Geology and Ground-Water Resources of the Rawlins Area Carbon County, Wyoming

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By Delmar W. Berry

ABSTRACT

The Rawlins area in west-central Carbon County, south-central Wyoming includes approximately 634 square miles of plains and valleys grading into relatively rugged uplifts. The climate is characterized by low precipitation, rapid evaporation, and a wide range of temperature. Railroading and ranching are the principal occupations in the area.

The exposed rocks in the area range in age from Precambrian through Recent. The older formations are exposed in the uplifted parts, the oldest being exposed along the apex of the Rawlins uplift. The formations dip sharply away from the anticlines and other uplifts and occur in the subsurface throughout the remainder of the area.

The Cambrian rocks (undifferentiated), Madison limestone, Tensleep sandstone, Sundance formation, Cloverly formation, Frontier formation, and Miocene and Pliocene rocks (undifferentiated) yield water to domestic and stock wells in the area. In the vicinity of the Rawlins uplift, the rocks of Cambrian age, Madison limestone, and Tensleep sandstone yield water to a few public-supply wells. The Cloverly formation yields water to public-supply wells in the Miller Hill and Sage Creek basin area. Wells that tap the Madison limestone, Tensleep sandstone, and Cloverly formation yield water under sufficient artesian pressure to flow at the land surface. The Browns Park formation yields water to springs that supply most of the Rawlins city water and supply water for domestic and stock use.

Included on the geologic map are location of wells and test wells, depths to water below land surface, and location of springs. Depths to water range from zero in the unconsolidated deposits along the valley of Sugar Creek at the southern end of the Rawlins uplift to as much as 129 feet below the land surface in the Tertiary sedimentary rocks along the Continental Divide in the southern part of the area.

The aquifers are recharged principally by precipitation that falls upon the area, by percolation from streams and ponds, and by movement of ground water from adjacent areas. Water is discharged from the ground-water reservoirs by evaporation and transpiration, by seeps and springs, through wells, and by underflow out of the area.

Although most water supplies in the area are obtained from springs, some domestic, stock, and public supplies are obtained from drilled wells, many yielding water under artesian pressure, and some flowing.

Dissolved solids in the water from several geologic sources, ranging from 181 to 6,660 parts per million (ppm), indicate the varied chemical quality of ground water in the Rawlins area.

Water from the Cambrian rocks, Tensleep sandstone, Cloverly formation, Frontier formation, Browns Park formation, and Miocene and Pliocene rocks is generally suitable for domestic and stock use. However, water yielded to the only well sampled in the lower part of the Frontier formation contained a high concentration of fluoride. Water from the rocks mentioned above contains less than 1,000 ppm of dissolved solids but in some places may contain iron in troublesome amounts. Water from the Madison limestone and Tensleep sandstone combined, Permian rocks, and Sundance formation contains more than 1,000 ppm of dissolved solids. Water in the Sundance, Cloverly, and Frontier formations is very soft.

More ground water can be obtained in the Rawlins area than is now being used. Many springs are undeveloped, and water can be obtained from additional wells without unduly lowering ground-water levels.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

Investigation was begun in Wyoming in November 1940 by the United States Geological Survey in cooperation with the Wyoming State Planning and Water Conservation Board. Owing to the curtailment of activities by the Planning Board in 1945, cooperative ground-water investigations in Wyoming were transferred to the Wyoming State Engineer. As a result of added interest in development of ground water for industrial and agricultural purposes, the program was expanded in September 1954 by a cooperative agreement with the Wyoming Natural Resource Board.

At the request of the Wyoming Natural Resource Board, a study of the geology and ground-water resources in the vicinity of Rawlins, Wyo., was begun in November 1954. A need for additional water supplies for an increasing city population and for potential industrial development in the area warranted an investigation to determine the quantity and quality of ground water available. Approximately 3 months was spent in the field during the fall and winter of 1954–55. The investigation was made under the supervision of H. M. Babcock, district engineer of the Ground Water Branch, of the Geological Survey for Wyoming.

Records of 22 wells and 26 springs were obtained during the investigation. Available information regarding the character and thickness of the water-bearing materials, the discharge from the wells and springs, and logs of test holes and wells was obtained from well drillers and from the owners or tenants of property on which the wells and springs are situated. Well depths and water-level measurements were determined using a steel tape. Data pertaining to the springs that supply water to Rawlins were obtained from records in the city clerk's file; other pertinent data were reported by the city pipeline superintendent. Samples of material, penetrated in five test wells drilled for the city of Rawlins, were studied by the author. Aquifer tests were made of five wells to determine the hydrologic properties of the water-bearing formations.

Chemical analyses of water from 12 wells and springs in the area and of a composite sample of water from the 19 springs that supply water to the city of Rawlins were made in the laboratory of the U.S. Geological Survey, Lincoln, Nebr.

The geology shown on plate 1 is based in part on field investigations made with the aid of aerial photographs and was adapted in part from unpublished maps prepared by J. A. Barlow in 1952, I. H. Buehner in 1936, and G. L. Del Mauro in 1953. Field data were recorded on a base map adapted from the Wyoming State Highway planning map of Carbon County. The roads and drainage were checked and modified by field observation and by comparison with the aerial photographs. The wells shown on plate 1 were located by means of an automobile odometer and by inspecting aerial photographs; the locations are believed to be accurate to within 0.1 mile.

DESCRIPTION OF THE RAWLINS AREA

The Rawlins area encompasses approximately 634 square miles in the Wyoming Basin physiographic province as described by Fenneman (1931). It is in Carbon County in the south-central part of the State (fig. 1), extends from T. 17 N. to T. 23 N., inclusive, and from the first tier of sections in R. 86 W. to about the center of R. 89 W.

According to the census of 1950 Rawlins, the county seat of Carbon County, had a population of 7,415. This was approximately half the population of Carbon County. The principal occupations are railroading, agriculture, and the development of the natural resources. Agriculture, primarily the raising of cattle and sheep, contributes substantially to the economy of the area; oil and coal production make a lesser contribution. Many employees of the Union Pacific Railroad Co. reside in Rawlins.

Oil production within the area was limited to the Hatfield pool during 1954; however, future exploration may bring about further oil discovery. During 1954, production from the Hatfield pool amounted to 80,100 barrels of oil, according to E. A. Swedenborg, formerly district engineer, U.S. Geological Survey, Casper, Wyo. (oral communication). Coal production within the Rawlins area is very small; however, large coal reserves are being developed in adjacent areas. Coal reserves in the vicinity of Rawlins are abundant and may induce industries associated with the use of coal to be established within the area.

The Union Pacific Railroad and U.S. Highway 30 pass through Rawlins from east to west. U.S. Highway 287 extends northward from Rawlins, and an improved road has been constructed southward from Rawlins.

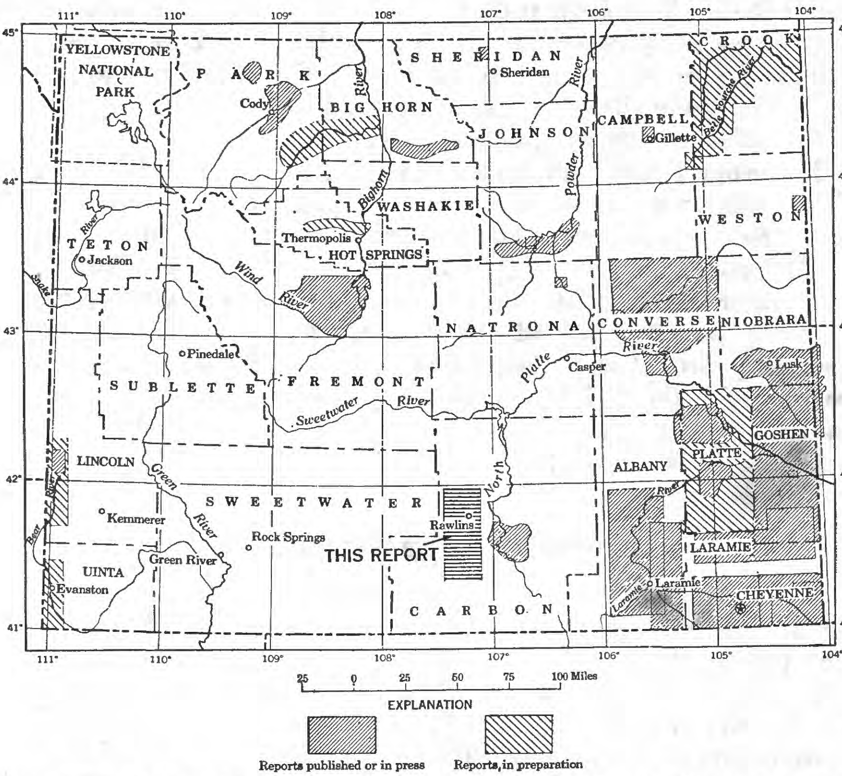

FIGURE 1.—Area described in this report and other areas in Wyoming for which ground-water reports have been published or are in preparation.

TOPOGRAPHY AND DRAINAGE

Low-lying dissected plans and basins, grading upward into high relatively rugged uplifts, are characteristic of the area. The altitude ranges from about 6,380 feet above sea level in a basin at the northern end of the area to approximately 8,300 feet at a point in the southwestern part of the area, locally known as Miller Hill.

Miller Hill, one of the conspicuous topographic features within the area, is an erosional remnant of moderately resistant, nearly horizontal strata of Miocene and Pliocene age resting unconformably on the crest of a Laramide fold. The fold, which is reflected in the older rocks, extends northward from the Sierra Madre and forms the Miller Hill-Lake Valley anticline. (See fig. 2 and pl. 1.) The fold extends northward nearly to Rawlins, where it terminates in a structure known as the Rawlins uplift. The Rawlins uplift is a complexly folded and thrust-faulted anticline, also a prominent topographic feature in the area.

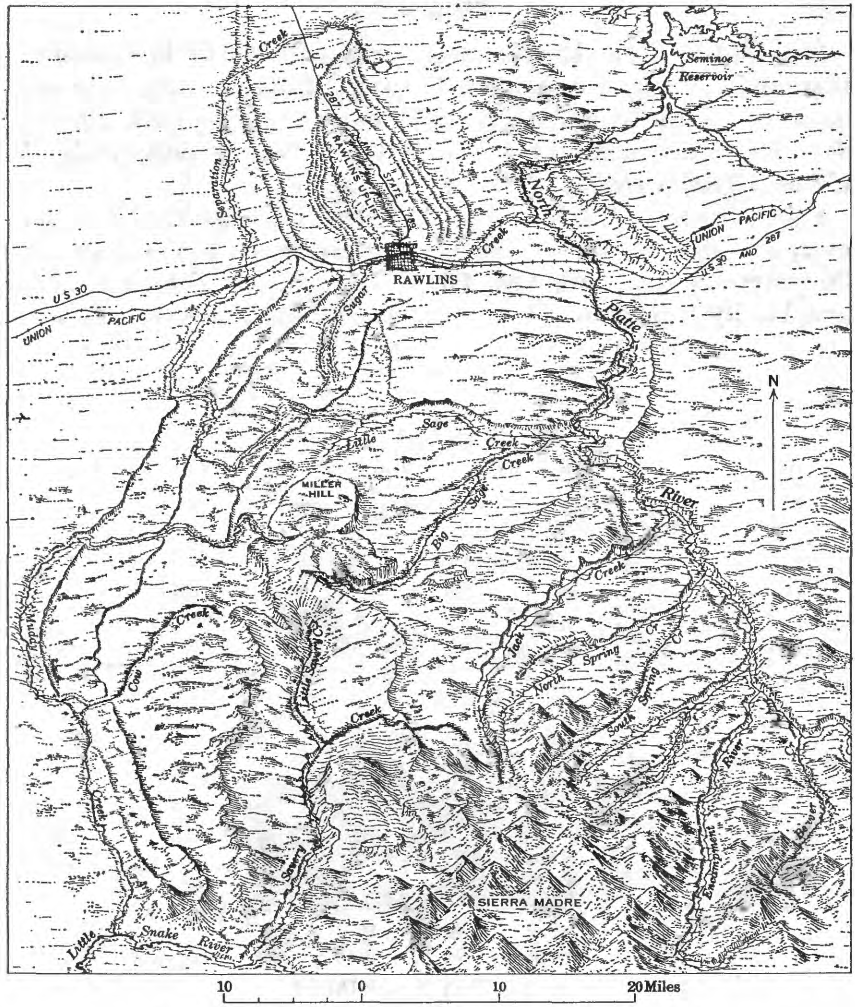

Figure 2.—Physiographic diagram of the Rawlins vicinity.

A dendritic drainage pattern has formed on both sides of the Continental Divide, which lies along the western margin of the area in the vicinity of Miller Hill and separates the drainage of the Colorado River and the Missouri River. Relatively few streams or gullies drain northward from the Miller Hill-Lake Valley anticline. Sugar Creek, which flows eastward through Rawlins, drains the southern and part of the eastern flank of the Rawlins uplift. The northern and western parts of the uplift are drained by Separation Creek and several small intermittent streams that flow into an undrained depression at the northern end of the area.

CLIMATE

The climate of the Rawlins area is characterized by low precipitation, rapid evaporation, and a wide range of temperature. The summers are usually dry and mild and the winters are very cold. Summer days are occasionally hot, but wind and a low humidity make the nights relatively cool.

Climatological records at Rawlins were begun during 1899; however, complete annual precipitation records were kept during only 36 years between 1899 and 1954. Precipitation data are shown graphically in figure 3. The normal annual precipitation (computed

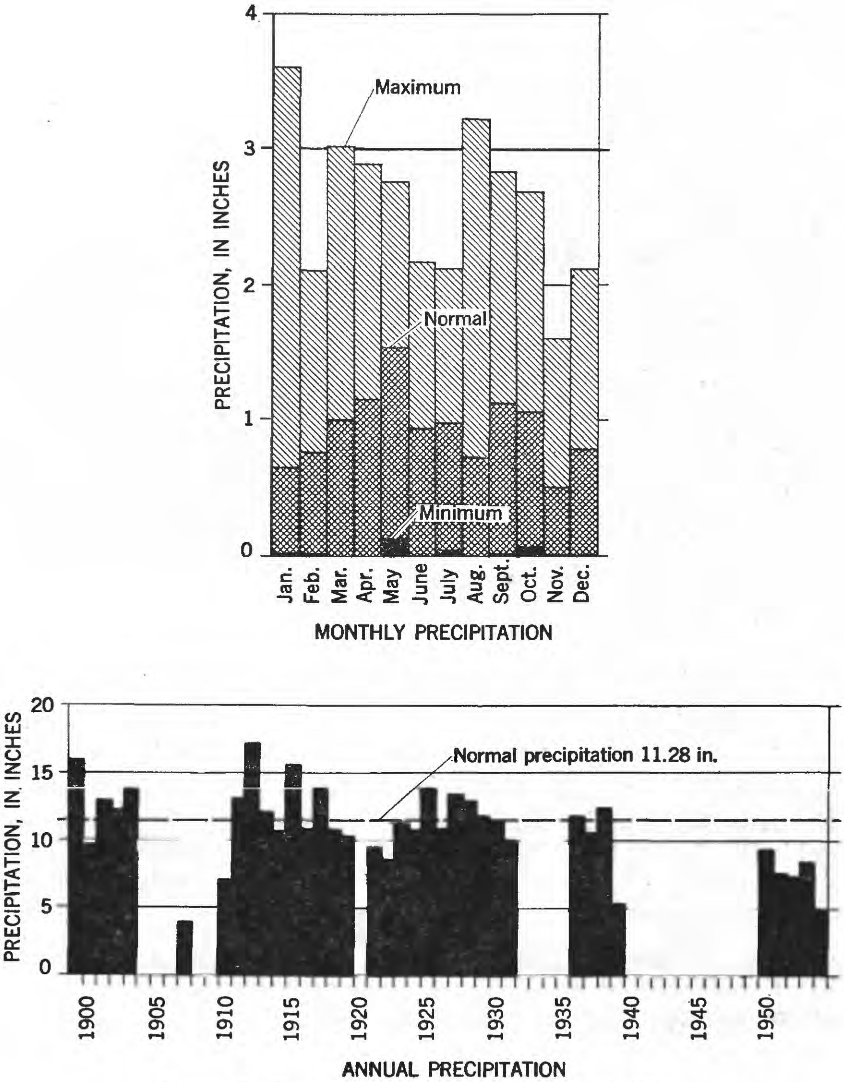

FIGURE 3.—Precipitation at Rawlins, Wyo., 1899–1954.

through 1950) at Rawlins is 11.28 inches; the highest recorded annual precipitation is 17.00 inches (1912), and the lowest is 3.8 inches (1907).

The mean annual temperature is 43.5°F at Rawlins and the length of the growing season generally is about 4 months. In 1953, however, the last day in the spring having a temperature below 32°F was June 25, and the earliest day in the fall having a temperature below 32F° was September 3.

PREVIOUS INVESTIGATIONS

Several investigations of the geology and ground-water resources of the general area have been made previously. However, the investigations have been concerned primarily with the geology and to only a very limited extent with the water resources. The reports on those studies were very useful in the preparation of this report. I. H. Buehner in 1936 made a study of the geology in an area north of the Sierra Madre, Carbon County, Wyo., as partial fullfillment of work required for an advanced degree, J. A. Barlow in 1952 prepared a report on the geology of the Rawlins uplift, and G. L. Del Mauro in 1953 made a study of the geology in the Miller Hill and Sage Creek area. Theses for these studies are in the files of the University of Wyoming Library. A study of uranium deposits in the Miller Hill area was made by Love (1953), who discussed the possibility of ground water leaching, transporting, and redepositing radioactive substances. Dobbin and others (1927, 1929) reported on the geology and oil and gas possibilities of the Bell Springs district, Carbon County, and discussed geology and coal and oil resources of the Hanna and Carbon basins, Carbon County, respectively.

WELL-NUMBERING SYSTEM

The wells, test holes, and springs are numbered according to their location within the system of land subdivision of the United States Bureau of Land Management in the following order: township, range, section, quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). A graphic illustration of the well-numbering system is shown by figure 4. The first numeral of a well number indicates the township; the second, the range; and the third, the section in which the well is located. The lowercase letters after the section number indicate the position of the well within the section. The first letter denotes the quarter section; the second, the quarter-quarter section; and the third, the quarter-quarter-quarter section (10-acre tract). The subdivisions of the sections are lettered a, b, c, and d in a counterclockwise direction, beginning in the northeast quarter. When more than one well is situated in a 10-acre tract, consecutive numbers beginning with 1 are added to the well number. For example, as shown in figure 4, well 21–87–26bca is in the NE¼SW¼NW¼ sec. 26, T. 21 N., R. 87 W., and is the only well shown there.

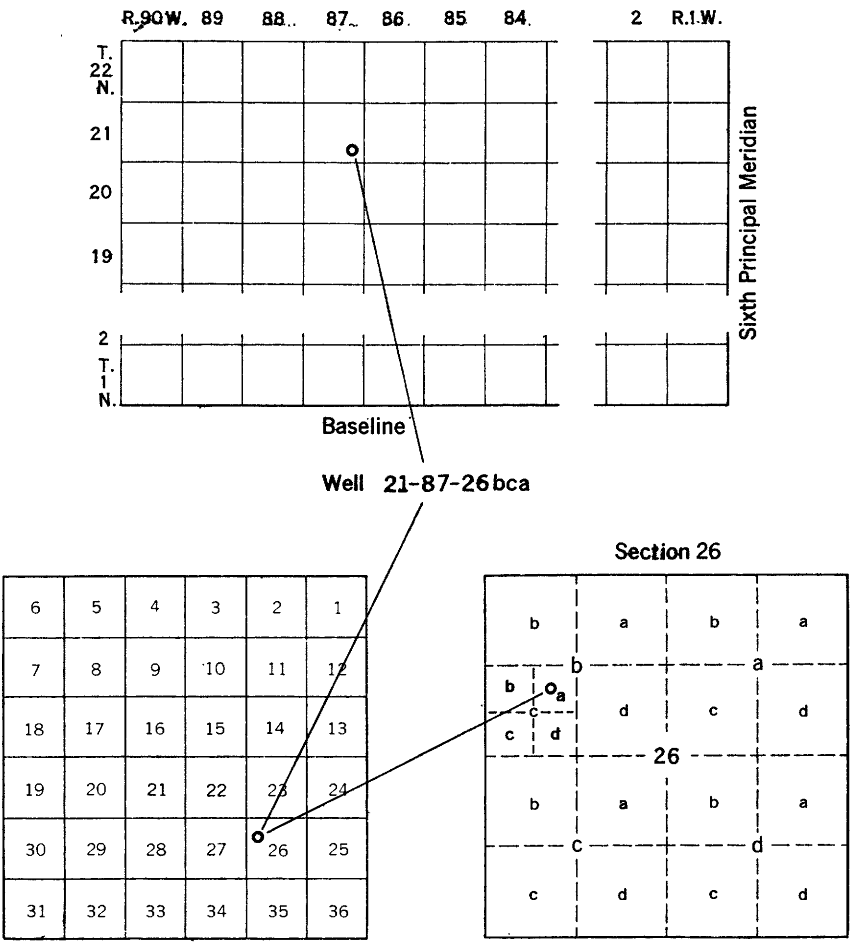

FIGURE 4.—Diagram showing well-numbering system.

ACKNOWLEDGMENTS

The residents of the Rawlins area supplied information relative to their wells and springs, character of material penetrated in drilling, and type of water obtained. Special thanks are extended to the members of the Rawlins Board of Public Utilities for their cooperation and to B. G. Davis, city pipeline superintendent of Rawlins, for his assistance with the field investigations and for supplying data concerning the Rawlins city water supply.

GEOLOGY

SUMMARY OF GEOLOGIC HISTORY

The Rawlins area (see pl. 1) lies north of the Front Range-Uinta mountains unit of the Colorado mountains or "Ancestral Rockies" as described by Ver Wiebe (1930, p. 765–788). During Paleozoic and Mesozoic time, many periods of submergence, deposition, emergence, folding, and faulting of the mountainous regions brought about stratigraphic changes.

During Early and Middle Cambrian time the Rawlins area was a land mass. A Cambrian sea, occupying the Cordilleran geosyncline to the west, expanded eastward and by Late Cambrian time had submerged the area. Sediments deposited during this time are progressively thinner toward the southeast. The Cambrian period ended when the land again emerged from the sea.

There are no rocks of Ordovician, Silurian, and Devonian age within the report area; thus, either there was no deposition during these periods or the rocks were subsequently removed by erosion.

The sea reoccupied the area during Early Mississippian time, and thick limestone sections were deposited over the State. Widespread crustal disturbances during Late Mississippian time were followed by other intermittent disturbances during the remainder of Paleozoic time. An uplifted area extending from near Leadville, Colo., to near Hartville, Wyo., marked the beginning of the Colorado mountains, the "Ancestral Rockies." As the sea retreated westward, the Mississippian rocks were exposed and eroded to form karst topography.

Early Pennsylvanian seas then expanded from the east and west to join and cover the area. The Amsden formation and the Tensleep sandstone were deposited in these seas. The seas then withdrew and the land emerged; consequently, only Lower Pennsylvanian rocks were deposited in the report area.

During early Permian time the sea again transgressed eastward. This, the Phosphoria sea, probably advanced rapidly as far as eastern Wyoming. A thin sandstone bed was deposited in the report area during this period. The Phosphoria sea withdrew and formed a new shoreline farther west. Interfingering marine facies of the Phosphoria formation and a red-bed facies of siltstone, limestone, and shale units were deposited along the eastern margin of the sea as the basal beds of the Phosphoria were accumulating farther west. Sedimentation probably continued through late Permian time and into Triassic time, as indicated by the absence of a recognizable hiatus between the two periods.

During Triassic time the report area was covered periodically by a sea that advanced from the west. Sediments deposited during this time indicate that the shoreline of the sea fluctuated. Thus, the Dinwoody, Chugwater, and Jelm formations were deposited under continental, littoral, lagoonal, and marine conditions. At the end of Triassic time, the sea again withdrew.

A vast desert existed in western and central Wyoming during Early Jurassic time and eolian deposits that form the Nugget sandstone accumulated. A sea, which covered northern and western Wyoming during Middle Jurassic time, advanced southward over the Rawlins area in Late Jurassic time. The Sundance formation was deposited under marine conditions during advances and retreats of the sea. After the final withdrawal of the Sundance sea during Late Jurassic time, continental conditions again existed, and the silt, clay, and sand of the Morrison formation were deposited, the Rawlins area was uplifted and subsequent erosion removed part of the Jurassic deposits.

Early in Cretaceous time, seas from the south and north expanded to submerge Wyoming by middle Cretaceous time. The sea retreated southward during Late Cretaceous time and sediments were deposited under continental and lagoonal conditions, during many fluctuations of the shoreline. Thus, the Cretaceous deposits in the Rawlins area are composed of a thick section of alternating beds of sand and shale and lesser amounts of limestone and chalk. Lower Cretaceous formations are relatively and uniformly thick over much of central and eastern Wyoming, but they thicken abruptly and contain much more sand toward the west.

The Cloverly formation is typical in the area studied. Fossils from the lower part of the formation indicate deposition under continental conditions, whereas deposits of the upper part of the formation indicate deposition under continental and lagoonal conditions during a transgression of the sea. The Thermopolis shale was deposited during an advance of the sea, and alternating sandstone and shale beds represent changes in deposition caused by the changing shoreline. Volcanism before deposition of the Mowry shale contributed large amounts of volcanic ash to the sea; consequently, the marine sediments composing the Mowry shale contain much siliceous material. The Cretaceous sea advanced again during Frontier time, when marine shale containing lenses of sandstone accumulated. Marine sediments deposited in the Rawlins area during Niobrara time were calcareous shale and contain only a few limestone lenses; east of the area the sediments were chalk and limestone. The sea persisted throughout nearly all Niobrara and Steele time and the contact between those formations is indistinct. A transition from the calcareous shale in the Niobrara formation and lower part of the Steele shale to the glauconitic sandstone in the upper part of the Steele shale probably occurred while the sea was receding. The sandstone sediments were laid down in much shallower water than were the Niobrara formation and lower part of the Steele shale.

The Laramide revolution, a major geologic disturbance, began during Late Cretaceous time after the Steele shale was deposited. It reached a climax at the end of the Cretaceous period and ended during early Tertiary time. The Rocky Mountains system was formed during that disturbance, and provided the source material for ensuing formations.

A slow transition from marine to continental conditions began after the initial uplift in Late Cretaceous time, and the lignite, soft coal, and sandstone deposits of the Mesaverde formation were formed. The Lewis shale, composed of interbedded shale and thin sandstone, was then deposited in an advancing sea. The Lance formation, shale and sandstone interbedded, was deposited during the gradual recession of the latest Cretaceous sea and, in the Rawlins area, marked the close of Cretaceous time.

During Tertiary time thick sections of detrital material from older deposits accumulated in areas adjacent to the major uplifts; the coarser materials generally accumulated near the mountains and at the base of a given formation. The Fort Union formation, a coarse conglomerate overlain by sandstone and shale, is a typical example of this type of deposit.

On the Tertiary sediments a drainage system developed whose pattern probably was modified by faulting and crustal movement that persisted through Pliocene and into Pleistocene time. Remnants of stream-laid deposits throughout the Rawlins area give evidence of the post-Tertiary drainage pattern.

Erosion and deposition continued through Pliocene time into Pleistocene and Recent times. During the climatic changes, uplifting, faulting, and erosion after the close of Pliocene time, Pleistocene sediments, Recent landslide material, gravel, and alluvium were deposited.

STRATIGRAPHIC UNITS AND THEIR WATER-BEARING PROPERTIES

Deposits of each geologic period of the Paleozoic era—except the Ordovician, Silurian, and Devonian—and of the Mesozoic and Cenozoic eras crop out within the Rawlins area. During periods not represented, sediments may have been deposited that subsequently were removed by erosion. The following generalized geologic section presents the character, distribution, thickness, and water-bearing properties of each stratigraphic unit in the area, and detailed geologic sections measured by Messrs. Barlow and Del Mauro (p. 57–71) are given at the end of this report.

Generalized section of the rock formations and their water-yielding character, Rawlins area, Carbon County, Wyo.

System	Series	Subdivision		Thickness[1] (feet)	Physical character	Water supply
Quaternary	Recent	Alluvium		0–5±	Silt, sand, and gravel, stream-laid; locally derived.	Yields very little or no water to wells. Generally lies above water table.
		Gravel deposits		0–10	Gravel and sand; composed of reworked Pliocene and Miocene deposits.	Do not yield water to wells. Generally lie above water table.
		Landslide material		0–200	Sandstone and conglomerate; derived from the Browns Park formation.	Does not yield water to wells. Small springs issue at base of material.
	Pleistocene	Undifferentiated deposits		0–3	Conglomerate, gray; contains pebbles, cobbles, and boulders, derived from rocks of Mesozoic and Cenozoic age.	Generally above the water table and do not yield water to wells.
Tertiary	Pliocene and Miocene	Undifferentiated deposits		0–624	Sandstone, gray to brown, fine- to coarse-grained; contains lenses and beds of conglomerate; basal section is a conglomerate of rocks of Precambrian, Paleozoic, and Mesozoic age.	Yield moderate supplies of water to wells. May be capable of yielding large supplies.
	Miocene (?)	Browns Park formation	Upper part	0–1,000	Sandstone, gray, white, and brown, fine- to medium-grained; contains fragments of older deposits.	Source of water for springs. Could yield moderate supplies of water to wells.
			Basal conglomerate.	0–135	Conglomerate composed of quartz, quartzite, and diabase, interbedded with sandstone and volcanic ash.	Yields moderate to large supplies of water to springs. Where saturated, can yield moderate to large supplies of water to wells.
	Paleocene	Fort Union formation		0–2, 450+	Shale and sandstone, interbedded; alternates with shale beds; contains carbonaceous material and coal beds.	Aquifer of limited potential. Areal extent of formation is too small for it to be a source of much water for the area. Sandstone will yield small quantities of water to wells.
	Upper	Lance formation		0–4, 540	Shale and sandstone beds, alternating; contains fossils.	Yields water to wells in other areas of the State, and is a potential aquifer in the area studied; limited to western part of area.
		Lewis shale		0–2, 700	Shale, dark-gray, fissile to sandy, buff; contains bentonite and sandstone lenses.	Sandstone lenses will yield very small quantities of water to wells.
		Mesaverde formation		0–2, 800	Sandstone, fine- to medium-grained, gray to brown, and sandy dark-gray to gray shale.	Generally lies above the water table in the Rawlins area. Where saturated will yield small quantities of water to wells.
		Steele shale		0–2, 980	Shale, blue-gray and gray; contains some sandstone beds.	Sandstone can yield small quantities of water to wells.

Cretaceous		Niobrara formation	0–2,070	Shale and clay, chalky, calcareous, gray to yellow.	Fractured zones probably can yield small quantities of water to wells.
		Frontier formation	0–810	Shale, dark-gray, sandy; contains sandstone beds.	Yields moderate supplies of water to wells. One well measured yielded 50 gpm.
	Lower	Mowry shale	0–493	Shale, gray to dark-gray, dense, siliceous; contains fossil fish scales.	Yields little or no water to wells.
		Thermopolis shale	0–177	Shale, gray to dark-gray; contains thin sandstone lenses.	Do.
		Cloverly formation	0–187	Sandstone; contains shale that separates the upper sandstone from a basal conglomerate.	Yields moderate to large quantities of water, generally under artesian head.
Jurassic	Upper	Morrison formation	0–326	Shale and sandstone, variegated; contains thin lenses of limestone.	Yields little or no water to wells.
		Sundance formation	0–447	Limestone and shale in upper part; sandstone containing lenses of shale and limestone in lower part.	Sandstone probably would yield small to moderate supplies of water.
	Lower	Nugget sandstone	0–100	Sandstone, quartzitic, fine- to coarse-grained, buff to white, in part crossbedded.	Will yield very small quantities of water to wells. Too quartzitic to yield large quantities.
Triassic		Chugwater formation	0–1,200	Shale and sandstone; contains a thin bed of limestone; very highly colored.	Sandstone will yield quantities of water adequate for stock consumption.
		Dinwoody (?) equivalents	0–82	Siltstone and thin sandstone, greenish-gray to brownish-gray.	Sandstone will yield very small quantities of water.
Permian		Undifferentiated rocks	0–260	Shale, limestone, and sandstone; colors range from gray to purple and some shades of green and orange.	Water probably is very limited in quantity and very mineralized.
Pennsylvanian		Tensleep sandstone	0–838	Sandstone, medium- to fine-grained; contains some beds of limestone. Sandstone is slightly calcareous.	Yields moderate quantities of water with high concentrations of sodium sulfate, except in outcrop areas where water is of good quality.
		Amsden formation	0–260	Shale, sandy, reddish; interbedded limestone and sandy shale; and hard fine-grained sandstone,	Probably will yield little or no water, highly mineralized.
Mississippian		Madison limestone	0–215	Limestone, gray; contains chert, lenses of brownish dolomite, and, at base, sandstone.	Yields moderate to large quantities of water, which is highly mineralized locally.
Cambrian		Undifferentiated rocks	0–587	Sandstone, medium-grained, varicolored; contains lenses of quartzite, shale, and siltstone.	Yields moderate quantities of relatively hard water to wells and springs.
Precambrian		Undifferentiated rocks	?	Quartz-diorite, gneiss, and schist	Weathered material could yield small quantities of water.

[1] Thickness determined from interpretation of electric logs and drillers' logs, geologic maps, and measured sections.

PRECAMBRIAN ROCKS

Precambrian quartz diorite, gneiss, and schist lie beneath the entire area but crop out only along the apex of the Rawlins uplift. Included with the major rock types are diabase and pegmatite dikes. Water wells are not drilled into the Precambrian rocks; consequently, little is known about the possibility of developing water from them. Large quantities of water probably cannot be obtained from the Precambrian rocks; however, small quantities of water possibly can be obtained from weathered zones.

CAMBRIAN SYSTEM

Two lithologic divisions of the Cambrian system, a lower sandstone sequence and an upper shale sequence, are recognizable in outcrops along the apex of the Rawlins uplift. The lower section is a medium-grained sandstone partially cemented by silica. The upper sequence is red to reddish-brown shale that contains lenses of green glauconitic sandstone. Conglomerate of quartz pebbles, sandstone fragments, and some feldspar in a matrix of fine sand generally lies at the base of the sandstone. Cambrian rocks lie beneath the surface in the remainder of the area and range in thickness from a featheredge in the northern part of the area to about 600 feet in the southern part. Sandstone composes the major part of the section.

The sandstone and conglomerate yield moderate supplies of water to wells. Well 21–87–17ac drilled at the State Penitentiary to a depth of 416 feet is reported to yield as much as 150 gpm; Cambrian rocks probably yield the major part of the water, although rocks of Tertiary age above probably supply a part. The chemical quality of the water is within the standard limits set by the United States Public Health Service for use in interstate commerce. See p. 42.

CARBONIFEROUS SYSTEMS

MISSISSIPPIAN SYSTEM

MADISON LIMESTONE

The Madison limestone, which overlies the Cambrian rocks, is primarily a dark-gray dense limestone containing dark-brown to gray chert. Some of the limestone beds contain bands of crystalline limestone, and lenses of white to brown dolomite alternate with lenses of limestone. The limestone weathers gray-brown and has numerous pockets, whereas the dolomite weathers brown and is relatively stable. A thin bed of hard fine-grained red to brown sandstone lies at the base of the Madison limestone. Lenses of softer sandstone occur sporadically throughout the formation. The formation crops out in the Rawlins uplift, in the northern part of the mapped area, and lies beneath the remainder of the area. As much as 215 feet of the formation has been penetrated during oil-well tests.

Moderate to large quantities of water can be obtained from solution cavities in the Madison limestone, the yield depending upon the number and size of the cavities. Outside the Rawlins area, many large springs issue from this formation, and wells that yield more than 1,000 gpm have been developed. Well 21–87–16ccl drilled by the city of Rawlins taps both the Tensleep and the Madison formations and flows at a rate of 195 gpm, but the water is rather highly mineralized. A chemical analysis of a sample of water from this well is given in table 3.

PENNSYLVANIAN SYSTEM

AMSDEN FORMATION

The upper part of the Amsden formation is red sandy shale; gray dense limestone beds alternate with sandy shale in the lower part. Coarse feldspathic sandstone and quartz-pebble conglomerate separate the upper and lower parts of the formation. Locally, beds of hard fine-grained red to brown sandstone form the base of the formation. The limestone contains calcareous sandy shale lenses and a relatively high concentration of chert.

The Amsden formation crops out along the flanks of the Rawlins uplift and lies beneath the surface throughout the rest of the Rawlins area. The maximum thickness of the formation is about 260 feet.

Although very little is known about the water-bearing properties of the Amsden formation, the author believes that it would yield very little water and that the chemical quality of the water would be such as to make the water unsatisfactory for most uses.

TENSLEEP SANDSTONE

The Tensleep sandstone consists predominantly of medium- to fine-grained buff to gray sandstone that contains thin beds of dense gray limestone. The sandstone generally is crossbedded and contains varying amounts of calcareous material. On a weathered surface it is light-brown and generally is slabby. The limestone beds weather to dark gray and blue gray and contain solution pockets.

The Tensleep sandstone crops out in the Rawlins uplift and is beneath the surface throughout the remainder of the Rawlins area. It has a maximum thickness of about 840 feet.

The Tensleep sandstone is known to yield water within the area studied, but at depth the water is comparatively hard and has a high concentration of sodium and sulfate. However, water obtained from the outcrop areas of the formation is of good quality. The depth to the formation throughout most of the Rawlins area is so great that the development of water from the formation probably would not be economically feasible. The most suitable locality from which to obtain ground water at economical depths is that immediately surrounding the Rawlins uplift. The Tensleep sandstone yields water under artesian pressure and, locally, wells will flow.

Well 21–87–16ccl (table 3) yields water from both the Tensleep sandstone and the Madison limestone. The sample was hard and rather highly mineralized.

PERMIAN SYSTEM

Rocks of Permian age in the Rawlins area consist predominantly of beds of shale alternating with limestone, but a few siltstone and sandstone beds lie near the base of the sequence. The deposits range from drab gray through orange to red and contain greenish lenses. The limestone beds are generally gray to reddish-gray and weather to purple and light gray; some are dense, whereas others are platy and thin bedded. The shale is pliable to hard and is red, green, gray, and mottled. The formation locally contains beds of calcareous green splintery shale. Thin beds of medium-grained sandstone lie in the lower part of the formation; these beds range from light-gray to dark-gray, depending upon the calcareous material and foreign matter included.

Permian rocks crop out in the Rawlins uplift and underlie the remainder of the area; they probably include some sediments equivalent in age to the Phosphoria formation. The Permian rocks are about 260 feet thick except within the Rawlins uplift where they have been eroded.

Small quantities of highly mineralized water probably can be obtained from any of the more permeable materials of the Permian rocks. Well 21–87–22bc is thought to obtain at least part of its water from the Permian rocks. The water from this well is very highly mineralized (6,660 ppm of dissolved solids, see table 1).

TRIASSIC SYSTEM

EQUIVALENTS OF THE DINWOODY(?) FORMATION

Gray-green and brownish-gray siltstone and thin sandstone lenses, probably equivalent to the Dinwoody formation to the northwest, constitute the basal unit of the Triassic system in this area. The unit is so similar in character to the overlying Chugwater formation and the underlying Permian rocks that it has not been recognized in outcrops within the Rawlins area; consequently, it is mapped with either the Permian rocks or the Chugwater formation on plate 1. These probable Dinwoody equivalents have been recognized from cuttings of oil-well tests and are believed to be present throughout the area except where they have been eroded from the highest part of the Rawlins uplift. Data obtained from oil-well tests indicate that the unit attains a maximum thickness of about 80 feet.

Although the unit contains some sandstone lenses, the lenses are not sufficiently extensive to yield appreciable quantities of water. The unit is so far below the land surface throughout most of the Rawlins area that it probably would not be economically feasible to develop wells in it and the water probably would be very highly mineralized.

CHUGWATER FORMATION

Del Mauro (p. 7) divided the Chugwater formation into three members; Alcova, Popo Agie, and Red Peak. However, all Triassic rocks lying above the probable Dinwoody equivalents are referred to in this report as the Chugwater formation.

The Chugwater formation in the Rawlins area is composed mainly of highly colored shale and sandstone beds. The shale beds are soft, red to green, and contain a few lenses of very fine grained sandstone. The green shale occurs as lenses sporadically throughout the red shale. Beds of light-gray and buff fine- to medium-grained sandstone alternate with the shale beds. Some sandstone beds are calcareous and crossbedded, and weather orange and light red varying to buff and gray. A limestone bed, generally not more than 15 feet thick, lies near the middle of the formation. It is a dense-gray to gray-brown silty limestone containing small- to medium-size cavities. This bed weathers from gray to gray buff.

The Chugwater formation was deposited during Triassic time over the Rawlins area. Differential deposition and subsequent upwarping and erosion caused the formation to vary in thickness from place to place; the approximate range in thickness is from 1,140 feet to 1,200 feet, except in the Rawlins uplift where later erosion removed the entire formation.

No wells in the Rawlins area are known to obtain water from the Chugwater formation; however, the sandstone beds probably will yield small domestic and stock supplies. The water probably would be highly mineralized and similar to that which would be derived from the rocks of Permian age.

JURASSIC SYSTEM

NUGGET SANDSTONE

The Nugget sandstone of Early Jurassic age unconformably overlies the Triassic sedimentary rocks and is composed of fine- to coarse-grained, buff to white, massive sandstone, commonly crossbedded. Cementation, which causes a quartzitic appearance, varies throughout the formation. The quartz grains that compose most of the sandstone are subrounded and range from frosted to clear in appearance. Upon weathering the formation appears rusty to rusty yellow.

The Nugget sandstone crops out in the Rawlins area only along the eastern flank of the Rawlins uplift, where upwarping followed by erosion has removed the younger deposits, and along streams that cross anticlinal structures in the southern part of the area. The sandstone probably underlies the remainder of the area and has a maximum thickness of approximately 100 feet.

No wells are known to obtain water from the formation in the Rawlins area; however, small quantities of water probably can be obtained, as sandstones of comparable composition elsewhere yield quantities of water adequate for stock and domestic use.

SUNDANCE FORMATION

The Sundance formation consists of beds of sandstone, limestone, and shale. Light-gray to white fine-grained sandstone, in part calcareous, containing thin lenses of limestone and shale is characteristic of the lower part of the Sundance formation. Thin beds of red and green shale and siltstone sporadically separate the sandstone beds. The upper part is brown to gray limestone alternating with green sandy glauconitic shale. The limestone beds contain thin lenses of shale; the shale beds contain lenses of green and red siltstone and glauconitic sandstone.

The Sundance formation crops out along the apex and east flank of the Rawlins uplift and in the banks of streams that cross anticlinal structures in the southern part of the Rawlins area. Because of uplifting and faulting, the formation dips sharply from the uplifted areas and lies several thousand feet below the land surface in the remainder of the area. The formation has a maximum thickness of about 450 feet.

Well 19–88–34da obtains water from the Sundance formation and flows at a rate of 28 gpm. A chemical analysis of the water from this well indicates a fairly high concentration of dissolved solids. (See table 1.) The formation lies so far below the land surface throughout most of the Rawlins area that development of a water supply from it probably would be uneconomical for most uses.

MORRISON FORMATION

Interbedded colorfully variegated shale, sandstone, and limestone constitute the Morrison formation of Late Jurassic age. The sandstone is generally fine grained, the grains being subangular to round. The rock is partly calcareous and takes the coloring of the adjacent red, gray, green, and buff shale, which is sandy to fissile. Thin limestone lenses separate the sandstone and shale beds. Soil formed by the weathering of this formation generally is reddish and nonproductive.

Highly colored strata of the Morrison formation crop out in the southern and northern parts of the Rawlins area. Samples of cuttings taken from wells indicate that the formation underlies the remainder of the area. The Morrison formation has a maximum thickness of about 325 feet in the Rawlins area.

The Morrison formation generally is relatively impermeable and is not known to yield water to wells in the Rawlins area. Very little exploration of the Morrison formation to obtain water has been done because water generally can be obtained from rocks above it.

CRETACEOUS SYSTEM

CLOVERLY FORMATION

The basal part of the Cloverly formation of Early Cretaceous age generally is a conglomerate of gray, white, black, and reddish quartz, quartzite, and chert fragments within a sandstone matrix; the fragments range in size from fine sand to 3-inch cobbles. Beds of gray-white to dark-gray clay and sandy shale containing lenses of sandstone and some fossil plants, overlie the conglomerate. The upper part of the formation is fine- to coarse-grained, brown, buff, or gray-brown thick, massive sandstone that is crossbedded in some places. The sandstone is dense and partly quartzitic, is composed of subangular to subrounded quartz grains, and weathers to a rust brown or yellow brown.

The Cloverly formation crops out in uplifted localities in the northern and southern parts of the Rawlins area. The formation dips abruptly southward and northward away from the uplifts and lies at considerable depths in the remainder of the area. An oil well (19–88–2bd) at Hatfield (pl. 1) tapped the Cloverly formation at 3,933 feet. The formation is persistent throughout the area; however, near the southern end of the Rawlins uplift, where formations above and below the Cloverly are exposed, it is obscured by Tertiary strata. The Cloverly formation has a maximum thickness of about 190 feet.

The Cloverly formation is an artesian aquifer in the Rawlins area, and water in the formation is generally under sufficient pressure to flow at the land surface. Five flowing wells have been developed in the Cloverly formation along the base of Miller Hill; the largest well, 17–88–11aa, flows 85 gpm, and the others flow 25–65 gpm. Aquifer tests of wells obtaining water from the Cloverly formation indicate that most wells have leaky casings or are improperly cased, thereby allowing some water to escape into overlying formations. If properly cased, these wells probably would have larger flows; also, wells drilled at lower elevations would have larger flows, resulting from increased pressure.

The water from the Cloverly is the best for domestic and municipal use of all the water examined during this study. (See table 1.)

THERMOPOLIS SHALE AND MOWRY SHALE

The Thermopolis and Mowry shales are very similar in composition, although they are mapped as separate units (pl. 1). Their character, distribution, thickness, and water-bearing properties are discussed collectively.

The Thermopolis and Mowry shale within the Rawlins area are composed of gray to dark-gray shale beds separated by bentonite lenses and, in places, by sandstone and sandy siltstone. Fossil fish scales in the Mowry shale help to differentiate it from the underlying Thermopolis shale. The upper part of the Thermopolis shale is gray to gray-white fine-grained sandstone, locally referred to as the Muddy sandstone. The sandstone is massive to thin-bedded quartzite composed of clear and frosted quartz containing small amounts of dark-colored minerals.

Both formations either crop out or lie beneath the surface in the area. The Thermopolis shale has a thickness of approximately 175 feet and the Mowry shale a thickness of approximately 495 feet.

Although the shales can store large quantities of water, their permeability will not permit water to move freely through them. Thus, the Thermopolis and Mowry shales probably will yield little or no water to wells.

FRONTIER FORMATION

The Frontier formation consists of gray to gray-brown calcareous shale interbedded with lenses of fine- to medium-grained sandstone. The sandstone beds occur at intervals within the formation and serve as characteristic key beds. The shale generally is silty to sandy and contains lenses of bentonite. Differential weathering of the resistant and nonresistant beds forms hogbacks where the formation is exposed.

The Frontier formation crops out in the northern and southern parts of the Rawlins area. Rocks of Frontier age have been penetrated in the subsurface, and data indicate that the formation is continuous throughout the mapped area. Three distinct sandstone beds, the first, second, and third Wall Creek, occur within the formation. Although the characteristic Wall Creek sandstone member (first Wall Creek) of the Frontier formation and the second and third Wall Creek sandstones have been recovered from drill cuttings, all three may not be at any one place. The formation has a maximum thickness of 810 feet; the thickness of individual sandstone beds ranges from a few feet to as much as 120 feet.

The sandstone beds of the Frontier formation yield moderate amounts of water. Well 18–88–10ac tapping the so-called first Wall

Creek, yields 50 gpm; possibly as much as 100 gpm could be obtained under ideal conditions. Water in the formation generally is under artesian pressure, and in some areas the water will flow at the land surface. The water in the first Wall Creek generally is of fair quality for domestic use, whereas the water in the lower sandstone beds may contain too much fluoride for domestic use. Detailed measurements and descriptions of the water-bearing sandstones are given in the table of measured sections on pages 57–71.

NIOBRARA FORMATION AND STEELE SHALE

The Niobrara formation and Steele shale are composed of fossiliferous massive gray shale, calcareous shale, and argillaceous limestone, grading upward into sandy gray-brown shale intercalated with yellow to tan calcareous sandstone. Freshly exposed shale in the upper part is dark gray to brown. A zone containing septarian concretions has been observed at the base of the Niobrara formation in the southern part of the Rawlins area. Similarity of color, composition, and weathering characteristics makes it difficult to differentiate between the Steele shale and the Niobrara formation. Consequently, the two formations have been mapped as a single unit over much of the Rawlins area. However, where the contact can be identified, the formations were mapped separately.

Thick sections of shale containing beds of sandstone and limestone have been observed in outcrops. The formation crops out in the southwestern part of the Rawlins area, throughout much of the central part of the area, and along both sides of the Rawlins uplift. Deposition on an uneven surface, variable rates of deposition, and erosion have caused the formations to differ considerably in thickness from place to place, the combined maximum being about 5,050 feet.

No wells in the Rawlins area are known to obtain water from either the Niobrara formation or the Steele shale; however, weathered or fractured zones in the Niobrara formation or sandstone beds in the Steele shale probably will yield very small quantities of water. The water undoubtedly would be very highly mineralized.

MESAVERDE FORMATION

The Mesaverde formation is composed mainly of sandstone containing lenses and beds of shale. The sandstone is massive and forms prominent bluffs throughout the central part of the Rawlins area. The sandstone generally is fine to medium grained and light gray to brown, and locally it contains lenses of carbonaceous sandy shale. The shale beds are gray to dark gray, calcareous to noncalcareous, and contain thin lenses of lignite and thick sections of coal.

The formation crops out in the central and western parts of the Rawlins area. Post-Mesaverde uplift and subsequent erosion removed the formation from the northern and southern parts of the area. The formation has a maximum thickness of approximately 2,800 feet.

Sandstone beds form a prominent escarpment at the contact of the Mesaverde formation with the underlying Steele shale on the east and west flanks of the Miller Hill-Lake Valley anticline. Because of their topographic position, these beds are dry near the edge of the escarpment. Downdip from the escarpment, the beds probably are saturated and would yield sufficient water for domestic and stock use. The sandstone beds probably will yield water to wells along the western flank of the Rawlins uplift; however, owing to the steep dip of the beds, the area in which the formation could be reached practicably is small.

LEWIS SHALE

The Lewis shale is composed of dark-gray fissile shale that grades into buff sandy shale and contains sporadic lenses of gray to buff sandy calcareous siltstone. Thin bentonite beds, light-brown to gray calcareous sandstone lenses, brown sandstone concretions, and lenses of dark-gray to brown carbonaceous deposits occur throughout the formation.

The Lewis shale crops out in the western part of the Rawlins area in a narrow band along the west flank of the Rawlins uplift and progressively widens southwestward toward the west flank of the Miller Hill-Lake Valley anticline. The formation has a maximum thickness of approximately 2,700 feet.

The Lewis shale is of minor importance as an aquifer in the Rawlins area. Most of the shale is relatively impermeable and will yield only very small quantities of water. Thin sandstone lenses scattered throughout the formation are more likely to yield water, but in very small amounts. However, no wells are known to obtain water from the Lewis shale.

LANCE FORMATION

The Lance formation of Late Cretaceous age is composed of dark-gray fissile and carbonaceous shale and brown to light-brown very fine to fine-grained sandstone. The upper part of the formation is a dark-gray fissile carbonaceous shale that grades downward to a light-brown sandy shale; a fossiliferous zone is present deep within the formation. Throughout the formation, shale as previously described is interbedded with brown to light-brown fine-grained sandstone. Beds of very fine- to fine-grained sandstone as much as 20 feet thick occur at intervals within the formation.

The Lance formation crops out in the northwestern quarter of the Rawlins area, along the west flank of the Rawlins uplift and Miller Hill-Lake Valley anticline, and parallels the Lewis shale outcrop. The formation dips westward, the greatest dip being along the flank of the Rawlins uplift. The maximum thickness of the Lance formation is about 4,540 feet. A stratigraphic section as measured by J. A. Barlow (p. 7) in sec. 12, T. 21 N., R. 89 W. is 4,541 feet thick.

No wells in the Rawlins area are known to obtain water from the Lance formation; however, the formation probably will yield sufficient water for domestic and stock use.

TERTIARY SYSTEM

FORT UNION FORMATION

The Fort Union formation is the oldest unit of Tertiary age in the Rawlins area. It is composed of dark-gray carbonaceous, lignitic shale interbedded with light-gray to brown fine to coarse-grained sandstone, sandstone beds containing lenses of conglomerate, and light-brown to brown conglomerate composed of subrounded to well-rounded black, red, and gray chert pebbles and pink and white quartz within a matrix of coarse- to medium-grained sandstone. The shale commonly contains coal beds. The formation contains also some lenses of calcareous material. Differential weathering of the sandstone and shale beds has created a bench-and-basin topography in the outcrop area.

The Fort Union formation crops out only in a small area that flanks the western slope of the Rawlins uplift. Crustal movement and erosion since deposition have caused a wide range in the thickness of the Fort Union. In the area studied, the formation attains a maximum thickness of about 2,450 feet.

No wells are known to obtain water from the Fort Union formation; however, saturated parts of the formation, especially the sandstone beds, can yield small supplies of water.

BROWNS PARK FORMATION

BASAL CONGLOMERATE OF BROWNS PARK FORMATION

The basal conglomerate of the Browns Park formation of Miocene(?) age consists predominantly of subangular to subrounded boulders, cobbles, and pebbles of quartz and quartzite embedded in sandstone and, in places, volcanic ash. The conglomerate contains some lenses and beds of mottled gray to buff fine-grained sandstone and scattered fragments of chlorite.

The basal conglomerate in the mapped area contains white quartz pebbles and black chert. Buehner (p. 7) in an area north of the Sierra Madre, Carbon County, mapped a unit as the Bishop conglomerate. Love (1953) designated this unit as the basal conglomerate of the Browns Park formation and his usage is followed in this report. The reports of Buehner and Love cover part of the area included in this study. The basal conglomerate of the Browns Park formation has been recognized only in the southern part of the area. At one time it probably covered most of the Rawlins area, but subsequent erosion removed most of the sediments so that only small remnants remain. As a result of unequal deposition and subsequent erosion the deposits range in thickness from a thin veneer to as much as 135 feet.

The basal conglomerate of the Browns Park formation is one of the best aquifers in the Rawlins area. Medium to large springs, which maintain the base (low) flow of streams in the southern part of the area, issue along the contact of the conglomerate with the less permeable underlying deposits. One spring is reported to flow at a rate of 343 gpm. Most of the water supply for the city of Rawlins is piped from a number of springs issuing from the base of the conglomerate. No wells are known to obtain water from the conglomerate; however, materials in the conglomerate that might yield as much as 500 gpm to properly constructed wells, have been penetrated by drills prospecting for oil. The water is of generally good quality, though hard.

UPPER PART OF THE BROWNS PARK FORMATION

The upper part of the Browns Park formation of Miocene(?) age is a white to gray fine- to medium-grained sandstone. The upper part of this unit is a white limy tuffaceous sandstone, which is underlain by limestone interbedded with similar white to gray sandstone. The basal part of the unit is a very persistent algal limestone, which serves as a marker bed and which is about 12 feet thick. The lower part of this unit contains also lenses of quartzitic conglomerate consisting of chert, quartz, and feldspar pebbles and some hematite and volcanic ash. Scattered throughout the unit is a matrix of gray calcareous or brown siliceous material that contains gray to gray-brown quartz grains and weathers to red and green.

The upper part of the Browns Park formation forms a high plateau between Sage Creek and McKinney Creek in the southern part of the Rawlins area. (See pl. 1.) The central part of the area is devoid of any rocks of the Browns Park formation; however, Tertiary rocks, of Miocene or Pliocene age, are recognized in the northern part of the area, but no definite correlation between them and the Browns Park formation has been made. The upper part of the Browns Park formation in the southern part of the Rawlins area ranges in thickness from a thin veneer to approximately 1,000 feet.

No wells are known to obtain water from the upper part of the Browns Park formation in the Rawlins area. How much of the unit is saturated is not known, but wells entering it along the Continental Divide immediately south of the Rawlins area have found water at depths ranging from 5 to 128 feet below the land surface; thus, locally the zone of saturation in the upper part of the Browns Park formation may be as much as 870 feet thick. The surface of the material is very permeable and affords an excellent opportunity for ground-water recharge from precipitation. Some of the water moves downward and issues from springs and seeps along the base of the unit; some of the water percolates through the upper part of the Browns Park formation into the underlying basal conglomerate and issues as springs at the base of the conglomerate. On the basis of water supplies that are obtained from wells in comparable sediments, it is believed that properly constructed wells tapping the Browns Park formation could yield moderate to large supplies of water.

MIOCENE AND PLIOCENE ROCKS

Miocene and Pliocene rocks are composed of gray to brown fine- to medium-grained sandstone and conglomerate. The sandstone is tuffaceous, calcareous and crossbedded. Lenses and beds of conglomerate composed of pebbles of chert and quartz and cobbles derived from Precambrian rocks occur sporadically. Thin beds of tuffaceous light-gray limestone containing chert, quartz, and feldspar grains and pebbles and material derived from Precambrian rocks, grading into sandy limestone and calcareous sandstone, are contained within the sequence. The basal part of the sequence is composed of subangular to angular pebbles, cobbles, and boulders derived from Precambrian, Paleozoic, and Mesozoic rocks in a matrix of calcareous, partly tuffaceous yellow-brown fine to coarse-grained sandstone.

The rocks of Miocene and Pliocene age are limited to the perimeter of the Rawlins uplift. The deposits are more extensive on the east flank of the uplift than they are on the south and west. Although the deposits at one time may have covered the Rawlins area uniformly, faulting, warping, and erosion have resulted in removal of most of the materials. The deposits have a maximum thickness of approximately 624 feet.

A well at the Wyoming State Penitentiary is reported to obtain as much as 150 gpm of water from the undifferentiated Miocene and Pliocene rocks and the fractured Cambrian rocks below; however, most of the water is believed to be derived from the Cambrian rocks. Other wells, tapping only the upper part of the rocks of Miocene and Pliocene age, yield adequate water for domestic and stock use.

The sequence generally is sufficiently permeable to allow free movement of water, and, as the water table generally lies at a relatively shallow depth, moderate to large amounts of water can be obtained from the thick saturated sections of the formation. One sample was of fairly good quality except for iron content.

QUATERNARY SYSTEM

Deposits of Quaternary age in the Rawlins area include rocks of Pleistocene age (undifferentiated) and landslide material, gravel, and alluvium of Recent age. Although the character of the materials may differ, the ground-water potential of the Quaternary deposits is very similar; in general, the deposits are capable of yielding little or no water. However, where they overlie permeable older rocks they serve to absorb water from precipitation and streamflow and transmit it to the underlying rocks.

The Pleistocene deposits are composed of a gray conglomerate of angular pebbles, cobbles, and boulders derived from sandstones and shales of Mesozoic age, and conglomerates of Miocene and Pliocene age, in a matrix of calcareous very fine sandstone. The deposits exist only in the northeastern corner of the Rawlins area and are only about 3 feet thick.

The landslide material is primarily sandstone and conglomerate derived from the Browns Park formation. These deposits were eroded from the parent material and moved down slope to cover older sediments at the base of the escarpment formed by the Browns Park formation in the southern part of the Rawlins area. The deposits are approximately 200 feet thick.

Gravel has collected to a depth of as much as 10 feet along the flanks of the streams in the northern part of the Rawlins area. It consists of reworked rocks of Miocene and Pliocene age that have accumulated as a result of water action during periods of large runoff. These deposits generally are composed of quartz, feldspar, and fragments of granite but include some fragments of sandstone and shale.

The alluvium consists of narrow bands of stream-laid silt, sand, and some gravel deposited in the stream valleys. The thickness differs from place to place but generally does not exceed 5 feet.

Rocks of Quaternary age are thin and generally lie above the water table; thus they are relatively unimportant as a source of water. However, small seeps occur locally at the base of the landslide material.

GROUND WATER

OCCURRENCE

GOVERNING FACTORS

The following discussion of the occurrence of ground water is adapted in part from a report by Meinzer (1923, p. 2–102), to which the reader is referred for a more complete discussion of the subject.

The rocks that form the outer crust of the earth generally contain numerous open spaces, or interstices, which may contain air, natural gas, oil, or water. The amount of water that may be stored in a rock depends upon the volume of the rock that is occupied by these open spaces—that is, the porosity of the rock. Porosity is expressed as a percentage and is the ratio of the aggregate volume of the rock interstices to its total volume. A rock is said to be saturated when all its interstices are filled with water or other liquid. The porosity of a rock determines only the amount of water a rock can hold, not the amount it may yield to wells. The amount of water a rock will yield to a well depends upon its permeability. The permeability of a rock is its capacity for transmitting water under pressure. Fine-grained deposits, such as silt or clay, may have a high porosity but, because the openings are very small, they have a low permeability and will transmit water very slowly. Well-sorted sand or gravel, which contains large openings that are freely interconnected, has both a high porosity and a high permeability and will transmit water readily. Part of the water in any aquifer is not available to wells because it is held against the force of gravity by molecular attraction—that is, by cohesion of the molecules of water and by their adhesion to the walls of the interstices. Thus, essentially all the water in a saturated clay may be prevented from draining into a well.

Below a certain level the permeable rocks generally are saturated with water and are said to be in the zone of saturation. The upper surface of the zone of saturation is called the water table except where that surface is formed by an impermeable body. The rocks above the zone of saturation are in the zone of aeration (zone of vadose water), which normally consists of three parts, from the water table up: the capillary fringe, the intermediate vadose belt, and the belt of soil water.

The capillary fringe lies directly above the water table and is formed by water rising from the zone of saturation by capillary action. Water in the capillary fringe is not available to wells, even though the pores in the lower part of the fringe may be filled with water; wells must tap the zone of saturation before water will enter them. The water in the fringe, however, is available to plant roots where they can reach it. The capillary fringe is of negligible thickness in coarse sand or gravel but may be several feet thick in fine-grained sediments.

The intermediate vadose zone lies between the belt of soil water and the capillary fringe. The larger interstices in the rocks in this zone generally are filled with air; however, when the belt of soil water contains water in excess of its field capacity, the intermediate zone contains water moving downward from the belt of soil water to the water table. The intermediate zone may be entirely absent in places, such as river valleys where the water table is near the surface, or it may be quite thick, as in the upland or interstream segments.

