine Bow mountains. The only supply of water that this basin receives from the west is from Rawlins uplift. Along the eastern slopes of this anticlinal as far north as Belle springs, artesian water may be found. A large number of wells would greatly decrease the flow, since the uplift is low and only a few miles long.

The city of Rawlins obtains its water supply from the Carboniferous strata. Wells drilled to the eastward of the fold a few miles would also produce water, but it would almost be folly to drill in the Cretaceous rocks on account of the lack of water supply.

Along the Ferris mountains, on the north, the Paleozoic rocks, which include the Cambrian, Carboniferous, and possibly Permian, dip to the southward. At Whiskey Gap the dip is quite sharp, but beyond, toward the Seminoe, these rocks are practically vertical. The soft sandstones of the Triassic outcrop along the foot of the range, and beyond the Triassic there is a complete series of the Jurassic and Cretaceous. No streams of any importance rise along the southern slope of this range. It is a question whether well drilling would be successful along these slopes. It is another case where the rocks are so highly inclined that a tunnel would be more desirable than a well. The range reaches an elevation of 10,000 feet, is partially clothed with forest and would furnish a considerable supply of water.

The Ferris range merges into the Seminoe in the vicinity of Sand Creek canon, beyond which the trend is to the south-east as far as Bradley peak, where it again assumes a southerly course. Between Bradley's peak and Sand creek there

are no sedimentary rocks exposed along the slopes and the valleys are covered with sand dunes, which in some places are now accumulating an elevation of over 8,000 feet. Southwest of Bradley's peak the Cretaceous rocks form a long ridge extending many miles and connecting with the Cretaceous rocks farther to the east. In this section the Cretaceous rocks appear to rest unconformably upon the Algonkian schists and consequently would not be a means of carrying water into a basin. From a point south of Bradley's peak eastward to the Platte river conditions change. As soon as the Archæan replaces the Algonkian to the eastward, the Paleozoic rocks are again seen in nearly vertical bands extending high up along the mountains. Paralleling the range on the south side is a secondary anticlinal fold in the Cretaceous rocks. On account of the highly inclined strata along the range, tunnels may be driven for a water supply, in the place of drilling wells. All along the range opposite the Algonkian schists conditions for either wells or a tunnel are unfavorable. The schists are water-bearing in the section and a cross-cut tunnel into Bradley's peak would no doubt yield quite a stream of water. Across the Platte river the Shirley* mountains are similar to the eastern end of the Seminoe, except that the dip gradually decreases to the east. Wells may be obtained along the foot of the range at any point between the Platte river and Difficulty creek. What has been said of the northern slope of the Freezeout hills in the Shirley basin is equally applicable to the southern slopes in the Carbon.

The eastern boundary of the basin will not be considered as important territory, since it connects with the Laramie basin on the east. There are, however, numerous places where wells may be drilled with profit. About the termination of the

*Since writing the above I have been in the field and have discovered that the Seminoe is a range entirely separated from the Shirley, and that the Shirley represents an individual uplift. This changes the structure as given in the geological map accompanying this bulletin.

Medicine Bow anticlinal can be considered as valuable territory for small wells.

The southern boundary presents many peculiar phases. The Medicine Bow range rises to a height of over 12,000 feet, but separating it from the Sierra Madre there is a broad valley that has been filled with Tertiary and the Sierra Madre mountains are largely Algonkian, about which nothing older than the Cretaceous rocks have been found. Elk mountain forms the northern termination of the Medicine Bow mountains, and about this very prominent peak are bent the Paleozoic and Mesozoic strata, the Paleozoic lying high up along the slopes and continuing to a considerable distance to the eastward and to the southward. About this mountain there is ample room for many wells, all of which should be large producers. The best flow will be obtained by drilling through the Paleozoic and reaching bed-rock. In the Platte valley, in the vicinity of Saratoga, all of the Mesozoic and Paleozoic strata have been covered with the Tertiary. At Saratoga there is evidence, in the warm springs, which are justly celebrated for their medicinal qualities, that there are some large faults that bring the heated water supply to the surface. It is very probable that the Saratoga valley is a synclinal basin between the two ranges. If this is the case, wells may be found of some importance by drilling through the Tertiary strata at points near the ranges.

The Sierra Madre range presents several features that have not been studied and the country about the base of this range cannot be recommended for artesian wells, but nevertheless a careful investigation might prove it of some importance.

The interior of the Carbon basin is largely made up of the Laramie Cretaceous and cannot be considered as artesian territory on account of the great depth it would be necessary to sink to reach a flowing water zone.

THE UINTA ARTESIAN BASINS.

In Uinta county, south of the Gros Ventre mountains, there are several anticlinal folds that extend south towards the Utah line. For this reason I have used the term basins, instead of basin, for there are several anticlinal folds that will prove to be of some value in securing flowing wells. Unfortunately, much of this area is covered with Tertiary rocks, which seriously interfere with working out the stratigraphical conditions. So far as investigation has gone, there are two prominent anticlinals extending north and south. The axis of the first passes just west of Opal and the second west of Twin Creek. These folds are exposed to some extent along the line of the Union Pacific railroad and also north of the Oregon Short-Line railroad. The rocks exposed, so far as known, are the Carboniferous, and these are nearly all north of the Oregon Short Line railroad, and do not form very high ranges. In some instances the axis has been deeply dissected but the Ordovician or Cambrian rocks have not been reported. On account of these sedimentary ranges being low and not accumulating much snow, the basins in this region will not produce large flows. Again, on account of the slight elevation of the surrounding country, the pressure will also be insufficient to produce a large flow, provided the water supply is sufficient.

In the country north of Opal, and along the Carboniferous exposures, wells will be found by drilling in the lowest exposures of the Carboniferous or Triassic rocks. Wells obtained in these bands will undoubtedly produce the greatest water supply and will also furnish the most desirable water. Wells drilled in the Jurassic will without question secure water in the Triassic sandstone provided they are drilled to a depth of 500 feet or more. It will also be possible to drill in the Jurassic bands and reach the Carboniferous water supply with deep wells. In no instance can the Cretaceous bands be recommended for artesian wells. They are water-producing and slight flows may

be secured in many localities, but as a rule the water supply would not be large enough to supply a large ranch.

South of Opal the conditions are much more unfavorable for well drilling than to the north. The Carboniferous, Triassic and Jurassic bands are entirely covered with the Tertiary. In a few places where the erosion has been very great the Tertiary has been removed and the Cretaceous bands are exposed. The Tertiary covering prevents the accumulation of water in the lower strata and has also made it impossible to drill to the valuable water zones, even if they did carry a large supply of water.

In the vicinity of Hilliard, especially to the eastward, artesian wells can be secured, but the water supply will be very limited and the water very questionable. Along the Bear river slight flows will be found, but there is nothing to warrant any great expense in drilling. There are numerous slight Cretaceous exposures in southern Uinta county, where artesian wells can be drilled, but in no instance should anyone expect to secure a large volume of water.

THE GROS VENTRE ARTESIAN BASIN.

This is a small basin where boundaries have not been traced out on account of the country being very mountainous, forest clad, and having no roads and but few trails. It is also in a region that is well watered and there can never be more than a limited demand for artesian wells. The southern limit of this basin is the Gros Ventre mountains, which rise to a height of 12,000 feet and extend from the big bend of the Green river northwest of Jackson's hole. The eastern boundary is the Wind River mountains, which have furnished a vast accumulation of glacial debris that has buried the sedimentary exposures, or in many instances they have been covered with Tertiary sediments. On the north the structure is only ap-

proximately known, but the sedimentary rocks are sufficiently exposed to warrant me in saying that this side of the basin is well supplied with artesian water. On nearing Jackson's hole the valleys and to some extent the high lands are covered with gravel so that the structure is not known. Jackson's hole forms the western boundary and it is very probable that the Archæan exposures along the Teton range were originally covered with Paleozoic rock which dipped to the eastward, but which have been entirely removed by the excessive erosion of Snake river, assisted by glaciers, and their upturned edges buried with the wash from Snake river. The formations entering into the structure of this basin are Cambrian, Ordovician, Devonian, Carboniferous, Triassic, Jurassic, Cretaceous and Tertiary. The Paleozoic rocks are rather steeply inclined to the northeast along the Gros Ventre range and in most instances they are exposed at such an elevation that wells could not be utilized if drilled, on account of the location. In the valley of the south fork of the Gros Ventre river wells may be drilled to some advantage in the Paleozoic. To the west of this tributary the Triassic or some of the other Mesozoic strata would furnish ample water, until within a few miles of the Hole, where the Paleozoic rocks outcrop along the river. Along the eastern side of the basin, wells would not avail anything on account of the country being high and very rough. The same conditions are known along the greater portion of the northern side. In Jackson's hole, the Snake river and its tributaries furnish much more water than can be utilized. There are, however, numerous places in the valley where artesian wells can be secured. Especially are the conditions favorable in the southern end of the Hole in a region that has not been assigned to any basin on account of its being very small. The central portion of the Gros Ventre basin is made up chiefly of high, broken country, much of which has been drained by the deep gulches and canons. The most desirable

water zones lie beneath the Dakota sandstones in this as in nearly all of the basins in Wyoming.

THE TETON ARTESIAN BASIN.

This basin lies on the west of the Teton mountains and is in reality tributary to Idaho. The formations entering into its structure, as far as exposed, are largely Paleozoic. The Cambrian, Ordovician and Carboniferous extend up the mountain slopes to perpetual snow. Along this range artesian conditions are ideal, but the demand for artesian water in Wyoming from this source will never amount to anything, since there are abundant streams to provide all the water that the Wyoming area of the Teton will ever need. For this reason the basin has been merely mentioned.

Index.

Algonkian	111, 113, 115, 116
Amphibians, introduction of	123
Appalachian mountains	118
Archaean	111, 113, 114
Artesian basins	203
Artesian wells	184, 185, 192
Azoic	111, 113
Baculites	151, 157
Bates' Hole	167
Bear River stage	111, 142, 146
Bed-rock, defined	114
Belemnites	115
Big Horn Artesian Basin	203
Bituminous shale	170
Big Horn Basin	167
Bridger stage	111, 169, 170, 171
Brontosaurus excelsus	140
Cambrian	111, 119, 120
Carbon Artesian Basin	242
Carboniferous	111, 126, 127, 128, 129, 130
Cenozoic era	111, 166, 167
Champlain period	111
Coal	146, 160, 161
Como stage	111, 138, 139
Colorado formation	111, 142
Cretaceous period	111, 141
Cycads	139
Dakota stage	111, 142, 143, 144
Dinosaurs	133, 138, 139, 142, 161
Dip, estimating	194. Tables, 195, 196
Devonian period	111, 123
Drained artesian territory	198, 199, 201
Drilling artesian wells	188, 189, 200

Eocene period	111, 169
Eozoic era	111
False bedding	197
Fishes, introduction of	122
Fort Benton stage	111, 146, 147, 148, 149
Fort Pierre stage	111, 151, 152, 153
Fort Union sub-stage	111, 160
Fox Hills stage	111, 156, 157, 158, 159
Geological sketch	111
Glacial period	111, 168, 174, 175
Gneiss	113
Goshen Hole	167
Granite	113
Green River stage	111, 169, 170
Green River basin	167
Green River Artesian Basin	225
Gros Ventre Artesian Basin	246
Ichthyosaur	132, 135
Inoceramus	151
Introduction	107
Jurassic period	111, 134
Jura-Trias	134
Laramie Artesian Basin	230
Laramie stage	111, 142, 157, 162, 163, 164, 165
Lower Silurian	122
Mammals, introduction of	134
Mastodon	117
Mesozoic era	111, 132
Miocene period	111, 169, 172
Montana formation	111, 142
Mososaurs	142, 150
New Red Sandstone	133
Niobrara stage	111, 150
Oligocene period	111, 169, 171
Old Red Sandstone	123
Ordovician period	111, 122, 124, 125
Paleozoic era	111, 112, 117, 118

Permian period	111, 130, 131
Petroleum	146, 147, 150, 151, 157
Pleistocene period	111, 174
Pliocene period	111, 169, 174
Plesiosaur	132, 135, 142, 150
Powder River Artesian Basin	216
Proterozoic era	111, 115
Pterosaur	133
Puerco	169
Recent	111
Red Beds	133
Reptiles, introduction of	131
Rocky mountains, when made	161
Schist	113
Seed bag	188
Shirley Artesian Basin	234
Shirley stage	111, 135, 136, 137
Shoshone Artesian Basin	207
Silurian period	111, 122
Sweetwater valley	234
Tertiary period	111, 169
Titanotherium	172, 173
Triassic period	111, 133
Tunnels for water	202
Uinta Artesian Basin	245
Upper Silurian	122
Wasatch stage	111, 169, 170
Water associated with—Archaean, 114, 183; Algonkian, 183; Ordovician, 122, 183; Carboniferous, 130, 183; Triassic, 134, 182; Jurassic, 139, 182; Dakota, 146, 179, 182; Fort Benton, 147, 182; Niobrara, 150; Fort Pierre, 156, 182; Fox Hills, 157, 182; Laramie, 166, 182; Wasatch, 182; Green River, 179, 182; Bridger, 182; Oligocene, 182; Mio- cene, 182.	
Water analyses	180, 181
Water-bearing zones	178
Wyoming artesian wells	191, 192

NOTICE.

This map was made expressly for Bulletin No. 45 of the Wyoming Experiment Station, which is a preliminary report on the artesian basins of Wyoming. The map embraces all published data pertaining to the geology of the state, excepting the National park together with a considerable amount of original material. Since completing this map I have discovered three errors which should be corrected. The country lying north of the Stinkingwater river, marked Tertiary, is Fort Union; the central portion of Bates' hole is Cretaceous, and the Cretaceous exposure along the Platte below the Hole should extend up Camp creek nearly to its head. There is also an anticlinal fold paralleling the Laramie mountains along the north side of the Hole, which is partially exposed. The Shirley mountains are not connected with the Seminoe, as has been reported, but form an independent range which is separated from the Seminoe mountains by a narrow synclinal valley. This makes the Seminoe mountains extend about six miles east of the North Platte river, and the Shirley mountains a range of only fifteen or twenty miles in length, which extends from Difficulty creek north and west to the head of the Muddy fork of the Little Medicine river.

WILBUR C. KNIGHT.