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HYDROGEOLOGY OF THE DAKOTA GROUP AQUIFER WITH EMPHASIS ON THE RADIUM-226 CONTENT OF ITS CONTAINED GROUND WATER, CANON CITY EMBAYMENT, FREMONT AND PUEBLO COUNTIES, COLORADO

by

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PREFACE

This report is a summarized version of Thomas A. Vinckier's Master of Science thesis, Department of Geological Science, University of Colorado, Boulder, 1978, which was prepared with funding from the Colorado Geological Survey.

Due to the nature of the subject matter and considering that very little information exists on the origin and occurrence of contained radioactive minerals in the ground waters of south central Colorado, the Colorado Geological Survey decided to publish Mr. Vinckier's paper. The Colorado Geological Survey wishes to express its gratitude to Mr. Vinckier for allowing the Colorado Geological Survey to summarize and publish his thesis.

ACKNOWLEDGMENTS

Particular thanks is extended to Richard Pearl of the Colorado Geological Survey for introducing this thesis to me, offering much needed monetary support and endless consultations, and, in effect, making it all possible. I also thank Dr. Theodore Meiggs and William Abbott of the Environmental Protection Agency in Denver for allowing me to use their facilities and equipment and for the radium-226 analyses and teaching me the proper analytical procedures. I thank Dr. Bruce F. Curtis and Dr. Donald D. Runnells who were sources of many helpful suggestions, technical advice, and constant moral support.

I give special appreciation to Willard Owens who graciously and openly provided many geophysical logs which are an integral part of this thesis. In today's highly secretive and competitive society, such a gracious and open willingness to help is quite unique and, indeed, reassuring.

I am most grateful to Nancy who was always present and willing to help in any possible way, and who made this otherwise enduring ordeal a pleasurable experience. To her, I dedicate this thesis.

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ABSTRACT

The Dakota Group aquifer of the Canon City embayment comprises two primary water bearing units, the Lytle Sandstone Member at the base and the Dakota Sandstone at the top, separated by the semiconfining, arenaceous Glencairn Shale Member. The estimated storage coefficient, median transmissivity and hydraulic conductivity of the aquifer as a whole are 10^{-4} to 10^{-5}, 940 gpd/ft. and 4.3 gpd/ft^2, respectively. In the southern half of the embayment where the aquifer is relatively shallow and recharge outcrops are plentiful, the Dakota Group ground water is of predominantly calcium-bicarbonate type and contains moderate to high amounts of dissolved solids (410 mg/l TDS, median value). This ground water is primarily of local meteoric origin. The ground water in the northwest part of the embayment, within, and immediately east of, the Florence Oil Field, is of sodium-bicarbonate type, mildly thermal (89°F (31.5°C), median temp.), and slightly brackish (1530 mg/l TDS, median value). The aquifer is very deep in this area, attaining a depth of over 6,000 ft. The ground water in this area probably represents a mixture of some or all of the following genetic types: 1) ground water connate to the Dakota Group, 2) ground water, connate or otherwise, entering the aquifer as leakage from adjacent semiconfining strata, 3) deeply circulated meteoric ground water, and 4) hydrothermal fluids (magmatic or metamorphic ground water) purged from the crystalline basement complex underlying the embayment.

The contents of the radium-226 in ground water from 117 wells completed in part or all of the Dakota Group were determined by the dissolved radon-222 emanation method. Sixty-seven percent of the ground water samples have radium-226 activities greater than 5.0 picocuries per liter of water (5.0 pCi/l), the recommended maximum permissible concentration of radium-226 in drinking water established by the Environmental Protection Agency in 1973. The radium-226 activities range from 0.0 pCi/l to 620.3 pCi/l. The mean and median activities are 24.4 pCi/l and 8.1 pCi/l, respectively.

Inspection of gamma-ray logs of about 20 wells revealed the presence of moderate to extremely high gamma radiation in strata of the Dakota Group, the Morrison Formation, the Fountain Formation, and in the crystalline basement rocks. Ground water samples from these and nearby wells commonly have high radium-226 activities. The intervals of high gamma radiation are considered to indicate accumulations of radium-bearing minerals (and/or uranium minerals) in the strata and/or aqueous raium species in the contained ground water. These rocks are considered local sources of the radium-rich ground water produced from nearby wells. Many occurrences of radium-rich ground water and high radioactivity in the formations near major faults in the embayment suggest radium and/or uranium-rich (hydrothermal?) fluids may migrate up portions of the fault planes from parent uranium deposits within the crystalline basement rocks. The fluids eventually enter hydrogeologically and hydrogeochemically suitable sedimentary hosts. Some high formation radioactivities may represent accumulations of uranium-rich detrittal material incorporated with the sediments during deposition, or pods of secondary uranium mineralization (roll front type deposits) introduced to the strata by uranium bearing ground water.

High levels of radium-226 in drinking water supplies pose potentially serious health hazards to the users. Owners of wells producing such water supplies are advised to 1) install, at the homesite, ion exchange (filtering units) capable of removing $^{226}Ra^{2+}$ ions and other aqueous radium species from the water or 2) effectively case out those stratigraphic intervals in the bore hole showing high gamma radiation preventing possible radium-rich ground water within these intervals from entering the well.

INTRODUCTION

The Canon City embayment is a plains area lying between the southern limit of the Front Range and the east flank of the Wet Mountains. The area occupies a structural reentrant in the Rocky Mountain front that extends westward to Canon City, for which the embayment is named (Fig. 1). The basal Cretaceous age Dakota Group is a major aquifer underlying the entire embayment. Water from this aquifer is an important source of water for irrigation, stock, domestic, and municipal uses in the Canon City embayment. This pertains especially to those areas within the embayment removed from the fluvial and alluvial deposits that are in direct hydraulic communication with major perennial streams, such as the Arkansas and St. Charles River. An excellent case in point is the new and rapidly growing Pueblo West development. All the water supplies for Pueblo West come from numerous large capacity municipal wells completed in the Dakota Group aquifer. As this and other rural and suburban developments continue to grow, so will the demand for water. Inevitably, ground water from the Dakota Group aquifer will be used to supply all or a large part of the ever increasing demand for water in the Canon City embayment.

Unfortunately, a problem exists concerning the suitability of the ground water for general domestic purposes. Much of the ground water from the Dakota Group aquifer contains high amounts of the radioactive isotope, radium-226. Of the 117 Dakota Group wells listed in Appendix E, 67 percent produce ground water containing radium-226 activities exceeding the limit of 5.0 picocuries per liter of water (pCi/l) established by the Environmental Protection Agency (1973). Untreated, this water may cause adverse physical effects in the users.

The primary purpose of this report is to determine the source and distribution of the radium-226 in the Dakota Group aquifer and the contained water. In seeking this source, an elucidation of the hydrogeology and hydrogeochemistry of the aquifer and the contained water, the local stratigraphy and the general structure of the embayment is necessary since any or all of these factors may contribute to, or control, the source and distribution of the radium-226.

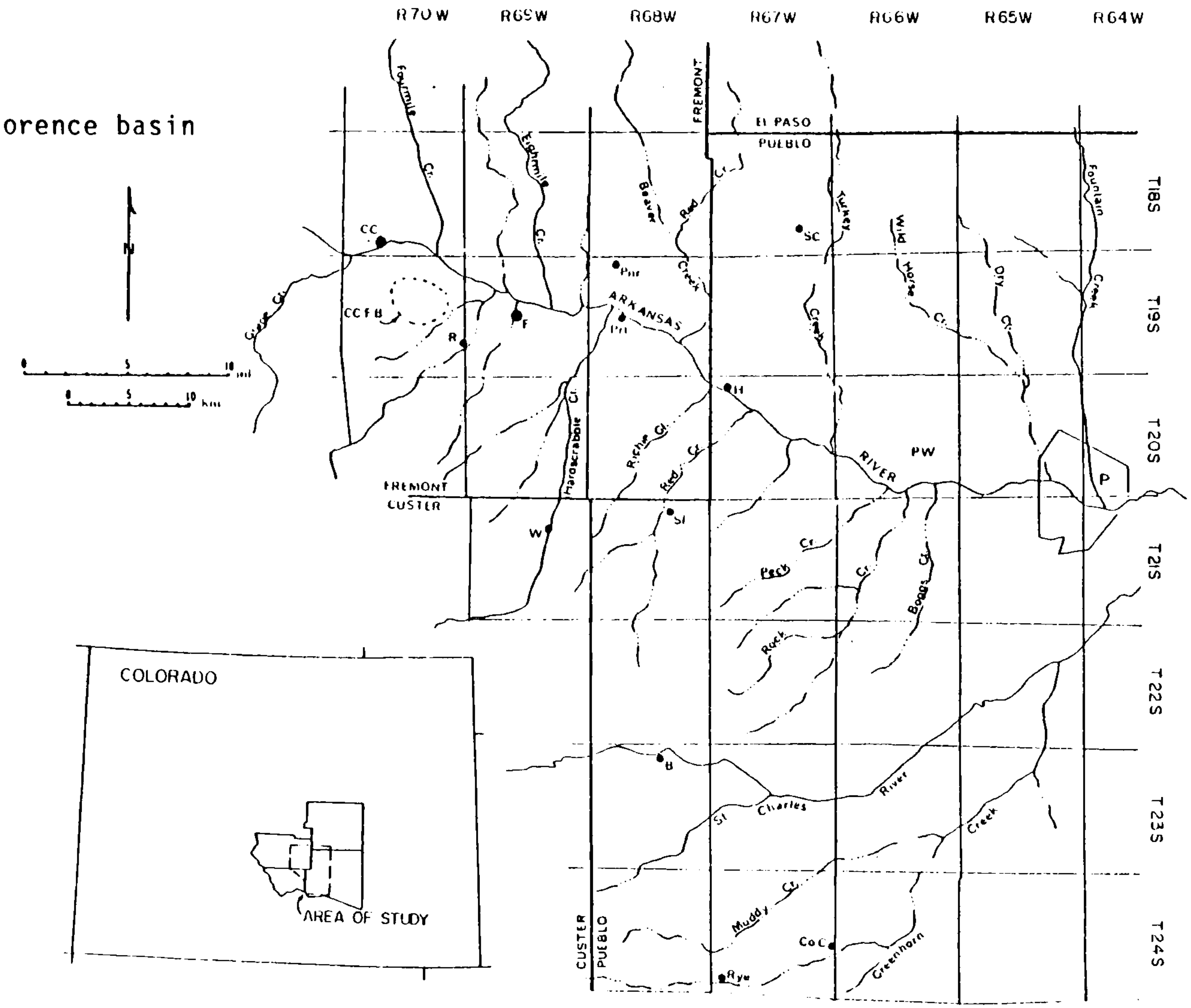
Methods of Investigation

Approximately 85 wells producing water from the Dakota Group aquifer were sampled in the summer of 1977 and analyzed the following fall. The Denver branch of the National Field Investigations Center of the Environmental Protection Agency graciously allowed use of their facilities for the radium-226 analyses. Additional radium-226 determinations performed by the Colorado State Health Department during the period from 1972 to 1974 also are included.

About 20 suites of gamma-ray and electric logs were obtained from Petro-well Libraries Inc., Rocky Mountain Well Logging Service, and Willard Owens and Associates. Comparisons of the gamma-ray deflections in the gamma-ray logs with the radium-226 content of the ground water from the same well or nearby wells provided valuable information on the possible stratigraphic control of the radium-226 in the ground water.

Figure 1. Index map of the area of study.

B = Beulah
CC = Canon City
CC-FB = Canon City-Florence basin
CoC = Colorado City
F = Florence
H = Hobson
P = Pueblo
Pnr = Penrose
Prt = Portland
PW = Pueblo West
R = Rockvale
SC = Stone City
Si = Siloam
W = Wetmore



The locations, depths, water levels, yields, uses, pump test data, and driller's logs of Dakota Group wells were obtained from the Colorado State Water Resources Engineer in Denver, Colorado. These data were used to determine the transmissivity, storage coefficient, and hydraulic conductivity of the Dakota Group aquifer. These data, coupled with data from geophysical well logs and updated water level data obtained from the Water Resources Division of the U.S. Geological Survey (U.S.G.S.), were used to construct a potentiometric contour map of the aquifer and a structure contour map of the top of the aquifer (Plate 2). Driller's logs, geophysical well logs, and measured sections from Long (1966) were used to construct an isopachous map of the Lytle Sandstone Member, an integral water bearing unit of the Dakota Group aquifer. Unfortunately, data are insufficient to produce a meaningful isopachous map of the entire Dakota Group.

Chemical analyses of the ground water from the aquifer were obtained from the U.S.G.S., Water Resources Division, Pueblo subdistrict office. These analyses constitute the backbone of the water quality section of this report.

A sufficient quantity of adequate geologic maps and stratigraphic reports on the bedrock formations of the Canon City embayment exist and were used extensively in this report.

Previous Investigations

There are numerous published and unpublished reports on the geology and stratigraphy of all or parts of the Canon City embayment. Hydrogeologic reports, however, are scarce. Unpublished Master of Science theses by Ganguli (1950), Herrera (1951), Kim (1951), Miller (1951), Ruley (1952), Van Arsdale (1952), Demaison (1954), Mann (1957), Stout (1958), and Blanco (1971) and the unpublished Ph.D. thesis by Malek-Aslani (1952) contain useful information on the geology, stratigraphy, and structure of most of the foothills belt along the western margin of the Canon City embayment. Work by Waage (1953) and Long (1966) provides extremely detailed and complete stratigraphic descriptions and a developmental history of the basal Cretaceous deposits in the embayment and areas to the southeast. Johnson (1969), Scott (1964, 1969a&b, 1972a,b,&c, 1973, 1977), Scott and Taylor and others (1975) provide invaluable geologic maps covering the entire embayment and surrounding areas. Classical work by Meek and Hayden (1861) and Gilbert (1897) paved the way for much of the more recent stratigraphic and geologic investigations in southeastern Colorado, but contributed little directly to this report. The general physiography of the Canon City embayment is reviewed by Fenneman (1931).

The only hydrogeologic investigations on the bedrock aquifers of the embayment are included in Gilbert (1896) and Darton (1906). Although these works are quite old, they provide a basic understanding of the hydrogeologic characteristics of the Dakota Group aquifer and are excellent references on the early development of this aquifer. Romero (1976) provides informative hydrogeologic data on the bedrock aquifers of the Denver basin, north of the Canon City embayment. Much of the data on the Dakota Group aquifer in Romero's report are applicable to the aquifer in the embayment.

Radiochemical data on the ground water of the Dakota Group aquifer of the embayment are confined to works by Scott and Barker (1962), Scott and Voegeli (1961), and Pearl (1972). These reports contain several radium-226 analyses of the Dakota Group ground water in the embayment. Cadigan and Felmlee (1977) provide interesting hypotheses on the possible structural and hydrochemical controls of the radioactivity in mineral springs and well waters in parts of Colorado, New Mexico, Arizona, and Utah.

GEOGRAPHY

Location and Accessibility

The Canon City embayment is located in the southeast portion of central Colorado and lies between 27°51'N and 38°35'N latitude and 104°35'W and 105°20'W longitude. The study area is confined primarily to approximately 1400 square miles south and east of the foothills belt along the mountainous extent of the embayment. This area, shown in Plate 1, includes townships T. 18-20 S., R. 64-70 W; T. 21 S., R. 64-69 W.; and T. 22-24 S., R. 64-68 W.

Physiography

The Canon City embayment is a plains area roughly triangular in shape lying between the south end of the Front Range and the east flank of the Wet Mountains. The plains area occupies a structural reentrant in the Rocky Mountains front that extends westward to Canon City. It lies within the extreme east-central boundary of the Colorado Piedmont area of the Great Plains physiographic province (Fenneman, 1931).

A transitional belt of hogbacks, cuestas, and foothills forms the north and west margins of the embayment. Hogbacks and cuestas are best developed on the folded, differentially erodable Cretaceous strata along the embayment margin. The Dakota Sandstone is the most prominent hogback former, and the Greenhorn Limestone, resistant sandstone members of the Carlile Shale, and limestone of the Niobrara Formation form minor hogbacks and cuestas. The hogback ridges are generally 50 feet to 150 feet in vertical relief and attain a maximum vertical relief of 800 feet along parts of the moderately steep-dipping west limb of the Chandler syncline adjacent to Canon City (Plate 1). The hogback ridges are dissected by several perennial and ephermeral streams which drain the crystalline mountainous areas. These streams are tributary to the Arkansas River which flows through a large water gap just west of the State Penitentiary in Canon City (see Fig. 1). Only four of the tributary streams are perennial, and they traverse a relatively narrow outcrop band of the Dakota Group.

In the Beulah area and east, along the southern part of the west embayment margin, the transitional zone consists of gently northeast-sloping foothills and low relief hogbacks of predominantly Dakota Group strata. In contrast to the moderate to steep dips of the Dakota Group along the embayment margin to the north, northeasterly dips of less than five degrees are more typical of the Dakota Group east of Beulah. This yields a large areal exposure of about 46 square miles, primarily of Dakota Sandstone. This large area is crossed by numerous ephemeral streams and one large perennial stream, the St. Charles River, which flow northeast into the Arkansas River.

The central plains region is a plateau-like surface lying predominantly upon Pierre Shale in and around the apical area of the embayment and on resisitant calcareous strata of the Niobrara Formation throughout the remainder of the embayment (see Plate 1). It slopes southeast from an average altitude of 5600 feet above sea level at the base of the foothills belt north of Canon City to about 4900 feet along Interstate Highway 25. The central region is nearly bisected by the southeastward flowing Arkansas River which occupies a relatively narrow trench, essentially devoid of a flood plain, cut from 120 feet to 200 feet deep in the plateau-like surface of the Niobrara Formation. Two large northeastward flowing perennial streams, the St. Charles and Greenhorn Rivers, traverse the southern end of the plains area in the embayment. The upper reaches of these streams have incised channels similar to that of the Arkansas River, but commonly cross a more hilly topography in contrast to the plateau-like surface traversed by the Arkansas River. The lower reaches of the St. Charles and Greenhorn Rivers, where they join and eventually flow as a single stream into the Arkansas River, have broad, meandering stream channels.

SUMMARY OF REGIONAL GEOLOGY

The Canon City embayment contains a thick body of Paleozoic, Mesozoic, and minor Cenozoic age sedimentary rocks overlying structurally depressed igneous and metamorphic basement rocks. The embayment may be considered a south-southeastward plunging synclinal tectonic basin with steeply dipping limbs that lies between the southern limit of the Front Range and the east flank of the Wet Mountains. The west margin of the embayment is bounded by a generally northwest-trending, west-dipping thrust fault, the Wet Mountain Fault (Plate 1). Along the northern and central segments of this fault, the sedimentary rocks are steeply upturned against the Precambrian crystalline rocks of the Wet Mountains. The sedimentary rocks dip steeply eastward to the axial region of the Chandler syncline, immediately east of the thrust fault. Here, the sedimentary rocks attain a maximum thickness of over 10,000 feet. South of the Chandler syncline, in the area east of Beulah, the sedimentary rocks dip gently eastward, resulting in a large areal exposure of the basal Cretaceous Dakota Group. The north margin of the embayment is characterized by roughly sinuous shaped hogback ridges of dominantly Mesozoic strata. The shape of the hogbacks reflects a series of synclines and anticlines which plunge southward into the embayment.

SUMMARY OF STRUCTURAL FEATURES

The most prominent structural feature within the embayment is the Chandler syncline (Plate 1). The west limb of the syncline comprises steeply dipping and locally overturned Paleozoic and Mesozoic strata that form hogbacks at the base of the Wet Mountains. The strata of the east limb of the syncline generally dip less than 15° to the west. The axis of the syncline is somewhat sigmoidal in shape with a south to southeast trend parallel to the core of the Wet Mountains. From the extreme northwest corner of the embayment, the axis plunges moderately to steeply southward and attains a maximum depth in the central portion of the Canon City-Florence basin about four miles south of Canon City. The axis curves abruptly southeastward and then gradually curves back to the south where it rises toward termination in the Wetmore area. The abrupt deflection in the axis of the syncline is a result of an east-striking tear fault that effect about 16,000 feet of left lateral strike separation (Mann, 1957). The strata on the east limb of the Chandler syncline rise gently eastward to the vicinity of the Brush Hollow anticline. Here, the strata rise abruptly, in the monoclinal fashion, and form the eastern margin of the Florence Oil Field. This and other structual features discussed in this section are best displayed in the structural contour map of the top of the Dakota Sandstone (Plate 2).

The Wet Mountain fault, a low-angle reverse or thrust fault at the base of the Wet Mountains, bounds the embayment on the west. Precambrian crystalline rocks of the Wet Mountains occupy the upper plate of the thrust. Sedimentary rocks of the west limb of the Chandler syncline which lie beneath the eastward-displaced upper plate are dragged into generally steep attitudes and locally are overturned. The fault is terminated at the north end by the same tear fault responsible for the abrupt southeastward deflection of the Chandler syncline just south of Canon City (Plate 2).

The south-central part of the embayment, near Beulah and Siloam, is marked by numerous major northwest-striking normal faults and a single large transverse normal fault, the Rush fault, which strikes northeast and curves due north across the Arkansas River. Based on limited water level data from Dakota Group wells in the vicinity of these faults, it appears the fault planes act as nearly impermeable boundaries inhibiting the general eastward flow of the ground water across the faults. Stout (1958) reports from about 150 feet to 250 feet of separation along these faults. A similar set of northwest-striking normal faults has been mapped to the north of the first set and they may represent the northern extension of the first set.

The eastern boundary of the embayment may be considered as the major south-trending Red Creek anticline (also called the Rock Canyon or Columbia Heights anticline). The anticline, which plunges south-southeast along a slightly sinuous axis, extends nearly the full length of the area of study (see Plate 2). This anticline and the County Line syncline immediately to the west are the westernmost of three major southeast-trending syncline-anticline pairs that occupy the eastern portion of the study area. Perhaps the most prominent of these pairs is the Pueblo anticline pair which extends from the southwestern quarter of township T. 16 S., R. 65 W. to near the center of township T. 22 S., R. 63 W., 37 miles to the south.

Numerous minor folds and faults occur throughout the embayment.

DAKOTA GROUP STRATIGRAPHY

Nomenclature

Week and Hayden (1861) first applied the name Dakota Group to the basal Cretaceous deposits at the type area near the town of Dakota City in northeastern Nebraska. Since that time, "Dakota" nomenclature has undergone considerable change. Today it is, at best, complex and obscure and a source of constant controversy. Long (1966) gives an extremely informative review of the historical development of the terminology of the basal Cretaceous deposits in the western Great Plains. Figure 2 summarizes the "Dakota" nomenclature used by various authors since its inception in 1861, and the nomenclature adopted in this report.

Usage in This Report

It is the nature of hydrogeologic investigations to disregard conventional rules of stratigraphic classification and group rock units solely by their water bearing characteristics. I have chosen, therefore, to lump all basal Cretaceous strata under the Dakota Group heading while maintaining the formational divisions appearing in much of the literature on the stratigraphy

Meek & Hayden 1862 NE Nebr.	Gilbert 1897 & Hills 1900 SE Colo.	Stose 1912 SE Colo.	Finlay 1916 So. Cent. Colo.	McLaughlin 1954 SE Colo.	Waagé 1953 SE Colo.	Long 1966 So. Cent. & SE Colo.	THIS REPORT 1978 Cañon City embayment
DAKOTA GROUP	upper sandstone	Dakota Sandstone	Dakota Sandstone	Dakota Sandstone	DAKOTA SANDSTONE: upper sandstone unit	DAKOTA SANDSTONE: transit. unit	DAKOTA GROUP: DAKOTA SANDSTONE: upper sandstone unit
						upper sandstone unit	
					Dry Creek Canyon Member	Dry Creek Canyon Member	Dry Creek Canyon Member
					lower sandstone unit	lower sandstone unit	lower sandstone unit
	middle shale	PURGATOIRE FORMATION: middle shale	PURGATOIRE FORMATION: Glencairn Shale Member	PURGATOIRE FORMATION: Kiowa shale	PURGATOIRE FORMATION: Glencairn Shale Member	PURGATOIRE FORMATION: Glencairn Shale Member	PURGATOIRE FORMATION: Glencairn Shale Member
						basal Glencairn ss.	
	lower sandstone	lower sandstone	Lytle Sandstone Member	Cheyenne Sandstone	Lytle Sandstone Member	Lytle Sandstone Member	Lytle Sandstone Member

(modified from Long, 1966)

Figure 2. Nomenclature chart.

of the Dakota southeastern Colorado. I aim to conform to the most familiar terminology used in this area and still to allow ready reference to the entire sequence for hydrogeologic purposes.

Purgatoire Formation

Lytle Sandstone Member

General Description

The Lytle Sandstone Member at the base of the Purgatoire Formation is a massive, white-weathering, fine- to medium-grained sandstone that typically crops out as somewhat rounded cliffs overlying nonresistant, commonly grass-covered variegated siltstones and shales of the Morrison Formation. The Lytle is extremely variable in thickness, conglomerate content, and amount of variegated siltstone. The basal contact with the Morrison typically is covered and the upper contact delineates a sharp change from white sandstone and variegated siltstone of the Lytle to brown-weathering sandstone and gray shale of the overlying Glencairn Shale Member.

Lithology

The Lytle is dominated by white, fine- to medium-grained, rounded, moderately to well sorted, cross-laminated to cross-bedded, massive to thickly lenticular, quartz sandstone. In a few outcrops it weathers light buff with a pinkish cast contributed by oxidation of finely disseminated grains of ferruginous material. Generally it is weakly cemented and very friable. White argillaceous cement is most common, but mixtures of argillaceous, calcareous, and siliceous cement are not uncommon.

Distribution and Thickness

The Lytle Sandstone Member crops out along most of the more or less continuous belt of moderately to steeply dipping Dakota Group strata bordering the mountainous extent of the Canon City embayment.

The Lytle Sandstone Member is between 25 and 190 feet in thickness in the Canon City embayment area. Plate 3, an isopachous map of the Lytle in the Canon City embayment, substantiates the presence of the northeast-trending elongate areas of alternating thick and thin deposits first revealed by Long (1966). Long (1966) also found a remarkably consistent correspondence of thicker and coarser conglomerates with thicker Lytle deposits. This relationship, coupled with data obtained from paleocurrent and provenance studies, led Long to believe these belts of alternating thick and thin deposits may represent deposition in erosional valleys and upon stream divides by a northeast-flowing stream system developed in Morrison deposits prior to and during Lytle deposition.

Sedimentary Features and Depositional Environment

The sedimentary features observed in the Lytle, and the nature of the texture and lithology of the strata strongly suggest deposition in a sediment-laden fluvial environment. Paleogeographic, paleocurrent, and provenance studies by Long (1966) coupled with his data on the spatial distribution of sediment thickness and conglomerate pebble size indicate the presence of major northwest-flowing stream channels in which Lytle sediments were deposited.

Glencairn Shale Member

General Description

The Glencairn Shale Member of the upper Purgatoire Formation consists of alternating units of gray, commonly uniform, silty shale, and brown-weathering, fine-grained, sheet sandstone. It typically forms a grass-covered bench between Lytle and Dakota cliffs.

Lithology

The following two distinct lithologies, in addition to that of the locally dominating basal sandstone, characterize Glencairn strata throughout the study area: 1) gray, uniform and fissile, homogeneous shale and silty shale interlaminated with light gray to white siltstone or a gray and black mottled mixture of shale and siltstone displaying disturbed bedding; and 2) brown-weathering, fine- to medium-grained, well sorted, subrounded, thin-bedded, horizontally stratified, laterally persistent sandstone containing abundant burrows, tracks, and trails. Minor lithologies include carbonaceous mudstone, thin coals, sublignite, and conglomerate veneers.

The predominant sequence in outcrops and in the subsurface (as reflected in geophysical well logs) is three units of shale alternating with three units of sandstone. Locally, however, either lithology may dominate the entire member with the subordinate lithology occuring as scarce interbeds or thin partings.

The uppermost shale, occupying the top of the Glencairn, is the thickest and most persistent of the shale alternations. The remaining shale units are thinner and, in places, become highly carbonaceous.

Distribution and Thickness

The Glencairn attains a thickness of 100 feet to 120 feet in the Stone City area along the northeast embayment margin. The section is predominantly shale in this area with minor interbedded sheet sandstone and scarce, thin, conglomerate veneers containing pebbles no greater than one inch in diameter. In this area the basal Glencairn sandstone is less than 25 feet thick and commonly is absent.

The Glencairn becomes thicker and more sandy towards the west. In exposures north and west of Canon City, it has the following features: 1) ranges from 120 feet to 130 feet in thickness, 2) the basal sandstone averages 55 feet thick, 3) sandstone constitutes from 50 percent to 70 percent of the section, and 4) it contains more conglomeratic sandstone and conglomerate veneers with clasts up to five inches in diameter.

Southeastward from Canon City, the Glencairn becomes progressively thinner and finer. The basal sandstone is only 15 feet to 20 feet thick in exposures near Wetmore. Here, shale strata make up about 75 percent of the 75 foot to 95 foot Glencairn section.

The section continues to thin southeastward to the Beulah-Rye area where the basal sandstone makes up 65 percent of the Glencairn.

Dakota Sandstone

General Description

The Dakota Sandstone is divided into three units, upper and lower sandstone units and a middle unit of shale, claystone, and sandstone termed the Dry Creek Canyon Member. The sequence commonly appears as a thick, massive, cliff-forming sandstone with a small break or bench of less resistant strata usually midway up the cliff. The steep, sharp-ledged, brown sandstone cliffs of the Dakota differ markedly from the lighter colored, rounded cliffs of the Lytle below the intervening grass-covered Glancairn benches.

In places, the Dry Creek Canyon Member is absent, making it impossible to distinguish the upper sandstone unit from the lower sandstone unit. In these areas the Dakota appears as a single, massive sandstone body with interspersed conglomeratic sandstone and conglomerate lenses. Where the Dry Creek Canyon Member is present, the upper and lower sandstone units appear as distinctive units and are easily identified.

Distribution and Thickness

The Dakota Sandstone is present in all Dakota Group outcrops fringing the Canon City embayment. Complete thicknesses of the Dakota Sandstone in outcrops are difficult to determine because recent erosion has stripped the Dakota-Graneros contact many miles from canyon rims and far down hogback dipslopes. Because of this only regional thickness trends can be determined.

The majority of the area of study is underlain by a moderately thin Dakota Sandstone section, where the average thickness is 85 ft. The Dakota Sandstone becomes thicker in the southern part of the embayment, near Rye and to the east, and attains a thickness of 100 ft to 120 ft. Plate 5 contains general thicknesses of the Dakota Sandstone in numerous surface and subsurface locations throughout the embayment.

HYDROGEOLOGIC PROPERTIES OF THE DAKOTA GROUP AQUIFER

Occurrence of the Dakota Group Aquifer

In this report, the Dakota Group aquifer comprises the combined saturated thicknesses of the Dakota Sandstone and the Lytle Sandstone Member. The contribution of ground water from the Glencairn Shale Member is considered only if the dominance of sandstone strata within the Glencairn can be substantiated in driller's or geophysical well logs. Unless otherwise noted, all hydrogeologic properties reported herein represent combined averages of the properties of the water bearing strata within the Dakota Group.

The Dakota Group aquifer is accessible for development in all parts of the Canon City embayment except for the central portion of the Florence Oil Field (Plate 2). Here, the aquifer is extremely deep, reaching depths of more than 6,000 feet below the surface (up to 500 feet below sea level). Aside from the economic burden involved, the chances of producing palatable ground water or water of adequate quality for stock or irrigation uses are slim at such depths. Plate 3 offers a general idea of the accessibility of the aquifer in most of the Canon City embayment.

Plate 3, an isopachous map of the Lytle Sandstone Member in the embayment, also shows the distribution of approximate thicknesses of the Dakota Sandstone and the Dakota Group in various outcrops and in the subsurface. Unfortunately, there are insufficient data on the thicknesses of the Dakota Sandstone to construct a meaningful isopachous map of the Dakota Sandstone or the Dakota Group. This is due to: 1) incomplete surface sections due to recent erosion which has stripped away the upper strata of the Dakota Sandstone and 2) the casing of wells below the top of the Dakota Sandstone, making identification of the top of the aquifer impossible in electric logs run subsequent to installation of the casing.

Additional data from driller's logs and geophysical well logs substantiate the presence of northeast-trending elongate belts of alternating thick and thin Lytle deposits first revealed by Long (1966, Fig. 2). Aside from a few modifications, the Lytle isopachous map (Fig. 11) shows the same northeast-trending belt of thick Lytle deposits and bounding belts of thin deposits as does Long's map.

Potentiometric Surface

Water level measurements made primarily during the period from 1971 to 1973 were used to construct an equipotential contour map of Dakota Group ground water in parts of the Canon City embayment (Plate 6). The potentiometric surface only approximates the actual surface, which is all that can be expected considering the nature of the water level measurements available. Some of the problems encountered in constructing the map from the available data are given below.

First, water level measurements taken from wells completed in different stratigraphic horizons within the Dakota Group have different head potentials. In areas virtually isolated from the effects of pumping wells, the ground water contained in the Lytle and the overlying Dakota probably have reached a pressure equilibrium due to leakage across the semiconfining Glencairn Shale. On the other hand, disequilibrium, and therefore different heat potentials, can exist in the two water bearing units in areas experiencing excessive withdrawal of ground water from one of the units. The result is that water level measurements from wells in the same area, but producing water from different stratigraphic positions, can be strikingly different.

Second, most of the water level measurements were made in pumping wells rather than observation wells. The resulting water level values represent "pumping" water levels rather than true static water levels (heat potentials). Of most concern is the presence of local cones of depression resulting from excessive pumping or pumping from inadeqately designed and/or completed wells. Water level measurements taken from such areas or wells will indicate head potentials that are lower than actual head one would observe if pumping were discontinued and the ground water allowed to approach static conditions.

Third, the water level measurements were taken over a three year period. Temperal fluctuations in the potentiometric surface due to climatic variations and seasonal variations in ground water withdrawal can be expected. The magnitude and extent of the temporal changes in the potentiometric surface are not known. It is probable that some variations did occur during the measuring period.

The equipotential contour map (Plate 4) reveals not only the elevation to which ground water will rise in a well completed in the Dakota Group aquifer, but also the general direction of flow of the ground water in the aquifer. Assuming flow is perpendicular to the contours, it can be seen that the ground water flows out of the embayment towards the northeast, east, and southeast, generally corresponding to the regional dip of the aquifer. In addition, there appears to be a slight convergence of ground water flow (flow lines) in the vicinity of Pueblo (T. 20 S., R. 66 W). This may be a reflection of the first stages of development of a large-scale cone of depression centering in the general area of the many large capacity municipal wells furnishing water for the Pueblo West municipal water supply.

Over seventy years ago, Darton (1906, p. 59-62) observed numerous flowing wells in the Canon City embayment. The flowing wells south of Pueblo and in the vicinity of Florence and Penrose are of special interest. Surprisingly, some of the same wells and other wells drilled in the same areas (subsequent to Darton's report) flow today. For instance, one well six miles north of Florence (T18N, R69, Sec 26 cb), completed in 1905, was reported to have a surface flow of 360 gpm (Darton, 1906, p. 61). Today the water level in this well stands about 65 feet below the land surface. Much of this decline may be attributed to deterioration of the well bore and casing(?) rather than a decline in the potentiometric surface. Today the well is without pump and appears to have been abandoned for many years. Individual flowing wells are listed in Appendix B and labeled as such in Plate 4.

Storage Coefficient

The storage coefficient (S) of an aquifer is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head potential normal to the surface area. The volume of water released from (taken into) storage is the sum of: 1) water released from the entire saturated thickness of the aquifer due to the compression of the intergranular skeleton, and 2) water released from the entire saturated thickness of the aquifer due to the expansion of the contained water.

By considering the part of the storage coefficient that results only from the expansion of the confined water, a minimum value for the storage coefficient is obtained and can be used to check the validity of the value of the storage coefficient determined from pump test data. Since the approximate value does not incorporate that volume of water released from storage due to the compression of the aquifer, it is obviously too small. If the value of the storage coefficient as determined by pump test data is comparable to or less than this minimum value, the determined value is in error.

Figures 3, 4, and 5 show the straight-line (Jacob's) solution of the Theis nonequilibrium well formula for pump tests performed on three wells each completed in the Dakota Sandstone and the Lytle Sandstone Member. The determined storage coefficient approximated from the expansion of water alone is calculated from the equation

$$S = \gamma b \phi \beta$$

where

γ = specific weight of water (0.434 $lb/in^2 ft$),
b = saturated thickness (ft),
ϕ = porosity (decimal fraction), and
β = compressibility of the confined water at ordinary temperatures (3.3 X 10^{-6} in^2/lb).

The values for γ and β are constant (assuming fresh water at 25°C) and are given above. The saturated thickness was determined from electric logs and well driller's logs and is given in each plate. The average porosity of the saturated interval was determined from Schlumberger sonic logs and the methods outlined in Schlumberger (1972, 1978). A conservative average porosity of 15 percent (.15) was calculated and used in the above equation. Solving for S in the equation above yields a storage coefficient of $10^{-4.3}$ for each case.

It can be seen that the storage coefficient values determined from the pump tests are smaller than the approximated values indicating the pump test or the values used in calculating the approximate storage coefficient are in error. Reevaluation of the figures used in calculating the approximate storage coefficient point to only one potential source of error, the saturated thickness. It is conceivable that only a small part of the sandstone interval effectively releases water from storage, thus reducing the calculated approximate storage coefficient. Reduction of the saturated thickness value by 75 percent, however, yields an approximated storage coefficient of about 10^{-5}, which is still larger than the determined values. The pump tests, therefore, are in error. Unfortunately, the reasons for the faulty pump test may be innumerable and a knowledgeable discussion of the error is beyond the scope of this report.

In light of the storage coefficient values given above, a range of 10^{-4} to 10^{-5} is considered a fair estimation of the storage coefficient for the Dakota group aquifer of the Canon City embayment.

Transmissivity

The transmissivity (T) is the rate at which ground water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Values of the transmissivity of the Dakota Group aquifer from Figures 3, 4, and 5 range from 1119 gpd/ft to 1539 gpd/ft. The relations of these units to consistent English and metric units are given in Table 1.

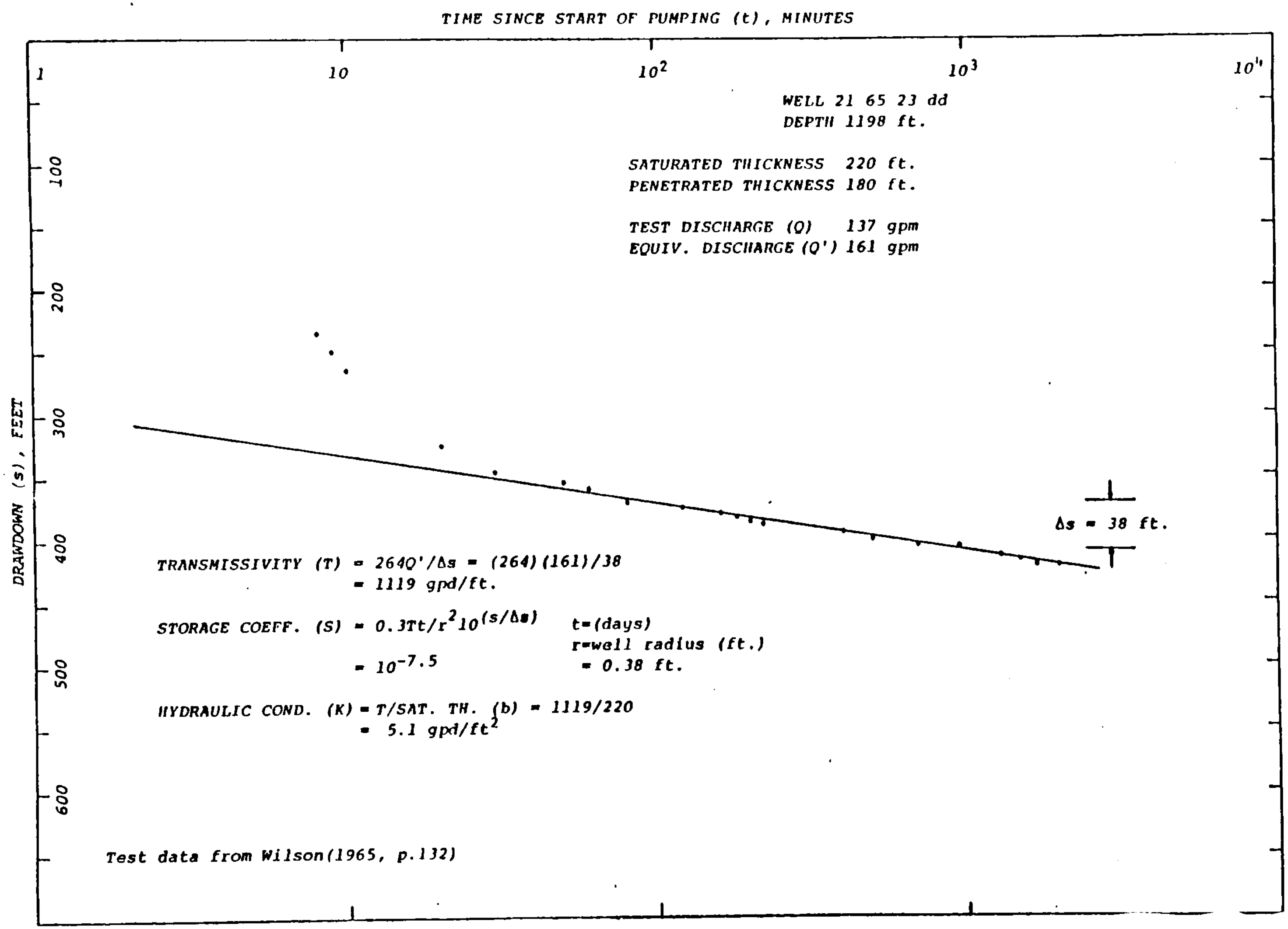


Figure 3. Straight line solution (Jacob's method) of aquifer characteristics.

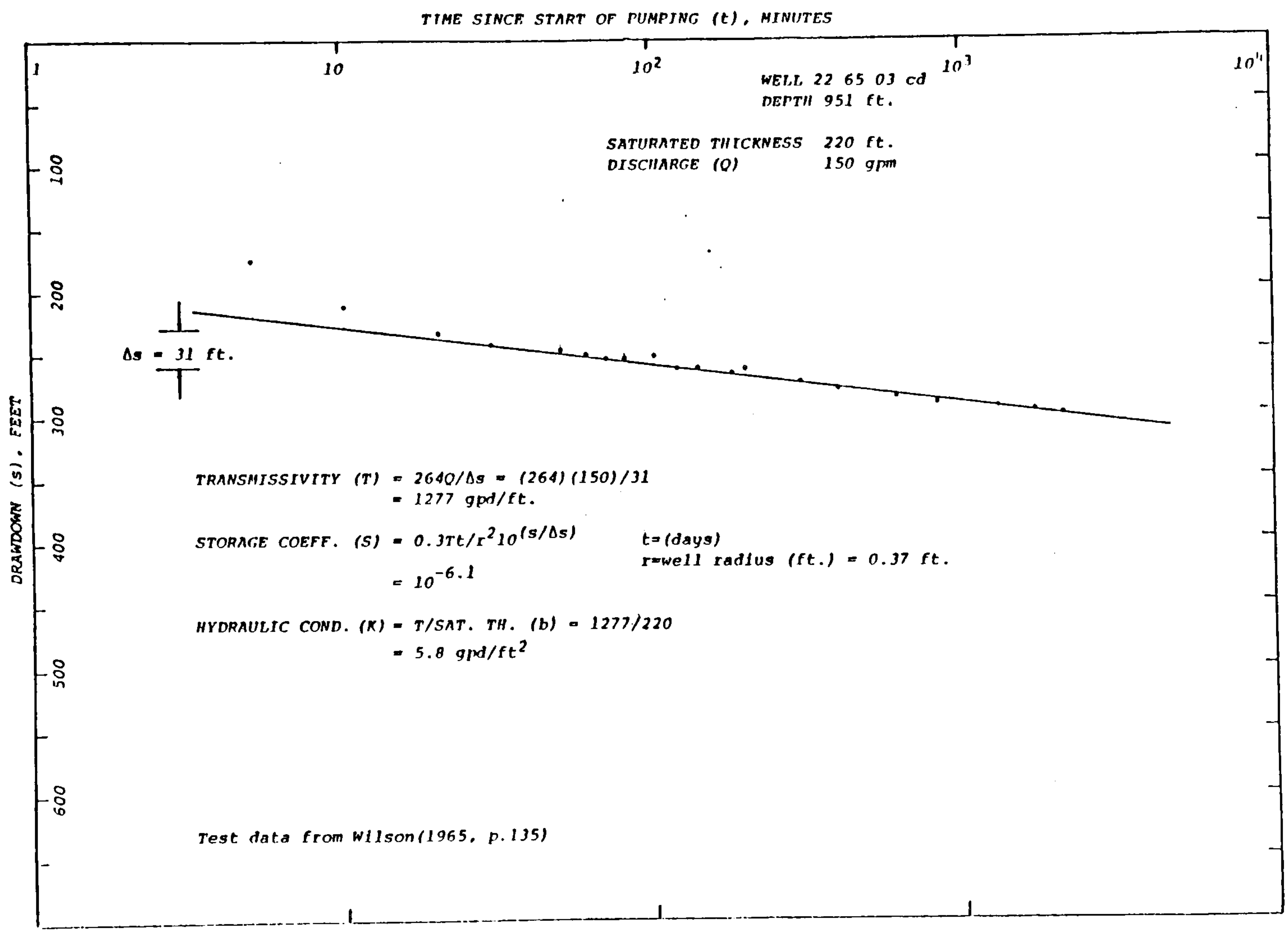


Figure 4. Straight line solution (Jacob's method) of aquifer characteristics.

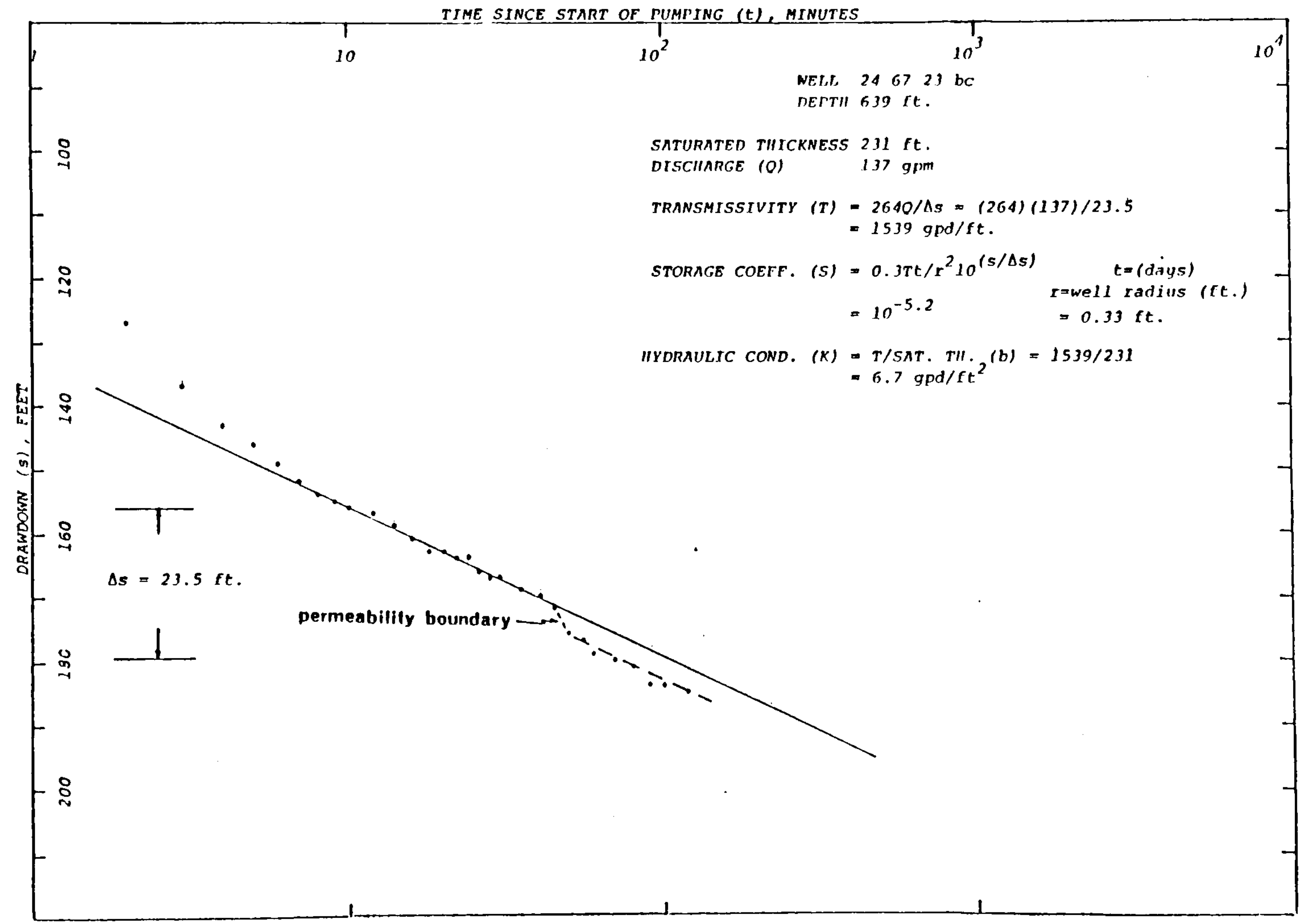


Figure 5. Straight line solution (Jacob's method) of aquifer characteristics.

Additional transmissivity values were calculated from the specific capacities of wells using the equation

$$T = \frac{2.3\ Q/s}{4} \log \frac{2.25\ Tt}{\bar{r}^2\ S}$$

condition: $u = \dfrac{\bar{r}^2\ S}{4Tt} \leq 0.01$

where

Q/s = specific capacity of a well that penetrates the full saturated thickness of the water bearing unit(s),
t = total time of pump test,
$\bar{r}$ = mean radius of the well,
S = storage coefficient = 10^{-5}, and
T = transmissivity

The specific capacities of partially penetrating wells were corrected to appropriate values for similar fully penetrating wells with the same respective total drawdowns using equation 4.56 in Todd (1959, p. 102). The condition of ≤ 0.01 was met in all calculations. The results are summarized in Table 2.

Hydraulic Conductivity

The hydraulic conductivity of an aquifer is readily calculated from its transmissivity by the equation

$$K = T/b$$

where

K = hydraulic conductivity,
T = transmissivity, and
b = saturated thickness of the aquifer.

The hydraulic conductivity is the transmissive character of the aquifer measured in a unit area of the aquifer rather than in a strip of unit width extending the full saturated thickness of the aquifer as is implied in the definition of transmissivity. Values of the hydraulic conductivity of the Dakota Group aquifer are given in Table 2. The estimated specific yield of the aquifer (Romero, 1976, p. 35), the specific capacities of the wells, and well yields also are given in Table 2.

Table 1. Relation of units of various aquifer and well characteristics (equivalent values on the same horizontal line).

Transmissivity

gallons per day per foot	$feet^2$ per day	$meters^2$ per day
1.00	0.134	0.012
7.48	1.00	0.093
80.5	10.76	1.00

Hydraulic Conductivity

gpd/ft^2	feet per day	meters per day
1.00	0.134	0.041
7.48	1.00	0.305
24.5	3.28	1.00

Well Specific Capacity

gallons per min. per foot	$feet^2$ per min.	$meters^2$ per min.
1.00	0.134	0.012
7.48	1.00	0.093
80.5	10.76	1.00

Well Discharge

gpm	$feet^3$ per min.	$meters^3$ per min.
1.00	0.134	0.0038
7.48	1.00	0.0283
264.15	35.31	1.00

Natural and Artificial Recharge

The Dakota Group aquifer is naturally recharged by the infiltration of precipitation in the areas of outcrop along the mountainous margin of the Canon City embayment, and possibly along the numerous faults traversing the embayment floor and the margin to the west (Wet Mountain fault). The contribution of seepage from perennial streams in water gaps and stream channels eroded into the Dakota Group cannot be determined at the present but should be considered relatively small. There is a definite possibility that the aquifer is recharged by water contained in overlying and underlying formations as seepage or leakage through semiconfining strata, as seepage along fault planes, and as flow through uncased wells which penetrate the strata above and perhaps below the aquifer.

Table 2. Summary of the characteristics of the Dakota Group aquifer of the Canon City embayment and wells penetrating the aquifer (pump data from fourteen wells represented).

	RANGE	MEAN	MEDIAN
Storage Coefficient (dimensions)	10^{-4}-10^{-5}		
Transmissivity (gpd/ft.)	180-2630	1220	940
Hydraulic Conductivity (gpd/ft^2)	0.8-10.5	5.3	4.3
Well Discharge (gpm)	10-500	130	45
Specific Capacity (gpm/ft)	0.09-1.4	0.6	0.45
Specific Yield (%)	10		

Weather data from the U.S. Department of Commerce indicate that the average annual precipitation in the outcrop areas of the aquifer is 13 inches. Since much of the winter precipitation is snow and occurs when the surficial veneers of the outcrops are partially frozen and subject to strong winds, it is suggested that the "effective" precipitation occurs during the period from April to September, inclusive. Approximately 70 percent, or 9 inches, of precipitation occur during this period.

Romero (1976) suggests that about 0.02 to 0.05 inches of precipitation per year recharge the Dakota Group aquifer along the outcrop areas of the west margin of the Denver basin which receive about the same amount of precipitation as the Dakota Group outcrops in the Canon City embayment.

The paucity of the accurate historic water level (head) measurements of the Dakota Group ground water prevents any quantitative evaluation of the recharge to the aquifer. The importance of a widespread network of observation wells in which water level changes can be monitored cannot be over-emphasized, and until such a network is implemented, the evalution of recharge to the aquifer should remain qualitative.

The aquifer may be artifically recharged by the infiltration of water through ditches, water diversion canals, stock ponds, and from excess lawn and garden irrigation in areas in contact with the aquifer.

Natural and Artificial Discharge and Ground Water Use

Ground water is artificially discharged from the Dakota Group aquifer via numerous domestic, stock, commercial, municipal, and irrigation wells. Most of these wells are listed in Appendix B. Unfortunately, the yields of many of these wells are not known since they have not been registered with the State Engineer. The existing information is sufficient, however, to estimate the annual well discharge from the aquifer.

Domestic and stock wells account for 35 percent and 32 percent, respectively, of the registered wells. The average yield of these wells is 16 gallons per minute (gpm). Municipal and commercial wells, most owned and operated by the Pueblo West Metropolitan District, account for 19 percent of the registered wells and have an average yield of 130 gpm. The remaining 14 percent of the registered wells are used for irrigation purposes and have an average yield of 180 gpm. Conservative estimates of the numbers of each type of wells operating in the embayment during 1978 are 160 domestic and stock wells, 35 commercial and municipal wells, and 18 irrigation wells.

Many of the wells do not operate on a 24-hour basis (especially the irrigation wells) and the registered yields often are greater than the actual pumping rates during normal daily use. Therefore, the well yields are reduced by a factor of 30 percent to 11 gpm (domestic and stock), 90 gpm (commercial and municipal), and 125 gpm (irrigation). Based on these values, the volume of ground water withdrawn annually from the Dakota Group aquifer is estimated to be between 3.8×10^9 and 4.0×10^9 gallons per year (11,700 to 12,300 acre-feet/year).

Natural discharge from the aquifer is confined to a few springs issuing from Dakota Group outcrops of the southernmost part of the area (T24S, R67W, Sec 27 cbcc, T24S, R67W, Sec 29 ddc, and T24S, R67W, Sec 33 acbc). Data on the discharges of the springs are not available.

NON-RADIUM CHEMICAL QUALITY OF DAKOTA GROUP GROUND WATER

The chemical quality of a ground-water resource is a determining factor in deciding whether or not it can be used for a given purpose. Ground water used for drinking and culinary purposes should not exceed the maximum permissible concentrations of dissolved constituents listed in Table 3. These requirements are not always compulsory for water supplies from private water wells, but, if exceeded, do constitute grounds for rejection of the water supply by local health agencies.

Chemical data on the ground water of the Dakota Group aquifer are presented in this section in order to inform those wishing to develop the ground water resource of the expected chemical quality of the water from place to place within the embayment. The major obstacle preventing a thorough discussion of the chemical quality of the aquifer is the paucity of available chemical analyses from a large portion of the embayment. The water quality of the two areas in the embayment with ample chemical analysis coverage, however, probably represent nearly extreme values of the quality of Dakota Group ground water one may expect in the embayment. This excludes ground water in the aquifer underlying the central portion of the Florence Oil Field.

The highest density of ground water analyses comes from wells along the southwest margin of the embayment from the Beulah area south to the Colorado City-Rye area. An additional cluster of analyses comes from Dakota Group wells in the area between Siloam and Penrose, the west-central part of the embayment (see Plates 5 and 6).

Southwest Margin of the Canon City Embayment

The ground water from the Dakota Group aquifer of the southwestern and southern parts of the Canon City embayment is predominantly calcium-bicarbonate in composition with lesser amounts of calcium-sulfate-bicarbonate and calcium-sulfate types. It is hard to very hard according to the classification adopted by the U.S. Geological Survey (see Table 3). The calculated total hardness ranges from 140 mg/l to 730 mg/l, with mean and median values of 328 mg/l and 290 mg/l, respectively. On the basis of total dissolved solids, the ground water ranges from very good (199 mg/l) to unacceptable (1640 mg/l) for domestic use. The mean and median values of TDS are 534 mg/l and 410 mg/l, respectively. Figure 6 contains frequency distributions of the chemical constituents and some chemical properties (hardness and TDS) of the Dakota Group ground water in this area. In each case, the median value provides a first approximation of the amount of the respective chemical constituent or chemical property one may expect in the ground water of this area. The range, mean, and median concentrations of the constituents and properties of this ground water are listed in Table 4. Comparing the median values in this table with the water quality requirement values listed in Table 3 reveals the ground water is generally suitable for domestic use. Personal preference, however, may require softening of the water for many household uses.

Figure 7 is a trilinear diagram showing the dominant chemical types of ground water from the Dakota Group aquifer of the entire embayment (all areas for which water analyses were available). Those points clustered near the Ca apex of the cation triangle and along the HCO_3+ CO_3-SO_4+ NO_2+ NO_3 limb of the anion triangle represent most of the ground water analyses from this area. The generally restricted composition of this ground water is most noticeable in Figure 8, a trilinear diagram showing the variation in the chemistry of the ground water of the two areas of analysis coverage. The ground water analyses of this area are represented by the small solid circles in this diagram. It can be seen that the Dakota Group wells in this area produce primarily calcium-bicarbonate ground water and lesser amounts of ground water with higher sulfate concentrations. Complete analyses of ground water in this area are given in Appendix C.

The most characteristic chemical feature of this ground water is the high Ca/Na ratio. Calcium is usually two to three times more abundant than Na. This high Ca/Na ratio and the high bicarbonate concentration (relative to SO_4) of this ground water give it the characteristic diamond-shaped Stiff diagram shown in Plate 5. The distributions of selected chemical properties of this ground water, including the Ca/Na ratio, the specific conductance, and the sodium adsorption ratio (an indicator of the usefulness of the water for irrigation purposes) are shown on Plate 6. Again, the relatively constant composition of this ground water results in only small variations in the values of these properties.

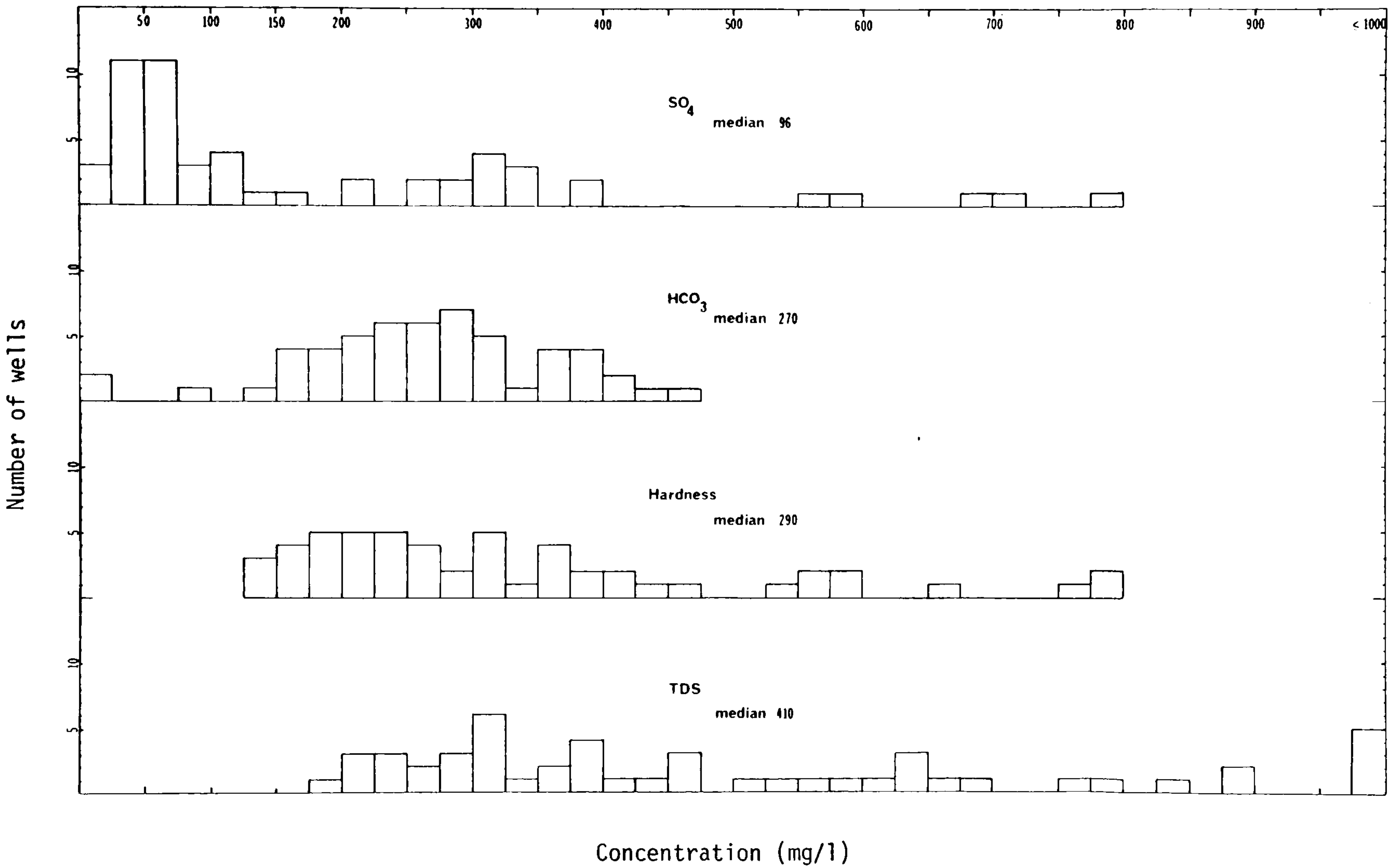


Figure 6. Frequency distribution of chemical properties and constituents of ground water of the Dakota Group aquifer of southwestern and southern Canon City embayment.

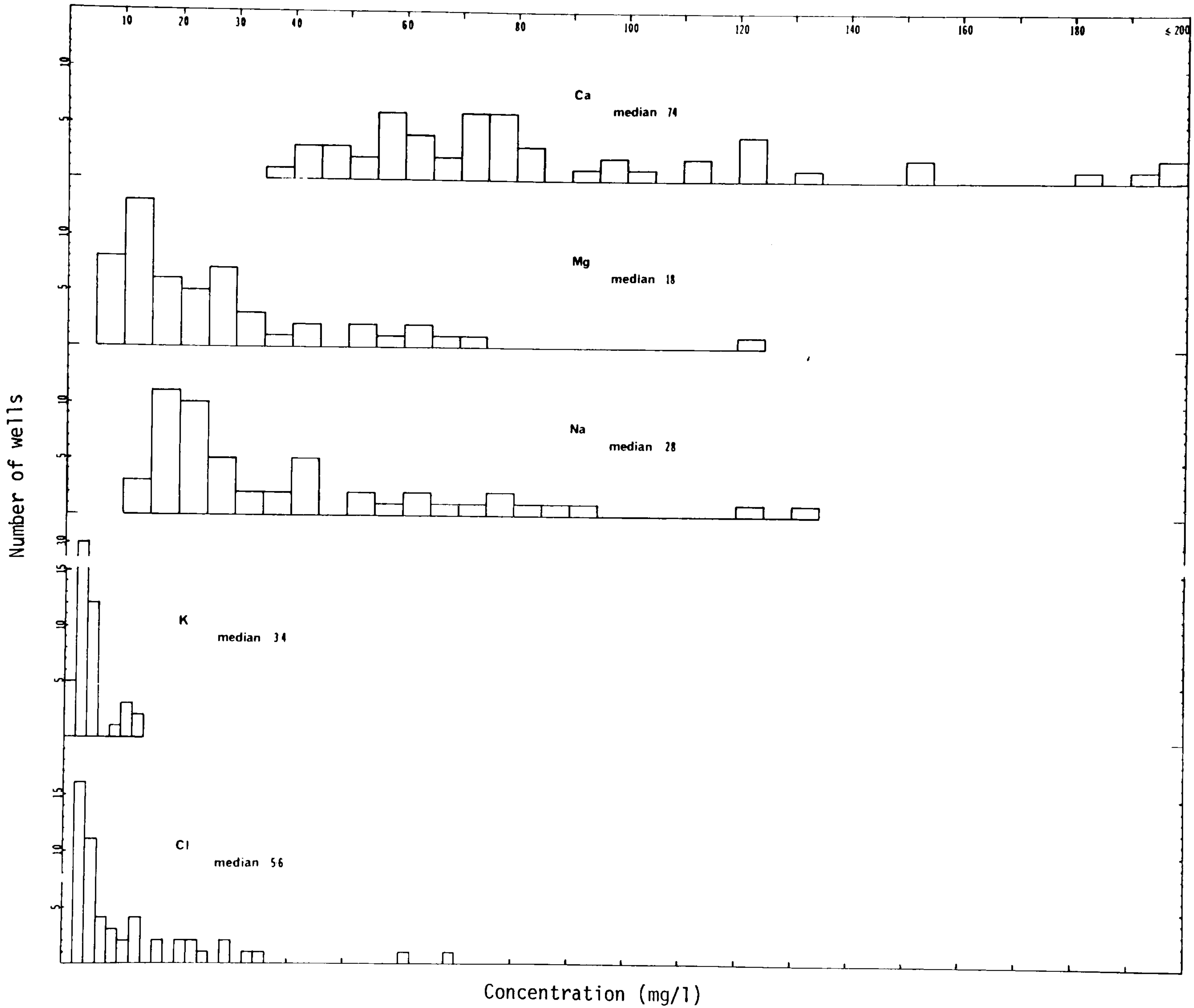


Figure 6. Continued.

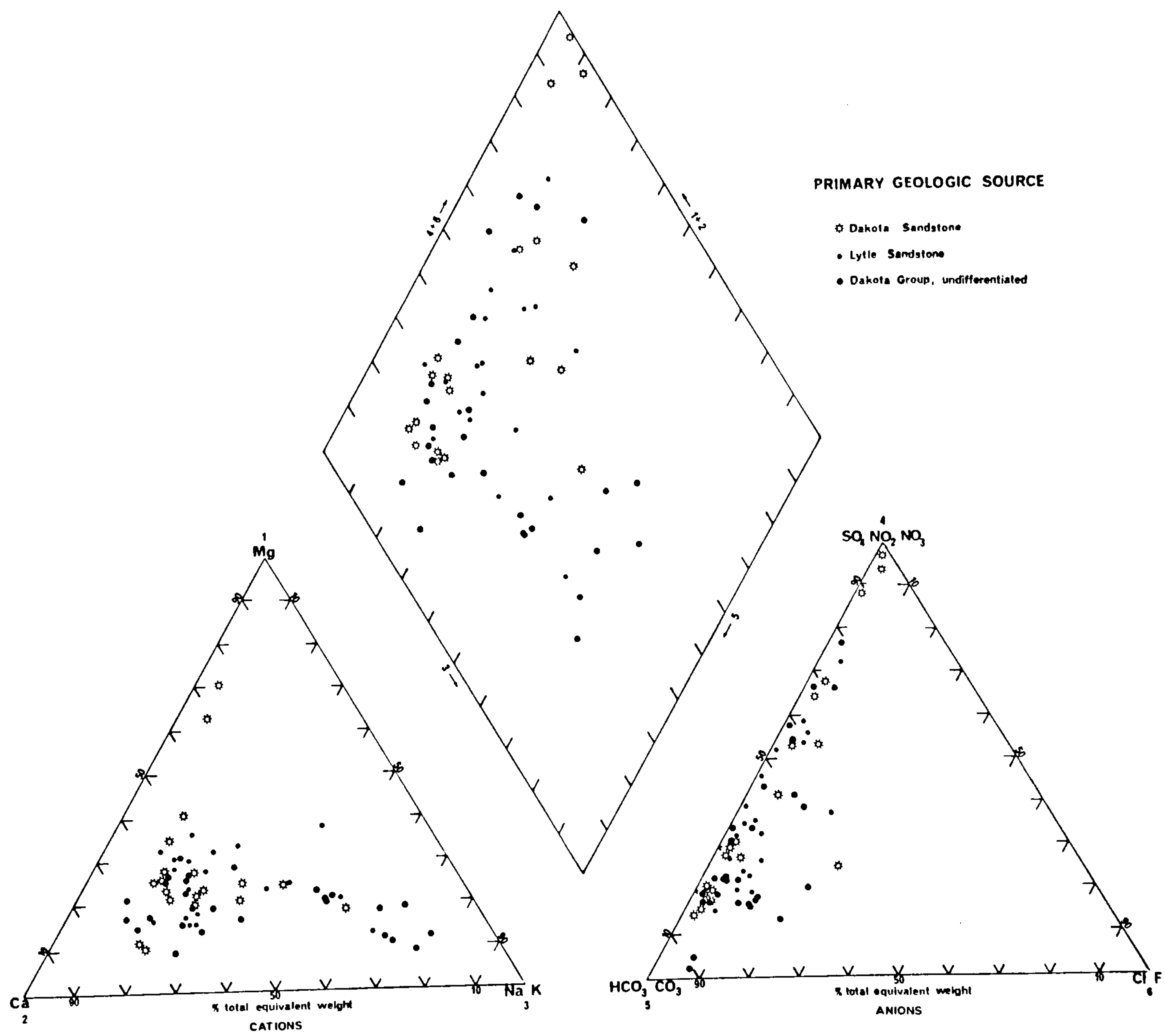


Figure 7. Chemistry of Dakota Group ground water in the Canon City embayment.

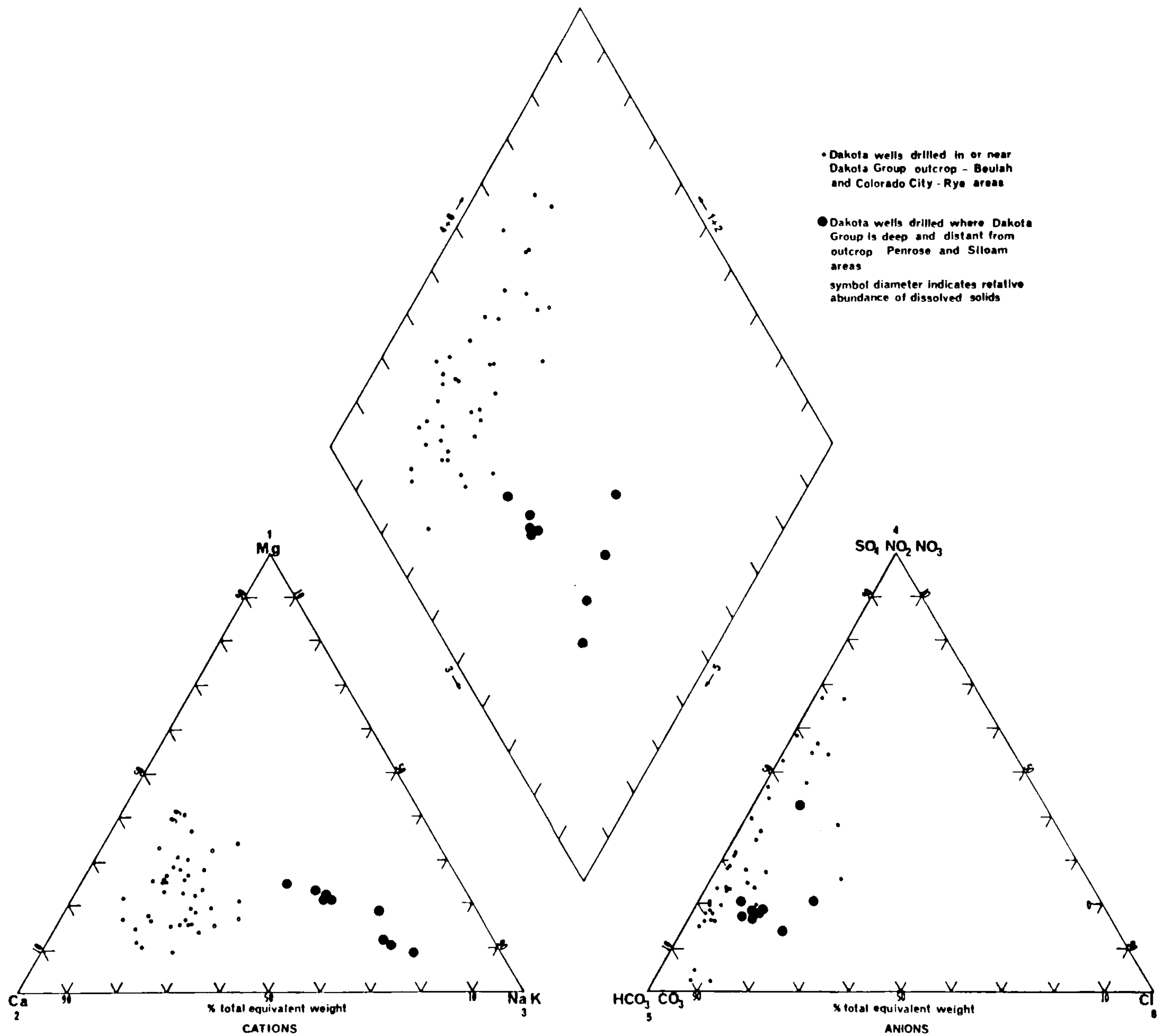


Figure 8. Variation of chemical constituents in Dakota Group ground water in different parts of the Canon City embayment.

Table 3. Recommended water quality requirements for domestic and public water supplies (from Davis and DeWiest, 1966 and Public Health Service, 1962).

CONSTITUENT	MAXIMUM CONCENTRATION (mg/l)
Ca	200
Mg	125
Mn	.05
Na	200
K	-
HCO_3	150
Cl	250
SO_4	250
NO_3	45
Fe	.3
Zn	5
TDS	500

Fluoride	Mean Annual Max. Daily Temp.(°F)	Recommended Limits (mg/l)
	50.0-53.7	.9-1.7
	53.8-58.3	.8-1.5
	58.4-63.8	.8-1.3
	63.9-70.6	.7-1.2
	70.7-79.2	.7-1.0
	79.3-90.5	.6- .8

Hardness (U.S.G.S. Classification)	Class
<60 mg/l	soft
60-120	moderately hard
120-180	hard
>180	very hard

The chemical composition of the ground water in this area is summarized in Table 4. Added to this table are approximate values of the various chemical constituents and properties that can be expected in the ground water from newly completed Dakota Group wells. These values are approximate and should be used only as guides to the expected chemical composition of Dakota Group ground water in this area.

A more accurate estimation of the composition of the ground water in the area can be made with a specific conductance measurement and the aid of Figures 9, 10, and 11. The empirically derived curves in these figures show the relation of the major ion concentrations and TDS to the specific conductance of the Dakota Group ground water. The curves are intended to allow owners of Dakota Group wells to estimate the composition of their ground water from specific conductance measurements. Inasmuch as specific conductance measurements can be made quickly and cheaply, they, along with Figures 9, 10, and 11 provide a quick method of estimating the chemical quality of ground water supplies.

Table 4. Chemical characteristics of Dakota Group ground water in the southwestern and southern parts of the Canon City embayment.

CONSTITUENT	RANGE*	MEAN*	MEDIAN*	APPROX. EXPECTED CONCENTRATION IN THIS AREA*
Ca	37-260	87	74	70-80
Mg	7-120	26	18	15-24
Na	13-160	41	28	25-35
K	1.3-12	4.1	3.4	3.0-4.0
HCO_3	12-464	268	270	260-280
Cl	2.2-69	11.4	5.6	3-8
F	.2-1.5	1.0	.6	.4-.8
SO_4	16-800	180	96	85-110
NO_2+NO_3	0-30	2.6	.075	.07-.08
Fe	.009-34	4.7	.65	-
Hard.	140-780	328	290	270-310
TDS	199-1640	534	410	390-430
Sp. Cond.**	217-2240	775	660	640-680

Dominant water types Ca-HCO_3, Ca-SO_4-HCO_3, Ca-SO_4 (in order of decreasing abundance)

* Values in mg/l
** Sp. Cond. (mmho/cm @ 25°C)

West-Central Canon City Embayment

The Dakota Group in the area between Siloam and Penrose is relatively deep and hydrogeologically removed from outcrop areas. The wells just south of Penrose (see Plates 2 and 5) penetrate the aquifer at the eastern edge of the Florence Oil Field where the beds begin to dip steeply westward toward the central part of the oil field basin. The wells near Siloam are structurally separated from the large areal exposure of the aquifer to the south by the numerous major faults in this area.

The ground water produced in this area is generally warm and ubiquitously sodium-bicarbonate in composition. It is extremely hard and contains a considerable amount of dissolved solids. Hardness ranges from 230 mg/l to 950 mg/l with mean and median values of 600 mg/l and 650 mg/l, respectively. Total dissolved solids range from 995 mg/l to 1960 mg/l with mean and median values of 1546 mg/l and 1530 mg/l, respectively. This ground water is generally unsuitable for domestic use.

The distinct composition of this ground water is represented by the large solid circles in Figure 8. The most striking chemical characteristics of this ground water are the large amounts of dissolved solids and the dominance of sodium over calcium. The Ca/Na ratio lies between 0.2 and 0.76 as opposed to the range of 1.95 to 4.65 for the ground water in the southern part of the embayment. These and other differences are readily observed in Plates 5 and 6.

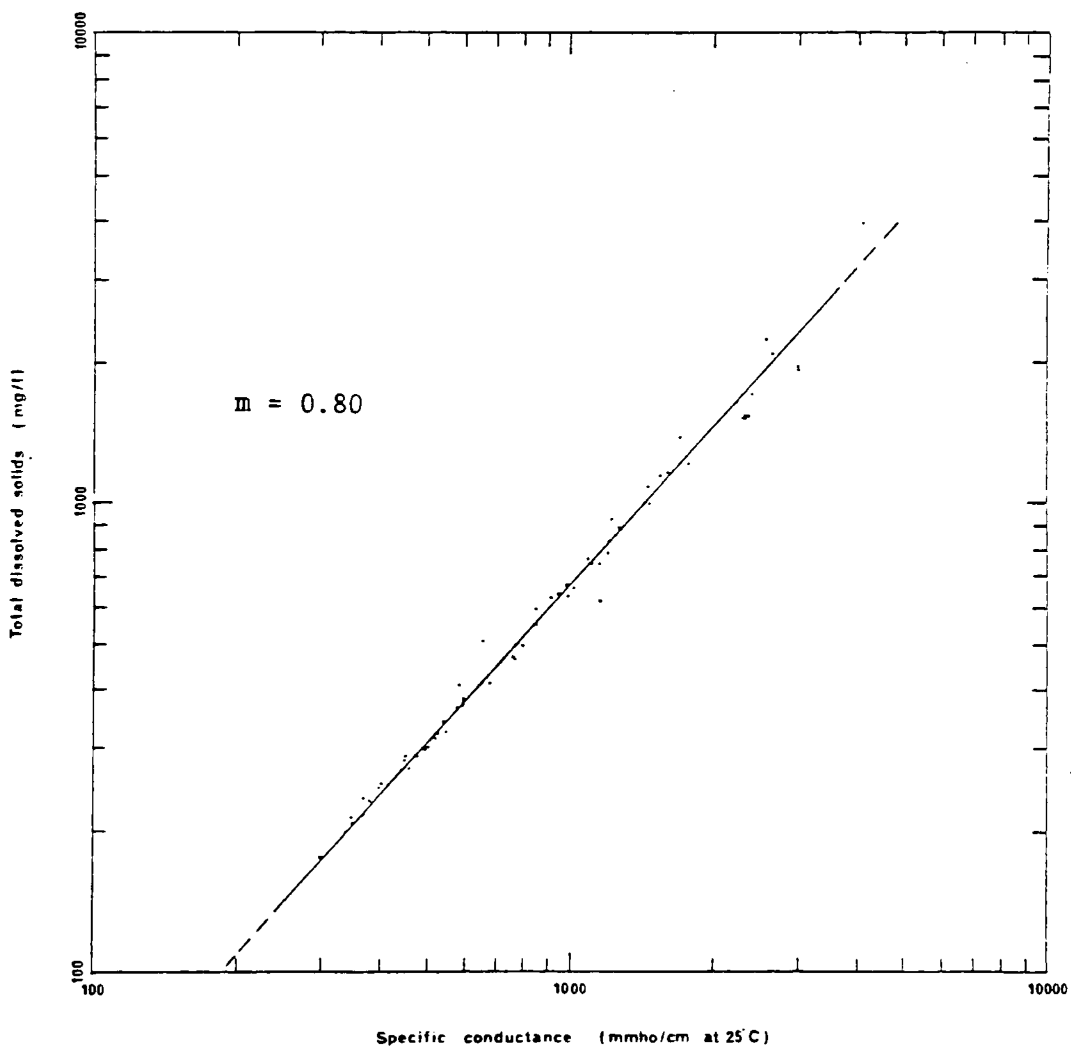


Figure 9. Relation of total dissolved solids to the specific conductance of ground water of the Dakota Group aquifer of the Canon City embayment.

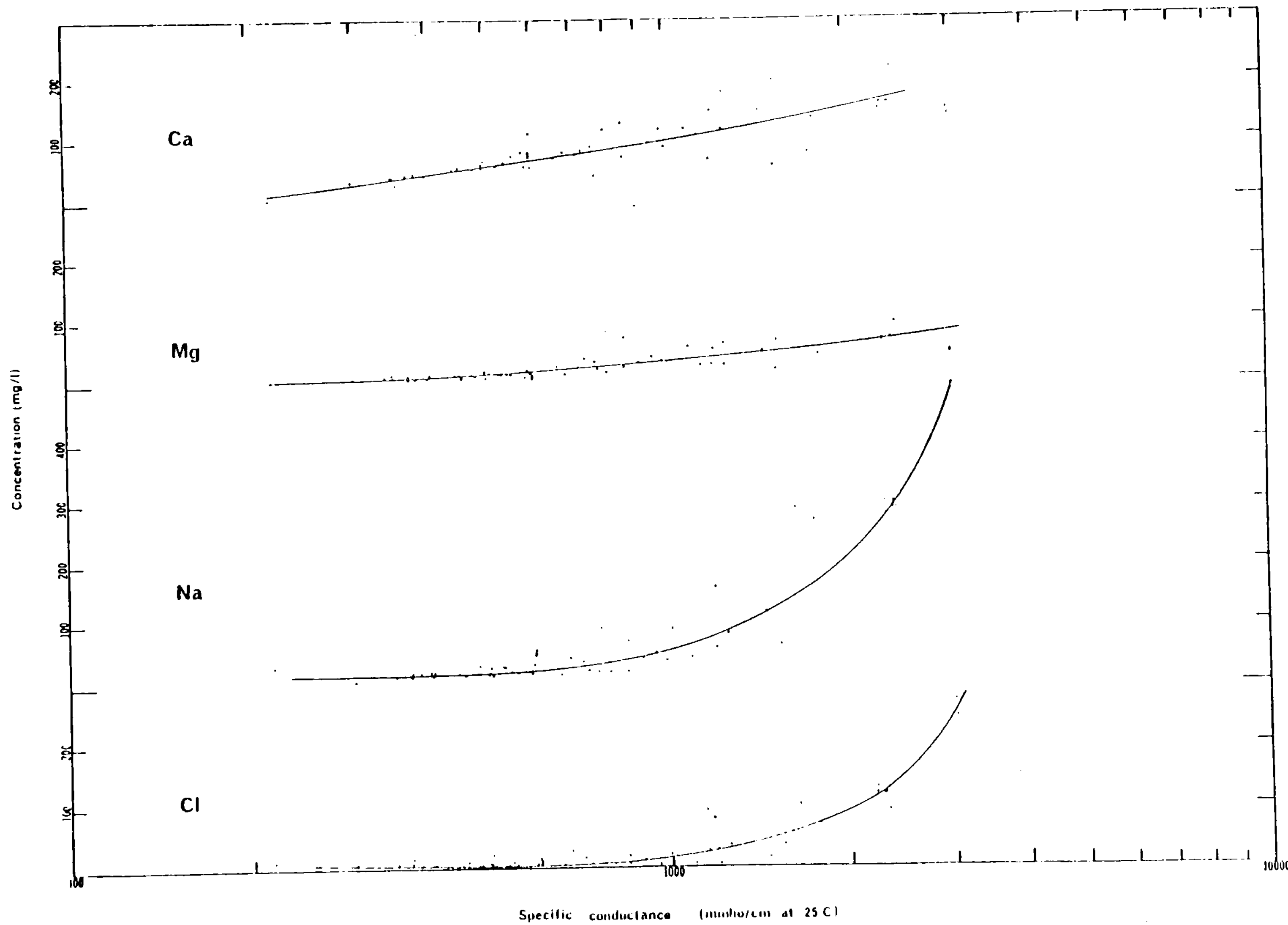


Figure 10. Relation of the concentrations of Ca, Mg, Na, and Cl to the specific conductance of ground water of the Dakota Group aquifer of the Canon City embayment.

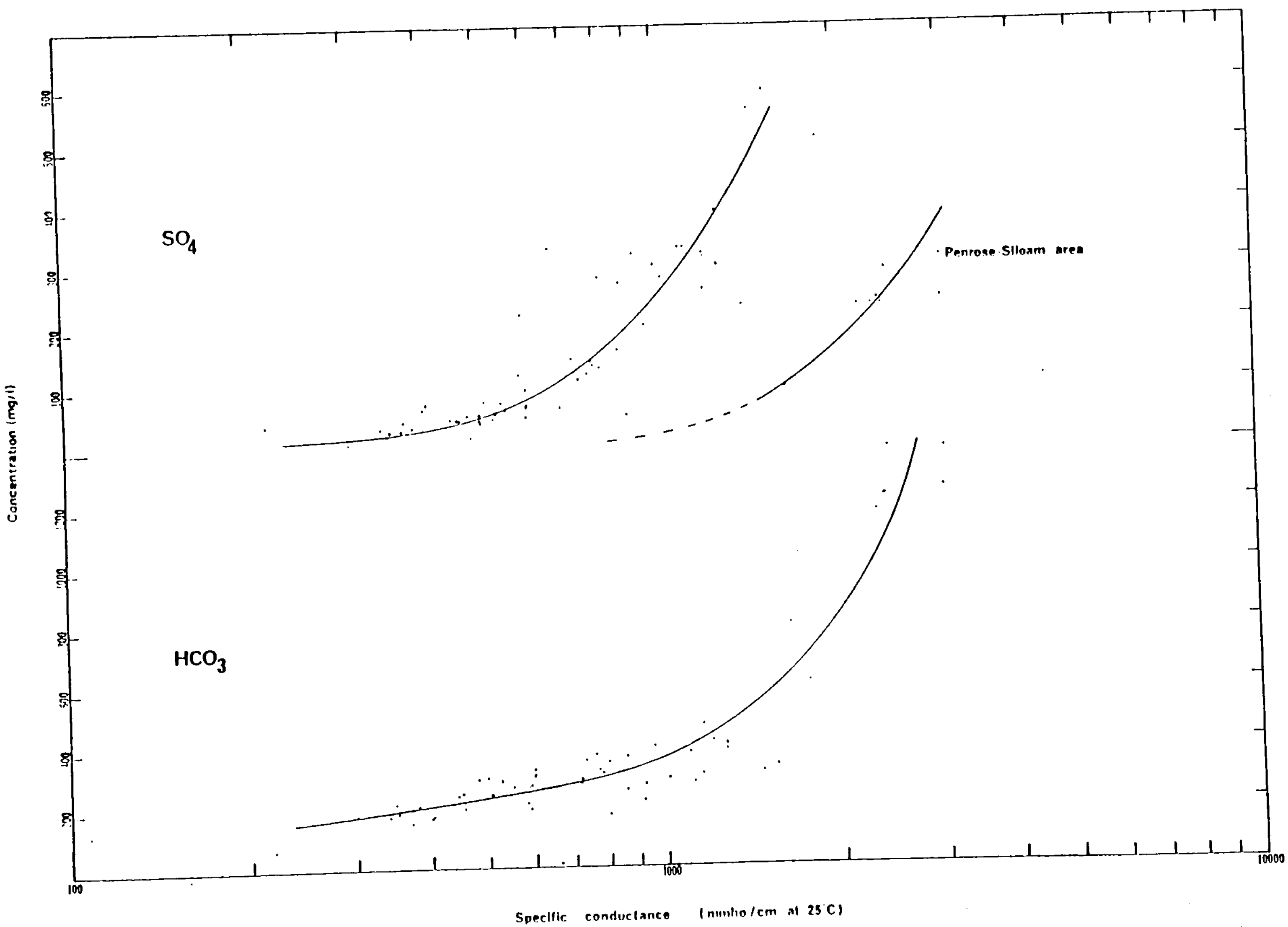


Figure 11. Relation of the concentration of SO_4 and HCO_3 to the specific conductance of ground water of the Dakota Group aquifer of the Canon City embayment.

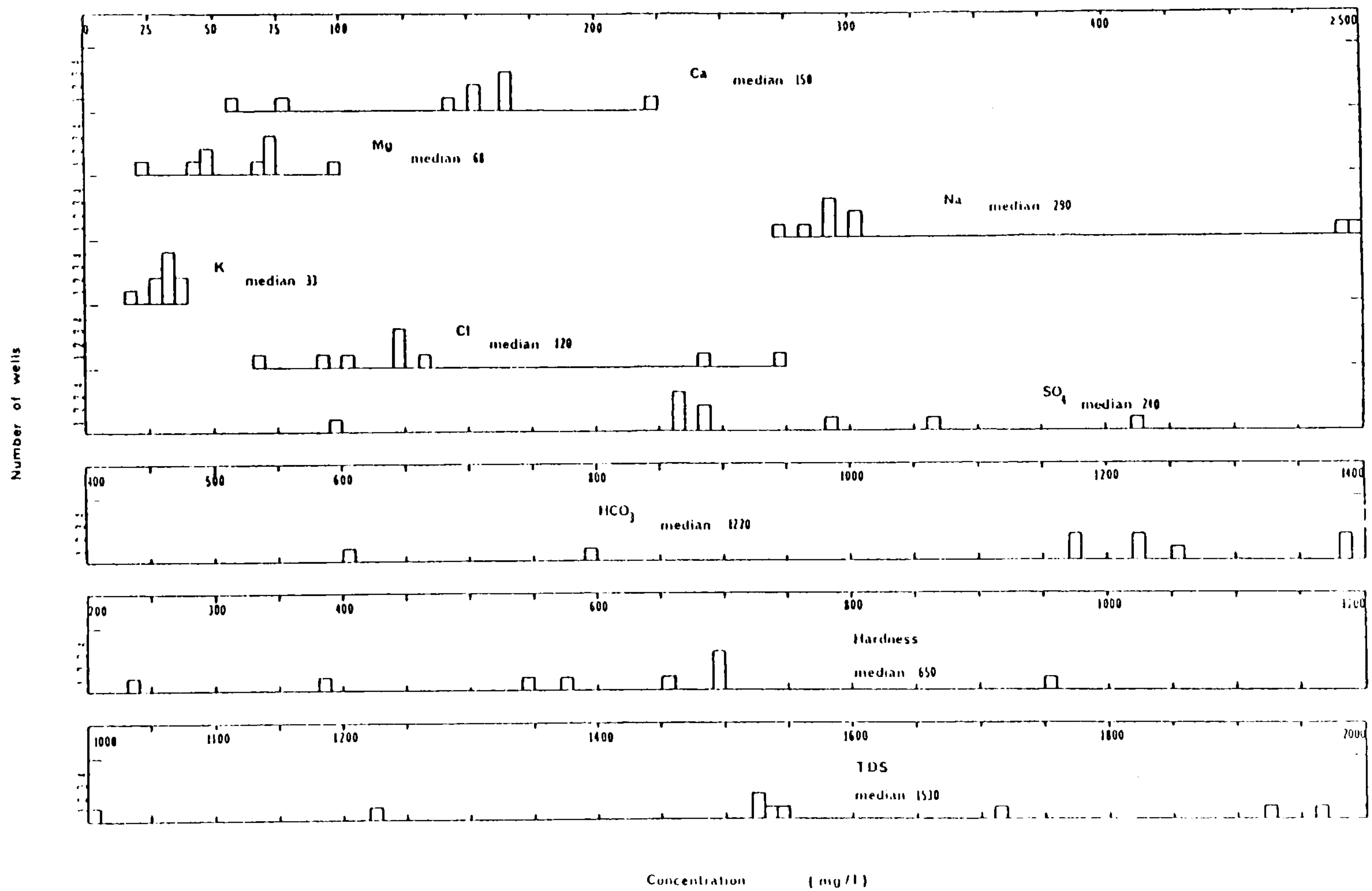


Figure 12. Frequency distribution of chemical properties and constituents of of ground water of the Dakota Group aquifer of the area between Siloam and Penrose, northwest-central Canon City embayment.

The distribution of the chemical constituents and the major chemical properties of this ground water are shown by the histograms in Figure 6. These values are summarized in Table 5. As stressed previously, the median values of the various chemical parameters provide a first approximation of the chemical composition one may expect of the ground water of this area. The data given in Figure 8 and Table 5 represent only nine analyses and, therefore, should be used with this limitation in mind. A more accurate estimation of the composition of a ground water supply from the Dakota Group aquifer in this area can be made with a specific conductance measurement and Figures 9, 10, and 11 in the manner discussed previously. Note the separate SO_4-specific conductance curve to be used strictly in this area. Appendix C contains complete ground water analyses for this area.

Table 5. Chemical characteristics of Dakota Group ground water of the area between Siloam and Penrose, northwest-central Canon City embayment.

CONSTITUENT	RANGE	MEAN*	MEDIAN*	APPROX. EXPECTED CONCENTRATION IN THIS AREA*
Ca	59-220	142	150	130-160
Mg	20-98	59	68	60-75
Na	270-500	334	290	280-300
K	17-38	30	33	30-35
HCO_3	607-1380	1132	1220	1190-1250
Cl	67-270	140	120	110-130
F	.6-2.4	1.5	1.4	1.3-1.5
SO_4	94-410	255	240	230-250
NO_2+NO_3	0-.38	.1	.06	.05-.07
Fe	0-4.77	.98	.06	-
Hard.	230-950	600	650	630-670
TDS	995-1960	1546	1530	1500-1560
Sp. Cond.**	1640-3020	2364	2390	2350-2430

Dominant water type Na-HCO_3, minor Na-SO_4-HCO_3.

* Values in mg/l
** Sp. Cond. (mmho/cm @ 25°C)

Chemical Variations and Possible Origins of the Ground Water

The two basic ground water types known to occur in the Dakota Group aquifer in the Canon City embayment are summarized in Tables 4 and 5, and can be seen graphically in Figure 8.

Characteristics displayed in the few available analyses reflect the dominant chemical nature of the ground water of this area. The Dakota Group aquifer in the southerwestern part of the embayment is heavily sampled and, consequently, the chemical nature of the ground water is well established. Local variations in the ground water chemistry are not uncommon and can be expected.

The ground water from the Dakota Group aquifer in the Beulah and Colorado City-Rye areas is primarily calcium-bicarbonate and less commonly calcium-sulfate-bicarbonate and calcium-sulfate in composition; contains a moderate amount of dissolved solids; is generally hard; contains moderate to high concentrations of particluate iron; and is generally suitable for drinking and culinary uses. Neglecting the unusual iron concentrations, the chemical nature of this ground water is typical of ground water from arenaceous and arkosic sandstones in general (White and others, 1963, Table 4). The typical and consistent chemical composition of this ground water, the proximity of the sampled wells to Dakota Group outcrop areas, and the general direction of ground water flow in this area suggest the ground water is largely of meteoric origin and is chemically modified as it flows through the aquifer and progresses toward chemical equilibrium with the mineral constituents of the aquifer. A few unusual magnesium-sulfate ground water samples, not included in Figures 6 and 12, are shown in Plate 5 (T22S, R67W, Sec. 22 cc, T23S, R67W, Sec. 26 bb). These samples reflect local contamination of the primary Dakota Group ground water with ground water from other sources, such as the overlying Graneros Shale.

The salient chemical features of the Dakota Group ground water in the area between Siloam and Penrose include 1) abundant dissolved solids (1530 mg/l median value), 2) high Na and HCO_3 concentrations (290 mg/l and 1220 mg/l respective median values), 3) very low Ca/Na ratios (less than 0.76), and 4) moderately high water temperatures (89°F (31.5°C) median value).

It is likely the ground water in this area is derived, in part, from the aquifer within the central portion of the Florence Oil Field where the Dakota Group is from 4,000 feet to 6,000 feet deep (see Plate 2). At these depths, the ambient temperature ranges from about 120°F (48°C) to 160°F (71°C) (resulting from a geothermal gradient of 18°F/1000 ft (33°C/km) characteristic of this area) which can account for the warm or mildly thermal nature of the ground water produced in the Siloam-Penrose area. The large hydraulic head of the ground in this area is capable of forcing the ground water upward from the deep central and surrounding parts of the Florence Oil Field to the shallower eastern margin of the oil field basin.

The origin of the ground water is not known at present. Some possible origins may include ground water connate to the Dakota Group aquifer, ground water entering the aquifer as leakage from adjacent semiconfining strata, deeply circulated meteoric ground water, or hydrothermal fluids (magmatic or metamorphic ground water) purged from the crystalline basement complex underlying the embayment.

Regardless of the source, the ground water has undergone chemical modification resulting in a distinct and consistent sodium-bicarbonate composition. Perhaps a major factor controlling the chemical composition of this ground water is ion exchange or membrane filtration processes occurring in the semipermeable clay strata within the water bearing units of the Dakota Group. Selective filtration of ions by semipermeable clay membranes can result in high concentrations of sodium and bicarbonate relative to calcium and chloride, respectively. A thorough discussion of the processes involved in producing a membrane-filtered water concentrated in Na and HCO_3 relative to Ca and Cl is given by White (1965) and will not be discussed here.

Membrane filtration is just one process that can result in sodium-bicarbonate rich ground water. No doubt other geochemical processes occurring in the complex hydrogeochemical environment of the Dakota Group aquifer contribute to or control the chemical nature of the ground water in this area.

Summary of the Chemical Composition of the Dakota Group Ground Water in the Canon City Embayment

The two basic ground water types that occur in the Dakota Group aquifer of the Canon City embayment are: 1) a fairly hard, calcium-bicarbonate, calcium-sulfate-bicarbonate, or calcium-sulfate (in order of decreasing abundance) ground water generally suitable for domestic use, and 2) a hard to very hard, commonly warm, sodium-bicarbonate ground water containing abundant dissolved solids and generally unsuitable for domestic use.

The first ground water is typical of the areas within or near Dakota Group outcrops where infiltration of locally derived meteoric water (stream water, precipitation) constitutes a large part of the recharge to the aquifer. It appears this general ground water type may exist throughout most of the southern part of the Canon City embayment.

The warm or mildly thermal ground water typical of the area between Siloam and Penrose probably originates in the Dakota Group aquifer deep within the central part of the Florence Oil Field where the ambient temperature ranges from about 120°F to 160°F. It flows upward, under considerable hydraulic head, outward toward the east margin of the oil field basin where it probably mixes with fresher, near surface ground water, perhaps similar to the ground water in the Dakota Group outcrop areas. Wells penetrating the aquifer within the central part of the Florence Oil Field probably would produce warm to hot, highly brackish, sodium-bicarbonate ground water possibly similar to the metamorphic ground water discussed by White and others (1963, Table 22, p. F48-49).

RADIUM-226 IN THE GROUND WATER

Introduction

Radium-226 is one of four naturally occurring radioisotopes of radium; the others are radium-223, radium-224, and radium-228. Radium-224 and radium-228 are disintegration products of thorium, and radium-223 and radium-226 are disintegration products of uranium-235 and uranium-238, respectively. The half life of radium-226, 1620 years, is much longer than any of the other radium isotopes. Consequently, radium-226 is the dominant isotope in natural waters.

From the standpoint of water pollution and health standards, radium-226 is the most hazardous of any of the radioisotopes in the uranium-238 decay series. The maximum permissible concentration of radium-226 in domestic water supplies regarded as acceptable by the Environmental Protection Agency is nearly an order of magnitude less than any of the other isotopes in the decay series. The reason for this is that radium, a well established carcinogen, readily and irreversily replaces calcium in bone. Severe physical disorders may result, especially in infants and children where skeletal tissue is rapidly developing. Therefore, guidelines have been established by various agencies to limit the intake of radium as well as other radioisotopes.

Radium-226 Guidelines and Standards in Drinking Water

Numerous agencies have adopted various guidelines, recommendations, and standards for protection against radiation. The following summary gives an indication of the allowable quantities of radium-226 in drinking water established by some of these agencies:

1. The Public Health Service (1962) limits the concentration of radium-226 in drinking water to 3.0 picocuries per liter of water (3.0 pCi/l). A water supply with a radium-226 activity at or near this level may still be approved if the user's total daily intake of the water results in less than 20 pCi of radium-226, a limit recommended by the Federal Radiation Council.

A curie is a unit of measurement of radioactivity, defined as the equivalent of 37 X 10^9 disintegrations per second, which is approximately equal to the radioactivity of one gram of radium. A picocurie equals 10^{-12} curie.

2. The National Bureau of Standards Handbook 69 (1959) indicates a maximum permissible concentration of radium-226 in water of 100 pCi/l for "continuous occupational exposure to the critical organ", in this case bone. For persons immediately outside the controlled area (occupational area), this limit is reduced to 10 pCi/l.

3. The International Commission of Radiological Protection (1959) recommends the same limits given in the NBS Handbook 69. However, the ICRP recognizes a third population group, the "population at large" and recommends a limit of 3.3 pCi/l in drinking water for this group.

4. The Environmental Protection Agency (1973) sets a maximum acceptable concentration of radium-226 in drinking water consumed raw at 5.0 pCi/l.

Field Sampling Procedures

Where possible, ground water samples were taken from faucets immediately adjoining the water well housing and pump assembly. In other cases, faucets outside the dwelling were used, provided the water was not first diverted from the well to a cistern, water softener, or any other device that could modify the chemical nature of the ground water. In either case, the water sample came directly from the water well.

The faucet at the sampling point was allowed to run for about one minute. A one-liter polyethylene container was filled to about one-half inch below the top; the water was acidified with about 5 ml of concentrated HCl; and the container was capped and shaken vigorously to completely mix the acid and water. The acid was added to prevent adsorption of $^{226}Ra^{2+}$ ions or aqueous radium-226 complexes to the container walls. In all cases, the samples appeared to be free of suspended material, so no samples were filtered.

After shaking and mixing, the container was uncapped, squeezed until slightly overflowing, and then recapped. This created a slight negative pressure inside the container to ensure any leakage to be into rather than out of the container. In some samples, carbon dioxide gas exsolved from the water upon exposure to atmospheric pressure and acidification. These samples had to be "depressurized" periodically until all of the CO_2 gas was expelled. The field number was marked on two places on the container and the containers were stored in cardboard boxes.

Additional procedures and information performed and obtained at each sample site include:

1. The well was precisely located and marked on 7 1/2 minute quadrangle topographic maps. In many cases, the actual well location was different from the location reported in the files of the State Water Resources Engineer's Office.

2. The date and time of sampling and the owner's name and address were recorded.

3. The water level in the well was measured by a chalked steel tape with weighted end. Where the pump housing of the well prevented measurement, the well owner was asked the water level in his well.

4. The water temperature was estimated and any unusual physical features of the water or the well were recorded. These included odor, color, turbidity, and the presence of gases in the water, and iron oxide staining around the well and faucets delivering well water.

Error resulting from sampling procedures would involve the presence of suspended material in the water sample. Radium-226 readily adsorbs onto particulate matter in natural waters and it is released into solution upon acidification of a sample containing the particulate matter. This would yield determined radium-226 activities higher than the actual activities of aqueous radium-226 species in water free of particulates. All samples appeared to be free of suspended material although undetectable amounts may have been present. Nonetheless, error resulting from sampling procedures is considered negligible.

The unusual distribution of sample points, evident in Plate 7, is explained by the following reasons: 1) wells are concentrated in areas experiencing higher growth rates and increased development (Beulah, Penrose, and, particularly, Pueblo West); 2) wells are scarce or absent in the Florence Oil Field and the central embayment area because of the extreme depth of the Dakota Group aquifer in the first area, and because of the dominance of private ranch lands throughout the latter area; and 3) poor accessibility deterred sampling in the more isolated central and northeastern portions of the embayment.

The majority of the samples in the northern three-quarters of the area studied were collected and analyzed in the summer and fall of 1977, respectively. The remaining samples were collected and analyzed by the Colorado State Health Department from 1972 to 1974. Where samples have been duplicated, the radium-226 activities indicated in Plate 7 are the author's 1977 values.

Occurrence and Amounts of Radium-226

The frequency of distribution of radium-226 activities of the ground water samples from Dakota Group wells is given in Plate 8. The activities range from 0.0 pCi/l to 620.3 pCi/l. The mean and median activities are 24.4 pCi/l and

8.1 pCi/l, respectively. Surprisingly, of the 117 wells sampled and analyzed, 78 (67%) produce ground water with radium-226 activities above the limit established by the Environmental Protection Agency for a domestic water supply (Plate 8). Also shown on the cumulative curve in Plate 8 is the "anomaly threshold" value for radium, 5.9 pCi/l, calculated by Scott and Barker (1962) from 120 ground water samples from the Rocky Mountain Orogenic Belt. Approximately 62 percent of the sampled wells in the Canon City embayment, most of which is included in this geographic division, exceed the "anomaly threshold" value.

Only gross generalizations can be made about the spatial distribution of high versus low radium-226 activities of Dakota Group ground water throughout the Canon City embayment. The reason is that most wells producing radium-rich ground water lie within a cluster of wells producing radium-poor ground water and vice versa. For example, in the northwest and northeast quarters of townships T. 23 S., R. 67 W., and T. 23 S., R. 68 W., respectively, are seven wells within a one-mile radium producing water with radium-226 activities all below 9.5 pCi/l. Near the center of this cluster is a well producing ground water with a radium-226 activity of 620.3 pCi/l. Numerous similar and converse examples can be observed in Plate 7.

The one area with ground water consistently high in radium-226 is immediately northeast of Colorado City. High radium levels are still quite variable, ranging from 24.4 pCi/l to 178.4 pCi/l. Conversely, ground water in the region of Pueblo West and to the south have radium-226 activities near the median value of 8.1 pCi/l. The range of activities in this area is from 0.2 pCi/l to 22.8 pCi/l.

Prediction of the radium-226 activity in Dakota Group ground water simply by geographic position within the embayment obviously is no easy task. Other controlling factors including the local structure, stratigraphy, and hydrogeochemistry must be considered as well.

Factors Controlling Radium-226 Occurrences

Stratigraphy

Figures 13, 14, 15, and 16 display electric and gamma-ray logs from selected wells in the Canon City embayment. These logs were chosen among many others because 1) the gamma-ray logs show high gamma radiation activity adjacent to sedimentary or crystalline rocks penetrated by the borehole (in most cases the high gamma radiation originates from strata within the Dakota Group or the Morrison Formation), and/or 2) the logs are supplemented by other data such as radium and water quality analyses of the ground water produced from the same or nearby wells. Unfortunately, in only a few cases is there a complete set of data on a single well (electric and gamma-ray logs, radium and water quality analyses, and informative well driller's logs). Nonetheless, the data at hand do suggest a strong stratigraphic control over the occurrence and quantity of radium-226 in the ground water of the Canon City embayment.

The areas under high gamma-ray deflections in gamma-ray logs from Western Well Logging (Plates 17 and 18) were quantified by the method described by Hallenburg (1973). The results are expressed in parts per million equivalent eU_3O_8 (ppm eU_3O_8). This is the quantity of uranium indicated by the gamma-ray

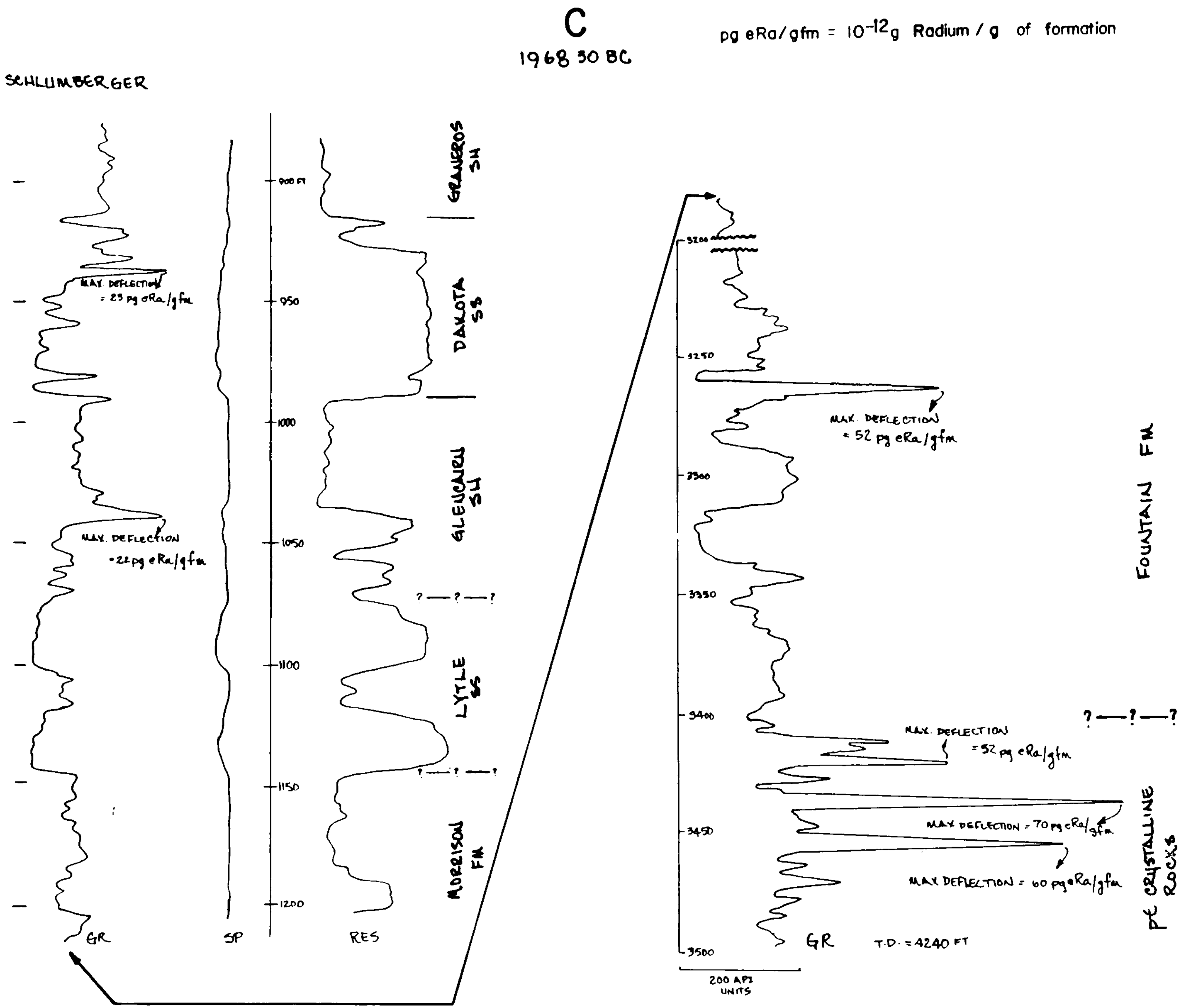


Figure 13. Quantification of gamma-ray deflections on gamma-ray log of a well south of Penrose.

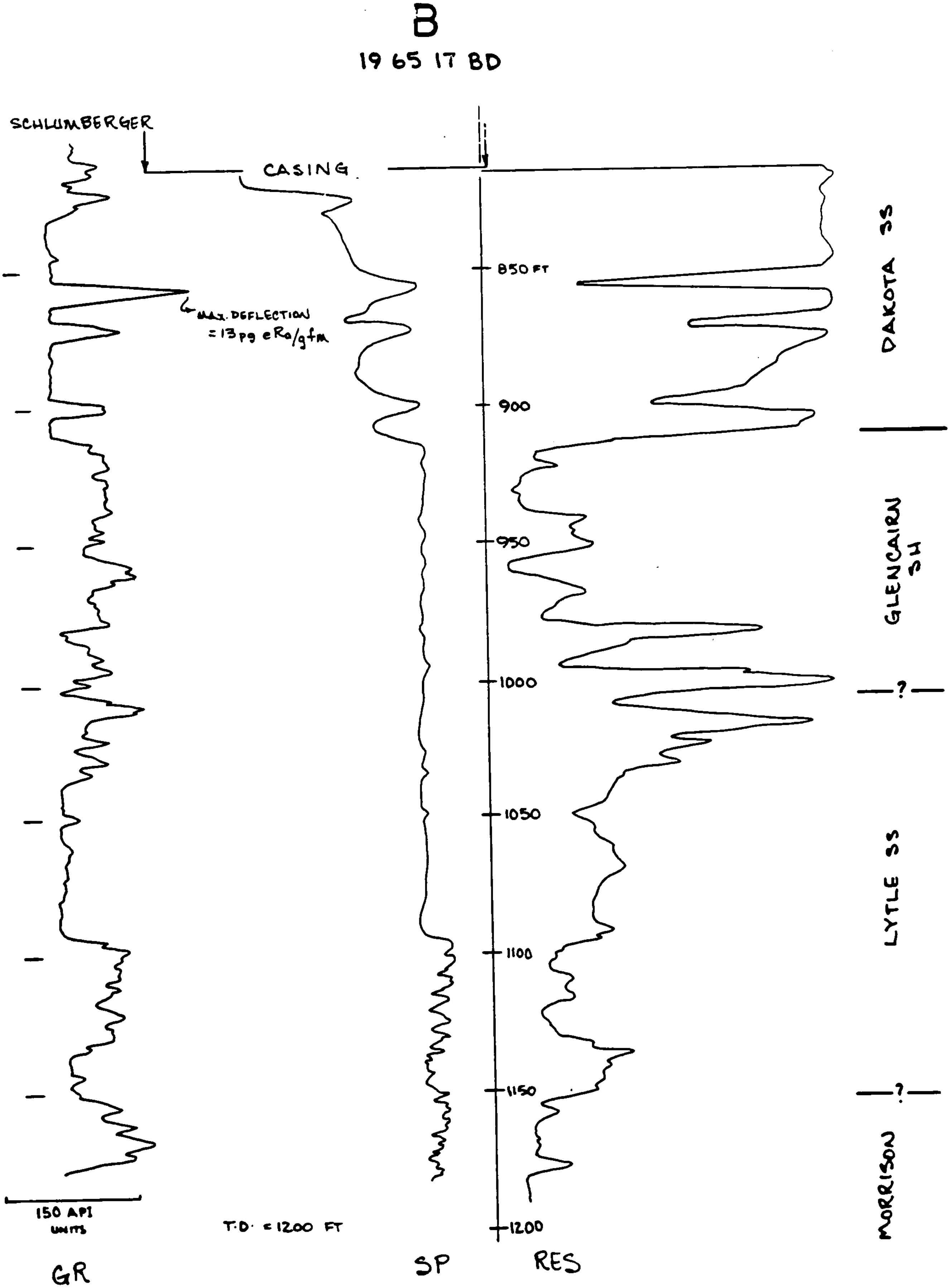


Figure 14. Quantificaiton of gamma-ray deflections of gamma-ray logs of wells in Pueblo West. pg eRa/gfm = 10^{-12} g equivalent Radium / g of formation

E

20 66 01 AB

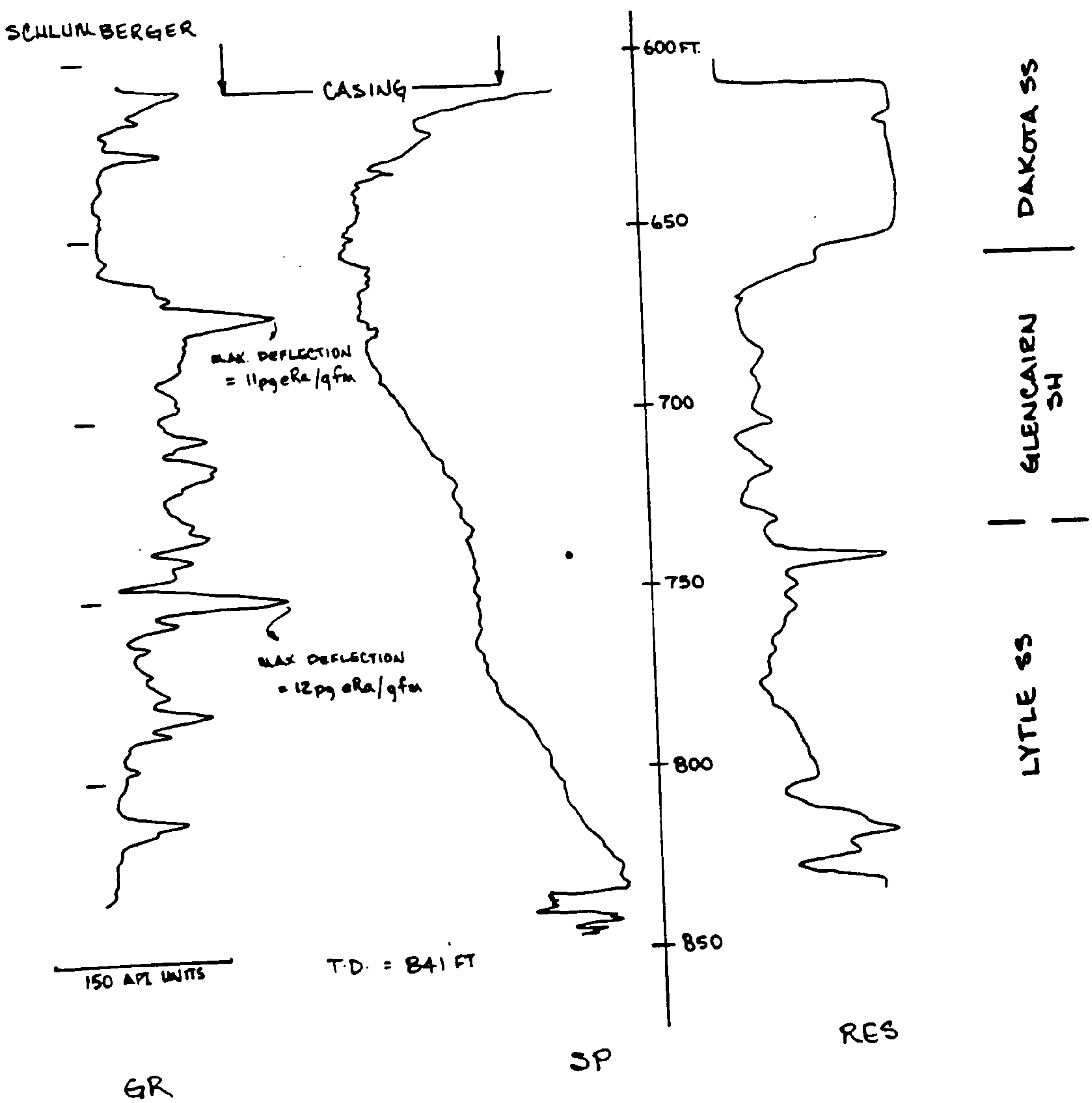


Figure 14. Continued.

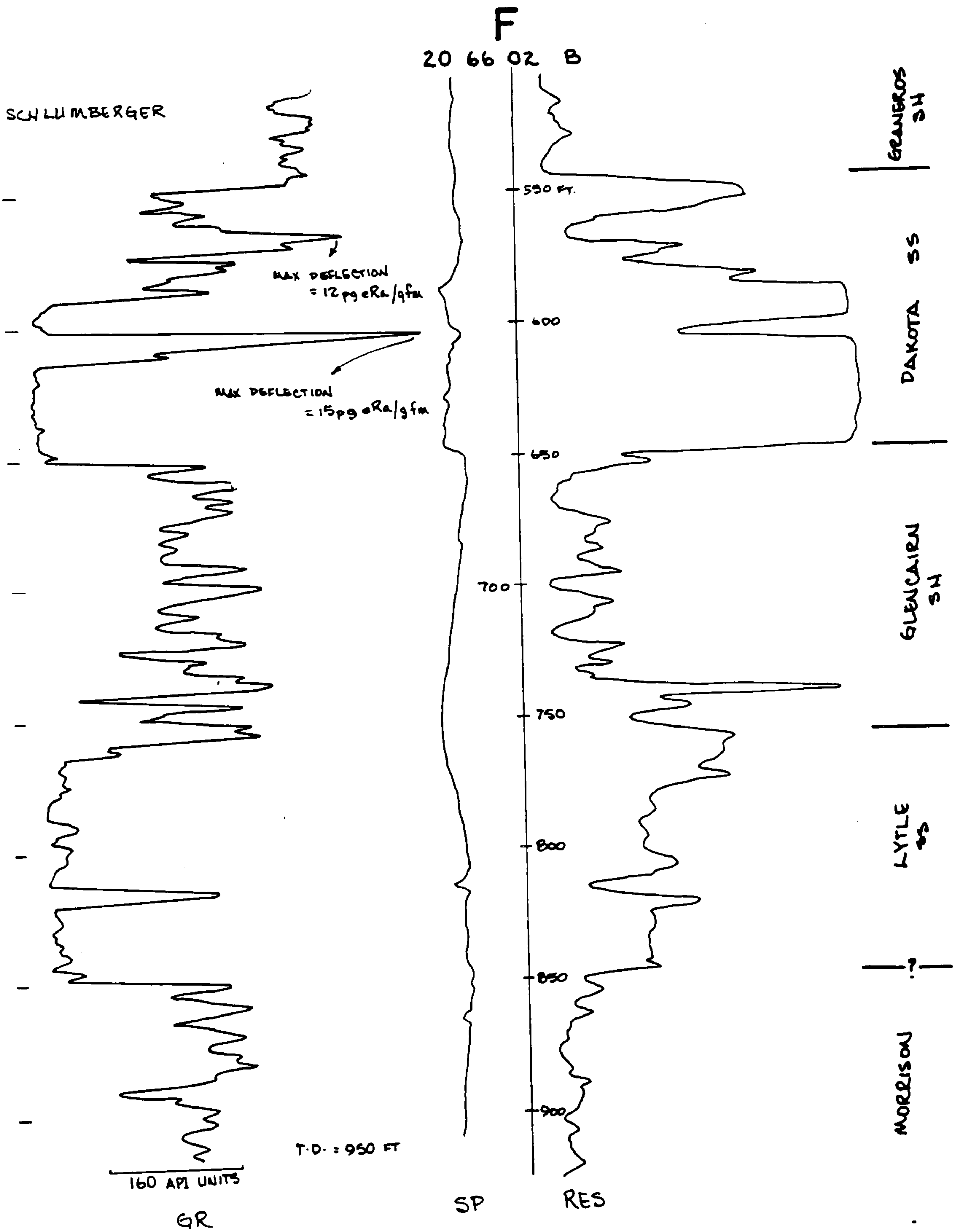


Figure 14. Continued.

G
20 66 11 AC

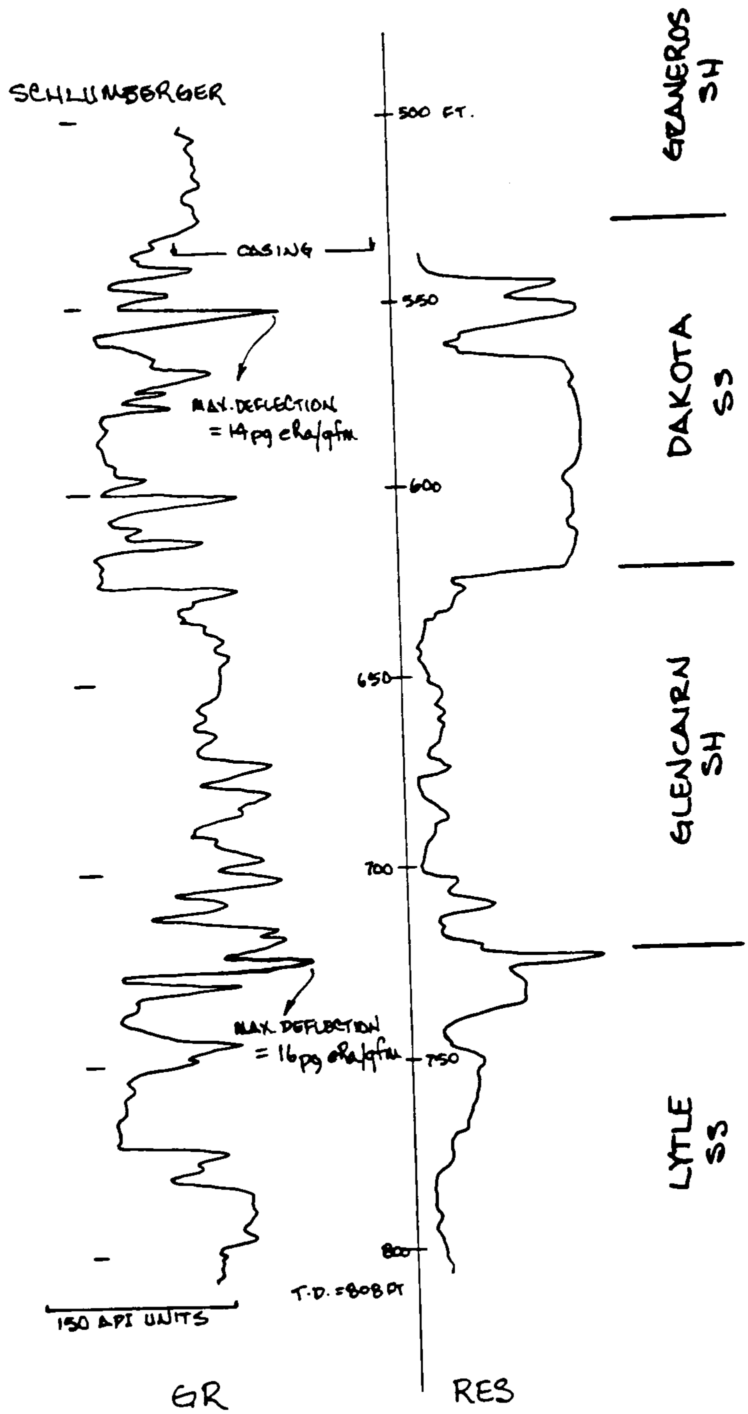


Figure 14. Continued.

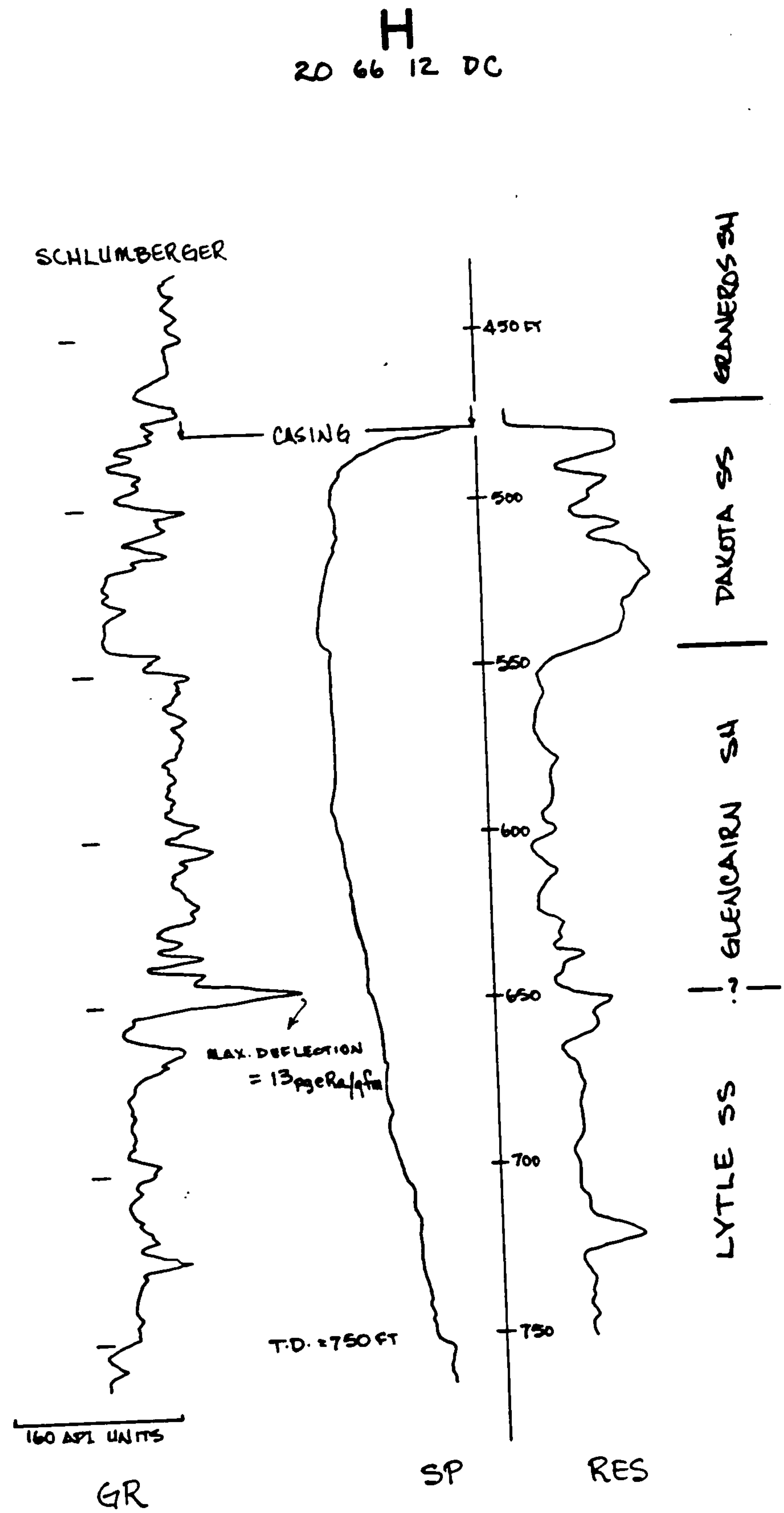


Figure 14. Continued.

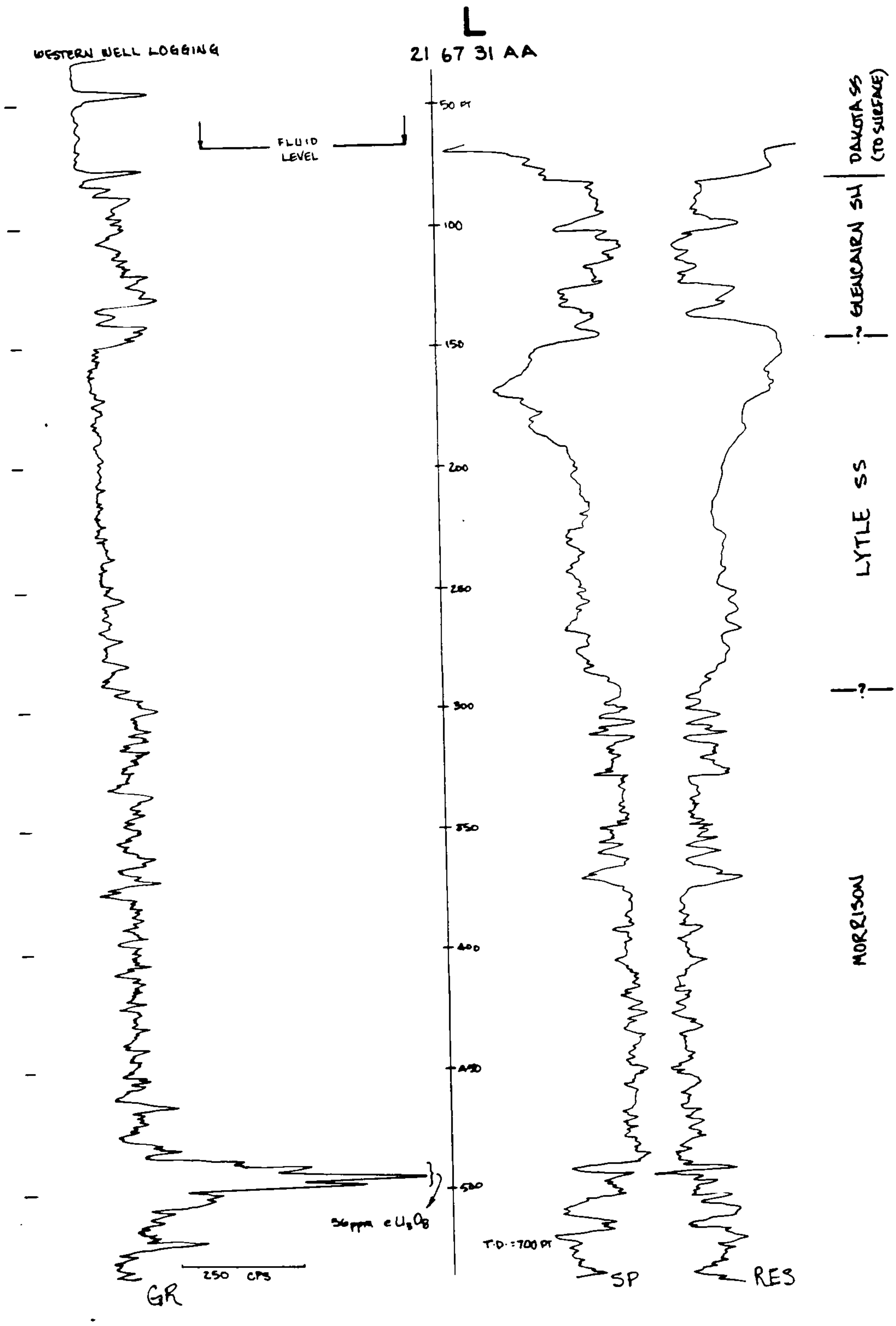


Figure 15. Quantification of gamma-ray deflections of gamma-ray logs of wells in Siloam area.

eU_3O_8 = equivalent U_3O_8

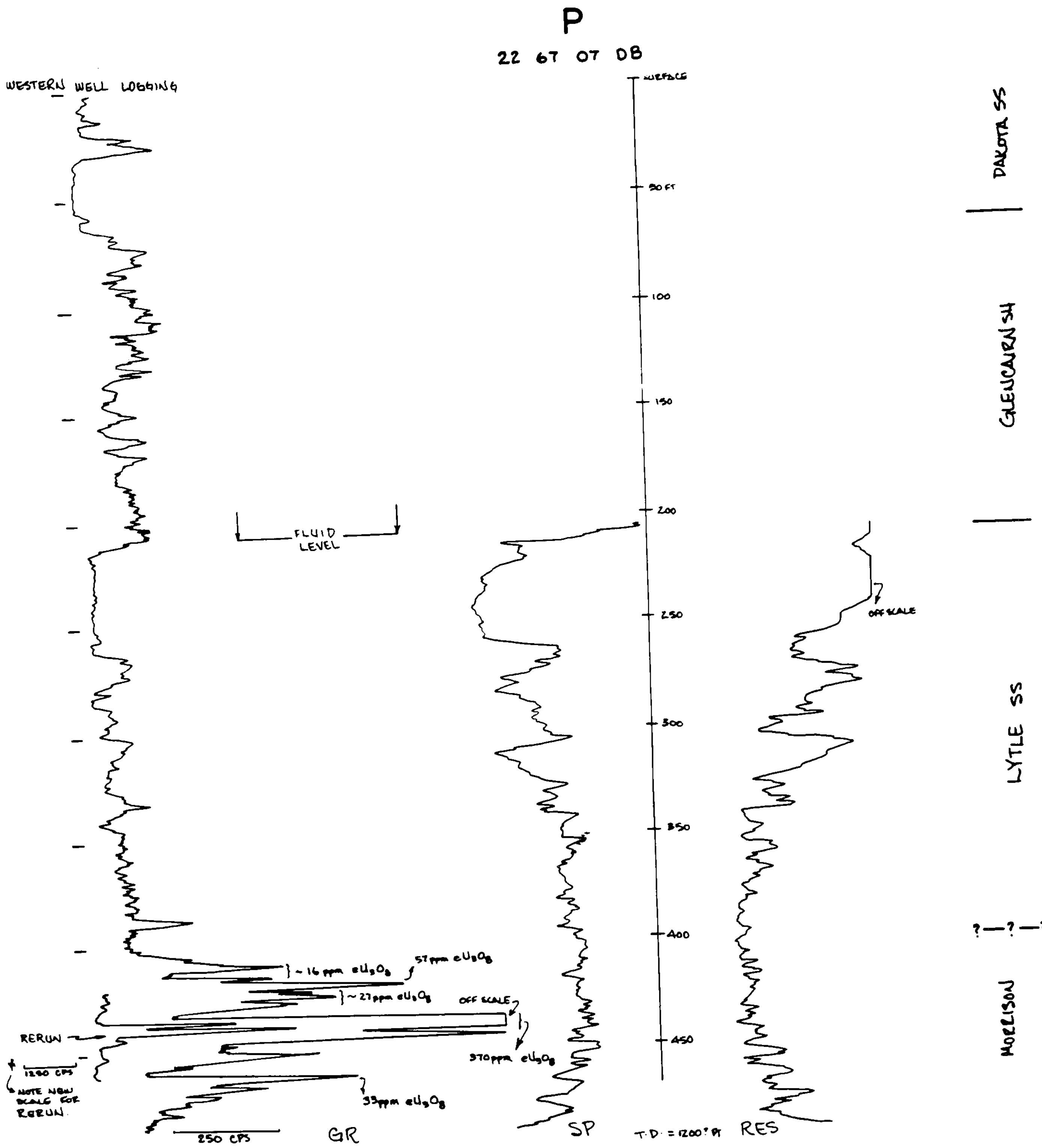


Figure 15. Continued.

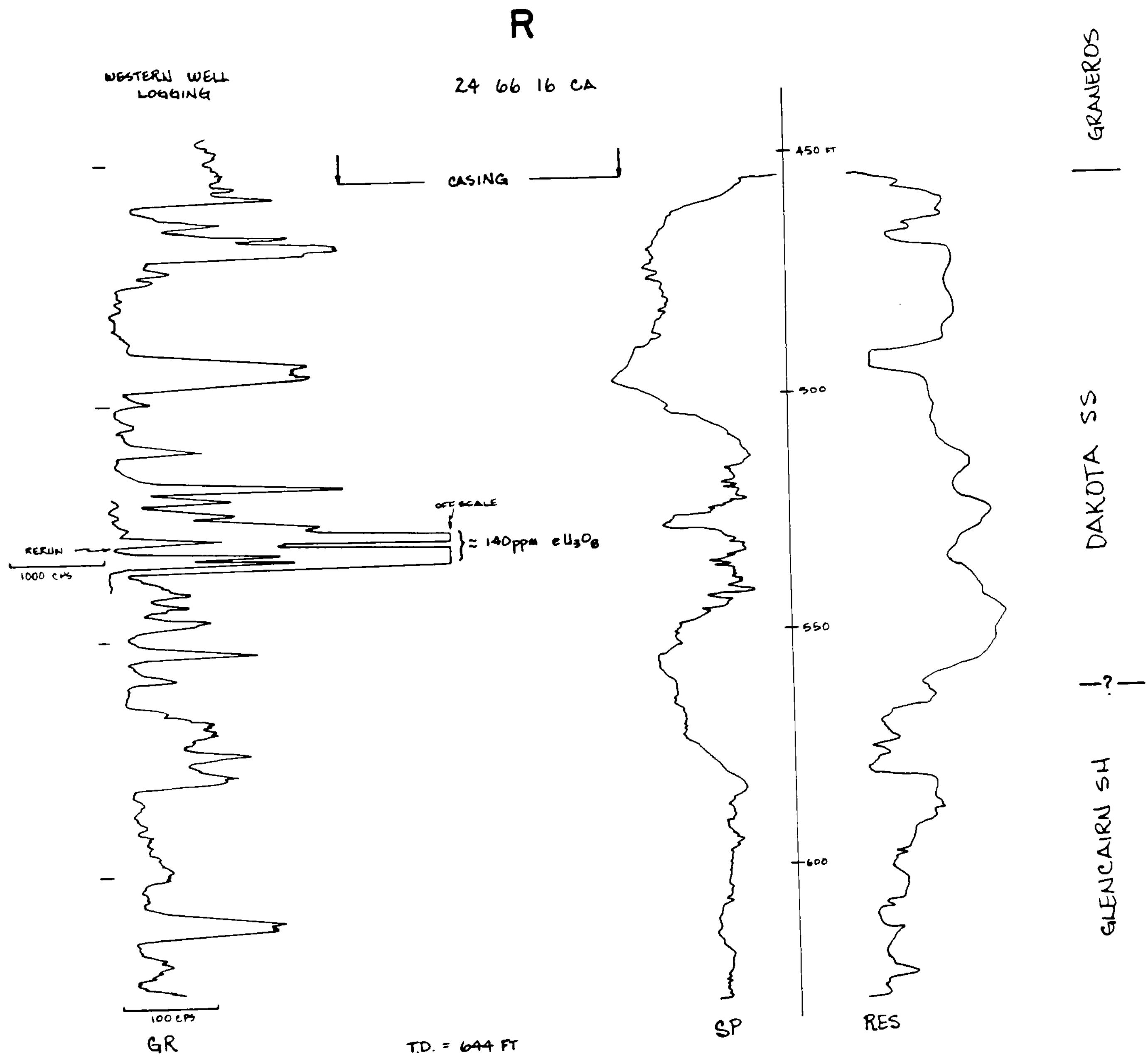


Figure 16. Quantification of gamma-ray deflections on gamma-ray logs of wells in Colorado City area.

eU_3O_8 = equivalent U_3O_8

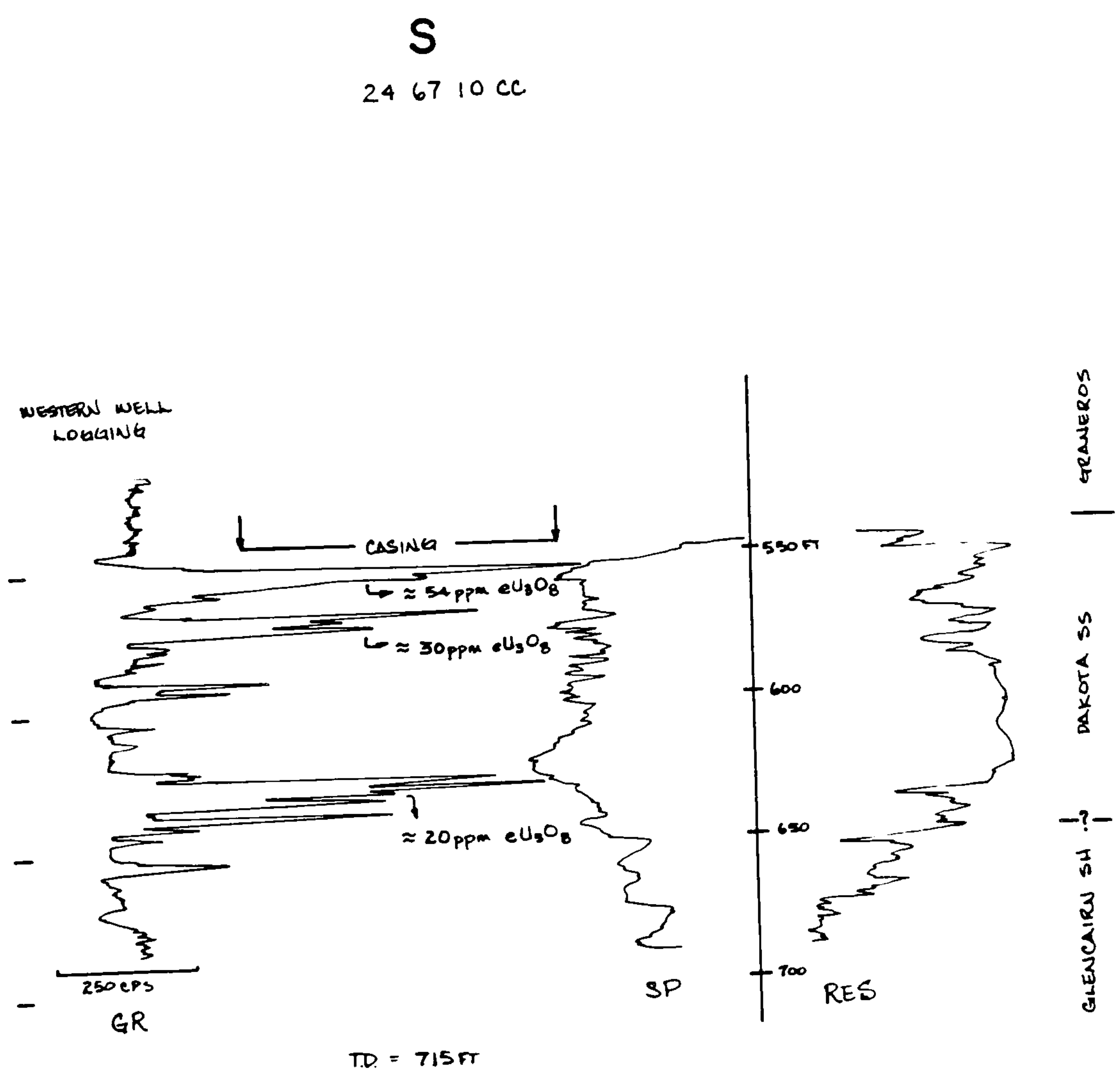


Figure 16. Continued.

T
24 67 23 BD

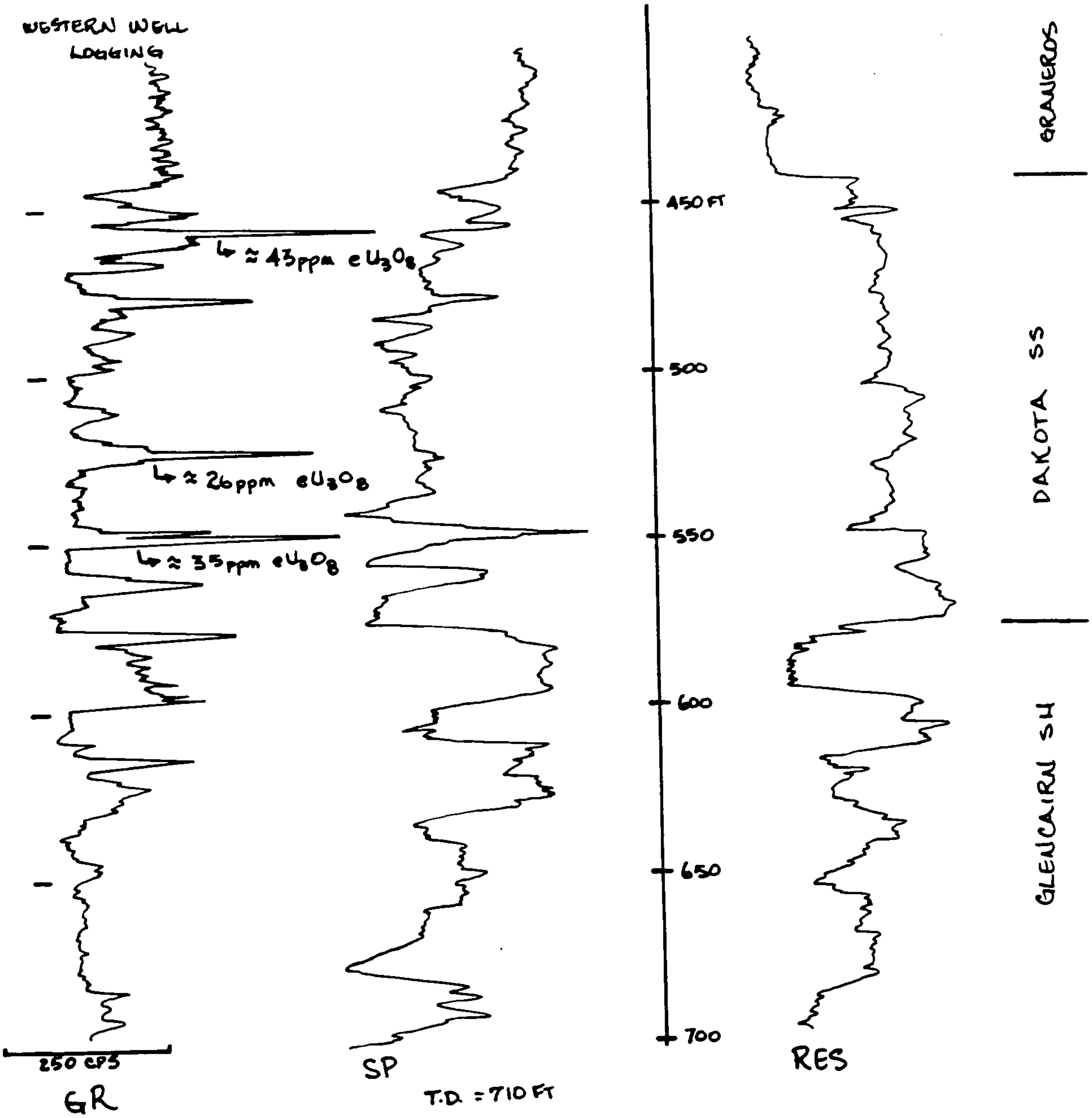


Figure 16. Continued.

deflection that would exist if it was in equilibrium with its daughter products, which may or may not be the case. The gamma-ray deflections in the Schlumberger gamma-ray logs (Figs. 13 and 14) are expressed in picograms equivalent radium per gram of formation (pg eRa/gfm). These values were derived from the logs using the correction tables and nomographs in Schlumberger (1972, 1974, 1978).

The objective in quantifying the gamma-ray deflections was to establish a meaningful and more accurate qualitative indicator of the magnitude of the potential radium source (i.e., Ra- or U-rich strata), or an indicator of the radium in the water itself. The gamma-ray sonde, usually a thallium-doped, sodium iodide crystal which scintillates in the visible light range when a gamma photon passes through it, detects the natural gamma radiation flux emitted from the formation within a spherical volume of detection centered at the sonde. Logically, it follows that the sonde cannot discriminate between a gamma photon emitted from a radionuclide within a solid framework and one emitted from a radionuclide within a liquid framework. In other words, it cannot differentiate between radiation emitted from the radioactive species in the rock from those in the water filling the pore spaces of the rock. On this basis, it is believed that comparing radioactive occurrences in the formation to the radioactivity of the water is a valid approach in delineating potential local sources of the radiation. Whether or not the gamma radiation flux from the formation or the contained water (detected in gamma-ray logs) is from radium-226 or uranium remains speculation in many cases. However, if anomalously high incidences of gamma radiation are detected in the formations penetrated by a wall which produced radium-rich ground water, it is safe to assume that radium-226 contributes a large part of the total detected gamma radiation flux. Furthermore, Cadigan and Felmlee (1977, p. 329) show that most of the gamma radiation in water and mineral precipitates from thermal springs and wells in parts of Colorado, New Mexico, Arizona, and Utah comes from radium-226 and radium-228 and their decay products.

Gamma-ray log R (Fig. 16) shows an extremely high incidence of gamma radiation within the lower sandstone unit of the Dakota Sandstone (from 582 ft to 534 ft). This deflection represents approximately 140 ppm eU_3O_8, over 300 times the normal background level for sandstone (Parker, 1967). Six wells within 2.5 miles of this well, each of which penetrate part or all of the Dakota Sandstone, produce ground water high in radium-226 (see Plate 14). The radium-226 activities range from 24.4 pCi/l to 178.4 pCi/l. No radium analysis is available from the logged well.

Gamma-ray logs S and T (Fig. 16), respectively 4.2 miles southwest and 5.7 miles west of logged well R, also show moderately high gamma-ray deflections adjacent to the Dry Creek Canyon Member and shale interebeds in the upper and lower sandstone units of the Dakota Sandstone. These deflections represent from 20 ppm eU_3O_8 to 54 ppm eU_3O_8. The only additional Dakota Group ground water sample in the vicinity of logged wells S and T has a radium activity of 37.9 pCi/l (well 24 67 24 dc).

In each of the three logged wells in Figure 16, sandstone and shale strata within the Dakota Sandstone exhibit equivalent uranium values much higher than normal background levels for these lithologies (Parker, 1967). Moreover, all the Dakota wells sampled in the vicinity of these logged wells produce ground water with radium-226 activities in excess of 24.4 pCi/l.

Five gamma-ray logs in the Pueblo West area (logs B, E, F, G, H; Figure 14) all show low to moderate gamma radiation activity in Dakota Group strata. The gamma activities are not restricted to any specific stratigraphic position in the Dakota Group, but occur at many positions throughout the aquifer. The gamma-ray deflections in these logs are expressed in picograms of equivalent radium per gram of formation (pg eRa/gfm). Since one gram of radium has a disintegration rate of approximately one curie, then a gamma-ray deflection of say 20 pg eRa/gfm indicates a formation (or formation water) radioactivity of approximately 20 pCi/gfm. The radium-226 activities of ground water from the same and nearby wells support this relation. For example, log G shows two gamma-ray deflections of 14.1 pg eRa/gfm and 16.3 pg eRa/gfm from the upper sandstone unit of the Dakota Sandstone and the Glencairn-Lytle contact (?), respectively. The radium-226 activity of the ground water from this well is 10.5 pCi/l. Log H shows a single gamma-ray deflection of 12.8 pg eRa/gfm at the base of the Glencairn. The ground water from this well has a radium-226 activity of 12.1 pCi/l. The range of maximum gamma-ray deflections in the logs in plate 16 is 11 pg eRa/gfm to 16 pg eRa/gfm. These values are comparable to the radium-226 activities of the ground water from the same and nearby wells which range from 2.3 pCi/l to 22.8 pCi/l.

The occurrence of high gamma radiation is not restricted to strata of the Dakota Group. In fact, the higher gamma-ray deflections occur in the variegated beds of the upper Morrison in log P (Fig. 15) and in the uppermost part of the crystalline basement rocks in log C (Fig. 13). The area under the largest gamma-ray deflection in log P (@ 435 ft to 440 ft) represents about 370 ppm eU_3O_8, or 100 times the normal background level of 3.7 ppm uranium for shale (Parker, 1967). The smaller gamma-ray deflections in this log occur in the Dakota Group and represent equivalent U_3O_8 values of 17 ppm and 57 ppm. The radium-226 activities of two ground water samples about one mile south of this logged well are 0.9 pCi/l and 1.4 pCi/l. However, these two wells only penetrate to the upper Lytle and are separated from the logged well by a major fault. Both situations may explain the low radium-226 activities in ground water adjacent to a well showing high formation gamma radiation. Other explanations may exist but will not be discussed.

Log C shows three high gamma-ray deflections in the crystalline basement complex just below the basal contact of the Fountain Formation. The large amount of potassium-bearing minerals in these rocks may account for a large part of the total gamma-radiation indicated by the deflections. Keeping this in mind, the values of the deflections are 52 pg eRa/gfm, 60 pg eRa/gfm, and 70 pg eRa/gfm. Other deflections in this log include one of 52 pg eRa/gfm in the lower Fountain Formation and two of 22 pg eRa/gfm and 23 pg eRa/gfm in the Glencairn Shale Member and the Dakota Sandstone, respectively. A group of three wells and a group of two wells exist within 1.5 miles of this logged well. The average radium-226 activities of ground water samples from each group are 92.8 pCi/l and 134 pCi/l.

Several of the more marked cases relating the gamma radiation in the formation with the radium-226 activity of the contained water are discussed above. Other cases appearing in Plates 15, 16, 17, and 18 show similar relations between formation radioactivity and radium-226 activity of the contained ground water.

Structure

The previous section deals with the occurrence and quantification of primarily highly gamma-ray emitting sedimentary strata of the Dakota Group and the Morrison Formation in light of the radium-226 activities of their contained ground water. These occurrences reflect strictly local sources of radium and/or uranium responsible for the observed radioactivity in the strata and its contained ground water. In this section, more regional sources of the radium and/or uranium are considered with respect to the spatial occurrence of radium-rich ground water and high formation radioactivities.

Some of the more outstanding occurrences of high formation radioactivity and ground water radium activity in the Dakota and Morrison are observed in wells drilled near the major faults in the southwestern part of the embayment. The assumption is that radium and/or uranium may have been introduced to the strata from radium- and/or uranium-rich solutions (hydrothermal fluids?) migrating up isolated, permeable zones in the fault planes from the crystalline basement complex underlying these areas. Log P (Fig. 15) and log R (Plate 18), which show the highest gamma-ray activity in Morrison and Dakota strata, respectively, are each located within two miles of the surface traces of major faults (see Plate 7). Moreover, the ground water samples showing the highest radium-226 activities are from wells adjacent to these same faults (21 68 15 cd, 178.9 pCi/l; 23 68 01 da, 620.3 pCi/l).

It must be noted, however, that many of the wells adjacent to the major faults in the embayment produce ground water with relatively low radium-226 activities. Therefore, if radium- and/or uranium-rich (hydrothermal?) solutions migrating up fault planes from the crystalline rock below did (or still do) contribute to the high formation and ground water radioactivity, their effects were not ubiquitous but, instead, are limited in stratigraphic and areal position along the fault planes. This may be due to one or more of the following.

1. The radioactive fluids from depth are concentrated along isolated conduits of highly fractured, highly permeable fault gouge separated great distances from one another by nearly impermeable rock within the fault plane.

2. The radium and/or uranium sources at the end of the (hydrothermal?) pipe system are widely separated so the fluids are rich in the constituents in some areas and nearly barren in others.

3. The hydrogeochemical conditions prevailing in some areas favored the precipitation and subsequent concentration of radium and/or uranium species in the formation, while the hydrogeochemical conditions in other areas prevented it.

It is obvious that many other, equally reasonable factors could account for the inconsistent formation and ground water radioactivities in wells near the major faults in the embayment. One factor not yet considered is the possible irregular occurrence of roll front type uranium deposits which resulted when uranium-bearing, oxidizing ground water encountered reducing conditions within the strata. This may well be the case in the Morrison Formation which is known for its uranium deposits of this type and is an important source of uranium ore mined in Colorado.

Hydrogeochemistry

A detailed investigation of the hydrogeochemical control of the radioactivity of Dakota and Morrison strata and their contained ground water is well beyond the scope of this thesis, and an excellent topic for another thesis. The paucity of available and pertinent data severely restricts the thoroughness of such a study at this time. "Pertinent" data would include: 1) up-to-date analyses of major ions, trace elements, and additional radioactive elements including isotopes of uranium, radium, and thorium in the ground water of the Dakota Group and the Morrison Formation; 2) accurate field determinations of Eh, pH, and temperature of the ground water; 3) gross gamma-ray or, better yet, gamma-ray spectrometric logs of those wells producing ground water extremely high in radium-226; and 4) detailed mineral and chemical analyses of core samples from one or more strategically located boreholes. Research currently underway by J. K. Felmlee and R. A. Cadigan of the Uranium and Thorium Branch of the U.S. Geological Survey (Golden, CO) incorporates many of the pertinent chemical parameters of the Dakota Group ground water from the southern portion of the Canon City embayment. This work should provide an important contribution to a more complete understanding of the hydrogeochemical parameters controlling radium and uranium in the Dakota Group A Aquifer and adjacent formations and their confined ground water.

Cadigan and Felmlee (1977) reveal evidence that suggests the high concentrations of radium-226 in spring and well water in parts of Utah, New Mexico, Arizona, and Colorado (the wells penetrated the Dakota Group aquifer of the southern portion of the Canon City embayment) result from hydrothermal fluids that leach mostly radium from parent uranium deposits probably of igneous or metamorhic origin. They maintain that the "highly soluble ^{226}Ra is transported in bicarbonate and chloride waters and is co-precipitated on degassing, oxidation, or cooling of the hydrothermal solutions." This conclusion is based on the correlation of radium-226 activities of the water with its concentration of dissolved fluids. They found that, in general, higher radium activities were associated with higher concentrations of dissolved solids which were due to higher bicarbonate and/or chloride concentrations. The radium-226 coprecipitates with barium sulfate, arsenic-bearing iron oxide or hydroxide, and manganese oxide or hydroxide; coprecipitation with calcium carbonate is minimal (Cadigan and Felmlee, 1977).

Several attempts were made at correlating the concentration of various chemical constituents of the Dakota Group ground water of the area studies with their radium-226 activities. No apparent correlations exist. Other simple regressions were run on radium-226 activities using water temperature, pH, cation-cation ratios, and anion-anion ratios as the dependent variables. Again, no apparent correlations exist.

This simple approach to an obviously complex hydrogeochemical problem does reveal two things: the necessity for a more complete set of chemical data as mentioned above and a thorough treatment of such data.

Summary

Several interrelated factors appear to control the occurrence and amount of radium-226 in the ground waters of the Dakota Group (and the Morrison Formation) of the Canon City embayment. These include: 1) proximity to that portion of a fault plane that may (or did) transmit radium- and/or uranium-rich (hydrothermal?) fluids from a parent uranium deposit probably within the crystalline basement complex beneath the embayment, 2) the presence of a suitable host within the Dakota (or Morrison) that can accept and store such fluids, 3) the hydrogeochemical characteristics of the aquifer, and 4) the presence of pods of secondary uranium-rich mineralization (roll front type uranium deposits) in Dakota and Morrison strata.

It must be stressed that, based on available data, these factors appear to provide the major control over the radium-226 activities in the ground water of the Dakota Group aquifer. Further investigations utilizing more complete data may reveal additional controlling mechanisms.

CONCLUSIONS AND RECOMMENDATIONS

The immediate problems confronting users of the ground water of the Dakota Group aquifer of the Canon City embayment are those associated with the chemical quality of the ground water and its suitability for drinking and culinary uses. Approximately 67 percent of the 117 ground water samples from wells completed in part or all of the Dakota Group aquifer have radium-226 activities exceeding the limit of 5.0 picocuries per liter of water (5.0 pCi/l) established by the Environmental Protection Agency (1973). If the water supply is properly treated at the homesite, health afflictions resulting from water consumption may be eliminated. This would necessitate the installation of cation exchange units capable of removing radium-226 and the proper maintenance of such units to ensure maximum radium-226 removal at all times.

Another precaution that may prove more economically feasible in the long run would be to effectively case out all stratigraphic horizons in the well bore showing high gamma radiation. This would require running gamma-ray logs in newly drilled wells or in old wells and installing blank casing opposite and well above and below (5 to 10 feet each direction) the interval showing high gamma radiation. Provided ground water leakage or flow across bedding planes is minimal, this precaution should reduce the amount of radium-rich ground water entering the well.

These precautions provide only temporary solutions to a potentially major problem of which little is understood, hydrogeochemically. They may be the only solutions. Nonetheless, the need for a detailed hydrogeochemical study of the radium-bearing strata and their contained ground waters is imperative. Such a program should involve the following:

1. Sampling and analyzing ground water from those wells producing radium-rich water. The analyses should include, at least, <u>field</u> Eh, pH, and water temperature determinations, major ion and trace element determinations, and radium, uranium, and thorium isotope determinations. Field determination of radon-222 gas of the ground water samples may prove useful.

2. Gross gamma-ray or gamma-ray spectrometric logs should be run in wells producing ground water very high in radium-226 activities.

3. Chemical data should be analyzed by a modified version of the WATEQF computer program (Plummer and others, 1976) capable of evaluating the chemical equilibrium of radium species in natural waters. WATEQF, a modified fortran version of WATEQ (Truesdell and Jones, 1974), is now capable of evaluating the

equilibrium distribution of 21 aqueous uranium species and 17 uranium minerals in natural waters (Lueck, 1978). Further modification of WATEQF to evaluate the equilibrium distribution of aqueous radium species and radium-bearing minerals is necessary and could be patterned after Lueck (1978).

A hydrogeochemical study of this nature should reveal more about the origin and migration of radium-226 in the ground water, and the nature of the dominant radium species in the ground water and rock. Further recommendations alleviating the potential health hazards associated with a radium-rich water supply also may result from such a study.

Aside from the radium problem, users of the ground water of the Dakota Group aquifer will confront, in the near future, problems associated with declining water levels. Continuing development and population growth in the Canon City embayment will require larger water supplies, thus increased ground water withdrawal from the Dakota Group aquifer and associated declining water levels. For this reason, management of this resource should be initiated as soon as possible. Romero (1976) summarizes quite succinctly what is entailed in the successful management of the bedrock aquifers of the Denver basin.

> Successful future management of the bedrock aquifers of the Denver basin will require the collection and utilization of a considerable amount of additional data, particularly in those areas where data are either scarce or totally lacking. The importance of additional electric logs, geologic sample logs, and aquifer test data cannot be over-emphasized. Water quality tests are inexpensive and should be made at every opportunity. Of major importance is the need for an extensive network of observation wells in which water level fluctuations can be monitored. . . Accurate measurements of the quantities of water withdrawn from the aquifer are needed to predict the useful lives and the response to additional development (Romero, 1976, p. 101).

This is precisely applicable to the Dakota Group aquifer of the Canon City embayment. Such a program, properly administered, should maximize the life of the resource with minimum financial input. If properly and cautiously developed and managed, the Dakota Group aquifer should supply the water needs of the population in the Canon City embayment for several generations.

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APPENDIX A

EXPLANATION OF WELL NUMBERING SYSTEM

EXPLANATION OF WELL NUMBERING SYSTEM

The numbering system designating the location of a given well is based on the U.S. Bureau of Land Management's system of land subdivision. The number shows the location of the well by township, range, section, and position within the section. The entire area of study exists south of the baseline and west of the 6th principal meridian (quadrant C, see figure 1). The quadrant letter which usually precedes the township designation, therefore, is deleted from the location number in this report but is inferred for all well locations. A graphical illustration of this method of well location is given in figure A1. The first number indicates the township, the second the range, the third the section, and the following letters the quarter, quarter-quarter, and quarter-quarter-quarter sections, respectively, in which the well is located.

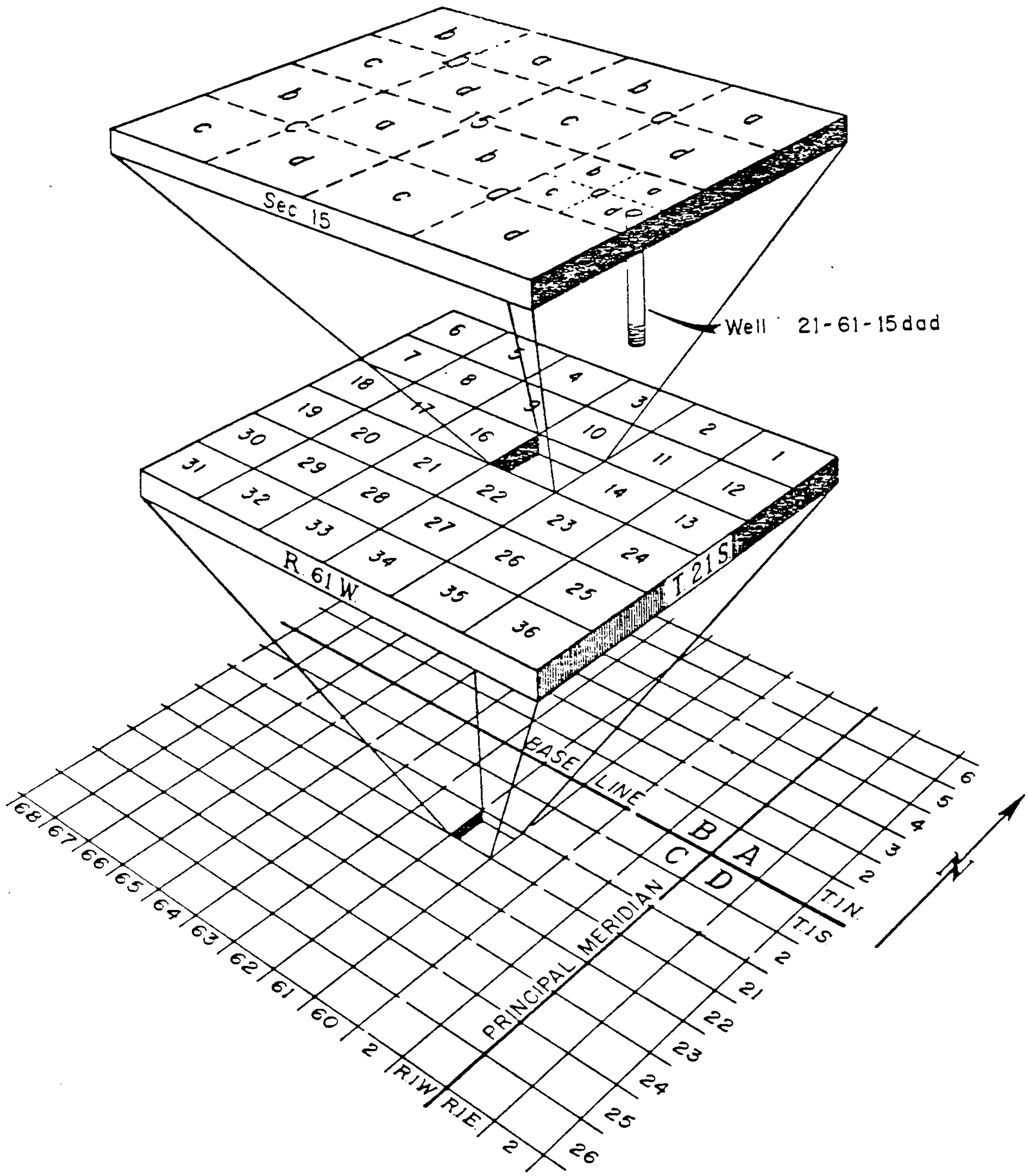

Figure A1. Well numbering system (from McGovern and others, 1964).

APPENDIX B

LIST OF SELECTED WELLS COMPLETED IN THE DAKOTA GROUP

AQUIFER OF THE CANON CITY EMBAYMENT

WATER WELLS COMPLETED IN THE DAKOTA GROUP AQUIFER OF THE CANON CITY EMBAYMENT

Explanation: F = flowing well, (77) indicates year flowing well was measured; geologic source Kd = Dakota Sandstone, Kpug = Glencairn Shale Member of the Purgatoire Formation, Kpul = Lytle Sandstone Member of the Purgatoire Formation, Kdgu = Dakota Group undifferentiated (all or parts), Jm = Morrison Formation; S.L. = sea level; gpm = gallons per minute; use 1 = domestic, 2 = stock, 3 = domestic & stock, 4 = commercial, 5 = industrial, 6 = irrigation, 7 = irrigation and stock, 8 = municipal; asterisks (*) indicate additional information in following appendices.

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
18 66 08 ab	385	5840	5655	5	2	Kd	-	-
18 66 33 ac	804	5535	5281	-	-	Kdgu	-	-
18 67 30 cd	375	5720	5428	11	2	Kdgu	-	-
18 68 33 ab	210	5444	5265	15	-	Kdgu	-	*
18 68 33 db	136	5400	5286	15	2	Kd	-	*
19 65 12 cntr	1652	5597	5517	-	-	Kdgu ± Jm	-	-
19 65 16 cc	1340	5040	4670	-	4	Kdgu ± Jm	-	*
19 65 17 bd	1200	-	-	-	4	Kdgu ± Jm	-	-
19 65 17 ca	833	5065	4809	50	4	Kd	-	-
19 65 18 bc	923	5174	4957	45	4	Kdgu ± Jm	-	*
19 65 20 cc	725	5060	5019	-	4	Kd	-	-
19 65 21 bb	1343	5044	5044 F(72)	150	4	Kdgu ± Jm	-	-
19 65 31 ca	-	4631	4631	50	4	Kdgu	-	-
19 66 21 aa	695	5325	5130	5	2	Kdgu	-	-
19 67 01 cc	556	5305	5305 F(77)	1	1	Kd	-	*
19 67 08 cc	803	5370	5370 F(77)	2	2	Kdgu	-	*
19 67 08 da	-	5365	-	-	-	-	-	*
19 67 09 bb	675	5398	5382	10	2	Kdgu	-	*
19 67 19 da	710	5249	5249 F(77)	-	-	Kdgu	-	*
19 67 20 d	900	-	-	-	-	Kdgu	-	*

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
19 67 21 dc	493	5231	5195	-	-	Kdgu	-	-
19 67 22 bd	532	5245	5201	-	-	Kdgu	-	-
19 67 22 db	500	5235	5212	-	-	Kdgu	-	-
19 67 27 bb	500	5233	5230	-	-	Kdgu	-	-
19 67 29 ca	777	5212	5182	50	4	Kdgu	-	*
19 68 07 bb	733	5250	-	200	7	Kd	-	*
19 68 07 cc	-	5185	-	6	-	Kdgu	*	*
19 68 23 ba	658	5110	-	50	6	Kpul	*	*
19 68 30 bc	1096	5200	-	250	5	Kpul ± Jm	*	-
19 69 01 c	-	-	-	-	-	Kdgu	-	*
19 69 01 da	1200	5241	5241 F(77)	30	6	Kd	*	*
19 69 01 dc	1200	5245	5245 F(77)	30	6	Kd	*	*
19 69 14 dd	1400?	5100	5100 F(77)	-	-	Kd	-	*
"	"	"	"	-	-	Kd	-	*
"	"	"	"	-	-	"	-	*
19 69 24 cd	2000	5195	5195 F(77)	-	-	Kdgu	-	*
"	"	"	"	-	-	"	-	*
20 65 01 bb	1631	4861	-	32	1	Kdgu ± Jm	-	-
20 65 08 bb	855	5020	-	150	4	Kpul	-	-
20 65 11 ba	875	5095	-	70	4	Kdgu	-	-
20 65 13 ab	1390	4830	4775	40	4	Kd	-	-
20 65 13 cb	1501	4832	4822	200	4	Kdgu	-	-
20 65 33 cb	865	4740	4737	15	4	Kdgu	-	*
20 65 33 cd	700	-	-	-	8	Kdgu	-	*
20 65 36 ba	1491	4650	-	60	4	Kpul	-	-
20 65 36 dd	1425	4670	-	45	4	Kdgu ± Jm	-	-

LOCATION	DEPTH ft.	WELL ELEVATION ft. abovve S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
20 66 01 ab	841	5065	4947	-	4	Kdgu	-	-
20 66 01 ba	830	5062	4945	-	4	Kdgu	-	-
20 66 01 cc	556	5085	5057	-	2	Kd	-	-
20 66 02 ba	950	5097	5090	20	4	Kdgu ± Jm	-	-
20 66 02 bb	876	5120	5025	100	4	Kdgu	-	-
20 66 07 aa	865	5040	4810	188	4	Kd	-	-
20 66 08 cd	1040	5005	4920	120	4	Kpul	-	-
20 66 09 bd	785	5042	4917	30	1	Kd	-	-
20 66 11 ac	637	5145	4956	80	4	Kdgu	-	*
20 66 11 bb	808	5080	4700	-	4	Kdgu	-	-
20 66 14 da	750	5075	4792	15	4	Kdgu	-	*
20 66 14 da	510	5130	4800	-	4	Kdgu	-	-
20 66 16 ac	1035	4998	4858	80	4	Kdgu	-	*
20 66 22 ba	1510	4950	4700	50	4	Kpul ± Jm	-	-
20 66 24 aa	830	5135	4725	350	8	Kd + $\overline{K}$pul	-	*
20 66 24 bb	847	5191	4749	600	8	Kd + Kpul	-	*
20 66 24 ca	815	5185	4735	30	8	Kd + Kpul	-	-
20 67 04 ca	2445	5160	5160	600	4	Kdgu + Jm	-	-
20 67 06 0ba	343	4950	4950 F(77)	40	1,6	Kd	-	*
20 67 08 ab	525	4928	4928 F(77)	-	-	Kdgu	-	*
20 67 14 ba	750	5040	4875	170	6	Kd + Kpul	-	-
21 65 04 cd	608	4880	-	18	8	Kd	-	*
21 65 05 ab	841	4840	-	28	6	Kpul	-	*
21 65 16 ab	546	5080	5070	135	6	Kdgu	-	-
21 65 16 ad	797	5080	5005	30	1	Kdgu	-	-
21 65 16 dd	1462	5060	4960	186	6	Kdgu + Jm	-	-
21 65 19 ac	565	5225	4978	25	1,6	Kdgu	-	-

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
21 65 21 aa	600	4950	4890	80	2	Kdgu	-	-
21 65 23 dd	1198	4851	4851	137	4	Kd + Kpul	-	-
21 65 28 cd	560	5058	4992	-	-	Kdgu	-	-
21 65 29 db	760	5115	4977	38	8	Kdgu	-	-
21 65 30 dc	683	5285	5108	-	-	Kdgu	-	-
21 65 32 cc	535	5100	5040	20	2	Kdgu	-	*
21 65 35 ac	1125	5080	5074	-	7	Kdgu	-	*
21 66 12 db	530	5135	4895	25	2	Kdgu	-	-
21 66 13 d	560	-	-	-	-	Kdgu	-	*
21 66 19 db	530	5258	5131	5	2	Kdgu	-	-
21 66 24 bb	750	5040	5010	200	6	Kdgu	-	*
21 66 25 db	1045	5065	5035	500	6	Kd + Kpul	-	-
21 66 26 ca	1035	5045	5040	500	6	Kd + Kpul	-	*
21 66 30 cc	519	5120	4970	15	2	Kd	-	-
21 66 32 aa	534	5220	5175	19	2	Kdgu	-	-
21 66 33 da	1125	5175	5174	500	6	Kd + Kpul	-	-
21 67 01 bc	311	5120	4882	30	1	Kd	-	-
21 67 25 dc	279	5285	5225	7	2	Kd	-	-
21 67 27 dc	485	5320	5282	-	-	Kdgu	*	-
21 67 35 ac	342	5490	5178	8	2	Kd	-	-
21 68 01 ca	725	5375	-	-	-	Kdgu	*	-
21 68 03 ac	151	5420	5389	10	-	Kdgu	-	-
21 68 15 cd	650	5524	5380	-	-	Kdgu	*	-
21 68 15 cd	511	5650	5420	-	-	Kdgu	*	-
21 69 09 dc	600	-	-	-	-	Kdgu	*	-
21 69 33 aa	320	-	-	-	-	Kdgu	*	-
22 65 02 bc	644	4959	4346	15	1	Kd	*	-
22 65 03 cd	951	5530	5530 F(77)	185	8	Kd + Kpul + Jm	-	*
22 65 20 ca	362	5025	5025 F(73)	120	6	Kd	*	*

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
22 65 21 db	495	5070	5035	20	3	Kd	-	*
22 65 32 aa	600	5185	5070	15	3	Kd	-	*
22 66 02 cd	658	5181	5062	-	-	Kdgu	-	-
22 66 03 ab	770	5168	5087	400	6	Kdgu	-	*
22 66 04 a	500	-	-	-	-	Kdgu	*	*
22 66 04 db	630	5265	5115	-	-	Kdgu	-	*
22 66 07 aa	865	5460	5266	-	-	Kdgu	-	-
22 66 07 dd	510	5605	5203	13	2	Kd	-	*
22 66 08 ad	535	5380	-	17	2	Kd	-	*
22 66 08 bc	545	5448	5298	10	2	Kd	-	*
22 66 09 da	620	5350	5164	-	-	Kdgu	-	*
22 66 10 cb	695	5300	5132	30	2	Kd + Kpug	-	*
22 66 18 bc	330	5426	5285	15	3	Kdgu	-	*
22 66 21 ad	514	5480	5280	20	3	Kd	-	*
22 66 28 ba	505	5590	5340	14	2	Kd	-	*
22 67 01 aa	425	5379	5242	15	2	Kdgu	*	*
22 67 01 db	175	5315	5153	20	2	Kd	*	*
22 67 07 db	1200?	6130	5920	-	-	Kdgu + Jm	-	-
22 67 12 ba	210	5373	5203	20	2	Kdgu	*	*
22 67 13 bd	163	5435	5357	20	3	Kdgu	*	*
22 67 18 ac	400	6145	5945	150	1,6	Kdgu	-	*
22 67 18 bd	135	6155	6034	7	3	Kpul	-	*
22 67 22 cc	136	5750	5675	20	3	Kpul	*	*
22 67 23 dc	117	5450	5375	-	-	Kd	*	*
22 67 28 bd	245	5880	5730	15	1	Kpul	-	*
22 67 28 ca	225	5870	5770	-	-	Kpul	*	*
22 67 28 ca	227	-	-	-	-	Kpul	-	*

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
22 67 28 ca	214	5910	5725	-	-	Kpul	-	*
22 67 28 ca	245	-	-	-	-	Kpul	*	*
22 67 28 cc	235	-	-	-	-	Kpul	-	*
22 67 29 cd	237	5945	5780	10	3	Kpul	-	*
22 67 29 dd	300	5970	-	-	-	Kpul	-	*
22 67 30 b	214	5905	-	-	-	Kdgu	-	*
22 67 30 dc	300	6110	5907	-	-	Kpul	*	*
22 67 31 ab	315	6145	5900	10	2	Kpul	-	-
22 67 31 da	325	6122	5817	12	1	Kpul	*	*
22 67 31 db	397	6130	5843	15	3	Kpul	*	*
22 67 31 dc	140	6109	-	-	8	Kpul	*	*
22 67 32 ad	305	5970	5770	15	2	Kpul	-	-
22 67 32 cb	435	6102	5802	15	2	Kpul $\pm$ Jm	*	*
22 67 33 ca	252	5975	5805	15	3	Kpul	-	*
22 67 34 cd	273	-	-	-	-	Kdgu	-	*
22 68 11 dc	400	6560	6236	4	1	Kpul + Jm	*	-
22 68 12 dc	135	6217	-	3	3	Kdgu	*	-
22 68 13 da	365	6260	6001	-	-	Kpul $\pm$ Jm	*	*
23 65 06 cd	650	5420	5227	-	-	Kdgu	-	-
23 65 07 ac	500	5461	5182	15	1	Kd	-	-
23 65 07 bc	475	5440	5165	15	1	Kd	-	*
23 65 07 bc	650	-	-	-	-	Kdgu	-	*
23 65 08 b	320	-	-	-	-	Kdgu?	-	*
23 66 08 c	110	-	-	-	-	Kdgu?	-	*
23 66 09 d	100	-	-	-	-	Kdgu?	-	*
23 66 17 a	100	-	-	-	-	Kdgu?	*	*
23 66 20 dd	535	5830	5552	-	-	Kdgu	-	-

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
23 66 26 cc	250	5400	5320	50	3	Kdgu	-	-
23 66 28 bb	559	5820	5276	15	2	Kpul	-	-
23 66 29 ad	314	5670	5605	25	2	Kd	-	-
23 66 32 bb	342	5690	5509	15	2	Kd	-	-
23 66 32 cd	508	5840	5546	15	2	Kd	-	-
23 66 35 cc	887	5400	5294	-	-	Kdgu	-	-
23 67 03 dc	460	5912	-	-	-	Kpul	-	-
23 67 06 ba	277	6080	5885	50	1	Kdgu	-	*
23 67 06 cc	887	5400	5294	-	-	Kdgu	-	-
23 67 03 dc	460	5912	-	-	-	Kpul	*	*
23 67 06 ba	277	6080	5885	50	1	Kdgu	-	*
23 67 06 cc	250	6030	5967	15	1	Kpul	*	*
23 67 06 cc	151	6000	5888	12		Kdgu	-	*
23 67 07 cb	418	6200	5899	20	2	Kpul	*	*
23 67 07 cc	570	6230	5948	-	-	Kpul	*	*
23 67 11 dd	233	5750	5735	-	-	Kdgu	-	-
23 67 13 ad	130	5630	-	-	-	Kdgu	*	-
23 67 13 ba	120	-	-	-	-	Kdgu	*	-
23 67 22 d	185	-	-	10	1	Kdgu	*	*
23 67 22 dc	281	5830	5630	12	1	Kd	*	*
23 67 23 b	300	-	-	-	-	Kdgu	-	*
23 67 24 bb	315	5712	5531	500	6	Kdgu	*	*
23 67 24 cd	293	5685	5549	10	1	Kpug + Kpul	-	*
23 67 26 aa	244	5780	5626	200	6	Kd	-	-
23 67 26 b	300	-	-	-	-	Kdgu	-	*
23 67 26 bb	181	5780	5654	100	6	Kd	*	-
23 67 27 ac	380	5860	5662	200	6	Kd	-	-
23 67 27 cb	176	5940	5775	200	6	Kd	-	-
23 67 28 bd	118	5980	5940	200	6	Kd	-	-
23 67 28 cd	200	6040	5984	25	6	Kdgu	-	*

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
23 67 32 b	288	6200	-	8	-	Kdgu	-	*
23 67 33 b	400	-	-	-	-	Kdgu	*	*
23 67 34 aa	505	5905	4834	10	2	Kd	*	*
23 67 35 ad	500	6025	5599	12	2	Kd	-	-
23 67 35 cc	510	6080	5867	12	2	Kd	-	-
23 67 35 db	535	6000	-	20	3	Kd	-	*
23 67 35 dd	495	5920	5531	-	-	Kd	*	*
23 68 01 aa	247	6130	6005	-	-	Kpul	*	*
23 68 01 ad	150	-	-	-	-	Kpul	*	*
23 68 01 cd	335	6260	6120	-	-	Kpul	*	*
23 68 01 da	164	6095	5984	10	1	Kdgu	*	*
23 68 01 dc	300	6219	6009	-	-	Kdgu	*	-
23 68 01 dd	150	-	-	-	-			
23 68 12 aa	172	6119	6058	200	6			
23 68 14 ad	-	-	-	-	-			
23 68 15 dd	447	6940	6500	5	3			
23 68 24 bb	467	6320	6008	100	8			
23 68 24 bd	558	6330	6022	-	-			
23 68 24 da	400	-	-	-	-			
24 66 08 cd	645	5800	5565	-	-			
24 66 09 cd	359	5670	5560	25	2			
24 66 16 ca	644	5795	5573	200	-			
24 66 17 ad	500	5801	5551	15	-			
24 66 17 da	715	5770	-	110	-			
24 66 17 da	477	5790	5575	20	-			
24 66 17 dc	475	5790	5548	50	-			
24 66 18 cc	1300	5780	-	370	-			
24 66 19 cd	896	5842	-	-	-			

LOCATION	DEPTH ft.	WELL ELEVATION ft. above S.L.	WATER LEVEL ft. above S.L.	YIELD gpm	USE	GEOLOGIC SOURCE	WATER ANALYSIS	RADIUM-226 ANALYSIS
24 66 20 bb	500	5702	5604	12	1			
24 66 20 ca	635	5775	5590	250	8			
24 66 31 ba	333	6019	5770	-	-			
24 67 01 d	550	-	-	-	-	Kdgu	*	*
24 67 01 db	530	-	-	-	-	Kdgu	*	-
24 67 02 db	585	-	-	-	-	Kdgu	*	-
24 67 09 da	315	6130	5965	65	-	Kd	-	-
24 67 10 cc	715	6300	5975	300	-	Kd + Kpug	*	-
24 67 12 ac	620	5890	5567	12	-	Kd	*	*
24 67 13 db	585	5890	5706	-	-	Kdgu	-	-
24 67 14 ca	485	6020	5923	-	-	Kdgu	-	-
24 67 20 da	153	7005	6926	73	8	Kd	-	-
24 67 21 ac	134	7080	7006	10	8	Kd	*	-
24 67 22 ac	313	6241	6082	60	8	Kpul + Jm	-	-
24 67 23 bc	693	6080	5964	200	8	Kd + Kpul	-	-
24 67 24 dc	820	5865	-	150	8	Kdgu	*	*
24 67 30 ca	485	6835	6675	60	-	Kdgu ± Jm	*	-
24 67 30 da	260	6800	6618	-	-	Kpug ∓ Kpul	-	-
24 67 31 bb	702	6920	6631	40	8	Kdgu	*	-
24 67 32 aa	190	6460	6310	30	-	Kdgu	*	-
24 67 32 aa	178	-	-	-	-	Kdgu	*	-
24 67 36 ad	228	-	-	-	-	Kdgu	-	-
24 68 23 ab	160	-	-	-	-	Kdgu	*	-

APPENDIX C

CHEMICAL ANALYSES OF GROUND WATER FROM SELECTED WELLS COMPLETED IN THE DAKOTA GROUP AQUIFER OF THE CANON CITY EMBAYMENT

CHEMICAL ANALYSES OF GROUND WATER FROM SELECTED DAKOTA GROUP WELLS

Explanation: SAR = sodium absorption ratio; TDS = total dissolved solids (mg/1); SP.COND. = specific conductance (mmho/cm at 25 C); pH is field determined unless followed by "L" which indicates lab determination; T = temperature (C); concentrations of remaining constituents in mg/1.

LOCATION	Ca	Mg	K	Na	HCO	Cl	F	SO	NO + NO	Fe	Total Hard.	SAR	TDS	SP.COND.	pH	T
19 68 07 cc	170	73	22	280	1210	120	1.3	240	0.05	0.90	720	4.5	1530	2370	5.2	31.0
19 68 23 ba	220	98	26	290	1380	91	0.6	290	0.10	3.80	950	4.1	1720	2420	6.9L	-
19 68 30 bc	160	70	33	280	1170	130	1.2	230	0.17	0.06	690	4.6	1520	2330	6.5	55.0
19 69 01 da	160	70	33	300	1120	120	1.3	230	0.02	0.01	690	5.0	1540	2390	6.8L	31.5
19 69 01 dc	150	68	33	300	1170	120	1.4	240	0.15	0.02	650	5.1	1520	2320	6.5L	41.0
21 67 27 dc	80	44	25	270	607	67	1.0	410	0.38	0.38	390	6.0	1220	1760	6.9	14.0
21 68 01 ca	150	48	38	490	1250	270	2.1	330	-	4.70	570	8.9	1960	3010	6.2	21.0
21 68 11 cc	59	20	17	290	798	100	2.4	94	0.00	0.06	230	8.3	995	1640	6.8	19.0
21 68 15 cd	140	46	37	500	1380	240	2.0	240	0.02	3.10	540	9.4	1920	3020	6.3	22.0
21 69 09 dc	41	13	3.3	13	210	2.2	0.4	20	0.08	0.40	160	0.5	214	349	7.2L	15.0
21 69 33 aa	58	20	3.9	17	253	6.4	0.5	44	0.02	0.14	230	0.5	301	497	7.5	-
21 65 02 bc	76	33	12	91	287	16	1.1	280	0.02	22.00	330	2.2	681	1020	7.1	19.0
22 65 20 ca	99	32	5.6	44	214	10	0.8	320	0.45	3.00	200	1.0	631	915	6.7L	19.0
22 66 04 a	190	73	11	130	280	10	0.9	800	-	24.00	780	2.0	1380	1720	7.3	16.0
22 67 01 aa	74	62	19	390	692	22	1.3	720	0.00	5.30	440	8.1	1640	2240	8.3	17.0
22 67 01 db	150	51	8.6	120	307	13	0.8	560	0.04	9.30	590	2.2	1080	1460	6.4	15.5
22 67 12 ba	74	27	12	71	360	17	1.5	160	0.01	4.80	300	1.8	556	857	6.3	15.5
22 67 13 bd	59	21	3.4	19	92	6.3	0.5	220	0.13	22.00	230	0.5	410	589	6.1	8.0
22 67 22 cc	71	120	1.3	15	9	3.7	0.8	690	0.02	11.00	670	0.3	927	1240	5.2L	14.0
22 67 23 dc	73	28	3.0	17	12	4.4	0.4	330	0.01	30.00	300	0.4	505	660	6.4	14.0
22 67 28 ca	120	37	4.4	40	269	20	0.7	300	0.94	0.05	450	0.8	672	992	7.6L	13.0
22 67 28 ca	78	26	3.9	37	292	12	0.5	140	0.03	3.90	300	0.9	460	718	6.8	13.5
22 67 30 dc	59	8.7	2.4	15	194	9.4	0.2	47	2.90	0.03	180	0.5	290	455	6.8	11.0

LOCATION	Ca	Mg	K	Na	HCO	Cl	F	SO	NO + NO	Fe	Total Hard.	SAR	TDS	SP.COND.	pH	T
22 67 31 da	120	57	5.5	43	376	5.6	0.5	330	0.04	1.60	540	0.8	761	1090	7.2	12.5
22 67 31 db	35	38	7.0	74	200	6.4	0.4	240	0.01	0.009	240	2.1	503	780	7.7	14.0
22 67 31 dc	43	7	2.7	20	147	13	0.5	43	1.40	0.03	140	0.7	236	371	7.6	10.5
22 67 32 cb	120	62	5.9	82	381	25	0.6	390	2.00	0.03	560	1.5	893	1270	7.6	5.5
22 67 11 dc	24	6.2	5.1	220	273	12	0.6	330	0.12	0.07	85	10	743	1120	8.0L	15.0
22 68 12 dc	66	15	2.3	21	237	9.2	0.6	71	2.50	0.009	230	0.6	341	543	8.0	14.0
22 68 13 da	43	21	5.1	93	319	5.5	0.7	140	0.03	0.05	200	2.9	476	771	7.9	13.0
23 66 17 a	120	18	3.3	21	170	6.5	0.9	280	---	0.5	370	0.5	549	798	6.8	13.0
23 67 03 dc	150	52	5	60	464	3.1	0.4	320	0.00	0.09	590	1.1	831	1210	7.5	---
23 67 06 cc	41	9.8	2.3	16	180	4.8	0.8	28	0.01	1.90	140	0.6	209	351	7.3	15.5
23 67 07 cb	39	14	4.8	120	342	4.0	0.8	130	1.10	0.05	160	4.2	497	800	8.0	14.0
23 67 07 cc	98	41	5	52	397	2.6	0.5	200	0.04	34.00	410	1.1	642	954	6.8	15.5
23 67 13 ad	63	16	2.1	19	243	5.5	0.9	57	1.40	0.06	220	0.6	300	496	7.2	7.5
23 67 13 ba	83	6.8	1.8	38	297	13	0.6	64	0.55	0.09	240	1.1	376	598	7.3	13.0
23 67 22 d	68	17	2.5	16	240	2.4	0.4	76	---	0.59	---	---	---	508	7.1	19.0
23 67 22 dc	370	200	4.9	46	370	21	0.3	1400	---	0.19	1700	0.5	2240	2580	7.3	15.0
23 67 24 bb	200	68	4.5	63	325	35	0.6	590	1.90	0.05	780	1.0	1140	1540	7.5L	---
23 67 26 bb	390	480	5.3	76	421	29	1.0	2700	12	0.55	3000	0.6	3960	4110	6.6	11.0
23 67 33 b	64	13	3.6	54	300	9.9	0.6	69	----	0.65	210	1.6	377	600	7.1	16.0
23 67 34 aa	54	13	3	19	237	2.2	0.5	48	0.04	2.80	190	0.6	269	444	7.1	14.0
23 67 35 dd	56	14	3.6	25	248	2.6	0.6	52	0.01	2.50	200	0.8	289	475	7.3L	13.5
23 68 01 aa	110	21	2.3	57	270	69	0.3	83	30	0.08	360	1.3	638	999	7.2	12.0
23 68 01 ad	82	13	1.9	42	309	23	0.7	65	4.90	0.04	260	1.1	427	682	7.2L	6.0
23 68 01 cd	59	9.6	2.2	28	223	20	0.7	40	2.40	0.04	190	0.9	307	502	7.2	11.0
23 68 01 da	47	13	2.9	14	170	5.0	0.6	72	0.05	1.60	170	0.5	253	404	6.7	13.0
23 68 01 dc	37	11	3.5	14	167	3.4	0.8	33	0.07	0.69	140	0.5	199	339	7.6	14.5
23 68 14 ad	260	22	5.5	79	434	61	0.5	390	24	0.13	740	1.3	1160	1620	7.3L	10.5
23 68 24 bb	76	40	4.1	22	354	4.2	0.4	110	5.80	1.00	360	0.5	469	733	7.3L	16.5

LOCATION	Ca	Mg	K	Na	HCO	Cl	F	SO	NO + NO	Fe	Total Hard.	SAR	TDS	SP.COND.	pH	T
23 68 24 bd	93	33	4.2	20	373	5.5	0.2	120	0.04	0.14	370	0.5	471	761	7.5L	16.5
23 68 24 da	180	26	5	68	397	33	0.7	300	12	0.05	560	1.3	876	1270	7.6L	12.0
24 66 17 da	70	29	10	160	412	28	1.0	260	0.03	12.00	290	4.1	783	1200	7.1	---
24 66 17 dc	110	28	3.8	87	300	92	0.6	120	---	0.21	390	1.9	602	1150	7.2	18.0
24 66 19 cd	77	13	2.6	19	266	4	0.6	61	0.04	0.51	250	0.5	324	551	7.6L	14.5
24 66 20 bb	60	15	3.4	30	282	4.3	0.7	48	0.52	3.50	210	0.9	315	526	7.3L	---
24 66 20 ca	5	2.7	3.7	31	65	8.5	0.6	40	0.38	0.05	24	2.8	126	217	8.5L	14.0
24 67 01 d	55	13	3.1	22	240	1.9	0.6	46	---	1.70	190	0.7	271	461	7.3	16.0
24 67 01 db	53	13	3.2	22	246	2.0	0.6	42	0.04	1.90	190	0.7	269	453	7.4	15.0
24 67 02 db	75	16	3.3	25	271	3.3	0.4	96	0.02	3.30	250	0.7	372	595	7.2L	19.0
24 67 10 cc	100	9.9	1.9	28	360	5.1	0.4	50	---	0.05	290	0.7	398	855	7.2	12.0
24 67 12 ac	63	14	3.4	29	278	3.7	0.6	55	0.06	5.90	220	0.9	321	531	6.8	16.0
24 67 21 ac	34	9.8	11	7.6	178	4.8	0.1	9.7	0.20	0.009	130	0.3	177	299	7.2	12.0
24 67 24 dc	130	24	2.8	21	250	3.6	0.2	270	---	2.10	420	0.4	594	856	7.3	17.0
24 67 30 ca	82	10	2	21	209	3.7	0.2	120	2.00	0.05	250	0.6	366	581	7.0L	12.0
24 67 31 bb	48	7.2	2.2	20	202	3.2	0.4	34	0.13	3.20	150	0.7	232	383	7.6L	14.5
24 67 32 aa	77	11	1.6	42	322	7.9	0.6	50	0.91	0.04	240	1.2	377	599	7.2	10.0
24 67 32 aa	45	9.2	2.4	22	166	3.3	0.4	63	0.01	9.90	150	0.8	248	399	6.9L	13.0
24 68 23 ab	55	11	0.8	34	291	3.8	0.2	16	0.63	0.03	180	1.1	289	481	6.9	9.0

APPENDIX D

VALUES OF RADIUM-266 ACTIVITY OF THE GROUND WATER F

FROM SELECTED WELLS COMPLETED IN THE DAKOTA GROUP

AQUIFER OF THE CANON CITY EMBAYMENT

RADIUM-226 ACTIVITY (picocuries per liter, pCi/1)

	Colorado State Health (Number in parentheses indicates month sampled)			Vinckier
LOCATION	1972	1973	1974	July 1977
18 68 33 ab	--	--	--	0.16
18 68 33 db	--	--	--	0.22
19 65 16 cc	--	--	--	2.32
19 65 18 bc	--	--	--	19.85
19 67 01 cc	--	(3) 1.5	--	2.49
19 67 08 cc	--	--	--	5.65
19 67 08 da	--	--	--	2.13
19 67 09 bb	--	--	--	8.49
19 67 19 da	--	(3) 5.3	--	4.41
19 67 20 d	--	(3) 4.5	--	--
19 67 29 ca	--	--	--	7.40
19 68 07 bb	--	--	--	34.95
19 68 07 cc	--	--	--	18.90
19 68 23 bb	--	--	--	80.23
19 69 01 c	--	(1) 6.5	--	--
19 69 01 da	--	--	--	11.8
19 69 01 dc	--	--	--	6.7
19 69 14 dd	--	--	--	38.00
19 69 14 dd	--	--	--	92.80
19 69 14 dd	--	--	--	45.00
19 69 24 cd	--	--	--	172.80
"	--	--	--	92.45
20 65 33 cb	--	--	--	0.24
20 65 33 cde	--	--	--	0.04
20 66 07 aa	--	--	--	18.81

LOCATION	1972	1973	1974	July 1977
20 66 11 ac	--	--	--	10.49
20 66 12 dc	--	--	--	12.15
20 66 16 ac	--	--	--	18.37
20 66 24 aa	--	--	--	14.52
20 66 24 bb	--	--	--	22.82
20 67 06 ba	--	(1)19.2	--	24.20
20 67 08 ab	--	(1)14.6	--	11.13
21 65 04 cd	(7) 3.7	--	--	--
21 65 05 ab	(7)11.0	--	--	--
21 65 32 cc	--	(1) 7.7	--	--
21 65 35 ac	(7) 0.0	--	--	--
21 66 13 d	(7) 6.8	--	--	--
21 66 24 bb	--	--	--	11.37
21 66 26 ca	(7) 0.3	--	--	--
21 68 15 cd	--	(3)239.0,(7)118.8	--	--
22 65 03 cd	--	--	--	12.76
22 65 20 ca	--	--	--	9.09
22 65 21 db	--	--	--	8.26
22 65 32 aa	--	--	--	11.57
22 66 03 ab	--	(7)10.4	--	10.29
22 66 04 a	(8)11.0,(12) 6.6	(7) 5.9	--	--
22 66 04 db	--	--	--	10.72
22 66 07 dd	(8) 6.3	--	--	10.79
22 66 08 ad	(8) 7.6	--	--	--
22 66 08 bc	(8) 9.6,(12)11.1	(7) 9.6	--	5.71
22 66 09 da	(7) 6.0	(7) 8.7	--	--
22 66 10 cb	--	--	--	14.00
22 66 18 bc	--	--	--	10.80
21 66 21 ad	(7) 3.0	--	--	--
22 66 28 ba	(7) 6.9	--	--	--

LOCATION	1972	1973	1974	July 1977
22 67 01 aa	--	--	--	3.83
22 67 01 db	--	--	--	6.50
22 67 12 ba	--	--	--	2.55
22 67 13 bd	(8) 6.3	--	--	2.61
22 67 18 ac	--	--	--	1.40
22 67 22 cc	(12) 3.8	-	-	0.81
22 67 23 dc	(10)14.6	(3) 6.0,(7) 9.1	-	8.12
22 67 28 bd	-	-	-	3.86
22 67 28 ca	(10)37.7	(3)17.0,(6)12.1	-	19.30
22 67 28 ca	-	(8)17.9	-	19.71
22 67 28 ca	-	-	-	27.51
22 67 28 ca	(10)84.3	(8)29.9	-	-
22 67 28 cc	-	(8)48.2	-	88.15
22 67 29 cd	(12)10.8	(7)11.5	-	13.27
22 67 30 b	-	(7)20.0	-	-
22 67 30 dc	(12) 0.0	-	-	1.49
22 67 31 da	(10)22.4	(3) 9.8,(7) 8.5,(7) 7.8	-	-
22 67 31 db	(12) 1.8	(4) 0.7	-	5.49
22 67 31 db	(8) 0.0	-	-	2.63
22 67 32 cb	(10)14.1	(8) 3.7	-	0.04
22 67 33 ca	(10)14.3	(3)19.9	-	-
22 67 34 dc	-	-	-	39.21
22 68 13 da	-	-	-	0.90
23 65 07 bc	(8) 6.8	-	-	-
23 65 07 bc	(8) 5.5	-	-	-
23 65 08 b	-	(7) 5.3	-	-
23 66 08 c	-	(7) 3.1	-	-
23 66 09 d	-	(3) 1.6	-	-
23 66 17 a	(12)29.6	(3)10.9	-	-
23 67 03 dc	-	(7) 2.2	-	-
23 67 06 ba	(10) 2.9	-	-	9.46
23 67 06 cc	(8) 4.5, (12)11.4	(3) 7.5, (7) 5.7	-	-

LOCATION	1972	1973	1974	July 1977
23 67 06 cc	-	-	-	0.35
23 67 07 cb	(12) 0.8	(3) 0.5	-	-
23 67 07 cc	-	(4) 0.8	-	-
23 67 22 d	(12)21.0	(3)32.0, (7)50.5	-	-
23 67 22 dc	-	(7)78.9	-	-
23 67 23 b	-	(3)44.0, (7)50.5	-	-
23 67 24 bb	(12) 1.1	(7) 3.0	-	-
23 67 24 cd	(12) 8.9	(7)38.2	-	-
23 67 26 b	(12) 7.0	(7) 1.6	-	-
23 67 28 cd	(12)10.3	(7) 5.7	-	-
23 67 32 b	-	(6) 6.4, (7) 1.9	-	-
23 67 33 b	(12)10.1	-	-	-
23 67 34 aa	(12) 3.5	-	-	-
23 67 35 db	(12) 1.8	-	-	-
23 67 35 dd	-	(4) 4.1	-	-
23 68 01 aa	(10) 7.7	-	-	-
23 68 01 ad	(8) 0.0, (12) 0.4	-	-	-
23 68 01 cd	(8) 9.1	(4) 3.5, (7) 4.1	-	-
23 68 01 da	(8)426.0,(12)315.8,431.6	(3)359.4,(4)184.6,(7)192.8	420.0	620.32
23 68 01 dd	(8) 1.1	-	-	0.65
24 66 17 da	-	(1)24.4	-	-
24 66 17 da	(8)15.2,92.2,(12)32.5	(1)32.3,28.2	-	-
24 66 17 dc	(8)96.3	(1)96.3,88.3,76.5,72.9, 70.6,67.4,66.4	-	-
24 66 18 cc	(10)29.4	(1)38.2	-	-
24 66 19 cd	(10)178.4	(1)32.3	-	-
24 66 20 bb	(8)26.5,(10)78.8,(12)32.5	(7)35.6,31.1	-	-
24 67 01 d	(12) 7.7	-	-	-
24 67 12 ac	(12) 8.9	(7)10.3	-	-
24 67 24 dc	(10)37.9	-	-	-

COLORADO GEOLOGICAL SURVEY
DEPT. OF NATURAL RESOURCES

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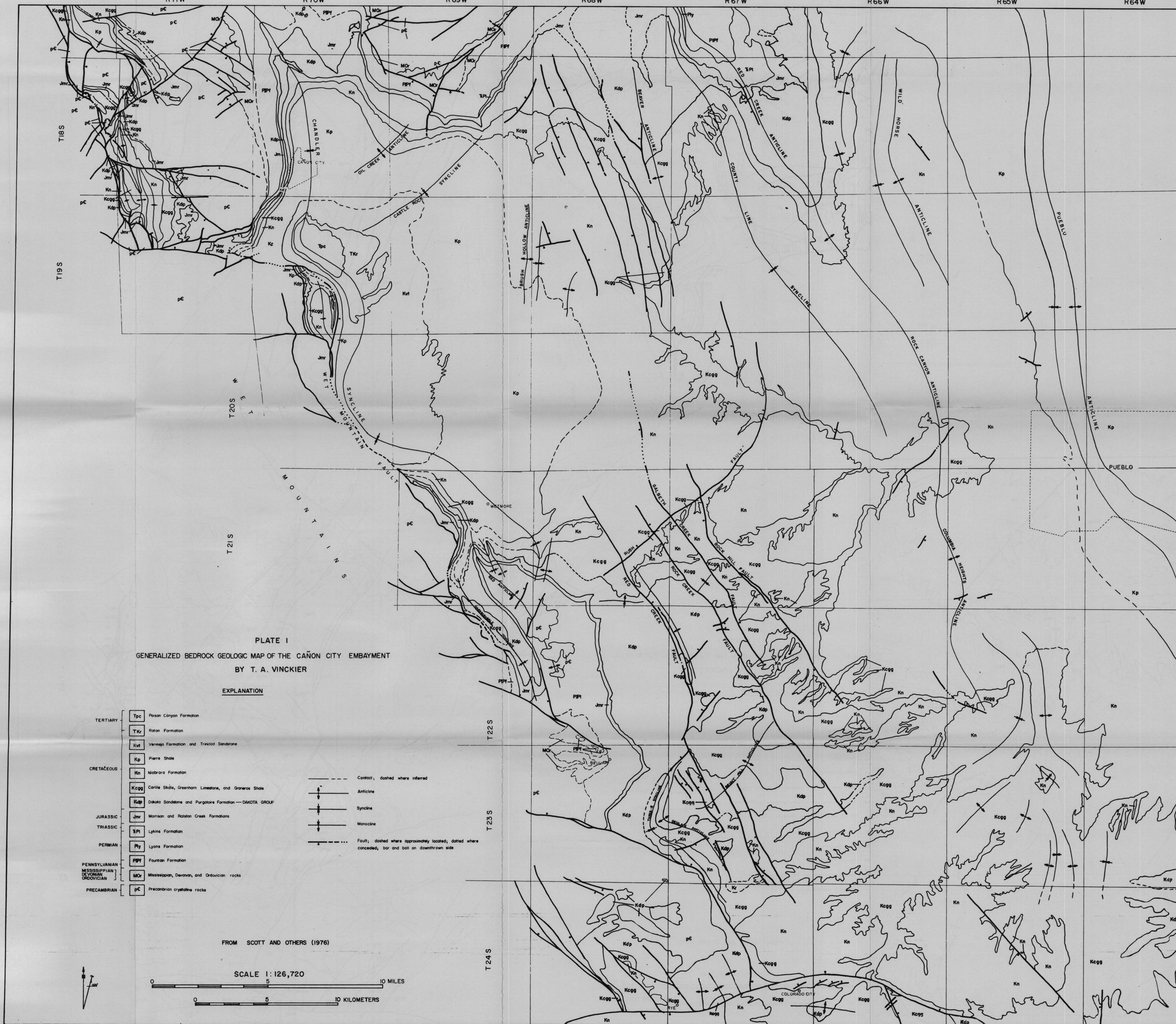
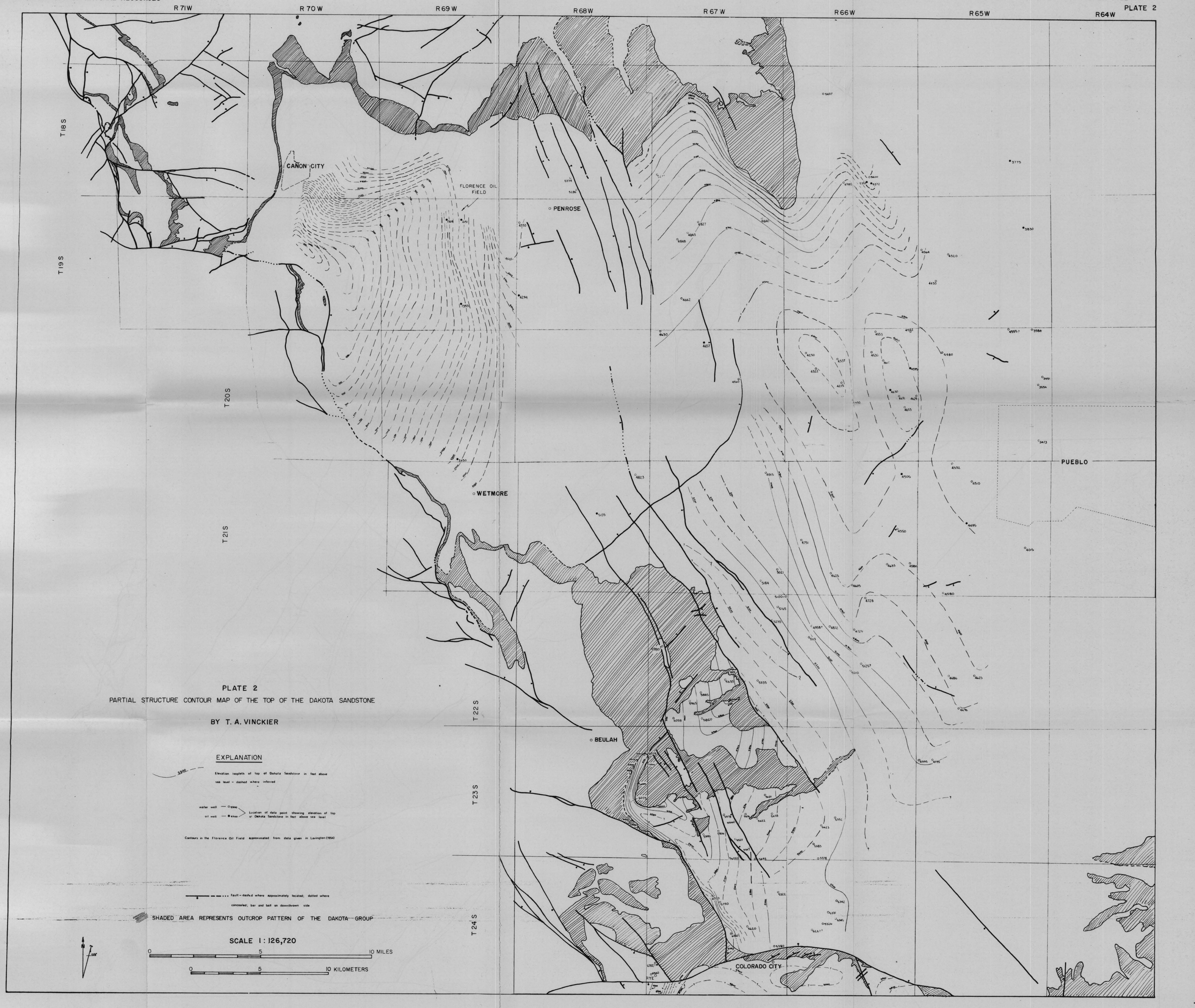
PLATE I



COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES

OPEN FILE 82-3
PLATE 2



COLORADO GEOLOGICAL SURVEY
DEPT. OF NATURAL RESOURCES

OPEN FILE 82-3
PLATE 3

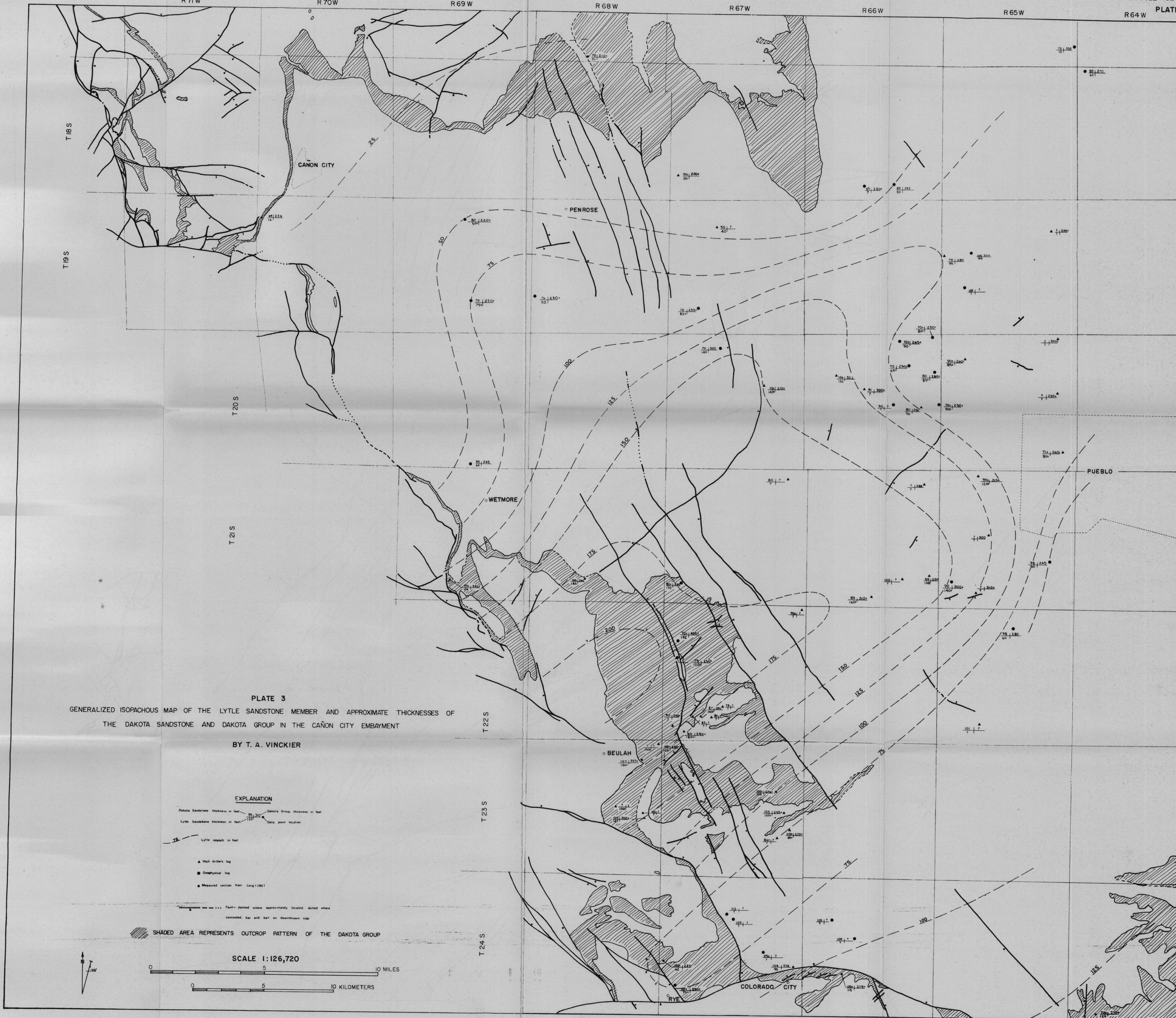


PLATE 3

GENERALIZED ISOPACHOUS MAP OF THE LYTLE SANDSTONE MEMBER AND APPROXIMATE THICKNESSES OF THE DAKOTA SANDSTONE AND DAKOTA GROUP IN THE CAÑON CITY EMBAYMENT

BY T. A. VINCKIER

COLORADO GEOLOGICAL SURVEY
DEPT. OF NATURAL RESOURCES

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PLATE 4

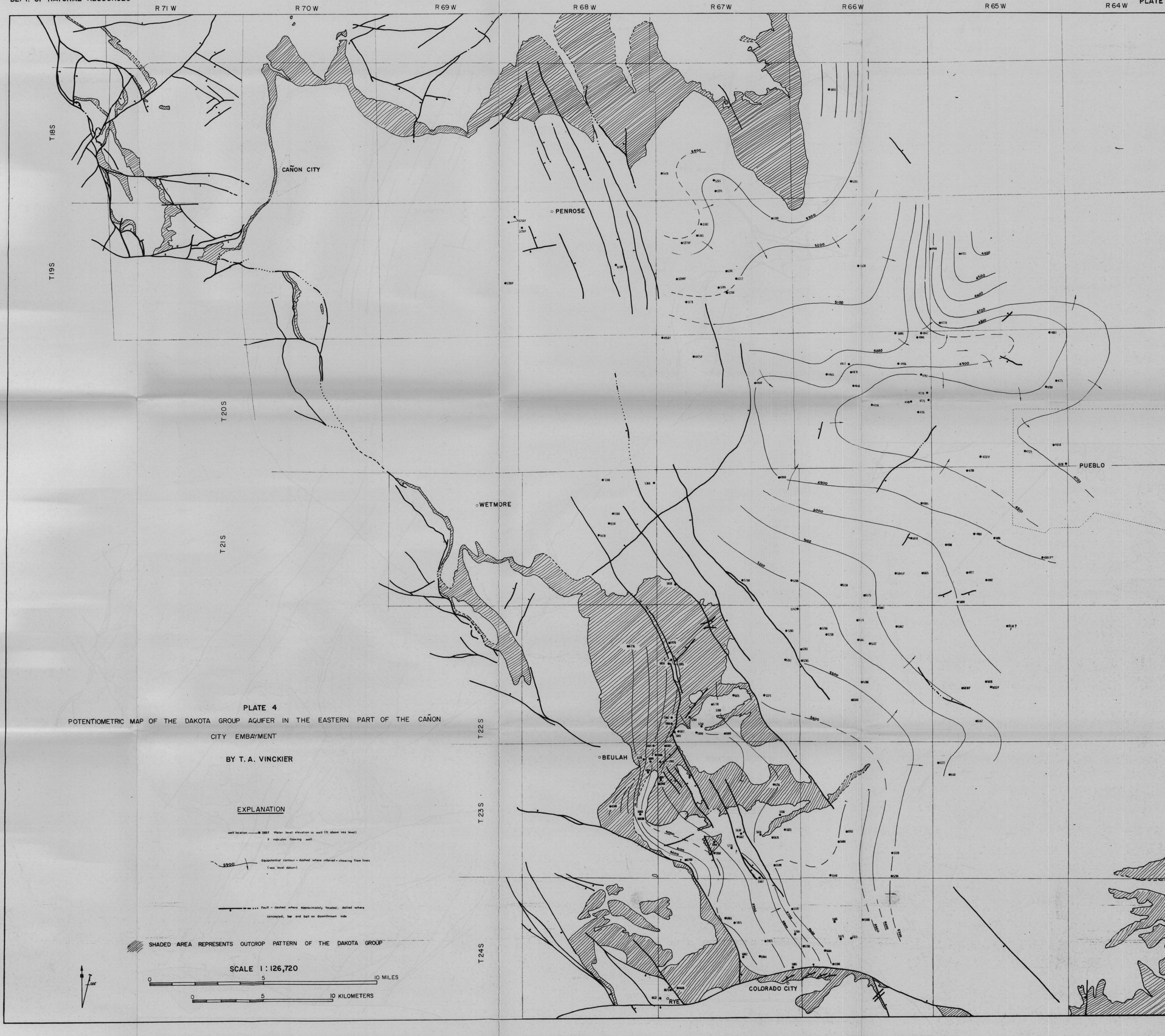

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PLATE 5

PLATE 5

MAP OF STIFF DIAGRAMS SHOWING THE MAJOR CHEMICAL CONSTITUENTS OF GROUND WATER FROM THE DAKOTA GROUP AQUIFER

BY T. A. VINCKIER


R71W
R70W
R69W
R68W
R67W
R66W
R65W
R64W
T18S
T19S
T20S
T21S
T22S
T23S
T24S
CAÑON CITY
PENROSE
WETMORE
PUEBLO
BEULAH
RYE
COLORADO CITY
PLATE 6
DISTRIBUTION OF SELECTED CHEMICAL CHARACTERISTICS OF DAKOTA GROUP GROUND WATER
BY T. A. VINCKIER
EXPLANATION
Ca/Na
SAR
5·3 | 2·9
982
Sp. cond.
well location
Specific conductance in mmho cm at 25°C
Sodium absorption ratio = Na / √((Ca+Mg)/2)
Ca, Na, Mg in meq/l
Fault - dashed where approximately located; dotted where concealed; bar and ball on downthrown side
SHADED AREA REPRESENTS OUTCROP PATTERN OF THE DAKOTA GROUP
SCALE 1: 126,720
0
5
10 MILES
0
5
10 KILOMETERS

COLORADO GEOLOGICAL SURVEY
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PLATE 7

PLATE 8. Cumulative curve and histogram showing the frequency distribution of radium-226 in Dakota Group ground water in the Cañon City embayment