The belt of soil water lies just below the land surface and contains water held by molecular attraction. The soil zone generally must be filled to field capacity before appreciable amounts of water can percolate down to the water table. The thickness of the belt of soil water is dependent upon that of the soil, which in turn depends upon the precipitation, vegetation, character of parent rock material, and other factors.

The depth to the water table below the land surface and the thickness of the zone of saturation differ greatly in different localities. In some places the zone of saturation is overlain by relatively impervious formations, which confine the ground water under pressure. Water confined under pressure beneath a relatively impervious body of rock, and that has sufficient pressure to rise above the zone of saturation is called artesian water. Both water-table and artesian conditions exist in the Rawlins area.

WATER-TABLE CONDITIONS

Within the Rawlins area ground water occurs under water-table conditions in the Tertiary rocks on the perimeter of the Rawlins uplift and in the Miller Hill area, and in the Quaternary rocks in the stream valleys. The principal units containing water under water-table conditions are the Browns Park formation, Miocene and Pliocene rocks and alluvium.

The water table is not a plane surface but has irregularities comparable with and related to those of the land surface, although it is less rugged. It is not stationary but fluctuates up and down. The irregularities are due chiefly to local differences in gain and loss of water, and the fluctuations are due to variations from time to time in the rate of gain or loss. Whether the water table rises or declines depends upon the amount of recharge into the ground-water reservoir and the amount of discharge. If the recharge exceeds the discharge, the water table will rise; conversely, if the discharge exceeds the recharge into the ground-water reservoir the water table will decline. The water table fluctuates more by the addition or depletion of a given quantity of water than does the water surface of a reservoir. For example, if the sand and gravel of an unconfined water-bearing formation has a storage coefficient (p. —) of about 0.25, the addition of 1 foot of water to the sand and gravel will raise the water table in that material about 4 feet. Changes of water levels in wells reflect the fluctuations of the water table and hence the recharge and discharge of the ground-water reservoir. Owing to the short duration of the observations of the water-table fluctuations in the area, there is not enough information to determine whether there is any persistent trend upward or downward. However, only a small number of wells withdraw water, and it is believed that recharge and discharge are in equilibrium, and that at present the water table fluctuates principally from season to season and from year to year with changes in precipitation.

RECHARGE

Addition of water to the ground-water reservoir may be accomplished in several ways. In the Rawlins area, the ground-water reservoir in the unconsolidated Tertiary deposits on the perimeter of the Rawlins uplift is recharged principally from local precipitation, the reservoir of the Tertiary deposits (Browns Park formation) in the southern part of the area is recharged primarily by ground-water movement from the south, and the Quaternary deposits are recharged mainly by seepage from streams and ponds.

All water that falls on an area does not reach the ground-water reservoir; some is lost by direct runoff and some percolates downward into the soil zone, from which a large part may be discharged by evapotranspiration, depleting the soil moisture during the growing season more rapidly than it can be replenished by precipitation. At the end of the growing season the moisture in the soil may be largely depleted. Water that enters the soil zone during the fall and winter tends to replenish the soil moisture because there is less evapotranspiration during these seasons. Once the soil moisture is replenished, and until evapotranspiration again becomes an important factor during the next spring, the part of the precipitation that escapes direct runoff and evaporation moves downward through the soil to the water table.

DISCHARGE

The discharge of subsurface water has been divided by Meinzer (1923a, p. 48–56) into vadose-water discharge (discharge of soil water not derived from the zone of saturation) and ground-water discharge (discharge of water from the zone of saturation).

The discharge of soil water not derived from the zone of saturation includes the evaporation of water directly from the soil and transpiration by plants. Soil-water discharge generally reduces recharge to the ground-water reservoir because the deficiency of soil moisture must first be replenished before recharge can take place. Transpiration is relatively small in the Rawlins area because vegetation is scarce; thus, vadose water is discharged primarily by evaporation from the soil.

Ground-water discharge is the discharge of water directly from the zone of saturation or from the capillary fringe; in the Rawlins

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area, it includes discharge by evapotranspiration and discharge from springs, seeps, and wells.

The principal ground-water discharge from the unconfined aquifers in the Rawlins area is from springs and seeps; lesser amounts are discharged by wells and evapotranspiration. Much of the domestic and stock water and most of the water supply for the city of Rawlins is obtained from springs that issue at the base of the basal conglomerate of the Browns Park formation in the Sage Creek basin. Seeps and springs occur along the contact between Tertiary and Cretaceous rocks in the Miller Hill area. The largest springs are in the Sage Creek drainage basin and in the Muddy Creek drainage basin east and southwest of Miller Hill. Water flows also from a few springs in the Tensleep sandstone at the north end of the Rawlins uplift and in the Cambrian deposits along the west flank of the Rawlins uplift.

Twenty-four springs in the Sage Creek basin had a total flow of about 3,000 gpm in 1920 according to measurements made during an investigation of the city water supply. The city of Rawlins developed 19 of the springs, which now supply most of the city's water. According to records of the city of Rawlins, the flow from the 19 springs varies from about 1,100 gpm in the winter to about 2,000 gpm in the summer. The source of most of the spring water is a large outcrop area extending several miles south from the springs; thus, a relatively constant ground-water level and a steady spring flow would be expected. The variable flow probably results from freezing and thawing in the area of the springs rather than from changes in the rate of recharge to the ground-water reservoir. Freezing of the soil and rocks around the springs, and of the springs, probably retards movement of water and reduces the flow from the springs.

A few wells have been drilled in the area for the purpose of obtaining domestic or stock supplies; the discharge from these wells is very small compared to the discharge from springs and seeps.

Evapotranspiration of ground water occurs mostly during the growing season and where the water table is close to the land surface. Water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe, and discharged from the plants by transpiration. The depth from which plants will lift ground water varies with plant species and types of soil. Ordinary grasses and field crops will lift water only a few feet; however, alfalfa and some desert plants send their roots to depths of several tens of feet to reach the water table (Meinzer, 1923, p. 82). The Rawlins area is covered sparsely by sage brush, and in a few localities native grass and alfalfa are cultivated for hay crops;

thus, only small quantities of ground water are discharged by evapotranspiration.

ARTESIAN CONDITIONS

Artesian head, or artesian pressure, may be defined as the height to which a column of water will rise in a tightly cased well that has no discharge. Ground water that rises in wells above the level at which it is first tapped is said to be artesian water (Meinzer and Wenzel, 1942, p. 451).

Most of the consolidated formations (Fort Union and older) in the Rawlins area contain beds of relatively permeable material, principally sandstone, alternating with beds of relatively impermeable material, such as shale or clay. Most of the strata dip away from the anticlines so that water entering the outcrop areas of the permeable beds moves downdip and becomes confined between the relatively impermeable beds. Under such conditions, wells drilled to the water-bearing beds obtain water under artesian pressure, which is sufficient to cause the wells to flow in much of the Rawlins area.

Artesian water has been obtained from wells in the Sundance, Cloverly, and Frontier formations in the Sage Creek basin; and from wells in the Cambrian rocks and the Madison and Tensleep formations combined at the south end of the Rawlins uplift. The other water-bearing bedrock formations in the Rawlins area also can be expected to contain water under artesian pressure.

Precipitation on the outcrops is believed to be the most important source of recharge for artesian aquifers in the Rawlins area, even though the normal annual precipitation is small, only about 11 inches. Almost all the artesian aquifers crop out within the area studied; consequently, much of the recharge is from local precipitation. Some recharge takes place as surface runoff moves downslope over outcrops of the permeable formations. Where the artesian aquifers are overlain by saturated rocks of Tertiary age, the aquifers are recharged by water moving downward from the overlying saturated formations. In the Miller Hill area, saturated Tertiary rocks overlie and provide excellent means for recharge to the sandstone beds in the Cretaceous and older rocks. Along the margin of the Rawlins uplift, artesian aquifers ranging in age from Cambrian to Late Cretaceous are overlain by and recharged from saturated deposits of Tertiary age.

Most of the water discharged from the confined aquifers within the Rawlins area is discharged through flowing wells. A very small quantity discharges through seeps and springs. Wells drilled into the Frontier, Cloverly, Sundance, and Tensleep and Madison formations combined yield water under sufficient pressure to flow. A well drilled into the Cambrian rocks is under artesian pressure but does not flow; however, it is possible that wells drilled into those rocks farther downdip would flow. The average discharge of ground water from artesian wells in the Rawlins area is small, less than 900 gpm.

AQUIFER TESTS

The rate of ground-water movement is determined by the size, shape, number, and degree of interconnection of the interstices in the aquifer; by the density and viscosity of the water; and by the slope (hydraulic gradient) of the water table or its counterpart under artesian conditions, the piezometric or pressure-head-indicating surface. The capacity of a water-bearing material for transmitting water under a hydraulic gradient is known as its "permeability." Meinzer's "coefficient of permeability" is the rate of flow, in gallons per day, through a cross section 1 foot square, under a hydraulic gradient of 100 percent, at a temperature of 60°F (Stearns, 1928). The "field coefficient of permeability" is the same unit except that it is given for the prevailing conditions, including ground-water temperature, in the area concerned. The "coefficient of transmissibility" is a similar measure for the entire thickness of the water-bearing formation and may be expressed as the number of gallons of water per day transmitted through each 1-foot vertical strip extending the thickness of the aquifer, under a hydraulic gradient of 100 percent, or through each mile width of the aquifer at a gradient of 1 foot per mile. It is the field coefficient of permeability multiplied by the thickness of the aquifer, in feet.

The specific capacity of a well is expressed as the number of gallons per minute that a well will yield for each foot of drawdown of water in the well. A comparison of specific capacity of wells is useful in estimating the relative efficiency of wells and the relative transmissibility of formations.

The coefficient of storage of an aquifer is a fundamental factor in determining the effects of withdrawal or addition of water on the head of the ground water. It is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The aquifer tests made in the Rawlins area were not adequate to permit computing the coefficient of storage.

RESULTS OF TESTS

Aquifer tests were made of the Sundance formation, Cloverly formation, and Cloverly and Frontier formations combined. The results of these tests are given in the following table. Similar tests in exploratory holes drilled for the city of Rawlins into the Miocene and Pliocene deposits and the Cambrian rocks were unsuccessful because the holes had been badly clogged by mud during drilling. The construction of wells obtaining water from the Cambrian rocks, Madison and Tensleep formations, Permian rocks, and Miocene and Pliocene rocks was not suitable for aquifer tests. No wells are known to obtain water from the Browns Park formation. The coefficients of permeability and transmissibility were determined by the recovery method (Theis, 1925, p. 519–524) for 4 wells and by both flow method (Jacob and Lohman, 1952, p. 559–569) and recovery method for 1 well (17–88–11aa).

Results of aquifer tests of wells in the Rawlins area, Carbon County, Wyo., in November 1954

Well No.	Formation	Duration of test (hours)	Flow from wells (gpm)	Drawdown (ft)	Specific capacity (gpm per ft of drawdown)	Saturated thickness (ft)	Coefficient of transmissibility (gpd per ft)	Average field coefficient of permeability (gpd per sq ft)
17–88–11aa	Cloverly	3	85	99	0.86	----------	[1] 1,600	
18–88–3da	Cloverly and Frontier.	2.5	38	127	.29	20	340	17
18–88–10bda	Cloverly	24	65	250	.26	55	450	8
18–88–10bdd	do	3	43	[2] 31.5	1.36	69	1,700	25
19–88–34da	Sundance	2.5	28	167	.17	60	240	4

[1] Value of 1,700 obtained by flow test.
[2] Well is only slightly higher in altitude than well 18–88–10bda and should have had about the same shut-in pressure and drawdown. Well is not cased to total depth and probably is leaking water into other formations.

The flow method permits determining the coefficient of transmissibility of an aquifer by measuring the change in the rate of discharge from a flowing well that obtains water from the aquifer. The formula used is based on the assumption that the drawdown remains essentially constant during the test and that the aquifer is extensive, homogeneous, and uniformly thick.

In making the test in the Rawlins area, the "static" artesian head was measured with a pressure gage (calibrated in feet) after the well had been shut in for several days. Then the valve was opened, allowing the well to discharge freely, and the discharge was measured with the use of a calibrated container and a stopwatch at intervals throughout the test. The discharge was measured at gradually increasing intervals of time, ranging from half a minute or so at the beginning to 30 minutes at the end.

The effective radius of the well, r_w, in feet (assumed to be the same as the actual radius); the drawdown, s_w, or shut-in artesian head minus the flowing head, in feet; the discharge measurements made during the test, Q, in gallons per minute; and the time that the discharge measurements were made after the well began flowing, t, in minutes, were used to compute the coefficient of transmissibility, T, by the formula devised by Jacob and Lohman (1952).

$$T=\frac{264}{\Delta\left(\frac{s_w}{Q}\right)}$$

Using semilog paper, experimental values of $\frac{s_w}{Q}$ were plotted on the linear scale and corresponding values of $\frac{t}{r_w^2}$ were plotted on the logarithmic scale. The slope was determined by taking the change in $\frac{s_w}{Q}$ over one log cycle of $\frac{t}{r_w^2}$. Using data obtained in this manner, the value of T for well 17–88–11aa was computed as follows:

$$T=\frac{264}{\Delta\left(\frac{s_w}{Q}\right)}$$

$$=\frac{264}{.155}$$

$$=1{,}700 \text{ gallons per day per foot}$$

At the end of the flow test, the valve was closed and the rate of recovery of artesian head in the well was measured. These data were used to compute the value of transmissibility by the recovery method. The coefficient of transmissibility was determined only by the recovery method for the four wells tested other than No. 17–88–11aa. These wells had been flowing for rather long periods of time prior to the tests. The wells were shut off and the rate of recovery of head was measured.

From the nonequilibrium formula, expressing the relation between the drawdown and the rate and duration of discharge of a well, Theis developed the following recovery formula:

$$T=\frac{264\ Q}{S}\log_{10}\frac{t}{t'}$$

in which T=coefficient of transmissibility, in gallons per day per foot;
Q=discharge, in gallons per minute;
t =time since discharge began;
t'=time since discharge stopped;
s =residual drawdown of the well, in feet, at time t'.

Values of residual drawdown, s, to linear scale are plotted against corresponding values of the ratio of the time since discharge began to the time since discharge stopped t/t' to logarithmic scale. A straight line is then drawn through these points. The value Δs for one log cycle of t/t' (for which the value of $\log_{10} t/t'$ is unity) is determined and T is computed from the simplified formula

$$T=\frac{264\ Q}{\Delta s}$$

in which Q is the weighted average discharge, in gallons per minute, during the period of flow for the flow test.

DESCRIPTION OF TESTS

SUNDANCE FORMATION

A recovery ttest was made of well 19–88–34da, which obtains water from a bed of sandstone 60 feet thick in the Sundance formation. The well had been flowing steadily for several years before the test; its flow was 28 gpm immediately before the test was begun. The flow was stopped and the rate of recovery of the artesian pressure in the well was measured at intervals for 2.5 hours. At the end of the 2.5-hour period the shut-in pressure of the well was 167 feet. The coefficient of transmissibility was about 240 gallons per day per foot, and the average field coefficient of permeability was about 4 gallons per day per square foot. The specific capacity of the well was 0.17 gallon per minute per foot of drawdown, computed from the shut-in pressure after only 2.5 hours of recovery. Had the shut-in pressure been measured after a longer period of recovery, the pressure would have been greater; consequently, the computed value of specific capacity would have been less.

CLOVERLY FORMATION

The coefficient of transmissibility was determined at well 17–88–11aa by both the flow method and the recovery method. The values of transmissibility computed were about 1,700 and 1,600 gallons per day per foot, respectively. During the test the flow of the well dropped from 132 gpm, measured 1 minute after the valve was opened, to 85 gpm, 3 hours after the valve was opened. The shut-in pressure of the well was 99 feet before the valve was opened, and the specific capacity of the well was computed to be 0.86 gpm per foot of drawdown, after flowing for 3 hours. The coefficient of permeability of the formation at the well site was not determined, as no accurate information was available on the thickness of the material penetrated.

Wells 18–88–10bda and 18–88–10bdd had been flowing for a long time prior to the test, and only the recovery method was used in determining the coefficients of transmissibility. The coefficients of transmissibility were computed to be about 450 and 1,700 gallons per day per foot, respectively. The value obtained from the test on well 18–88–10bdd is not very reliable, as the well was only partially cased, and there was leakage into the overlying formations. This well, which is only a few feet higher in altitude than well 18–88–10bda, had a shut-in pressure of only 31.5 feet compared to a shut-in pressure of 290 feet for 18–88–10bda. The average field coefficient of permeability for the formation at the two well sites was computed to be about 8 and 25 gallons per day per square foot, respectively, and the specific capacities, about 0.26 and 1.36 gpm per foot of drawdown.

CLOVERLY AND FRONTIER FORMATIONS

Well 18–88–3da obtains water from both the Cloverly and Frontier formations and had been flowing steadily for several years prior to the test. Immediately before the test was begun, the well was flowing at a rate of 38 gpm. The well was shut off and the rate of recovery of the artesian pressure in the well was measured at intervals during a 2.5-hour period. Computations showed the coefficient of transmissibility to be about 340 gallons per day per foot; the average field coefficient of permeability, about 17 gallons per day per square foot; and the specific capacity of the well, about 0.29 gpm per foot of drawdown.

CHEMICAL QUALITY OF THE GROUND WATER

ANALYSES OF GROUND WATER

Ground water dissolves some of the rock materials that it contacts; thus, all ground water contains mineral matter in solution. The major constituents in the ground water in the Rawlins area include the cations calcium, magnesium, sodium, and potassium and the anions bicarbonate, sulfate, chloride, and nitrate. Lesser amounts of carbonate, fluoride, nitrate, boron, iron, and silica also are present. The results of analysis of selected samples are given in table 1. A graphic representation of the chemical composition, in equivalents per million of the principal ions, of typical water from the principal water-bearing formations in the area is shown in figure 5. The cations appear on the left side of the column and the anions on the right side. The sum of the equivalents as represented by the height of the two columns is an approximate measure of the dissolved mineral content of the water.

The dissolved mineral constituents are reported in parts per million (ppm), the unit weight of a constituent in a million unit weights of water. Parts per million can be converted to grains per United States gallon by dividing parts per million by 17.12. Equivalents per million used in preparing figure 5 are not given in this report. An equivalent per million is a constituent's unit chemical combining weight in a million unit weights of water and is calculated by dividing the concentration in parts per million by the chemical combining weight of the constituent. The following tabulation, giving the reciprocals of the combining weights, is useful for converting parts per million to equivalents per million:

Ion	*Multiply by*	*Ion*	*Multiply by*
Calcium (Ca^{++})	0.04990	Carbonate (CO_3^{--})	0.03333
Magnesium (Mg^{++})	.08224	Sulfate (SO_4^{--})	.02082
Sodium (Na^{+})	.04350	Chloride (Cl^{-})	.02820
Potassium (K^{+})	.02558	Fluoride (F^{-})	.05263
Bicarbonate (HCO_3^{-})	.01639	Nitrate (NO_3^{-})	.01613

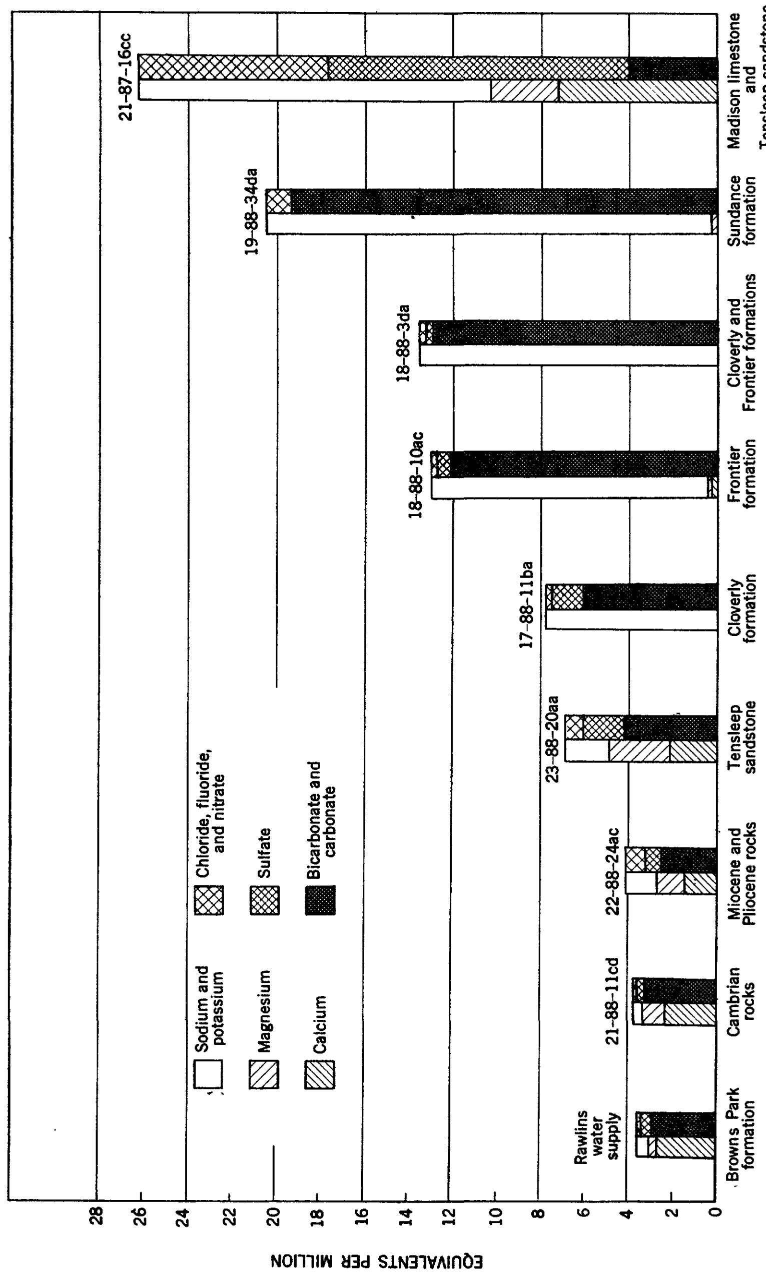

FIGURE 5.—Graphical representation of analyses of water from the principal water-bearing formations in the Rawlins area, Carbon County, Wyo.

TABLE 1.—*Chemical analyses of ground water in the Rawlins area, Carbon County, Wyo.*

[Chemical constituents in parts per million]

Well No.	Depth (ft)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25° C)	pH
Pliocene and Miocene rocks																							
22-88-24ac	47	12- 8-54	49	1.9	4.2	26	16	19	2.4	145	0	35	11	0.0	0.1	0.08	181	129	119	10	24	332	7.6
Browns Park formation																							
Combined flow from 19 springs[1]	19 Springs	10-23-51	52	32	0.27	53	3.8	14	2.7	179	0	33	2.0	0.1	1.2	0.04	237	148	147	1	17	345	7.8
Frontier formation																							
18-88-10ac	210	12- 8-54	47	7.8	0.69	5.5	1.3	290	1.0	556	89	37	6.5	1.2	0.0	0.37	720	19	19	0	97	1,170	9.3
Frontier and Cloverly formations																							
18-88-3da	1,026	12- 6-54	57	10	0.09	------	------	310	1.0	651	68	16	4.5	7.0	0.0	0.44	742	3	3	0	99	1,220	9.0

Cloverly formation																							
17-88-11aa	580	12- 6-54	46	10	0.11	1.5	0.4	222	0.9	342	65	85	3.0	0.5	0.0	0.35	557	5	5	0	99	913	9.4
-11ba	620	12- 6-54	50	11	.07	------	------	178	.5	210	75	76	3.0	.0	.0	.19	468	2	2	0	99	731	9.5
18-88-10bda	1,000	12- 6-54	57	9.7	.56	3.5	1.1	75	2.6	175	0	32	2.0	.5	.4	.08	223	13	13	0	91	346	7.5
Sundance formation																							
19-88-34da	1,890	12- 6-54	62	11	4.2	2.0	0.0	465	1.6	1,120	31	1.0	26	6.0	0.1	0.45	1,100	5	5	0	99	1,750	8.6
Permian rocks																							
21-87-22bc	279	12-10-54	50	6.3	3.0	898	351	1,060	31	128	0	318	3,930	0.0	0.6	0.46	6,660	3,690	100	3,590	38	11,500	7.5
Tensleep sandstone																							
23-88-20aa	Spring	12- 7-54	38	3.6	0.09	43	35	27	2.4	222	0	93	20	0.1	1.0	0.09	339	250	182	68	19	581	7.9
Tensleep sandstone and Madison limestone																							
21-87-16ccl [2]	650	12- 7-54	53	11	0.02	144	40	350	19	246	0	663	299	0.8	1.2	1.2	1,650	525	202	323	58	2,480	7.6
Cambrian rocks																							
21-87-17ac [3]	416	12-10-54	51	12	0.15	108	21	95	5.9	210	0	189	124	0.6	0.2	0.24	663	354	172	182	36	1,060	7.6
21-88-11cd	Spring	12- 6-54	44	7.8	.07	46	13	9.3	1.4	190	0	24	3.0	.0	1.1	.02	214	170	156	14	10	353	7.6

[1] Source of water for Rawlins, Wyo., Analyses from U.S. Geol. Survey, Water-Supply Paper 1300, 1952.
[2] Sample collected from combined flow of 21-87-16ccl and 21-87-16cc2. Combined flow of two wells was 217 gpm of which 195 gpm was from well 21-87-16ccl.
[3] Most of the water is derived from Cambrian rocks; however, the well may derive some water from Tertiary deposits.

CHEMICAL CONSTITUENTS AND THEIR SIGNIFICANCE

The significance of the chemical and physical characteristics of water have been set forth in detail by E. W. Lohr and S. K. Love (1952) and many others. Only a brief discussion of the subject will be made here; the reader is referred to the above publication for a more detailed discussion.

Calcium and magnesium cause most of the hardness in ordinary water and are responsible for increased soap consumption and for the undesirable curd formed in washing. However, iron, aluminum, strontium, barium, zinc, and free acid also impart hardness to water but these constituents generally are not present in appreciable quantities in natural water. The hardness-forming constituents and silica are the active agents in forming most scale that collects in steam boilers and other vessels in which water is heated or evaporated. Water that has a hardness of less than 60 ppm (as $CaCO_3$) is considered soft and is suitable for many uses without further softening. Hardness in excess of 60 ppm is generally noticeable and the water may require softening before it can be used for some purposes. The concentration of calcium in samples of water from the Rawlins area ranged from less than 1 to 898 ppm, and of magnesium from less than 1 to 351 ppm. Total hardness ranged from 2 to 3,690 ppm.

In addition to the total hardness, the table of analyses gives the carbonate and noncarbonate hardness. Carbonate hardness is that caused by calcium and magnesium bicarbonate. It may be almost completely removed from water by boiling. This type of hardness sometimes is called temporary hardness. Noncarbonate hardness usually is caused by sulfate, chloride, or nitrate of calcium and magnesium; it cannot be removed by boiling. It is sometimes called permanent hardness. Both carbonate and noncarbonate hardness have the same effect on soap. The noncarbonate hardness generally forms the harder scale in steam boilers.

High concentrations of chloride and nitrate may contribute to the corrosiveness of water and also may be indicative of contamination of water by sewage or other organic matter. Nitrate in concentrations that exceed 45 ppm in drinking water may have a toxic effect on the blood of infants, resulting in cyanosis (Maxcy, 1950). Nitrate concentrations in all water samples in the Rawlins area were less than 45 ppm.

Fluoride in small quantities is necessary for the normal development of teeth, but more than about 1.5 ppm may cause permanent mottling of the tooth enamel of children (Dean, 1936). Fluoride is added to municipal water supplies in some places where the fluoride content of the water is below the optimum amount of about 1 ppm.

Fluoride in water samples from the Rawlins area ranged from 0 to 7 ppm. The higher concentration of fluoride appears to be associated principally with water from the Sundance formation and from the lower part of the Frontier formation; water from other sources contained less than 1.3 ppm of fluoride.

The iron content of natural water, next to hardness, usually receives the most attention. The quantity of iron in ground water may differ greatly from place to place, even though the water is derived from the same formation. If water contains more than 0.3 ppm of iron, the iron may precipitate as a reddish sediment. A high iron content may give a disagreeable taste to water and may stain fixtures, utensils, and fabrics. Iron in small quantities can be removed from most water by simple aeration and filtration, but water having large concentrations of iron may require other methods of treatment. The iron content in samples of water from the Rawlins area ranged from 0.02 to 4.2 ppm. About three-fifths of the samples contained less than 0.3 ppm. The highest iron content was in water from the Permian rocks, Sundance formation, and Miocene and Pliocene rocks.

Maximum limits of concentration for some of the chemical constituents commonly found in water have been prescribed by the U.S. Public Health Service (1946) for drinking water use by carriers and others subject to Federal quarantine regulations. Though these standards are not compulsory for other water users they are believed suitable for use generally in evaluating the quality and safety of water supplies. The standards have been accepted by the American Water Works Association as the standard for all public-water supplies. They are reproduced in part below.

Constituent	*Maximum content (ppm)*
Iron and manganese (Fe+Mn)	0.3
Magnesium (Mg)	125
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.5
Dissolved solids	[1] 500

[1] 1,000 permitted when water of better quality is not available.

No limit on nitrate concentration has been established, but as pointed out previously 45 ppm may represent the safe limit.

Water containing less than 500 ppm of dissolved solids generally is acceptable for domestic use. However, in many places in the arid and semiarid West the only water available for domestic supply might contain constituents greatly in excess of the recommended limits. Water containing more than 1,000 ppm of dissolved solids generally is not satisfactory for many domestic and industrial uses because some constituents may produce a noticeable taste or make the water unsuitable in some other respect. Of the 13 water samples collected in the Rawlins area, 7 contained more than 500 ppm of dissolved solids and 3 contained more than 1,000 ppm. (See table 1.)

The chemical-quality requirements of water for industrial use differ with the industry; however, water from most public-supply systems is satisfactory for many industries. To discuss the chemical-quality requirements and maximum limits of chemical constituents of water for numerous industrial uses is beyond the scope of this report, but criteria have been established for many uses. (California State Water Pollution Board, 1952.)

Ground water in the Rawlins area generally cannot be obtained in sufficient quantities for irrigation other than of lawns or small garden plots. For those localities in which irrigation is carried on, the following factors should be considered in determining the suitability of water: the total concentration of dissolved solids; the percent sodium, and the quantity of boron or other elements that may be toxic. Each must be considered with respect to other factors, such as soil composition, permeability, drainage, irrigation practices, and plant tolerances. The factors affecting the suitability of water for irrigation are discussed in a report by the U.S. Salinity Laboratory (1954). For the Rawlins area the percent sodium is too high in the samples of water from all units from the Sundance formation to the Frontier formation, inclusive, to be suitable for irrigation.

CHEMICAL QUALITY IN RELATION TO WATER-BEARING FORMATIONS

Cambrian rocks.—Two water samples were collected from the Cambrian rocks, one from a spring and the other from a well, 416 feet deep. The hardness of the two samples was 170 and 354 ppm, respectively, and the dissolved solids were 214 and 663 ppm, respectively. The much greater content of sulfate and chloride in the well sample accounts, for the most part, for the difference in mineral content of the two samples.

Madison limestone and Tensleep sandstone.—Only one sample of water was collected from a well tapping the Tensleep sandstone and the Madison limestone. The water was hard (525 ppm) and had a concentration of 1,650 ppm of dissolved solids. Most of the hardness is of the noncarbonate type.

Tensleep sandstone.—The water from the Tensleep sandstone, as shown by the analysis of one sample from a spring issuing from the formation, is magnesium bicarbonate in type. The sample had a hardness of 250 ppm and a concentration of dissolved solids of 339 ppm. Water obtained at greater distances from the outcrop of the Tensleep probably would be much more mineralized.

Permian rocks.—Water from the Permian rocks had the highest concentration of dissolved minerals, 6,660 ppm, of any water analyzed during this study. However, only one sample of water from these rocks was analyzed. The hardness of the water was 3,690 ppm, of which 3,590 ppm was noncarbonate, and the chloride content, 3,930 ppm. The water is unsuitable for most uses.

Sundance formation.—Water from one well in the Sundance formation was one of the softest collected, having a hardness of only 5 ppm. It is a typical sodium bicarbonate water. The dissolved-solids content was 1,100 ppm. The fluoride content, 6.0 ppm, and the iron content, 4.2 ppm, are high. Although the water is soft, it is undesirable for domestic use.

Cloverly formation.—Water from the Cloverly formation is the most desirable for domestic and municipal use of all the water examined during this study. The water is very soft, the hardness ranging from 2 to 13 ppm, is of the sodium bicarbonate type, and contains 223 to 557 ppm of dissolved solids. One water sample contained no fluoride in detectable amounts, and each of the other two contained only 0.5 ppm. The iron content ranged from 0.07 to 0.56 ppm, and only 1 of the 3 samples contained detectable nitrate (0.4 ppm).

Cloverly and Frontier formations.—The hardness of a water sample from the Cloverly and Frontier formations combined was 3.0 ppm, and the dissolved-solids content was 742 ppm. The water contained the greatest concentration of fluoride, 7.0 ppm, of all the water samples collected in the area. Such a high concentration of fluoride in water used regularly by children would cause dental fluorosis (mottling of the tooth enamel). Because water derived only from the Cloverly formation seems to be low in fluoride, the high fluoride content of this combined water sample is believed to be caused by an admixture of water from the lower part of the Frontier formation.

Frontier formation.—A water sample collected from the upper sandstone bed of the Frontier formation was very similar to water from the Cloverly formation. The hardness and dissolved solids, 19 ppm and 720 ppm, respectively, were only slightly greater than those of water from the Cloverly formation. The fluoride content of the water was 1.2 ppm. The water, except for an iron content of 0.69 ppm which could be reduced by aeration, is suitable for domestic use.

The Frontier formation contains three distinct sandstone beds, each separated by shale. The quality of water from the three sandstone beds may differ considerably. On the basis of the fluoride content of 7.0 ppm in a combined water sample from the Cloverly and Frontier formations (well 18–88–3da), water from the lower sandstone unit of the Frontier formation probably has the greatest concentration of fluoride of any of the waters in the area.

Browns Park formation.—A water sample was collected from the combined flow from 19 springs that issue at the base of the basal conglomerate of the Browns Park formation (Bishop conglomerate of earlier reports). The water is derived from both the upper part and the basal conglomerate of the Browns Park formation. The sample had a hardness of 148 ppm and a dissolved-solids concentration of 237 ppm. Fluoride, iron, and nitrate concentrations were 0.1, 0.27, and 1.2 ppm, respectively.

Miocene and Pliocene rocks.—One sample of water from the Miocene and Pliocene rocks was moderately hard, 129 ppm, and contained 181 ppm of dissolved solids. The iron content of 4.2 ppm was probably caused, in part, by corrosion of the well casing, as iron scale from the casing was found in the water sample. Except for the iron content the water is suitable for most domestic uses.

UTILIZATION OF GROUND WATER

Most ground water that is used in the Rawlins area is obtained from springs and seeps that issue from the Cambrian rocks, the Tensleep sandstone, and the Browns Park formation. The springs are contact gravity springs that issue at or near the contact between relatively permeable saturated deposits and underlying relatively impermeable deposits, which impede or prevent further downward movement of water. Flow of the individual springs ranges from a trickle to more than 300 gpm.

Relatively small quantities of ground water are obtained from wells in the Rawlins area. Many existing wells are artesian, some flowing and others pumped. All the wells are drilled and most are cased with steel casing, the diameter ranging from 4 to 11 inches.

DOMESTIC AND STOCK SUPPLIES

Most water for domestic and stock use in the Rawlins area is obtained from springs, although some water for those uses is obtained from wells.

Spring water that is used for domestic purposes generally is collected by perforated pipe laid in one or more trenches, which are dug into the deposits from which the springs issue. The water flows through pipes either to the place of use or to a closed catchment basin or tank, and then to the point of use.

Water from undeveloped springs that is used for watering stock flows from the springs into open tanks, pits, or drainage courses. To develop the springs a small pit is dug into, or a small pipe is forced into, the water-bearing deposits at the spring sites, and the water is collected in a small open basin or tank. The development of springs, as currently practiced, generally does not make maximum use of the available water.

PUBLIC SUPPLIES

Rawlins, the only municipality in the Rawlins area, obtains most of its water supply from 19 springs and 2 wells (18–88–10bda and 17–88–11aa) about 17 and 23 miles, respectively, south of the city. The flow from only 19 of the 24 springs owned by the city of Rawlins has been developed and utilized. Three wells within the city limits (21–87–16cc1, cc2, and cc3) are used occasionally to supplement the supply. Another city well, 18–88–10bdd, has been drilled, but water from it had not yet been added to the supply in 1955. The wells are artesian and all flow.

Water from the springs is collected by perforated pipes, which are buried in trenches dug into the water-bearing deposits at the spring sites, and which are directed into a central catchment basin. From the catchment basin the water flows into the main collection line. Water from the springs and wells flows by gravity through the 16-inch collection line, which is about 30 miles long, into 4 storage tanks at the south edge of the city. The storage tanks have a combined capacity of 18 million gallons, and the water flows from them by gravity through the city's distribution lines.

The average daily water use at Rawlins was 2,290,000 gallons during 1954; the maximum daily use was 3,020,000 gallons, and the minimum daily use was 1,150,000 gallons.

The Wyoming State Penitentiary, at the north side of the city of Rawlins, obtains water from a 416-foot well drilled into the Cambrian rocks. The water is pumped by an electrically powered turbine pump, having a rated capacity of 150 gpm, into a 75,000-gallon elevated storage reservoir. The average daily water use at the penitentiary is approximately 75,000 gallons.

FUTURE DEVELOPMENT OF GROUND-WATER SUPPLIES

The amount of water that can be withdrawn from a ground-water reservoir without causing excessive permanent lowering of the ground-water levels depends on the transmissibility and storage capacity of the reservoir and on the amount of recharge to it. If water is withdrawn from the reservoir faster than it is added by recharge, the water levels will decline, and eventually the reservoir will be depleted. The amount of water than can be withdrawn annually over a long period of years without causing depletion of the available supply may be called the safe or perennial yield of the reservoir.

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The feasibility of developing additional ground-water supplies for industry, public supplies, or agricultural development in the Rawlins area is dependent upon the safe yield of the ground-water reservoirs, which in turn is governed by geologic, hydrologic, and economic factors.

Water is a renewable natural resource and is constantly moving between the land and the atmosphere. It can be stored by artificial means in surface reservoirs, and is stored by natural means—in places supplemented artificially—in ground-water reservoirs. The greatest use is made of a surface-water reservoir when it is periodically emptied and refilled. Likewise, the greatest use is made of a ground-water reservoir when it is periodically emptied or partly emptied. Lowering the natural water levels in a ground-water reservoir provides additional space in the ground to store some of the precipitation that otherwise might be, and often is, removed from an area by surface runoff. In areas where the water table is close to the land surface, lowering the water table often conserves for beneficial use water normally lost by evaporation and by nonbeneficial transpiration.

Water cannot be removed from a ground-water reservoir at an average greater than the average recharge without depleting the supply. The safe yield of a ground-water reservoir is, therefore, equal to the average annual recharge to the reservoir less remaining natural discharge that cannot be recovered.

In developing an aquifer, care should be taken to space the wells so that the maximum amount of water may be withdrawn without undue interference between the wells. When a well is pumped the water table near the well declines and takes the form of an inverted cone called the cone of depression. The cone of depression may extend for great distances laterally from the discharging well. The difference between the static water level and the discharging water level in the well, which is at the apex of the cone of depression, is called the drawdown of the well. The higher the rate at which a given well is pumped, the greater the drawdown and, also, the larger the cone of depression. At the start of pumping, the water level in a well lowers very rapidly and then more slowly until, if conditions are favorable, it becomes almost stationary or declines very slowly. At the completion of pumping, the water level rises rapidly in the well for a time and then more slowly until it approaches its original level. The cones of depression of artesian wells develop very much in the same manner as do those of a pumped water-table well, except that they develop much more rapidly. Drawdown is measured as the difference between the "static" head and the head during flow.

In areas where wells are closely spaced, the decline of the water level is greatly increased by interference between wells. For example, wells 18–88–10bda and 18–88–10bdd are flowing artesian wells that tap the Cloverly formation and are fairly close together. Because of the overlapping of the cones of depression of these wells, there is undoubtedly considerable interference between them.

Within the area studied, the present development of ground water is relatively small. Most of the formations that are potential aquifers are tapped by only a few wells, and even the formations that have been exploited for ground water are not pumped heavily. Springs that issue within the area have been developed only to a small extent, and many springs have not been tapped.

Additional supplies of water can be obtained from springs in the general locality of the springs that now supply the city of Rawlins. The flow from 24 springs that were measured in 1920 was approximately 3,000 gpm. The maximum yield of the collection works at the springs developed by the city of Rawlins is about 2,000 gpm. The combined measured flow of these 19 springs in 1920 was approximately 2,800 gpm; thus, unless the total flow has decreased which is believed not to be the case, a considerable part of the flow is not captured and is still available for use. The spring line extends along the base of Miller Hill on both sides of the Continental Divide.

Wells can be developed for domestic and stock water supplies from sandstone beds and unconsolidated deposits of the various formations throughout most of the area. The chemical quality of the water varies from one formation to another; the water from some formations may be so highly mineralized that it would not be suitable for domestic use. Water supplies large enough for municipal and small industrial needs can be developed from the Cambrian rocks, Madison limestone, Tensleep sandstone, Cloverly formation, Browns Park formation, and Miocene and Pliocene rocks.

