UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY DATA FOR NORTHERN GREAT PLAINS TEST WELL 1, NW¼NE¼ SEC. 11, T.55N., R.77W., SHERIDAN COUNTY WYOMING

by. David H. Lobmeyer, Lawrence O. Anna, and John F. Busby

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METRIC CONVERSION TABLE

Factors for converting inch-pound units to metric units are shown in the following table:

Inch-pound	Multiply by	Metric
inch	25.4	millimeter
foot	0.305	meter
cubic foot	0.02832	cubic meter
square mile	2.59	square kilometer
gallon	3.785	liter
gallon per minute	0.0631	liter per second
gallon per minute per foot	0.207	liter per second per meter
pound	0.453	kilogram
pound per square inch	6.8948	kilopascal
mile	1.609	kilometer
pound per gallon	0.1198	gram per cubic centimeter
foot squared per second	0.0929	meter squared per second
foot squared per day	0.0929	meter squared per day

SYMBOLS AND DEFINITIONS LIST

b	Thickness of the tested interval, in feet.
B	Well efficiency factor.
Δs	Change in recovery in one log cycle.
H	Water level in tubing above or below initial hydraulic head in aquifer, in feet, at time, t.
H'	Static water level in feet above ground level.
H_o	Water level in tubing above or below initial hydraulic head in aquifer immediately after discharge, in feet.
k	Hydraulic conductivity.
Q	Discharge rate, in gallons per minute.
Q/s	Specific capacity, in gallons per minute per foot of drawdown.
r_c	Radius of injection tubing, in feet.
r_s	Radius of casing, in feet.
s	Recovery (or drawdown), in feet.
S	Storage coefficient.
t	Time, in days, unless otherwise stated.
T	Transmissivity, in feet squared per day.

PRELIMINARY DATA FOR NORTHERN GREAT PLAINS TEST WELL 1

NW¼NE¼ SEC. 11, T.55N., R.77W., SHERIDAN COUNTY, WYOMING

by

David H. Lobmeyer, Lawrence O. Anna, and John F. Busby

ABSTRACT

This report provides the preliminary data for Northern Great Plains test well 1, including test-well history, geology penetrated by the test well, hydrologic testing, and chemical quality of the water. The report also describes the preliminary results and future testing plans. The intended audience includes: The hydrologist interested in the regional aquifer system; the local water user interested in new sources of water; the drill contractor interested in drilling and well construction; and the water manager.

The test well was drilled as part of the study to determine the water-resource potential of the regional aquifer system in the Northern Great Plains, an area of about 250,000 square miles. Drilling and testing were designed to obtain maximum stratigraphic, structural, geophysical, and hydrologic information.

The test well was drilled in the NW¼NE¼ sec. 11, T.55N., R.77W., Sheridan County, Wyoming, to a depth of 4,485 feet below land surface. The well is cased with 10 3/4-inch casing from the land surface to a depth of 497 feet, and with 7 5/8-inch casing from a depth of 419 to 4,482 feet. The well is constructed so additional hydrologic tests and geophysical logs can be made at a later date.

Nine cores were drilled (five in the Fort Union Formation, two in the Lance Formation, and two in the Pierre Shale) totaling 182 feet; 157.42 feet

of core were recovered. Sidewall cores were obtained from 24 horizons (17 in the Fox Hills Sandstone, and 7 in the Fort Union Formation). Gamma and density scans of the cores were made, and selected parts were tested for density, porosity, and vertical and horizontal permeability. Further analyses of the lithology of the cores are being made.

Eight zones were perforated and tested using conventional drill-stem tests and swabbing. Water samples were obtained from seven zones.

No major potential sources of ground-water were penetrated by the test well. Estimated yields range from about 240 gallons per minute with 400 feet of drawdown to about 5 gallons per minute flow at the surface. No fresh water (less than 1,000 milligrams per liter of dissolved solids) was found in any of the zones tested in the well. Dissolved-solids concentrations ranged from about 1,800 to 3,000 milligrams per liter.

INTRODUCTION

Energy development, power generation, industrial development, increasing irrigation, and increasing use of domestic and municipal water in the Northern Great Plains of Montana, North Dakota, South Dakota, and Wyoming, will depend in a large part on development of ground-water supplies. Streamflow has historically supplied many of the water needs; however, surface water is fully appropriated in much of the area, and it is not always a dependable supply, because flows are extremely variable. Long-term, large-scale water needs will require development of productive aquifers, some of which have been used very little. Generally, maximum sustained yields of ground water cannot be efficiently produced without knowledge of the ground-water system; the system must be sufficiently defined to be predictable. The U.S. Geological Survey conducted a 4-year study of the Northern Great Plains aquifer system that was completed at the end of September, 1981 (U.S. Geological Survey, 1979). The objectives of this study were to define the regional aquifer system in the Northern Great Plains, an area of about 250,000 square miles, and to predict the effects of the development of ground-water supplies. The study area is shown in figure 1.

Many wells have penetrated the rocks (Eocene and Paleocene series) of Tertiary age in the Northern Great Plains, but few data have been collected for hydrologic purposes. The deeper aquifers beneath the Powder River basin are almost completely unused for water supplies. A test hole was necessary to obtain better geologic and hydrologic information. Drilling and testing were designed to obtain maximum stratigraphic, structural, geophysical, and hydrologic information. Careful analysis of cuttings and cores and correlation with geophysical log characteristics will have transfer value with data obtained from oil-well tests and surface geophysical surveys.

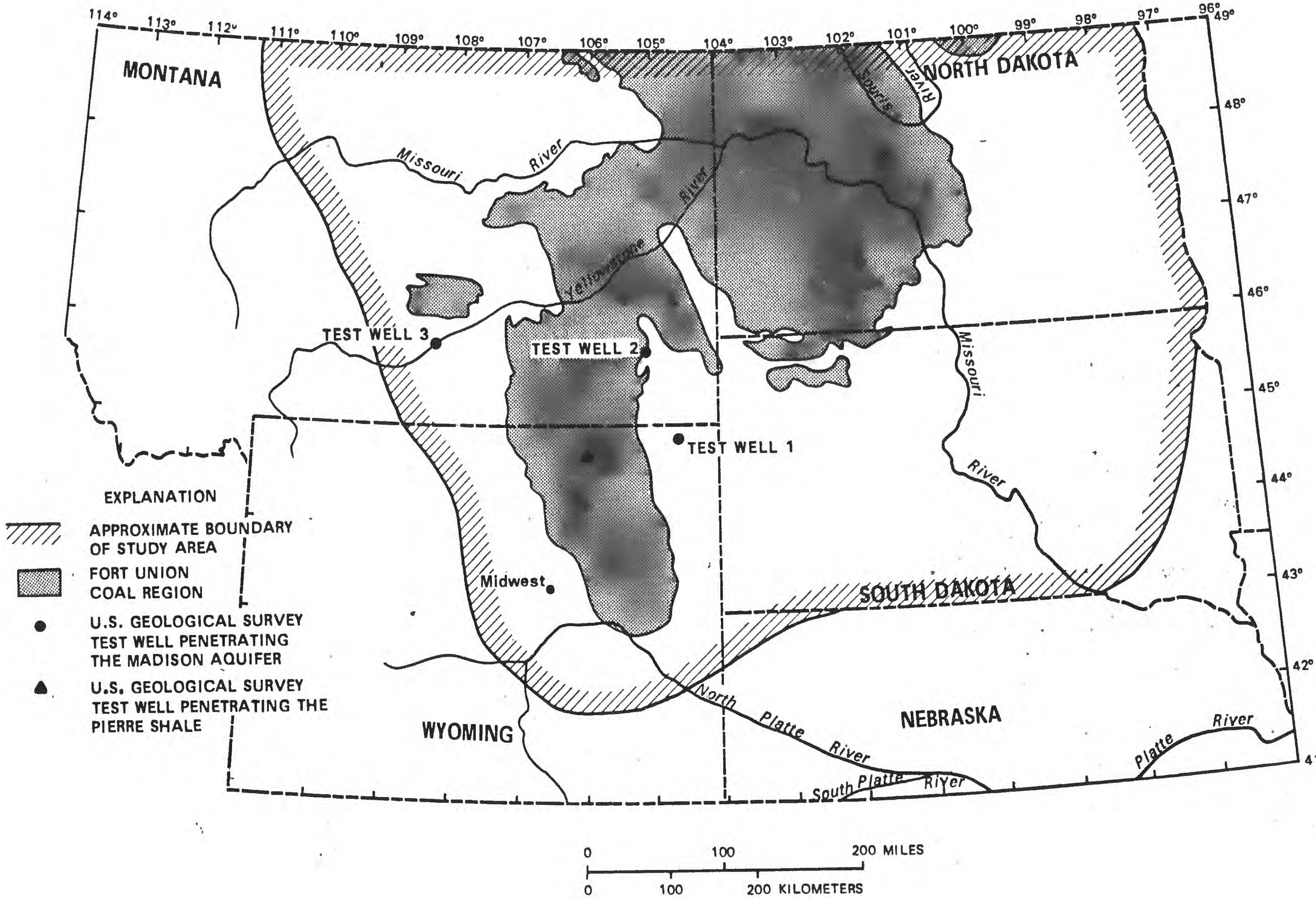


Figure 1.--Location of study area, Northern Great Plains.

This report provides the preliminary data for Northern Great Plains test well 1. The report describes test-well history, geology penetrated by the test well, hydrologic testing, chemical quality of the water, and preliminary results and future plans.

Hydraulic tests were designed to obtain pressure data and subsurface water samples from discrete intervals. These data were used to determine the water yield of isolated zones, the composite yield of the well, and the quality of water.

The site for Northern Great Plains test well 1 was chosen to confirm the ground-water flow model of the upper part of the Powder River Basin and is far enough from wells completed in the Fox Hills Sandstone, that data were needed to define the hydraulic gradient. Northern Great Plains test well 1 is in the NW¼NE¼ sec. 11, T.55N., R.77W., Sheridan County, Wyoming, near the center of the Powder River basin (fig. 2). It is along the Lower Powder River Road, an all-weather gravel-surface road, about 1/4 mile west of the Powder River, 8 miles north of Arvada, Wyoming, about 42 miles east of Sheridan, Wyoming and 44 miles northwest of Gillette, Wyoming.

The well was spudded in the Tongue River Member of the Fort Union Formation of early Tertiary age on September 15, 1978, and bottomed 154 feet below the top of Pierre Shale of Late Cretaceous age at 4,485 feet below land surface on October 4, 1979. The well is cased with 10 3/4-inch casing from the land surface to a depth of 497 feet, and 7 5/8-inch casing from 419 to 4,482 feet below land surface. The well is constructed so additional hydrologic tests and geophysical logs could be made at a later date (figs. 3 and 4). The equipment for the well was designed so that high fluid pressures that were thought to exist could be handled.

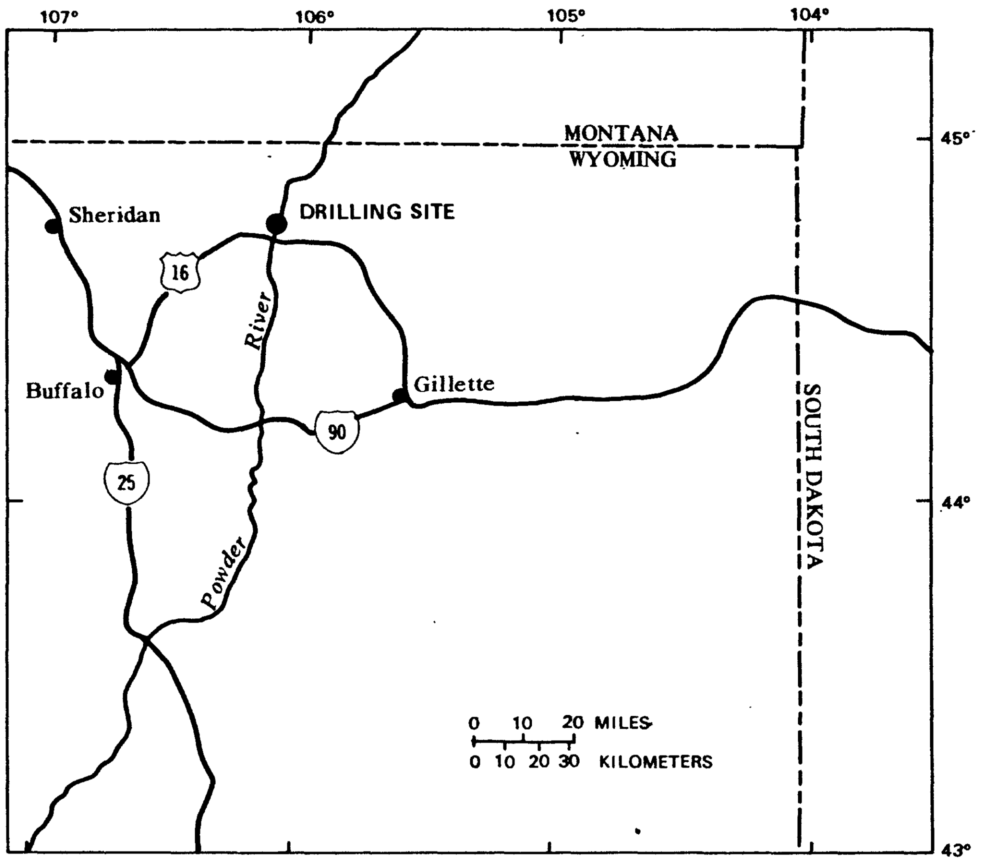


Figure 2.--Location of Northern Great Plains test well 1.

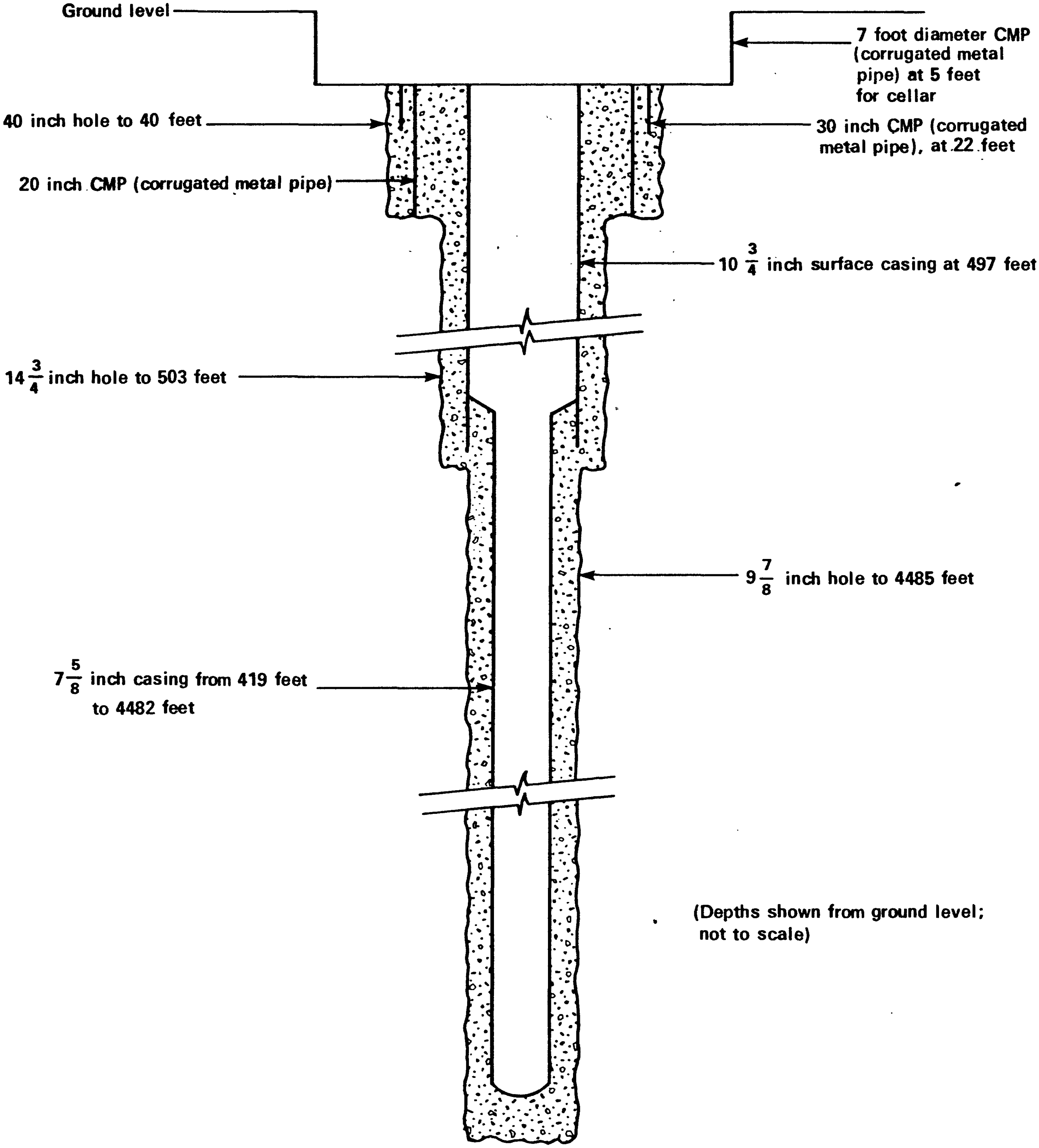


Figure 3.--Construction of Northern Great Plains test well 1.

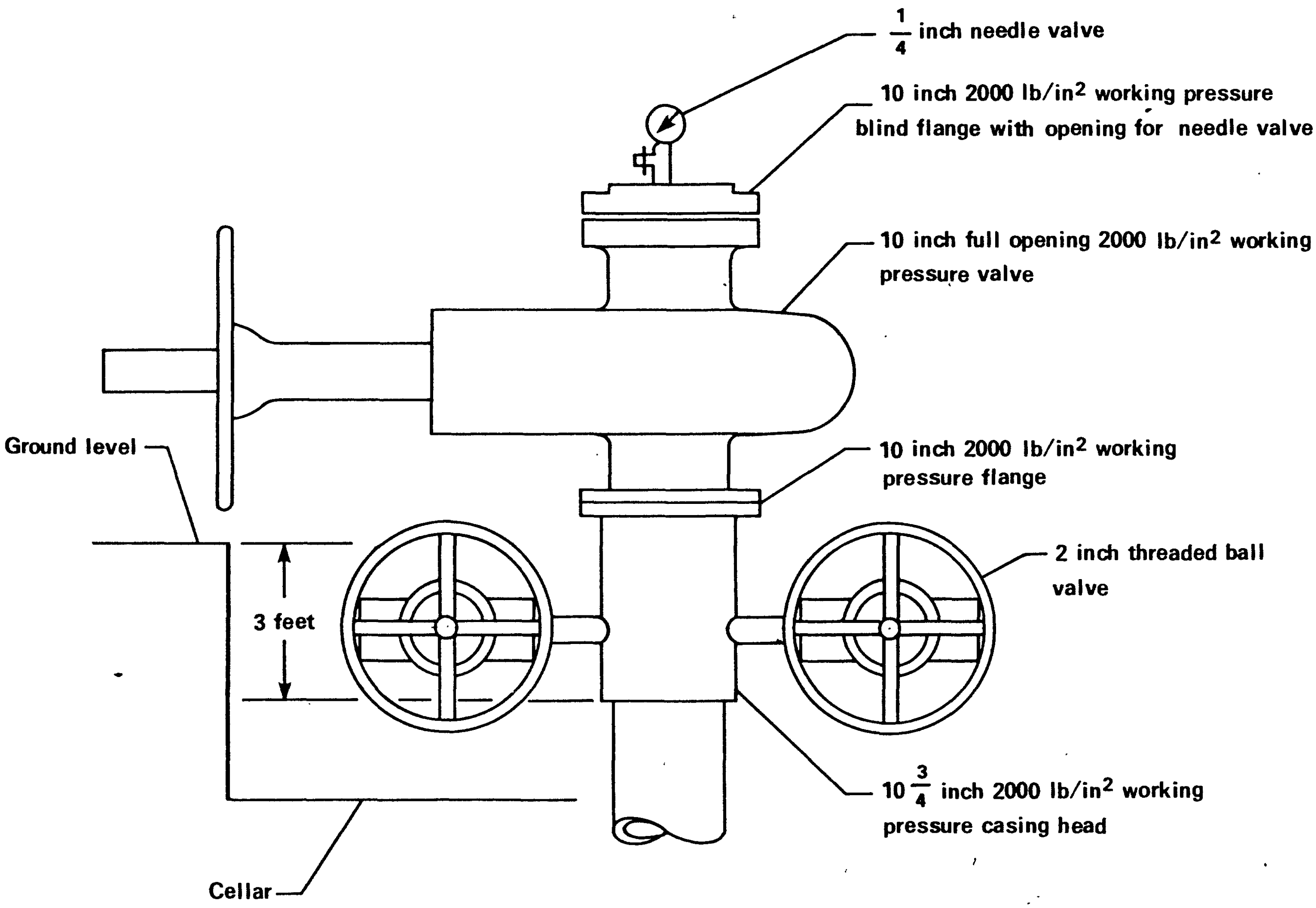


Figure 4.--Well-head equipment of Northern Great Plains test well 1.

Eight zones were perforated and tested with drill-stem tests and swabbing tests. Hydraulic-head data were obtained from all eight zones; water samples were obtained from seven zones.

Nine cores were obtained during drilling; a total of 182 feet were cored, of which 157.42 feet were recovered. Sidewall cores were obtained from 24 horizons. Gamma and density scans of the cores were made, and selected parts were tested for density, porosity, and vertical and horizontal permeability.

Many individuals from the U.S. Geological Survey, other Federal agencies, State agencies, and industry contributed to the successful completion of Northern Great Plains test well 1. No attempt will be made to list all the U.S. Geological Survey personnel involved in the operation; however, special recognition must be given to Thad Custis (deceased), H. Lee Case, William R. Hotchkiss, and Dwight T. Hoxie for their contribution in the site selection, drilling operation, and testing of the well.

Fenix & Scisson, Inc., Tulsa, Oklahoma, the drilling contractor, assisted with preparation of the drilling specifications and provided a drilling specialist at the drill site. Fenix & Scisson, Inc. also prepared the well history included in this report.

E. T. Hegna, J. R. Kerns, and J. D. Traut of Hegna, Kerns, and Traut, consulting geologists, Casper, Wyoming, were employed by the drilling contractor during drilling operations. They assisted with selection of cored intervals and identified formation tops. Their descriptions of cuttings and cores are included in the report and summarized in plate 1 (in pocket). Brown Logging Company also was employed by the drilling contractor to make a strip log with mud-gas analysis (pl. 2 in pocket).

Geophysical logging was done by Birdwell Division, Seismograph Service Corp., and Schlumburger Well Services. A representative geophysical log is included for comparison with oil-field logs in nearby areas (pl. 3 in pocket). Packer tests were made by Halliburton Services. Other companies were involved in the drilling, coring, down-hole equipment retrieval, cementing, and perforating operations. Gamma-ray-attenuated-porosity-evaluator (GRAPE) logs of the cores were made by Marathon Oil Research Center, Denver, Colorado. Analysis was by Core Laboratories Inc., in Denver, Colorado. All elevations are referenced to National Geodetic Vertical Datum of 1929 (NGVD of 1929), formerly called Mean Sea Level.

TEST-WELL HISTORY

The following historical data on the test well, consisting of hole-history data (fig. 5), time breakdown (fig. 6), hole history (table 1), bit record (table 2), deviation surveys (table 3), and log index (table 4) were obtained from the Fennix & Scisson, Inc. report provided to the U.S. Geological Survey at the completion of the drilling, coring, and preliminary logging and testing of Northern Great Plains test well 1. The mud report (table 5) is from the Hegna, Kerns, and Traut report. The use of trade names in the following data is for identification only and does not constitute endorsement by the U.S. Geological Survey.

FENIX & SCISSON, INC.

HOLE HISTORY DATA

January 12, 1978 Revision #1
DATE: December 21, 1978

HOLE NO.: Sheridan Exploratory NGP #1		I. D. NO.:
USER: USGS	TYPE HOLE: Exploratory/Hydrologic	
LOCATION Wyoming	COUNTY: Sheridan	AREA:
SURFACE COORDINATES: NW/4, NE/4, Sec. 11, T55N, R77W		
GROUND ELEVATION: 3575'	PAD ELEVATION:	TOP CASING ELEVATION:
RIG ON LOCATION:	SPUDDED: 9-15-78	COMPLETED: 10-25-78
CIRCULATING MEDIA: mud.		
MAIN RIG & CONTRACTOR		NO. OF COMPRESSORS & CAPACITY:

BORE HOLE RECORD			CASING RECORD							
FROM	TO	SIZE	I.D.	WT./FT.	WALL	GRADE	CPL'G.	FROM	TO	CU. FT. CMT.
*0'	5'	Excav.	(7'	diameter	CMP cel	lar)		0'	5'	Dirt
*			30"			CMP		5'	22'	
*5'	40'	40"	20"			CMP		5'	40'	324
40'	503'	14-3/4"	10.050"	40.50#		H-40	ST&C	3'	497'	1068
503'	4485'	9-7/8"	6.969"	26.40#		K-55	ST&C	419'	4482'	1800

TOTAL DEPTH: 4485' GL	AVERAGE MANDREL DEPTH:	FROM REFERENCE ELEVATION @
JUNK & PLUGS LEFT IN HOLE:		
SURVEYS PAGE:	CORING PAGE:	CU. FT. CMT. TOTAL IN PLUGS, ETC:
LOGGING DATA: Page 6		
BOTTOM HOLE COORDINATES:		REFERENCE:

RIGS USED *(Site Prep Rigs *)*

RIG NO.	NAME	TYPE	CLASS	DAYS OPERATING	SECURED W CREW	SECURED W/O CREW	TOTAL DAYS ON LOC.
1	Prairie Drilling Co	Ideco H-35		40.22	0.07		40.29

REMARKS: * *Site Prep Items*

Above depth are from ground level, 12' below kelly bushing elevation.

PREPARED BY: WDS:it

TIME BREAKDOWN ON NEXT PAGE

Figure 5.--Page from driller's log showing hole-history data.

SHERIDAN EXPLORATORY #1

TIME BREAKDOWN

SITE PREPARATION

DRILLING OPERATION TIME (DOT)		OTHER SCHEDULED TIME (OST)		OPERATIONAL DELAY TIME (ODT)	
DRILL		MOVE		RIG REPAIRS	
TRIPS		RUN CASING		W. O. DRILLING SUPPLIES	
SURVEYS		CEMENT CASING		CLEAN OUT FILL	
				SECURED WITH CREWS	
SITE DOT ____ DAYS		SITE OST ____ DAYS		SITE ODT ____	

TOTAL SITE PREP TIME ____ DAYS | REMARKS:

MAIN HOLE CONSTRUCTION

DRILLING OPERATION TIME (DOT)		OTHER SCHEDULED TIME (OST)		OPERATIONAL DELAY TIME (ODT)	
DRILL	7.71	MOBILIZATION & DEMOBILIZATION		RIG REPAIRS	0.01
TRIPS	2.26	CORE	4.62	W. O. EQUIPMENT	0.71
DRESS DRILLING ASSEMBLY		LOG	2.08	FISH , Birdwell Gun	0.33
SINGLE SHOT DEV. SURVEYS	0.46	CASED HOLE DIR. SURVEYS		CLEAN OUT FILL	
OPEN HOLE DIRECTION SURVEYS		UNLOAD CASED HOLE		UNLOAD WATER INFLOW	
		RUN MANDREL		REAM CROOKED HOLE	
		HYDROLOGICAL TESTS	9.06	PLUG BACK	
		Mob & Domob B.O.P.	1.60	DRILL OUT PLUGS	
MAIN HOLE DOT 10.43 DAYS		Circulate Samples	0.21	SECURED WITH CREWS	0.07
CASING OPERATION TIME (COT)		Lay Down Drill Pipe	0.24	Perf. & