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Groundwater flow, hydrochemistry, and uranium deposition in the Powder River Basin, Wyoming

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GROUNDWATER FLOW, HYDROCHEMISTRY, AND URANIUM DEPOSITION IN THE POWDER RIVER BASIN, WYOMING

by
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Bachelor of Science, Eastern Kentucky State University 1966
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A Dissertation

Submitted to the Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Grand Forks, North Dakota

August
1971

This Dissertation submitted by J. Ladd Hagmaier in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is herby approved by the Faculty Advisory Committee under whom the work has been done.

Lee Clayton
(Chairman)

Walter L Moore

Syed M Jalal

Frank Karner

A William Johnson
Dean of the Graduate School

Permission

Title GROUNDWATER FLOW, HYDROCHEMISTRY, AND URANIUM DEPOSITION IN THE POWDER RIVER BASIN, WYOMING

Department Geology

Degree Doctor of Philosophy

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Date July 9, 1971

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ABSTRACT

The relation between regional groundwater flow, hydrochemistry, and uranium distribution in the Powder River Basin indicates that uranium was deposited during the Tertiary Period in groundwater recharge areas where the groundwater changed from a sulfate-bicarbonate water to a bicarbonate-rich water.

The regional recharge and discharge areas of present-day groundwater-flow systems have about the same location as the recharge and discharge areas of the Tertiary groundwater-flow systems. The present-day groundwater is recharged in the eastern, western, and especially in the southern margins of the basin and is discharged in the valley of the Powder River, especially in the north. Flow nets for the groundwater were constructed on the basis of piezometric data from existing water wells in the Powder River Basin.

The Tertiary groundwater-flow systems had a larger longitudinal flow component than present-day groundwater-flow systems. The present-day topography causes a large lateral and vertical groundwater-flow component toward the large river valleys. The topography during the Tertiary was a result of deposition and had little relief, whereas, the present-day topography is a result of erosion and has large relief.

The groundwater chemistry of this area during the Tertiary was probably similar to that of today because the groundwater flowed

through the same sediment as present-day groundwater. Anions in the present-day groundwater undergo the following sequence of hydrochemical changes along the regional flow path from the southern recharge area to the northern discharge area:

$$HCO_3^- + SO_4^{--} \longrightarrow SO_4^{--} + HCO_3^- \longrightarrow HCO_3^-.$$

An abrupt decrease in sulfate concentration occurs where the sulfate is removed from solution in the transition zone between the $SO_4^{--} + HCO_3^-$ and HCO_3^- facies. The most likely cause of this decrease is a strong reducing environment, which may be caused by sulfate-reducing bacteria. Cations in the present-day groundwater undergo the following sequence of hydrochemical changes along a flow path from shallow to deep groundwater in recharge areas:

$$Ca^{++} + Na^+ \longrightarrow Na^+ + Ca^{++} \longrightarrow Na^+.$$

The decrease in calcium and increase in sodium with depth is caused by base exchange and the precipitation of calcite cement.

Major unoxidized uranium deposits in the Powder River Basin occur near the transition zone between the $SO_4^{--} + HCO_3^-$ and HCO_3^- facies. The uranium is transported in solution by groundwater in the $HCO_3^- + SO_4^{--}$ and the $SO_4^{--} + HCO_3^-$ facies and precipitated in the transition zone between the $SO_4^{--} + HCO_3^-$ and HCO_3^- facies. Precipitation occurs where strong reducing conditions exist around abundant organic material in which sulfate-reducing bacteria may live and multiply.

CHAPTER I

INTRODUCTION

There is general agreement among geologists working on uranium deposits in sedimentary basins that the uranium was transported and deposited by groundwater (Bailey, 1965; Grutt, 1957; Harshman, 1966, 1968; Hart, 1968; Langen and Kidwell, 1971; Love, 1952; Melin, 1964; Mrak, 1968). There are, however, few reports on the role of groundwater in uranium deposition that utilize recent developments in groundwater geology.

The objective of this report is to relate groundwater theory to the uranium geology of the Powder River Basin in Wyoming. First the sedimentary history of the basin is outlined (Chapter II) to provide the framework for reconstructing past groundwater-flow systems. Next the theory used to reconstruct past groundwater-flow systems and evaluate present-day groundwater-flow systems is presented (Chapter III). Then a model is presented to relate the past groundwater-flow systems to uranium transport and deposition in the basin (Chapter IV). This model is then evaluated by comparing it with the present-day groundwater-flow systems and hydrochemistry of the basin (Chapter V). Finally a unified theory on the origin of the uranium deposits in the Powder River Basin is given (Chapter VI).

The Powder River Basin is an ideal area in which to study the relation between groundwater and uranium deposition because the density of water wells is great enough to permit statistically valid results, an adequate amount of subsurface information is available, and a considerable amount of uranium exploration is now taking place in the basin.

Setting

The Powder River Basin is located in northeastern Wyoming and has an areal extent of approximately 12,000 square miles (Figure 1). The basin is structurally an asymmetrical syncline with the axis displaced west of the basin center. Generally the boundaries of the basin are defined by the Big Horn Mountains and Casper Arch on the west, by the Laramie Range and Hartville Uplift on the south, and by the Black Hills on the east. In the north the basin gradually terminates in Montana.

Topography

The topography of the Powder River Basin is important in this study because the establishment and maintenance of any groundwater-flow system is controlled by topography, which provides the difference in energy potential necessary to drive the system. The basin topography is gently rolling except where river valleys and isolated buttes such as the Pumpkin Buttes break the land surface (Figure 2). The Powder River is the main river in the study area. It heads in the Big Horn Mountains, flows northward into Montana and empties into the Yellowstone River. The Powder River is a braided, perennial, sand river and is described by local residents as a river that is "a mile wide, an inch deep, and flows uphill." The water is generally so muddy that it is

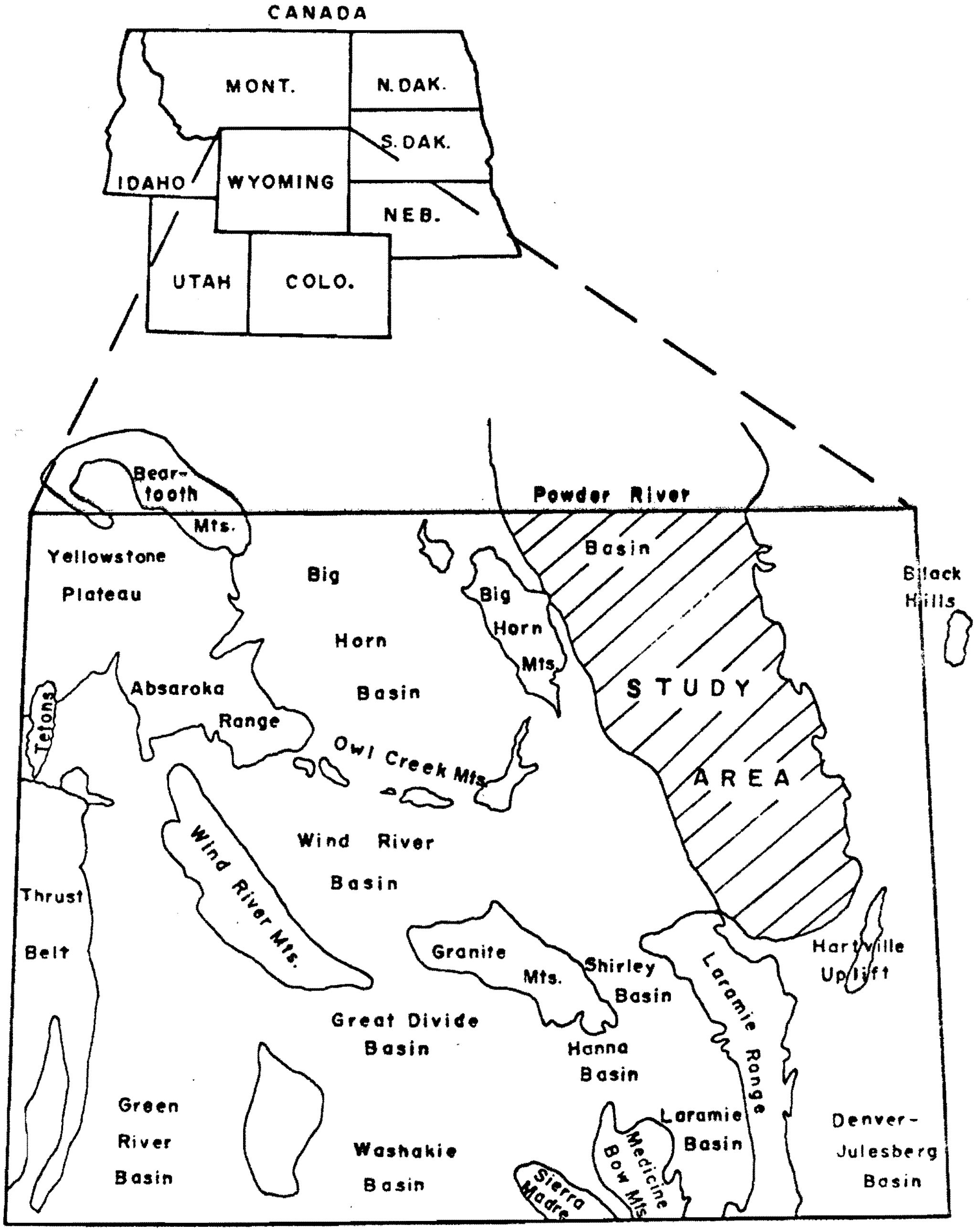


Fig. 1.--Map showing location of the study area in Wyoming.

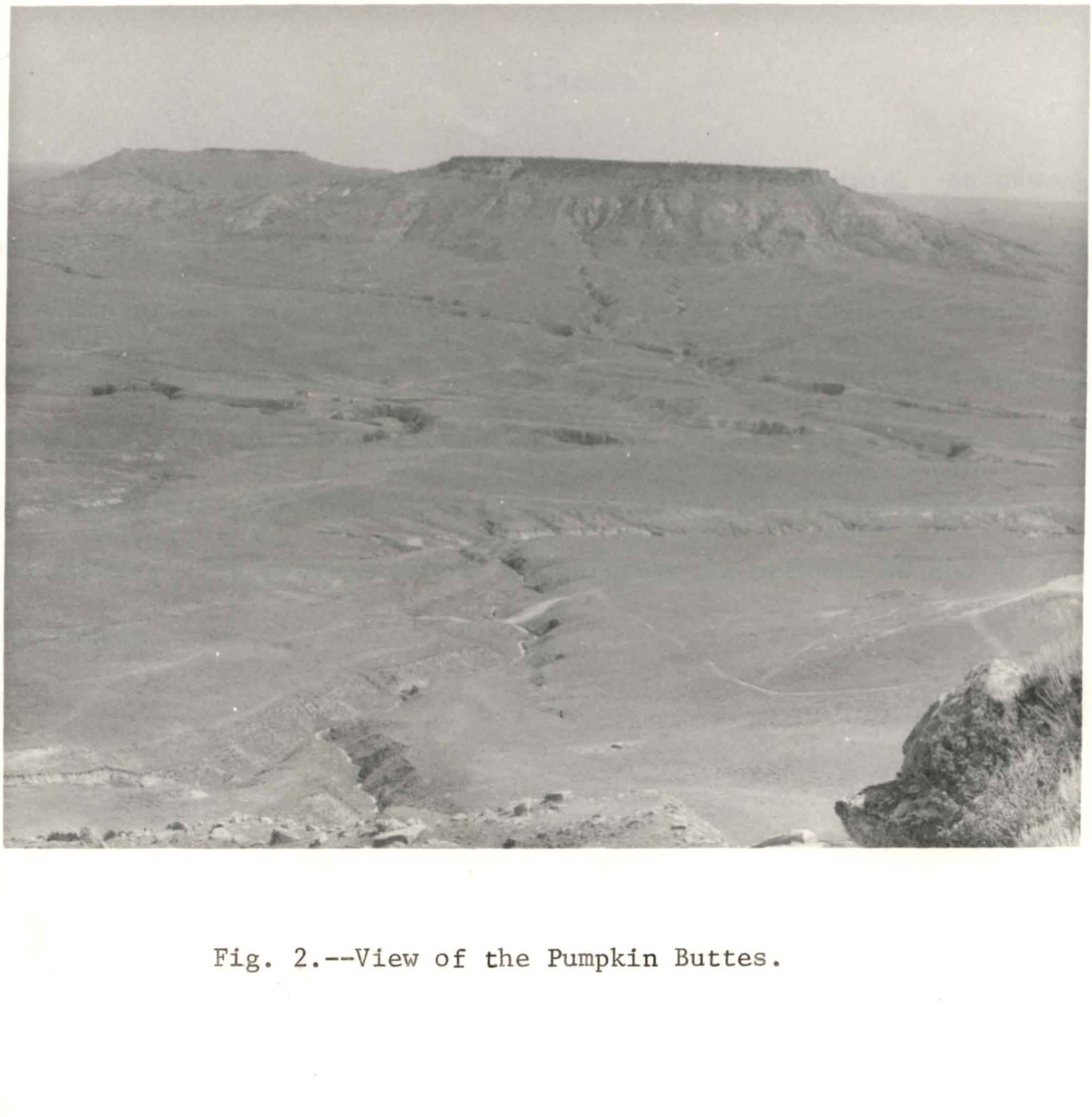


Fig. 2.--View of the Pumpkin Buttes.

described as "too thick to drink and too thin to plow." Along the Powder River rugged badlands have been eroded into the sides of the valley walls. These badlands are very similar to those described by Hagmaier (1970a) along the Little Missouri River in North Dakota. The badlands extend for several miles on either side of the river and produce the major topographic feature of the study area (Figure 3).

Climate

The climate in northeastern Wyoming is semiarid. An average annual precipitation of 14 to 15 inches occurs mostly as snow during the late winter and early spring and as short-duration thunder storms during the summer months. The mean potential evaporation is several times the mean annual precipitation. The temperature averages about 20 degress Fahrenheit in the winter and about 70 degrees Fahrenheit in the summer. The average annual temperature is between 40 and 50 degrees Fahrenheit.

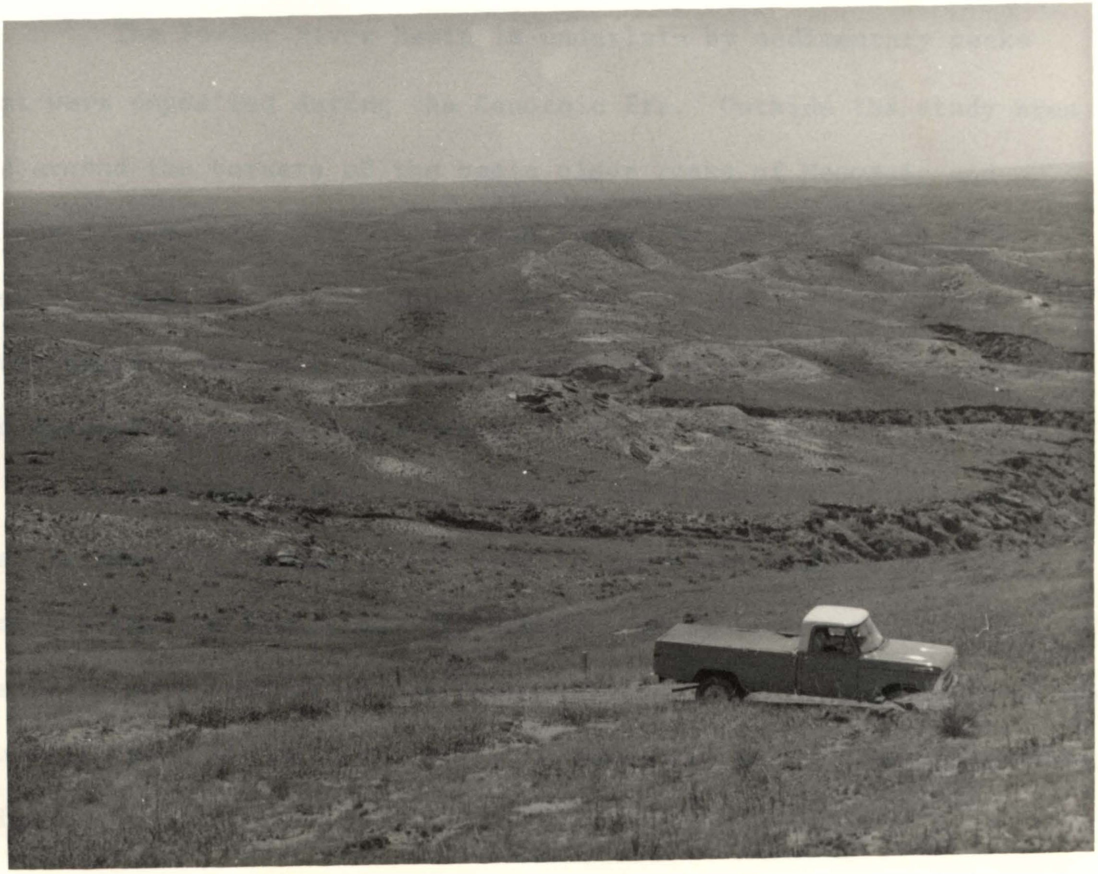


Fig. 3.--View of the badlands along the Powder River in Wyoming.

CHAPTER II

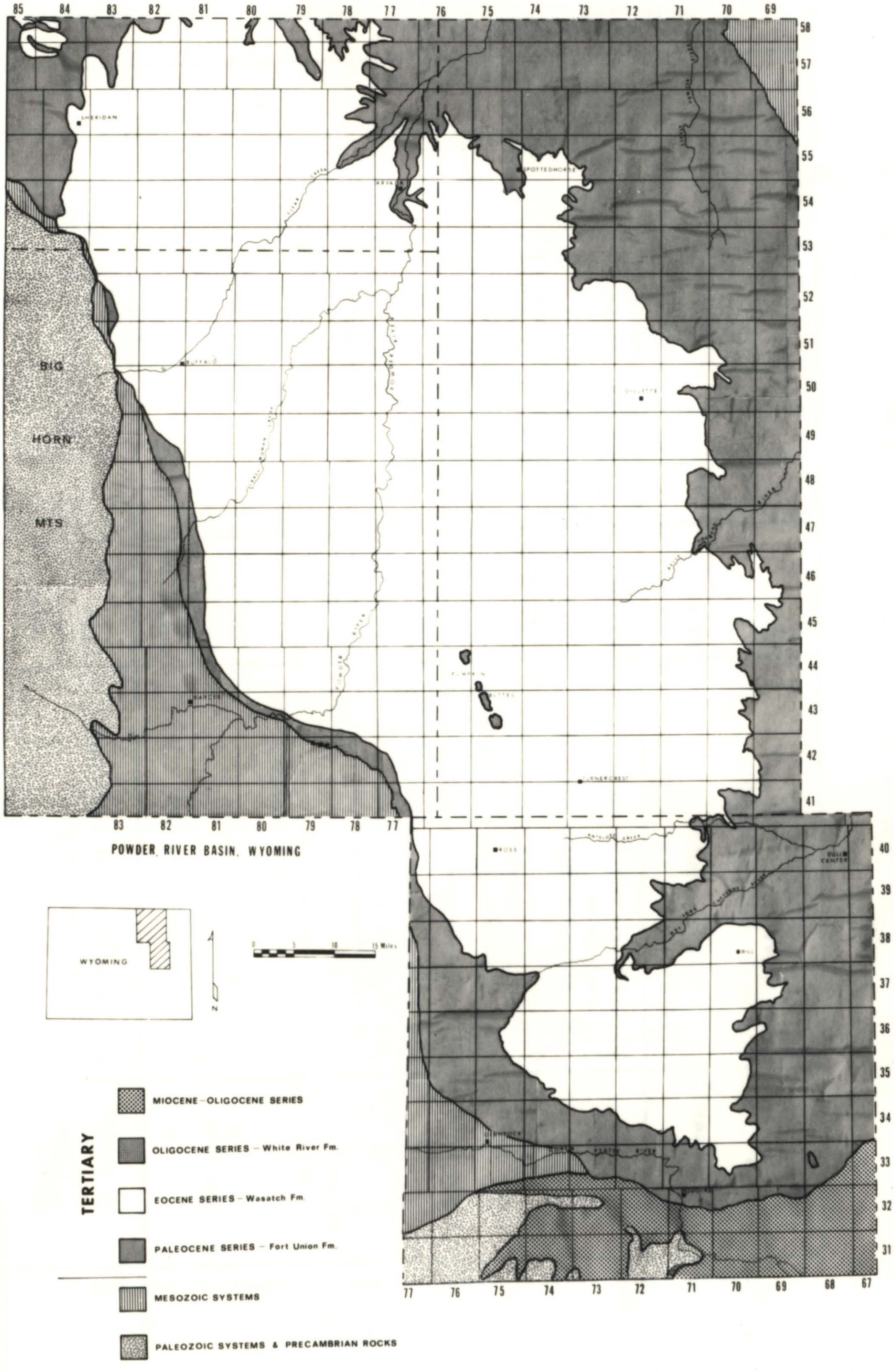
GEOLOGY

The Powder River Basin is underlain by sedimentary rocks that were deposited during the Cenozoic Era. Outside the study area and around the borders of the basin older rocks of Mesozoic and Paleozoic age outcrop. The Wasatch Formation, which is mostly Eocene in age, is exposed throughout most of the central Powder River Basin. The Fort Union Formation, of Paleocene age, underlies the Wasatch Formation and outcrops in a band around the periphery of the Wasatch exposures. The White River Formation, of Oligocene age, is the only Tertiary rock unit in the basin that is younger than the Wasatch Formation. It occurs locally in the center of the basin as a caprock on the Pumpkin Buttes. It is also found in the southeast part of the basin where it overlies the Fort Union Formation (Figure 4).

Stratigraphy and Sedimentology

The Tertiary stratigraphy of the Powder River Basin has generally evolved with time and need, rather than having been lithostratigraphically defined (Figure 5). For this reason there has been a considerable amount of confusion about the location of formation contacts, representative formation characteristics, and correlation. One of the major problems is the lack of distinction

Fig. 4.--Geologic map of the Powder River Basin, Wyoming.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SHERIDAN
ARVADA
SPOTTED HORSE
BUFFALO
GILLETTE
BIG HORN MTS
POWDER RIVER
PUMPKIN BUTTES
KAYCEE
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0 5 10 15 Miles
TERTIARY
MIOCENE-OLIGOCENE SERIES
OLIGOCENE SERIES - White River Fm.
EOCENE SERIES - Wasatch Fm.
PALEOCENE SERIES - Fort Union Fm.
MESOZOIC SYSTEMS
PALEOZOIC SYSTEMS & PRECAMBRIAN ROCKS

Origin of Lithology	Thickness	Generalized Lithology		Lithostratigraphic Name			Age
siltstone and clay: fluvial overbank sediment sandstone: fluvial channel sediment lignite and shale: backswamp and floodbasin sediment	30 feet to 50 feet	light brown, forms steep slopes 15% siltstone and clay 85% sandstone and conglomerate	Pumpkin Buttes area	White River Formation			Oligocene
	1000 feet to 3000 feet	45% siltstone and clay 45% sandstone 10% lignite and shale	northern Powder River Basin	Wasatch Formation			Eocene
		drab brown, forms rounded and steep slopes 20% siltstone and clay 75% arkosic sandstone 5% lignite and shale	southern Powder River Basin				
	1500 feet to 1900 feet	dull grayish-white, forms soft gently rounded slopes 70% siltstone and clay 15% sandstone 15% lignite and shale	southern Powder River Basin	upper member	Tongue River Member ?-----? Lebo Member	Fort Union Formation	Paleocene
	1200 feet to 1500 feet	dull yellow, forms hard and steep slopes 60% siltstone and clay 30% sandstone 10% lignite and shale		lower member	?-----? Tullock Member		

Fig. 5.--Composite stratigraphic section for Tertiary sediments in the Powder River Basin, Wyoming.

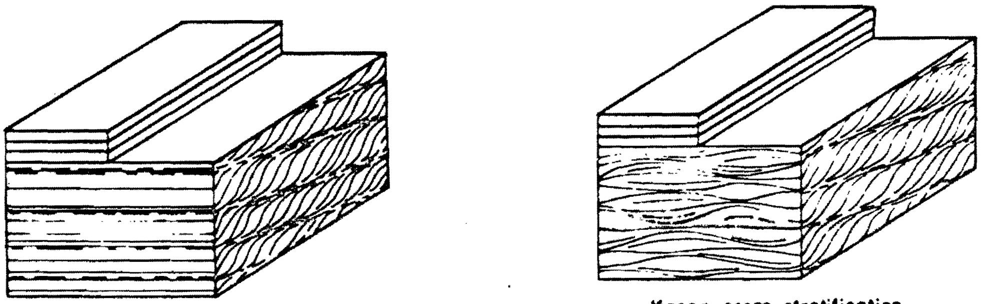
between lithostratigraphic units and time-stratigraphic units. For this study Sharp's (1964, p. 5) discussion of the Tertiary stratigraphy in the southern Powder River Basin was used as an initial guide to examine the geology. The formation names used are in accordance with the Wyoming Geological Association Stratigraphic Nomenclature Committee's (1969) revision of Wyoming stratigraphic names.

Fort Union Formation

The Fort Union Formation, of Paleocene age, conformably overlies the Lance Formation, of late Cretaceous age. The Fort Union generally has a thickness between 3,000 and 3,800 feet. It consists of continental sandstone, siltstone, shale, clay, and lignite. The Fort Union has been divided into an upper and lower member in the southern Powder River Basin (Sharp, 1964, p. &); elsewhere in the basin the Tongue River, Lebo, and Tullock Members have been recognized (Love and others, 1955). Excellent exposures, which are representative of the Fort Union Formation in the study area, are located along the Great Pine Ridge around the southwestern rim of the basin.

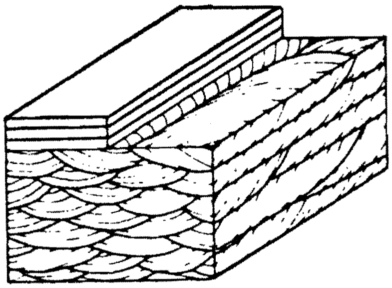
The Fort Union Formation contains three distinct sedimentary facies: a sandstone facies, a siltstone-clay facies, and a lignite-shale facies. These facies are complexly intertongued.

The sandstone facies consists of medium-grained to fine-grained, well-rounded sandstone except where coarse, subangular sandstone occurs locally in the uppermost part of the formation in the southern end of the basin. The sandstone contains both large-scale and small-scale cross-stratification. The large-scale cross-stratification consists primarily of trough-shaped cosets, which have been called pi cross-stratification by Allen (1963) (Figure 6). The small-scale cross-

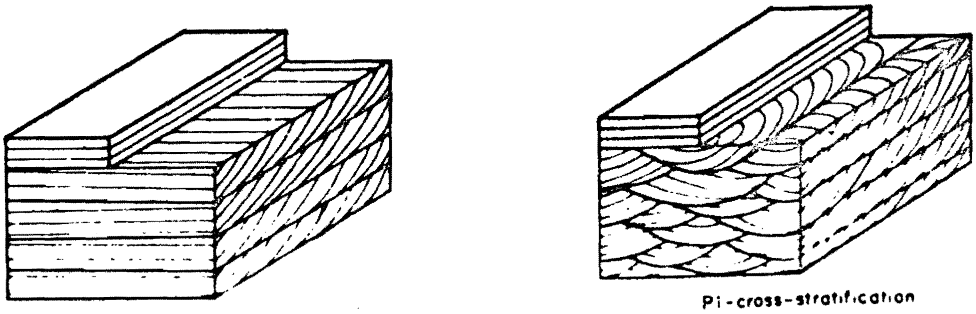


Lambda-cross-stratification

Kappa-cross-stratification



Nu-cross-stratification



Omikron-cross-stratification

Pi-cross-stratification

Fig. 6.--Types of cross-stratification found in the Wasatch and Fort Union Formations in the Powder River Basin, Wyoming (From Allen, 1963, p. 109).

stratification, which have been called lambda, nu, and kappa cross-stratification by Allen (1963), occur commonly within the large-scale cross-stratification. Of the small-scale types, the kappa cross-stratification was the type most commonly observed.

The sandstone facies is interpreted to be the fluvial channel deposits of high-discharge perennial rivers in the lower low-flow-regime with tranquil flow and low gradient. Most of the sediment was transported as bedload and deposited in point bars and channel bars.

The siltstone-clay facies consists mostly of clayey silt and to a lesser extent sandy silt and in some places silty sand. The bedding is indistinct and somewhat irregularly horizontal or draped. These deposits commonly contain poorly preserved organic material. This facies is interpreted to be sediment deposited on river levees and floodplains.

The lignite-shale facies consists of lignite, carbonaceous shale, and variegated shale. Distinct horizontal bedding is the characteristic feature of this facies. It is interpreted to be floodbasin sediment deposited in backswamps, marshes, and mudflats between the meander belts of the major rivers draining the area.

Primary sedimentary structures indicate that the flow direction of the major rivers draining the Powder River Basin during the Paleocene Epoch was to the northeast. The climate during this time was hot and humid, probably similar to the present-day tropical climate (Hager, 1970, p. 13). The topography during the accumulation of the Fort Union Formation is interpreted to have consisted of low-relief and forested plains that contained abundant freshwater lakes, swamps, and extensive river systems.

Wasatch Formation

The Wasatch Formation, of Eocene age, unconformably overlies the Fort Union Formation. The Wasatch ranges in thickness from around 1,000 feet in the southern part of the basin to around 3,000 feet near the center of the basin. The recognition of the Wasatch Formation in the Powder River Basin is based on information published by Wegemann (1917). Prior to his work the entire Tertiary section was thought to be the Fort Union Formation except where local occurrences of the White River Formation were known to exist (Darton, 1905). Even though the Wasatch and Fort Union Formations have been established for some time there is still some question about the location of their contact. Nevertheless, physical differences between the Fort Union and Wasatch Formations are adequate to distinguish between them, especially in the southern Powder River Basin, where the two formations are separated by an angular unconformity around the basin margins. In this area the sandstone facies of the Wasatch is a coarse-grained, angular arkose differing significantly from the underlying well-rounded, medium-grained quartz sandstone of the Fort Union Formation.

In the Powder River Basin two lignite beds, the D Coal of Dobbin (1927) and the H Coal of Wegemann (1917), occur near the top of the Fort Union Formation and are used to mark the Wasatch-Fort Union contact in the subsurface. Although these lignite units correspond to the lithologic break between the Wasatch and Fort Union in some outcrop areas, it is suggested here that there may be several hundred feet difference between the lignite units and the lithologic break several miles away in the subsurface. This type of stratigraphic error has been pointed out by Denson and Pipiringos (1969, p. 15) in the northeastern part of the Powder River Basin east of Gillette, Wyoming.

Here the Wyodak Coal lies at the lithologic boundary between the Wasatch and Fort Union Formations. Southward a lignite bed that had earlier been interpreted to be the equivalent of the Wyodak Coal lies several hundred feet below the lithologic break.

The use of physical lithologic characteristics in defining the Tertiary units in the Powder River Basin appears to be a more reliable criteria than the use of coal units. Denson and Pipiringos (1969) have suggested that heavy minerals suites are reliable criteria for the distinction between the Eocene and Paleocene Series in Wyoming. This suggestion is supported by Sharp's (1964, p. 14) summary of the lithologic differences between the Wasatch and Fort Union Formations in the Powder River Basin; it could be very useful in picking the contact in the subsurface.

> The Wasatch and Fort Union generally differ in appearance; the Fort Union lacks the thick coarse-grained sandstone lenses of the Wasatch and the clay and siltstone components differ in appearance. The Fort Union consists of thin interbedded clay, coal, shale, and sandstone beds in a regular sequence or cyclic arrangement. The fine-grained beds of the Wasatch are generally more massive and in a far less regular sequence. The Fort Union is white weathering, whereas the Wasatch is drab weathering. Montmorillonite is the chief clay mineral in the Wasatch Formation, whereas kaolin dominates the Fort Union rocks throughout the basin. Heavy mineral fractions of the Wasatch . . . consist largely of relatively unstable minerals; the Fort Union contains mostly durable minerals, including some species not found in the Wasatch, suggesting perhaps a different source and a different parent rock.

In the northern Powder River Basin the Wasatch and Fort Union Formations are difficult to distinguish because there is an increase in the amount of silt, clay, lignite, and shale; a decrease in the amount of sandstone; and a decrease in grain size of the sandstone in the Wasatch Formation from south to north. The two formations appear to be conformable or nearly conformable throughout most of the northern Powder River Basin.

Like the Fort Union Formation, the sediments of the Wasatch Formation may be divided into three distinct sedimentary facies: the sandstone facies, the siltstone-clay facies, and the lignite-shale facies. These facies are complexly intertongued. Montmorillonite clay is common in all the facies and was apparently derived from volcanic ash.

The sandstone facies consists of angular to subangular arkose in the southern Powder River Basin. It gradually becomes finer and more rounded toward the northern part of the basin. Locally, coarse sandstone occurs in the northern Powder River Basin; however, it is not as abundant as in the south. Plant fragments and other organic material are common throughout the sandstone facies, but fossils are generally poorly preserved. The sandstone contains predominately large-scale cross-stratification of trough-shaped cosets called pi cross-stratification by Allen (1963). To a lesser extent, large-scale planar cross-stratification, Allen's omicron cross-stratification, was also observed. Frequently, individual troughs of the sandstone, which are cemented with calcite, weather out and either protrude from outcrops or remain as erosional remnants on the surface (Figure 7). Apparently the individual troughs have been selectively cemented while surrounding sandstone remains semi-unconsolidated. The amount of small-scale cross-stratification observed was negligible but that which was observed was kappa cross-stratification.

The sandstone facies is interpreted to be the fluvial channel deposits of perennial, braided, sand rivers in the upper middle and upper, low-flow regime. The rivers probably had a relatively high gradient with both tranquil and rapid flow (Froude

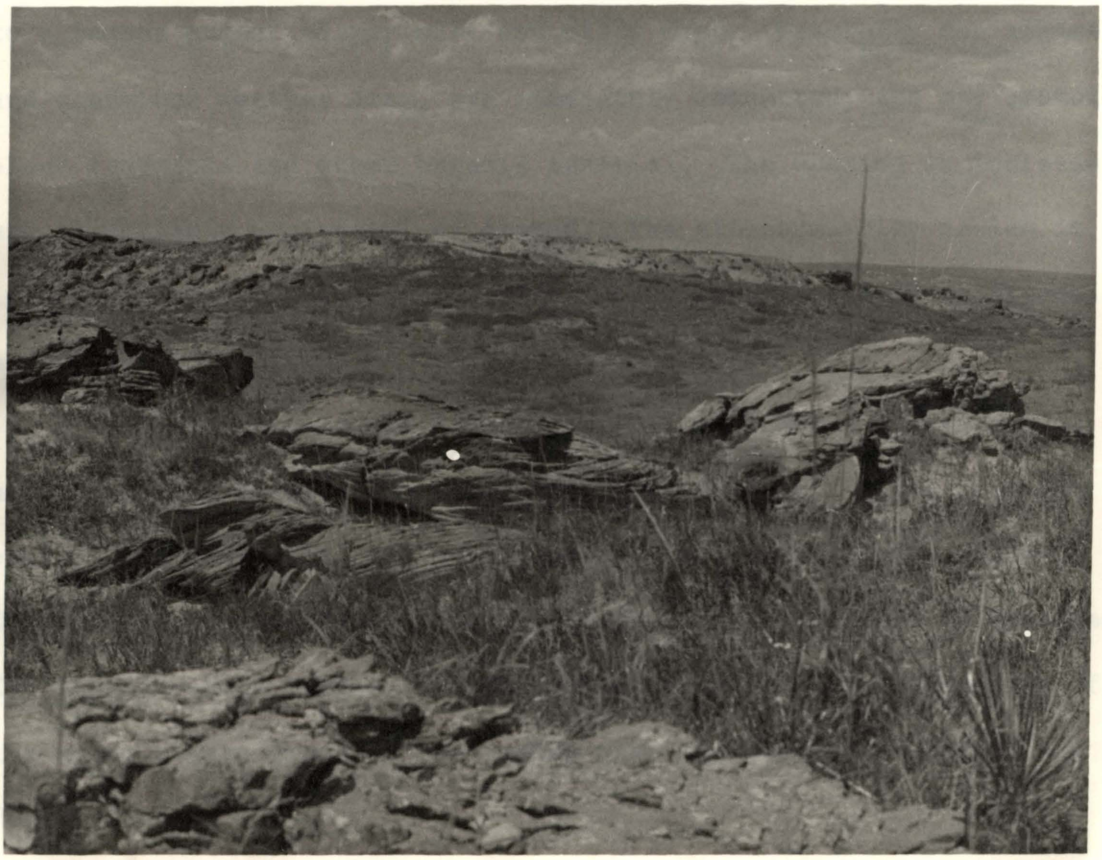


Fig. 7.--View of calcite-cemented fluvial troughs left on the surface as erosional remnants in the Powder River Basin, Wyoming.

number around 1). Most of the sediment was probably transported as bedload and was deposited in channel bars and point bars. In the northern most part of the basin the rivers that transported and deposited the sandstone had gradually changed to become physically similar to those of the Fort Union Formation.

The siltstone-clay facies consists mostly of sandy silt and to a lesser extent clayey silt and silty sand. Generally the siltstone and claystone weather gray, are moderately compacted, and may contain plant fragments and other organic material. The bedding is indistinct and irregularly horizontal or draped. The siltstone-clay facies is interpreted to be overbank deposits, which were deposited on floodplains and levees.

The lignite-shale facies consists of lignite, carbonaceous shale, and gray silty shale. The lignite is more abundant in the northern part of the basin and bivalve shells commonly occur in the shales. Distinct horizontal bedding is the characteristic feature of this facies. The lignite-shale facies is interpreted to be floodbasin deposits of the major rivers draining the region when the Wasatch Formation was deposited.

Primary sedimentary structures indicate that the flow direction of the major rivers draining the Powder River Basin during the Eocene Epoch was to the north. The climate during this time was hot but somewhat drier than the climate of the Paleocene Epoch (Hager, 1970, p. 14). The topography during the accumulation of the Wasatch Formation is interpreted to have consisted of low-relief plains. Scattered forests surrounded freshwater lakes and marshes that were associated with the major river systems.

White River Formation

The White River Formation, of Oligocene age, caps the Pumpkin Buttes in the central part of the basin. Darton (1905) was the first to recognize the White River Formation on the Pumpkin Buttes. The formation was included in the Wasatch Formation by later workers (Wegemann, 1917; Wegemann and others, 1928) and then once again recognized as White River by Love (1952). The White River Formation on the Pumpkin Buttes unconformably overlies the Wasatch Formation and consists of coarse-grained sandstone, which has characteristics similar to the sandstone of the Wasatch. The White River Formation in this area was deposited by streams similar to those that deposited the Wasatch sandstone. Volcanic ash was a significant sediment source for this formation; white tuff is found in some of the sandstone and is the dominant sediment type in some areas to the east and southeast of the Powder River Basin.

Rocks of the White River Formation are interpreted to have once covered the entire Powder River Basin but have been almost completely removed by erosion since the Pliocene Epoch. This interpretation is based on isolated occurrences of the White River Formation around the margins of the basin. Primary sedimentary structures in the caprock on the Pumpkin Buttes indicates that the rivers draining the area during the Oligocene Epoch flowed in a northeasterly direction. The climate during this time was cooler and drier than in the Eocene (Hager, 1970, p. 15).

Geologic History

The Powder River Basin is structurally related to the Laramide Orogeny. During this orogeny, which began near the end of the Cretaceous Period, the mountains adjacent to the basin were uplifted and eroded. Repeated episodes of uplift during the early Cenozoic Era are evident in the sediments deposited in the basin during this time. For example, an angular unconformity separates the Wasatch and Fort Union Formations along the western and southern rim of the Powder River Basin, indicating substantial uplift near the end of the Paleocene Epoch.

The rocks of the Fort Union Formation consist mostly of reworked sediments. These reworked sediments were derived from the older Mesozoic and Paleozoic systems that initially covered the uplifted mountains and therefore were the first to be removed by erosion. Near the end of the Paleocene Epoch most of the igneous core of the surrounding highlands had been exposed by erosion. Additional uplift at this time (described above) placed the igneous cores of the mountains in an erosional energy environment of substantial disequilibrium, which resulted in rapid weathering and erosion. The resulting sediment was transported into the basin and deposited as the arkose of the Wasatch Formation. In addition to the igneous cores, the Mesozoic and Paleozoic systems and the Fort Union Formation contributed to the sediments of the Wasatch.

Contemporaneously with the surrounding uplift, subsidence in the basin was apparently rapid enough to maintain a coastal plain, which persisted northward into Montana and North Dakota where a large Tertiary lake existed in the Williston Basin (Clayton and Hagmaier, 1970). Evidence of continued uplift during the Eocene

Epoch along the east flank of the Big Horn Mountains has been reported by Sharp (1948, p. 14). This uplift was responsible for the conglomerate of the Kingsbury and Moncrief Members of the Wasatch Formation and was also responsible for the thrust faults that placed Paleozoic rocks over the Moncrief Member.

During the Oligocene Epoch the Powder River Basin was filled with sediment derived from two sources: the volcanic centers in the Yellowstone-Absaroka region to the west and the surrounding highlands (Huston, 1969). The climate became more arid during this time and a prairie environment developed (Hager, 1970, p. 15). Presumably, sedimentation in the basin continued into the Miocene and Pliocene Epochs. Although this record is no longer present in the Powder River Basin, there is evidence from adjacent areas where these rocks are preserved that the climate became progressively more arid during the late Cenozoic Era (Mackin, 1937).

Erosion during the Pleistocene and Holocene Epochs removed all the late Cenozoic sediments that may have been present and most of the Oligocene sediments. An erosional history was left in the fluvial terraces along the modern river systems. These terraces have been studied and interpreted by Leopold and Miller (1954). Generally the modern river systems draining the Powder River Basin flow in the same general direction as the past drainage systems of the Tertiary Period, except in the southeastern part of the basin where the drainage has been diverted to the east and southeast since the Tertiary Period. For example, my observations of primary sedimentary structures indicate that the Tertiary equivalent of the North Platte River flowed north-northeast across the basin during the Tertiary Period but its present course is now around the southern end of the basin and southeastward.

CHAPTER III

GROUNDWATER THEORY

In 1940, M. King Hubbert published a paper, The Theory of Groundwater Motion, in which the physical laws governing the steady-state flow of groundwater were first presented in a comprehensive mathematical framework. During this period from 1940 to 1960 most of the emphasis in groundwater geology was placed on the description and prediction of transient hydrological phenomena of discrete aquifers. Throughout this time Hubbert's work was generally ignored. In the 1960's, attention was again turned to the regional picture and the study of integrated groundwater-flow systems was re-established as an acceptable subject of hydrological investigation. Among the first significant additions to Hubbert's work were studies published by Toth in 1962 and 1963. These two papers offered a theoretical approach to compliment fieldwork by establishing the basic concept that groundwater-flow patterns could be obtained mathematically as solutions to formal boundary-value problems. Since Toth's work, many models that describe the large-scale movement and chemistry of groundwater in terms of continuous flow systems have been proposed. The general applicability of the existing models which are used in this study has been demonstrated for areas ranging in size from thousands of square miles to a few miles or less (Freeze, 1969; Maxey, 1958; Meyboom, 1963, 1966a, 1967a, 1967b; Hitchon, 1969a, 1969b; and Williams, 1968).

Terminology and Concepts

Throughout the literature of groundwater hydrology the terminology tends to be inconsistent. It is necessary therefore to define some of the terms and concepts as they are used in this report.

Terms and Concepts Pertaining to the Flow System

A flow system as defined by Toth (1963, p. 4806) is

> . . . a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region; they can be intersected anywhere by an uninterrupted surface across which flow takes place in one direction.

Three types of flow systems may be defined on the basis of their relationship to topography and the length of the flow path involved.

(1) A local flow system is developed where groundwater flows from a topographic high to an adjacent low and has a flow path ranging in length from a few thousand feet to several thousand feet.

(2) An intermediate flow system is developed where groundwater flows from a topographic high to some low in the region and has a flow path ranging in length from several thousand feet to a few miles.

(3) A regional flow system is developed where groundwater flows from the highest to the lowest regionally significant topographic features in the region and has a flow path ranging in length from a few miles to several tens of miles.

Groundwater flow is three-dimensional and therefore must be evaluated in terms of flow components and flow resultants. The flow components are the longitudinal component, which is parallel to a river or divide, the vertical component, which is either up or down, and the lateral component, which is normal to the plane of the longitudinal and vertical components. The three components can be resolved into a total flow vector, a horizontal component, and a flow resultant (Meyboom, Van Everdingen and Freeze, 1966). The total flow vector is a function of the horizontal flow component and the flow resultant. The horizontal flow component may be approximated by constructing maps of the piezometric surface or watertable, which is generally a subdued replica of the topography. The flow resultant may be approximated by the construction of cross sections across the flow field.

A cross section of the flow field may be constructed by contouring values of potential in the plane of the section and by drawing flow resultants at right angles to the isopotential lines. This applies only for homogeneous and isotropic conditions. Most cross sections that are based on field measurements must be constructed with the consideration of anisotropic conditions in the sediments. Under these conditions isopotential lines and flow resultants are refracted at a permeability interface according to the tangent law (Hubbert, 1940, p. 943). The flow resultants must be corrected for distortion on a vertically exaggerated section (Van Everdingen, 1963).

In this report the two-dimensional approach described above is used to evaluate the distribution of groundwater potential in the Powder River Basin. The two-dimensional approach is used because three-dimensional modeling requires detailed information on permeability and boundary conditions that is not available for the study area. Three-dimensional modeling is not yet practical for large, complex basins. Freeze (1969, p. 113), in his evaluation of three-dimensional models concluded that:

> . . . at the present time (1966), the use of three-dimensional models should be limited to small, simple basins that can be adequately represented by 7,500 nodes [the data limit using an IBM 7094 computer with storage capacity of 3,200] . The best way to handle large, complex basins is with a series of two-dimensional models representing vertical sections taken parallel to the direction of dip of the water-table slope.

The watertable is an imaginary surface beneath the surface of the ground where the pore pressure is equal to atmospheric pressure.

Recharge is the addition of water to the groundwater-flow system by water moving down through the unsaturated zone to the watertable. Discharge is the loss of water from the groundwater-flow system by means of stream baseflow, springs, seepage areas, and evapotransportation.

A recharge area is an area where the direction of groundwater flow is away from the watertable. A discharge area is an area where the direction of groundwater flow is toward the watertable.

Terms and Concepts Pertaining to the Water Chemistry

The concentration of chemical constituents in water may be expressed in various ways. Two units for expressing concentration are used in this report: (1) parts per million (ppm) and (2) equivalents per million (epm). Parts per million expresses the parts of dissolved matter by weight in a million parts by weight of solution. Equivalents per million is the normality multiplied by 1,000.

A hydrochemical facies is a mass of water within a groundwater-flow system which may be distinguished on the basis of its chemical characteristics from other water masses of the same system. In this study the classification of hydrochemical facies follows that of Back (1960). His classification uses percentage values based on equivalents per million of the anions and cations in solution.

The following examples represent the general scheme of the classification: (1) "bicarbonate water" describes water in which the total anions are composed of at least 90 percent bicarbonate; (2) double terms, such as bicarbonate-sulfate, describe water in which the total anions are composed of at least 50 percent but less than 90 percent of the first-named ion and at least 10 percent but less than 50 percent of the second-named ion; (3) the double term, calcium-magnesium, describes water in which the total cations are composed of at least 90 percent calcium and magnesium; and, (4) the double term, calcium-sodium, represents water in which the total cations are composed of at least 50 percent but less than 90 percent calcium and magnesium and at least 10 percent but less than 50 percent sodium.

Groundwater Flow

Groundwater moves from levels of high potential to levels of low potential. In most cases the potential gradient is produced by topography and the driving force is gravity. The purpose of this section is to summarize the theory of groundwater flow.

Hydraulic Potential

The hydraulic potential can be obtained as a generalization of the Bernoulli Theorem. The Bernoulli Theorem relates the elevation, pressure, and velocity along a given flow line and assumes frictionless flow. In groundwater flow the velocity term is negligible. For this reason, the hydraulic potential can be written as the sum of the gravitational and pressure potentials:

$$\phi = gZ + \int_{P_o}^{P} \delta P/\rho \tag{1}$$

By integration, equation 1 becomes

$$\phi = gZ + (P - P_o)/\rho \tag{2}$$

where ϕ = hydraulic potential at a point P in the field,

g = gravitational acceleration,

Z = elevation of P above a standard horizontal datum,

P = pressure at the point P,

P_o = atmospheric pressure,

ρ = density of water.

If a piezometer is placed at point P the fluid will rise to a height (h) above the standard datum (sea level in this study). Applying the identity

$$P = \rho g(h - Z) + P_o \tag{3}$$

to equation 2

$$\phi = gZ + \left[\rho g(h - Z) + P_o - P_o\right]/\rho = gh. \tag{4}$$

The magnitude of the fluid potential is a function of the height (h) of the fluid in the piezometer and equal to the height (h) multiplied by the acceleration due to gravity. The quantity

$$h = \phi/g \tag{5}$$

is the hydraulic head and is measured in linear units above a standard datum (feet above sea level in this study). Because the hydraulic head equals the hydraulic potential divided by a constant, it too is an expression of potential and obeys the laws of potential theory. Head is measured in simple units that have geometrical significance in groundwater-flow studies and is therefore the potential function used throughout this study.

Darcy's Law

Darcy's law relates the rate of flow through a porous medium to permeability and hydraulic head. It is an important concept in the evaluation of groundwater flow and is stated below for flow in the X direction of an X, Y, Z coordinate system in an homogeneous medium.

$$V_x = K(\delta h/\delta X) \qquad (6)$$

where V_x = apparent velocity in the X direction,
K = permeability (hydraulic conductivity),
$\delta h/\delta X$ = differential change in head (h) in the X direction.

Recent investigations as outlined by Meyboom (1966b) suggest that Darcy's law is a special case of a more complicated relation between fluid flow in a porous medium and the conditions that prevail in that medium.

Continuity and Laplace Equations

The continuity equation obeys the law of the conservation of matter and is the basis for evaluating the water budget of any flow system. The equation, generally stated, says that the volume of water entering a flow system must equal the volume that leaves that same system. For flow through a porous medium the continuity equation is stated below in its complete form:

$$\delta(\rho V_x)/\delta X + \delta(\rho V_y)/\delta Y + \delta(\rho V_z)/\delta Z = (-F)(\delta\rho/\delta T) \qquad (7)$$

where V_x, V_y, V_z = velocity in the three coordinate directions,
ρ = density of water,
F = porosity,
T = time.

If the assumption is made that ρ is constant at any given time, equation 7 becomes

$$\delta V_x/\delta X + \delta V_y/\delta Y + \delta V_z/\delta Z = (-F/\rho)(\delta\rho/\delta T). \qquad (8)$$

If we further assume no change with time, steady-state conditions, the right side of equation 8 becomes zero, and we are left with the common form of the continuity equation

$$\delta V_x/\delta X + \delta V_y/\delta X + \delta V_z/\delta Z = 0. \qquad (9)$$

A combination of the continuity equation and Darcy's law results in the Laplace equation:

$$\partial^2 h/\partial X^2 + \partial^2 h/\partial Y^2 + \partial^2 h/\partial Z^2 = 0. \qquad (10)$$

The Laplace equation describes the spatial distribution of total hydraulic head (h) for isotropic and homogeneous conditions. When only two dimensions are considered the Laplace equation becomes

$$\partial^2 h/\partial X^2 + \partial^2 h/\partial Y^2 = 0. \qquad (11)$$

Groundwater Flow Models

General models for predicting regional groundwater flow were developed in the early 1960's. Two of the more significant contributions were made independently about the same time by Toth and Meyboom. Toth (1963) presented a mathematical model for regional groundwater flow which was theoretical and used ideal boundary conditions. Meyboom (1963) described groundwater-flow systems in the semiarid prairie of Saskatchewan, Canada. His model was based on field observations and information from various scientific disciplines. Since their initial work the models have been critically evaluated and expanded by other workers.

Toth's (1962, 1963) theoretical approach to defining groundwater-flow systems made several significant contributions. He showed that groundwater-flow systems of different sizes, local, intermediate, and regional, could be superimposed on one another (Figure 8). Although his initial model was based on ideal assumptions he recognized and suggested that the more complicated aspects of groundwater flow could be handled mathematically when techniques became available to determine their proper functional relationships. Advances have recently been made in this area. The solution to some

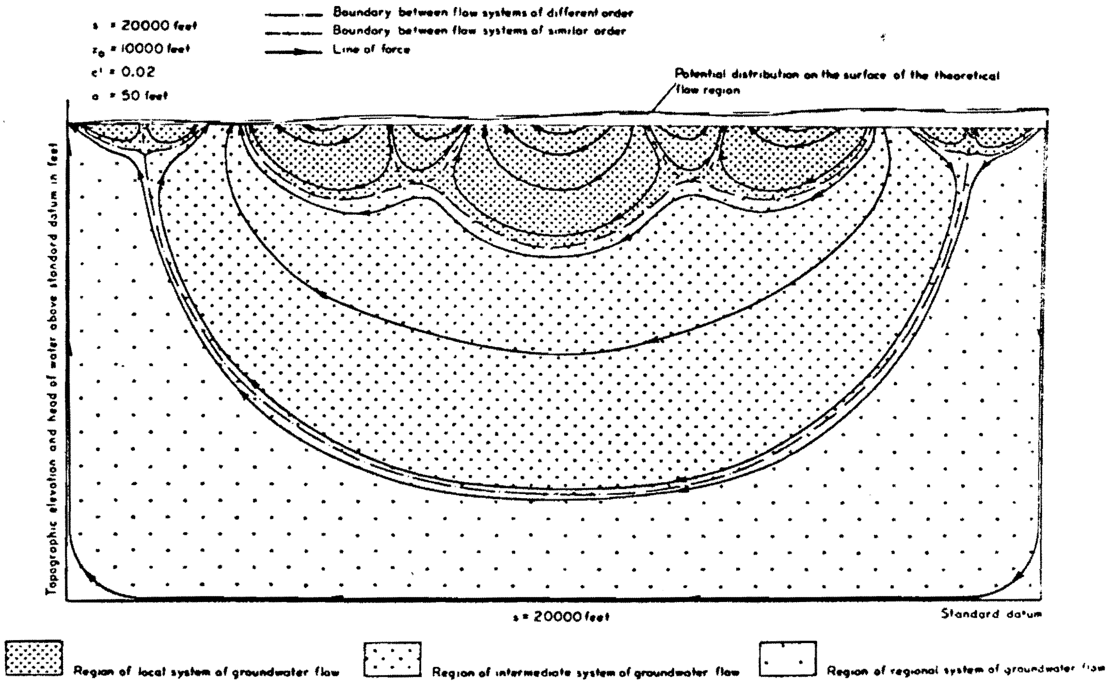


Fig. 8.--Theoretical flow pattern and boundaries between different flow systems (From Toth, 1963, p. 4807).

complicated problems such as stratigraphic pinchouts, heterogeneous sediment, non-isotropic conditions, irregular watertables, and three-dimensional modeling has been approached through the application of digital computers. Freeze and Witherspoon (1966, 1967, 1968) and Freeze (1969) have done extensive research on the theoretical analysis of groundwater flow by using digital computers to construct and evaluate models. Many of these models are now being used to quantitatively evaluate groundwater flow in actual basins.

Meyboom's (1963) Prairie Profile model was specifically designed for application in the western Canadian prairie regions, for which it was named. The generalizations that underlie the model are applicable throughout most of the semiarid plains of North America, including the Powder River Basin, Wyoming. Meyboom (1963, p. 9) defined the Prairie Profile as follows:

> . . . the Prairie Profile consists of a central topographic high bounded at either side by an area of lower elevation. Geologically the profile is made up of two layers of different permeability, the upper layer having the lower permeability. Through the profile is a steady flow of groundwater from the area of recharge to the area of discharge. The ratio of permeabilities is such that groundwater flow is essentially downward through the material of low permeability and lateral and upward through the underlying more permeable layer. The potential distribution in the profile is governed by the differential equation of Laplace.

The Prairie Profile model (Figure 9) shows how a large-scale flow system bounded by topographically significant lows may occur. The question of whether large, unconfined systems of flow (several tens of miles) can extend across the valleys of large rivers or highly-elevated watersheds has been submitted by Toth. This seems to be a major point of disagreement between Toth's theoretical model and Meyboom's Prairie Profile. Meyboom (1963, p. 27) has cited field evidence indicating that large-scale flow

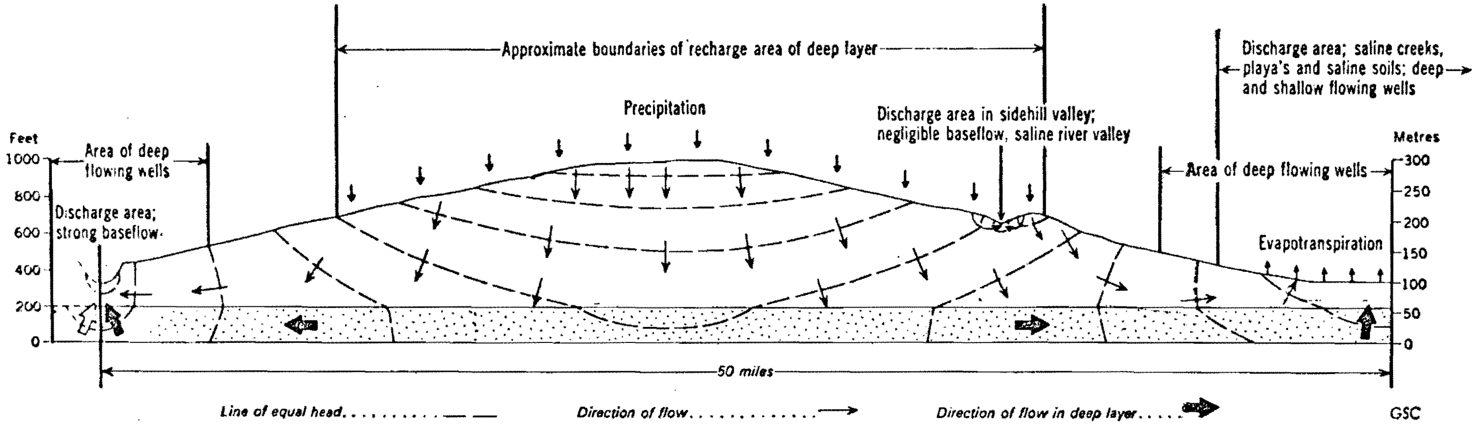


Fig. 9.--The Prairie Profile (From Meyboom, 1966, p. 27).

systems are possible. Generally the combined picture of Meyboom's Prairie Profile and the theoretical models by Toth give a good description of unconfined regional groundwater flow. Concepts from both models are used throughout this study and are thought to be ideal for the initial evaluation of regional groundwater flow in large basins such as the Powder River Basin.

Hydrochemical Model

Groundwater chemistry can be used to determine the direction of groundwater flow. It can also be used as a means to determine what part of a groundwater-flow system individual water samples come from. Brown (1963) elaborated on the various ways of using chemistry as a tool in studying hydrogeology. It has been used as a primary means of evaluating groundwater flow direction by Charron (1965) and by Back (1960) and has been used as a secondary indicator by Meyboom (1966) and Toth (1968).

A generally accepted hydrochemical model that predicts the predominant ions in solution along an individual groundwater-flow path from recharge to discharge areas is as follows:

$$HCO_3^- \longrightarrow HCO_3^- + SO_4^{--} \longrightarrow SO_4^{--} \longrightarrow SO_4^{--} + Cl^- \longrightarrow Cl^-$$

(Figure 10).

This model is based on original work by Chebotarev (1955). He compared the solubility products of the most common salts and used several thousand water analyses to demonstrate that groundwater tends toward an increased saline composition along its flow path. That is, the length of time that water has been in contact with sediments determines the concentration of the most soluble ions. For example, older water is likely to contain the greatest concentration of chloride

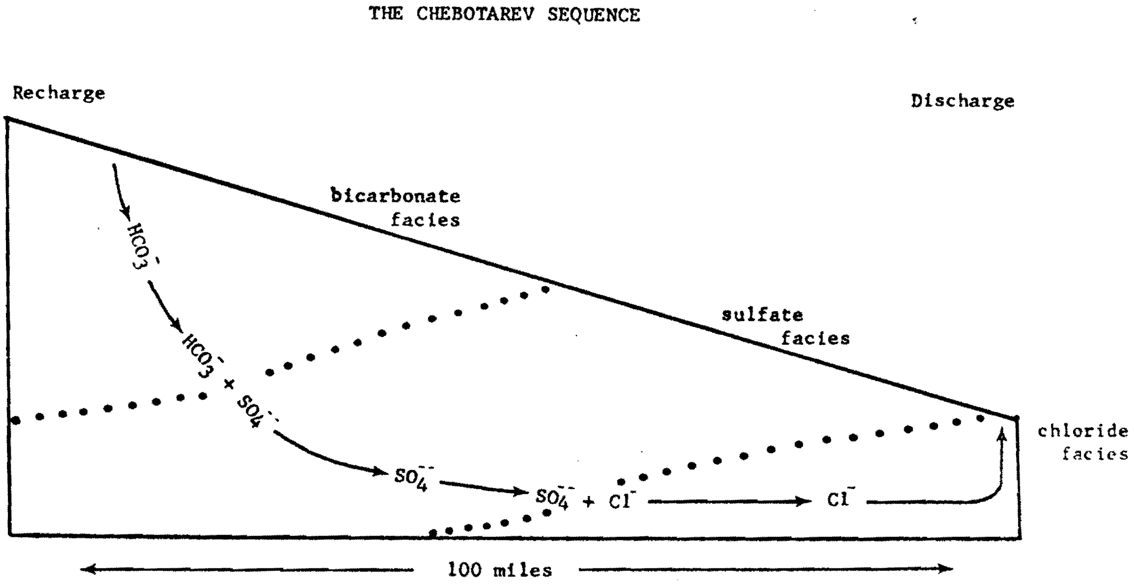


Fig. 10.--Hydrochemical model for regional groundwater-flow systems.

and total dissolved solids.

In the model more emphasis is placed on the residence time of the water in sediment for the development of hydrochemical facies than is placed on the mineralogical framework of the sediments through which the water passes. For example, in local flow systems almost all the water should be bicarbonate rich, in intermediate flow systems both the bicarbonate and sulfate facies are likely to develop and in the regional flow systems bicarbonate, sulfate, and chloride facies are commonly present. Observations by Michel (1965) in western Germany and by Charron (1965) in the Winnipeg, Manitoba, area indicate that the size of the flow system determines the prevailing hydrochemical facies, as much or more than does the mineralogical composition of the host rock.

Variations from the model are generally the result of a flow path that is too short to develop the entire sequence or are the result of the presence of a particularly soluble rock or homogeneous lithology, such as rock salt or limestone.

CHAPTER IV

THEORETICAL GROUNDWATER-URANIUM MODEL

Early in the study a model was developed to guide the data collecting (Hagmaier, 1970b, 1971). The objective of this chapter is to review briefly the model, which relates groundwater flow, hydrochemistry, and uranium deposition in the Powder River Basin.

Although there are many references on the subject of uranium hydrochemistry, the two most frequently used in this study are Hostetler and Garrels (1962) and Krauskopf (1967). Much of the following discussion is based on these references.

Relation of Uranium Chemistry to Hydrochemistry

Uranium has many valence states (+2, +3, +4, +5, +6) but the only states of geologic interest are the +4 reduced state and the +6 oxidized state. The other states are unstable in geologic environments. Transitions from the +4 to the +6 state may occur in nature because uranium in these states has a redox potential within the normal range for geologic environments:

$$U^{+4} + 2H_2O \rightleftarrows UO_2^{++} + 4H^+ + 2e; \quad E^o = +0.33 \text{ volt.} \qquad (12)$$

The uranous ion (reduced form; U^{+4}) reacts with bases to form an insoluble hydroxide ($U(OH)_4$), whose low ionization potential, which is about 10^{-46} at 25 degrees Centigrade, is such that the concentration of uranium in the +4 state is negligibly small in neutral or even acid (pH 4) solutions. This is the underlying principal reason that pitchblende and uraninite are so stable in reducing environments. However, disseminated primary uranium minerals such as pitchblende and uraninite in near-surface environments are easily oxidized to the +6 uranyl ion, which is somewhat mobile in acid solutions and in neutral to slightly alkaline solutions if carbonate ions are present. The uranyl ion (UO_2^{++}) may be transported in a simple soluble hydroxide form:

$$UO_2(OH)_2 \rightleftharpoons UO_2OH^+ + OH^- \qquad K = 10^{-12.1} \tag{13}$$

$$UO_2OH^+ \rightleftharpoons UO_2^{++} + OH^- \qquad K = 10^{-9.9}. \tag{14}$$

In a solution at pH 7 the concentration of uranyl hydroxide (UO_2OH^+) is $10^{-5.1}$ moles and the concentration of the uranyl ion (UO_2^{++}) is 10^{-8} moles. However, with the acidity increased to pH 4 the concentration of each ion rises to about 10^{-2} moles. Decaying humus in soil commonly lowers the pH of natural waters to about 4.5 or 5 but any solution in contact with silicate minerals cannot long remain appreciably acid; if contact is continued, the solution must eventually become alkaline (Krauskopf, 1967, p. 115). Hence, acid solutions are probably important only in the near-surface leaching of uranium. However, if acid conditions were to persist to significant depths, perhaps through weathering pyrite or a symbiotic relationship between the oxygen-acid producing bacteria Thiobacillus and a sulfate reducing genus Desulfovibrio as has been suggested by Rackley and others (1968), it is possible that acid solutions could transport and deposit significant amounts of uranium. It should be pointed out, however, that these conditions are not found in present-day environments on a scale that is large enough to produce uranium deposits of the magnitude known to exist in sandstone bodies.

In solutions containing carbonate ions the solubility of sexivalent uranium is greatly increased by the formation of carbonate complexes:

$$UO_2(CO_3)_2^{--} \rightleftarrows UO_2^{++} + 2CO_3^{--} \qquad K = 10^{-14.6} \qquad (15)$$

$$UO_2(CO_3)_2^{-4} \rightleftarrows UO_2(CO_3)_2^{--} + CO_3^{--} \qquad K = 10^{-3.8}. \qquad (16)$$

For example, a solution at pH 7 and 0.01 mole total carbonate contains approximately 10 times the amount of total dissolved uranium as that estimated for a carbonate-free solution at the same condition. The contribution of the carbonate complex increases rapidly as the amount of carbonate is increased. Because neutral to slightly alkaline carbonate groundwater is more common in the geologic environment than acid groundwater and because carbonate complexes are efficient transportation agents of uranium, it is likely that uranium ore bodies are associated with the bicarbonate facies in groundwater-flow systems. That is, uranium should be found in groundwater recharge areas.

Carbonate from bicarbonate-rich groundwater can form a uranium-carbonate complex and carry the uranium along flowpaths into the transition zone between the bicarbonate and sulfate groundwater facies. In this zone the carbonate in solution is precipitated, usually in the form of calcite. Precipitation is caused by a number of interrelated factors such as increased pH, increased temperature, and sulfate reduction.

The association of calcite cement and uranium has been noted by Sharp (1964, p. 31), by Langen and Kidwell (1971, p. 9), and by Davis (1969, p. 137) in the southern Powder River Basin, and by Gott (1956) in the Black Hills area. The precipitation of the carbonate releases the uranyl ion of uranium, which has a very low solubility and a low oxidation potential in basic solutions and is therefore ready for precipitation. The presence of organic material in the transition zone between the bicarbonate and sulfate groundwater facies accelerates the reduction and precipitation of uranium. It is in this zone that bacteria could become significant in the reduction of uranium to the +4 state. For example, hydrogen sulfide, a uranium reductant, could be formed by anaerobic bacteria from the reduction of the sulfate anion in groundwater.

Application of Model to the Powder River Basin

The early Cenozoic history of the Powder River Basin has been generally established for some time. However, details are mostly speculation, especially for the post-Eocene part of the Cenozoic, because few post-Eocene rocks remain. Observations of primary sedimentary structures in the Eocene Wasatch and the Paleocene Fort Union Formations indicate that surface drainage was consistently to the north-northeast in the Powder River Basin during the early Tertiary Period. During the Oligocene Epoch the sediment source changed from the surrounding Laramie and Big Horn highlands to the Absaroka-Yellowstone province, where intense volcanic activity existed (Huston, 1969, p. 13). The deposition of volcanic clastic sediment probably continued into the Miocene and Pliocene Epochs, with the major rivers continuing to flow north.

The most likely source for the uranium now found in the Eocene arkosic sediment was the tuffaceous Oligocene sediment. It has been demonstrated by Denson and others (1956) and by [illegible]ost 1956) that groundwater from tuffaceous rocks is frequently uranium-rich. Bicarbonate-rich groundwater that is capable of leaching and transporting uranium as uranyl-carbonate complexes probably leach uranium from the tuffaceous Oligocene sediments or some other disseminated source in recharge areas and carried it deep into the Eocene sediments where reducing environments and changes in groundwater chemical facies precipitated the uranium (Figure 11).

The depositional history of the Powder River Basin indicates that the drainage was to the north, providing a low elevation potential in the north, throughout the Tertiary Period just as there is today. A low potential to the north necessitates regional groundwater flow to the north. Therefore, present-day groundwater-flow systems are physically similar to past groundwater-flow systems, and present-day recharge areas were recharge areas in the past. For these reasons an evaluation of present-day groundwater-flow systems and their hydrochemistry is one way to gain insight into the groundwater conditions at the time the uranium was deposited. If the groundwater-flow systems of the Tertiary Period can be interpreted, then the distribution of uranium deposits may be explained.

In summary the southern Powder River Basin is a present-day groundwater recharge area and was probably one throughout the Tertiary Period, whereas most of the northern part of the basin is a regional discharge area and was probably one throughout the Tertiary Period. For this reason uranium ore deposits occur in the southern part of the basin rather than the northern part.

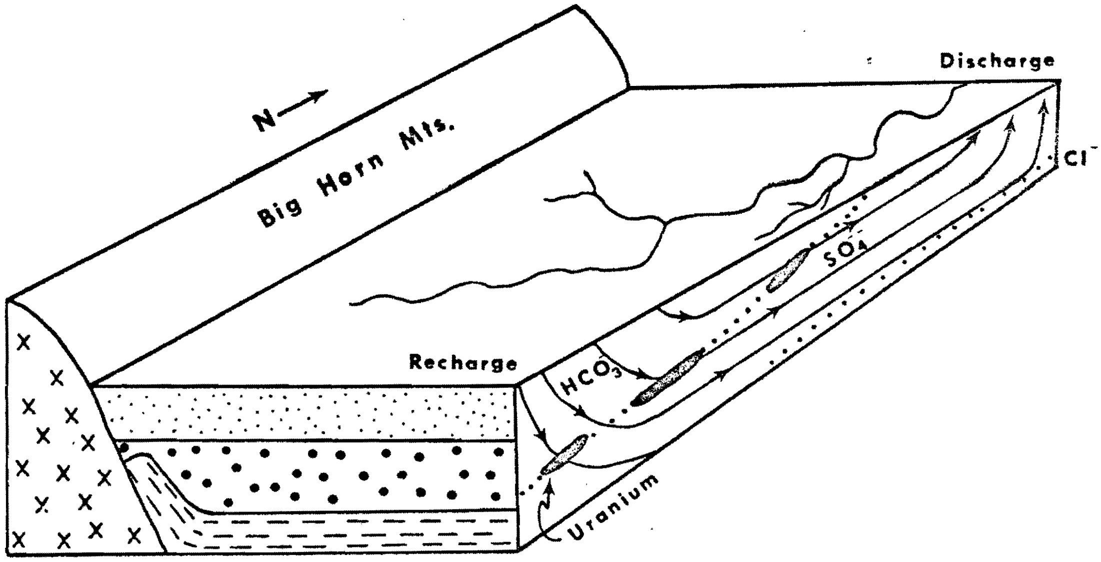


Fig. 11.--Theoretical groundwater-uranium model for Powder River Basin, Wyoming.

CHAPTER V

PRESENT-DAY HYDROGEOLOGY

The purpose of this section is to evaluate the piezometric and chemical data collected in the Powder River Basin. The data was collected entirely from groundwater in the sediments of the Tertiary system at depths of less than 2,000 feet. The two major types of aquifers in the region are lignite beds and sandstone units.

Previous and Present Studies

Two regional studies of groundwater geology were done in the Powder River Basin prior to 1970 (Lowry and Cummings, 1966; and Whitcomb and others, 1966). Both studies consist predominantly of appraisals of the quantity and availability of groundwater from the various formations underlying the northwestern corner of the Powder River Basin. A project by Dana (1962) for the Wyoming Natural Resource Board outlines in table form the physical aspects of 2,743 water wells, oil wells, and test wells. Groundwater studies of local interest include studies on irrigation projects and specific reconnaissance surveys (Kohout, 1957; Littleton, 1950; and Morris, 1957). Currently the United States Geological Survey is compiling data on the water resources of the Powder River Basin and adjacent areas. The data is being used to determine the availability and quality of groundwater and surface water in the area. The project is scheduled to be published as part of the United States Geological

Survey Hydrologic Atlas Series in the near future.

Potential Distribution

Three assumptions are included in the evaluation of potential distribution: (1) the sediment was assumed to be homogeneous, where no other information was available, (2) steady-state conditions were assumed, and (3) an impermeable boundary was assumed to exist at some depth.

There are two major groundwater discharge areas that significantly affect groundwater flow in the study area. They are the Powder River, which is the larger of the two, and the Dry Fork Cheyenne River. The Belle Fourche and the Little Powder Rivers are at the eastern edge of the study area and were not considered in this study. The North Platte River, which is at the southern margin of the study area, has only local affect on groundwater flow; the potential of the river, approximate elevation 5,000 feet, is larger than that in most of the recharge areas in the Powder River Basin.

Dry Fork Cheyenne River Drainage Basin

The Dry Fork Cheyenne River originates in the southern Powder River Basin and flows eastward into South Dakota. The stream valley is small in the study area and affects only local and intermediate groundwater-flow systems. The potential distribution of the groundwater is represented by two vertical cross sections constructed at right angles to the axis of the regional ground slope (Figures 12 and 13). The cross sections show that the potential distribution is locally focused around tributary channels near the head of the basin (Figure 13). Here, the groundwater movement is affected by

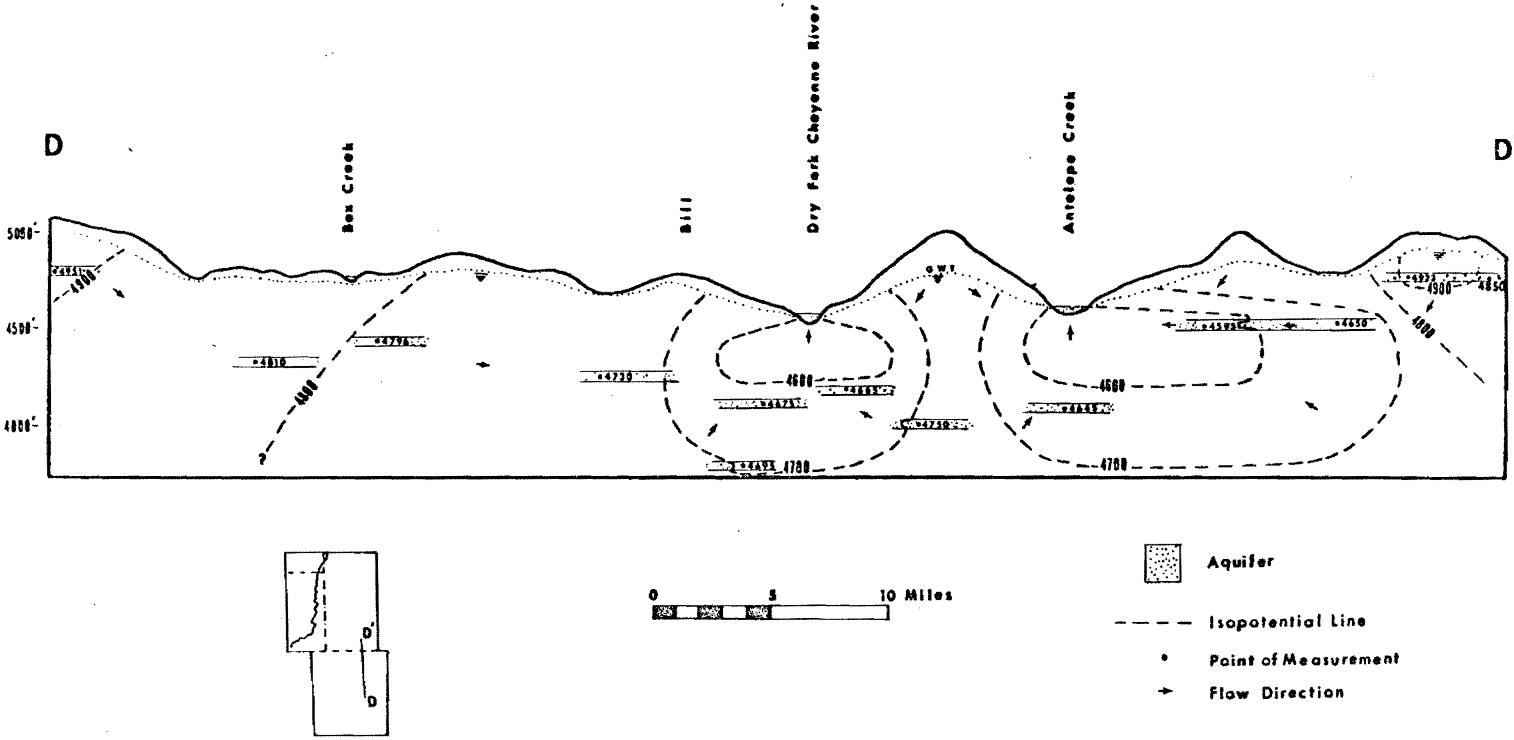


Fig. 12.--Pattern of regional groundwater flow in the Dry Fork Cheyenne River flow system, near Bill, Wyoming.

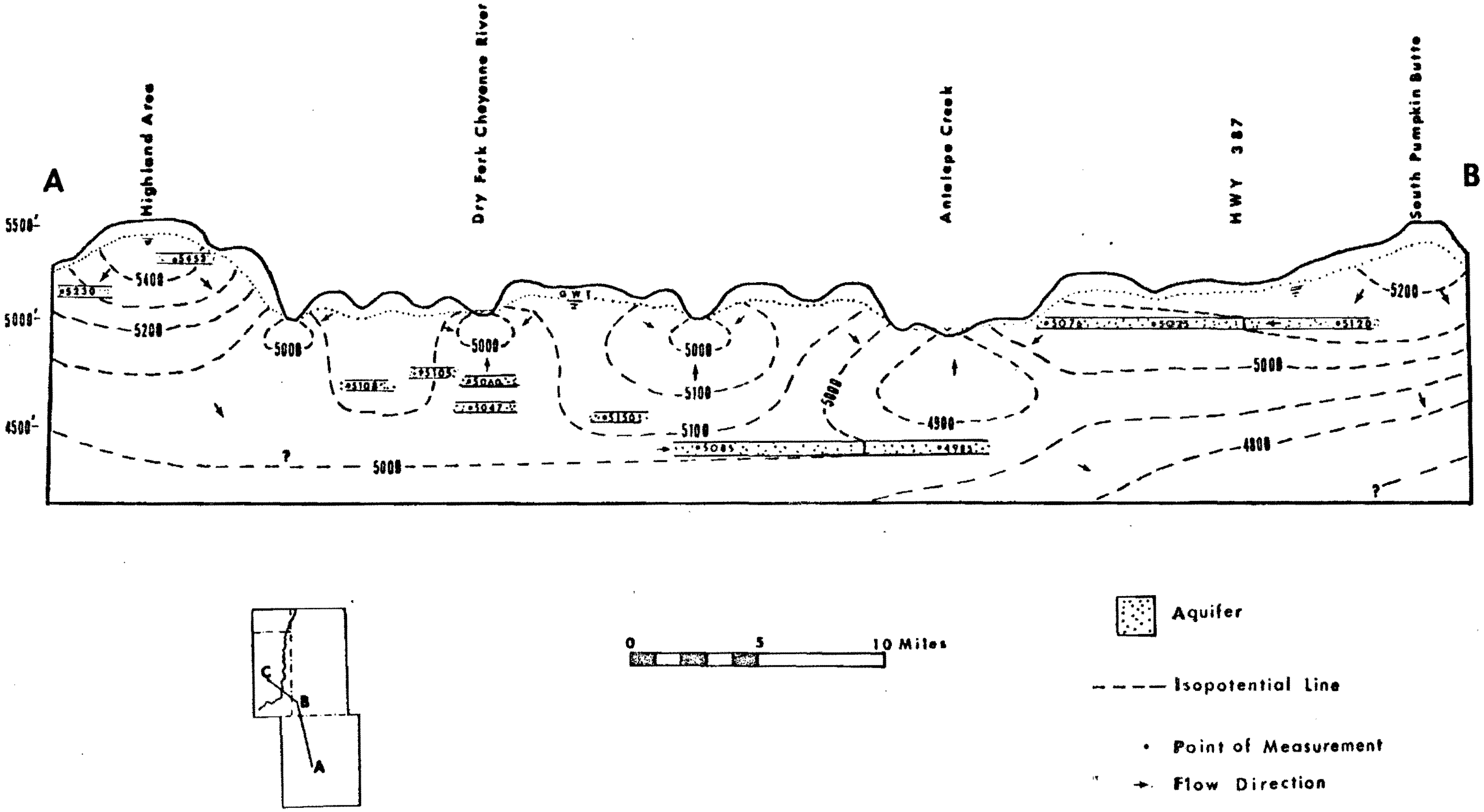


Fig. 13.--Pattern of regional groundwater flow in the southern Powder River Basin, Wyoming.

the stream valleys down to a depth of only about 500 feet. About 30 miles downstream and structurally updip the stream valleys integrate into larger valleys and the groundwater movement is affected down to a depth of approximately 1,000 feet (Figure 12). The Dry Fork Cheyenne River significantly influences regional groundwater flow farther to the east and outside the area considered in this study.

Ranges of potential gradient are given in Table 1. The largest flow components are the vertical and longitudinal components.

TABLE 1.--Representative values of potential gradient with respect to the flow components for the Dry Fork Cheyenne River drainage basin

Flow Component	Ranges of Values (ft./ft.)
Lateral Component	1×10^{-3} to 3×10^{-3}
Longitudinal Component	3×10^{-3} to 4×10^{-3}
Vertical Component	2×10^{-1} to 4×10^{-1}

In most flow systems of the northern plains, such as the Powder River drainage basin and the Little Missouri drainage basin (Hamilton, 1970, p. 57), the vertical and lateral components are the largest. The longitudinal component is larger than the lateral component in the Dry Fork Cheyenne River groundwater system because the tributary basins to the main stream valleys are oriented in a radial pattern in the headwater area of the basin, and the major stream valley is not significantly deep with respect to surrounding topography to cause a major flow component perpendicular to the valley.

If the mean of the representative gradients for each flow component given in Table 1 is used, the total flow vector in discharge areas is oriented at approximately 30 degrees to the longitudinal component in the horizontal plane and at 87 degrees to the horizontal plane in a vertical plane. The ratio of the vertical to horizontal (either lateral or longitudinal) piezometric gradient is approximately 100. If the assumption is made that the ratio of horizontal to vertical permeability is approximately 100, one value will cancel the effect of the other and the total flow vector will be oriented at about 45 degrees to the horizontal plane rather than the 87 degrees as calculated. An anisotrophy value of 100 is based on estimates made by Hamilton (1970, p. 62) for sediments in western North Dakota that are similar to those in the Powder River Basin.

In the southern Powder River Basin there is a regional groundwater-flow system in which the water moves northward toward the Powder River valley and passes under the easterly moving water in the local and intermediate flow systems associated with the Dry Fork Cheyenne River (Figure 13). Geologically, this deep lateral movement is likely because there are extensive lignite aquifers underlying the area at depths between 500 and 1,000 feet. In addition, the aquifers dip to the north in the same general direction as potential decreases.

It may be that the local and intermediate flow systems of the Dry Fork Cheyenne River basin are more an anomaly than the northward moving regional flow path under them. The Dry Fork Cheyenne River is interpreted to have developed during the Pleistocene and Holocene Epochs. Prior to that time, the geology indicates that the drainage and the regional slope were to the north in the same direction that the regional flow path follows. The regional flow path has probably persisted from the Tertiary Period, while the smaller flow systems have been superimposed on it by the later geomorphic evolution of the Dry Fork Cheyenne River basin.

Powder River Drainage Basin

The Powder River originates in the southwestern Powder River Basin and the southern Big Horn Mountains and flows northward. The river occupies a valley that is 500 to 1,000 feet below the surrounding recharge areas.

The Powder River is the most significant groundwater discharge area in the Powder River Basin. Numerous flowing wells occur along the river from the Sussex area to the Montana-Wyoming border. Some of the flowing wells along the Powder River contain abundant gas (mostly methane), especially those that are completed in or near the lignite of the Fort Union Formation. The dissolved gas expands as it passes to the top of a well and creates an additional lift which aids flowing wells. The gas contributes to the drive in those wells that contain it; however, it is not the primary driving force. The primary driving force for the flowing wells is the hydraulic potential. This is shown on the four vertical cross sections of the groundwater potential distribution in the flow systems associated with the Powder River drainage basin (Figures 14, 15, 16, and 17).

The cross sections of groundwater potential distribution show that the potential decreases from surrounding high areas toward the valley of the Powder River. The regional groundwater flow converges in the Powder River valley and discharges in an

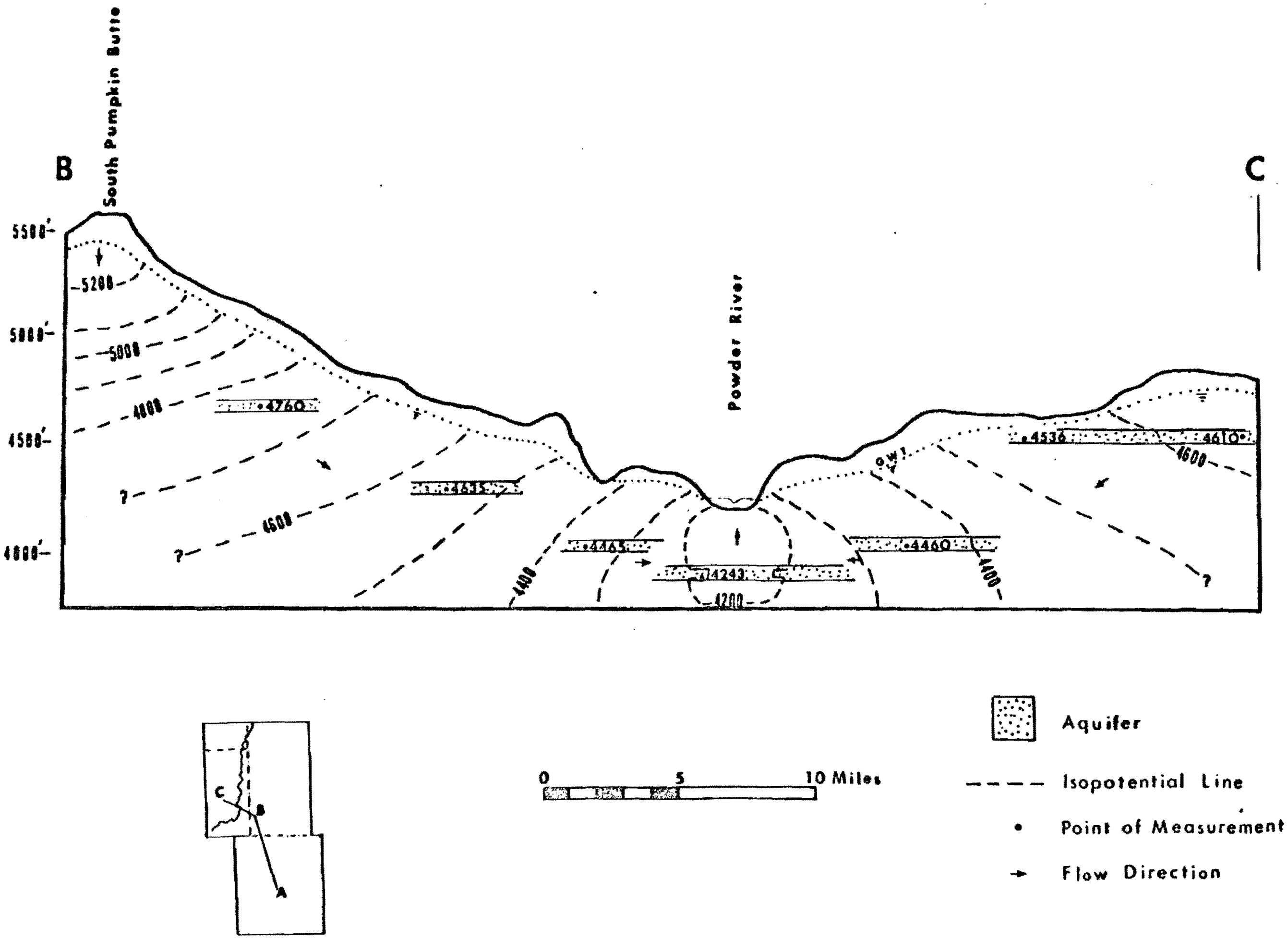


Fig. 14.--Pattern of regional groundwater flow in the south central Powder River Basin, Wyoming.

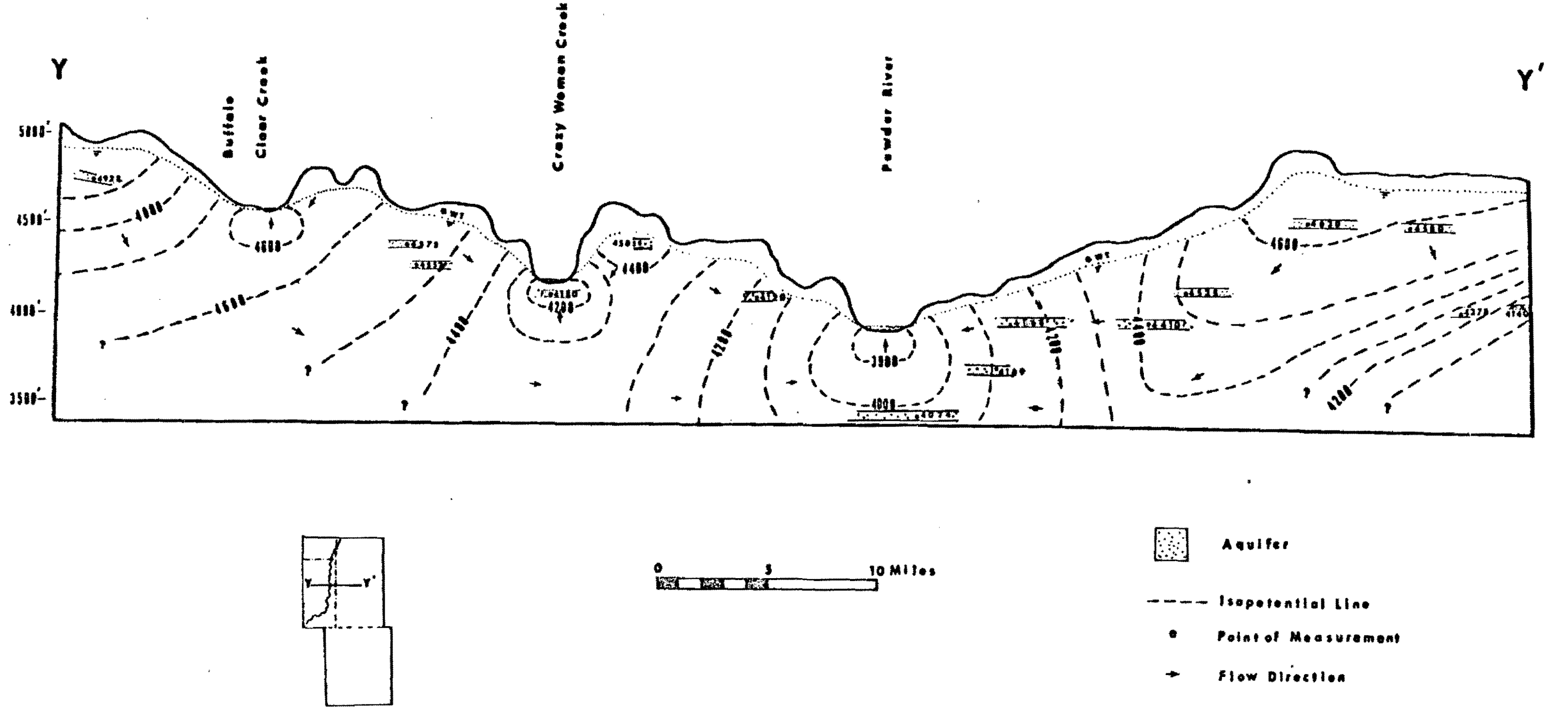


Fig. 15.--Pattern of regional groundwater flow in the north central Powder River Basin, Wyoming.

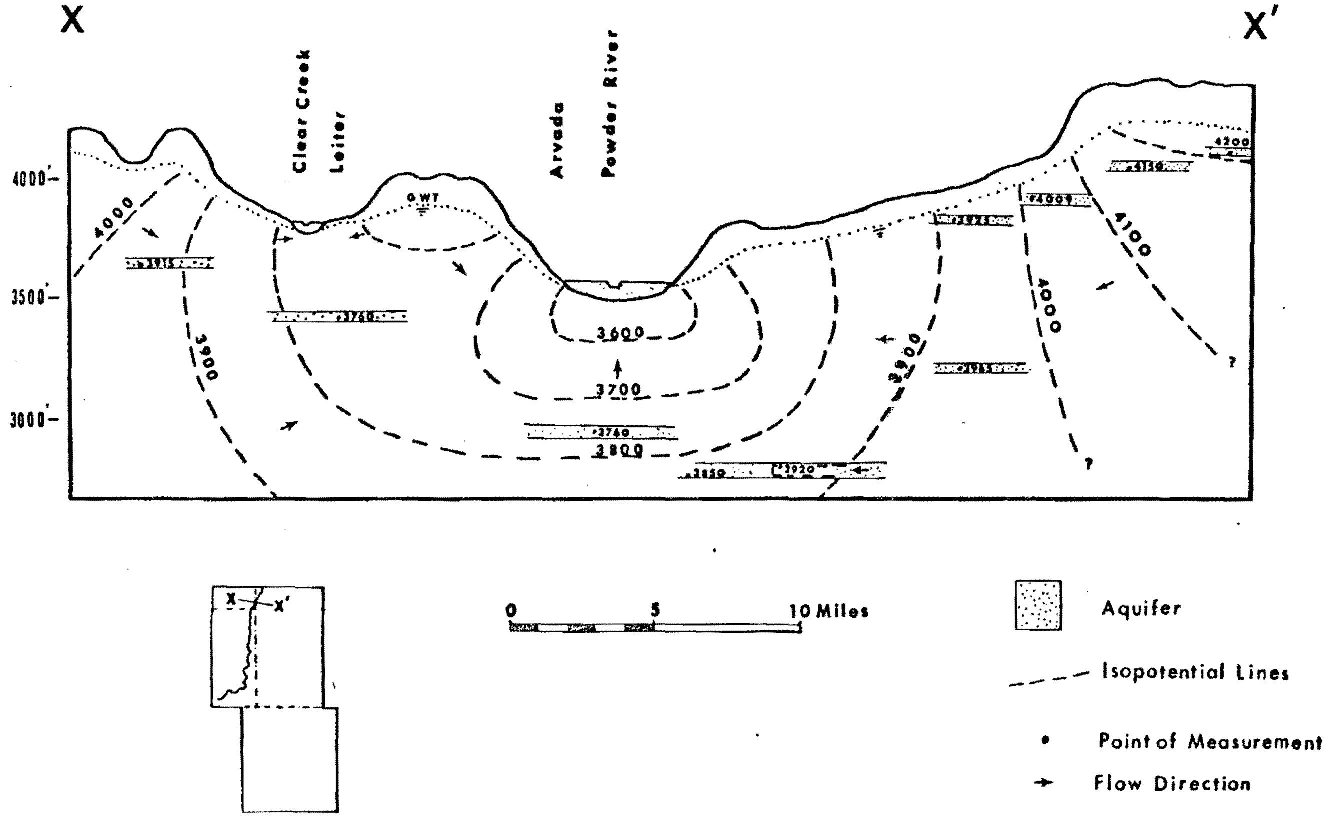


Fig. 16.--Pattern of regional groundwater flow in the northern Powder River Basin, Wyoming.

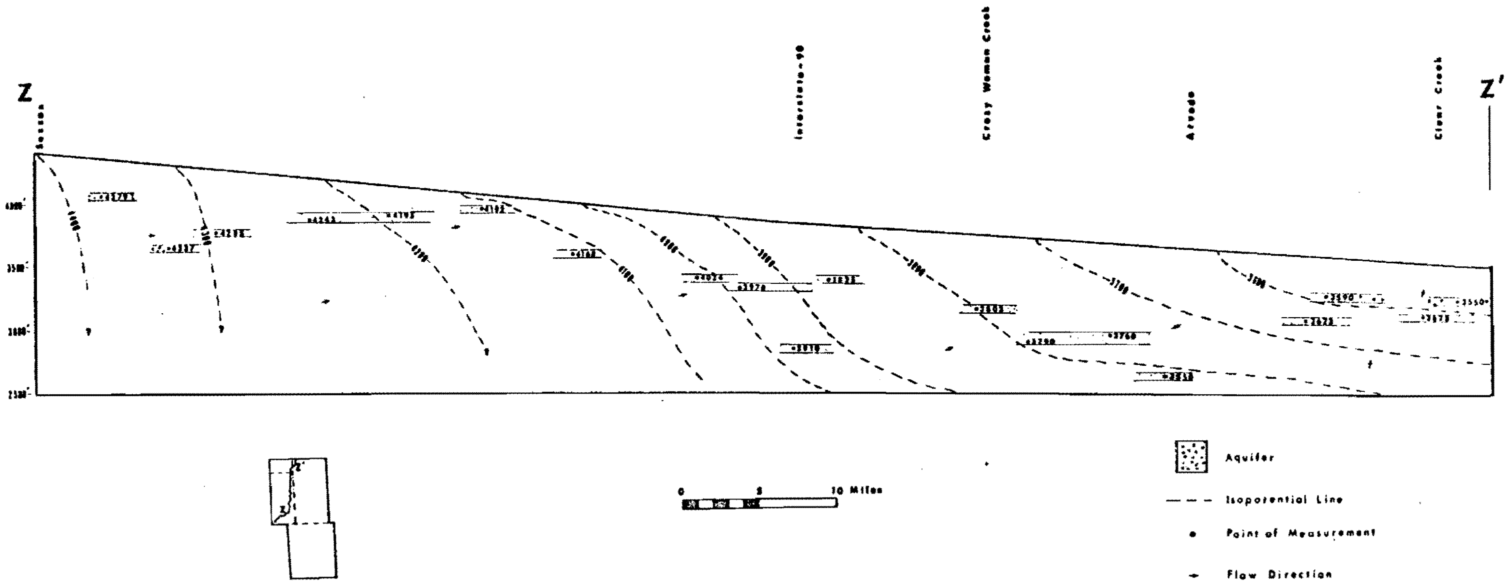


Fig. 17.--Pattern of regional groundwater flow along the Powder River from the southern to the northern Powder River Basin, Wyoming.

area approximately the same width as the valley bottom. Local and intermediate flow systems are shown beneath Crazy Woman Creek and Clear Creek (Figures 15 and 16). These flow systems are separate from the regional groundwater-flow system. Smaller, local flow systems are not shown on the cross sections.

The longitudinal section (Figure 17) shows that the longitudinal flow component decreases significantly to the north (downstream) resulting in an increased groundwater discharge. The increased discharge in this area may be caused by structure. Longitudinal groundwater movement is in a direction opposite that of the structural dip in the northern Powder River Basin. The structure likely causes the longitudinal flow component to be deflected toward the vertical, decreasing the longitudinal flow and increasing the upward flow.

Representative potential gradients for the Powder River drainage basin are given in Table 2. The largest flow components are the vertical and lateral components. If the mean of the representative gradients for each flow component given in Table 2 is used, the total flow vector along the Powder River discharge area is oriented at approximately 55 degrees to the longitudinal component. If the same reasoning is applied here as was applied in the Dry Fork Cheyenne River drainage basin, the total flow vector will be oriented at about 45 degrees to the horizontal plane in a vertical plane. The lateral flow component is larger than the longitudinal flow component because of the large elevation difference between the river valley and the surrounding topography.

TABLE 2.--Representative values of the potential gradient with respect to the flow components for the Powder River drainage basin

Flow Component	Ranges of Values (ft./ft.)
Lateral Component	3×10^{-3} to 5×10^{-3}
Longitudinal Component	1×10^{-3} to 3×10^{-3}
Vertical Component	3×10^{-1} to 5×10^{-1}

In summary, the regional groundwater-flow systems in the Powder River Basin are recharged on the eastern, western, and southern margins of the basin. The largest recharge area is the southern Powder River Basin. The regional groundwater movement is generally in the same direction as structural dip, toward the central axis of the basin. Exceptions occur in the northern end of the basin where the longitudinal flow component moves in a direction opposite that of structural dip and in the southeastern part of the basin where the longitudinal flow component associated with the Dry Fork Cheyenne River drainage basin moves in a direction opposite that of the structural dip. The valley of the Powder River is the most significant topographic low in the Powder River Basin and is therefore the discharge area for the regional groundwater-flow systems. The Powder River influences the groundwater flow down to a depth of at least 2,000 feet below its valley.

Groundwater Flow During the Tertiary Period

The present-day groundwater flow supports the model presented in Chapter IV. The drainage was to the north-northeast throughout the Tertiary Period and present-day drainage is to the north-northeast. The groundwater of the Tertiary was driven by a potential gradient from south to north similar to that of present-day groundwater flow, and their recharge and discharge areas are similar.

Differences between the geomorphology of the Tertiary Period and the geomorphology of today caused some significant differences between past and present-day groundwater flow. The present-day topography is one of erosion. It is characterized by high relief and deeply dissected river valleys. The Tertiary topography was one of deposition. It was characterized by low relief and rivers with low, wide valleys.

These differences in geomorphology were responsible for some differences in groundwater flow. For example, during the Tertiary Period, the lateral and vertical flow components, which are dominant in present-day flow systems, were less important and the longitudinal flow component was dominant. This occurred because the lateral and vertical potential gradient created by river valleys was decreased significantly in comparison to the longitudinal component, because the relief between recharge areas and river valleys was not large. A somewhat similar situation was described earlier for the flow systems in the Dry Fork Cheyenne River drainage basin where relief between local recharge areas and the river valleys was much less than that in the Powder River drainage basin. Here the longitudinal flow component is greater than the lateral flow component.

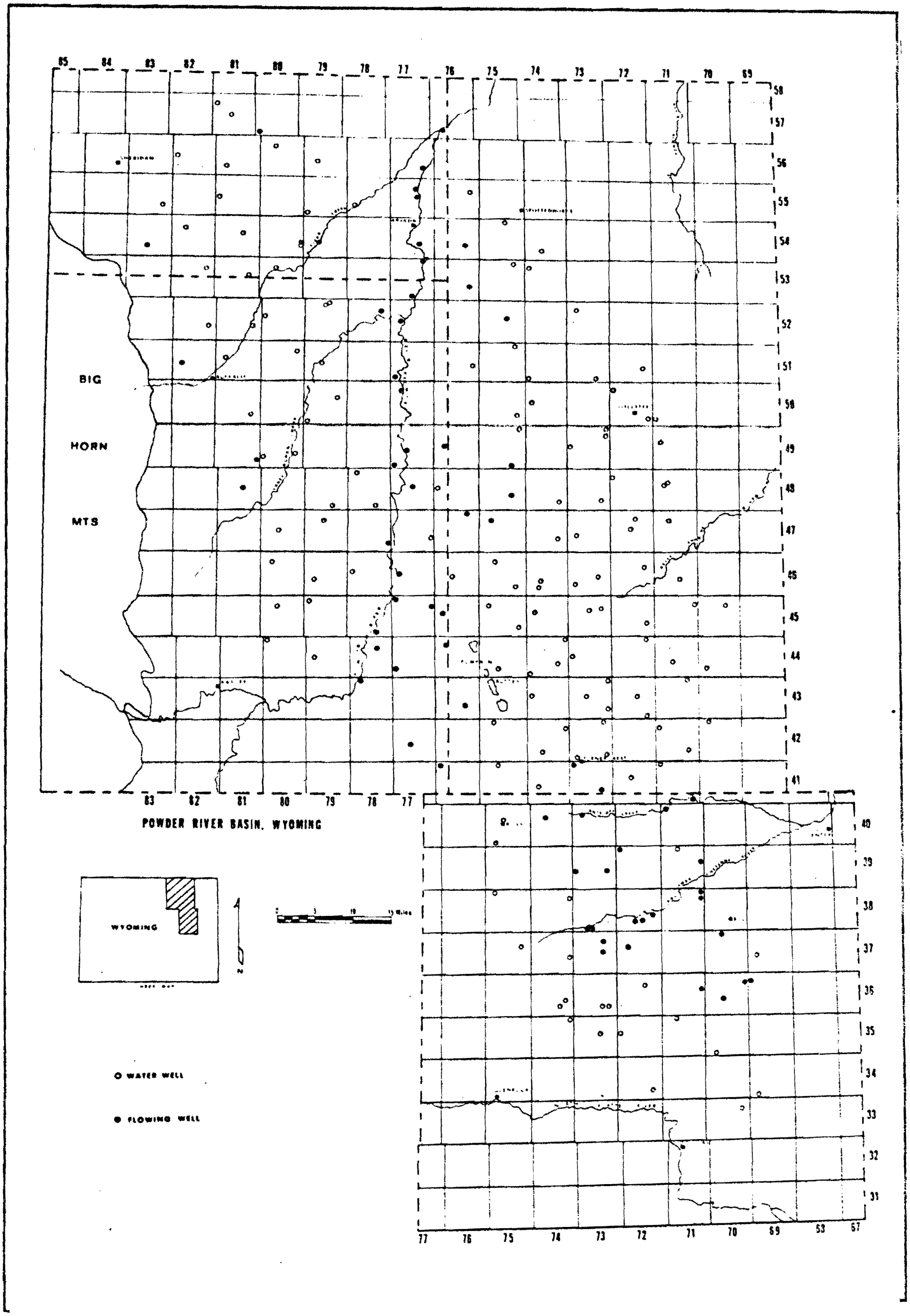
In summary, the regional groundwater-flow systems of the past were recharged around the eastern, western, and southern margins of the Powder River Basin. The southern part of the basin was the most significant groundwater recharge area. The total flow vector of the regional groundwater flow was oriented in a northerly direction parallel to the surface drainage systems and the longitudinal flow component. The longitudinal flow component was deflected upward in the northern part of the basin where flow was in a direction opposite that of structural dip. The resulting increase of the vertical component and decrease of the longitudinal component likely created a regional groundwater discharge area in the northern Powder River Basin during the Tertiary Period.

Groundwater Chemistry

Chemical analyses of 208 groundwater samples were made during this study. Of the 208 samples, 140 were collected from deep water sources (depths greater than 200 feet). The remaining 68 were collected from shallow water sources and springs (depths less than 200 feet). An attempt was made to collect the water samples on 6-mile centers throughout the Powder River Basin. In some locations this density was exceeded while in others it was not achieved, depending on the availability of wells. The distribution of the wells sampled is illustrated in Figure 18. The results of the groundwater chemical analyses are listed by well in Appendix C.

Three distinct groundwater divisions have been established on the basis of the groundwater chemistry and the associated sediments from which the water was collected. The three divisions are shallow groundwater, deep groundwater from the Wasatch Formation, and deep groundwater from the Fort Union Formation.

Fig. 18.--Map showing the location of water wells from which data was collected.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38
37
36
35
34
33
32
31
BIG
HORN
MTS
SHERIDAN
83
82
81
80
79
78
77
POWDER RIVER BASIN, WYOMING
WYOMING
N
0
5
10
15 Miles
O WATER WELL
● FLOWING WELL
77
76
75
74
73
72
71
70
69
68
67

Shallow Groundwater

The shallow groundwater samples were collected from both the Wasatch and Fort Union Formations at depths of less than 200 feet. The chemistry of all samples from the shallow groundwater unit is summarized in Figure 19. The water is classified as calcium-sodium, bicarbonate-sulfate water in the recharge areas of the southern Powder River Basin grading to a calcium-sodium, sulfate-bicarbonate water in the northern recharge areas. In local discharge areas the shallow groundwater is generally of the sodium-calcium, bicarbonate-sulfate type.

The variation of sulfate with respect to bicarbonate is shown by Figure 20. A trend toward an increase in sulfate in recharge areas toward the north is apparent. There is no apparent trend in the discharge areas. One reason is that some wells in the discharge areas intersect local flow paths, whereas others are influenced by deeper groundwater-flow paths.

Generally the wells in the shallow groundwater intersect short and shallow groundwater-flow paths. This is reflected in the variability of the water chemistry which is summarized in Figure 19. The groundwater motion of the shallow groundwater is affected more by local topography than are any of the deeper groundwater units.

A major distinguishing factor between shallow groundwater and underlying deeper groundwater is hardness. The shallow groundwater is hard (high in calcium and magnesium). The hard water gradually becomes soft (high in sodium and potassium) with increasing depth in recharge areas.

Some of the highest values of total dissolved solids were obtained from the shallow groundwater. This is an indication of

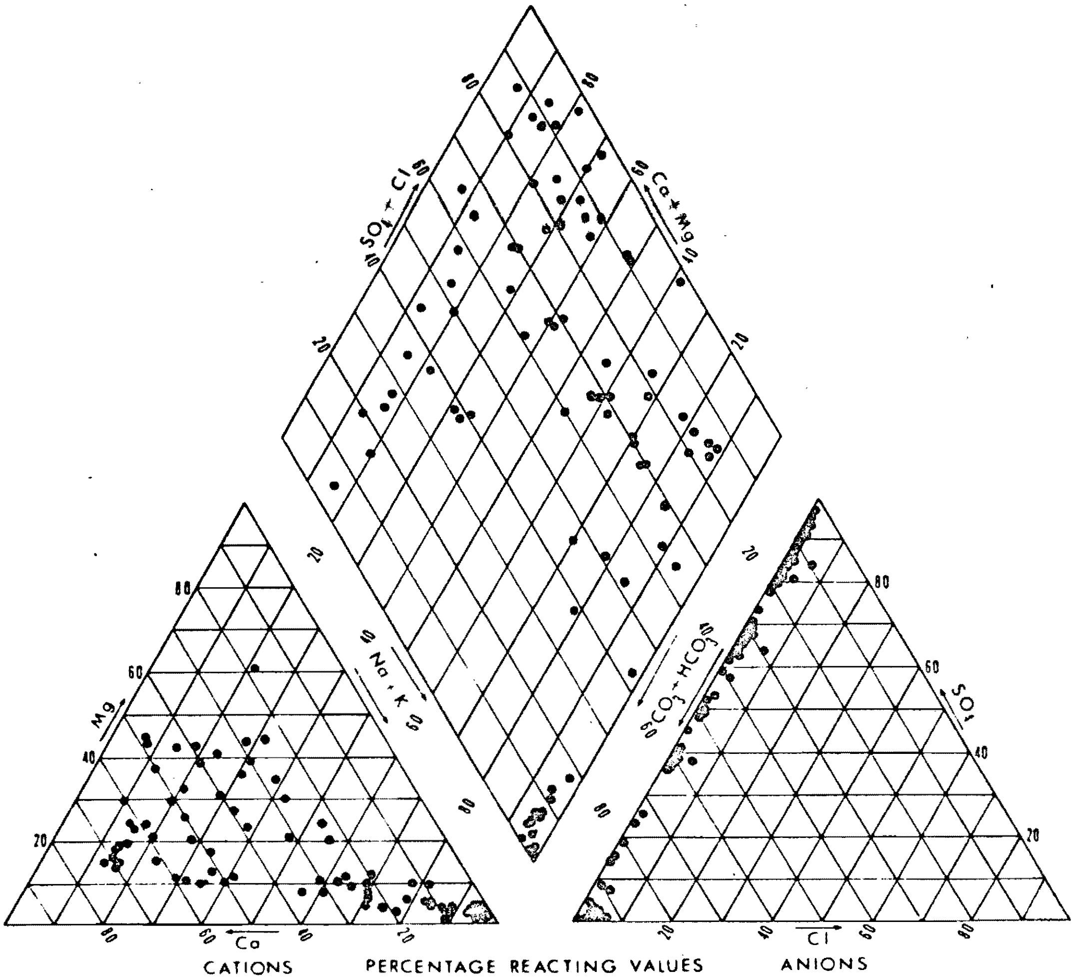
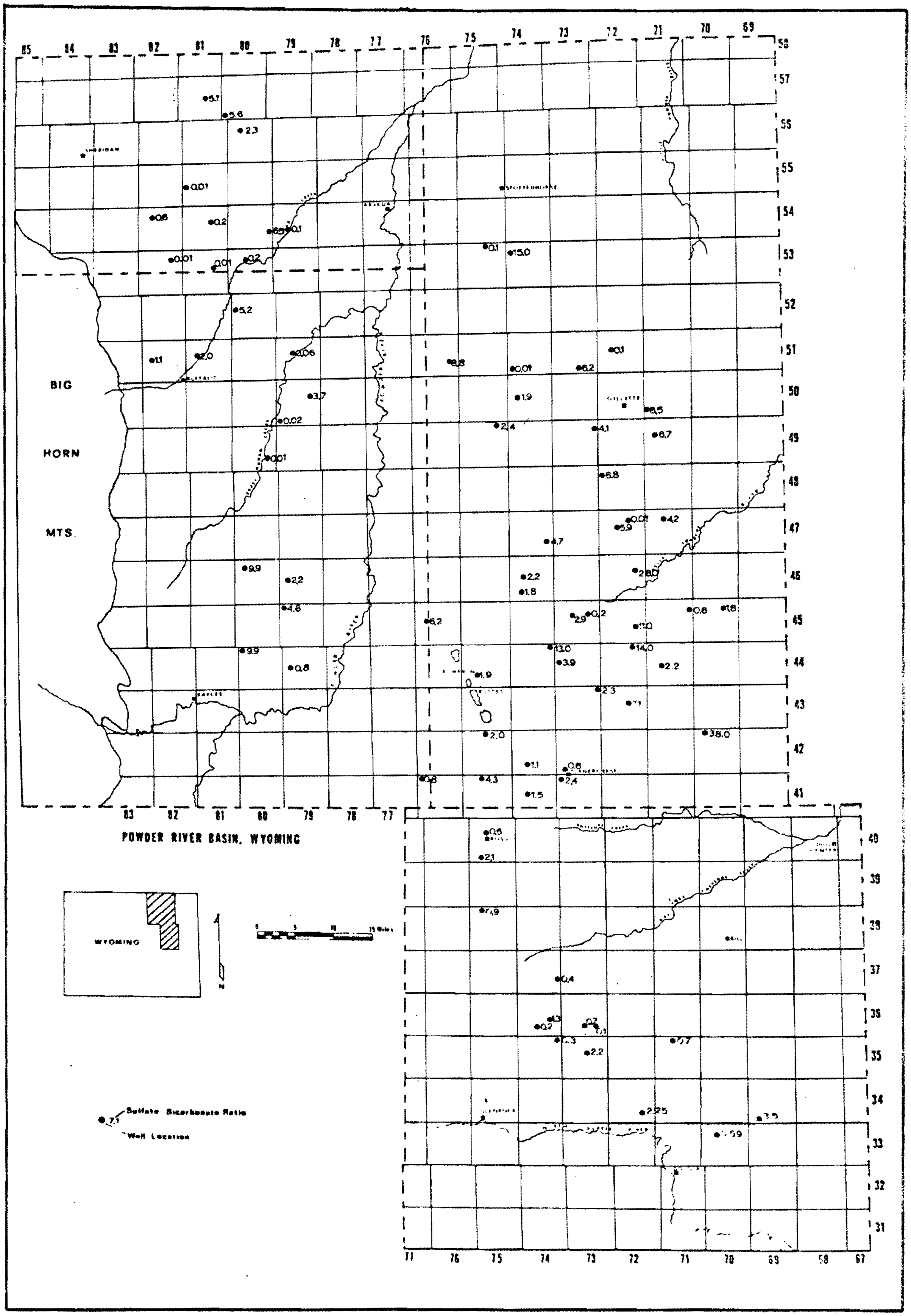


Fig. 19.--Chemical-analysis diagram of shallow groundwater from both the Wasatch and Fort Union Formations.

Fig. 20.--Map showing variation of the sulfate-bicarbonate ratio in shallow groundwater from the Wasatch and Fort Union Formations.


POWDER RIVER BASIN, WYOMING
BIG
HORN
MTS.
WYOMING
N
0
5
10
15 Miles
Sulfate Bicarbonate Ratio
7.1
Well Location
85
84
83
82
81
80
79
78
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74
73
72
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33
32
31
5.1
5.6
2.3
0.01
0.6
0.2
6.5
0.1
0.01
0.01
0.2
0.1
15.0
5.2
1.1
2.0
0.06
8.8
0.01
6.2
0.1
3.7
1.9
8.5
0.02
2.4
4.1
6.7
0.01
6.8
0.01
4.2
5.9
4.7
9.9
2.2
2.2
2.8
1.8
4.6
6.2
2.9
0.2
0.6
1.6
1.0
9.9
0.8
13.0
14.0
3.9
2.2
1.9
2.3
7.1
2.0
38.0
1.1
0.6
0.8
4.3
2.4
1.5
0.5
2.1
4.9
0.4
1.3
0.2
0.7
0.1
1.3
2.2
0.7
2.25
3.5
1.59

abundant soluble salts and a lack of mineral precipitation (diagenetic cementation) in the shallow sediments. Anions and cations other than those mentioned are in most cases evenly distributed throughout the groundwater unit.

The primary characteristics of the shallow groundwater are its hardness and its large amount of total dissolved solids. Table 3 summarizes the chemical aspects of the shallow groundwater in both recharge and discharge areas. The values from recharge areas rather than discharge areas are considered representative of the shallow groundwater because of the possible influence of deeper groundwater flow paths in the discharge areas.

Deep Groundwater from the Wasatch Formation

The deep groundwater from the Wasatch Formation is slightly different from the stratigraphically higher shallow groundwater. The deeper groundwater generally has an increase in pH, fluoride, sodium, and potassium; a slight decrease in total dissolved solids, sulfate, and bicarbonate; and a substantial decrease in calcium and magnesium. The chemistry of all deep groundwater samples from the Wasatch is summarized in Figure 21. The groundwater is classified as sodium-calcium, sulfate-bicarbonate water throughout most of the recharge areas. Calcium is the dominant cation in many samples but there does not appear to be a pattern to its occurrence. Locally in the southern Powder River Basin the groundwater is of the sodium-calcium, bicarbonate-sulfate type. These areas generally correspond to the same areas where the shallow groundwater is bicarbonate-rich. In regional discharge areas such as the Powder River, the groundwater of the Wasatch Formation ranges from a sodium bicarbonate-sulfate to a sodium-bicarbonate water.

TABLE 3.--Summary of the chemistry of shallow groundwater, Powder River Basin, Wyoming.

Ions	Location in Flow System	No. of Samples	Range (ppm)	Mean (ppm)	Median (ppm)
Bicarbonate + Carbonate	Recharge	66	20.00-1040	327	286
	Discharge	18	92.00- 748	507	548
Sulfate	Recharge	66	1.00-6000	933	525
	Discharge	18	0.50-1800	303	70
Chloride	Recharge	66	1.00- 131	10	6
	Discharge	18	1.50- 30	9	8
Fluoride	Recharge	66	0.05- 1.7	0.63	0.60
	Discharge	18	0.40- 1.6	0.95	0.97
Calcium + Magnesium	Recharge	66	9.00-1231	240	164
	Discharge	18	6.00- 198	68	26
Sodium + Potassium	Recharge	66	23.00- 860	244	190
	Discharge	18	126.00- 828	360	326
Silica	Recharge	66	2.00- 33	13	11
	Discharge	18	5.00- 19	10	10
Total Dissolved Solids	Recharge	66	297.00-7960	1541	1030
	Discharge	18	369.00-3030	1005	815
pH	Recharge	66	5.80- 9.4	7.5	7.5
	Discharge	18	7.20- 9.1	8	8.1

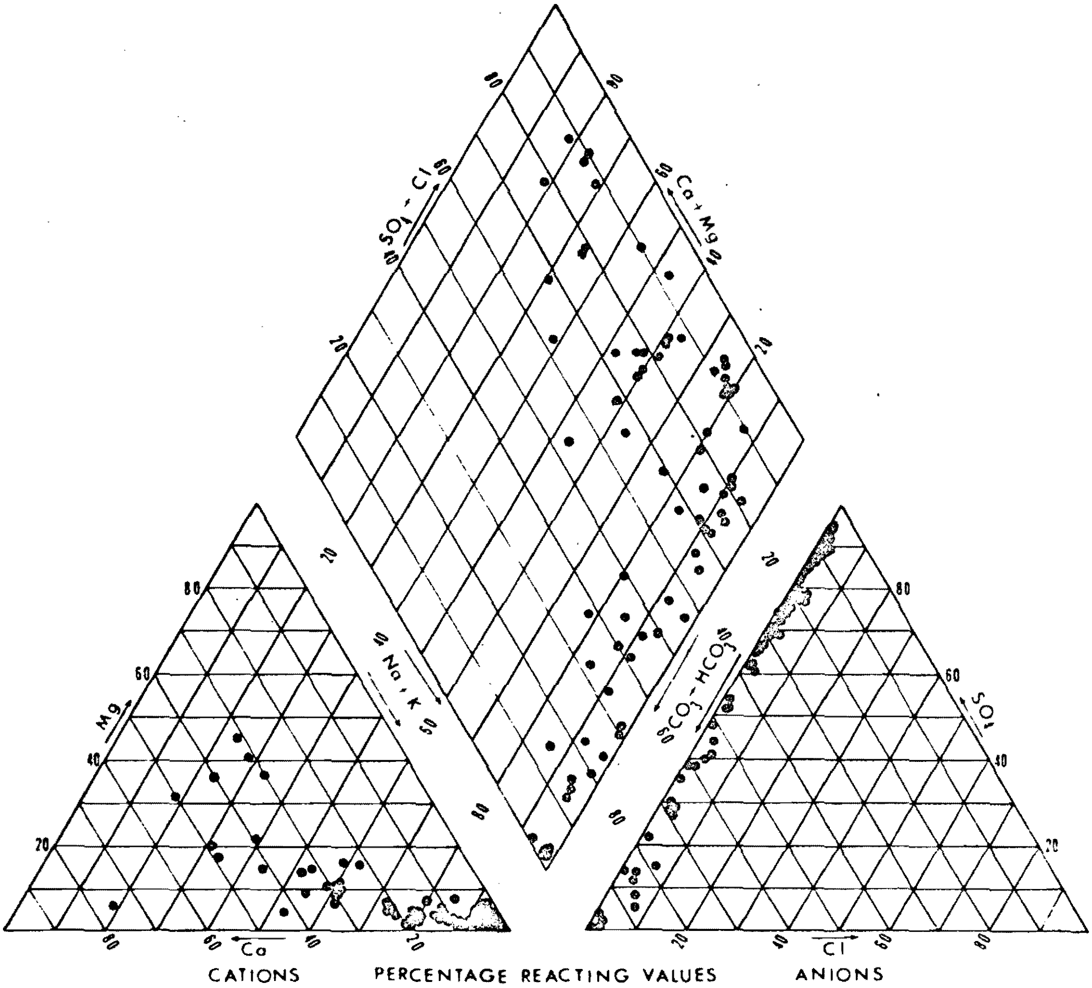


Fig. 21.--Chemical-analysis diagram of deep groundwater from the Wasatch Formation.

TABLE 4.--Summary of the chemistry of groundwater from depths greater than 200 feet in the Wasatch Formation

Ions	Location in Flow System	No. of Samples	Range (ppm)	Mean (ppm	Median (ppm)
Bicarbonate + Carbonate	Recharge	47	84.00-1300	319	248
	Discharge	36	76.00-1080	288	205
Sulfate	Recharge	47	0.50-3125	812	700
	Discharge	36	0.50-2250	260	140
Chloride	Recharge	47	0.50- 33	9.6	6.3
	Discharge	36	1.00- 20	7.3	6.5
Fluoride	Recharge	47	0.05- 1.2	0.71	0.7
	Discharge	36	0.05- 1.6	0.61	0.53
Calcium + Magnesium	Recharge	47	6.00- 810	162	124
	Discharge	36	3.00- 117	27	13
Sodium + Potassium	Recharge	47	37.00- 748	301	313
	Discharge	36	101.00- 768	239	200
Silica	Recharge	47	5.00- 16	9.2	9
	Discharge	36	6.00- 18	10	10
Total Dissolved Solids	Recharge	47	278.00-4550	1424	1200
	Discharge	36	328.00-3330	693	494
pH	Recharge	47	6.90- 8.9	7.8	7.8
	Discharge	36	7.50- 9.1	8.3	8.2

The regional distribution of sulfate as related to bicarbonate is shown in Figure 22. The decrease in sulfate, calcium, and total dissolved solids in the discharge areas (see Table 4) is related to the reduction and precipitation of the various constituents from solution. This will be discussed in detail in the next section.

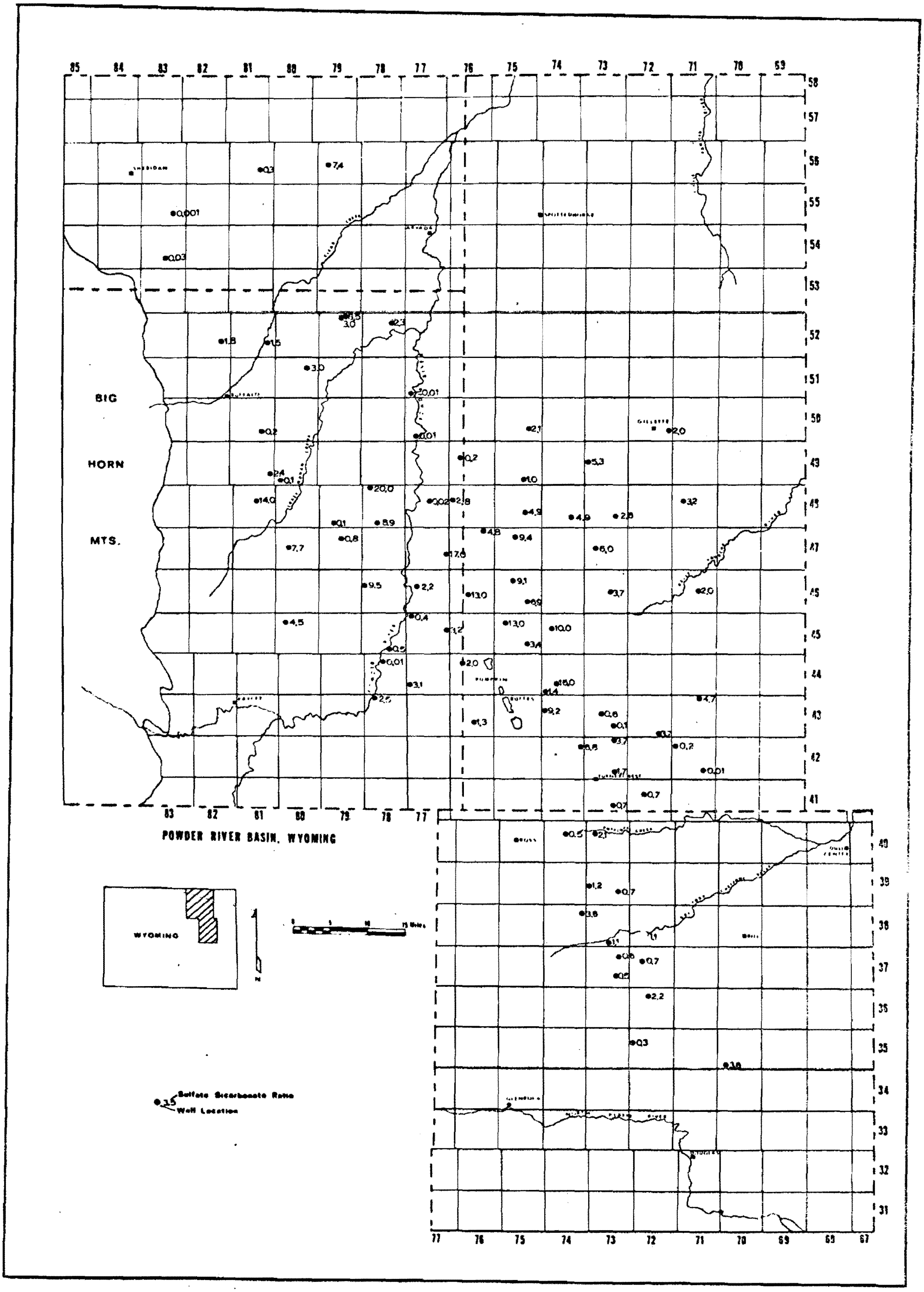
Base Exchange in Groundwater

Throughout the recharge areas in the Powder River Basin the groundwater becomes softer with increasing depth. The calcium and magnesium concentrations are apparently inversely related to depth and flow path length. A comparison of the groundwater units and their associated calcium and magnesium content in recharge areas is given in Table 5. The calcium and magnesium cations change from a dominant to a subordinate concentration relative to total cations somewhere between a depth of 200 and 300 feet.

TABLE 5.--Variation of calcium plus magnesium (expressed as percentage of total cations) with depth in recharge areas

Groundwater Unit	Number of Samples	Range of Values (%)	Mean (%)	Median (%)
Shallow Groundwater (<200 ft. deep)	66	4-93	58	67
Groundwater from Wasatch Formation (200 to 1,000 ft. deep)	47	3-83	36	37
Groundwater from Fort Union Formation (300 to 1,200 ft. deep)	8	3-18	9	10

Fig. 22.--Map showing variation of the sulfate-bicarbonate ratio in deep groundwater from the Wasatch Formation.


POWDER RIVER BASIN, WYOMING
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HORN
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N
Miles
Sulfate Bicarbonate Ratio
Well Location
3.5

Hamilton (1970) and Renick (1924) made similar observations in western North Dakota and east-central Montana. Hamilton (1970, p. 94) found an abrupt change in total hardness between depths of 200 and 300 feet. The values he found below 300 feet in recharge areas were equivalent to those found in regional discharge areas along the Little Missouri River. A similar change occurs in the Powder River Basin. Hamilton attributed the change in calcium and magnesium to cation exchange in clay minerals and zeolites. An example of the general process involved in the exchange of solid-phase sodium for dissolved calcium is

$$2NaX + Ca^{++} \rightleftharpoons CaX_2 + 2Na^{+} \qquad (17)$$

where the X is a unit of exchange capacity in the solid phase material. In this process sodium is easily exchanged for calcium even in very dilute solutions of calcium. However, the reverse reaction requires a very high concentration of sodium in solution. For example, if the solid phase in the above reaction is a zeolite, an equilibrium is not established until the ratio of calcium concentration to sodium concentration is much less than 1 (Krauskopf, 1967, p. 152).

Hamilton (1970, p. 98) suggested an explanation for the cause of the 200-foot thickness of the calcium-magnesium groundwater facies:

> A reasonable explanation of the thickness of this zone of groundwater rich in Ca^{++} and Mg^{++} is that it is a result of the near-exhaustion of the exchange capacity of the sediment. The water chemistry reflects the present position of a downward migrating front of altered sediment (the originally Na-rich clays and zeolites have been altered to Ca types), with the most complete alteration occurring near the surface.

In addition to the cation-exchange process, precipitation of calcium-carbonate cement is an important process in the removal of calcium from groundwater in the Powder River Basin. As mentioned earlier in the description of the Wasatch Formation, sandstone masses cemented by calcium carbonate are common throughout the Wasatch Formation. The distribution of organic material in the sediments is likely an influencing factor. Methane gas associated with concentrations of organic material precipitates carbonate cement according to the following simplified reactions postulated by Eaton (1963, p. 515):

$$CaSO_4 + CH_4 \rightleftharpoons CaCO_3 + H_2S + H_2O, \tag{18}$$

$$MgSO_4 + CH_4 \rightleftharpoons MgCO_3 + H_2S + H_2O. \tag{19}$$

Gases, such as methane (CH_4) are common in water from wells in the Wasatch Formation, especially those completed in or near lignite. Hydrogen sulfide (H_2S) is even more common than methane.

Deep Groundwater from the Fort Union Formation

A plot of the chemical constituents in the groundwater from the Fort Union Formation is presented in Figure 23. The groundwater occurring at this stratigraphic level is a sodium-bicarbonate type.

Sulfate, calcium, and magnesium are essentially absent throughout the deep groundwater of the Fort Union Formation. The absence of sulfate, calcium, and magnesium contrasts sharply with the chemistry of the groundwater moving into the Fort Union Formation from the overlying Wasatch Formation. The spatial distribution of the occurrence of sulfate relative to bicarbonate in the Fort Union Formation is shown in Figure 24. There is a decrease in the concentration of total dissolved solids and chloride, a slight increase in the pH and in the sodium and potassium concentration,

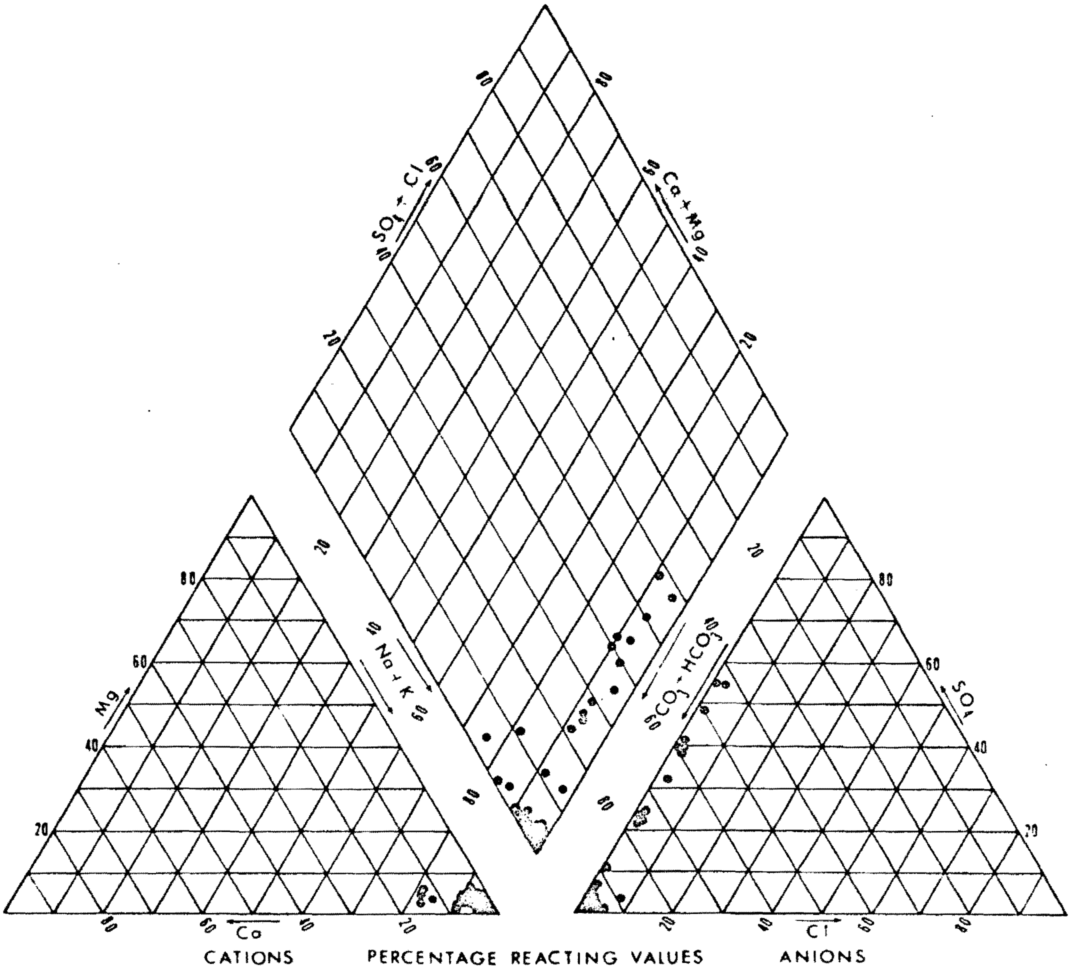
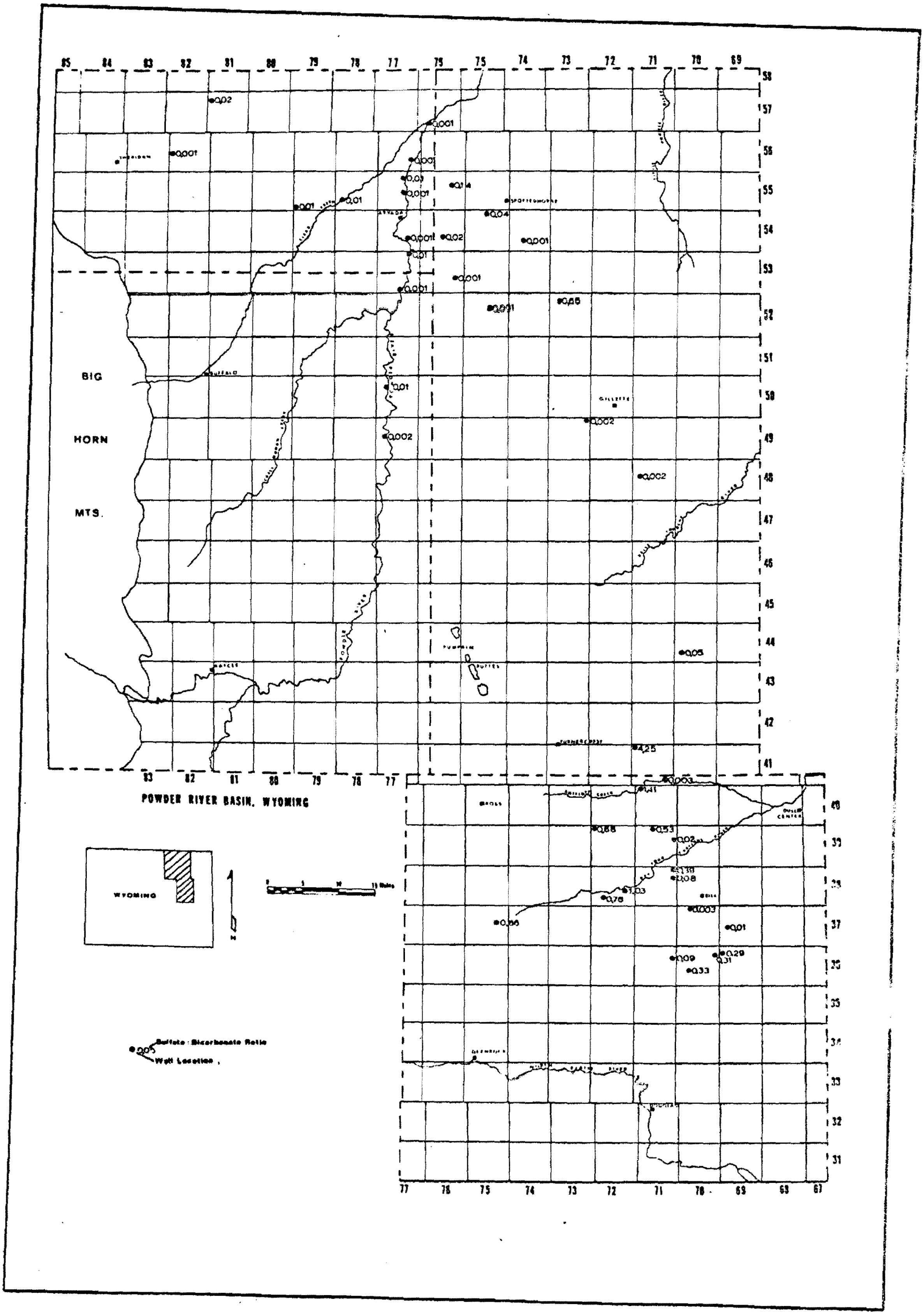


Fig. 23.—Chemical-analysis diagram of deep groundwater from the Fort Union Formation.

Fig. 24.--Map showing variation of the sulfate-bicarbonate ratio in deep groundwater from the Fort Union Formation.


POWDER RIVER BASIN, WYOMING

and a substantial increase in the bicarbonate concentration relative to the groundwater flowing through the overlying Wasatch Formation (Table 6).

No lateral trend was observed in the spatial distribution of the various ions in the groundwater from the Fort Union Formation.

In recharge areas, sulfate, as well as lesser amounts of calcium and magnesium, is present in the groundwater as it moves into the transition zone between the Wasatch Formation and Fort Union Formation. However, groundwater from the Fort Union Formation contains very little of these constituents. The only apparent explanation is that the sulfate, calcium, and magnesium are being removed as rapidly as they are being introduced into the sediments of the Fort Union Formation.

Before an explanation is presented for the process which removes the sulfate, calcium, and magnesium ions from the groundwater, two major differences between the Wasatch and Fort Union Formations will be outlined. (1) The Fort Union Formation consists predominantly of reworked sediments from the Paleozoic and Mesozoic systems. In contrast, the Wasatch Formation consists mostly of first-generation sediments that were eroded from the igneous cores of nearby mountains. (2) The Fort Union Formation contains far more organic material and lignite than the Wasatch Formation.

It is likely that the more soluble minerals in the reworked sediments of the Fort Union Formation were removed in the process of erosion and redeposition. If this reasoning is correct it explains why there is little change in the concentration of deep groundwater constituents between recharge and discharge areas of the Fort Union Formation (Table 6). The more stable minerals of the Fort Union Formation simply do not readily go into solution.

TABLE 6.--Summary of the chemistry of groundwater from depths greater than 200 feet in the Fort Union Formation

Ions	Location in Flow System	No. of Samples	Range (ppm)	Mean (ppm)	Median (ppm)
Bicarbonate + Carbonate	Recharge	8	174.00-1430	675	667
	Discharge	33	161.00-1410	645	568
Sulfate	Recharge	8	0.50- 375	77	23
	Discharge	33	0.50- 750	52	5
Chloride	Recharge	8	0.50- 24	5.9	4.2
	Discharge	33	0.30- 16	4.8	4.5
Fluoride	Recharge	8	0.48- 1	0.63	0.58
	Discharge	33	0.20- 2.6	1.2	1.0
Calcium + Magnesium	Recharge	8	11.00- 71	40	36
	Discharge	33	5.00- 147	19	12
Sodium + Potassium	Recharge	8	43.00- 665	409	400
	Discharge	33	67.00- 634	327	272
Silica	Recharge	8	7.50- 13	8.9	8.3
	Discharge	33	6.00- 16	10	10
Total Dissolved Solids	Recharge	8	294.00-1380	845	850
	Discharge	33	259.00-1300	742	681
pH	Recharge	8	7.50- 8.3	7.8	7.7
	Discharge	33	7.60- 8.7	8.1	8.1

Lignite and other organic material in the Fort Union Formation have large amounts of gas associated with them. This is evident where gas and water are discharged together from wells which penetrate zones of lignite and organic concentrations. The gas is composed primarily of methane with lesser amounts of oxygen, nitrogen, carbon dioxide, ethane, propane, isobutane, and the higher parrafin hydrocarbons (Lowry and Cummings, 1966, p. 46). Hydrogen sulfide is also present in most wells. I tested for hydrogen sulfide only where the groundwater was suspected to contain it and therefore did not include it in the chemical analysis data in the Appendix. The screening method was used to test for hydrogen sulfide (Water and Wastewater Procedures, 1967, p. 34). The values found range between 0 and 5 ppm. These values are similar to those reported by Lowry and Cummings (1966, p. 31) for groundwater from the Fort Union Formation. Lowry and Cummings (1966, p. 46) also reported chromatographic analysis of gas from several water wells completed in the Fort Union Formation; their data is presented in Table 7.

There are two likely origins of the hydrocarbon gases. (1) The gas may be produced by the coalification process associated with the formation of lignite. Lewis (1934) stated that carbon dioxide and methane in coal are being formed continuously, primarily by internal molecular adjustment during transitions from rank to rank in the coal series. (2) The gas may also be produced by the anaerobic decay of organic compounds. The organic compounds can be either the lignite or organic material in the sediment. Lignite contains a larger percentage of carbon and smaller amounts of hydrogen, oxygen, and nitrogen than the uncoalified organic material.

TABLE 7.--Quantity and quality of gas discharged with water from the Fort Union Formation[a]

Well Location	Gas-Water Ratio	Percentage Composition (by volume)						
		Oxygen (O_2)	Nitrogen (N_2)	Carbon Dioxide (CO_2)	Methane (CH_4)	Ethane (C_2H_6)	Propane (C_3H_8)	Isobutane (C_4H_{10}) and higher paraffin hydrocarbons
54-76-5ac	- - -	0.14	8.87	0.37	90.66	0.02	trace	trace
54-77-5db	0.5	0.63	8.69	0.47	90.10	0.08	0.03	trace
57-76-20bd	0.3	4.82	23.13	0.78	71.18	0.07	0.02	trace
58-82-30aa	2.2	1.03	6.14	0.94	91.82	0.07	- - -	trace

[a] Data from Lowry and Cummings (1966, p. 46).

The anaerobic decay process is the likely cause of much of the gas in the Fort Union Formation because hydrogen sulfide is found in most wells. Certain anaerobic bacteria are known to be capable of producing hydrogen sulfide at rapid rates (Feely and Kulp, 1957, p. 1809). Both processes probably contribute to the production of hydrocarbon gases in the Fort Union and lower Wasatch Formations.

Sulfate Reduction in Groundwater

The reduction of sulfate to sulfide is responsible for the removal of sulfate, calcium, and magnesium from the groundwater as it passes from the Wasatch into the Fort Union Formation. This process also results in an increase in bicarbonate and generally explains most of the anomalies associated with the groundwater of the Fort Union Formation. In the presence of organic material, sulfate is reduced by methane (CH_4), the simplest organic compound. Krauskopf (1967, p. 276) presents the following reduction reaction in which sulfur is reduced from a +6 to -2 valence state:

$$2H^+ + SO_4^{--} + CH_4 \rightleftharpoons H_2S + CO_2 + 2H_2O, \quad \Delta F^o = -24.8 \text{ kcal.} \qquad (20)$$

This reaction is too slow to be significant in nature without the help of anaerobic bacteria, which use the reduction process as both a source of energy and oxygen (Krauskopf, 1967, p. 276).

Sulfate-reducing bacteria belong to a single genus Desulfovibrio. They are characterized by their use of sulfate ions in place of elemental oxygen as a hydrogen acceptor for the oxidation of their energy source and are therefore anaerobic. That is, they require a sulfate source instead of atmospheric oxygen (Feely and kulp, 1957, 1809). The optimum conditions for Desulfovibrio growth are pH values between 6.3 and 8.6 and sulfate concentration of 0.96 gram per liter (960 ppm) (conditions described in studies by Postgate, 1951, as quoted by Feely and Kulp, 1957, p. 1809). *Desulfovibrio* have a wide distribution in nature. They may be found wherever organic material and sulfate are available. They have been reported to occur at depths exceeding 1,500 feet (Feely and Kulp, 1957, p. 1810). The Fort Union Formation in the Powder River Basin is a likely place for sulfate reducing bacteria to exist. The Fort Union Formation contains abundant organic material, has an average pH of 8.3, and has an average sulfate concentration in water entering the Fort Union Formation of 812 ppm, all of which are nearly optimum for *Desulfovibrio* growth. In addition, hydrogen sulfide, a product of sulfate reduction, occurs in most water wells which are completed in the Fort Union Formation. The ingredients necessary for sulfate reduction are available in the Fort Union Formation, and the groundwater chemical data indicates that sulfate is being reduced.

The likelihood of sulfate-reducing bacteria in the Powder River Basin is supported by the work of Jensen (1968), Cheney and Jensen (1966), and Austin (1970). They have shown that hydrogen sulfide of biogenic origin likely provided the sulfur for the pyrite (FeS_2) that is directly associated with many Wyoming uranium deposits. This same hydrogen sulfide may have been the reducing agent which caused the precipitation of the uranium. In contrast, a study by Granger and Warren (1969) has shown that the pyrite in association with uranium may form in the absence of bacteria. However, it should be pointed out that even though the bacteria are not directly related to the reduction of uranium in this case, the initial reduction of sulfate by bacteria is a necessary part of their concept.

I am not aware of any sulfur isotope studies which have been made in the Powder River Basin. Such a study would be useful because it would give some insight into the role of bacteria in sulfate reduction in the Powder River Basin

The reduction of sulfate is the initial step in a complete alteration of the groundwater chemistry. The products of sulfate reduction indicated in equation 20 are carbon dioxide (CO_2), water (H_2O), and hydrogen sulfide (H_2S). If the carbon dioxide and water are considered to be the metabolic products of sulfate-reducing bacteria, then the heat loss (24.8 kcal) would be the amount of energy utilized by the bacteria in the reduction process. The hydrogen sulfide produced is a weak acid and can dissociate:

$$H_2S \leftrightharpoons H^+ + HS^-. \tag{21}$$

Dissociation generally happens in reducing solutions with pH values greater than 7 (Krauskopf, 1967, p. 271). However, if ionization is incomplete, hydrogen sulfide remains as a dissolved gas. Measurements of hydrogen sulfide as a dissolved gas in groundwater from the Fort Union Formation were described earlier. The hydrogen sulfide is also capable of precipitating many heavy metal ions (Krauskopf, 1967, p. 271). One of particular interest in this study is uranium. It will be discussed in the next chapter.

Carbon dioxide, another product of equation 20, combines with water to form carbonic acid (H_2CO_3), which subsequently ionizes to form hydrogen (H^+) and bicarbonate (HCO_3^-):

$$H_2CO_3 \leftrightharpoons H^+ + HCO_3^-. \tag{22}$$

The hydrogen ions produced by equations 21 and 22 could result in the solution of calcium carbonate ($CaCO_3$) (if $CaCO_3$ is available)

$$CaCO_3 + H^+ \rightleftharpoons Ca^{++} + HCO_3^-. \qquad (23)$$

Hem (1959, p. 103) has presented a general synopsis of the individual reactions presented in equations 20 through 23 using a somewhat different approach, but producing the same products:

$$CaSO_4 + CH_4 \longrightarrow CaS + CO_2 + 2H_2O \qquad (24)$$

$$CaS + CO_2 + 2H_2O \longrightarrow H_2S + Ca(HCO_3)_2. \qquad (25)$$

Regardless of the approach used to illustrate sulfate reduction, its direct effect on groundwater chemistry is to decrease the sulfate concentration and to increase the bicarbonate and perhaps the calcium concentration. This readily explains the low sulfate and high bicarbonate concentrations in the groundwater of the Fort Union Formation.

The reactions also imply an increase in calcium. It was noted earlier that calcium and magnesium are practically nonexistent in deep groundwater of the Fort Union Formation. Cation exchange is one possible way to remove the calcium and magnesium ions. This process was discussed in the previous section. Hamilton (1970, p. 90) suggested zeolites as a likely exchange mechanism to remove calcium from groundwater under similar conditions in the Cannonball Formation of North Dakota. I do not think this mechanism can be applied to the groundwater in the Fort Union Formation because the ratio of calcium to sodium is less than 1 (Appendix F). It was noted earlier that the zeolite cation exchange is reversible when the concentration ratio of calcium to sodium is less than 1. A reversible reaction would decrease the likelihood of exchange of calcium in solution for solid-phase sodium and increase the likelihood of exchange of sodium in solution for solid-phase calcium resulting in an increase in calcium concentration.

The calcium and magnesium can be precipitated however, using sulfate reduction as a mechanism (equations 18 and 19). The reaction will precipitate calcium and magnesium carried into the sulfate reduction zone by groundwater and reprecipitate any calcite that may have been dissolved by weak acids in the reduction zone. The reaction as presented by Eaton (1936, p. 515) is restated below:

$$CaSO_4 + CH_4 \rightleftharpoons CaCO_3 + H_2S + H_2O. \qquad (26)$$

Evidence for calcite precipitated by sulfate reduction in a natural environment has been cited by Feely and Kulp (1957, p. 1837) in their report on salt-dome sulfur deposits. In the Powder River Basin the occurrence of calcite in uranium deposits, which are thought to have been deposited by sulfate-reducing bacteria (Langen and Kidwell, 1971, p. 9 and 13), suggests that sulfate reduction is a cause of calcite precipitation in the basin.

The net result of reactions 20 through 26 is a decrease in sulfate, calcium and magnesium concentration and an increase in bicarbonate concentration. These results are characteristic of the groundwater from the Fort Union Formation. The reaction scheme presented is believed to be a reasonable explanation of the observed chemical changes that occur in the Fort Union Formation.

Summary of Regional Groundwater Chemistry

The hydrochemical model presented in Chapter III does not apply to the Powder River Basin, as first predicted. Instead, the sequence is as follows:

$$HCO_3^- + SO_4^{--} \longrightarrow SO_4^{--} + HCO_3^- \longrightarrow HCO_3^-.$$

The sequence extends from regional recharge areas to regional discharge areas. It is illustrated in a north-south vertical cross section of the basin (Figure 25). An east-west vertical cross section, which also shows the variation in dominant anions, is illustrated in Figure 26. This cross section is located farther north than the $HCO_3^- + SO_4^{--}$ facies extends. Therefore, a general hydrochemical facies sequence in this area from recharge to discharge area is simply

$$SO_4^{--} + HCO_3^- \longrightarrow HCO_3^-.$$

A vertical cross section showing the dominant cation variation is given in Figure 27. It shows the shallow $Ca^{++} + Na^+$ facies grading into deeper $Na^+ + Ca^{++}$ facies, which finally becomes a Na^+ facies at about the location of the contact between the Fort Union and Wasatch Formations in the recharge area.

Generally, the groundwater with the highest values of sulfate and total dissolved solids in the Powder River Basin is from the areas of the shortest groundwater-flow path. Both constituents decrease in concentration with increasing flow-path length. This is contrary to what would be expected but may be generally explained by sulfate reduction. The bicarbonate and fluoride increase with increasing flow-path length. The increased bicarbonate is probably the result of secondary reactions related to sulfate reduction. Fluoride minerals have a relatively low solubility and consequently go into solution slowly. Higher concentrations of fluoride would therefore be expected in water that has been in contact with sediments for the greatest period of time. The high values of fluoride in water from wells in the valley of the Powder River, when compared to the low values from wells in recharge areas,

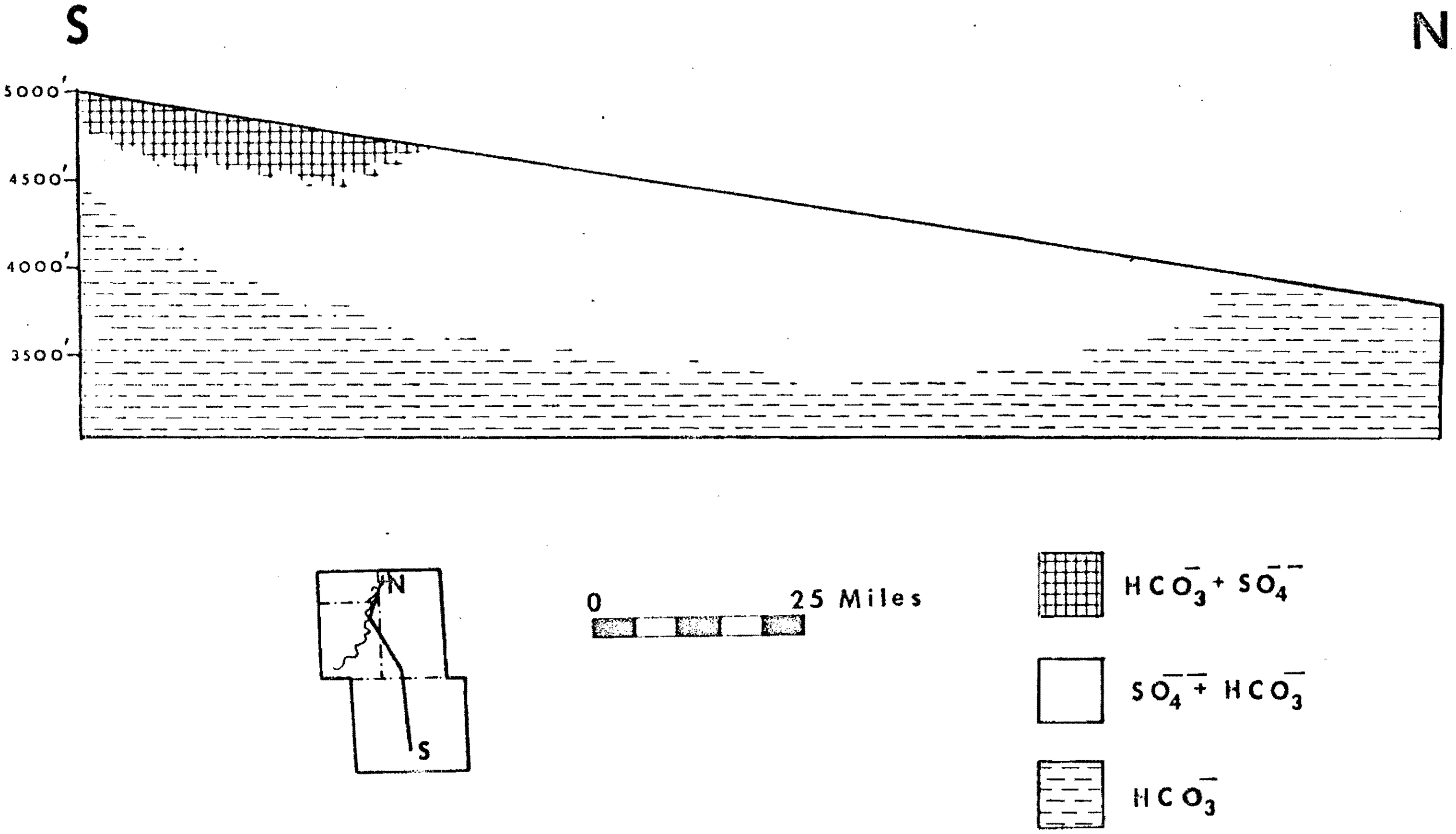


Fig. 25.--Cross section showing regional variation of the groundwater anion facies from the southern to the northern Powder River Basin, Wyoming.

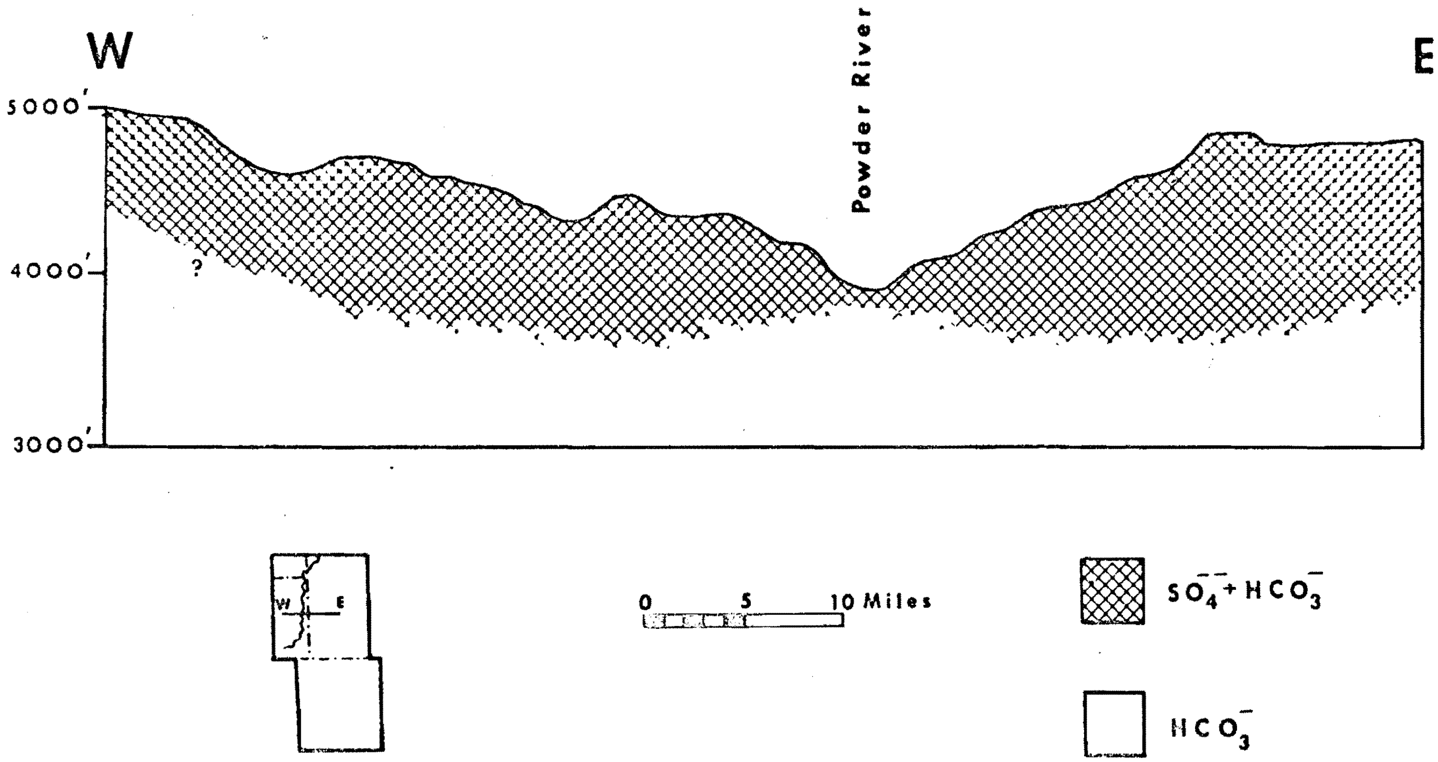


Fig. 26.--Cross section showing the variation of groundwater anion facies in the central Powder River Basin, Wyoming.

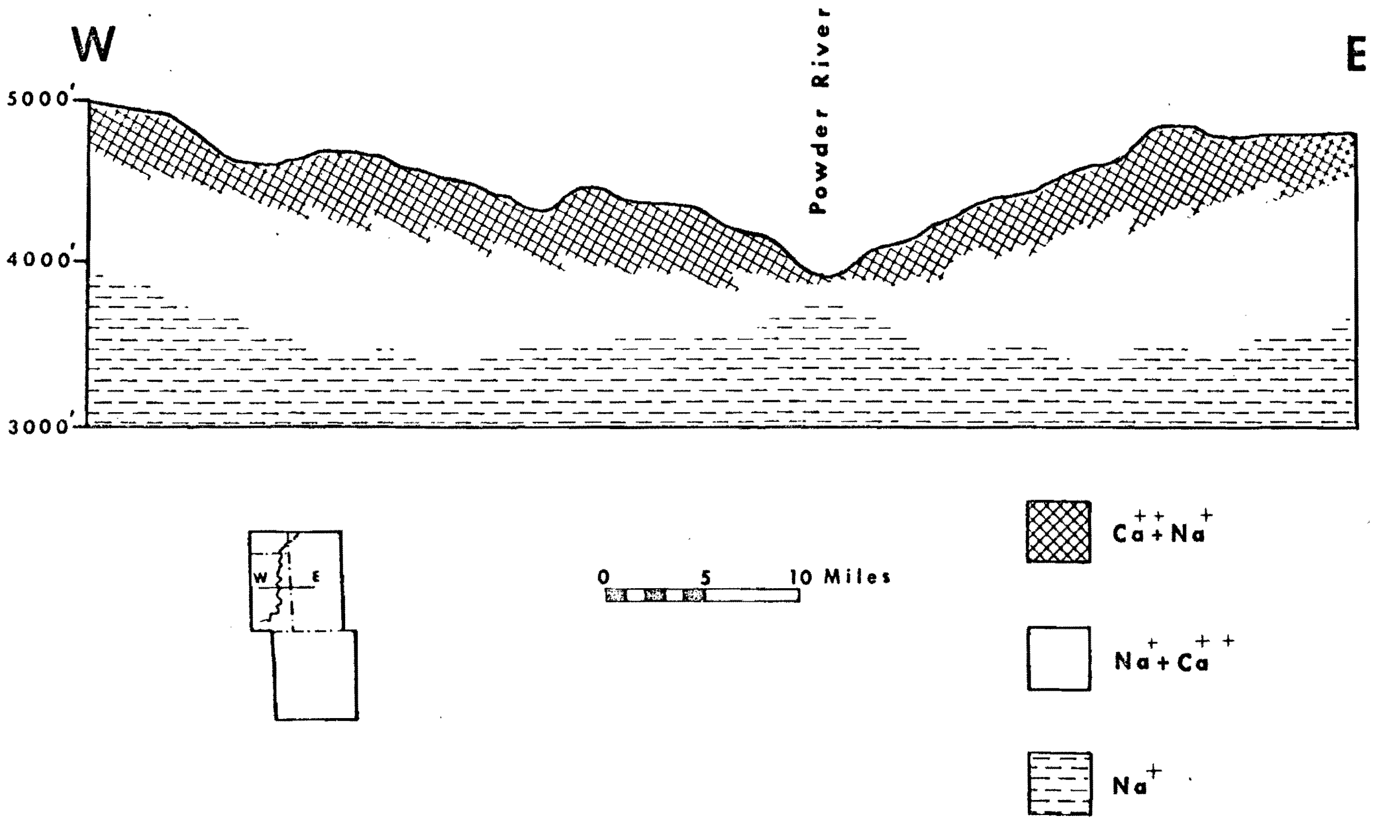


Fig. 27.--Cross section showing the vertical variation of the groundwater cation facies in the Powder River Basin, Wyoming.

is a regional groundwater discharge area. The very low values of chloride in the water samples from all stratigraphic horizons probably reflect a general absence of soluble chlorides in most of the sediment.

Calcium and magnesium concentrations decrease with increased flow-path length, and sodium increases. The calcium and magnesium ions are removed from solution by cation exchange and by the precipitation of carbonates. The cation exchange process results in an increase in the sodium concentration. Sodium feldspar (albite) is also a source of sodium. When it is attacked by water containing carbon dioxide it decomposes to yield silica, sodium carbonate, and clay minerals. Carbon dioxide is abundant in the sulfate reduction zone. Therefore, feldspar could be an additional source of sodium, as well as bicarbonate. Sodium feldspars are common in the sediments of the Wasatch Formation.

The pH values increase with increasing flow-path length. The sediments are predominantly composed of silicates, which cause a rise in the pH of groundwater with time because of the process of silicate hydrolysis (Krauskopf, 1967, p. 115).

The groundwater chemistry during the Tertiary Period is interpreted to have been similar to the present-day groundwater chemistry because the same sediments were present then and the groundwater-flow directions were similar.

It is not likely that groundwater-flow reversals or extensive flushing occurred in the Powder River Basin during the Pleistocene Epoch. Glacial flushing has been suggested by McGinnis (1968) for the origin of the Mississippi Valley lead-zinc deposits and by Hamilton (1970, p. 81) for the removal of chloride from the

Hell Creek Formation in North Dakota. Continental glaciation did not extend far enough south to influence the groundwater flow in the Powder River Basin. Alpine glaciers were present in the Big Horn Mountains and groundwater flushing may have occurred locally along the eastern margin of the mountains. However, I found no physical or chemical evidence which would indicate that groundwater flushing had occurred in this area.

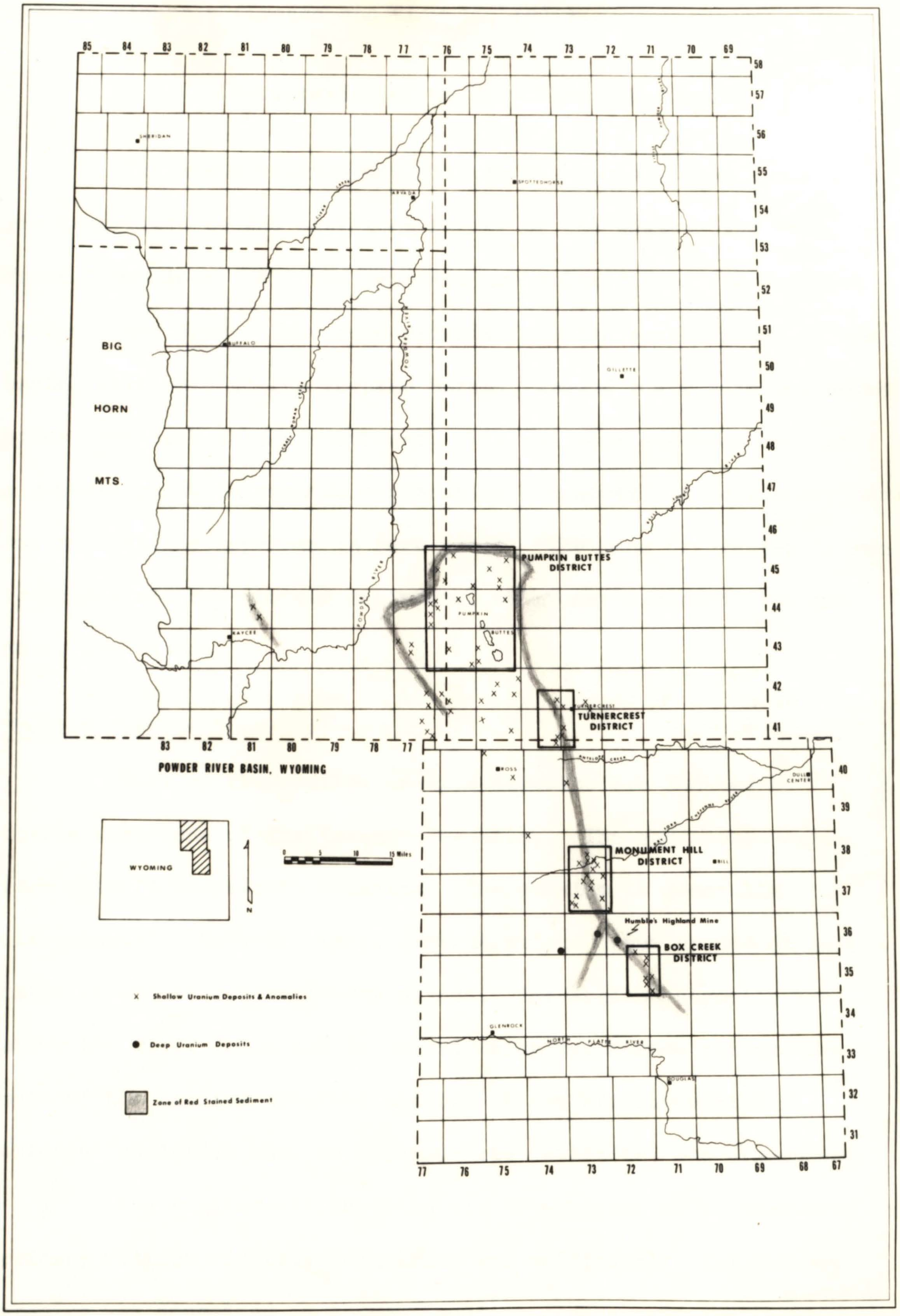
CHAPTER VI

URANIUM DISTRIBUTION AND GROUNDWATER

Uranium was first found in the Powder River Basin by J. D. Love (1952). The first mining of uranium was near Pumpkin Buttes, where localized high-grade concentrations of ore were mined. Mining later spread to other districts. The major mining district are the Pumpkin Buttes, Turnercrest, Monument Hill, and Box Creek districts (Figire 28). The Monument Hill district was most productive. It produced about 90 percent of the ore from the basin during this early period. Many of the deposits are composed of patchy and low-grade, oxidized uranium minerals. Most of the mines in these areas are no longer being actively operated. A detailed description of the mineralogy and geology of these districts is given by Sharp (1963 and 1964).

Renewed interest in uranium during the late 1960's led to extensive exploration programs by numerous companies. As a result, significant discoveries were announced by the Cleveland Cliffs Iron Company, Humble Oil and Refining Company, Kerr McGee Corporation, Teton Exploration and Drilling Incorporated, and the Union Pacific Railroad Company. Most of these discoveries were deep, unoxidized deposits found as a result of extensive test drilling programs. At the present time, Humble Oil and Refining Company is the only company actively developing its discovery. Its ore body is in the lower member of the Fort

Fig. 28.--Map showing location of the mining districts, red-sediment zone, and uranium occurrences in the Powder River Basin, Wyoming.


POWDER RIVER BASIN, WYOMING
BIG HORN MTS.
SHERIDAN
ARVADA
SPOTTEDHORSE
BUFFALO
GILLETTE
KAYCEE
PUMPKIN BUTTES DISTRICT
PUMPKIN
BUTTES
TURNERCREST
TURNERCREST DISTRICT
ROSS
DULL CENTER
MONUMENT HILL DISTRICT
BILL
Humble's Highland Mine
BOX CREEK DISTRICT
GLENROCK
NORTH PLATTE RIVER
DOUGLAS
POWDER RIVER
ANTELOPE CREEK
WYOMING
N
0 5 10 15 Miles
85 84 83 82 81 80 79 78 77 76 75 74 73 72 71 70 69
58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41
83 82 81 80 79 78 77
40 39 38 37 36 35 34 33 32 31
77 76 75 74 73 72 71 70 69 68 67
× Shallow Uranium Deposits & Anomalies
● Deep Uranium Deposits
▨ Zone of Red Stained Sediment

Union Formation and consists of sooty, black uraninite and coffinite uranium minerals (Langen and Kidwell, 1971)

Characteristics of Known Uranium Deposits

The known uranium deposits in the Powder River Basin are restricted to the sandstone facies of the Wasatch and Fort Union Formations. All the deposits are related to a red and pink, iron-stained zone. This zone extends from the southern end of the basin, northward to the Pumpkin Buttes, around their east and north sides, and back to the southwest. The red zone has been used as a general guide to uranium exploration. However, it is discontinuous and not readily apparent in some areas. The zone bifurcates in some locations and red-stained sediments, which are isolated from the zone, are common.

Shallow Uranium Deposits

Most of the shallow uranium deposits are located in coarse sandstone of the Wasatch Formation. The sandstone ranges from friable to calcite cemented. The uranium is generally disseminated. However, local concentrations occur around organic material and as concretionary masses. The shallow deposits are above the water table and in an oxidizing environment; therefore, most of the uranium minerals consist of the bright-colored oxidized varieties such as tyuyamunite, carnotite, and uranophane.

The shallow ore deposits are interpreted to be weathered primary uranium minerals (uraninite and coffinite). The primary uranium was deposited in a deep reducing environment and later exposed to weathering and oxidation by erosion. The exposure to weathering led to the solution of much of the uranium, allowing it to either be washed away or to re-enter the groundwater-flow system and migrate along flow paths to enrich some deeper ore body.

Deep Uranium Deposits

The deep, unoxidized uranium deposits of the Powder River Basin are geometrically similar to the uranium deposits found throughout the intermontane basins of the Rocky Mountain region. They consist mostly of uraninite and coffinite. The uranium ore characteristically has organic material, calcite cement, and iron minerals associated with it. According to Langen and Kidwell (1971), Humble's Highland uranium deposit in the southern Powder River Basin is typical. The iron oxides (hematite and goethite) are restricted to the thicker, more permeable parts of the sandstone. Organic material in the deposit consists of carbonized wood and disseminated lignite lenses, partings, and fragments. The sandstone that is cemented by calcite occurs most commonly at the top of the uranium-rich zone and is occasionally present at the base. Vanadium anomalies in the deposit coincide with uranium concentrations; however, vanadium is not appreciably enriched in the Highland Mine. The selenium distribution is extremely erratic. Molybdenum was not detected in samples from the deposit. Lead, zinc, manganese, nickel, and cobalt concentrations are small.

Davis (1970, p. 137) reported a distinct correlation between concentrations of carbonate cement and uranium mineralization in unoxidized ore bodies in the Powder River Basin. He found that the carbonate cement is higher on the unaltered side of the main uranium ore body than on the altered side. He also found an increase in pyrite concentration in those zones that contain the most uranium.

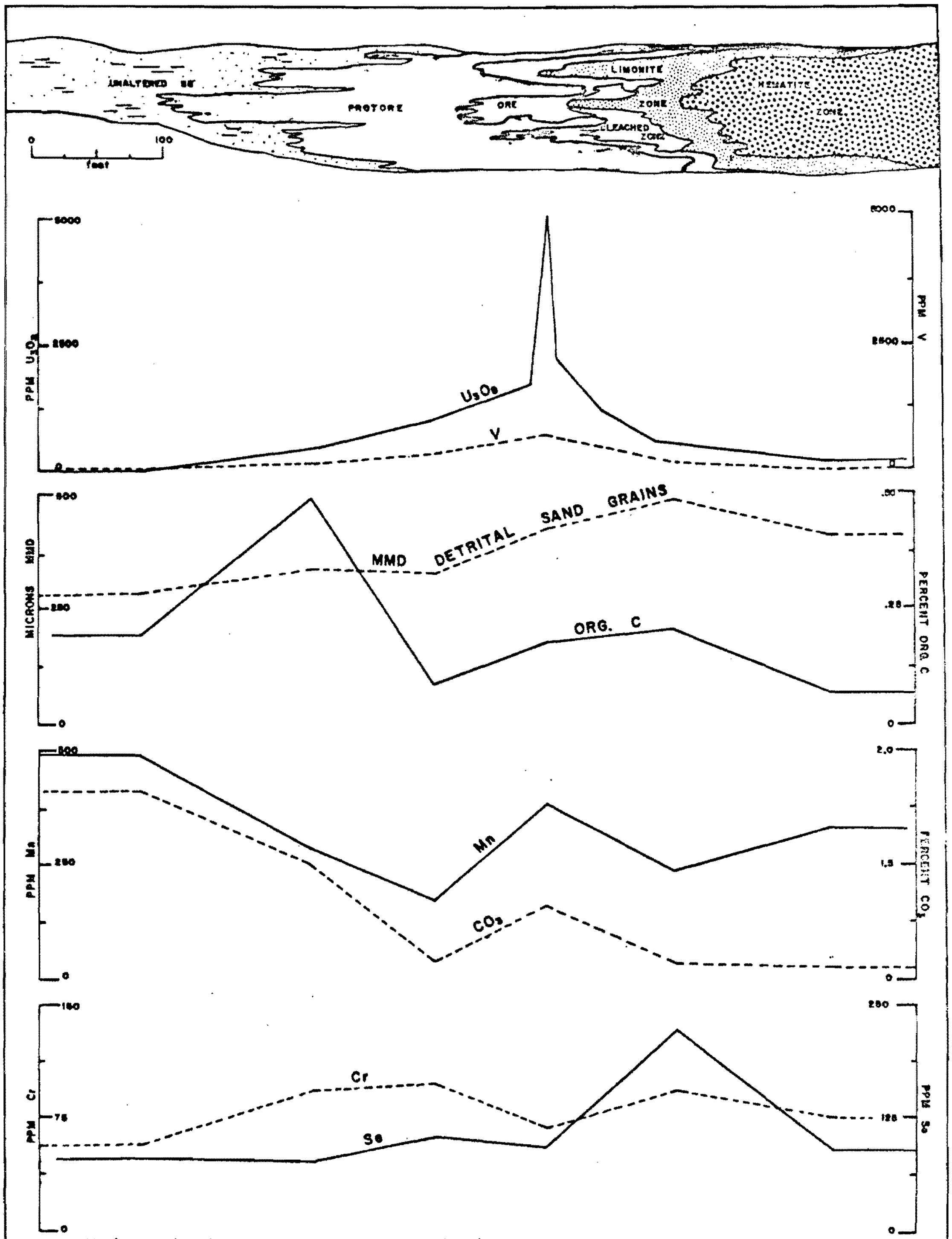
Davis did not observe a direct relationship between organic carbon and uranium in the highly mineralized zones; however, abundant organic carbon immediately on the unaltered side of the main uranium ore was reported. A summary of Davis' observations is presented in Figure 29.

Generally, the deep, unoxidized uranium ore bodies occur in the lower Wasatch Formation and in the Fort Union Formation. Most of the unoxidized deposits that have been announced are located in the southern Powder River Basin between the Box Creek and Monument Hill mining districts (Figure 28).

Uranium Distribution in Present-Day Groundwater

Uranium in Groundwater

All the water samples collected from the Powder River Basin were analyzed for uranium. Among these, four contained abundant organic material in solution and therefore their uranium content could not be determined. These samples were reported as less than 2 ppb. The average background of the groundwater in the Wasatch and Fort Union Formations in the Powder River Basin is 2ppb uranium. Sixteen anomalies (5 ppb or greater) were found, with the highest being 125 ppb (Table 8). All but two of the anomalies found are in water from the Wasatch Formation and all but four of the anomalies are from depths ranging between 150 and 250 feet. The four deep anomalies are from depths of 296, 340, 468, and 540 feet. Seven of the anomalies are in the bicarbonate-sulfate groundwater facies, and the remaining nine are in the



Vertical section with analytical data from an unoxidized Powder River Basin ore body.

UNION PACIFIC RR CO., NATURAL RESOURCES DIVISION CORE HOLE DATA

Fig. 29.--Cross section showing variation in geochemistry across an unoxidized uranium deposit in the Powder River Basin, Wyoming (From Davis, 1969, p. 139).

TABLE 8.--Comparison of uranium anomalies and dominant anions from groundwater in the Wasatch and Fort Union Formations in the Powder River Basin, Wyoming

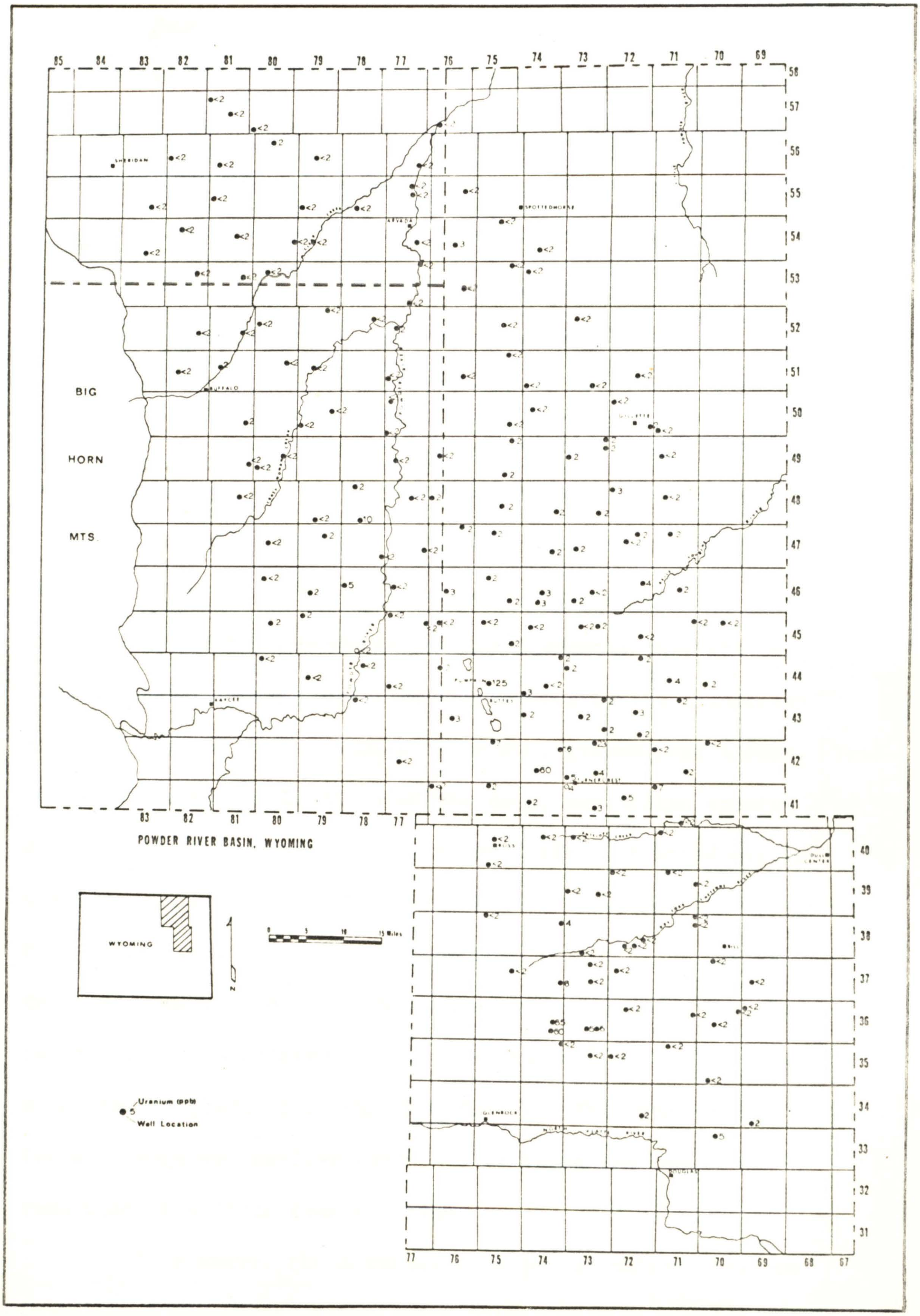
Well Number	Well Location	Formation	U (ppb)	HCO_3 (ppm)	HCO_3 (epm)	SO_4 (ppm)	SO_4 (epm)	pH	Well Depth in Feet
1	33-70-09ac	Ft. Union	5	302	4.9	140	2.9	7.6	210
14	36-73-26ad	Wasatch	6	367	6.0	15	0.3	7.3	190
15	36-73-27ab	Wasatch	5	253	4.1	140	2.9	7.6	180
16	36-74-23cd	Wasatch	65	300	4.9	300	6.2	7.5	145
17	36-74-27bd	Wasatch	60	284	4.7	55	1.2	7.0	145
23	37-74-24b	Wasatch	6	288	4.7	80	1.7	7.6	140
46	41-71-06cc	Ft. Union	7	224	3.7	750	15.6	8.0	340
47	41-72-16bb	Wasatch	5	260	4.3	150	3.1	8.1	253
55	42-73-02bd	Wasatch	23	308	5.0	900	19.0	7.4	468
56	42-73-31dc	Wasatch	5	320	5.2	140	2.9	8.0	160
58	42-74-12ac	Wasatch	16	350	5.7	1875	39.0	7.1	296
59	42-74-28cd	Wasatch	60	226	3.7	200	4.1	7.5	100
60	42-75-04dd	Wasatch	7	250	4.1	400	8.3	7.6	185
76	44-75-27cc	Wasatch	125	318	5.2	475	10.0	7.4	150
147	46-78-18ca	Wasatch	5	200	3.3	1500	31.0	7.8	540
157	48-78-33bc	Wasatch	10	446	7.3	3125	65.0	7.4	250

sulfate-bicarbonate facies. All the anomalies except one are in regional groundwater recharge areas. The exception contains the only significant anomaly found north of Pumpkin Buttes.

The distribution of the wells tested for uranium and their associated concentrations of uranium is shown in Figure 30.

The uranium content of groundwater has been used by many companies as an exploration guide for uranium. This is generally not very useful, unless the investigator understands the physical aspects of the groundwater-flow systems from which the water sample was collected. If uranium anomalies are found in groundwater samples, a reasonably sound conclusion is that uranium is present somewhere in the area; however, uranium may be present in an area but not present in groundwater samples from the area. The presence of uranium in groundwater depends on where the water is sampled in the flow system. For example, a well (number 21, Appendix B) located less than 200 yards from an open pit uranium mine in the Monument Hill area was found to contain less than 2 ppb uranium. The well is 300 feet deep and intersects the deep flow path of an intermediate groundwater-flow system in a discharge area. Had a shallow well been sampled in the area it would probably have contained anomalous uranium concentrations because it would have intersected local flow paths, which would have passed through the shallow uranium deposits. Sharp (1964, p. 43) reported anomalous uranium in water from a windmill (probably shallow) about 1 mile southeast of well number 21. Numerous examples of similar occurrences can be found in the various mining districts of the Powder River Basin. Water sampling has its optimum value as an exploration guide only when the investigator conducting the sampling program is knowledgeable of where the sample is from relative to the groundwater-flow systems in

Fig. 30.--Map showing the concentration of uranium (ppb) in groundwater from the wells sampled.


POWDER RIVER BASIN, WYOMING
BIG
HORN
MTS.
SHERIDAN
BUFFALO
KAYCEE
ARVADA
SPOTTED HORSE
GILLETTE
PUMPKIN BUTTES
WRIGHT
BILL
DULL CENTER
GLENROCK
DOUGLAS
NORTH PLATTE RIVER
WYOMING
N
0 5 10 15 Miles
Uranium (ppb)
5
Well Location
85 84 83 82 81 80 79 78 77 76 75 74 73 72 71 70 69
58 57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41
40 39 38 37 36 35 34 33 32 31
77 76 75 74 73 72 71 70 69 68 67

Relation of Uranium Occurrences to Present-Day Groundwater-Flow Systems

Fewer uranium anomalies were found in groundwater than expected and too few were found to draw valid conclusions regarding the type of groundwater in which maximum concentrations of uranium should be expected. However, almost all the uranium anomalies were from water wells in recharge areas where the dominant groundwater movement is downward. No anomalies were found in regional discharge areas where wells intercept regional groundwater-flow paths. This supports the hypothesis presented earlier that uranium is transported in solution in recharge areas and precipitated somewhere along the flow path between recharge and discharge areas.

The fact that all the uranium anomalies were from the $HCO_3^- + SO_4^{--}$ and $SO_4^{--} + HCO_3^-$ groundwater facies and none were found in the deeper HCO_3^- groundwater facies indicates that the uranium in solution is being precipitated somewhere in the transition zone between the $SO_4^{--} + HCO_3^-$ and the HCO_3^- groundwater facies. This is supported by the location of the deep, unoxidized uranium deposits in the southern Powder River Basin. As noted earlier, these deposits occur in the lower Wasatch Formation and in the Fort Union Formation. This is the zone that was earlier shown to be the positon in the flow system where significant changes in groundwater chemistry occur. Here the $SO_4^{--} + HCO_3^{--}$ groundwater facies grades into the HCO_3^- facies. This groundwater facies change was earlier explained as being the result of the reduction of sulfate from solution.

In summary, the location of major unoxidized uranium deposits of the Powder River Basin coincides with a major change in groundwater chemistry. The groundwater loses sulfate and calcium from solution where the change occurs and the concentration of bicarbonate is increased. This change in the chemical facies of groundwater generally occurs near the contact between the Wasatch and Fort Union Formations. The associated uranium deposit is probably the result of reduction by hydrogen sulfide, a product of sulfate reduction. In similar areas, studies have shown that the associated pyrite contains sulfur of biogenic origin indicating the presence of sulfate reducing bacteria. In addition, the calcite cement commonly associated with uranium deposits may also be the result of precipitation by sulfate reduction (see equation 18).

The Relation of Uranium Occurrences to Past Groundwater-Flow Systems

The uranium in the Powder River Basin was probably transported and deposited during the Miocene and Pliocene Epochs. At this time the uranium host rocks were buried under an estimated 1,000 to 2,000 feet of clastic and tuffaceous rocks. The groundwater chemical facies present during the time of uranium implacement were probably not significantly different from present-day groundwater facies, except perhaps for the $HCO_3^- + SO_4^{--}$ facies, which may have been more extensive than it is today, especially in the more tuffaceous sediments of the White River Formation. The $Ca^{++} + Na^+$ facies has probably maintained its relative position with respect to the ground surface because of the approximate equilibrium of cation-exchange saturation with the removal of sediments by erosion.

Uranium was leached from some disseminated source such as the tuffaceous rocks of the White River Formation or the arkose of the Wasatch Formation, the tuffaceous rocks being the most likely source. It was transported in carbonate complexes by slightly alkaline water in the $HCO_3^- + SO_4^{--}$ and $SO_4^{--} + HCO_3^-$ groundwater facies. When the water entered the flow system it was probably rich in dissolved oxygen. However, the oxygen became depleted with increasing length of flow path, resulting in mild reducing conditions. When the water transporting the uranium entered a zone where abundant organic material was present, strong reducing conditions, probably generated by sulfate-reducing bacteria, caused precipitation of the uranium and associated minerals. Local occurrences of organic material probably caused small concentrations of uranium throughout the stratigraphic sequence. Many of the small concentrations such as shallow uranium deposits have been destroyed or are being destroyed by erosion.

Major accumulations of uranium were associated with the regional groundwater-flow path in recharge areas and were concentrated where the flow path intersected abundant organic material. These deposits are still preserved in their reduced state in many locations.

The groundwater recharge areas during the depositon of the uranium were similar to those of present-day groundwater-flow systems except as they have been modified by topography. Generally the groundwater was recharged around the eastern, western, and especially the southern part of the basin, and was discharged in the northern part of the basin. An illustration of the general interpretation is given in Figure 31.

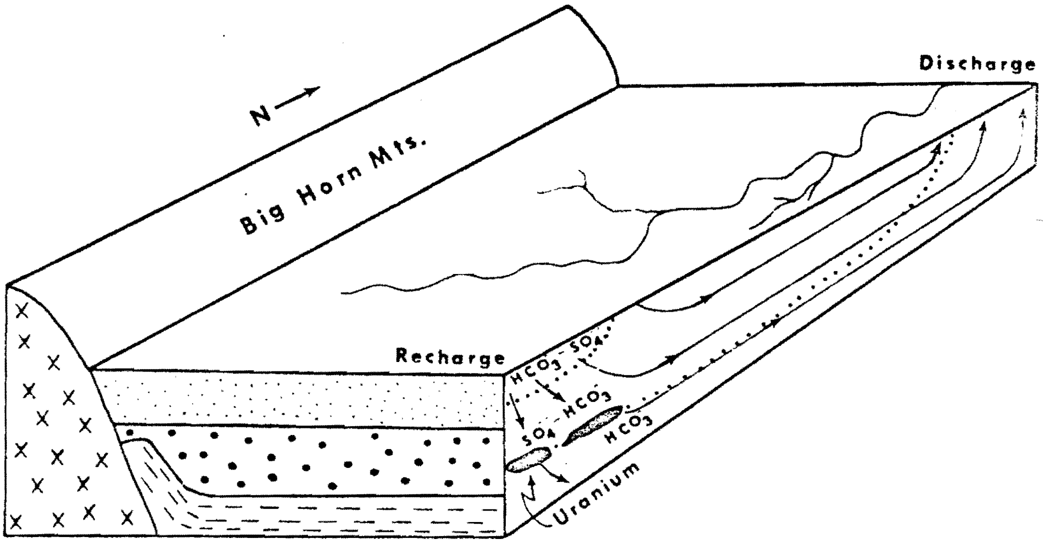


Fig. 31.--Block diagram showing the relation between groundwater flow, hydrochemistry, and uranium deposits in the Powder River Basin, Wyoming.

Utilization of Groundwater-Flow Theory in Uranium Exploration

The principles used in this study could be applied in other sedimentary basins in the Rocky Mountain region. However, a separate model must be constructed for each individual basin on the basis of its geology, history, and groundwater-flow systems. Generally, the principle of the association of uranium deposits and groundwater recharge areas appears to be one that can be applied in most intermontane basins. The interpretation of past groundwater-flow systems and the utilization of groundwater-flow theory provides a tool through which target areas in unexplored basins may be narrowed rapidly. A procedure that may be utilized to determine past groundwater-flow directions to help localize target areas is outlined below.

(1) First, a reconnaissance of the general geology should be done so that the past geomorphology can be reconstructed. The interpretation of the past geomorphic conditions provides insight into the relative distribution of the hydraulic potential during the time of uranium deposition. From this the orientation of the total flow vector may be approximated and the relative locations of past groundwater recharge and discharge areas can be determined.

(2) The chemistry of present-day groundwater from various depths and from both recharge and discharge areas should be evaluated. Any significant changes in groundwater chemistry, particularly an abrupt decrease in sulfate concentration, is important. If an abrupt change in the groundwater chemistry is found at a particular depth, in areas where the groundwater was recharged in the past, it is the most likely place to find uranium deposits. Other conventional uranium exploration techniques will help to further narrow the target in the area.

CHAPTER VII

CONCLUSIONS

The following conclusions were reached from this investigation:

(1) The Powder River is the discharge area for regional groundwater-flow systems in the Powder River Basin.

(2) The Dry Fork Cheyenne River is a discharge area for intermediate groundwater-flow systems.

(3) The valley of the Powder River affects groundwater potential down to at least 2,000 feet below its valley floor, and the Dry Fork Cheyenne River affects groundwater potential to depths ranging between 500 and 1,000 feet below its valley floor.

(4) Regional groundwater recharge occurs around the east, south, and west margins of the basin.

(5) The northern Powder River Basin is an area of groundwater discharge. Groundwater flow is in a direction opposite to that of the structural dip in this area.

(6) Regional groundwater flow, which is recharged in the southern Powder River Basin, moves northward under the smaller flow systems associated with the Dry Fork Cheyenne River.

(7) Groundwater-flow systems of the late Tertiary Period had recharge and discharge areas in similar locations to those of present-day flow systems.

(8) Past groundwater flow differed from present-day

groundwater flow with respect to the relative magnitudes of flow components. Past groundwater-flow systems had a larger longitudinal flow component than present-day flow systems.

(9) Groundwater chemistry is characterized by a sodium facies in regional groundwater discharge areas as well as regional recharge areas at depths greater than 200 to 300 feet.

(10) A calcium-sodium facies dominates most of the shallow groundwater.

(11) The dominant anions (bicarbonate and sulfate) show both a vertical and lateral variation. Much of the variation is attributable to a sequence of chemical reactions initiated by the reduction of sulfate.

(12) The sequence of the groundwater anion facies from recharge to discharge areas is

$$HCO_3^- + SO_4^{--} \longrightarrow SO_4^{--} + HCO_3^- \longrightarrow HCO_3^-.$$

(13) The total dissolved solids, sulfate, calcium, and magnesium concentration decrease with increased length of groundwater-flow path. This decrease in concentration reflects the diagenesis of the sediment by precipitation of the dissolved constituents from solution.

(14) The groundwater chemistry reflects the abundance of soluble sulfate in the sediments of the recharge areas and the lack of soluble chlorides in most of the sediments.

(15) The sediment of the basin contains minerals that are altered from sodium-rich types to calcium-rich types in recharge areas as a result of cation exchange.

(16) The groundwater chemistry of the late Tertiary Period probably did not differ significantly from the groundwater chemistry

of today.

(17) Uranium anomalies in groundwater are restricted to the $HCO_3^- + SO_4^{--}$ and $SO_4^{--} + HCO_3^-$ groundwater facies and were found only in groundwater recharge areas.

(18) Known unoxidized uranium deposits are located in both the regional groundwater recharge areas of the past and those of the groundwater-flow systems of today.

(19) The major uranium deposits occur at the stratigraphic position where the groundwater chemistry changes from the $SO_4^{--} + HCO_3^-$ to the HCO_3^- facies.

(20) The uranium was probably precipitated from solution by hydrogen sulfide. Hydrogen sulfide is a product of sulfate reduction, which is interpreted to be the reaction responsible for the abrupt change in groundwater chemistry at the $SO_4^{--} + HCO_3^- \longrightarrow HCO_3^-$ facies interface.

(21) The uranium was deposited during the late Tertiary Period when recharging groundwater leached uranium from a disseminated source and transported it into the zone of transition between the $SO_4^{--} + HCO_3^-$ and HCO_3^- groundwater facies where sulfate-reducing bacteria caused the uranium to precipitate.

(22) The calcite found in association with uranium deposits was also precipitated from solution by sulfate reduction.

(23) This study can be used as a guide for uranium exploration in other areas provided the necessary data is available from which to construct a reasonably representative model of the sedimentary basin being investigated.

APPENDICES

Appendix A

METHODS OF DATA COLLECTION AND ANALYSIS

Location Format

The location format used in this study for sample collection sites follows the scheme shown in Figure 32. In this system the first numeral of a well location indicates the township north of its base line, the second indicates the range west of the principal meridian, and the third represents the section in which the well is located. The lower case letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section and the second letter the quarter-quarter section (40 acre tract). The subdivisions of the sections and quarter sections are lettered a, b, c, and d in a counterclockwise direction beginning in the northeast quarter. For example, a well located in the NW¼,SE¼, sec. 20, T. 38 N., R. 74 W., is designated 38-74-20db.

Collection of Water Samples

The collection of uncontaminated water samples that are representative of the source at the time of collection is necessary if a meaningful interpretation of their chemistry is to be attempted. The procedure followed by the United States Geological Survey is outlined by Rainwater and Thatcher (1960). Generally their

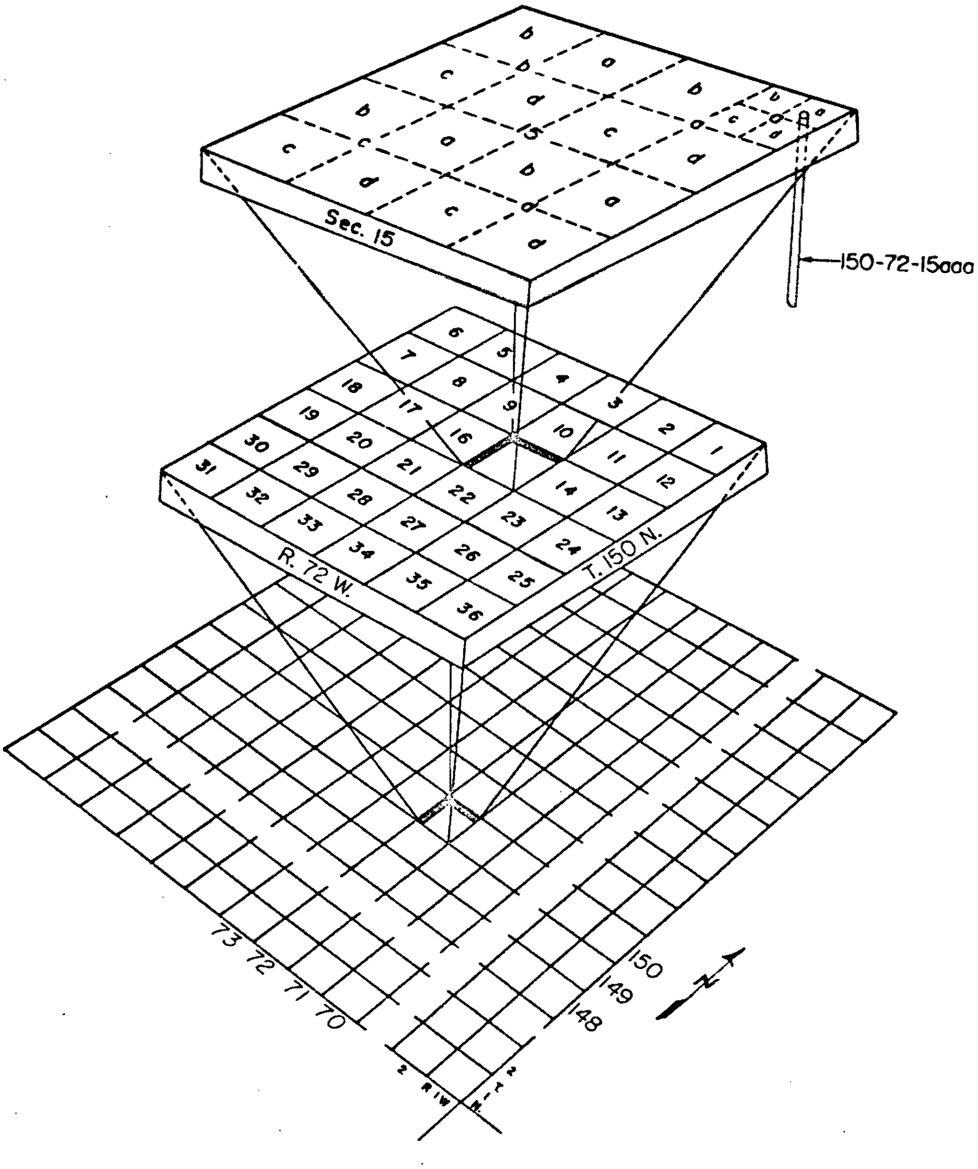


Fig. 32.—Diagram showing the location format.

recommendations were followed for this study except where circumstances required different procedures. The source of the water sampled in this study was limited to groundwater from wells and springs. The water samples were collected in high-density polyethylene bottles with polyethylene-lined bakelite screw-caps. The sample bottles were rinsed several times with the water to be sampled before collection. After the water samples were collected and the cap tightly screwed on, they were sealed with plastic tape to insure a lasting seal during transport.

The groundwater samples came from two kinds of wells, pumped wells and flowing wells. The pumped wells ranged in depths from less than 100 feet to several hundred feet. The types of lift on these wells varied from windmills to submersible pumps with every imaginable comination in between. If the well to be sampled had not been actively pumped immediately prior to sampling it was pumped until the casing was cleared of stagnant water before the sample was collected. The length of time a well was pumped ranged from thrity minutes to an hour and sometimes longer for windmills.

Except for a limited few, the flowing wells were unrestricted at the surface and flowed continuously. This eliminated the problem of acquiring a fresh water sample. The introduction of air into the sample by turbulence was reduced by choking down the flow where possible. Most of the flowing wells are deep and therefore intersect intermediate and regional groundwater-flow paths. This makes them ideal sampling sites for studies in which the primary focus is on regional groundwater flow. The data from flowing wells is generally more reliable than that from non-flowing wells because they must by necessity be completed properly or they will not flow for any extended period of time.

Water Level Measurements

In this study the elevation of the static water level in a well was considered to be the potential at the bottom of the casing. This assumes that the well casing does not leak and that it is sealed to the borehole. In addition, it assumes that the static water level has completely recovered from pumping or flowing at the time of measurement.

It is known in fact that the above conditions were not met in some of the wells sampled. These wells were the shallow stock wells that were pumped by windmills. In general the data from most other wells is reliable. I was able to obtain well completion details on most wells from the United States Geological Survey, the Wyoming State Engineer's Office in Cheyenne, and from local well drillers. On the basis of these records I determined which wells were most reliable and therefore avoided poorly completed wells. If the well casing was cemented to the borehole and the age of the well was such that a rusted-through casing was unlikely, the well was considered to yield reliable data.

I believe that the assumed conditions were satisfied for most of the wells sampled (90 percent), at least within the bounds of an acceptable error (plus or minus 5 feet) for the values of head used in this report.

Non-flowing Wells

The water level in non-flowing wells was measured with a battery operated electric water-level indicator (Soiltest, model

DR-760A). The total head was determined by substracting the measured depth to water from the elevation of the ground level.

Flowing Wells

The static pressure of water in flowing wells was determined with a bourdon test gauge. The pressure measurement was converted to feet of water and added to the ground surface elevation at the well to obtain total head. It was necessary to shut in most wells for a period of time to obtain a reliable estimate of potential. The length of shut-in time ranged from one-half an hour to an hour or the amount of time necessary for the gauge to stablize. Static conditions were assumed to have been reached at this time.

The gauge was attached to the well head with threaded adaptors except where the threads on the well head pipe were corroded or nonexistent. In this case a rubber packer was attached to the gauge and inserted into the well pipe. The packer was then expanded to shut off the flow by tightening a nut which compressed and expanded the packer to fill the pipe. This method is explained in detail by Hamilton (1970, p. 128).

Elevation Determinations

Topographic map coverage of the study area ranges from excellent to poor. About one-thrid of the area is covered with topographic maps with a scale of 1:24,000, another one-third is covered with maps with a scale of 1:62,500, and the northern one-third is covered with maps with a scale of 1:250,000. The 1:250,000 maps have 100 foot contour intervals and are not adequate for determining the surface elevations at the wells. I was fortunate in that many of the wells had bench marks established by the United States Coast and Geodetic Survey, and many of the wells that lacked bench marks had spot elevations noted on the topographic maps. Nevertheless, it was necessary to determine the well site elevation in areas with poor topographic coverage.

Elevations were determined with an American Paulin Micro Altimeter (Model M-1). Vertical control stations were established using existing bench marks and changes in barometric pressure were recorded on a micro-barograph for base control. Generally each surveying loop that was closed ended in an uncontrolled deluge of unacceptable language because of the inability to accurately redetermine the elevation of the base control. Although the base elevation was seldom pin-pointed on a return loop, the measured elevation was always within 10 feet and more often within 5 feet of the known elevation. This gives a precision within plus or minus 10 feet for the well-head elevation measurements made in this study. The survey procedure and methods of correction are given in the instrument manual for the Paulin M-1 or in most field geology text books.

Analysis of Water Samples

The major chemical constituents, pH, specific conductance, and uranium were determined for 208 groundwater samples. Other chemical analyses published by the United States Geological Survey were utilized but not included as part of the data evaluation. The following discussion on methods applies only to those samples I analyzed.

All the samples were transported from the field to the laboratory for chemical analysis. There were undoubtedly some changes in the water chemistry between the time of collection and analysis; however, those changes that occurred during transport were not significant enough to effect the overal outcome of the study.

The following procedures are described in the order in which the samples were analyzed. The reproducibility of the methods was determined by duplicating the analyses on about 10 percent of the samples.

Specific Conductance

The specific conductance was determined at the time of collection with a Solu Bridge Conductivity Meter (Model A-105, Soiltes, Inc.). The meter measures the conductance in a range of 50 to 8,000 micromhos and had a manual temperature compensator. The measurements were made by filling a 3 gallon plastic bucket with water from the source, determining its temperataure, and fully submerging the electrode into the water.

pH

The pH was measured in the field with a Beckman Zeromatic pH meter. The instrument was standardized with buffered solutions of pH 7 and pH 8. The general range of most readings was between pH 7 and pH 8.5. All solutions were temperature corrected with a manual temperature compensator. The readings were reproducible to ± 0.05 pH unit.

The pH values were re-measured in the laboratory with the same instrument to check for significant changes in pH during transport. Some changes did occur, particularly in those samples whose original pH values were between 7 and 8. These changes were as large as ± 0.5 pH unit but generally did not exceed 0.3 pH unit.

Those samples whose original pH values were greater than 8 showed essentially no change during transport. The change in pH was considered of little significance if the variation between field and laboratory measurements was no greater than ± 0.3 pH unit.

Alkalinity ($HCO_3^- + CO_3^{--}$)

Alkalinity, as used in groundwater chemistry, is the capacity of a water to neutralize a strong acid and is primarily a function of the carbonate and bicarbonate in solution (Rainwater and Thatcher, 1960, p. 93). The potentiometric method was used to determine the alkalinity of water samples in this study. It consisted of titrating a 50 ml sample of water with a 0.01639 normal solution of sulfuric acid against a pH meter to the end points of pH 8.2 (carbonate) and pH 4.5 (bicarbonate). The calculation of total alkalinity, carbonate, and bicarbonate was performed following the procedure of Rainwater and Thatcher (1960, p. 95).

The normality of the acid was frequently checked against a sodium-carbonate standard to insure its stability. The values determined for alkalinity as calcium carbonate were reproducible to within ± 2 percent.

Calcium and Magnesium (Hardness)

Calcium and magnesium ions are the principle cause of hardness in natural water. Their concentrations were determined by titration with a 0.02 normal solution of CDTA (disodium dihydrogen 1, 2-cychlhexanediaminetetraacetate). The calcium determination was made by adding ½ ml of 8 normal potassium hydroxide to a 50 ml water sample and titrating with CDTA in the presence of murexide to an end point (color change from red to pure blue). The total hardness of a 50 ml buffered sample was determined by titration with CDTA in the presence of ManVer (trade name for a combination indicator and inhibitor solution manufactured by Hach Chemical Company) to an end point (color change from wine-red to pure blue). The concentration of the magnesium was calculated as the difference between the total hardness and calcium concentrations. The stability of the reagent was checked frequently by titrating a standard solution of calcium chloride.

The calcium determination was found to be reproducible to within ± 1 ppm and the magnesium to within ± 2 ppm.

Chloride

The chloride concentration was determined by titrating a 100 ml water sample with a 0.141 normal solution of mercuric nitrate ($HgNO_3$) in a sample buffered to pH 2.5. Diphenylcarbazone was used as the end point indicator. The titrations were reproducible to within 1 ppm of the initial determinations.

Sulfate

The turbidimetric method was used to determine sulfate concentration (APHA, 1965). A filter photometer was used to objectively determine the value of light absorbance through a suspension of the sulfate in the water sample. The absorbance values were determined by passing light through a blue filter with a maximum wavelength transmittance around 420 nm and a light path of 23 mm. A suspension of barium sulfate was formed in the sample using a powder reagent called SulfaVer (trade name for combined conditioning reagent and barium chloride, manufactured by Hach Chemical Company). Absorbance values were compared with a calibration curve constructed on the basis of five standard solutions over the range of 0 to 100 ppm. The concentration of sulfate in the unknown samples was read directly from the curve. Samples that contained concentrations of sulfate exceeding the range of the working curve were diluted.

The error involved in this determination is estimated to be about ± 10 percent and possibly larger in those samples containing abundant sulfate. The instrument accuracy was ± 0.5 percent or better in the range of optimum light conditions.

Fluoride

The SPADNS method was used to determine fluoride concentrations (APHA, 1965). A filter photometer with a greenish-yellow filter having maximum wavelength transmittance between 550 and 580 nm and a light path of 23 mm was used to measure absorbance. A 25 ml water sample was treated with 5 ml of commercially prepared SPADNS fluoride reagent (Hach Chemical Company). The absorbance of light by samples of unknown concentrations was compared with a calibration curve prepared from standards whose concentration ranged from 0 to 2 ppm fluoride. The results were reproducible to within ± 2 percent.

Sodium and Potassium

The concentrations of sodium and potassium were determined for the water samples with a Perkin-Elmer (Model 403) atomic absorption/flame emission spectrophotometer using an acetylene flame. The instrument was calibrated each time it was used with prepared standards whose concentrations were in the optimum operating range for the particular element being determined. The instrument has a direct read-out for concentrations which average several tens of measurements in a short period of time. Sodium was measured at a wavelength setting of 589 nm; however, it was necessary to adjust the wavelength indicator slightly above and below the specific wavelength indicated until a setting for the maximum peak was obtained. A similar procedure was followed for potassium using a wavelength setting of 768 nm. The concentration range for optimum instrument response in the sodium determination was well below the average concentration contained in the water samples. It was therefore necessary to dilute the samples tested for sodium by factors ranging between 100 and 300. The values for potassium concentration generally coincided with the optimum operating range of the instrument; however, it was necessary to dilute some samples by a factor of 10.

The results were reproducible to within ± 1 percent under ideal instrument conditions.

Silica

The molybdosilicate method was used for silica determination (APHA, 1965). This method uses acid and molybdate to complex both silica and phosphate. Oxalic acid is then added to destroy any color due to phosphate. The intensity of the remaining yellow color is then directly proportional to the amount of silica present. A filter photometer with a violet filter having maximum wavelength transmittance near 410 nm and a 23 mm light path was used to measure the absorbance due to silica color development. The measured absorbance was then used to determine the unknown silica concentration from a calibration curve derived from standard solutions of silica. The concentrations of the unknowns fell well within the working range of the calibration curve and no dilution was necessary.

The results were reproducible to ± 0.5 ppm.

Uranium

The dibenzoylmethane method was used to determine uranium concentrations in this study. This method was originally described by Yoe and others (1953). It was later refined by Smith and Chandler (1958) for use as a field method for the determination of uranium in natural water and in 1964 it was adopted, after slight modification, by the Geological Survey of Canada for the determination of uranium in the field (Chamberlain, 1964a).

A generalized outline of the dibenzoylmethane method is given below.

(1) The water sample is filtered, acidified, and placed in a separatory funnel.

(2) Sodium chloride is added to lower the solubility of carbon tetrachloride in the aqueous phase.

(3) EDTA (ethylenediamine tetra-acetic, disodium salt) solution is added to complex interfering metals.

(4) Dibenzoylmethane (1, 3-diphenyl-1, 3-propanedione) solution is added to complex the uranium. The dibenzoylmethane was obtained from Eastman Organic Chemicals, Rochester, New York, (Catalog Number 2197) and did not require purification.

(5) Pyridine and carbon tetrachloride are added to dissolve and concentrate the uranium complex.

(6) The carbon tetrachloride forms a separate phase which is removed from the separatory funnel and compared with standards to determine the concentration of uranium.

A Bausch and Lomb Spectronic 20 spectrophotometer was used to establish a calibration curve from standards and to make determinations of the unknown uranium concentrations. A wavelength setting of 395 nm as recommended by Yoe and others (1953) and a mean light path length of 11.68 mm was used.

I feel that the determinations made are reliable down to 2 ppb. The results were reproducible to within 5 percent. A comparison of the dibenzoylmethane method with fluormetric and other techniques of uranium determination have been performed by all the above mentioned workers as well as Chamberlain (1964b). Their studies indicate that the lower limit of the sensitivity of the method is between 1 and 2 ppb uranium.

Total Dissolved Solids

The total dissolved solids were determined by calculation following the procedure of Rainwater and Thatcher (1960, p. 271). The constituents were converted to forms that would be expected to exist in the anhydrous state and summed. This method assumes that all the constituents were analyzed. In the analyses, no values are reported for iron, nitrate, or trace elements, other than uranium. Some samples were analyzed for iron and nitrate but the quantity of each present was very small (generally less than 1 ppm). It is assumed, therefore, that no large error was introduced by ignoring them.

Error Analysis

As an estimate of the analytical error, a numerical calculation was made for each water sample analyzed. The total equivalent weight of all the cations and anions in solution theoretically must balance. The difference between the cations and anions determined in the analysis was assumed to approximate the analytical error, because the unanalyzed constituents are believed to represent an insignificant percentage of the total ions. The values for percent-error were determined by:

$$\text{Error} = \frac{\left|\text{total cations} - \text{total anions}\right|}{\text{total cations} + \text{total anions.}} \qquad (27)$$

All values are expressed in equivalent weights for the calculation.

The mean percent error was 4.7 for the 208 water samples analyzed in this study.

Appendix B

PHYSICAL WELL DATA

Explanations of the data headings used on pages 125 to 131 are given below.

NUMBER = well numbers where:

numbers 1 to 45 are from Converse County,

numbers 46 to 133 are from Campbell County,

numbers 134 to 181 are from Johnson County,

numbers 182 to 208 are from Sheridan County.

LOCATION = location of well (see Location Format in Appendix A).

FORMATION = formation in which well is completed.

ELEVATION = vertical distance in feet above mean sea level.

DEPTH = vertical distance in feet from ground surface to bottom of well.

STATIC-SURFACE = elevation of static water level in well expressed in feet (potential).

TEMP.C = temperature in degrees Centigrade of water from well (-1 indicates that reliable measurement was not possible).

SP.COND = specific conductance of water from well expressed in micromhos.

DATE = month-day-year water sample was collected.

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
1	33-70- 9AC	FTUNION	5280.0	210.0	5160.0	15	640	6-14-70
2	34-69-32AC	FTUNION	5200.0	200.0	5105.0	14	1150	6-14-70
3	34-72-26AB	FTUNION	5090.0	210.0	5015.0	11	1150	8-20-70
4	35-71- 4BB	WASATCH	5083.0	125.0	5008.0	12	580	8-20-70
5	35-70-32BC	WASATCH	5096.0	275.0	4951.0	-1	1325	6-14-70
6	35-72-18A	WASATCH	5420.0	255.0	5340.0	-1	500	6-15-70
7	35-73-15B	WASATCH	5300.0	145.0	5230.0	-1	650	6-14-70
8	35-74- 1BD	WASATCH	5365.0	105.0	5310.0	-1	440	6-15-70
9	36-69- 7AB	FTUNION	4750.0	615.0	4762.0	15	600	6-17-70
10	36-70-12CC	FTUNION	4800.0	800.0	4805.0	-1	625	6-17-70
11	36-70-21CB	FTUNION	4800.0	960.0	4810.0	15	700	6-18-70
12	36-71-13DB	FTUNION	4780.0	315.0	4796.0	15	620	6-22-70
13	36-72- 9DD	WASATCH	5420.0	212.0	5228.0	14	900	6-16-70
14	36-73-26AD	WASATCH	5370.0	190.0	5300.0	-1	580	6-16-70
15	36-73-27AB	WASATCH	5523.0	180.0	5453.0	12	650	6-16-70
16	36-74-23CD	WASATCH	5590.0	145.0	5495.0	-1	900	6-15-70
17	36-74-27BD	WASATCH	5570.0	145.0	5488.0	14	540	6-22-70
18	37-69-20DB	FTUNION	4800.0	656.0	4795.0	-1	720	6-10-70
19	37-70- 4AC	FTUNION	4690.0	430.0	4730.0	14	720	6-18-70
20	37-72-17CA	WASATCH	5490.0	410.0	5530.0	14	520	6-22-70
21	37-73-10BD	WASATCH	5080.0	300.0	5105.0	-1	500	6-16-70
22	37-73-22AD	WASATCH	5080.0	375.0	5108.0	-1	430	6-16-70
23	37-74-24B	WASATCH	5290.0	140.0	5200.0	-1	560	6-16-70
24	37-75-14DB	FTUNION	5402.0	840.0	5332.0	13	440	6-22-70
25	38-71- 1CA	FTUNION	4645.0	515.0	4675.0	14	500	6-17-70
26	38-71-12AB	FTUNION	4660.0	865.0	4695.0	18	440	6-17-70
27	38-72-23DB	FTUNION	4764.0	375.0	4794.0	14	590	6-18-70
28	38-72-27AC	FTUNION	4840.0	310.0	4865.0	14	650	6-18-70
29	38-72-28DB	WASATCH	4822.0	350.0	4862.0	14	520	6-22-70
30	38-73-33CB	WASATCH	5085.0	600.0	5100.0	-1	625	6-16-70
31	38-73-33CB	WASATCH	5050.0	300.0	5060.0	-1	550	6-16-70
32	38-73-33CB	WASATCH	5035.0	450.0	5047.0	-1	450	6-16-70
33	38-74-12BC	WASATCH	5180.0	620.0	5150.0	14	1150	6-19-70
34	38-75- 5AA	FTUNION	5400.0	200.0	5295.0	20	700	6-19-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
35	39-71- 4DC	FTUNION	4920.0	885.0	4750.0	13	500	6-17-70
36	39-71-13DC	FTUNION	4650.0	450.0	4665.0	15	650	6-24-70
37	39-72- 6BD	FTUNION	4840.0	1106.0	4890.0	19	440	6-20-70
38	39-73-19DC	WASATCH	5040.0	594.0	5055.0	15	650	6-20-70
39	39-73-23DC	WASATCH	5000.0	1092.0	5050.0	20	525	6-20-70
40	40-71- 6DD	FTUNION	4620.0	510.0	4645.0	17	600	6-23-70
41	40-73- 8CD	WASATCH	4836.0	300.0	4846.0	13	850	6-20-70
42	40-74- 9CA	WASATCH	4980.0	575.0	4985.0	15	560	6-19-70
43	40-75- 8DC	WASATCH	5395.0	190.0	5335.0	14	570	6-19-70
44	40-75-32DB	WASATCH	5280.0	210.0	5180.0	14	800	6-19-70
45	41-71-35AC	FTUNION	4560.0	310.0	4565.0	18	600	6-22-70
46	41-71- 6CC	FTUNION	4875.0	340.0	4595.0	14	1600	6-23-70
47	41-72-16BB	WASATCH	4900.0	253.0	4755.0	13	650	6-24-70
48	41-73- 6BD	WASATCH	4990.0	180.0	4992.0	14	1000	6-27-70
49	41-73-23DA	WASATCH	4837.0	400.0	4850.0	16	520	6-24-70
50	41-74-20BA	WASATCH	5121.0	110.0	5076.0	13	850	6-25-70
51	41-75- 4AB	WASATCH	4355.0	175.0	4255.0	14	1650	7-28-70
52	42-70- 5DD	FTUNION	4820.0	200.0	4700.0	12	8000	6-23-70
53	42-71- 7CC	WASATCH	4800.0	251.0	4650.0	14	400	6-23-70
54	42-71-26DA	WASATCH	4735.0	225.0	4665.0	14	1100	6-23-70
55	42-73- 2BD	WASATCH	5080.0	468.0	4830.0	15	2000	6-26-70
56	42-73-31DC	WASATCH	5114.0	160.0	4984.0	14	650	6-27-70
57	42-73-35AD	WASATCH	5075.0	300.0	4926.0	14	850	6-24-70
58	42-74-12AC	WASATCH	5214.0	296.0	5094.0	12	2900	6-29-70
59	42-74-28CD	WASATCH	5120.0	100.0	5075.0	11	700	6-25-70
60	42-75- 4DD	WASATCH	5062.0	185.0	4962.0	13	1100	6-27-70
61	43-71- 3AB	WASATCH	4750.0	220.0	4720.0	18	2100	6-26-70
62	43-72-15AB	WASATCH	4900.0	110.0	4850.0	11	2400	6-24-70
63	43-72-35CD	WASATCH	5000.0	210.0	4925.0	13	725	6-27-70
64	43-73- 1DD	WASATCH	5090.0	205.0	5055.0	16	1400	6-26-70
65	43-73-16CB	WASATCH	5076.0	300.0	4856.0	12	950	6-26-70
66	43-73-25BC	WASATCH	5020.0	400.0	4770.0	-1	400	6-26-70
67	43-74-18DD	WASATCH	5300.0	265.0	5120.0	11	1950	6-28-70
68	43-76-22DD	WASATCH	4745.0	455.0	4760.0	14	520	6-27-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
69	44-70-29AA	FTUNION	4815.0	300.0	4720.0	20	650	7- 5-70
70	44-71-21AD	WASATCH	4820.0	100.0	4740.0	13	950	7- 5-70
71	44-72- 2D	WASATCH	4860.0	175.0	4795.0	10	2800	7- 9-70
72	44-73-18AC	WASATCH	4900.0	100.0	4860.0	12	900	7- 3-70
73	44-74- 1BD	WASATCH	4890.0	160.0	4833.0	12	2500	7- 9-70
74	44-74-27AC	WASATCH	4080.0	215.0	3971.0	11	2200	7- 3-70
75	44-74-31DB	WASATCH	5160.0	235.0	5050.0	14	800	7- 3-70
76	44-75-27CC	WASATCH	5300.0	150.0	5260.0	11	1200	7- 3-70
77	44-76- 8CD	WASATCH	4628.0	360.0	4635.0	14	660	7-21-70
78	45-70-10DA	FTUNION	4810.0	110.0	4750.0	11	1400	7- 5-70
79	45-71-12AB	WASATCH	4820.0	172.0	4750.0	14	1850	7- 5-70
80	45-72-23BB	WASATCH	4953.0	75.0	4903.0	11	3100	7- 9-70
81	45-73-14BB	WASATCH	4785.0	75.0	4760.0	12	1350	7- 9-70
82	45-73-16AC	WASATCH	4809.0	100.0	4769.0	13	2000	7- 9-70
83	45-74-17AC	WASATCH	5125.0	380.0	4865.0	13	1650	7- 9-70
84	45-75- 8AC	WASATCH	4857.0	245.0	4722.0	12	1550	7- 1-70
85	45-75-26AC	WASATCH	5020.0	300.0	4895.0	14	1300	7-10-70
86	45-77-13AB	WASATCH	4460.0	429.0	4465.0	15	715	7-11-70
87	46-71-22CB	WASATCH	4750.0	320.0	4650.0	12	2200	7- 5-70
88	46-72-14BC	WASATCH	4710.0	100.0	4685.0	11	1000	7- 9-70
89	46-73-22DA	WASATCH	4960.0	303.0	4860.0	17	1800	7- 9-70
90	46-73-29DC	WASATCH	4883.0	200.0	4788.0	11	2800	7- 9-70
91	46-74-21BB	WASATCH	5059.0	200.0	4939.0	15	1300	7-10-70
92	46-74-28DD	WASATCH	4970.0	196.0	4910.0	10	1200	7-10-70
93	46-75- 9BD	WASATCH	4716.0	450.0	4566.0	12	1300	7-11-70
94	46-75-26CD	WASATCH	4878.0	298.0	4798.0	11	1800	7-10-70
95	46-76-21BB	WASATCH	4645.0	306.0	4520.0	12	2000	7-11-70
96	47-71- 9CC	WASATCH	4725.0	120.0	4670.0	12	2100	7- 6-70
97	47-72-10CB	WASATCH	4650.0	190.0	4575.0	16	520	7- 9-70
98	47-72-16AC	WASATCH	4690.0	60.0	4665.0	9	1300	7- 9-70
99	47-73-20DD	WASATCH	4895.0	500.0	4795.0	12	2200	7- 9-70
100	47-74-23BD	WASATCH	4925.0	82.0	4895.0	11	2000	7-10-70
101	47-75- 9CC	WASATCH	4580.0	500.0	4595.0	11	1650	7-12-70
102	47-76- 2DB	WASATCH	4395.0	421.0	4410.0	15	945	7-12-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
103	48-71-17DD	WASATCH	4620.0	215.0	4442.0	17	2000	7- 6-70
104	48-71-17AD	FTUNION	4570.0	276.0	4490.0	14	950	7- 6-70
105	48-72- 7B	WASATCH	4760.0	130.0	4710.0	11	2100	7- 9-70
106	48-73-26AC	WASATCH	4750.0	450.0	4630.0	15	1250	7- 9-70
107	48-74-26CA	WASATCH	4950.0	540.0	4850.0	17	1500	7-10-70
108	48-75-22BB	WASATCH	4575.0	340.0	4605.0	14	955	7-12-70
109	49-71-17DD	WASATCH	4610.0	107.0	4571.0	12	1500	7- 6-70
110	49-73- 1CC	FTUNION	4790.0	700.0	4140.0	13	850	7-13-70
111	49-73-12CB	WASATCH	4780.0	170.0	4730.0	14	2000	7-13-70
112	49-73-19CB	WASATCH	4320.0	320.0	4580.0	14	2250	7-13-70
113	49-75- 2CB	WASATCH	4715.0	100.0	4635.0	15	1300	7-13-70
114	49-75-34CD	WASATCH	4520.0	400.0	4535.0	13	650	7-12-70
115	50-71-30CA	WASATCH	4735.0	145.0	4637.0	14	4000	7-14-70
116	50-72- 7AA	WASATCH	4338.0	390.0	4278.0	14	1100	7-14-70
117	50-72-25AD	WASATCH	4720.0	260.0	4610.0	12	2600	7-14-70
118	50-74-20BD	WASATCH	4560.0	163.0	4539.0	11	1200	7-13-70
119	50-75-26AC	WASATCH	4768.0	400.0	4676.0	17	1400	7-13-70
120	51-72-22CD	WASATCH	4310.0	184.0	4285.0	11	765	7-14-70
121	51-73-34AC	WASATCH	4530.0	236.0	4465.0	12	2000	7-14-70
122	51-74-31AC	WASATCH	4350.0	108.0	4315.0	13	800	7-15-70
123	51-75- 2BC	WASATCH	4190.0	200.0	4180.0	13	900	7-15-70
124	51-76-23CA	WASATCH	4175.0	90.0	4155.0	13	6000	7-13-70
125	52-73- 8AA	FTUNION	4175.0	225.0	4115.0	14	1600	7-16-70
126	52-75-15BB	FTUNION	3970.0	514.0	3980.0	14	915	7-15-70
127	53-74- 7AD	FTUNION	4190.0	123.0	4150.0	14	5000	7-16-70
128	53-75- 2BB	WASATCH	4085.0	124.0	4009.0	18	910	7-16-70
129	53-76-23DC	FTUNION	3915.0	900.0	3935.0	20	1800	7-15-70
130	54-74-28D	FTUNION	4350.0	230.0	4200.0	14	840	7-16-70
131	54-75- 3C	FTUNION	4075.0	225.0	3925.0	17	1150	7-17-70
132	54-76-22AC	FTUNION	3930.0	1120.0	3920.0	20	2100	7-16-70
133	55-76-14DD	FTUNION	3985.0	225.0	3965.0	14	1350	7-17-70
134	41-76- 6AB	FTUNION	4960.0	200.0	4962.0	14	530	8- 7-70
135	42-77-21AD	FTUNION	4926.0	730.0	4928.0	15	750	7-21-70
136	43-78- 5DA	WASATCH	4372.0	300.0	4379.0	14	1300	7-22-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
137	44-77-30BB	WASATCH	4383.0	255.0	4389.0	12	1150	7-22-70
138	44-78-10DA	WASATCH	4325.0	685.0	4337.0	15	630	7-22-70
139	44-79-20DA	WASATCH	4573.0	150.0	4518.0	13	1100	7-22-70
140	44-80- 6CA	WASATCH	4819.0	200.0	4699.0	11	3500	7-24-70
141	45-76-17BD	WASATCH	4560.0	150.0	4563.0	13	1000	7-25-70
142	45-77- 6BC	WASATCH	4220.0	335.0	4243.0	14	495	7-25-70
143	45-78-34BA	WASATCH	4270.0	500.0	4285.0	14	600	7-22-70
144	45-79- 6BD	WASATCH	4500.0	175.0	4450.0	11	2200	7-24-70
145	45-80- 9DA	WASATCH	4618.0	230.0	4619.0	14	1500	7-23-70
146	46-77-17CC	WASATCH	4189.0	250.0	4195.0	15	575	7-26-70
147	46-78-18CA	WASATCH	4570.0	540.0	4460.0	13	2900	7-26-70
148	46-79-20BB	WASATCH	4555.0	44.0	4536.0	12	1600	7-24-70
149	46-80- 8BD	WASATCH	4653.0	95.0	4593.0	10	3500	7-24-70
150	47-77-24DC	WASATCH	4465.0	253.0	4343.0	14	2650	7-20-70
151	47-78-25AC	WASATCH	4180.0	200.0	4192.0	13	480	7-25-70
152	47-79-10BB	WASATCH	4590.0	315.0	4530.0	16	1400	7-26-70
153	47-80-16BA	WASATCH	4710.0	220.0	4610.0	13	1400	7-23-70
154	48-76-13CA	WASATCH	4590.0	481.0	4390.0	15	900	7-13-70
155	48-77-15DB	WASATCH	4160.0	200.0	4168.0	15	1000	7-20-70
156	48-78- 5BA	WASATCH	4390.0	300.0	4190.0	-1	4000	7-25-70
157	48-78-33BC	WASATCH	4220.0	250.0	4170.0	11	4500	7-27-70
158	48-79-33CC	WASATCH	4450.0	253.0	4396.0	17	940	7-26-70
159	48-81-15BC	WASATCH	4570.0	300.0	4600.0	11	1700	7-27-70
160	49-76-17CC	WASATCH	4105.0	404.0	4109.0	14	560	7-20-70
161	49-77-21BA	FTUNION	4015.0	600.0	4024.0	19	1090	7-20-70
162	49-80-23AC	WASATCH	4275.0	145.0	4271.0	19	1075	7-29-70
163	49-80-30CC	WASATCH	4548.0	250.0	4528.0	12	800	7-27-70
164	49-81-25DD	WASATCH	4550.0	265.0	4552.0	18	1600	7-27-70
165	50-77- 8DA	FTUNION	3875.0	1000.0	3910.0	20	1600	7-20-70
166	50-77-31CD	WASATCH	3965.0	618.0	3970.0	16	580	8- 2-70
167	50-79-14AC	WASATCH	4605.0	140.0	4505.0	12	3750	7-29-70
168	50-79-30CB	WASATCH	4200.0	100.0	4180.0	11	915	8- 6-70
169	50-81-26AC	WASATCH	4590.0	215.0	4575.0	13	1700	7-27-70
170	51-77-30DA	WASATCH	3830.0	400.0	3835.0	15	700	8- 2-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
171	51-79-16BA	WASATCH	4025.0	80.0	3995.0	13	1030	7-30-70
172	51-80-11BC	WASATCH	4190.0	215.0	4157.0	12	2400	7-30-70
173	51-81-17DA	WASATCH	4405.0	50.0	4385.0	17	1900	7-31-70
174	51-82-20DD	WASATCH	4920.0	180.0	4927.0	10	955	8- 7-70
175	52-77-17DC	FTUNION	3780.0	600.0	3803.0	15	1950	8- 2-70
176	52-78-11DC	WASATCH	3840.0	200.0	3850.0	11	2050	7-30-70
177	52-79- 3BA	WASATCH	4375.0	260.0	4210.0	12	4000	7-30-70
178	52-79- 3BC	WASATCH	4370.0	240.0	4210.0	11	2200	7-30-70
179	52-80-18DC	WASATCH	4370.0	170.0	4240.0	14	4100	8- 5-70
180	52-81-23AD	WASATCH	4260.0	200.0	4200.0	15	1790	8- 3-70
181	52-82-23DB	WASATCH	4640.0	190.0	4615.0	13	2100	8- 1-70
182	53-77- 2BD	FTUNION	3750.0	780.0	3760.0	15	1675	8- 2-70
183	53-77-34BD	FTUNION	3775.0	865.0	3790.0	19	1850	8- 2-70
184	53-80- 9CA	WASATCH	4075.0	134.0	4065.0	15	950	7-31-70
185	53-81-14BC	WASATCH	4195.0	180.0	4075.0	15	975	8- 2-70
186	53-82-11CD	WASATCH	4318.0	143.0	4299.0	11	1450	8- 4-70
187	54-77-23CD	FTUNION	3790.0	1003.0	3850.0	23	1625	7-16-70
188	54-79-21BD	WASATCH	3880.0	200.0	3790.0	13	1300	7-31-70
189	54-80-24BC	WASATCH	4090.0	100.0	4072.0	14	5000	8- 5-70
190	54-80-24BC	WASATCH	4090.0	160.0	4070.0	14	950	8- 5-70
191	54-81-15BA	WASATCH	4510.0	0.0	4510.0	10	800	8- 3-70
192	54-82- 9BB	WASATCH	4160.0	50.0	4140.0	13	1200	8- 3-70
193	54-83-27CD	WASATCH	4490.0	305.0	4491.0	17	490	8- 3-70
194	55-77-10DC	FTUNION	3585.0	297.0	3590.0	13	1600	7-31-70
195	55-77-15BD	FTUNION	3595.0	520.0	3623.0	16	1825	7-31-70
196	55-78-29AA	FTUNION	3790.0	350.0	3760.0	18	1700	7-31-70
197	55-79-30AD	FTUNION	4045.0	400.0	3915.0	13	1100	8- 1-70
198	55-81-19BB	WASATCH	4155.0	120.0	4121.0	14	1100	8- 3-70
199	55-83-26BD	WASATCH	4315.0	240.0	4245.0	15	1800	8- 3-70
200	56-77-26CC	FTUNION	3600.0	500.0	3625.0	16	1600	7-31-70
201	56-79-21AC	WASATCH	4190.0	240.0	4115.0	14	4000	8- 1-70
202	56-80- 9BD	WASATCH	4550.0	150.0	4519.0	17	2700	8- 1-70
203	56-81-29BD	WASATCH	4310.0	378.0	4120.0	15	1000	8- 1-70
204	56-82-19DA	FTUNION	3780.0	287.0	3750.0	17	915	8- 3-70

NUMBER	LOCATION	FORMATION	ELEVATION	DEPTH	STATIC-SURFACE	TEMP.C	SP.COND	DATE
205	57-76-29AC	FTUNION	3520.0	275.0	3550.0	15	2000	7-31-70
206	57-80-31BB	FTUNION	3995.0	160.0	4020.0	11	4100	8- 4-70
207	57-81- 7CB	FTUNION	3815.0	510.0	3735.0	15	1350	8- 3-70
208	57-81-22AA	WASATCH	3800.0	140.0	3769.0	13	3700	8- 3-70

Appendix C

CHEMICAL DATA

Explanations of the data headings used on pages 133 to 138 are given below.

NUM = well number.

LOCATION = location of well (see Location Format in Appendix A).

HCO3 = ppm bicarbonate concentration.

CO3 = ppm carbonate concentration.

SO4 = ppm sulfate concentration.

CL = ppm chloride concentration.

F = ppm fluoride concentration.

CA = ppm calcium concentration.

MG = ppm magnesium concentration.

NA = ppm sodium concentration.

K = ppm potassium concentration.

SIO4 = ppm silica concentration.

U = ppb uranium concentration.

ALK = ppm alkalinity as calcium carbonate.

T.HRD = ppm total hardness as calcium carbonate.

TDS = ppm total dissolved solids.

PH = negative logarithm of the hydrogen-ion concentration.

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
1	33-70- 9AC	302.0	0.0	140.0	4.5	0.05	60.0	35.0	35.0	5.0	18.0	5.0	248.0	295.0	447.0	7.6
2	34-69-32AC	228.0	0.0	625.0	6.0	0.40	120.0	56.0	93.0	14.0	7.5	2.0	186.0	530.0	1030.0	7.3
3	34-72-26AB	310.0	0.0	550.0	5.0	0.50	71.0	21.0	204.0	5.1	9.0	2.0	254.0	258.0	1020.0	7.8
4	35-71- 4BB	244.0	0.0	140.0	4.0	0.15	175.0	22.0	35.0	4.1	16.0	1.0	200.0	263.0	411.0	8.0
5	35-70-32BC	214.0	0.0	600.0	4.0	0.45	34.0	3.6	294.0	3.0	8.5	1.0	176.0	100.0	1050.0	8.2
6	35-72-18A	270.0	0.0	60.0	2.0	0.05	60.0	16.0	36.0	3.9	15.0	1.0	221.0	214.0	326.0	7.7
7	35-73-15B	143.0	0.0	250.0	4.5	0.50	36.0	3.6	144.0	4.1	10.0	1.0	117.0	107.0	523.0	8.2
8	35-74- 18D	214.0	0.0	50.0	2.0	0.40	71.0	9.7	18.0	4.8	17.0	1.0	176.0	214.0	297.0	7.6
9	36-69- 7AB	287.0	5.0	65.0	7.0	0.95	8.8	3.6	192.0	3.4	10.0	1.0	239.0	33.0	437.0	8.5
10	36-70-12CC	309.0	0.0	75.0	7.5	1.02	8.4	2.4	189.0	2.9	12.0	1.0	253.0	31.0	450.0	8.1
11	36-70-21CB	324.0	6.0	85.0	8.5	1.20	6.8	4.9	210.0	2.8	11.0	1.0	271.0	36.0	496.0	8.5
12	36-71-13DB	340.0	4.0	25.0	6.5	0.60	8.8	2.4	168.0	3.1	9.0	1.0	282.0	30.0	394.0	8.3
13	36-72- 9DD	183.0	0.0	320.0	5.5	0.20	45.0	3.6	186.0	2.9	11.0	1.0	150.0	123.0	664.0	8.1
14	36-73-26AD	367.0	0.0	15.0	2.0	0.0	89.0	16.0	23.0	3.2	12.0	6.0	301.0	286.0	341.0	7.3
15	36-73-27AB	253.0	0.0	140.0	4.5	0.20	83.0	7.3	56.0	5.9	16.0	5.0	208.0	235.0	438.0	7.6
16	36-74-23CD	300.0	0.0	300.0	13.0	0.25	140.0	24.0	31.0	3.1	14.0	65.0	246.0	450.0	673.0	7.5
17	36-74-27BD	284.0	0.0	55.0	2.0	0.25	81.0	19.0	19.0	3.5	16.0	60.0	233.0	282.0	336.0	7.0
18	37-69-20DB	474.0	0.0	2.0	6.0	1.40	4.4	4.9	207.0	3.0	9.5	1.0	389.0	30.0	471.0	8.1
19	37-70- 4AC	468.0	0.0	1.0	5.5	0.95	25.0	2.4	195.0	4.8	8.5	1.0	384.0	69.0	474.0	7.8
20	37-72-17CA	191.0	4.0	100.0	3.0	0.20	13.0	1.8	141.0	2.2	12.0	1.0	160.0	40.0	371.0	8.7
21	37-73-10BD	200.0	0.0	90.0	3.0	0.30	24.0	3.6	126.0	3.6	12.0	1.0	164.0	75.0	362.0	8.1
22	37-73-22AD	187.0	7.0	70.0	4.0	0.35	14.0	3.6	123.0	2.6	11.0	1.0	159.0	48.0	328.0	8.4
23	37-74-24B	288.0	0.0	80.0	3.8	0.15	80.0	21.0	24.0	5.6	12.0	6.0	236.0	285.0	369.0	7.6
24	37-75-14DB	174.0	0.0	90.0	4.5	0.48	54.0	8.5	30.0	13.0	7.5	1.0	143.0	172.0	294.0	7.5
25	38-71- 1CA	210.0	0.0	65.0	5.5	0.65	6.0	1.2	135.0	2.0	8.0	1.0	172.0	19.0	326.0	8.1
26	38-71-12AB	252.0	0.0	15.0	3.5	0.45	34.0	8.5	57.0	9.5	7.0	1.0	207.0	120.0	259.0	8.0
27	38-72-23DB	172.0	0.0	140.0	5.0	0.45	7.6	1.2	159.0	1.7	6.0	1.0	141.0	23.0	406.0	8.2
28	38-72-27AC	196.0	0.0	120.0	3.5	0.20	6.8	1.9	153.0	1.6	6.5	1.0	161.0	24.0	391.0	8.2
29	38-72-28DB	168.0	0.0	150.0	4.3	0.28	8.0	1.7	171.0	1.6	6.5	1.0	138.0	27.0	426.0	8.0
30	38-73-33CB	206.0	0.0	175.0	3.0	0.25	70.0	9.7	93.0	9.0	12.0	1.0	169.0	217.0	473.0	7.9
31	38-73-33CB	204.0	0.0	150.0	3.5	0.35	26.0	2.4	141.0	3.4	12.0	1.0	167.0	74.0	439.0	8.2
32	38-73-33CB	194.0	0.0	100.0	4.0	0.38	42.0	4.9	96.0	4.8	14.0	1.0	159.0	127.0	362.0	8.1
33	38-74-12BC	194.0	0.0	550.0	4.0	0.60	157.0	21.0	108.0	13.0	15.0	4.0	159.0	475.0	965.0	7.6
34	38-75- 5AA	250.0	0.0	190.0	6.3	0.25	91.0	19.0	30.0	9.5	14.0	1.0	205.0	303.0	483.0	7.9
35	39-71- 4DC	192.0	3.0	80.0	6.5	0.70	4.0	1.2	162.0	2.1	10.0	1.0	160.0	13.0	365.0	8.7
36	39-71-13DC	410.0	0.0	5.0	4.0	1.00	30.0	7.3	144.0	13.0	10.0	1.0	336.0	106.0	416.0	7.6

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
37	39-72- 6BD	160.0	6.0	85.0	4.0	0.20	6.8	0.7	132.0	1.7	12.0	1.0	136.0	20.0	327.0	8.6
38	39-73-19DC	209.0	0.0	190.0	3.5	0.25	72.0	3.6	96.0	7.4	18.0	1.0	171.0	195.0	494.0	7.7
39	39-73-23DC	208.0	0.0	110.0	4.0	0.20	54.0	1.2	98.0	5.0	17.0	1.0	171.0	139.0	391.0	7.9
40	40-71- 6DD	158.0	3.0	175.0	7.0	0.55	5.6	0.7	177.0	2.5	9.0	1.0	132.0	17.0	458.0	8.5
41	40-73- 8CD	194.0	0.0	320.0	5.0	0.30	30.0	3.6	210.0	3.0	11.0	1.0	159.0	88.0	679.0	8.2
42	40-74- 9CA	230.0	10.0	85.0	7.0	0.10	10.0	1.7	165.0	2.4	12.0	1.0	197.0	32.0	406.0	8.5
43	40-75- 8DC	248.0	0.0	120.0	3.5	0.25	74.0	8.5	43.0	9.0	14.0	1.0	203.0	220.0	394.0	7.9
44	40-75-32DB	194.0	0.0	320.0	8.0	0.55	102.0	15.0	96.0	9.0	11.0	1.0	159.0	315.0	653.0	7.9
45	41-71-35AC	366.0	0.0	1.0	8.0	2.10	10.0	1.9	174.0	4.5	8.0	1.0	300.0	33.0	389.0	8.0
46	41-71- 6CC	224.0	0.0	750.0	16.0	0.70	128.0	19.0	264.0	4.8	8.0	7.0	184.0	402.0	1300.0	8.0
47	41-72-16BB	260.0	0.0	150.0	11.0	0.35	24.0	3.6	210.0	2.7	8.5	5.0	213.0	74.0	538.0	8.1
48	41-73- 6BD	210.0	0.0	400.0	10.0	0.40	84.0	12.0	186.0	5.4	11.0	3.0	172.0	262.0	812.0	7.8
49	41-73-23DA	200.0	7.0	110.0	5.5	0.35	8.8	1.7	156.0	1.9	9.5	4.0	170.0	29.0	400.0	8.7
50	41-74-20BA	245.0	0.0	280.0	13.0	0.35	116.0	16.0	87.0	5.8	12.0	2.0	201.0	357.0	651.0	7.5
51	41-75- 4AB	220.0	0.0	750.0	13.0	0.40	188.0	56.0	29.0	13.0	7.0	2.0	180.0	700.0	1157.0	7.5
52	42-70- 5DD	200.0	0.0	6000.0	40.0	1.70	382.0	849.0	540.0	18.5	33.0	1.0	164.0	4450.0	7960.0	6.8
53	42-71- 7CC	230.0	6.0	40.0	12.0	0.55	6.8	0.7	126.0	2.0	7.5	1.0	194.0	20.0	315.0	8.5
54	42-71-26DA	726.0	0.0	1.0	5.0	1.20	24.0	12.0	255.0	14.0	7.0	2.0	595.0	108.0	676.0	8.0
55	42-73- 2BD	308.0	0.0	900.0	6.0	0.65	301.0	113.0	120.0	13.0	12.0	23.0	25.3	1215.0	1620.0	7.4
56	42-73-31DC	320.0	0.0	140.0	2.5	0.20	96.0	21.0	25.0	4.9	14.0	5.0	262.0	323.0	462.0	8.0
57	42-73-35AD	226.0	0.0	300.0	4.0	0.50	87.0	30.0	96.0	4.8	14.0	4.0	185.0	341.0	647.0	8.1
58	42-74-12AC	350.0	0.0	1875.0	10.0	0.65	423.0	18.0	111.0	14.0	16.0	16.0	287.0	1950.0	2840.0	7.1
59	42-74-28CD	226.0	0.0	200.0	2.5	0.30	106.0	12.0	22.0	9.5	12.0	60.0	185.0	316.0	475.0	7.5
60	42-75- 4DD	250.0	0.0	400.0	2.5	0.40	136.0	17.0	120.0	9.0	15.0	7.0	205.0	408.0	823.0	7.6
61	43-71- 3AB	306.0	0.0	1125.0	11.0	0.55	124.0	29.0	315.0	11.0	9.0	2.0	251.0	430.0	1180.0	8.0
62	43-72-15AB	270.0	0.0	1500.0	7.5	0.85	345.0	196.0	54.0	10.0	15.0	3.0	221.0	1665.0	2260.0	7.2
63	43-72-35CD	109.0	0.0	320.0	5.0	0.70	216.0	44.0	168.0	2.6	8.0	2.0	89.0	720.0	818.0	8.0
64	43-73- 1DD	278.0	0.0	500.0	5.0	0.35	89.0	8.5	291.0	4.4	9.0	2.0	228.0	254.0	1044.0	8.1
65	43-73-16CB	396.0	0.0	200.0	4.5	0.15	76.0	16.0	156.0	4.3	9.0	2.0	325.0	256.0	661.0	7.5
66	43-73-25BC	200.0	10.0	8.0	19.0	0.55	4.0	1.5	129.0	1.7	5.5	2.0	172.0	16.0	278.0	8.9
67	43-74-18DD	155.0	0.0	1125.0	4.5	0.60	201.0	41.0	231.0	11.0	8.0	2.0	127.0	671.0	1700.0	7.5
68	43-76-22DD	152.0	5.0	150.0	6.0	0.10	10.0	1.2	381.0	2.6	9.0	3.0	129.0	28.0	640.0	8.5
69	44-70-29AA	364.0	0.0	15.0	24.0	1.00	12.0	4.4	630.0	3.4	8.5	2.0	298.0	48.0	877.0	8.1
70	44-71-21AD	182.0	0.0	320.0	27.0	0.90	91.0	60.0	165.0	4.1	22.0	4.0	149.0	468.0	780.0	7.4
71	44-72- 2D	182.0	0.0	2000.0	4.5	0.75	425.0	258.0	159.0	16.0	14.0	2.0	149.0	2120.0	2970.0	6.8
72	44-73-18AC	129.0	0.0	400.0	6.0	0.20	31.0	6.0	243.0	4.0	10.0	2.0	106.0	100.0	764.0	8.0

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
73	44-74- 1BD	154.0	0.0	1625.0	7.0	0.60	392.0	42.0	219.0	11.0	14.0	2.0	126.0	1565.0	2490.0	6.7
74	44-74-27AC	111.0	0.0	1375.0	5.5	0.65	182.0	54.0	351.0	11.0	9.5	1.0	91.0	678.0	2040.0	7.0
75	44-74-31DB	229.0	0.0	250.0	33.0	0.30	110.0	27.0	33.0	3.9	11.0	3.0	188.0	386.0	581.0	7.8
76	44-75-27CC	318.0	0.0	475.0	7.5	0.30	175.0	30.0	40.0	4.6	11.0	125.0	261.0	562.0	900.0	7.4
77	44-76- 8CD	142.0	5.0	225.0	8.3	0.05	10.0	2.0	180.0	2.0	9.5	2.0	121.0	34.0	512.0	8.8
78	45-70-10DA	422.0	0.0	600.0	7.0	0.60	180.0	98.0	32.0	5.4	5.5	1.0	346.0	855.0	1140.0	7.3
79	45-71-12AB	846.0	0.0	400.0	7.0	0.50	75.0	17.0	444.0	10.0	10.0	1.0	694.0	256.0	1380.0	7.1
80	45-72-23BB	238.0	0.0	2125.0	11.0	1.05	400.0	278.0	228.0	8.0	16.0	1.0	195.0	2145.0	3180.0	7.4
81	45-73-14BB	714.0	0.0	100.0	3.0	0.15	36.0	1.6	360.0	5.3	9.0	2.0	586.0	97.0	867.0	7.8
82	45-73-16AC	384.0	0.0	875.0	5.0	0.50	188.0	23.0	330.0	11.0	10.0	1.0	315.0	566.0	1630.0	7.6
83	45-74-17AC	102.0	0.0	800.0	5.0	0.65	102.0	7.3	369.0	4.8	7.5	1.0	84.0	285.0	1350.0	8.0
84	45-75- 8AC	76.0	0.0	750.0	3.5	0.70	78.0	5.7	351.0	5.1	7.0	1.0	62.0	218.0	1240.0	7.9
85	45-75-26AC	224.0	0.0	600.0	3.5	0.55	126.0	17.0	222.0	6.5	11.0	2.0	184.0	385.0	1200.0	7.9
86	45-77-13AB	109.0	4.0	275.0	7.5	0.50	9.2	2.2	210.0	2.0	9.0	1.0	93.0	32.0	573.0	8.5
87	46-71-22CB	563.0	0.0	875.0	7.5	0.90	135.0	62.0	375.0	15.0	8.5	2.0	462.0	650.0	1760.0	7.6
88	46-72-14BC	20.0	0.0	450.0	10.0	1.10	85.0	66.0	96.0	5.3	33.0	4.0	16.0	480.0	756.0	5.8
89	46-73-22DA	258.0	0.0	750.0	12.0	0.80	139.0	32.0	291.0	8.0	6.5	1.0	212.0	475.0	1370.0	7.7
90	46-73-29DC	46.0	0.0	1600.0	7.0	0.90	196.0	57.0	534.0	9.3	5.0	2.0	38.0	725.0	2430.0	7.5
91	46-74-21BB	360.0	0.0	625.0	3.5	0.45	200.0	64.0	105.0	8.5	18.0	3.0	295.0	765.0	1200.0	7.4
92	46-74-28DD	304.0	0.0	425.0	2.0	0.45	158.0	40.0	96.0	5.9	13.0	3.0	249.0	557.0	890.0	7.4
93	46-75- 9BD	84.0	0.0	600.0	18.0	0.55	40.0	4.4	333.0	3.8	7.5	2.0	69.0	118.0	1050.0	6.9
94	46-75-26CD	176.0	0.0	950.0	4.8	0.70	164.0	17.0	375.0	9.0	8.0	2.0	144.0	478.0	1620.0	7.7
95	46-76-21BB	100.0	0.0	1000.0	6.3	0.70	111.0	13.0	537.0	5.1	6.5	3.0	82.0	327.0	1730.0	7.5
96	47-71- 9CC	344.0	0.0	1125.0	5.5	0.65	208.0	135.0	216.0	17.0	8.0	2.0	282.0	1075.0	1880.0	7.3
97	47-72-10CB	346.0	0.0	3.0	8.5	0.35	8.0	2.7	192.0	3.1	8.5	2.0	284.0	31.0	396.0	8.0
98	47-72-16AC	161.0	0.0	750.0	5.5	0.70	202.0	30.0	90.0	5.7	18.0	1.0	132.0	630.0	1180.0	6.4
99	47-73-20DD	239.0	0.0	1125.0	7.5	0.85	172.0	36.0	408.0	9.0	7.5	2.0	196.0	578.0	1880.0	7.5
100	47-74-23BD	270.0	0.0	1000.0	12.0	0.95	230.0	89.0	162.0	5.3	11.0	2.0	221.0	942.0	1640.0	7.4
101	47-75- 9CC	108.0	0.0	800.0	12.0	0.60	81.0	9.7	405.0	4.7	9.0	2.0	89.0	242.0	1380.0	7.9
102	47-76- 2DB	100.0	4.0	375.0	15.0	0.45	10.0	1.9	264.0	2.7	9.0	2.0	85.0	33.0	731.0	8.5
103	48-71-17DD	354.0	0.0	900.0	7.5	0.60	150.0	32.0	345.0	13.0	9.0	1.0	290.0	505.0	1630.0	6.9
104	48-71-17AD	600.0	0.0	1.0	6.3	0.80	43.0	1.6	246.0	7.0	8.0	1.0	492.0	114.0	610.0	7.6
105	48-72- 7B	244.0	0.0	1300.0	3.0	0.80	363.0	32.0	221.0	15.0	12.0	3.0	200.0	1038.0	2070.0	7.4
106	48-73-26AC	265.0	0.0	550.0	13.0	0.50	114.0	28.0	198.0	4.6	7.5	2.0	217.0	402.0	1050.0	7.5
107	48-74-26CA	182.0	0.0	700.0	5.5	0.70	66.0	8.1	366.0	6.5	5.0	2.0	149.0	198.0	1250.0	8.1
108	48-75-22BB	102.0	10.0	390.0	14.0	0.55	12.0	8.5	285.0	2.6	9.0	2.0	92.0	38.0	782.0	8.9

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
109	49-71-17DD	166.0	0.0	875.0	8.0	1.65	200.0	89.0	52.0	11.0	25.0	1.0	136.0	868.0	1340.0	7.4
110	49-73- 1CC	568.0	0.0	1.0	4.5	0.45	18.0	3.6	267.0	5.3	12.0	2.0	466.0	60.0	592.0	9.0
111	49-73-12CB	351.0	0.0	1125.0	5.0	0.90	287.0	121.0	147.0	5.8	11.0	2.0	288.0	1215.0	1880.0	7.4
112	49-73-19CB	288.0	0.0	1200.0	4.0	0.75	176.0	26.0	405.0	11.0	11.0	2.0	236.0	548.0	1580.0	7.6
113	49-75- 2CB	260.0	0.0	500.0	2.5	0.60	79.0	13.0	261.0	5.0	10.0	2.0	213.0	252.0	999.0	8.0
114	49-75-34CD	188.0	8.0	140.0	13.0	0.50	6.4	1.2	192.0	1.8	8.5	2.0	161.0	20.0	464.0	8.6
115	50-71-30CA	430.0	0.0	2875.0	9.0	1.35	493.0	66.0	114.0	22.0	10.0	1.0	353.0	3150.0	4200.0	7.5
116	50-72- 7AA	802.0	0.0	5.0	2.8	0.80	33.0	25.0	267.0	7.5	9.0	1.0	656.0	184.0	745.0	7.7
117	50-72-25AD	684.0	0.0	1050.0	5.0	0.95	144.0	62.0	465.0	21.0	13.0	2.0	561.0	614.0	2100.0	7.4
118	50-74-20BD	290.0	6.0	425.0	7.5	0.60	25.0	4.5	309.0	3.9	8.0	1.0	243.0	81.0	933.0	8.4
119	50-75-26AC	384.0	0.0	625.0	8.0	0.55	182.0	45.0	126.0	5.9	8.0	1.0	315.0	638.0	1190.0	7.5
120	51-72-22CD	466.0	0.0	25.0	1.5	0.55	81.0	14.0	135.0	5.2	10.0	1.0	382.0	259.0	502.0	7.2
121	51-73-34AC	232.0	0.0	1125.0	2.3	0.65	204.0	77.0	221.0	15.0	17.0	1.0	190.0	825.0	1780.0	7.6
122	51-74-31AC	550.0	10.0	4.0	8.0	0.35	7.6	1.2	297.0	3.0	9.0	1.0	459.0	25.0	611.0	8.3
123	51-75- 2BC	620.0	0.0	0.5	11.0	1.05	12.0	4.1	327.0	4.3	11.0	1.0	508.0	47.0	676.0	7.9
124	51-76-23CA	542.0	0.0	3750.0	11.0	1.20	393.0	332.0	648.0	17.0	10.0	1.0	444.0	2350.0	5430.0	7.2
125	52-73- 8AA	734.0	0.0	375.0	3.8	0.60	59.0	12.0	408.0	6.0	9.0	1.0	602.0	196.0	1240.0	7.7
126	52-75-15BB	644.0	0.0	0.5	4.5	0.90	11.0	3.5	336.0	3.9	12.0	1.0	528.0	42.0	960.0	8.1
127	53-74- 7AD	312.0	0.0	3750.0	9.0	1.20	437.0	311.0	772.0	22.0	9.0	1.0	256.0	2370.0	5470.0	7.1
128	53-75- 2BB	624.0	10.0	25.0	7.5	0.80	8.4	4.9	315.0	3.9	10.0	1.0	520.0	40.0	693.0	8.3
129	53-76-23DC	1284.0	0.0	0.5	0.3	1.20	33.0	2.1	510.0	19.0	15.0	1.0	1053.0	91.0	1210.0	7.7
130	54-74-28D	524.0	0.0	0.5	6.0	0.50	18.0	4.9	270.0	5.1	8.0	1.0	430.0	65.0	572.0	7.5
131	54-75- 3C	736.0	0.0	25.0	1.5	0.65	8.0	3.4	411.0	3.9	9.0	1.0	604.0	34.0	825.0	8.0
132	54-76-22AC	1410.0	20.0	20.0	0.5	0.55	24.0	2.7	594.0	9.5	13.0	3.0	1156.0	71.0	1380.0	8.3
133	55-76-14DD	834.0	0.0	90.0	0.5	0.50	57.0	10.0	375.0	7.5	8.0	1.0	684.0	184.0	960.0	7.7
134	41-76- 6AB	152.0	12.0	100.0	5.5	0.65	12.0	1.5	156.0	2.4	8.5	1.0	135.0	36.0	374.0	8.6
135	42-77-21AD	190.0	12.0	235.0	4.0	0.40	12.0	2.2	180.0	3.0	10.0	1.0	166.0	39.0	553.0	8.7
136	43-78- 5DA	240.0	4.0	475.0	20.0	1.10	18.0	4.6	369.0	3.7	9.0	1.0	200.0	64.0	1020.0	8.3
137	44-77-30BB	170.0	4.0	410.0	8.0	0.90	20.0	3.9	333.0	4.0	9.0	1.0	143.0	66.0	877.0	8.3
138	44-78-10DA	402.0	16.0	1.0	4.5	1.10	3.2	1.7	255.0	2.7	10.0	1.0	343.0	15.0	493.0	8.6
139	44-79-20DA	410.0	0.0	265.0	4.0	0.30	61.0	13.0	216.0	5.6	9.0	1.0	336.0	205.0	776.0	7.6
140	44-80- 6CA	256.0	0.0	2000.0	20.0	1.00	173.0	46.0	636.0	12.0	8.5	1.0	210.0	620.0	3020.0	7.5
141	45-76-17BD	92.0	0.0	450.0	6.5	0.40	29.0	4.3	291.0	3.3	9.0	1.0	75.0	90.0	839.0	8.1
142	45-77- 6BC	216.0	18.0	75.0	7.0	0.85	4.0	0.5	165.0	1.5	9.5	1.0	192.0	12.0	387.0	8.9
143	45-78-34BA	250.0	8.0	90.0	6.5	0.90	3.6	1.2	231.0	1.9	10.0	1.0	212.0	14.0	476.0	8.7
144	45-79- 6BD	304.0	0.0	1100.0	13.0	0.85	131.0	30.0	393.0	9.0	8.5	2.0	249.0	452.0	1840.0	7.7

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
145	45-80- 9DA	196.0	0.0	700.0	27.0	0.90	28.0	2.4	333.0	3.6	9.0	2.0	161.0	84.0	1200.0	8.1
146	46-77-17CC	116.0	16.0	200.0	11.0	0.55	5.6	1.2	177.0	1.4	9.5	1.0	108.0	19.0	479.0	9.0
147	45-78-18CA	200.0	0.0	1500.0	18.0	0.95	103.0	14.0	585.0	7.5	7.0	5.0	164.0	316.0	2330.0	7.8
148	45-79-20BB	392.0	0.0	675.0	4.0	0.60	138.0	31.0	306.0	4.2	11.0	2.0	321.0	472.0	1360.0	7.5
149	46-80- 8BD	256.0	0.0	2000.0	131.0	1.05	289.0	114.0	504.0	13.0	10.0	1.0	210.0	1190.0	3190.0	7.3
150	47-77-24DC	110.0	0.0	1500.0	11.0	0.90	156.0	20.0	651.0	5.8	8.0	1.0	90.0	473.0	2410.0	7.8
151	47-78-25AC	130.0	20.0	90.0	8.5	0.65	3.6	0.5	171.0	1.2	10.0	1.0	123.0	11.0	369.0	9.1
152	47-79-10BB	460.0	16.0	300.0	25.0	0.80	11.0	9.1	345.0	4.1	5.5	2.0	390.0	65.0	944.0	8.6
153	47-80-16BA	124.0	28.0	750.0	25.0	0.75	23.0	10.0	321.0	9.0	2.0	1.0	125.0	100.0	1230.0	9.4
154	48-76-18CA	148.0	12.0	325.0	12.0	0.70	17.0	1.7	216.0	2.2	9.0	2.0	121.0	50.0	669.0	8.8
155	48-77-15DB	670.0	12.0	10.0	7.0	1.40	6.4	1.9	309.0	3.5	12.0	1.0	559.0	24.0	693.0	8.3
156	48-78- 5BA	146.0	0.0	2250.0	10.0	1.00	188.0	29.0	759.0	9.0	8.0	2.0	120.0	588.0	3330.0	7.5
157	48-78-33BC	446.0	0.0	3125.0	5.0	1.15	445.0	365.0	372.0	12.0	12.0	10.0	366.0	2575.0	4550.0	7.4
158	48-79-33CC	568.0	0.0	40.0	25.0	1.10	8.0	2.7	321.0	3.4	8.5	1.0	466.0	31.0	690.0	8.2
159	48-81-15BC	78.0	6.0	850.0	20.0	1.00	54.0	15.0	369.0	4.6	8.0	1.0	69.0	198.0	1370.0	8.5
160	49-76-17CC	260.0	10.0	40.0	11.0	0.90	4.0	0.2	195.0	1.7	10.0	1.0	221.0	11.0	401.0	8.7
161	49-77-21BA	780.0	0.0	1.0	6.0	2.00	5.6	3.4	369.0	3.9	7.0	1.0	640.0	28.0	782.0	8.2
162	49-80-23AC	630.0	0.0	1.0	30.0	1.15	8.8	4.4	426.0	3.7	5.0	1.0	558.0	40.0	815.0	8.1
163	49-80-30CC	396.0	14.0	25.0	20.0	0.85	8.8	2.4	273.0	2.7	5.5	1.0	336.0	32.0	547.0	8.4
164	49-81-25DD	316.0	0.0	600.0	14.0	1.05	36.0	7.3	375.0	5.1	6.0	1.0	259.0	120.0	1200.0	8.1
165	50-77- 8DA	1150.0	0.0	5.0	2.5	2.60	5.6	2.4	465.0	6.5	7.0	1.0	940.0	25.0	1060.0	8.2
166	50-77-31CD	360.0	16.0	0.5	9.5	1.25	3.6	0.7	204.0	1.8	11.0	1.0	308.0	12.0	426.0	8.8
167	50-79-14AC	624.0	0.0	1800.0	5.5	1.00	173.0	68.0	696.0	11.0	10.0	1.0	512.0	713.0	3070.0	7.4
168	50-79-30CB	548.0	10.0	8.0	22.0	0.90	8.0	2.9	378.0	3.1	9.0	1.0	458.0	32.0	712.0	8.4
169	50-81-26AC	982.0	0.0	125.0	6.0	1.10	34.0	21.0	492.0	5.5	9.0	2.0	805.0	172.0	1180.0	7.8
170	51-77-30DA	518.0	8.0	2.0	10.0	1.10	4.4	1.0	234.0	2.1	10.0	1.0	431.0	15.0	528.0	8.5
171	51-79-16BA	312.0	0.0	260.0	8.5	0.60	30.0	7.1	258.0	4.6	10.0	1.0	256.0	104.0	733.0	8.0
172	51-80-11BC	426.0	0.0	1000.0	16.0	1.10	63.0	14.0	585.0	5.8	7.0	1.0	349.0	215.0	1900.0	7.9
173	51-81-17DA	514.0	0.0	800.0	6.0	0.85	135.0	69.0	363.0	5.2	11.0	2.0	422.0	620.0	1640.0	7.5
174	51-82-20DD	230.0	12.0	200.0	5.0	0.40	36.0	4.4	183.0	1.5	11.0	1.0	198.0	108.0	566.0	8.3
175	52-77-17DC	1410.0	0.0	0.5	1.5	1.40	13.0	5.2	555.0	5.5	11.0	2.0	1160.0	54.0	1290.0	7.8
176	52-78-11DC	456.0	0.0	800.0	5.0	0.80	49.0	12.0	447.0	7.5	10.0	1.0	374.0	170.0	1560.0	8.0
177	52-79- 3BA	440.0	0.0	2250.0	5.0	1.20	223.0	128.0	150.0	9.5	8.0	1.0	361.0	1082.0	2990.0	7.4
178	52-79- 3BA	480.0	0.0	1125.0	2.0	1.20	299.0	83.0	741.0	6.5	12.0	1.0	394.0	1090.0	2510.0	7.1
179	52-80-18DC	444.0	0.0	1800.0	8.5	1.10	110.0	57.0	819.0	9.0	8.0	1.0	364.0	508.0	3030.0	7.9
180	52-81-23AD	548.0	0.0	650.0	5.5	0.80	111.0	64.0	276.0	8.5	12.0	1.0	449.0	540.0	1400.0	7.6

NUM	LOCATION	HCO3	CO3	SO4	CL	F	CA	MG	NA	K	SIO2	U	ALK	T.HRD	TDS	PH
181	52-82-23DB	560.0	0.0	775.0	2.0	1.10	27.0	9.4	669.0	5.7	9.5	1.0	459.0	106.0	1770.0	8.0
182	53-77- 28D	1170.0	0.0	5.0	0.5	0.80	14.0	4.6	486.0	7.5	11.0	1.0	963.0	54.0	1110.0	7.8
183	53-77-348D	1330.0	0.0	0.5	3.0	0.80	9.6	6.3	498.0	7.5	12.0	1.0	1090.0	50.0	1190.0	8.0
184	53-80- 9CA	478.0	14.0	80.0	2.0	1.45	6.4	2.9	318.0	2.9	8.5	1.0	403.0	28.0	671.0	8.4
185	53-81-14BC	678.0	0.0	0.5	2.5	1.30	5.6	2.9	333.0	3.2	9.0	1.0	556.0	26.0	693.0	8.2
186	53-82-11CD	1040.0	0.0	1.0	1.0	0.80	12.0	5.6	456.0	4.5	10.0	1.0	853.0	53.0	1000.0	7.9
187	54-77-23CD	1160.0	0.0	0.5	1.0	0.80	7.6	3.9	471.0	10.0	16.0	1.0	948.0	35.0	1080.0	8.0
188	54-79-21BD	712.0	0.0	60.0	10.0	1.20	14.0	5.1	459.0	3.9	9.5	1.0	584.0	56.0	914.0	8.2
189	54-80-24BC	612.0	0.0	3125.0	4.5	1.40	336.0	348.0	474.0	21.0	21.0	1.0	502.0	2270.0	4630.0	7.5
190	54-80-24BC	578.0	1.0	40.0	13.0	1.10	6.4	2.9	288.0	3.2	9.0	1.0	475.0	28.0	649.0	8.3
191	54-81-15BA	440.0	0.0	60.0	3.3	0.50	99.0	34.0	40.0	9.0	28.0	1.0	361.0	388.0	491.0	7.5
192	54-82- 9BB	544.0	0.0	250.0	3.0	0.80	121.0	50.0	114.0	12.0	19.0	1.0	446.0	508.0	838.0	7.3
193	54-83-27CD	264.0	26.0	7.0	1.0	0.85	2.0	0.7	201.0	1.3	9.5	1.0	238.0	8.0	379.0	9.1
194	55-77-10DC	628.0	0.0	4.0	1.0	1.40	11.0	5.0	495.0	5.1	9.5	1.0	515.0	48.0	841.0	7.9
195	55-77-15BD	1290.0	0.0	0.5	0.5	1.75	10.0	4.4	627.0	6.5	11.0	1.0	1060.0	43.0	1300.0	8.0
196	55-78-29AA	1130.0	0.0	5.0	1.0	1.60	12.0	4.1	549.0	4.5	10.0	1.0	930.0	47.0	1140.0	8.0
197	55-79-30AD	720.0	0.0	3.0	15.0	1.55	6.0	1.9	360.0	3.7	10.0	1.0	590.0	23.0	756.0	8.1
198	55-81-19BB	748.0	20.0	2.0	12.0	1.60	4.0	2.4	438.0	3.7	9.0	1.0	630.0	20.0	861.0	8.4
199	55-83-26BD	1300.0	0.0	0.5	0.5	1.00	19.0	6.9	465.0	9.0	9.5	1.0	1070.0	76.0	1150.0	7.9
200	56-77-26CC	1080.0	0.0	0.5	1.0	2.20	7.2	2.9	588.0	5.1	11.0	1.0	884.0	30.0	1150.0	8.2
201	56-79-21AC	474.0	0.0	2750.0	2.5	1.15	408.0	311.0	408.0	17.0	12.0	1.0	389.0	2300.0	3740.0	7.1
202	56-80- 9BD	712.0	0.0	1300.0	13.0	0.90	281.0	184.0	207.0	11.0	15.0	2.0	584.0	1460.0	2360.0	7.0
203	56-81-29BD	466.0	16.0	110.0	5.0	1.60	3.6	1.2	354.0	2.5	11.0	1.0	395.0	14.0	735.0	8.6
204	56-82-19DA	616.0	20.0	0.5	8.5	1.35	5.2	2.2	327.0	2.9	10.0	1.0	522.0	22.0	681.0	8.4
205	57-76-29AC	860.0	0.0	0.5	0.3	1.50	9.6	2.7	543.0	7.5	10.0	1.0	705.0	35.0	1000.0	7.9
206	57-80-31BB	426.0	0.0	1875.0	7.0	1.15	74.0	24.0	849.0	11.0	12.0	1.0	349.0	284.0	3060.0	7.9
207	57-81- 7CB	890.0	20.0	15.0	1.5	1.60	4.8	2.4	459.0	3.7	11.0	1.0	746.0	22.0	957.0	8.3
208	57-81-22AA	494.0	0.0	2000.0	11.0	1.15	75.0	43.0	768.0	13.0	10.0	1.0	405.0	364.0	3160.0	8.0

Appendix D

CHEMICAL DATA

Explanations of the data headings used on pages 140 to 145 are given below.

NUM = well number.

LOCATION = location of well (see Location Format in Appendix A).

EHCO3 = epm bicarbonate concentration.

ECO3 = epm carbonate concentration.

ESO4 = epm sulfate concentration.

ECL = epm chloride concentration.

EF = epm fluoride concentration.

ECA = epm calcium concentration.

EMG = epm magnesium concentration.

ENA = epm sodium concentration.

EK = epm potassium concentration.

EU = epb uranium concentration.

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
1	33-70- 9AC	4.950	0.0	2.915	0.127	0.003	2.994	2.878	1.522	0.128	0.126
2	34-69-32AC	3.737	0.0	13.012	0.169	0.021	5.988	4.605	4.045	0.358	0.050
3	34-72-26AB	5.081	0.0	11.451	0.141	0.026	3.543	1.727	8.874	0.130	0.050
4	35-71- 4BB	3.999	0.0	2.915	0.113	0.008	8.732	1.809	1.522	0.105	0.025
5	35-70-32BC	3.507	0.0	12.492	0.113	0.024	1.697	0.296	12.789	0.077	0.025
6	35-72-18A	4.425	0.0	1.249	0.056	0.003	2.994	1.316	1.566	0.100	0.025
7	35-73-15B	2.344	0.0	5.205	0.127	0.026	1.796	0.296	6.264	0.105	0.025
8	35-74- 1BD	3.507	0.0	1.041	0.056	0.021	3.543	0.798	0.783	0.123	0.025
9	36-69- 7AB	4.704	0.167	1.353	0.197	0.050	0.439	0.296	8.352	0.087	0.025
10	36-70-12CC	5.065	0.0	1.561	0.211	0.054	0.419	0.197	8.221	0.074	0.025
11	36-70-21CB	5.310	0.200	1.770	0.240	0.063	0.339	0.403	9.135	0.072	0.025
12	36-71-13DB	5.573	0.133	0.520	0.183	0.032	0.439	0.197	7.308	0.079	0.025
13	36-72- 9DD	2.999	0.0	6.662	0.155	0.011	2.245	0.296	8.091	0.074	0.025
14	36-73-26AD	6.015	0.0	0.312	0.056	0.0	4.441	1.316	1.000	0.082	0.151
15	36-73-27AB	4.147	0.0	2.915	0.127	0.011	4.142	0.600	2.436	0.151	0.126
16	36-74-23CD	4.917	0.0	6.246	0.367	0.013	6.986	1.974	1.348	0.079	1.638
17	36-74-27BD	4.655	0.0	1.145	0.056	0.013	4.042	1.563	0.826	0.090	1.512
18	37-69-20DB	7.769	0.0	0.042	0.169	0.074	0.220	0.403	9.004	0.077	0.025
19	37-70- 4AC	7.671	0.0	0.021	0.155	0.050	1.247	0.197	8.482	0.123	0.025
20	37-72-17CA	3.130	0.133	2.082	0.085	0.011	0.649	0.148	6.133	0.056	0.025
21	37-73-10BD	3.278	0.0	1.874	0.085	0.016	1.198	0.296	5.481	0.092	0.025
22	37-73-22AD	3.065	0.233	1.457	0.113	0.018	0.699	0.296	5.350	0.067	0.025
23	37-74-24B	4.720	0.0	1.666	0.107	0.008	3.992	1.727	1.044	0.143	0.151
24	37-75-14DB	2.852	0.0	1.874	0.127	0.025	2.695	0.699	1.305	0.333	0.025
25	38-71- 1CA	3.442	0.0	1.353	0.155	0.034	0.299	0.099	5.872	0.051	0.025
26	38-71-12AB	4.130	0.0	0.312	0.099	0.024	1.697	0.699	2.479	0.243	0.025
27	38-72-23DB	2.819	0.0	2.915	0.141	0.024	0.379	0.099	6.916	0.043	0.025
28	38-72-27AC	3.212	0.0	2.498	0.099	0.011	0.339	0.156	6.655	0.041	0.025
29	38-72-28DB	2.754	0.0	3.123	0.121	0.015	0.399	0.140	7.438	0.041	0.025
30	38-73-33CB	3.376	0.0	3.643	0.085	0.013	3.493	0.798	4.045	0.230	0.025
31	38-73-33CB	3.344	0.0	3.123	0.099	0.018	1.297	0.197	6.133	0.087	0.025
32	38-73-33CB	3.180	0.0	2.082	0.113	0.020	2.096	0.403	4.176	0.123	0.025
33	38-74-12BC	3.180	0.0	11.451	0.113	0.032	7.834	1.727	4.698	0.333	0.101
34	38-75- 5AA	4.097	0.0	3.956	0.178	0.013	4.541	1.563	1.305	0.243	0.025
35	39-71- 4DC	3.147	0.100	1.666	0.183	0.037	0.200	0.099	7.047	0.054	0.025
36	39-71-13DC	6.720	0.0	0.104	0.113	0.053	1.497	0.600	6.264	0.333	0.025

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
37	39-72- 6BD	2.622	0.200	1.770	0.113	0.011	0.339	0.058	5.742	0.043	0.025
38	39-73-19DC	3.426	0.0	3.956	0.099	0.013	3.593	0.296	4.176	0.189	0.025
39	39-73-23DC	3.409	0.0	2.290	0.113	0.011	2.695	0.099	4.263	0.128	0.025
40	40-71- 6DD	2.590	0.100	3.643	0.197	0.029	0.279	0.058	7.699	0.064	0.025
41	40-73- 8CD	3.180	0.0	6.662	0.141	0.016	1.497	0.296	9.135	0.077	0.025
42	40-74- 9CA	3.770	0.333	1.770	0.197	0.005	0.499	0.140	7.177	0.061	0.025
43	40-75- 8DC	4.065	0.0	2.498	0.099	0.013	3.693	0.699	1.870	0.230	0.025
44	40-75-32DB	3.180	0.0	6.662	0.226	0.029	5.090	1.234	4.176	0.230	0.025
45	41-71-35AC	5.999	0.0	0.021	0.226	0.111	0.499	0.156	7.569	0.115	0.025
46	41-71- 6CC	3.671	0.0	15.615	0.451	0.037	6.387	1.563	11.484	0.123	0.176
47	41-72-16BB	4.261	0.0	3.123	0.310	0.018	1.198	0.296	9.135	0.069	0.126
48	41-73- 6BD	3.442	0.0	8.328	0.282	0.021	4.192	0.987	8.091	0.138	0.076
49	41-73-23DA	3.278	0.233	2.290	0.155	0.018	0.439	0.140	6.786	0.049	0.101
50	41-74-20BA	4.016	0.0	5.830	0.367	0.018	5.788	1.316	3.784	0.148	0.050
51	41-75- 4AB	3.606	0.0	15.615	0.367	0.021	9.381	4.605	1.261	0.333	0.050
52	42-70- 5DD	3.278	0.0	124.920	1.128	0.089	19.062	69.822	23.490	0.473	0.025
53	42-71- 7CC	3.770	0.200	0.833	0.338	0.029	0.339	0.058	5.481	0.051	0.025
54	42-71-26DA	11.899	0.0	0.021	0.141	0.063	1.198	0.987	11.092	0.358	0.050
55	42-73- 2BD	5.048	0.0	18.738	0.169	0.034	15.020	9.293	5.220	0.333	0.058
56	42-73-31DC	5.245	0.0	2.915	0.070	0.011	4.790	1.727	1.087	0.125	0.126
57	42-73-35AD	3.704	0.0	6.246	0.113	0.026	4.341	2.467	4.176	0.123	0.101
58	42-74-12AC	5.736	0.0	39.037	0.282	0.034	21.108	1.480	4.828	0.358	0.403
59	42-74-28CD	3.704	0.0	4.164	0.070	0.016	5.289	0.987	0.957	0.243	1.512
60	42-75- 4DD	4.097	0.0	8.328	0.070	0.021	6.786	1.398	5.220	0.230	0.176
61	43-71- 3AB	5.015	0.0	23.422	0.310	0.029	6.188	2.385	13.702	0.281	0.050
62	43-72-15AB	4.425	0.0	31.230	0.211	0.045	17.215	16.119	2.349	0.256	0.076
63	43-72-35CD	1.787	0.0	6.662	0.141	0.037	10.778	3.619	7.308	0.067	0.050
64	43-73- 1DD	4.556	0.0	10.410	0.141	0.018	4.441	0.699	12.658	0.113	0.050
65	43-73-16CB	6.490	0.0	4.164	0.127	0.008	3.792	1.316	6.786	0.110	0.050
66	43-73-25BC	3.278	0.333	0.167	0.536	0.029	0.200	0.123	5.611	0.043	0.050
67	43-74-18DD	2.540	0.0	23.422	0.127	0.032	10.030	3.372	10.048	0.281	0.050
68	43-76-22DD	2.491	0.167	3.123	0.169	0.005	0.499	0.099	16.573	0.067	0.076
69	44-70-29AA	5.966	0.0	0.312	0.677	0.053	0.599	0.362	27.405	0.087	0.050
70	44-71-21AD	2.983	0.0	6.662	0.761	0.047	4.541	4.934	7.177	0.105	0.101
71	44-72- 2D	2.983	0.0	41.640	0.127	0.039	21.207	21.218	6.916	0.409	0.050
72	44-73-18AC	2.114	0.0	8.328	0.169	0.011	1.547	0.493	10.570	0.102	0.050

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
73	44-74- 1BD	2.524	0.0	33.832	0.197	0.032	19.561	3.454	9.526	0.281	0.050
74	44-74-27AC	1.819	0.0	28.627	0.155	0.034	9.082	4.441	15.268	0.281	0.025
75	44-74-31DB	3.753	0.0	5.205	0.931	0.016	5.489	2.220	1.435	0.100	0.076
76	44-75-27CC	5.212	0.0	9.889	0.211	0.016	8.732	2.467	1.740	0.118	3.150
77	44-76- 8CD	2.327	0.167	4.684	0.234	0.003	0.499	0.164	7.830	0.051	0.050
78	45-70-10DA	6.917	0.0	12.492	0.197	0.032	8.982	8.060	1.392	0.138	0.025
79	45-71-12AB	13.866	0.0	8.328	0.197	0.026	3.742	1.398	19.314	0.256	0.025
80	45-72-23BB	3.901	0.0	44.242	0.310	0.055	19.960	22.863	9.918	0.205	0.025
81	45-73-14BB	11.702	0.0	2.082	0.085	0.008	1.796	0.132	15.660	0.136	0.050
82	45-73-16AC	6.294	0.0	18.217	0.141	0.026	9.381	1.892	14.355	0.281	0.025
83	45-74-17AC	1.672	0.0	16.656	0.141	0.034	5.090	0.600	16.051	0.123	0.025
84	45-75- 8AC	1.246	0.0	15.615	0.099	0.037	3.892	0.469	15.268	0.130	0.025
85	45-75-26AC	3.671	0.0	12.492	0.099	0.029	6.287	1.398	9.657	0.166	0.050
86	45-77-13AB	1.787	0.133	5.725	0.211	0.026	0.459	0.181	9.135	0.051	0.025
87	46-71-22CB	9.228	0.0	18.217	0.211	0.047	6.736	5.099	16.312	0.384	0.050
88	46-72-14BC	0.328	0.0	9.369	0.282	0.058	4.241	5.428	4.176	0.136	0.101
89	46-73-22DA	4.229	0.0	15.615	0.338	0.042	6.936	2.632	12.658	0.205	0.025
90	46-73-29DC	0.754	0.0	33.312	0.197	0.047	9.780	4.688	23.229	0.238	0.050
91	46-74-21BB	5.900	0.0	13.012	0.099	0.024	9.980	5.263	4.567	0.217	0.076
92	46-74-28DD	4.983	0.0	8.848	0.056	0.024	7.884	3.290	4.176	0.151	0.076
93	46-75- 9BD	1.377	0.0	12.492	0.508	0.029	1.996	0.362	14.485	0.097	0.050
94	46-75-26CD	2.885	0.0	19.779	0.135	0.037	8.184	1.398	16.312	0.230	0.050
95	46-76-21BB	1.639	0.0	20.820	0.178	0.037	5.539	1.069	23.359	0.130	0.076
96	47-71- 9CC	5.638	0.0	23.422	0.155	0.034	10.379	11.102	9.396	0.435	0.050
97	47-72-10CB	5.671	0.0	0.062	0.240	0.018	0.399	0.222	8.352	0.079	0.050
98	47-72-16AC	2.639	0.0	15.615	0.155	0.037	10.080	2.467	3.915	0.146	0.025
99	47-73-20DD	3.917	0.0	23.422	0.211	0.045	8.583	2.961	17.748	0.230	0.050
100	47-74-23BD	4.425	0.0	20.820	0.338	0.050	11.477	7.319	7.047	0.136	0.050
101	47-75- 9CC	1.770	0.0	16.656	0.338	0.032	4.042	0.798	17.617	0.120	0.050
102	47-76- 2DB	1.639	0.133	7.807	0.423	0.024	0.499	0.156	11.484	0.069	0.050
103	48-71-17DD	5.802	0.0	18.738	0.211	0.032	7.485	2.632	15.007	0.333	0.025
104	48-71-17AD	9.834	0.0	0.021	0.178	0.042	2.146	0.132	10.701	0.179	0.025
105	48-72- 7B	3.999	0.0	27.066	0.085	0.042	18.114	2.632	9.613	0.384	0.076
106	48-73-26AC	4.343	0.0	11.451	0.367	0.026	5.689	2.303	8.613	0.118	0.050
107	48-74-26CA	2.983	0.0	14.574	0.155	0.037	3.293	0.666	15.921	0.166	0.050
108	48-75-22BB	1.672	0.333	8.120	0.395	0.029	0.599	0.699	12.397	0.067	0.050

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
109	49-71-17DD	2.721	0.0	18.217	0.226	0.087	9.980	7.319	2.262	0.281	0.025
110	49-73- 1CC	9.310	0.0	0.021	0.127	0.024	0.898	0.296	11.614	0.136	0.050
111	49-73-12CB	5.753	0.0	23.422	0.141	0.047	14.321	9.951	6.394	0.148	0.050
112	49-73-19CB	4.720	0.0	24.984	0.113	0.039	8.782	2.138	17.617	0.281	0.050
113	49-75- 2CB	4.261	0.0	10.410	0.070	0.032	3.942	1.069	11.353	0.128	0.050
114	49-75-34CD	3.081	0.267	2.915	0.367	0.026	0.319	0.099	8.352	0.046	0.050
115	50-71-30CA	7.048	0.0	59.857	0.254	0.071	24.601	5.428	4.959	0.563	0.025
116	50-72- 7AA	13.145	0.0	0.104	0.079	0.042	1.647	2.056	11.614	0.192	0.025
117	50-72-25AD	11.211	0.0	21.861	0.141	0.050	7.186	5.099	20.227	0.537	0.050
118	50-74-20BD	4.753	0.200	8.848	0.211	0.032	1.247	0.370	13.441	0.100	0.025
119	50-75-26AC	6.294	0.0	13.012	0.226	0.029	9.082	3.701	5.481	0.151	0.025
120	51-72-22CD	7.638	0.0	0.520	0.042	0.029	4.042	1.151	5.872	0.133	0.025
121	51-73-34AC	3.802	0.0	23.422	0.065	0.034	10.180	6.332	9.613	0.384	0.025
122	51-74-31AC	9.014	0.333	0.083	0.226	0.018	0.379	0.099	12.919	0.077	0.025
123	51-75- 28C	10.162	0.0	0.010	0.310	0.055	0.599	0.337	14.224	0.110	0.025
124	51-76-23CA	8.883	0.0	78.075	0.310	0.063	19.611	27.304	28.188	0.435	0.025
125	52-73- 8AA	12.030	0.0	7.807	0.107	0.032	2.944	0.987	17.748	0.153	0.025
126	52-75-15BB	10.555	0.0	0.010	0.127	0.047	0.549	0.288	14.616	0.100	0.025
127	53-74- 7AD	5.114	0.0	78.075	0.254	0.063	21.806	25.577	33.582	0.563	0.025
128	53-75- 2BB	10.227	0.333	0.520	0.211	0.042	0.419	0.403	13.702	0.100	0.025
129	53-76-23DC	21.045	0.0	0.010	0.008	0.063	1.647	0.173	22.185	0.486	0.025
130	54-74-28D	8.588	0.0	0.010	0.169	0.026	0.898	0.403	11.745	0.130	0.025
131	54-75- 3C	12.063	0.0	0.520	0.042	0.034	0.399	0.280	17.878	0.100	0.025
132	54-76-22AC	23.110	0.667	0.416	0.014	0.029	1.198	0.222	25.839	0.243	0.076
133	55-76-14DD	13.669	0.0	1.874	0.014	0.026	2.844	0.822	16.312	0.192	0.025
134	41-76- 6AB	2.491	0.400	2.082	0.155	0.034	0.599	0.123	6.786	0.061	0.025
135	42-77-21AD	3.114	0.400	4.893	0.113	0.021	0.599	0.181	7.830	0.077	0.025
136	43-78- 5DA	3.934	0.133	9.889	0.564	0.058	0.898	0.378	16.051	0.095	0.025
137	44-77-30BB	2.786	0.133	8.536	0.226	0.047	0.998	0.321	14.485	0.102	0.025
138	44-78-10DA	6.589	0.533	0.021	0.127	0.058	0.160	0.140	11.092	0.069	0.025
139	44-79-20DA	6.720	0.0	5.517	0.113	0.016	3.044	1.069	9.396	0.143	0.025
140	44-80- 6CA	4.196	0.0	41.640	0.564	0.053	8.633	3.783	27.666	0.307	0.025
141	45-76-17BD	1.508	0.0	9.369	0.183	0.021	1.447	0.354	12.658	0.084	0.025
142	45-77- 6BC	3.540	0.600	1.561	0.197	0.045	0.200	0.041	7.177	0.038	0.025
143	45-78-34BA	4.097	0.267	1.874	0.183	0.047	0.180	0.099	10.048	0.049	0.025
144	45-79- 6BD	4.983	0.0	22.902	0.508	0.045	6.537	2.467	17.095	0.230	0.050

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
145	45-80- 9DA	3.212	0.0	14.574	0.761	0.047	1.397	0.197	14.485	0.092	0.050
146	46-77-17CC	1.901	0.533	4.164	0.310	0.029	0.279	0.099	7.699	0.036	0.025
147	46-78-18CA	3.278	0.0	31.230	0.508	0.050	5.140	1.151	25.447	0.192	0.126
148	46-79-20BB	6.425	0.0	14.053	0.113	0.032	6.886	2.549	13.311	0.107	0.050
149	46-80- 8BD	4.196	0.0	41.640	3.694	0.055	14.421	9.375	21.924	0.333	0.025
150	47-77-24DC	1.803	0.0	31.230	0.310	0.047	7.784	1.645	28.318	0.148	0.025
151	47-78-25AC	2.131	0.667	1.874	0.240	0.034	0.180	0.041	7.438	0.031	0.025
152	47-79-10BB	7.539	0.533	6.246	0.705	0.042	0.549	0.748	15.007	0.105	0.050
153	47-80-16BA	2.032	0.933	15.615	0.705	0.039	1.148	0.822	13.963	0.230	0.025
154	48-76-18CA	2.426	0.400	6.766	0.338	0.037	0.848	0.140	9.396	0.056	0.050
155	48-77-15DB	10.981	0.400	0.208	0.197	0.074	0.319	0.156	13.441	0.090	0.025
156	48-78- 5BA	2.393	0.0	46.845	0.282	0.053	9.381	2.385	33.016	0.230	0.050
157	48-78-33BC	7.310	0.0	65.062	0.141	0.061	22.205	30.018	16.182	0.307	0.252
158	48-79-33CC	9.310	0.0	0.833	0.705	0.058	0.399	0.222	13.963	0.087	0.025
159	48-81-15BC	1.278	0.200	17.697	0.564	0.053	2.695	1.234	16.051	0.118	0.025
160	49-76-17CC	4.261	0.333	0.833	0.310	0.047	0.200	0.016	8.482	0.043	0.025
161	49-77-21BA	12.784	0.0	0.021	0.169	0.105	0.279	0.280	16.051	0.100	0.025
162	49-80-23AC	11.145	0.0	0.021	0.846	0.061	0.439	0.362	18.531	0.095	0.025
163	49-80-30CC	6.490	0.467	0.520	0.564	0.045	0.439	0.197	11.875	0.069	0.025
164	49-81-25DD	5.179	0.0	12.492	0.395	0.055	1.796	0.600	16.312	0.130	0.025
165	50-77- 8DA	18.848	0.0	0.104	0.070	0.137	0.279	0.197	20.227	0.166	0.025
166	50-77-31CD	5.900	0.533	0.010	0.268	0.066	0.180	0.058	8.874	0.046	0.025
167	50-79-14AC	10.227	0.0	37.476	0.155	0.053	8.633	5.592	30.276	0.281	0.025
168	50-79-30CB	8.982	0.333	0.167	0.620	0.047	0.399	0.238	16.443	0.079	0.025
169	50-81-26AC	16.095	0.0	2.602	0.169	0.058	1.697	1.727	21.402	0.141	0.050
170	51-77-30DA	8.490	0.267	0.042	0.282	0.058	0.220	0.082	10.179	0.054	0.025
171	51-79-16BA	5.114	0.0	5.413	0.240	0.032	1.497	0.584	11.223	0.118	0.025
172	51-80-11BC	6.982	0.0	20.820	0.451	0.058	3.144	1.151	25.447	0.148	0.025
173	51-81-17DA	8.424	0.0	16.656	0.169	0.045	6.736	5.675	15.790	0.133	0.050
174	51-82-20DD	3.770	0.400	4.164	0.141	0.021	1.796	0.362	7.960	0.038	0.025
175	52-77-17DC	23.110	0.0	0.010	0.042	0.074	0.649	0.428	24.142	0.141	0.050
176	52-78-11DC	7.474	0.0	16.656	0.141	0.042	2.445	0.987	19.444	0.192	0.025
177	52-79- 3BA	7.212	0.0	46.845	0.141	0.063	11.128	10.527	6.525	0.243	0.025
178	52-79- 3BA	7.867	0.0	23.422	0.056	0.063	14.920	6.826	32.233	0.166	0.025
179	52-80-18DC	7.277	0.0	37.476	0.240	0.058	5.489	4.688	35.626	0.230	0.025
180	52-81-23AD	8.982	0.0	13.533	0.155	0.042	5.539	5.263	12.006	0.217	0.025

NUM	LOCATION	EHCO3	ECO3	ESO4	ECL	EF	ECA	EMG	ENA	EK	EU
181	53-82-23DB	9.178	0.0	16.135	0.056	0.058	1.347	0.773	29.101	0.146	0.025
182	53-77- 2BD	19.176	0.0	0.104	0.014	0.042	0.699	0.378	21.141	0.192	0.025
183	53-77-34BD	21.799	0.0	0.010	0.085	0.042	0.479	0.518	21.663	0.192	0.025
184	53-80- 9CA	7.834	0.467	1.666	0.056	0.076	0.319	0.238	13.833	0.074	0.025
185	53-81-14BC	11.112	0.0	0.010	0.070	0.068	0.279	0.238	14.485	0.082	0.025
186	53-82-11CD	17.046	0.0	0.021	0.028	0.042	0.599	0.461	19.836	0.115	0.025
187	54-77-23CD	19.012	0.0	0.010	0.028	0.042	0.379	0.321	20.488	0.256	0.025
188	54-79-21BD	11.670	0.0	1.249	0.282	0.063	0.699	0.419	19.966	0.100	0.025
189	54-80-24BC	10.031	0.0	65.062	0.127	0.074	16.766	28.620	20.619	0.537	0.025
190	54-80-24BC	9.473	0.033	0.833	0.367	0.058	0.319	0.238	12.528	0.082	0.025
191	54-81-15BA	7.212	0.0	1.249	0.093	0.026	4.940	2.796	1.740	0.230	0.025
192	54-82- 9BB	8.916	0.0	5.205	0.085	0.042	6.038	4.112	4.959	0.307	0.025
193	54-83-27CD	4.327	0.867	0.146	0.028	0.045	0.100	0.058	8.743	0.033	0.025
194	55-77-10DC	10.293	0.0	0.083	0.028	0.074	0.549	0.411	21.532	0.130	0.025
195	55-77-15BD	21.143	0.0	0.010	0.014	0.092	0.499	0.362	27.274	0.166	0.025
196	55-78-29AA	18.521	0.0	0.104	0.028	0.084	0.599	0.337	23.881	0.115	0.025
197	55-79-30AD	11.801	0.0	0.062	0.423	0.082	0.299	0.156	15.660	0.095	0.025
198	55-81-19BB	12.260	0.667	0.042	0.338	0.084	0.200	0.197	19.053	0.095	0.025
199	55-83-26BD	21.307	0.0	0.010	0.014	0.053	0.948	0.567	20.227	0.230	0.025
200	56-77-26CC	17.701	0.0	0.010	0.028	0.116	0.359	0.238	25.578	0.130	0.025
201	56-79-21AC	7.769	0.0	57.255	0.070	0.061	20.359	25.577	17.748	0.435	0.025
202	56-80- 9BD	11.670	0.0	27.066	0.367	0.047	14.022	15.132	9.004	0.281	0.050
203	56-81-29BD	7.638	0.533	2.290	0.141	0.084	0.180	0.099	15.399	0.064	0.025
204	56-82-19DA	10.096	0.667	0.010	0.240	0.071	0.259	0.181	14.224	0.074	0.025
205	57-76-29AC	14.095	0.0	0.010	0.008	0.079	0.479	0.222	23.620	0.192	0.025
206	57-80-31BB	6.982	0.0	39.037	0.197	0.061	3.693	1.974	36.931	0.281	0.025
207	57-81- 7CB	14.587	0.667	0.312	0.042	0.084	0.240	0.197	19.966	0.095	0.025
208	57-81-22AA	8.097	0.0	41.640	0.310	0.061	3.742	3.536	33.408	0.333	0.025

Appendix E

PERCENTAGE OF VARIOUS CONSTITUENTS IN EQUIVALENTS PER MILLION

Explanations of the data headings used on pages 147 to 152 are given below.

NUM = well number.

LOCATION = well location (see Location Format in Appendix A).

PHCO3 = percent of total anions composed of bicarbonate.

PCO3 = percent of total anions composed of carbonate.

PSO4 = percent of total anions composed of sulfate.

PCL = percent of total anions composed of chloride.

PF = percent of total anions composed of fluoride.

PCA = percent of total cations composed of calcium.

PMG = percent of total cations composed of magnesium.

PNA = percent of total cations composed of sodium.

PK = percent of total cations composed of potassium.

PK+NA = percent of total cations composed of potassium plus sodium.

PCA+MG = percent of total cations composed of calcium plus magnesium.

PHCO3+CO3 = percent of total anions composed of bicarbonate plus carbonate.

PSO4+CL = percent of total anions composed of sulfate plus chloride.

PSIO2 = percent of total dissolved solids composed of silica (in ppm).

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
1	33-70- 9AC	61.92	0.0	36.46	1.59	0.03	39.80	38.26	20.24	1.70	21.94	78.06	61.92	38.05	4.03
2	34-69-32AC	22.06	0.0	76.82	1.00	0.12	39.93	30.71	26.98	2.39	29.36	70.64	22.06	77.82	0.73
3	34-72-26AB	30.43	0.0	68.57	0.84	0.16	24.82	12.10	62.17	0.91	63.08	36.92	30.43	69.42	0.38
4	35-71- 4BB	56.85	0.0	41.43	1.60	0.11	71.76	14.87	12.51	0.86	13.37	86.63	56.85	43.04	3.89
5	35-70-32BC	21.74	0.0	77.42	0.70	0.15	11.42	1.99	86.07	0.52	86.59	13.41	21.74	78.12	0.81
6	35-72-18A	77.18	0.0	21.79	0.98	0.05	50.10	22.02	26.21	1.67	27.88	72.12	77.18	22.77	4.60
7	35-73-15B	30.43	0.0	67.58	1.65	0.34	21.23	3.50	74.03	1.24	75.27	24.73	30.43	69.23	1.91
8	35-74- 1BD	75.82	0.0	22.50	1.22	0.46	67.53	15.21	14.92	2.34	17.26	82.73	75.82	23.72	5.72
9	36-69- 7AB	72.69	2.58	20.91	3.05	0.77	4.79	3.23	91.04	0.95	91.99	8.01	75.26	23.96	2.29
10	36-70-12CC	73.49	0.0	22.66	3.07	0.78	4.70	2.21	92.25	0.83	93.08	6.92	73.49	25.73	2.67
11	36-70-21CB	70.03	2.64	23.34	3.16	0.83	3.41	4.05	91.82	0.72	92.54	7.46	72.67	26.50	2.22
12	36-71-13DB	86.51	2.07	8.08	2.85	0.49	5.47	2.46	91.08	0.99	92.07	7.93	88.58	10.93	2.28
13	36-72- 9DD	30.52	0.0	67.79	1.58	0.11	20.97	2.77	75.57	0.69	76.26	23.74	30.52	69.37	1.66
14	36-73-26AD	94.22	0.0	4.89	0.88	0.0	64.93	19.24	14.63	1.20	15.83	84.17	94.22	5.78	3.52
15	36-73-27AB	57.60	0.0	40.49	1.76	0.15	56.51	8.19	33.24	2.06	35.30	64.70	57.60	42.25	3.65
16	36-74-23CD	42.60	0.0	54.11	3.18	0.11	67.24	19.00	12.98	0.76	13.74	86.24	42.60	57.29	2.08
17	36-74-27BD	79.31	0.0	19.51	0.96	0.22	61.97	23.96	12.67	1.37	14.05	85.93	79.31	20.47	4.76
18	37-69-20DB	96.47	0.0	0.52	2.10	0.91	2.26	4.15	92.79	0.79	93.58	6.42	96.47	2.62	2.02
19	37-70- 4AC	97.14	0.0	0.26	1.96	0.63	12.41	1.96	84.40	1.22	85.62	14.38	97.14	2.23	1.79
20	37-72-17CA	57.54	2.45	38.27	1.55	0.19	9.29	2.12	87.79	0.81	88.60	11.40	59.99	39.82	3.23
21	37-73-10BD	62.41	0.0	35.68	1.61	0.30	16.95	4.19	77.56	1.30	78.86	21.14	62.41	37.29	3.31
22	37-73-22AD	62.72	4.77	29.82	2.31	0.38	10.90	4.62	83.45	1.04	84.49	15.51	67.49	32.13	3.35
23	37-74-24B	72.61	0.0	25.62	1.65	0.12	57.80	25.01	15.12	2.07	17.19	82.81	72.61	27.27	3.25
24	37-75-14DB	58.47	0.0	38.41	2.60	0.52	53.56	13.89	25.94	6.61	32.55	67.45	58.47	41.02	2.55
25	38-71- 1CA	69.05	0.0	27.15	3.11	0.69	4.74	1.56	92.89	0.81	93.70	6.30	69.05	30.26	2.45
26	38-71-12AB	90.48	0.0	6.84	2.16	0.52	33.15	13.66	48.45	4.75	53.19	46.81	90.48	9.00	2.70
27	38-72-23DB	47.79	0.0	49.42	2.39	0.40	5.10	1.33	92.99	0.58	93.57	6.43	47.79	51.81	1.48
28	38-72-27AC	55.20	0.0	42.93	1.70	0.18	4.72	2.17	92.54	0.57	93.11	6.89	55.20	44.62	1.66
29	38-72-28DB	45.80	0.0	51.94	2.02	0.25	4.98	1.74	92.77	0.51	93.28	6.72	45.80	53.96	1.53
30	38-73-33CB	47.44	0.0	51.19	1.19	0.18	40.78	9.31	47.22	2.69	49.91	50.09	47.44	52.38	2.54
31	38-73-33CB	50.79	0.0	47.44	1.50	0.28	16.82	2.56	79.50	1.13	80.63	19.37	50.79	48.93	2.73
32	38-73-33CB	58.94	0.0	38.60	2.09	0.37	30.83	5.93	61.43	1.81	63.24	36.76	58.94	40.69	3.87
33	38-74-12BC	21.52	0.0	77.50	0.76	0.21	53.69	11.84	32.20	2.28	34.47	65.52	21.52	78.27	1.55
34	38-75- 5AA	49.70	0.0	47.98	2.15	0.16	59.35	20.42	17.06	3.18	20.23	79.77	49.70	50.14	2.90
35	39-71- 4DC	61.31	1.95	32.45	3.57	0.72	2.70	1.33	95.24	0.73	95.97	4.03	63.26	36.02	2.74
36	39-71-13DC	96.14	0.0	1.49	1.61	0.75	17.22	6.91	72.05	3.82	75.88	24.12	96.14	3.10	2.40

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
37	39-72- 6BD	55.61	4.24	37.53	2.39	0.22	5.49	0.93	92.88	0.70	93.58	6.42	59.85	39.92	3.67
38	39-73-19DC	45.72	0.0	52.79	1.32	0.18	43.53	3.59	50.59	2.29	52.89	47.11	45.72	54.11	3.64
39	39-73-23DC	58.55	0.0	39.33	1.94	0.18	37.51	1.37	59.34	1.78	61.12	38.88	58.55	41.27	4.35
40	40-71- 6DD	39.48	1.52	55.55	3.01	0.44	3.45	0.71	95.05	0.79	95.84	4.16	41.00	58.56	1.97
41	40-73- 8CD	31.80	0.0	66.63	1.41	0.16	13.60	2.69	83.01	0.70	83.71	16.29	31.80	68.04	1.62
42	40-74- 9CA	62.05	5.49	29.13	3.25	0.09	6.33	1.77	91.11	0.78	91.89	8.11	67.54	32.38	2.96
43	40-75- 8DC	60.89	0.0	37.43	1.48	0.20	56.88	10.77	28.81	3.55	32.36	67.64	60.89	38.91	3.55
44	40-75-32DB	31.49	0.0	65.99	2.23	0.29	47.44	11.50	38.92	2.15	41.07	58.93	31.49	68.22	1.67
45	41-71-35AC	94.38	0.0	0.33	3.55	1.74	5.98	1.87	90.76	1.38	92.14	7.86	94.38	3.88	2.06
46	41-71- 6CC	18.57	0.0	78.97	2.28	0.19	32.66	7.99	58.72	0.63	59.35	40.65	18.57	81.25	0.62
47	41-72-16BB	55.25	0.0	40.49	4.02	0.24	11.19	2.77	85.39	0.65	86.04	13.96	55.25	44.51	1.58
48	41-73- 6BD	28.51	0.0	68.98	2.34	0.17	31.26	7.36	60.35	1.03	61.38	38.62	28.51	71.32	1.35
49	41-73-23DA	54.86	3.90	38.33	2.60	0.31	5.92	1.89	91.53	0.66	92.19	7.81	58.77	40.93	2.37
50	41-74-20BA	39.25	0.0	56.98	3.58	0.18	52.44	11.92	34.29	1.34	35.63	64.37	39.25	60.57	1.84
51	41-75- 4AB	18.39	0.0	79.63	1.87	0.11	60.21	29.56	8.10	2.13	10.23	89.77	18.39	81.50	0.61
52	42-70- 5DD	2.53	0.0	96.53	0.87	0.07	16.89	61.87	20.82	0.42	21.24	78.76	2.53	97.40	0.41
53	42-71- 7CC	72.92	3.87	16.11	6.55	0.56	5.72	0.97	92.44	0.86	93.31	6.69	76.79	22.65	2.38
54	42-71-26DA	98.14	0.0	0.17	1.16	0.52	8.78	7.24	81.35	2.63	83.98	16.02	98.14	1.33	1.04
55	42-73- 2BD	21.04	0.0	78.11	0.71	0.14	50.29	31.12	17.48	1.11	18.59	81.41	21.04	78.81	0.74
56	42-73-31DC	63.65	0.0	35.37	0.86	0.13	61.97	22.34	14.07	1.62	15.69	84.31	63.65	36.23	3.03
57	42-73-35AD	36.71	0.0	61.91	1.12	0.26	39.08	22.21	37.60	1.11	38.70	61.30	36.71	63.03	2.16
58	42-74-12AC	12.72	0.0	86.58	0.63	0.08	76.00	5.33	17.38	1.29	18.67	81.32	12.72	87.20	0.56
59	42-74-28CD	46.57	0.0	52.35	0.89	0.20	70.73	13.20	12.80	3.25	16.05	83.93	46.57	53.23	2.53
60	42-75- 4DD	32.74	0.0	66.53	0.56	0.17	49.77	10.25	38.28	1.69	39.97	60.03	32.74	67.10	1.82
61	43-71- 3AB	17.43	0.0	81.39	1.08	0.10	27.43	10.57	60.75	1.25	61.99	38.00	17.43	82.47	0.76
62	43-72-15AB	12.32	0.0	86.96	0.59	0.12	47.90	44.85	6.54	0.71	7.25	92.75	12.32	87.55	0.66
63	43-72-35CD	20.71	0.0	77.23	1.63	0.43	49.51	16.62	33.57	0.31	33.87	66.13	20.71	78.86	0.98
64	43-73- 1DD	30.12	0.0	68.82	0.93	0.12	24.80	3.90	70.67	0.63	71.30	28.70	30.12	69.75	0.86
65	43-73-16CB	60.16	0.0	38.59	1.18	0.07	31.59	10.96	56.53	0.92	57.45	42.55	60.16	39.77	1.36
66	43-73-25BC	75.48	7.68	3.84	12.34	0.67	3.34	2.06	93.87	0.73	94.60	5.40	83.16	16.17	1.98
67	43-74-18DD	9.73	0.0	89.67	0.49	0.12	42.26	14.21	42.34	1.19	43.53	56.47	9.73	90.15	0.47
68	43-76-22DD	41.83	2.80	52.44	2.84	0.09	2.89	0.57	96.15	0.39	96.53	3.47	44.63	55.28	1.41
69	44-70-29AA	85.13	0.0	4.46	9.66	0.75	2.10	1.27	96.32	0.31	96.62	3.38	85.13	14.11	0.97
70	44-71-21AD	28.53	0.0	63.73	7.28	0.45	27.10	29.45	42.83	0.63	43.46	56.54	28.53	71.01	2.82
71	44-72- 2D	6.66	0.0	92.97	0.28	0.09	42.63	42.65	13.90	0.82	14.72	85.28	6.66	93.25	0.47
72	44-73-18AC	19.90	0.0	78.40	1.59	0.10	12.17	3.88	83.15	0.80	83.95	16.05	19.90	80.00	1.31

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
73	44-74- 1BD	6.90	0.0	92.48	0.54	0.09	59.60	10.52	29.02	0.86	29.88	70.12	6.90	93.01	0.56
74	44-74-27AC	5.94	0.0	93.44	0.51	0.11	31.24	15.28	52.52	0.97	53.49	46.51	5.94	93.95	0.47
75	44-74-31DB	37.89	0.0	52.55	9.40	0.16	59.37	24.02	15.53	1.08	16.61	83.39	37.89	61.95	1.89
76	44-75-27CC	34.00	0.0	64.52	1.38	0.10	66.86	18.89	13.32	0.90	14.22	85.75	34.00	65.90	1.22
77	44-76- 8CD	31.39	2.25	63.17	3.16	0.04	5.84	1.92	91.64	0.60	92.23	7.76	33.63	66.33	1.86
78	45-70-10DA	35.22	0.0	63.61	1.01	0.16	48.36	43.40	7.50	0.74	8.24	91.76	35.22	64.62	0.48
79	45-71-12AB	61.85	0.0	37.15	0.88	0.12	15.15	5.66	78.16	1.04	79.20	20.80	61.85	38.03	0.72
80	45-72-23BB	8.04	0.0	91.21	0.64	0.11	37.70	43.18	18.73	0.39	19.12	80.88	8.04	91.84	0.50
81	45-73-14BB	84.33	0.0	15.00	0.61	0.06	10.14	0.74	88.36	0.76	89.12	10.88	84.33	15.61	1.04
82	45-73-16AC	25.50	0.0	73.82	0.57	0.11	36.21	7.30	55.41	1.09	56.49	43.51	25.50	74.39	0.61
83	45-74-17AC	9.04	0.0	90.02	0.76	0.18	23.28	2.75	73.41	0.56	73.98	26.02	9.04	90.78	0.56
84	45-75- 8AC	7.33	0.0	91.87	0.58	0.22	19.70	2.37	77.27	0.66	77.93	22.07	7.33	92.45	0.56
85	45-75-26AC	22.54	0.0	76.68	0.61	0.18	35.91	7.99	55.16	0.95	56.10	43.90	22.54	77.29	0.92
86	45-77-13AB	22.66	1.69	72.63	2.68	0.33	4.67	1.84	92.97	0.52	93.49	6.51	24.35	75.31	1.57
87	46-71-22CB	33.31	0.0	65.76	0.76	0.17	23.61	17.87	57.17	1.34	58.52	41.48	33.31	66.52	0.48
88	46-72-14BC	3.27	0.0	93.35	2.81	0.58	30.34	38.82	29.87	0.97	30.84	69.16	3.27	96.16	4.37
89	46-73-22DA	20.91	0.0	77.21	1.67	0.21	30.92	11.73	56.43	0.91	57.35	42.65	20.91	78.88	0.47
90	46-73-29DC	2.20	0.0	97.09	0.58	0.14	25.78	12.36	61.23	0.63	61.86	38.14	2.20	97.66	0.21
91	46-74-21BB	31.00	0.0	68.36	0.52	0.12	49.83	26.28	22.81	1.09	23.89	76.11	31.00	68.88	1.50
92	46-74-28DD	35.82	0.0	63.61	0.41	0.17	50.86	21.22	26.94	0.97	27.91	72.09	35.82	64.01	1.46
93	46-75- 9BD	9.56	0.0	86.72	3.52	0.20	11.78	2.14	85.51	0.57	86.08	13.92	9.56	90.24	0.71
94	46-75-26CD	12.63	0.0	86.61	0.59	0.16	31.33	5.35	62.44	0.88	63.32	36.68	12.63	87.21	0.49
95	46-76-21BB	7.23	0.0	91.83	0.78	0.16	18.40	3.55	77.61	0.43	78.04	21.95	7.23	92.61	0.38
96	47-71- 9CC	19.28	0.0	80.08	0.53	0.12	33.15	35.46	30.01	1.39	31.40	68.60	19.28	80.61	0.43
97	47-72-10CB	94.65	0.0	1.04	4.00	0.31	4.41	2.45	92.26	0.88	93.14	6.86	94.65	5.04	2.15
98	47-72-16AC	14.31	0.0	84.65	0.84	0.20	60.69	14.86	23.57	0.88	24.45	75.55	14.31	85.49	1.53
99	47-73-20DD	14.19	0.0	84.88	0.77	0.16	29.07	10.03	60.12	0.78	60.90	39.10	14.19	85.64	0.40
100	47-74-23BD	17.26	0.0	81.22	1.32	0.20	44.18	28.17	27.13	0.52	27.65	72.35	17.26	82.54	0.67
101	47-75- 9CC	9.42	0.0	88.61	1.80	0.17	17.90	3.53	78.03	0.53	78.56	21.44	9.42	90.41	0.65
102	47-76- 2DB	16.35	1.33	77.87	4.22	0.24	4.09	1.28	94.07	0.57	94.63	5.37	17.68	82.09	1.23
103	48-71-17DD	23.41	0.0	75.61	0.85	0.13	29.40	10.34	58.95	1.31	60.26	39.74	23.41	76.46	0.55
104	48-71-17AD	97.61	0.0	0.21	1.76	0.42	16.31	1.00	81.33	1.36	82.69	17.31	97.61	1.97	1.31
105	48-72- 7B	12.82	0.0	86.77	0.27	0.13	58.92	8.56	31.27	1.25	32.52	67.48	12.82	87.04	0.58
106	48-73-26AC	26.83	0.0	70.74	2.26	0.16	34.02	13.77	51.51	0.70	52.21	47.79	26.83	73.01	0.71
107	48-74-26CA	16.81	0.0	82.11	0.87	0.21	16.43	3.32	79.42	0.83	80.25	19.75	16.81	82.99	0.40
108	48-75-22BB	15.85	3.16	76.97	3.74	0.27	4.35	5.08	90.09	0.48	90.57	9.43	19.01	80.72	1.15

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
109	49-71-17DD	12.80	0.0	85.73	1.06	0.41	50.30	36.89	11.40	1.42	12.82	87.18	12.80	86.79	1.87
110	49-73- 1CC	98.19	0.0	0.22	1.34	0.25	6.94	2.29	89.73	1.05	90.77	9.23	98.19	1.56	2.03
111	49-73-12CB	19.59	0.0	79.77	0.48	0.16	46.47	32.29	20.75	0.48	21.23	78.77	19.59	80.25	0.59
112	49-73-19CB	15.81	0.0	83.68	0.38	0.13	30.47	7.42	61.13	0.98	62.11	37.89	15.81	84.06	0.70
113	49-75- 2CB	28.84	0.0	70.46	0.48	0.21	23.90	6.48	68.84	0.78	69.62	30.38	28.84	70.94	1.00
114	49-75-34CD	46.30	4.01	43.79	5.51	0.40	3.62	1.12	94.74	0.52	95.26	4.74	50.30	49.30	1.83
115	50-71-30CA	10.48	0.0	89.03	0.38	0.11	69.20	15.27	13.95	1.58	15.53	84.47	10.48	89.41	0.24
116	50-72- 7AA	98.32	0.0	0.78	0.59	0.31	10.62	13.26	74.89	1.24	76.13	23.87	98.32	1.37	1.21
117	50-72-25AD	33.70	0.0	65.72	0.42	0.15	21.74	15.43	61.20	1.63	62.83	37.17	33.70	66.15	0.62
118	50-74-20BD	33.84	1.42	63.00	1.51	0.22	8.23	2.44	88.67	0.66	89.33	10.67	35.27	64.51	0.86
119	50-75-26AC	32.18	0.0	66.52	1.15	0.15	49.32	20.10	29.76	0.82	30.58	69.42	32.18	67.68	0.67
120	51-72-22CD	92.81	0.0	6.32	0.51	0.35	36.09	10.28	52.44	1.19	53.63	46.37	92.81	6.84	1.99
121	51-73-34AC	13.92	0.0	85.72	0.24	0.13	38.40	23.89	36.26	1.45	37.71	62.29	13.92	85.96	0.96
122	51-74-31AC	93.17	3.44	0.86	2.33	0.19	2.81	0.73	95.88	0.57	96.45	3.55	96.62	3.19	1.47
123	51-75- 2BC	96.43	0.0	0.10	2.94	0.52	3.92	2.21	93.15	0.72	93.87	6.13	96.43	3.04	1.63
124	51-76-23CA	10.17	0.0	89.40	0.36	0.07	25.96	36.15	37.32	0.58	37.89	62.11	10.17	89.76	0.18
125	52-73- 8AA	60.22	0.0	39.08	0.54	0.16	13.48	4.52	81.29	0.70	81.99	18.01	60.22	39.62	0.73
126	52-75-15BB	98.28	0.0	0.10	1.18	0.44	3.53	1.85	93.98	0.64	94.62	5.38	98.28	1.28	1.25
127	53-74- 7AD	6.12	0.0	93.50	0.30	0.08	26.75	31.37	41.19	0.69	41.88	58.12	6.12	93.80	0.16
128	53-75- 2BB	90.23	2.94	4.59	1.87	0.37	2.87	2.76	93.70	0.68	94.38	5.62	93.17	6.46	1.44
129	53-76-23DC	99.61	0.0	0.05	0.04	0.30	6.72	0.71	90.59	1.98	92.57	7.43	99.61	0.09	1.24
130	54-74-28D	97.66	0.0	0.12	1.92	0.30	6.82	3.06	89.13	0.99	90.12	9.87	97.66	2.04	1.40
131	54-75- 3C	95.28	0.0	4.11	0.33	0.27	2.14	1.50	95.83	0.53	96.36	3.64	95.28	4.45	1.09
132	54-76-22AC	95.35	2.75	1.72	0.06	0.12	4.35	0.81	93.95	0.88	94.84	5.16	98.10	1.78	0.94
133	55-76-14DD	87.72	0.0	12.02	0.09	0.17	14.10	4.08	80.87	0.95	81.82	18.18	87.72	12.11	0.83
134	41-76- 6AB	48.26	7.75	40.33	3.00	0.66	7.91	1.63	89.65	0.81	90.46	9.54	56.00	43.33	2.27
135	42-77-21AD	36.46	4.68	57.29	1.32	0.25	6.89	2.08	90.14	0.88	91.02	8.98	41.15	58.61	1.81
136	43-78- 5DA	26.98	0.91	67.84	3.87	0.40	5.16	2.17	92.13	0.54	92.67	7.33	27.90	71.71	0.88
137	44-77-30BB	23.76	1.14	72.78	1.92	0.40	6.27	2.02	91.07	0.64	91.71	8.29	24.89	74.70	1.03
138	44-78-10DA	89.92	7.28	0.28	1.73	0.79	1.39	1.22	96.78	0.60	97.39	2.61	97.19	2.02	2.03
139	44-79-20DA	54.34	0.0	44.62	0.91	0.13	22.30	7.83	68.82	1.05	69.87	30.13	54.34	45.53	1.16
140	44-80- 6CA	9.03	0.0	89.64	1.21	0.11	21.37	9.37	68.50	0.76	69.26	30.74	9.03	90.85	0.28
141	45-76-17BD	13.61	0.0	84.55	1.65	0.19	9.95	2.43	87.04	0.58	87.62	12.38	13.61	86.20	1.07
142	45-77- 6BC	59.56	10.09	26.27	3.32	0.75	2.68	0.55	96.26	0.51	96.77	3.23	69.66	29.59	2.45
143	45-78-34BA	63.34	4.12	28.97	2.83	0.73	1.73	0.95	96.85	0.47	97.32	2.68	67.47	31.80	2.10
144	45-79- 6BD	17.52	0.0	80.54	1.79	0.16	24.83	9.37	64.93	0.87	65.80	34.20	17.52	82.32	0.46

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
145	45-80- 9DA	17.28	0.0	78.38	4.09	0.25	8.64	1.22	89.57	0.57	90.14	9.86	17.28	82.47	0.75
146	46-77-17CC	27.40	7.69	60.02	4.47	0.42	3.44	1.22	94.90	0.44	95.34	4.66	35.09	64.49	1.98
147	46-78-18CA	9.35	0.0	89.06	1.45	0.14	16.10	3.61	79.70	0.60	80.30	19.70	9.35	90.51	0.30
148	46-79-20BB	31.15	0.0	68.15	0.55	0.15	30.13	11.16	58.24	0.47	58.71	41.29	31.15	68.69	0.81
149	46-80- 8BD	8.46	0.0	83.98	7.45	0.11	31.31	20.36	47.61	0.72	48.33	51.67	8.46	91.43	0.31
150	47-77-24DC	5.40	0.0	93.53	0.93	0.14	20.54	4.34	74.73	0.39	75.12	24.88	5.40	94.46	0.33
151	47-78-25AC	43.09	13.48	37.89	4.85	0.69	2.34	0.53	96.73	0.40	97.13	2.87	56.57	42.74	2.71
152	47-79-10BB	50.04	3.54	41.46	4.68	0.28	3.34	4.56	91.46	0.64	92.09	7.91	53.58	46.14	0.58
153	47-80-16BA	10.52	4.83	80.80	3.65	0.20	7.10	5.09	86.39	1.42	87.81	12.19	15.35	84.45	0.16
154	48-76-18CA	24.34	4.01	67.39	3.40	0.37	8.13	1.34	90.00	0.54	90.54	9.46	28.35	71.28	1.35
155	48-77-15DB	92.59	3.37	1.76	1.66	0.62	2.28	1.12	95.96	0.64	96.60	3.40	95.96	3.42	1.73
156	48-78- 5BA	4.83	0.0	94.50	0.57	0.11	20.84	5.30	73.35	0.51	73.86	26.14	4.83	95.07	0.24
157	48-78-33BC	10.07	0.0	89.65	0.19	0.08	32.32	43.69	23.55	0.45	24.00	76.00	10.07	89.84	0.26
158	48-79-33CC	85.37	0.0	7.64	6.46	0.53	2.72	1.51	95.17	0.59	95.77	4.23	85.37	14.10	1.23
159	48-81-15BC	6.46	1.01	89.41	2.85	0.27	13.41	6.14	79.87	0.59	80.45	19.55	7.47	92.26	0.58
160	49-76-17CC	73.66	5.76	14.40	5.36	0.82	2.28	0.19	97.03	0.50	97.53	2.47	79.42	19.76	2.49
161	49-77-21BA	97.74	0.0	0.16	1.29	0.80	1.67	1.67	96.06	0.60	96.65	3.35	97.74	1.45	0.90
162	49-80-23AC	92.32	0.0	0.17	7.01	0.50	2.26	1.86	95.39	0.49	95.88	4.12	92.32	7.18	0.61
163	49-80-30CC	80.26	5.77	6.44	6.97	0.55	3.49	1.57	94.39	0.55	94.94	5.06	86.04	13.41	1.01
164	49-81-25DD	28.58	0.0	68.94	2.18	0.30	9.54	3.19	86.59	0.69	87.28	12.72	28.58	71.11	0.50
165	50-77- 8DA	98.37	0.0	0.54	0.37	0.71	1.34	0.95	96.92	0.80	97.72	2.28	98.37	0.91	0.66
166	50-77-31CD	87.06	7.87	0.15	3.95	0.97	1.96	0.63	96.91	0.50	97.41	2.59	94.92	4.11	2.58
167	50-79-14AC	21.35	0.0	78.22	0.32	0.11	19.28	12.49	67.61	0.63	68.24	31.76	21.35	78.54	0.33
168	50-79-30CB	88.50	3.28	1.64	6.11	0.47	2.33	1.39	95.82	0.46	96.28	3.72	91.78	7.75	1.26
169	50-81-26AC	85.05	0.0	13.75	0.89	0.31	6.80	6.92	85.72	0.56	86.29	13.71	85.05	14.65	0.76
170	51-77-30DA	92.91	2.92	0.46	3.09	0.63	2.08	0.78	96.62	0.51	97.13	2.86	95.82	3.54	1.89
171	51-79-16BA	47.36	0.0	50.13	2.22	0.29	11.15	4.35	83.62	0.88	84.50	15.50	47.36	52.35	1.36
172	51-80-11BC	24.66	0.0	73.54	1.59	0.20	10.52	3.85	85.13	0.50	85.63	14.37	24.66	75.13	0.37
173	51-81-17DA	33.31	0.0	65.85	0.67	0.18	23.77	20.03	55.73	0.47	56.20	43.80	33.31	66.52	0.67
174	51-82-20DD	44.37	4.71	49.01	1.66	0.25	17.69	3.56	78.37	0.38	78.75	21.25	49.08	50.67	1.94
175	52-77-17DC	99.46	0.0	0.04	0.18	0.32	2.56	1.69	95.20	0.55	95.76	4.24	99.46	0.23	0.85
176	52-78-11DC	30.74	0.0	68.51	0.58	0.17	10.60	4.28	84.29	0.83	85.12	14.88	30.74	69.09	0.64
177	52-79- 3BA	13.29	0.0	86.33	0.26	0.12	39.15	37.04	22.96	0.85	23.81	76.19	13.29	86.59	0.27
178	52-79- 3BA	25.05	0.0	74.57	0.18	0.20	27.56	12.61	59.53	0.31	59.84	40.16	25.05	74.75	0.48
179	52-80-18DC	16.15	0.0	83.19	0.53	0.13	11.92	10.18	77.39	0.50	77.89	22.11	16.15	83.72	0.26
180	52-81-23AD	39.55	0.0	59.59	0.68	0.19	24.06	22.86	52.14	0.94	53.09	46.91	39.55	60.27	0.86

NUM	LOCATION	PHCO3	PCO3	PSO4	PCL	PF	PCA	PMG	PNA	PK	PK+NA	PCA+MG	PHCO3+CO3	PSO4+CL	PSIO2
181	52-82-23DB	36.10	0.0	63.46	0.22	0.23	4.30	2.46	92.78	0.46	93.24	6.76	36.10	63.68	0.54
182	53-77- 2BD	99.17	0.0	0.54	0.07	0.22	3.12	1.69	94.34	0.86	95.19	4.81	99.17	0.61	0.99
183	53-77-34BD	99.37	0.0	0.05	0.39	0.19	2.10	2.27	94.80	0.84	95.64	4.36	99.37	0.43	1.01
184	53-80- 9CA	77.57	4.62	16.49	0.56	0.76	2.21	1.65	95.63	0.51	96.14	3.86	82.19	17.05	1.27
185	53-81-14BC	98.67	0.0	0.09	0.63	0.61	1.85	1.58	96.02	0.54	96.57	3.43	98.67	0.72	1.30
186	53-82-11CD	99.47	0.0	0.12	0.16	0.25	2.85	2.19	94.41	0.55	94.96	5.04	99.47	0.29	1.00
187	54-77-23CD	99.58	0.0	0.05	0.15	0.22	1.77	1.50	95.54	1.19	96.74	3.26	99.58	0.20	1.48
188	54-79-21BD	87.98	0.0	9.42	2.13	0.48	3.30	1.98	94.25	0.47	94.72	5.28	87.98	11.54	1.04
189	54-80-24BC	13.32	0.0	86.41	0.17	0.10	25.20	43.01	30.99	0.81	31.79	68.21	13.32	86.58	0.45
190	54-80-24BC	88.01	0.31	7.74	3.41	0.54	2.43	1.81	95.14	0.62	95.76	4.24	88.32	11.14	1.39
191	54-81-15BA	84.05	0.0	14.56	1.08	0.31	50.89	28.81	17.93	2.37	20.30	79.70	84.05	15.64	5.70
192	54-82- 9BB	62.58	0.0	36.53	0.59	0.30	39.17	26.67	32.17	1.99	34.16	65.84	62.58	37.13	2.27
193	54-83-27CD	79.95	16.01	2.69	0.52	0.83	1.12	0.64	97.87	0.37	98.24	1.76	95.96	3.21	2.51
194	55-77-10DC	98.23	0.0	0.79	0.27	0.70	2.43	1.82	95.18	0.58	95.76	4.24	98.23	1.06	1.13
195	55-77-15BD	99.45	0.0	0.05	0.07	0.43	1.76	1.28	96.37	0.59	96.96	3.04	99.45	0.12	0.85
196	55-78-29AA	98.84	0.0	0.56	0.15	0.45	2.40	1.35	95.78	0.46	96.25	3.75	98.84	0.71	0.88
197	55-79-30AD	95.42	0.0	0.51	3.42	0.66	1.85	0.96	96.61	0.58	97.19	2.81	95.42	3.93	1.32
198	55-81-19BB	91.55	4.98	0.31	2.53	0.63	1.02	1.01	97.48	0.48	97.97	2.03	96.53	2.84	1.05
199	55-83-26BD	99.64	0.0	0.05	0.07	0.25	4.31	2.58	92.06	1.05	93.10	6.90	99.64	0.11	0.83
200	56-77-26CC	99.14	0.0	0.06	0.16	0.65	1.37	0.91	97.23	0.50	97.73	2.27	99.14	0.22	0.96
201	56-79-21AC	11.92	0.0	87.88	0.11	0.09	31.75	39.89	27.68	0.68	28.36	71.64	11.92	87.98	0.32
202	56-80- 9BD	29.81	0.0	69.13	0.94	0.12	36.48	39.37	23.42	0.73	24.16	75.84	29.81	70.07	0.64
203	56-81-29BD	71.47	4.99	21.43	1.32	0.79	1.14	0.63	97.83	0.41	98.23	1.77	76.46	22.75	1.50
204	56-82-19DA	91.09	6.01	0.09	2.16	0.64	1.76	1.23	96.51	0.50	97.01	2.99	97.10	2.26	1.47
205	57-76-29AC	99.31	0.0	0.07	0.06	0.56	1.95	0.91	96.36	0.78	97.14	2.86	99.31	0.13	1.00
206	57-80-31BB	15.09	0.0	84.36	0.43	0.13	8.61	4.60	86.13	0.66	86.79	13.21	15.09	84.78	0.39
207	57-81- 7CB	92.96	4.25	1.99	0.27	0.54	1.17	0.96	97.41	0.46	97.87	2.13	97.20	2.26	1.15
208	57-81-22AA	16.16	0.0	83.10	0.62	0.12	9.12	8.62	81.44	0.81	82.26	17.74	16.16	83.72	0.32

Appendix F

CHEMICAL RATIOS IN EQUIVALENTS PER MILLION

Explanations of the data headings used on pages 154 to 159 are given below.

NUM = well number.

LOCATION = well location (see Location Format in Appendix A).

CA/NA = ratio of calcium to sodium.

CA/MG = ratio of calcium to magnesium.

CL/NA = ratio of chloride to sodium.

SO4/NA = ratio of sulfate to sodium.

HCO3/NA = ratio of bicarbonate to sodium.

F/CL = ratio of fluoride to chloride.

K/F = ratio of potassium to fluoride.

CA/HCO3 = ratio of calcium to bicarbonate.

SO4/HCO3 = ratio of sulfate to bicarbonate.

TANI/TDS = ratio of total anions to total dissolved solids (in ppm).

THRD/TDS = ratio of total hardness to total dissolved solids (in ppm).

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRD/TDS
1	33-70- 9AC	1.967	1.040	0.083	1.914	3.251	0.021	48.603	0.605	0.589	0.999	0.660
2	34-69-32AC	1.480	1.300	0.042	3.217	0.924	0.124	17.011	1.602	3.482	0.834	0.515
3	34-72-26AB	0.399	2.051	0.016	1.290	0.573	0.187	4.958	0.697	2.254	0.849	0.253
4	35-71- 4BB	5.736	4.827	0.074	1.914	2.627	0.070	13.285	2.184	0.729	0.944	0.640
5	35-70-32BC	0.133	5.731	0.009	0.977	0.274	0.210	3.240	0.484	3.562	0.779	0.095
6	35-72-18A	1.912	2.275	0.036	0.798	2.826	0.047	37.911	0.677	0.282	1.019	0.656
7	35-73-15B	0.287	6.068	0.020	0.831	0.374	0.207	3.985	0.766	2.221	0.761	0.205
8	35-74- 1BD	4.525	4.441	0.072	1.330	4.480	0.373	5.832	1.010	0.297	0.897	0.721
9	36-69- 7AB	0.053	1.483	0.024	0.162	0.563	0.253	1.739	0.090	0.288	0.835	0.076
10	36-70-12CC	0.051	2.124	0.026	0.190	0.616	0.254	1.382	0.083	0.308	0.872	0.069
11	36-70-21CB	0.037	0.842	0.026	0.194	0.581	0.263	1.134	0.062	0.333	0.856	0.073
12	36-71-13DB	0.060	2.225	0.025	0.071	0.763	0.172	2.511	0.077	0.093	0.955	0.076
13	36-72- 9DD	0.278	7.585	0.019	0.823	0.371	0.068	7.047	0.749	2.221	0.766	0.185
14	36-73-26AD	4.439	3.375	0.056	0.312	6.012	0.0	0.082	0.738	0.052	1.126	0.839
15	36-73-27AB	1.700	6.899	0.052	1.197	1.702	0.083	14.338	0.999	0.703	0.908	0.537
16	36-74-23CD	5.181	3.539	0.272	4.632	3.646	0.036	6.027	1.421	1.270	0.911	0.669
17	36-74-27BD	4.890	2.587	0.068	1.385	5.632	0.233	6.804	0.868	0.246	1.016	0.839
18	37-69-20DB	0.024	0.545	0.019	0.005	0.863	0.435	1.042	0.028	0.005	1.026	0.064
19	37-70- 4AC	0.147	6.320	0.018	0.002	0.904	0.322	2.456	0.163	0.003	1.003	0.146
20	37-72-17CA	0.106	4.382	0.014	0.339	0.510	0.124	5.346	0.199	0.665	0.804	0.108
21	37-73-10BD	0.219	4.045	0.015	0.342	0.598	0.187	5.832	0.365	0.572	0.810	0.207
22	37-73-22AD	0.131	2.360	0.021	0.272	0.573	0.163	3.611	0.212	0.476	0.818	0.146
23	37-74-24B	3.824	2.311	0.103	1.595	4.521	0.074	18.145	0.846	0.353	1.008	0.772
24	37-75-14DB	2.065	3.855	0.097	1.436	2.185	0.199	13.163	0.945	0.657	0.915	0.585
25	38-71- 1CA	0.051	3.034	0.026	0.230	0.586	0.221	1.495	0.087	0.393	0.862	0.058
26	38-71-12AB	0.684	2.427	0.040	0.126	1.666	0.240	10.261	0.411	0.076	1.046	0.463
27	38-72-23DB	0.055	3.843	0.020	0.421	0.408	0.168	1.836	0.135	1.034	0.782	0.057
28	38-72-27AC	0.051	2.172	0.015	0.375	0.483	0.107	3.888	0.106	0.778	0.818	0.061
29	38-72-28DB	0.054	2.855	0.016	0.420	0.370	0.122	2.777	0.145	1.134	0.757	0.063
30	38-73-33CB	0.863	4.379	0.021	0.901	0.835	0.156	17.497	1.035	1.079	0.812	0.459
31	38-73-33CB	0.212	6.573	0.016	0.509	0.545	0.187	4.721	0.388	0.934	0.815	0.169
32	38-73-33CB	0.502	5.201	0.027	0.499	0.761	0.177	6.139	0.659	0.655	0.824	0.351
33	38-74-12BC	1.668	4.536	0.024	2.437	0.677	0.280	10.531	2.464	3.601	0.776	0.492
34	38-75- 5AA	3.480	2.906	0.136	3.031	3.140	0.074	18.469	1.108	0.965	0.925	0.627
35	39-71- 4DC	0.028	2.023	0.026	0.236	0.447	0.201	1.458	0.061	0.529	0.773	0.036
36	39-71-13DC	0.239	2.494	0.018	0.017	1.073	0.467	6.318	0.223	0.015	1.010	0.255

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRD/TDS
37	39-72- 6BD	0.059	5.894	0.020	0.308	0.457	0.093	4.131	0.120	0.675	0.780	0.061
38	39-73-19DC	0.860	12.135	0.024	0.947	0.820	0.133	14.387	1.049	1.155	0.815	0.395
39	39-73-23DC	0.632	27.304	0.026	0.537	0.800	0.093	12.151	0.790	0.672	0.824	0.355
40	40-71- 6DD	0.036	4.854	0.026	0.473	0.336	0.147	2.209	0.104	1.407	0.750	0.037
41	40-73- 8CD	0.164	5.056	0.015	0.729	0.348	0.112	4.860	0.471	2.095	0.765	0.130
42	40-74- 9CA	0.070	3.569	0.028	0.247	0.525	0.027	11.665	0.122	0.469	0.818	0.079
43	40-75- 8DC	1.974	5.282	0.053	1.336	2.173	0.133	17.497	0.908	0.615	0.944	0.558
44	40-75-32DB	1.219	4.126	0.054	1.595	0.761	0.128	7.953	1.601	2.095	0.794	0.479
45	41-71-35AC	0.066	3.193	0.030	0.003	0.793	0.490	1.042	0.083	0.003	0.969	0.085
46	41-71- 6CC	0.556	4.088	0.039	1.360	0.320	0.082	3.333	1.740	4.253	0.762	0.309
47	41-72-16BB	0.131	4.045	0.034	0.342	0.466	0.059	3.749	0.281	0.733	0.783	0.133
48	41-73- 6BD	0.518	4.247	0.035	1.029	0.425	0.075	6.561	1.218	2.420	0.764	0.323
49	41-73-23DA	0.065	3.141	0.023	0.337	0.483	0.119	2.638	0.125	0.699	0.807	0.072
50	41-74-20BA	1.530	4.399	0.097	1.540	1.061	0.050	8.054	1.441	1.452	0.827	0.548
51	41-75- 4AB	7.437	2.037	0.291	12.378	2.858	0.057	15.796	2.602	4.331	0.850	0.605
52	42-70- 5DD	0.811	0.273	0.048	5.318	0.140	0.079	5.289	5.815	38.109	0.784	0.559
53	42-71- 7CC	0.062	5.894	0.062	0.152	0.688	0.086	1.767	0.085	0.221	0.916	0.063
54	42-71-26DA	0.108	1.214	0.013	0.002	1.073	0.448	5.670	0.101	0.002	1.085	0.160
55	42-73- 2BD	2.877	1.616	0.032	3.590	0.967	0.202	9.721	2.975	3.712	0.750	0.750
56	42-73-31DC	4.405	2.774	0.065	2.680	4.823	0.149	11.908	0.913	0.556	1.002	0.699
57	42-73-35AD	1.040	1.760	0.027	1.496	0.887	0.233	4.666	1.172	1.686	0.820	0.527
58	42-74-12AC	4.371	14.259	0.058	8.085	1.188	0.121	10.468	3.680	6.805	0.787	0.687
59	42-74-28CD	5.527	5.360	0.074	4.351	3.871	0.224	15.391	1.428	1.124	0.903	0.665
60	42-75- 4DD	1.300	4.854	0.014	1.595	0.785	0.299	10.936	1.656	2.032	0.793	0.496
61	43-71- 3AB	0.452	2.594	0.023	1.709	0.366	0.093	9.721	1.234	4.670	1.222	0.364
62	43-72-15AB	7.329	1.068	0.090	13.295	1.884	0.212	5.718	3.890	7.057	0.787	0.737
63	43-72-35CD	1.475	2.979	0.019	0.912	0.244	0.261	1.805	6.033	3.729	0.531	0.880
64	43-73- 1DD	0.351	6.353	0.011	0.822	0.360	0.131	6.110	0.975	2.285	0.750	0.243
65	43-73-16CB	0.559	2.882	0.019	0.614	0.956	0.062	13.933	0.584	0.642	0.909	0.387
66	43-73-25BC	0.036	1.618	0.095	0.030	0.584	0.054	1.502	0.055	0.051	0.854	0.058
67	43-74-18DD	0.998	2.975	0.013	2.331	0.253	0.249	8.911	3.948	9.220	0.756	0.395
68	43-76-22DD	0.030	5.056	0.010	0.188	0.150	0.031	12.637	0.188	1.254	0.489	0.044
69	44-70-29AA	0.022	1.655	0.025	0.011	0.218	0.078	1.653	0.100	0.052	0.461	0.055
70	44-71-21AD	0.633	0.920	0.106	0.928	0.416	0.062	2.214	1.522	2.233	0.679	0.600
71	44-72- 2D	3.066	1.000	0.018	6.020	0.431	0.311	10.369	7.109	13.959	0.736	0.714
72	44-73-18AC	0.146	3.135	0.016	0.788	0.200	0.062	9.721	0.732	3.939	0.701	0.131

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRO/TDS
73	44-74- 1BD	2.053	5.663	0.021	3.551	0.265	0.160	8.911	7.750	13.404	0.718	0.629
74	44-74-27AC	0.595	2.045	0.010	1.875	0.119	0.221	8.225	4.992	15.736	0.731	0.332
75	44-74-31DB	3.824	2.472	0.648	3.626	2.615	0.017	6.318	1.462	1.387	0.882	0.664
76	44-75-27CC	5.019	3.539	0.122	5.684	2.995	0.075	7.453	1.675	1.897	0.890	0.624
77	44-76- 8CD	0.064	3.034	0.030	0.598	0.297	0.011	19.441	0.200	2.013	0.743	0.066
78	45-70-10DA	6.453	1.114	0.142	8.974	4.969	0.160	4.374	1.299	1.806	0.903	0.750
79	45-71-12AB	0.194	2.677	0.010	0.431	0.718	0.133	9.721	0.270	0.601	0.908	0.186
80	45-72-23BB	2.013	0.873	0.031	4.461	0.393	0.178	3.703	5.117	11.342	0.747	0.675
81	45-73-14BB	0.115	13.652	0.005	0.133	0.747	0.093	17.173	0.154	0.178	0.943	0.112
82	45-73-16AC	0.654	4.960	0.010	1.269	0.438	0.187	10.693	1.491	2.895	0.776	0.347
83	45-74-17AC	0.317	8.478	0.009	1.038	0.104	0.243	3.589	3.045	9.963	0.672	0.211
84	45-75- 8AC	0.255	8.303	0.006	1.023	0.082	0.373	3.541	3.125	12.536	0.670	0.176
85	45-75-26AC	0.651	4.497	0.010	1.294	0.380	0.293	5.744	1.713	3.403	0.690	0.321
86	45-77-13AB	0.050	2.537	0.023	0.627	0.196	0.124	1.944	0.239	3.205	0.691	0.056
87	46-71-22CB	0.413	1.321	0.013	1.117	0.566	0.224	8.101	0.730	1.974	0.822	0.369
88	46-72-14BC	1.016	0.781	0.068	2.244	0.078	0.205	2.342	12.939	28.581	0.636	0.635
89	46-73-22DA	0.548	2.636	0.027	1.234	0.334	0.124	4.860	1.640	3.693	0.745	0.347
90	46-73-29DC	0.421	2.036	0.008	1.434	0.032	0.240	5.022	12.972	44.184	0.681	0.298
91	46-74-21BB	2.185	1.896	0.022	2.849	1.292	0.240	9.181	1.691	2.205	0.824	0.637
92	46-74-28DD	1.888	2.397	0.014	2.119	1.193	0.420	6.372	1.582	1.776	0.822	0.626
93	46-75- 9BD	0.138	5.516	0.035	0.862	0.095	0.057	3.358	1.450	9.073	0.669	0.112
94	46-75-26CD	0.502	5.853	0.008	1.213	0.177	0.272	6.249	2.837	6.857	0.698	0.295
95	46-76-21BB	0.237	5.181	0.008	0.891	0.070	0.207	3.541	3.379	12.703	0.640	0.189
96	47-71- 9CC	1.105	0.935	0.017	2.493	0.600	0.221	12.712	1.841	4.154	0.785	0.572
97	47-72-10CB	0.048	1.798	0.029	0.007	0.679	0.077	4.305	0.070	0.011	0.904	0.078
98	47-72-16AC	2.575	4.086	0.040	3.989	0.674	0.238	3.958	3.820	5.917	0.777	0.534
99	47-73-20DD	0.484	2.899	0.012	1.320	0.221	0.212	5.146	2.191	5.979	0.730	0.307
100	47-74-23BD	1.629	1.568	0.048	2.954	0.628	0.148	2.712	2.593	4.705	0.782	0.574
101	47-75- 9CC	0.229	5.067	0.019	0.945	0.100	0.093	3.807	2.283	9.410	0.667	0.175
102	47-76- 2DB	0.043	3.193	0.037	0.680	0.143	0.056	2.916	0.282	4.764	0.676	0.045
103	48-71-17DD	0.499	2.844	0.014	1.249	0.387	0.149	10.531	1.290	3.230	0.774	0.310
104	48-71-17AD	0.201	16.307	0.017	0.002	0.919	0.237	4.253	0.218	0.002	0.997	0.187
105	48-72- 7B	1.884	6.883	0.009	2.815	0.416	0.498	9.113	4.529	6.768	0.748	0.501
106	48-73-26AC	0.660	2.470	0.043	1.330	0.504	0.072	4.472	1.310	2.636	0.789	0.383
107	48-74-26CA	0.207	4.944	0.010	0.915	0.187	0.238	4.513	1.104	4.886	0.711	0.158
108	48-75-22BB	0.048	0.857	0.032	0.655	0.135	0.073	2.298	0.299	4.857	0.661	0.049

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRO/TDS
109	49-71-17DD	4.412	1.364	0.100	8.054	1.203	0.385	3.240	3.668	6.696	0.784	0.648
110	49-73- 1CC	0.077	3.034	0.011	0.002	0.802	0.187	5.724	0.096	0.002	0.970	0.101
111	49-73-12CB	2.240	1.439	0.022	3.663	0.900	0.336	3.132	2.489	4.071	0.788	0.646
112	49-73-19CB	0.499	4.107	0.006	1.418	0.268	0.350	7.129	1.861	5.293	0.945	0.347
113	49-75- 2CB	0.347	3.687	0.006	0.917	0.375	0.448	4.050	0.925	2.443	0.764	0.252
114	49-75-34CD	0.038	3.236	0.044	0.349	0.369	0.072	1.750	0.095	0.946	0.753	0.043
115	50-71-30CA	4.951	4.532	0.051	12.070	1.421	0.280	7.921	3.491	8.493	0.789	0.750
116	50-72- 7AA	0.142	0.801	0.007	0.009	1.132	0.533	4.557	0.125	0.008	1.088	0.247
117	50-72-25AD	0.355	1.409	0.007	1.081	0.554	0.355	10.744	0.641	1.950	0.829	0.292
118	50-74-20BD	0.093	3.371	0.016	0.658	0.354	0.149	3.159	0.252	1.862	0.781	0.087
119	50-75-26AC	1.657	2.454	0.041	2.374	1.148	0.128	5.214	1.443	2.068	0.855	0.536
120	51-72-22CD	0.688	3.511	0.007	0.089	1.301	0.684	4.595	0.529	0.068	0.982	0.516
121	51-73-34AC	1.059	1.608	0.007	2.436	0.396	0.527	11.216	2.677	6.160	0.764	0.463
122	51-74-31AC	0.029	3.843	0.017	0.006	0.698	0.082	4.166	0.041	0.009	0.937	0.041
123	51-75- 2BC	0.042	1.776	0.022	0.001	0.714	0.178	1.990	0.059	0.001	0.936	0.070
124	51-76-23CA	0.696	0.718	0.011	2.770	0.315	0.204	6.885	2.208	8.789	0.793	0.433
125	52-73- 8AA	0.166	2.983	0.006	0.440	0.678	0.295	4.860	0.245	0.649	0.898	0.158
126	52-75-15BB	0.038	1.907	0.009	0.001	0.722	0.373	2.106	0.052	0.001	0.677	0.044
127	53-74- 7AD	0.649	0.853	0.008	2.325	0.152	0.249	8.911	4.264	15.268	0.744	0.433
128	53-75- 2BB	0.031	1.040	0.015	0.038	0.746	0.199	2.369	0.040	0.051	0.963	0.058
129	53-76-23DC	0.074	9.535	0.000	0.000	0.949	7.465	7.696	0.078	0.000	1.063	0.075
130	54-74-28D	0.076	2.229	0.014	0.001	0.731	0.156	4.958	0.105	0.001	0.928	0.114
131	54-75- 3C	0.022	1.428	0.002	0.029	0.675	0.809	2.916	0.033	0.043	0.925	0.041
132	54-76-22AC	0.046	5.393	0.001	0.016	0.894	2.053	8.395	0.050	0.018	1.051	0.051
133	55-76-14DD	0.174	3.459	0.001	0.115	0.838	1.866	7.291	0.208	0.137	0.964	0.192
134	41-76- 6AB	0.088	4.854	0.023	0.307	0.367	0.221	1.795	0.207	0.836	0.722	0.096
135	42-77-21AD	0.076	3.310	0.014	0.625	0.398	0.187	3.645	0.170	1.571	0.798	0.071
136	43-78- 5DA	0.056	2.374	0.035	0.616	0.245	0.103	1.635	0.221	2.514	0.726	0.063
137	44-77-30BB	0.069	3.112	0.016	0.589	0.192	0.210	2.160	0.342	3.064	0.676	0.075
138	44-78-10DA	0.014	1.142	0.011	0.002	0.594	0.456	1.193	0.022	0.003	0.861	0.030
139	44-79-20DA	0.324	2.847	0.012	0.587	0.715	0.140	9.073	0.453	0.821	0.875	0.264
140	44-80- 6CA	0.312	2.282	0.020	1.505	0.152	0.093	5.832	2.057	9.924	0.754	0.205
141	45-76-17BD	0.114	4.092	0.014	0.740	0.119	0.115	4.010	0.960	6.213	0.654	0.107
142	45-77- 6BC	0.028	4.854	0.028	0.218	0.493	0.227	0.858	0.048	0.441	0.819	0.031
143	45-78-34BA	0.018	1.820	0.018	0.186	0.408	0.258	1.026	0.041	0.457	0.747	0.029
144	45-79- 6BD	0.382	2.650	0.030	1.340	0.291	0.088	5.146	1.312	4.596	0.773	0.246

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRO/TDS
145	45-80- 9DA	0.096	7.079	0.053	1.006	0.222	0.062	1.944	0.435	4.537	0.770	0.070
146	46-77-17CC	0.036	2.832	0.040	0.541	0.247	0.093	1.237	0.115	2.190	0.717	0.040
147	46-78-18CA	0.202	4.464	0.020	1.227	0.129	0.098	3.837	1.568	9.527	0.738	0.136
148	46-79-20BB	0.517	2.701	0.008	1.056	0.483	0.280	3.402	1.072	2.187	0.788	0.347
149	46-80- 8BD	0.658	1.538	0.169	1.899	0.191	0.015	6.018	3.437	9.924	0.749	0.373
150	47-77-24DC	0.275	4.733	0.011	1.103	0.064	0.153	3.132	4.318	17.322	0.673	0.196
151	47-78-25AC	0.024	4.369	0.032	0.252	0.286	0.143	0.897	0.064	0.879	0.675	0.030
152	47-79-10BB	0.037	0.733	0.047	0.416	0.502	0.060	2.491	0.068	0.828	0.849	0.069
153	47-80-16BA	0.082	1.396	0.050	1.118	0.146	0.056	5.832	0.387	7.683	0.754	0.081
154	48-76-18CA	0.090	6.068	0.036	0.720	0.258	0.109	1.528	0.300	2.789	0.744	0.075
155	48-77-15DB	0.024	2.044	0.015	0.015	0.817	0.373	1.215	0.028	0.019	1.011	0.035
156	48-78- 5BA	0.284	3.933	0.009	1.419	0.072	0.187	4.374	3.920	19.576	0.723	0.177
157	48-78-33BC	1.372	0.740	0.009	4.021	0.452	0.429	5.072	3.038	8.901	0.786	0.566
158	48-79-33CC	0.029	1.798	0.050	0.060	0.667	0.082	1.502	0.043	0.089	0.919	0.045
159	48-81-15BC	0.168	2.184	0.035	1.103	0.080	0.093	2.236	1.823	13.843	0.697	0.145
160	49-76-17CC	0.024	12.135	0.037	0.098	0.502	0.153	0.918	0.043	0.195	0.803	0.027
161	49-77-21BA	0.017	0.999	0.011	0.001	0.796	0.622	0.948	0.022	0.002	1.009	0.036
162	49-80-23AC	0.024	1.214	0.046	0.001	0.601	0.072	1.564	0.039	0.002	0.874	0.049
163	49-80-30CC	0.037	2.225	0.047	0.044	0.547	0.079	1.544	0.063	0.080	0.833	0.059
164	49-81-25DD	0.110	2.992	0.024	0.766	0.318	0.140	2.361	0.347	2.412	0.776	0.100
165	50-77- 8DA	0.014	1.416	0.003	0.005	0.932	1.941	1.215	0.015	0.006	1.094	0.024
166	50-77-31CD	0.020	3.120	0.030	0.001	0.665	0.246	0.700	0.028	0.002	0.909	0.028
167	50-79-14AC	0.285	1.544	0.005	1.238	0.338	0.339	5.346	0.844	3.664	0.792	0.232
168	50-79-30CB	0.024	1.674	0.038	0.010	0.546	0.076	1.674	0.043	0.019	0.827	0.045
169	50-81-26AC	0.079	0.982	0.008	0.122	0.752	0.342	2.430	0.105	0.162	0.944	0.146
170	51-77-30DA	0.022	2.670	0.028	0.004	0.834	0.205	0.928	0.025	0.005	1.021	0.028
171	51-79-16BA	0.133	2.564	0.021	0.482	0.456	0.132	3.726	0.293	1.059	0.793	0.142
172	51-80-11BC	0.124	2.730	0.018	0.818	0.274	0.128	2.563	0.450	2.982	0.760	0.113
173	51-81-17DA	0.427	1.187	0.011	1.055	0.534	0.264	2.973	0.800	1.977	0.805	0.378
174	51-82-20DD	0.226	4.964	0.018	0.523	0.474	0.149	1.823	0.481	1.105	0.790	0.191
175	52-77-17DC	0.027	1.517	0.002	0.000	0.957	1.742	1.909	0.028	0.000	1.096	0.042
176	52-78-11DC	0.126	2.478	0.007	0.857	0.384	0.299	4.557	0.327	2.229	0.809	0.109
177	52-79- 3BA	1.705	1.057	0.022	7.179	1.105	0.448	3.848	1.543	6.496	0.902	0.362
178	52-79- 3BA	0.463	2.186	0.002	0.727	0.244	1.120	2.633	1.896	2.977	0.641	0.434
179	52-80-18DC	0.154	1.171	0.007	1.052	0.204	0.242	3.977	0.754	5.150	0.744	0.168
180	52-81-23AD	0.461	1.052	0.013	1.127	0.748	0.271	5.164	0.617	1.507	0.860	0.386

NUM	LOCATION	CA/NA	CA/MG	CL/NA	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3	SO4/HCO3	TANI/TDS	THRD/TDS
181	52-82-23DB	0.046	1.743	0.002	0.554	0.315	1.026	2.519	0.147	1.758	0.756	0.060
182	53-77- 28D	0.033	1.847	0.001	0.005	0.907	2.986	4.557	0.036	0.005	1.060	0.049
183	53-77-34BD	0.022	0.925	0.004	0.000	1.006	0.498	4.557	0.022	0.000	1.121	0.042
184	53-80- 9CA	0.023	1.339	0.004	0.120	0.566	1.353	0.972	0.038	0.213	0.858	0.042
185	53-81-14BC	0.019	1.172	0.005	0.001	0.767	0.970	1.196	0.025	0.001	0.985	0.038
186	53-82-11CD	0.030	1.300	0.001	0.001	0.859	1.493	2.734	0.035	0.001	1.043	0.053
187	54-77-23CD	0.019	1.182	0.001	0.001	0.928	1.493	6.075	0.020	0.001	1.076	0.032
188	54-79-21BD	0.035	1.666	0.014	0.063	0.584	0.224	1.580	0.060	0.107	0.857	0.061
189	54-80-24BC	0.813	0.586	0.006	3.155	0.486	0.581	7.291	1.672	6.486	0.808	0.490
190	54-80-24BC	0.025	1.339	0.029	0.066	0.756	0.158	1.414	0.034	0.088	0.976	0.043
191	54-81-15BA	2.839	1.767	0.053	0.718	4.145	0.283	8.749	0.685	0.173	1.026	0.790
192	54-82- 9BB	1.218	1.468	0.017	1.050	1.798	0.498	7.291	0.677	0.584	0.952	0.606
193	54-83-27CD	0.011	1.734	0.003	0.017	0.495	1.586	0.743	0.019	0.034	0.789	0.021
194	55-77-10DC	0.025	1.335	0.001	0.004	0.478	2.613	1.771	0.053	0.008	0.754	0.057
195	55-77-15BD	0.018	1.379	0.001	0.000	0.775	6.532	1.805	0.024	0.000	0.994	0.033
196	55-78-29AA	0.025	1.776	0.001	0.004	0.776	2.986	1.367	0.032	0.006	0.998	0.041
197	55-79-30AD	0.019	1.916	0.027	0.004	0.754	0.193	1.160	0.025	0.005	0.978	0.030
198	55-81-19BB	0.010	1.011	0.018	0.002	0.643	0.249	1.124	0.015	0.003	0.910	0.023
199	55-83-26BD	0.047	1.671	0.001	0.001	1.053	3.733	4.374	0.044	0.000	1.132	0.066
200	56-77-26CC	0.014	1.506	0.001	0.000	0.692	4.106	1.127	0.020	0.001	0.942	0.026
201	56-79-21AC	1.147	0.796	0.004	3.226	0.438	0.859	7.185	2.621	7.370	0.863	0.615
202	56-80- 9BD	1.557	0.927	0.041	3.006	1.296	0.129	5.940	1.202	2.319	0.858	0.619
203	56-81-29BD	0.012	1.820	0.009	0.149	0.496	0.597	0.759	0.022	0.300	0.814	0.019
204	56-82-19DA	0.018	1.434	0.017	0.001	0.710	0.296	1.044	0.024	0.001	0.949	0.032
205	57-76-29AC	0.020	2.157	0.000	0.000	0.597	9.332	2.430	0.034	0.001	0.862	0.035
206	57-80-31BB	0.100	1.871	0.005	1.057	0.189	0.307	4.649	0.529	5.591	0.755	0.093
207	57-81- 7CB	0.012	1.214	0.002	0.016	0.731	1.991	1.124	0.016	0.021	0.970	0.023
208	57-81-22AA	0.112	1.058	0.009	1.246	0.242	0.195	5.494	0.462	5.143	0.793	0.115

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