The city of Rawlins has developed wells that penetrate the Cloverly formation, Tensleep sandstone and Madison limestone combined, and Cambrian rocks and that yield moderate quantities of potable water. However, the water from the Tensleep sandstone and Madison limestone combined is somewhat mineralized (1,650 ppm of dissolved solids). Additional water can be obtained from these formations; the water from them would be under artesian pressure and in many places would flow at the land surface. The formations dip sharply away from the apex of the uplifts and lie beneath the surface at depths ranging from a few feet near the uplifts to several thousand feet only a short distance away. Additional wells could be drilled into the Cloverly formation along the flank of the Miller Hill-Lake Valley anticline, at the base of Miller Hill, and along the southern margin of the Sage Creek basin. Wells started in the Frontier formation in that locality would be expected to tap the Cloverly formation at depths of 1,000 feet or less. (See pl. 1.) At that locality the Tensleep sandstone, Madison limestone, and Cambrian rocks would be tapped at much greater depths. Wells drilled west of U.S. Highway 287 on the east flank of the Rawlins uplift would be expected to tap the Tensleep sandstone, Madison limestone, and Cambrian rocks at depths of 1,000 feet or less.

The Browns Park formation extends over much of the southern part of the mapped area. Ground water occurs in this formation at depths generally less than 150 feet. Although no wells are known to obtain water from this formation, the author believes that medium to large supplies of water can be developed wherever a thick section of saturated material is penetrated. The formation is capable of yielding large supplies of water because several large springs flow from the basal conglomerate. One spring in the area studied (17–88–33abc) had a measured discharge of 343 gpm. Several large springs are reported to flow from the conglomerate southwest of the report area.

A thick section of Tertiary rocks (Miocene and Pliocene) occur on the perimeter, mainly the east flank, of the Rawlins uplift. These deposits, where saturated, can yield moderate supplies of water to wells. In test holes as much as 216 feet of unconsolidated sand, gravel, pebbles, and clay were penetrated in these deposits southeast of the city of Rawlins. Depths to water in these test holes ranged from zero to 20 feet below the land surface, indicating thick sections of saturated material, as much as 196 feet in one hole.

RECORDS

RECORDS OF WELLS AND SPRINGS

The records of 22 wells and test holes and 26 springs obtained during this study are shown in the following table; their location is shown on plate 1. The flow from 24 springs belonging to the city of Rawlins was measured in 1920; more recent measurements were unavailable. The remaining yields shown in the table were measured or reported during this study.

Record of wells and springs in the Rawlins area, Carbon County, Wyo.

Well or spring No.: See text for description of well-numbering system.
Type of supply: Dr, drilled well cased with steel pipe; Sp, spring.
Depth of well: Depths are reported, except measured depths, which are given in feet and tenths.
Method of lift and type of power: C, cylinder; Cf, centrifugal; F, natural flow; N, none; T, turbine; E, electric motor; G, gasoline engine.
Use of water: D, domestic; N, not used; P, public supply; S, stock.
Measuring point: Ls, land surface; Tc, top of casing; Vpb, vent in pump base. Height above mean sea level is reported or interpolated from topographic maps.
Depth to water: Measured depths to water level are given in feet, tenths and hundredths; reported depths are given in feet. Measured artesian pressures are given in feet above land surface.
Remarks: Yield in gallons per minute; drawdown, in feet; temperature, T, in °F; chemical analysis and logs means that they are in this report.

Well or spring No.	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing unit: Character of material	Principal water-bearing unit: Geologic source	Method of lift and type of power	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (−) land surface (feet)	Measuring point: Height above mean sea level (feet)	Distance to water level above (+) or below (−) measuring point (feet)	Date of measurement	Remarks
16-87-22cb [1]	City of Rawlins.	Dr	60	8	Gravel	Upper part of Browns Park formation.	N	N	Tc	+1.2		−4.96	Nov. 5, 1954	
16-88-3bc [1]	do	Sp			Conglomerate and sandstone.	Browns Park formation.	F	P			7,758		1920	Yield 147.
-4bc [1]	Unknown	Dr	600	4	Gravel and sandstone.	Upper part of Browns Park formation.		N	Tc	0		−128.80	Nov. 5, 1954	
17-88-11aa	City of Rawlins.	Dr	580	11	Sandstone	Cloverly formation.	F	P	Ls	0		+96.00	Nov. 18, 1954	Yield 85; draw down 99; T46; chemical analysis.
-11ba	Art Rasmussen.	Dr	620	7	do	do	F	S					Dec. 6, 1954	Yield 25 (reported); T50; chemical analysis.
-33aac1	City of Rawlins.	Sp			Conglomerate and sandstone.	Browns Park formation.	F	P			7,634		1920	Yield 258.
-33aac2	do	Sp			do	do	F	P			7,634		do	Yield 178.
-33aac3	do	Sp			do	do	F	P			7,634		do	Yield 258.
-33aac4	do	Sp			do	do	F	N			7,634		do	Yield 18.
-33aac5	do	Sp			do	do	F	P			7,634		do	Yield 67.
-33aad	do	Sp			do	do	F	P			7,630		do	Yield 53.
-33abc	do	Sp			do	do	F	P			7,653		do	Yield 343.
-33abd	do	Sp			do	do	F	N					do	Yield 13.

Record of wells and springs in the Rawlins area, Carbon County, Wyo.—Continued

Well or spring No.	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Principal water-bearing unit: Character of material	Principal water-bearing unit: Geologic source	Method of lift and type of power	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (−) land surface (feet)	Measuring point: Height above mean sea level (feet)	Distance to water level above (+) or below (−) measuring point (feet)	Date of measurement	Remarks
17-88-34bca1	City of Rawlins.	Sp			Conglomerate and sandstone.	Browns Park formation.	F	P					1920	Yield 133.
-34bca2	do	Sp			do	do	F	N					do	Yield 67.
-34bca3	do	Sp			do	do	F	N					do	Yield 67.
-34bca4	do	Sp			do	do	F	P					do	Yield 133.
-34bca5	do	Sp			do	do	F	P					do	Yield 151.
-34bca6	do	Sp			do	do	F	P					do	Yield 138.
-35acd1	do	Sp			do	do	F	N			7,610		do	Yield 18.
-35acd2	do	Sp			do	do	F	P			7,610		do	Yield 36.
-35acd3	do	Sp			do	do	F	P			7,610		do	Yield 62.
-35acd4	do	Sp			do	do	F	P			7,615		do	Yield 320.
-35bc	do	Sp			do	do	F	P			7,659		do	Yield 68.
-35cac1	do	Sp			do	do	F	P			7,621		do	Yield 89.
-35cac2	do	Sp			do	do	F	P			7,623		do	Yield 205.
-35daa	do	Sp			do	do	F	P			7,659		do	Yield 80.
-36cad	do	Sp			do	do	F	P			7,805		do	Yield 178.
18-88-3da	do	Dr	1,026	10	Sandstone	Cloverly and Frontier formations.	F	S	Ls	0		−129	Aug. 23, 1954	Yield 38; drawdown 127; T57; chemical analysis; log; oil test.
-10ac	Eugene McCarthy.	Dr	210	8	do	Frontier formation.	T,G	S				−80	Dec. 8, 1954	Yield 50; T47; chemical analysis.
-10bda	City of Rawlins.	Dr	1,000	11	do	Cloverly formation.	F	P	Ls	0		+287	Aug. 23, 1954	Yield 65; drawdown 250; T57; chemical analysis; log.
-10bdd	do	Dr	960	11	do	do	F	N	Ls	0		+31.5[2]	Nov. 19, 1954	Yield 43; drawdown 31.5; log.

19-88-2bd	Hatfield Oil Co.	Dr	3,935											Oil well.
-34da	Ed Good	Dr	1,890	10	do	Sundance formation.	F	S	Ls	0		−167	Nov. 20, 1954	Yield 28; drawdown 167; T62; chemical analysis; log.
21-87-5aac	City of Rawlins.	Dr	113.5	6	Conglomerate, sandstone and limestone.	Madison limestone and Miocene and Pliocene rocks.	N	N			6,885		May 23, 1955	Test hole; log.
-16bad	do	Dr	185	6	Conglomerate	Miocene and Pliocene rocks.	N	N	Tc	+0.5	6,695	0.0	May 17, 1955	Test hole; log.
-16cc1	do	Dr	650	8	Sandstone and limestone.	Madison limestone and Tensleep sandstone.	F	P					Dec. 7, 1954	Yield 193; T53; chemical analysis.
-16cc2	do	Dr	650		do	do	F	P					do	Combined yield of two wells 200 (reported).
-16cc3	do	Dr	650		do	do	F	P					do	
-17ac	State Penitentiary.	Dr	416	8	Sandstone and conglomerate.	Cambrian rocks and Miocene and Pliocene rocks.	T,E	P	Vpb	+1.4		−64.50	Dec. 10, 1954	Yield 150 (reported); T51; chemical analysis; log.
-17bd	Joe Huner	Dr	200	4	Sand and gravel	Miocene and Pliocene rocks.	N	N	Ls	0		−19.72	Dec. 11, 1954	
-19bca	City of Rawlins.	Dr	249	6	Conglomerate and sandstone.	Cambrian rocks and Miocene and Pliocene rocks.	N	N	Tc	+1.5		−26.33	May 16, 1955	Test hole; log.
-19dbb	do	Dr	295	6	do	do	N	N	Tc	0		−5.00	May 17, 1955	Test hole; log.
-21bb	C. Ballard	Dr	348	7	Sandstone	Cambrian rocks	F	N					Dec. 10, 1954	
-22bc	Sid Thayer	Dr	279	6	do	Permian rocks	C,E	D,S	Ls	0		−100	do	T50; chemical analysis.
21-88-11cd	John Gale	Sp			do	Cambrian rocks	F	D,S					Dec. 6, 1954	Yield 100 (reported); T44; chemical analysis.
22-87-30aab	City of Rawlins.	Dr	106	6	Conglomerate, sandstone, and limestone.	Madison limestone and Miocene and Pliocene rocks.	N	N	Tc	0		−28.75	May 19, 1955	Test hole; log.
22-88-24ac	Raymond Smith.	Dr	47	8	Sand and gravel	Miocene and Pliocene rocks.	Cf,E	D	Tc	+1.0		−9.37	Dec. 7, 1954	T49; chemical analysis.
23-88-20aa	P. Olson	Sp			Sandstone	Tensleep sandstone.	F	D,S					do	Yield 200 (reported); T38; chemical analysis.

[1] Wells and springs are immediately south of Rawlins area.
[2] Total pressure not obtained as well casing leaks.

LOGS OF TEST HOLES AND WELLS

Logs of 12 test holes and wells in the Rawlins area, Carbon County, Wyo., are shown on the following pages. "Sample logs" are those for wells and test holes from which drill cuttings were collected and studied by the author. "Drillers' logs" are logs of wells that were obtained from drillers' written records or from other sources; their terminology is essentially unchanged, but the geologic interpretations were made by the author. The logs are arranged in numerical order by townships, ranges, and sections. Location of the test holes and wells is shown on the geologic map, plate 1.

18-88-3da.—*Driller's log of oil test*

	Thickness (feet)	Depth (feet)
Cretaceous system:		
Niobrara formation:		
Shale, gray	60	60
Frontier formation:		
Shale, sandy, hard	15	75
Sand and sandy shale	80	155
Shale, blue	25	180
Shale, black	75	255
Sand and sandy shale	85	340
Shale, sandy	10	350
Shale, black	15	365
Bentonite	5	370
Shale, black	16	386
Bentonite	2	388
Shale, black	7	395
Shell and sand [1]	5	400
Sand, hard	6	406
Shale, black	120	526
Sand—artesian sulfur water, gas	14	540
Shale, black	23	563
Shale	2	565
Shale, black	10	575
Shell	2	577
Shale, black	13	590
Shell and streaks of bentonite	4	594
Shale	2	596
Shell	4	600
Shale, black	10	610
Shale, brown	9	619
Shale, black	5	624
Shale, dark-brown	24	648
Shale, black	67	715
Cretaceous system—Continued		
Frontier formation—Con.		
Sand, black—fresh water and gas	5	720
Shale, sandy, black	20	740
Shale, sandy	7	747
Mowry shale:		
Bentonite	2	749
Shale, sandy	6	755
Shell, hard	5	760
Shale, sandy, black	40	800
Shale, gray	10	810
Shale, sandy	5	815
Shale, gray	5	820
Shale, sandy, hard	5	825
Shale, sandy, soft	10	835
Shale, gray	20	855
Shale, black	5	860
Shale, sandy, black	30	890
Shell	3	893
Thermopolis shale:		
Shale, sandy	8	901
Shale	13	914
Sand	12	926
Shale, gray	24	950
Cloverly formation:		
Shale, sandy, gray	15	965
Shale, gray	10	975
Shale, sandy, gray	15	990
Sand, fine, hard	15	1,005
Sand, fine, soft	10	1,015
Sand, very coarse—heavy flow of fresh water	6	1,021

[1] Shell probably refers to limestone, or lime cemented material.

18-88-10bda.—*Sample log of well*

	Thickness (feet)	Depth (feet)
Cretaceous system:		
Niobrara formation:		
Clay	22	22
Sandstone, brown	25	47
Frontier formation:		
Shale; black with sandstone stringers	130	177
Sandstone, very hard, gray-white	10	187
Sand, fine; "salt and pepper"	23	210
Shale, black; contains sand stringers	250	460
Sand, hard; flow 30 gpm, reported	16	476
Shale, hard, black	179	655
Mowry shale:		
Conglomerate, limestone, quartz; and streaks of hard black shale	162	817
Shale, black and bentonite	13	830
Cretaceous system—Continued		
Thermopolis shale:		
Sandstone, hard; contains shale streaks	7	837
Sand, hard, gray; and soft stringers	13	850
Shale, bentonite, and sandy shale	67	917
Sand, hard, tan	11	928
Cloverly formation:		
Sandstone, gray, very broken; flow 70 gpm, reported	27	955
Shale, gray, and bentonite	13	968
Sandstone, very fine, white; hard top, soft base; flow 50 gpm, reported	15	983
Jurassic system: Morrison formation: Shale, multicolored	17	1,000

18-88-10bdd —*Sample log of well*

	Thickness (feet)	Depth (feet)
Cretaceous system:		
Frontier formation:		
Clay and shale	25	25
Sandstone	1	26
Shale	11	37
Shale with sandstone stringers	41	78
Sandstone, hard, gray	20	98
Sandstone, hard; with streaks of sandy shale	24	122
Sandstone, hard, white	23	145
Sandstone with stringers of black shale	20	165
Sand, hard, white	5	170
Sandstone, gray; with black shale	10	180
Shale, black	34	214
Sandstone with streaks of bentonite	6	220
Shale, black; with streaks of bentonite	136	356
Sand, hard; with streaks of shale	14	370
Shale, black; contains shells	189	559
Sandstone, hard, white; with streaks of conglomerate; gas and water—flow 3.3 gpm, reported	4	563
Mowry shale:		
Shale with shells	7	570
Conglomerate and hard shale	28	598
Sand, soft	1	599
Quartz, hard	7	606
Conglomerate with streaks of shale	9	615
Shale, black	48	663
Conglomerate beds	5	668
Shale and bentonite with streaks of conglomerate	60	728
Thermopolis shale:		
Sandstone, gray	7	735
Sand, soft, gray	4	739
Shale, black	5	744
Sandstone, hard	2	746
Shale, sandy	15	761
Shale, gray; contains shells	37	798
Cretaceous system—Continued		
Cloverly formation:		
Conglomerate	4	802
Shale, sandy, gray; with bentonite and conglomerate	11	813
Sand, hard, fine; flow increased to 18 gpm, reported	15	828
Sand, hard, fine	5	833
Sand, shale, and bentonite	27	860
Sand, hard, fine; flow increased to 42 gpm, reported	7	867
Jurassic system:		
Morrison formation:		
Bentonite and shale	2	869
Sand, hard, fine	2	871
Shale and bentonite	11	882
Shale, blue-green; with bentonite and shells	8	890
Sandstone, brown; with streaks of shale	10	900
Shale and bentonite containing shells	33	933
Shale, sandy, and bentonite	8	941
Sand, fine	2	943
Conglomerate	2	945
Shale with bentonite streaks	32	977
Conglomerate	1	978
Shale, gray-green and blue	27	1,005
Conglomerate streak	2	1,007
Shale, gray, green, and blue	4	1,011
Bentonite	1	1,012
Shale, gray, green, and blue	22	1,034
Conglomerate streak	2	1,036
Shale, gray, green, and blue	12	1,048
Conglomerate streak	2	1,050
Bentonite	1	1,051
Shale, gray, green, blue, maroon, and purple; drilling fluid turned red and stayed same color	9	1,060

19–88–2bd.—*Driller's log of oil test by Hatfield Oil Co.*

	Thickness (feet)	Depth (feet)
Cretaceous system:		
Steele shale and Niobrara formation (undifferentiated):		
Shale, blue	792	792
Shale, sandy, blue	760	1,552
Shale, dark	258	1,810
Shale, sandy, light-colored	144	1,954
Sand, hard, dark, (contains water)	8	1,962
Lime, sandy, dark	15	1,977
Lime, sandy, hard, dark	3	1,980
Lime, sandy, dark	50	2,030
Shale, dark	6	2,036
Shale, dark, and shells	4	2,040
Shale, dark	8	2,048
Shale, dark, and shells	8	2,056
Shale, dark	7	2,063
Shale, dark, and shells	7	2,070
Shale, dark	365	2,435
Lime shell, light	18	2,453
Shale, dark	2	2,455
Lime, light	10	2,465
Shale, dark-brown	460	2,925
Frontier formation:		
Sand, dark	48	2,973
Sand, gray	92	3,065
Sand, broken, dark	6	3,071
Sand, gray	34	3,105
Shale, dark	5	3,110
Shale, sandy, dark	14	3,124
Shale, dark	20	3,144
Sand, gray	106	3,250
Shale, blue	12	3,262
Bentonite	3	3,265
Shale, blue	7	3,272
Shale, dark	10	3,282
Shale, sandy, dark	60	3,342
Cretaceous system—Continued		
Frontier formation—Con.		
Shale, light-gray	15	3,357
Bentonite	6	3,363
Shale, dark	15	3,378
Shale, sandy, dark	40	3,418
Shale, dark	36	3,454
Shale, sandy, dark	26	3,480
Shale, dark	60	3,540
Lime shell	6	3,546
Shale, dark	41	3,587
Shale, dark, and shells	36	3,623
Shale, black	37	3,660
Mowry shale:		
Shale, dark	18	3,678
Shale, limey, hard, dark	16	3,694
Shale, hard, dark	45	3,739
Shale, black	20	3,759
Shale, hard, dark	61	3,820
Shale, dark	13	3,833
Shale, hard, dark, and shells	12	3,845
Thermopolis shale:		
Sand, dark	11	3,856
Shale, dark	6	3,862
Sand, brown	18	3,880
Shale, black	26	3,906
Shell, hard (gas)	2	3,908
Shale, black	4	3,912
Shell, hard	3	3,915
Shale, black	2	3,917
Sand, gray	1	3,918
Shale, black	10	3,928
Shale, dark	2	3,930
Shell	3	3,933
Cloverly formation: Sand, gray	2	3,935

19–88–34da.—*Driller's log of well*

	Thickness (feet)	Depth (feet)
Cretaceous system:		
Niobrara formation:		
Surface soil	15	15
Shale, brown; sulphur water at 235 feet	220	235
Shale, brown	120	355
Sand, hard, dark, dry	10	365
Shale, brown	10	375
Frontier formation:		
Shale, gray, shelly, contains gas	75	450
Shale, sticky, blue	55	505
Lime shell, hard	4	509
Shale, brown	91	600
Sand	45	645
Sandstone, light-colored	15	660
Sandstone, coarse, gray	30	690
Sandstone, coarse, dark-gray	20	710
Sandstone, hard, dark	20	730
Talc and limestone shell	5	735
Lime, white, and talc	5	740
Sandstone, very dark	15	755
Shale, dark	20	775
Sandstone, soft, gray	20	795
Shale, black	30	825
Mowry shale:		
Shale, dark-brown	225	1,050
Bentonite, white	5	1,055
Cretaceous system—Continued		
Mowry shale—Continued		
Shale, sandy, hard, dark	45	1,100
Bentonite	5	1,105
Shale, very dark, rubbery	23	1,128
Thermopolis shale:		
Sand, hard, dark-gray; 275 feet water in hole	2	1,130
Sand, light-gray; gas blew water out of hole	6	1,136
Shale, hard, black	140	1,276
Cloverly formation:		
Shale and thin sandstone	74	1,350
Sand, very cavey and muddy	36	1,386
Jurassic system:		
Morrison(?) formation:		
Shale, black	114	1,500
Shell, hard	5	1,505
Shale, black	120	1,625
Shale, sandy, black	50	1,675
Shale, dark	75	1,750
Sundance formation:		
Sandstone, water-bearing	20	1,770
Shale, sandy; hole full of water and caving	65	1,835
Shale, dark, and thin sandstone; more water	40	1,875
Shale, green	15	1,890

21–87–5aac.—*Sample log of test hole.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Tertiary system:			Mississippian system:		
Pliocene and Miocene rocks (undifferentiated):			Madison limestone:		
Gravel, medium- to coarse-grained, quartzite, sandstone, and lime-cemented sand; contains some coarse sand to very fine gravel; sandstone is in part iron stained	20	20	Quartzite, sandstone, and limestone, angular and fragmental; weathered Paleozoic rocks	10	63
Sand, medium-grained to very coarse, quartz, subrounded, clear, frosted, and rose; sand particles are in part in a matrix of brown calcareous sandy silt	2	22	Chert, sandstone, quartzite, and limestone, angular, fragmental	7	70
Sand and gravel, medium-grained sand to coarse gravel, quartz, quartzite, and sandstone (larger gravel may be lag from above) lower part contains igneous fragments	11	33	Quartzite, angular, fragmental, pink	1	71
Sand and gravel, coarse sand to fine gravel, quartz, quartzite, sandstone, and igneous fragments; fragments are angular	20	53	Sandstone, lime-cemented and silica-cemented; contains chert fragments	3	74
			Chert, limestone, and sandstone, angular; contains some subrounded quartz grains	11	85
			Chert, limestone, and sandstone, angular; contains igneous fragments	10	95
			Sandstone and quartzite; contains some cherty limestone fragments, most particles are angular	5	100
			Limestone, cherty, gray-white to gray; contains some sandstone fragments; some particles contain pyrite	13.5	113.5

21–87–16bad.—*Sample log of test hole*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Tertiary system:			Tertiary system—Continued		
Pliocene and Miocene rocks (undifferentiated):			Pliocene and Miocene rocks (undifferentiated)—Con.		
Sand, fine- to medium-grained, quartz, subangular to subrounded; contains some feldspar and chlorite, quartz is clean to frosted	10	10	tuffaceous material and some slightly calcareous material with small amounts of limonite	10	60
Sand, fine to very fine, quartz, subrounded; contains tuffaceous material	10	20	Sand, fine- to medium-grained, quartz, clear, and frosted; contains calcareous material. Sand is subrounded and lime and tuff cemented	15	75
Sand, fine, quartz, clear, frosted, with some rose quartz; contains some limonite and tuffaceous material	10	30	Sand, medium-grained, quartz, clear, frosted, and rose; contains some calcium carbonate, sand particles are slightly cemented; from 85 feet to 105 feet calcareous material increases and sand grains are slightly smaller	30	105
Sand, fine to very fine, quartz, clear, frosted, and rose; contains more iron stain than above sample, and some calcareous material	5	35	Sand, medium-grained to coarse, quartz, clear, frosted, and rose; contains some quartzite fragments, biotite, and materials derived from Cretaceous deposits	23	128
Sand, fine- to medium-grained, quartz, clear, frosted, and rose; contains more calcareous material which cements the quartz particles	10	45	Sand and sandstone, coarse, quartz, clear, frosted, and rose; contains calcium carbonate material. Rose quartz constitutes the sandstone and causes reddish-brown coloring	1	129
Sand, fine- to medium-grained, quartz, clear, frosted, and rose; contains less calcareous material, and some chlorite and fluorite	5	50			
Sand, fine- to medium-grained, quartz, clear, and frosted; contains					

21–87–16bad.—*Sample log of test hole*—Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Tertiary system—Continued			Tertiary system—Continued		
Pliocene and Miocene rocks (undifferentiated)—Con.			Pliocene and Miocene rocks (undifferentiated)—Con.		
Sand, medium- to coarse-grained, quartz, subrounded, clear, frosted, and rose; contains some sandstone fragments and some calcareous material and fragments of muscovite and biotite	10	139	ments; grains are subangular to subrounded	4	159
Sand, coarse to very coarse, quartz, subrounded, clear, frosted, and rose; contains fragments of sandstone and quartzite	16	155	Silt and clay, pinkish-brown; contains angular quartzite fragments and imbedded subrounded quartz sand; silt and clay is very calcareous	1	160
Sand, medium- to coarse-grained, quartz, predominantly frosted and clear; contains some sandstone, limestone, and claystone frag-			Sand and gravel, quartz, shale, quartzite, sandstone, and limestone, very coarse sand to very fine gravel, fragments are angular and chipped	10	170
			Sand and gravel, quartz, chert, limestone, and quartzite, very angular, some fragments are subrounded	15	185

21–87–17ac.—*Driller's log of well at the State Penitentiary at Rawlins, Wyo.*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Tertiary system:			Cambrian system—Continued		
Pliocene and Miocene rocks (undifferentiated):			Cambrian deposits (undifferentiated)—Con.		
Sand and boulders, broken, cavey	160	160	Boulders, very mean formation	18	275
Cambrian system:			Cap rock [1]	10	285
Cambrian deposits (undifferentiated):			Sand, very fine, red	13	298
Limestone, solid, marblized	80	240	Limestone cap rock, very hard	14	312
Limestone, broken, marblized, quite cavey	17	257	Sand, coarse, white	16	328
			Boulders and sand	14	342

[1] Probably refers to hard cemented material.

21–87–19bca.—*Sample log of test hole*

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Tertiary system:			Tertiary system—Continued		
Pliocene and Miocene rocks (undifferentiated):			Pliocene and Miocene rocks (undifferentiated)—Con.		
Sand and gravel; contains reworked surface deposits; ranges in color from brown and yellow to green	55	55	cemented and conglomeratic	7	201
Sandstone, very fine to fine, well sorted, subangular, quartz; contains pink, green, and brown grains; has alternating beds of consolidated and unconsolidated material	131	186	Sandstone, fine to coarse, well-sorted, subangular, quartz; contains pink, green, and brown grains; has alternating beds of consolidated and unconsolidated material	38	239
Sand, sandstone, and gravel, white to gray-green; composed of angular fragments of quartzite and feldspar, and well-rounded quartz; contains some pyrite and chlorite fragments	8	194	Sand and conglomerate, white to gray-green; composed of angular fragments of sandstone, quartzite and feldspar, and well-rounded quartz; contains some pyrite and chlorite fragments	7	246
Sand and gravel, angular to subangular, quartz and feldspar; in part			Conglomerate, granitic; contains rounded quartz, some feldspar, and fragments of limestone	3	249

21–87–19dbb.—*Sample log of test hole*

	Thickness (feet)	Depth (feet)
Tertiary system:		
Pliocene and Miocene rocks (undifferentiated):		
Soil and surface deposits	3	3
Gravel, fine to very fine, and coarse to very coarse sand, quartz, feldspar and sandstone	1	4
Sand, coarse to very coarse, subangular to well rounded, quartz and feldspar; contains buff to tan silt, lower part contains material caved from above	22	26
Sand, fine to medium-grained, well-sorted, semirounded to rounded, quartz; contains thin lenses of silt, some feldspar, and pyrite	73	99
Sand, fine to medium-grained as above; contains some gypsum	111	210
Conglomerate, pebbles, cobbles, and boulders; composed of quartzite, sandstone, fluorite, chlorite, quartz, limestone, feldspar; contains some pyrite	85	295

21–88–24bb.—*Driller's log of oil well test*

	Thickness (feet)	Depth (feet)
Tertiary system:		
Pliocene and Miocene rocks (undifferentiated):		
Surface wash	50	50
Cambrian system:		
Shale, sandy, green, and sand	270	320
Shale, sandy	320	640
Sandstone, fine, soft, gray	10	650
Granite wash and sand	10	660
Sand, lime, cement, and some pyrite and feldspar	40	700
Precambrian rocks:		
Granite wash, boulders; cored 40 ft	30	730
Granite wash and sand, hard and compact	100	830
Granite, weathered, hard and compact	20	850

22–87–30abb.—*Driller's log of test hole*

	Thickness (feet)	Depth (feet)
Tertiary system:		
Pliocene and Miocene rocks (undifferentiated):		
Soil	4	4
Clay, sandy	14	18
Silt, sandy, gray	14	32
Sand, clayey, soft; contains tan to gray silt	9	41
Mississippian system:		
Madison limestone:		
Limestone and sandstone, gray; alternating hard and soft beds	65	106

MEASURED STRATIGRAPHIC SECTIONS

Stratigraphic sections are adapted from those measured in the field by J. A. Barlow in 1952 and G. L. Del Mauro in 1953 (p. 7). The sections are arranged in order of stratigraphic position from youngest to oldest.

Pleistocene deposits in sec. 15, T. 22 N., R. 87 W.

[Measured by J. A. Barlow]

	Feet
Conglomerate; pebbles, cobbles, and boulders derived from Tertiary conglomerates and Mesozoic sandstones and shales in a matrix of very calcareous, silty, fine-grained sandstone; boulders as much as 2 ft in diameter; some lenses and thin layers of gray sandstone	3

Pliocene and Miocene rocks in sec. 25, T. 21 N., R. 87 W.

[Measured by J. A. Barlow]

	Feet
Sandstone, fine- to medium-grained, silty, tuffaceous, calcareous in part, very light gray; sand grains are well rounded and frosted, many are pink or black; festoon-type crossbedding; contains lenses of conglomerate composed of pebbles of chert and quartz and cobbles of Precambrian rock as much as 6 in. in diameter. Thickness estimated	500±
Limestone, dense, very light gray; contains well-rounded grains and pebbles of chert, quartz, feldspar, and Precambrian rocks; grades laterally and vertically to sandy limestone and calcareous sandstone; forms conspicuous white marker bed	4
Sandstone, fine- to coarse-grained, brown and gray; fine grains are angular, coarse are rounded; contains lenses of pebbles and beds of conglomerate	40
Conglomerate; composed of pebbles, cobbles and boulders, as much as 20 ft in diameter, of Precambrian, Paleozoic, and Mesozoic rocks in a matrix of yellow-brown, tuffaceous, calcareous, fine- to coarse-grained sandstone	80±
Total thickness	624±

Browns Park formation; upper part in N½ sec. 14, T. 17 N., R. 88 W., and lower part in SE¼ sec. 16, T. 18 N., R. 89 W.

[Measured by G. L. Del Mauro]

	Feet
Upper part:	
Sandstone, fine- to medium-grained, white to light-gray; most beds slightly calcareous, some siliceous and tuffaceous; contains fragments of dark-gray shale throughout; near base contains lenses, about 2 in thick, of quartzitic conglomerate consisting of pebbles of chert, hematite, volcanic ash, feldspar, clear to frosted quartz, and soft calcareous material; unit forms conspicuous buttes and plateaus	290
Covered interval; float of weathered flat fragments of buff to iron-stained calcareous and siliceous sandstone	36
Sandstone, fine-grained, limy, gray; sand grains subrounded and mostly clear quartz; dark minerals constitute less than 5 percent of unit; calcite veins and stringers common	4.5
Sandstone, fine- to medium-grained, gray and gray-brown; sand grains subrounded and mostly clear to frosted quartz; some grains of rose quartz; dark minerals constitute less than 5 percent of unit; gray matrix is calcareous and brown matrix is siliceous; red and green banded where weathered	24.5
Sandstone, medium- to coarse-grained, siliceous, gray; sand grains are quartz, subrounded and mostly frosted; scattered grains of rose quartz; contains irregular pebbles of light-gray tuffaceous fine-grained sandstone	7
Sandstone, fine- to medium-grained, siliceous, poorly cemented, gray; sand grains are quartz, clear to frosted; interbedded in lower part with lenses of light-gray, tuffaceous, fine-grained sandstone containing pebbles of ash	8.5
Sandstone, fine-grained, tuffaceous, light-gray, finely crossbedded; sand grains are quartz, subangular to subrounded and clear to frosted; shards are clear to opaque; banded owing to alined grains of biotite, phlogopite, and muscovite	12

Browns Park formation; upper part in N½ sec. 14, T. 17 N., R. 88 W., and lower part in SE¼ sec. 16, T. 18 N., R. 89 W.—Continued

	Feet
Sandstone, fine- to medium-grained, siliceous, light-gray; contains some dark minerals; breaks readily into thin layers; brown and iron stained where weathered	3.5
Sandstone, medium-grained, slightly calcareous, light-gray, thin-bedded	18.5
Sandstone, fine- to medium-grained, calcareous; "salt and pepper" appearance; contains minute stringers of calcite; massively bedded	23
Lower part:	
Sandstone, medium-grained, white; buff where weathered	6
Sandstone, medium-grained, buff to light-gray; rusty colored where weathered	5
Sandstone, medium- to coarse-grained, buff to light-gray, massively bedded; quartz, subrounded and frosted sand grains; interbedded with layers of light-gray, bentonitic clay	27.5
Sandstone, medium-grained, light-gray; variegated red, light green, and buff where weathered	1.5
Sandstone, fine- to medium-grained, light-gray; many streaks of limonite	6
Sandstone, fine-grained, very calcareous, poorly cemented, buff; sand grains are quartz, subrounded to rounded, clear to frosted; a few beds contain grains of biotite and other dark minerals; buff yellow where weathered; interbedded with layers of light-gray bentonitic clay	15
Total thickness	498.5

Basal conglomerate of Browns Park formation in roadcut in SE¼ sec. 16, T. 18 N., R. 89 W.

[Measured by G. L. Del Mauro]

Conglomerate, pebbles in a matrix of gray to buff volcanic ash; pebbles are dark-colored chert, crystalline quartz, quartzite, and diabase; interbedded with thin lenses of buff volcanic ash; conspicuous channeling	1.5
Sandstone, fine-grained, gray to buff, crossbedded; interbedded with thin lenses of pebbly conglomerate; pebbles are subangular to subrounded	2
Conglomerate; quartz pebbles in a matrix of volcanic ash; subrounded and clear to frosted	1
Conglomerate; pebbles in a matrix of volcanic ash or calcareous material; most pebbles are black; interbedded with thin layers of gray to buff, fine-grained sandstone	13.5
Conglomerate; pebbles in a matrix of buff sandstone; pebbles are quartz and quartzite	4
Conglomerate; pebbles in a matrix of conspicuously variegated sandstone; most pebbles are dark quartz or quartzite; some white quartz pebbles subangular	41.5
Conglomerate; subangular to subrounded pebbles, cobbles, and boulders of dark-colored quartz, quartzite, and diabase in a matrix of calcareous or siliceous sand; scattered pebble-size fragments of chlorite; interbedded with lenses of buff fine-grained sandstone	71
Total thickness	134.5

Fort Union formation in sec. 11, T. 24 N., R. 89 W.

[Measured by J. A. Barlow]

	Feet
Mostly covered; exposed rocks are similar to those in underlying unit	400
Shale, carbonaceous and lignitic, dark-gray; interbedded with seven, evenly spaced, beds of light-gray and brown, fine- to coarse-grained sandstone; coal bed 20 ft thick at base of unit	874
Shale, mostly carbonaceous, interbedded with several thin beds of light-gray sandstone	787
Sandstone, fine- to coarse-grained, very light gray, crossbedded and lenticular; some sand grains angular, others well rounded; lower part contains lenses of conglomerate which differ in thickness and in resistance to weathering	222
Shale, carbonaceous, dark-gray; interbedded with a few layers of lignite and of hard dark-gray carbonaceous siltstone	93
Conglomerate, crossbedded and lenticular, composed of pebbles and small cobbles in a matrix of light-gray and brown medium-grained to very coarse grained sandstone; pebbles are black, red, and gray chert and pink and white quartzite and are well rounded	50
Total thickness	2,426

Lance formation in sec. 12, T. 21 N., R. 89 W.

[Measured by J. A. Barlow]

Mostly covered. Exposed rocks are fissile, dark-gray and light-brown, carbonaceous, sandy shale; fossiliferous bed 250 ft below top of unit	1,344
Shale, interbedded with sandstone; upper part fossiliferous	504
Sandstone, fine-grained, concretionary, light-brown, fossiliferous	3
Shale, sandy, carbonaceous and lignitic, interbedded with brown fine-grained sandstone; shale predominant in upper part of unit, sandstone in lower part	1,548
Sandstone, fine-grained, light-brown, interbedded with dark-gray to light-brown carbonaceous shale containing several thin beds of lignite	167
Sandstone, fine-grained, concretionary, brown	12
Shale, sandy, carbonaceous and lignitic, light-brown to dark-gray; bed of coal, 10 ft thick, 15 ft below top of unit	85
Sandstone, fine-grained, concretionary, light-brown	3
Shale, sandy, carbonaceous and lignitic, light-brown to dark-gray; contains many large brown sandstone concretions; bed of coal 31 ft below top of unit	59
Sandstone, fine-grained, gray-brown; contains many brown calcareous fine-grained sandstone concretions 2 in. in diameter	20
Shale, sandy, carbonaceous and lignitic, dark-gray to light-brown; zone of brown sandstone concretions at top of unit; coal bed, 5 ft thick, 71 ft below top of unit	86
Sandstone, fine-grained, silty, calcareous, light-brown; contains large concretionary masses	10
Shale, sandy, carbonaceous and lignitic, interbedded with large lenticular masses of brown, calcareous, fine-grained sandstone; fossiliferous in upper part; bed of coal, 7 ft thick, 25 ft below top of unit	178
Sandstone, fine-grained, light-brown; many brown sandstone concretions, 1–2 in. in diameter along bedding planes	37

Lance formation in sec. 12, T. 21 N., R. 89 W.—Continued

	Feet
Shale, sandy, carbonaceous, dark-gray	43
Shale, sandy in part, gray; concretions of brown sandstone at top; contains a few thin lenses of brown sandstone	31
Shale, dark-gray; sandy near top; contains a few thin beds of light-gray and brown sandstone	341
Sandstone, very fine grained, light-gray; contains grains of black calcareous material; interbedded with dark-gray to light-brown sandy shale	70
Total thickness	4,541

Lewis shale in sec. 7, T. 21 N., R. 88 W.

[Measured by J. A. Barlow]

Shale, sandy, buff; grading downward into fissile dark-gray shale; concretions of brown sandstone at top of unit	284
Bentonite, very light gray	2
Shale, dark-gray, fissile	150
Shale, buff; interbedded with three beds, each 4 in. thick, of gray, very calcareous, sandy siltstone; siltstone brown where weathered	20
Shale, sandy, light-gray; grading downward to fissile dark-gray shale	245
Shale, sandy, carbonaceous, light- to dark-gray; concretionary masses of soft, brown, sandy siltstone near top of unit	100
Shale, sandy, carbonaceous, light- to dark-gray, containing lenses of thin-bedded, light-brown to gray, calcareous, silty, fine-grained sandstone; concretions of brown sandstone in top part of unit	92
Mostly covered; exposed rock is dark-gray shale enclosing concretionary masses of brown siltstone	1,013
Total thickness	1,906

Mesaverde formation in sec. 6, T. 21 N., R. 88 W.

[Measured by J. A. Barlow]

Sandstone, fine-grained, silty, light-gray; contains round, hard concretions of fossiliferous sandstone; orange-brown hard medium-grained sandstone at top of unit	7
Shale, carbonaceous, dark-gray; contains thin lenses of sandstone	10
Sandstone, medium-grained, very calcareous, gray to brown; scattered black and pink grains of sand; interbedded with a few thin layers of gray sandy shale; top part of unit is fossiliferous	13
Sandstone, very fine grained, silty, calcareous, light-gray to brown; orange, brown, and light gray where weathered	5
Shale, sandy, gray	25
Sandstone, very fine grained, silty, calcareous, light-gray to brown, evenly bedded; orange, brown, and light gray where weathered	10
Shale, carbonaceous, dark-gray; interbedded with a few layers of light-gray sandy shale	50
Sandstone, very fine grained, calcareous, gray, thinly bedded; orange and brown where weathered	5

Mesaverde formation in sec. 6, T. 21 N., R. 88 W.—Continued

	Feet
Shale, carbonaceous, dark-gray; interbedded with a few layers of sandy shale	85
Siltstone, sandy, calcareous, dark-gray to brown, hard, thinly bedded; contains carbonaceous material; orange and brown where weathered	5
Shale, carbonaceous and lignitic, dark-gray	62
Sandstone, very fine grained, slightly calcareous, light-gray, hard	3
Covered. Mantling material is sandy	90
Sandstone, very fine to fine-grained, slightly calcareous, light-gray to brown-gray; interbedded with a few layers of carbonaceous shale and brown, slightly calcareous, sandy siltstone	110
Shale, light-brown, fissile; interbedded with a few thin layers of light-gray and light-brown sandy siltstone	45
Sandstone, very fine grained, very light gray; some grains are black	3
Shale, carbonaceous, brown; purple-gray where weathered	35
Sandstone, fine-grained, brown; some grains are black	2
Shale, carbonaceous and lignitic, very dark gray; interbedded with a few thin lenses of light-gray fine-grained sandstone; purple gray where weathered	35
Sandstone, very fine to fine-grained, light-gray to brown; contains scattered black grains, interbedded with soft sandy shale; fossiliferous bed 80 ft above base of unit	120
Mostly covered. Exposed rocks are very dark gray, lignitic and carbonaceous, calcareous sandstone and light-gray sandy shale; also a few lenticular masses of fine-grained sandstone as much as 50 ft long and 10 ft thick; forms valley along the strike of the unit	1,083
Sandstone, very fine to fine-grained, light-brown; scattered black and pink grains; forms large lenticular masses	40
Sandstone, fine-grained, light-gray to brownish-gray; scattered black and pink grains; calcareous in part; interbedded with a few layers of gray sandy shale and dark-gray carbonaceous shale	60
Covered. Sandy mantling material	120
Shale, carbonaceous, dark-gray; interbedded with layers of brown fine-grained silty sandstone and lignitic shale	30
Sandstone, very fine grained, slightly calcareous, light-gray, soft; contains flakes of mica	5
Mostly covered. Exposed rocks at top and bottom of interval are sandy shale	40
Sandstone, fine-grained, calcareous, gray to light-brown, hard, thinly and irregularly bedded; scattered black and pink grains	10
Mostly covered. Exposed rocks are concretionary masses of calcareous, fine-grained sandstone	188
Sandstone, fine-grained, calcareous, gray to grayish-brown; scattered black and pink grains; pinches out along strike	15
Covered	35
Shale, calcareous in part, drab-gray to dark-gray, fissile	75
Sandstone, fine-grained, gray-brown, lenticular; calcareous in part	15
Covered	20
Sandstone, fine-grained, calcareous, grayish-brown; scattered black and pink grains	10

Mesaverde formation in sec. 6, T. 21 N., R. 88 W.—Continued

	Feet
Covered	43
Sandstone, fine-grained, gray to brown; calcareous in part; interbedded with gray sandy shale and dark-gray carbonaceous shale	45
Shale, gray, fissile; interbedded with a few layers of carbonaceous shale and fine-grained sandstone	25
Sandstone, fine-grained, grayish-brown, irregularly bedded; contains veins of limonite pseudomorphs after pyrite	25
Shale, carbonaceous, dark-gray	10
Sandstone, very fine to fine-grained, light-gray, irregularly bedded; scattered black and pink grains	30
Total thickness	2,644

Steele shale and Niobrara formation in sec. 5, T. 21 N., R. 88 W.

[Measured by J. A. Barlow]

	Feet
Shale, calcareous, dark-gray; sandy in part; contacts with overlying and underlying units are gradational	360
Sandstone, fine- to medium-grained, glauconitic, gray to gray-green; silty in part; scattered black and pink grains; glauconite content as much as 50 percent; differs, along strike, in resistance to weathering	100
Shale, calcareous, dark-gray; sandy in part; contacts with overlying and underlying units are gradational	630
Sandstone, fine-grained, glauconitic, gray to grayish-green; silty in part; scattered black and pink grains; glauconite content as much as 50 percent; contains a few thin beds of rusty siltstone; differs, along strike, in resistance to weathering	120
Shale, dark-gray; sandy in part, calcareous in part; contacts with overlying and underlying units are gradational	580
Sandstone, fine-grained, gray; silty in part, glauconitic in part; scattered black and pink grains; weathers readily	50
Shale, noncalcareous, dark-gray; contains many thin sandy zones	1,700
Shale, calcareous in part, dark-gray	240
Shale, calcareous, dark-gray; contains several beds of thinly laminated, buff to brown, calcareous siltstone; light brown where weathered	1,000
Shale, calcareous, very dark gray; contains several thin fossiliferous beds, each underlain by a ¼- to 2-in. bed of fibrous aragonite in which the crystals are normal to the bedding planes; fossil fish scales become bright blue when weathered; erodes to a conspicuous white ridge	11
Shale, calcareous, dark-gray	44
Shale, calcareous, dark-gray; contains concretions of very hard, dense, very dark gray limestone as much as 2 ft in diameter; concretions break into small, angular, light-gray fragments where weathered	59
Shale, calcareous, dark-gray, soft	85
Shale, calcareous, dark-gray; concretions of hard, dense, dark-gray limestone in upper 10 ft of unit; fractures in concretions filled with calcite	28
Shale, calcareous, dark-gray; contains concretions of dark-gray very finely crystalline limestone as much as 8 ft in diameter	45
Total thickness	5,052

Frontier formation, upper part in sec. 15, T. 22 N., R. 87 W., and lower part in secs. 11 and 12, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

	Feet
Upper part:	
Sandstone, fine- to coarse-grained, gray, "salt and pepper;" silty in part, carbonaceous in part, poorly bedded and in part cross laminated; unit consists of six beds of resistant nonsilty sandstone separated by less resistant silty sandstone; top part of unit contains lenses of conglomerate consisting of well-rounded pebbles of black chert and white and green quartzite as much as ½ in. in diameter in a matrix of silty course-grained sand	121
Shale, sandy, dark-gray; contains stringers of gray "salt and pepper" sandstone	94
Sandstone, fine- to medium-grained, clayey, slightly glauconitic, light- to dark-gray, "salt and pepper," poorly bedded; in part cross laminated; sand grains are subangular; interbedded with beds of dark-gray silty shale; middle 30 ft of unit is dark-gray sandy shale that grades upward and downward into sandstone; unit forms high hogback	93
Lower part:	
Mostly covered. Exposed rock is dark-gray shale	88
Shale, silty, dark-gray; contains fossiliferous lenses and concretions of brown sandstone	29
Shale, dark-gray	39
Bentonite	.5
Shale, dark-gray	3
Bentonite	.5
Shale, dark-gray	20
Sandstone, fine-grained, brown, "salt and pepper," irregularly bedded	1
Shale, sandy, dark-gray	11
Sandstone, medium- to fine-grained, clayey, gray, "salt and pepper," thinly bedded and cross-laminated; contain thin beds of silty sandstone that is less resistant to weathering	13
Shale, dark-gray	51
Bentonite	.5
Shale, dark-gray	23
Bentonite	.5
Shale, dark-gray	6
Bentonite	.5
Shale, dark-gray	8.5
Bentonite	.5
Total thickness	603.5

Mowry shale in sec. 10, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Shale, siliceous, dark-gray, hard; silver gray and brown stained where weathered	1
Shale, dark-gray	5
Sandstone, very fine grained, dark-gray, irregularly bedded; interbedded with dark-gray silty shale; rusty brown where weathered	1.5

Mowry shale in sec. 10, T. 23 N., R. 88 W.—Continued

	Feet
Shale, silty, gray to brown, grading downward to dark-gray shale	80
Bentonite	.5
Shale, very dark gray, fissile	33
Shale, very dark gray	27
Shale, siliceous, very dark gray; silver gray and brown stained where weathered	295
Shale, very dark gray, fissile	50
Total thickness	493

Thermopolis shale in sec. 29, T. 22 N., R. 88 W.

[Measured by J. A. Barlow]

Shale; sandy toward top, calcareous in part; very dark gray; beds are paper-thin; contains thin platy lenses of very calcareous sandstone; fossil fish scales become blue when exposed to weathering	90
Siltstone, sandy, brown, hard, irregularly bedded; calcareous in part; interbedded with layers of dark-colored shale	8
Shale, dark-gray; beds are paper-thin; grades downward into sandy shale	39
Total thickness	137

Cloverly formation in sec. 15, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Sandstone, fine-grained, gray to brown, hard; ripple-marked in part; beds range in thickness from 6 in to 4 ft; weathers to rusty-yellow-brown slabs and blocks	46
Covered	5
Sandstone, coarse-grained, gray to brown, cross-laminated; sand grains subrounded; contains lenses of conglomerate consisting of well-rounded pebbles of chert and quartzite	10
Covered. Probably soft sandstone and shale	19
Conglomerate; well-rounded pebbles of black and light-gray chert and white and pink quartzite in a matrix of coarse-grained sandstone; interbedded with finely laminated buff to brown medium- to coarse-grained sandstone; highly crossbedded; weathers to blocks	49
Total thickness	129

Morrison formation in sec. 15, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Covered	194
Sandstone, very fine grained, greenish-gray, massive	1
Shale, red and green, fissile	4
Sandstone, very fine grained, greenish-gray, massive	1
Shale, sandy, gray-green and red	6
Sandstone, fine-grained, calcareous, light-gray, irregularly bedded	6
Covered	13
Limestone, dense, gray; brown where weathered	1

Morrison formation in sec. 15, T. 23 N., R. 88 W.—Continued

	Feet
Covered	5
Sandstone, very fine grained, calcareous, greenish-gray, interbedded with soft gray-green shale	11
Covered	11
Total thickness	253

Sundance formation in sec. 15, T. 23 N., R. 88 W. and sec. 12, T. 21 N., R. 87 W.

[Measured by J. A. Barlow]

Limestone, brown, thickly bedded, very fossiliferous; contains bed of shale, 1 ft thick, in middle of unit	4
Shale, sandy, glauconitic, green, fossiliferous; interbedded with many very thin layers of green silty sandstone	20
Limestone, brown, thickly bedded, very fossiliferous; contains round concretions, 2–4 in. in diameter, of brown calcareous siltstone	1
Mostly covered. Exposed rocks are red and drab-green shale interbedded with thin layers of green glauconitic fine-grained sandstone and, at base of unit, crossbedded highly calcareous sandstone	189
Sandstone, fine-grained, slightly calcareous, light-gray, irregularly bedded; upper part black-stained where weathered	16
Mostly covered. Exposed rocks are thin beds of calcareous fine-grained sandstone interbedded with gray-green shale	22
Sandstone, fine-grained, calcareous, light-gray, irregularly bedded; beds about 3 in. thick	4
Covered	12
Sandstone, very fine grained, pink, gray-green, and white, crossbedded and ripple-marked; contains a few thin beds of pink sandy limestone	45
Shale, calcareous, red; contains green and red sandy siltstone at top of unit	6
Sandstone, very fine-grained, calcareous, red, thinly and irregularly bedded; top of unit is a 6-in. bed of white calcareous very fine grained sandstone	17
Shale; calcareous in part, red	6
Sandstone, very fine grained, calcareous, red, thinly bedded and ripple-marked; crossbedded in part; top of unit is a 2-in. bed of green siltstone	5
Sandstone, very fine grained, calcareous, red and gray-green, thinly bedded and crossbedded; top of unit is a 2-in. bed of green siltstone	22
Sandstone, very fine grained, calcareous, gray, hard, crossbedded and ripple-marked; weathers to thin brown slabs	1
Sandstone, calcareous, white and gray-green, soft	1
Shale, red, fissile	3
Sandstone, fine-grained, calcareous, white; contains some well-rounded and frosted coarse grains of pink and white quartz	1
Siltstone, calcareous, red, massive	3
Shale, calcareous, red and green, fissile	5
Sandstone, fine-grained, calcareous, white, irregularly bedded; contains many rounded and frosted coarse grains of quartz	1
Shale, silty, calcareous, red	1
Sandstone, medium-grained, pink, massive; contains many rounded and frosted coarse grains of pink quartz	1

Sundance formation in sec. 15, T. 23 N., R. 88 W. and sec. 12, T. 21 N., R. 87 W.—Continued

	Feet
Shale, silty, calcareous, red; contains many green particles	3
Sandstone, fine-grained, calcareous, red and white; interbedded with red calcareous shale; sandstone contains many rounded coarse grains of pink and white quartz; shale contains green particles	12
Sandstone, fine-grained, very calcareous, white and light-gray, crossbedded and ripple-marked	2
Sandstone, very fine grained, calcareous, gray-green; interbedded with a few thin layers of gray-green silty shale; sandstone contains many rounded and frosted coarse grains of white and gray quartz	4
Sandstone, fine- to coarse-grained, calcareous, buff, crossbedded and ripple-marked; sand grains are rounded and frosted; beds are 3 in. to 3 ft thick	40
Total thickness	447

Chugwater formation in sec. 16, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Shale, soft, pink; contains a few lenses of soft, red, very fine grained sandstone and, in upper part, fragments of dark-red and green clay; unit forms steep slope under cliff formed by basal part of the Sundance formation	239
Sandstone, medium-grained, calcareous in part, light-gray to buff; thinly bedded in upper part; some beds characterized by festoon-type crossbedding; orange and buff to light gray where weathered; some beds more resistant to erosion than others	51
Sandstone, fine-grained, calcareous, brick-red; crossbedded in part; contains rounded and frosted coarse grains of dark-gray and white quartz; some beds contain pebbles of red clay; interbedded with a few layers of red calcareous siltstone	73
Shale, calcareous, red, soft; interbedded with red calcareous fine-grained sandstone; sandstone contains many rounded and frosted coarse grains of orange quartz	10
Sandstone, fine-grained, buff, thickly bedded; contains rounded and frosted grains of quartz; orange and brown where weathered	2
Shale, red, soft; interbedded with a few layers of orange-red fine-grained sandstone	22
Limestone, dense, blue-gray, thinly bedded; weathers to thin slabs	15
Shale, sandy shale, siltstone, and sandstone; mostly brick-red; upper half of unit is about 50 percent sandstone and lower half is mostly siltstone	730
Total thickness	1,142

Permian rocks in sec. 21, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Limestone, dense, light-gray to purple-gray, thinly bedded; weathers to pink and purple-gray thin slabs	8.5
Shale, silty in part, red streaked with green	52
Siltstone, gray, thinly bedded	1
Shale, red, hard; contains green particles	32

Permian rocks in sec. 21, T. 23 N., R. 88 W.—Continued

	Feet
Limestone, crystalline, light-gray; interbedded with a few thin layers of shaly limestone; limestone beds are ½–3 in. thick	2
Shale, calcareous, green, splintery	4
Limestone, dense, gray, very thinly bedded	3
Shale, drab-green; weathers to a grayish-green soil	49
Limestone, dense, gray; interbedded with light-brown porous limestone and gray shaly limestone; numerous calcite geodes; contains some blue-gray chert	4
Shale, calcareous, light-gray	3.5
Limestone, crystalline, dark-gray; interbedded with shaly limestone; beds are 1–2 ft thick and shaly limestone beds are ⅛–2 in. thick; contains calcite geodes 4 in. in diameter; light brown where weathered	8
Shale, dark-green, interbedded with a few thin layers of dark-gray silty crystalline limestone	31
Limestone, dense, cherty, light-brown to light-gray, poorly bedded; beds are 1–6 in. thick; stringers of blue-gray chert constitute about 50 percent of the top half of unit; veins of calcite common; surface of the weathered rock is jagged, the chert stringers standing out in relief; light gray and pinkish gray where weathered	9
Shale, drab-gray-green and orange-brown; interbedded with thin layers of shaly limestone containing green particles oriented with bedding	6
Limestone, dense, gray; grayish brown where weathered	2
Shale, drab-gray-green	2
Limestone, dense, gray; contains veins of calcite and stringers and nodules of gray and pink chert; brown and gray where weathered	1
Shale, drab-gray-green	3.5
Sandstone, medium-grained, calcareous, light-gray; sand grains are well rounded	1
Shale, buff to drab-gray; sandy in part	10.5
Sandstone, medium-grained, calcareous, light-gray to dark-gray; contains rounded and frosted coarse grains of quartz and, in lower part, subrounded pebbles of dark-gray chert	1
Total thickness	234

Tensleep sandstone in secs. 20 and 29, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Sandstone, fine- to medium-grained, calcareous, buff; festoon-type crossbedding; weather to light-brown slabs 2–4 in. thick	268
Sandstone, fine-grained, highly calcareous, light-gray; festoon-type crossbedding; light gray where weathered	28
Sandstone, fine-grained, calcareous to very calcareous, buff; festoon-type crossbedding; weathers to light-brown slabs 2–4 in. thick	56
Mostly covered. Exposed rock is buff and light-gray calcareous sandstone and blue-gray dense limestone that weathers to a blue-gray pocky surface	208
Limestone, dense, gray; weathers to a blue-gray pocky surface	4
Sandstone, fine- to medium-grained, noncalcareous to very calcareous, buff and white; festoon-type crossbedding; buff sandstone weathers to brown slabs 2–4 in. thick; white sandstone weathers to white rounded surface	53

Tensleep sandstone in secs. 20 and 29, T. 23 N., R. 88 W.—Continued

	Feet
Limestone, dense, gray; crinoids common; weathers to blue-gray pocky surface	2
Sandstone, medium-grained, calcareous, buff; interbedded with a few layers of white limy very fine grained sandstone and dense gray limestone; gradational boundaries between beds; buff sandstone weathers to slabs 2–4 in. thick, limy sandstone to white rounded surface, and limestone to blue-gray smooth surface	45
Mostly covered. Exposed rock is buff calcareous medium-grained sandstone interbedded with white limy sandstone	73
Sandstone, very fine-grained, calcareous, light-gray; festoon-type crossbedding; very calcareous upper half weathers to rounded gray surface, and slightly to moderately calcareous lower half weathers to iron-stained brown slabs	34
Limestone, dense, gray; grading downward to buff limy fine-grained sandstone; limestone contains many fragments of crinoids and weathers to blue-gray pocky surface; sandstone is crossbedded and weathers to buff and brown slabs	12
Limestone, dense, gray; contains many fragments of crinoids; weathers to blue-gray pocky surface	9
Sandstone, very fine grained, calcareous, white; beds 4 in. to 1 ft thick; light gray where weathered	10
Mostly covered. Exposed rock is white crystalline limestone that is light gray where weathered	36
Total thickness	838

Amsden formation in sec. 33, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Shale, sandy, red; bed of conglomerate, 10 ft thick, about 70 ft above base of unit, composed of pebbles of yellow altered chert and of red siltstone in a matrix of red calcareous silty sandstone; a bed, 2 ft. to 5 ft thick, about 10 feet above base of unit of white feldspathic coarse-grained sandstone and conglomerate of pebbles of clear, smoky, and rose quartz in a matrix of calcareous fine-grained sandstone	154
Limestone, dense, gray; interbedded with calcareous sandy shale; limestone beds are 4–6 ft thick and contain much red chert	50
Sandstone, fine-grained, hard, red, orange, and brown; interbedded with soft medium-grained sandstone; lower 20–30 ft is a conglomerate composed of pebbles and boulders of limestone and hematite-stained pebbles of quartz in a matrix of sandstone; blocks of Madison limestone, 40–50 ft in size, occur above contact of Amsden and Madison	46
Total thickness	250

Madison limestone in sec. 33, T. 23 N., R. 88 W.

[Measured by J. A. Barlow]

Limestone, dense, dark-gray; interbedded with layers of white crystalline limestone 2–3 ft thick; contains many bands of dark-brown chert; weathers to gray pocky surface	35
Covered	8

Madison limestone in sec. 33, T. 23 N., R. 88 W.—Continued

	Feet
Limestone, dense, dark-gray; contains beds and nodules of brown and gray chert; weathers to gray pocky surface	4
Covered	14
Dolomite, crystalline, white; contains nodules of fractured chert; weathers to smooth gray surface	6
Covered	7
Dolomite, crystalline, white; contains chert; gray where weathered	9
Covered	7
Limestone, crystalline, gray; contains brown chert; weathers to gray pocky surface	3
Covered	14
Limestone, dense, blue-gray; contains some brown chert; weathers to gray pocky surface	9
Covered	14
Dolomite, dense, brown; weathers to smooth brown surface	5
Sandstone, light-gray, crossbedded; sand grains are angular and poorly sorted; cement is calcareous in part and siliceous in part; contains lenses of conglomerate composed of rounded pebbles of quartz in a matrix of fine-grained sand; basal conglomerate, 4 in. thick, contains fragments of Cambrian red shale as much as 3 in. long	7
Total thickness	142

Cambrian rocks in sec. 33, T. 23 N., R. 88 W., sec. 9, T. 22 N., R. 88 W., and sec. 8, T. 21 N., R. 87 W.

[Measured by J. A. Barlow]

Shale, sandy, red; interbedded with red siltstone and finely laminated gray-green and red-specked glauconitic and micaceous sandstone; shale and siltstone marked by fossil worm trails; sandstone characterized by worm borings filled with red shale; unit thins southward	8 to 106
Sandstone, medium-grained, friable to quartzitic, white to purple-red; sand grains are subrounded; white with some red staining where weathered	2
Sandstone, medium-grained, red to purple-gray, ripple-marked; well rounded sand grains; worm markings abundant	45
Sandstone, medium- to coarse-grained, hard, light-gray; siliceous cement; beds are 4 in. to 3 ft thick; purple gray where weathered; forms conspicuous cliff	29
Mostly covered. Exposed rock is similar to above unit. Probably composed mostly of beds that weather readily, the unit forming a low saddle between overlying and underlying cliff-forming rocks	190
Sandstone, hard, light-gray and pink-gray; crossbedded in part; alternating beds differ in grain size; resistant beds 1 ft to 4 ft thick, interbedded with less resistant beds 1 in. to 5 in. thick; contains a few lenses of quartz-pebble conglomerate; weathers to hard purple-gray blocks	143
Conglomerate, light-gray to pinkish-gray, consisting of well-rounded quartz pebbles as much as 1 in. in diameter and angular pebbles of feldspar in a matrix of fine-grained quartz sand; crossbedded; beds 1 ft to 4 ft thick; contains lenses of fine- to coarse-grained sandstone; sand grains angular; purple-gray where weathered; cliff forming	62

Cambrian rocks in sec. 33, T. 23 N., R. 88 W., sec. 9, T. 22 N., R. 88 W., and sec. 8, T. 21 N., R. 87 W.—Continued

	Feet
Conglomerate; similar to above unit but containing many more pebbles of feldspar; contact with Precambrian rocks sharply defined by zone of weathered rock 6 in. to 3 ft thick	10
Total thickness	489 to 587

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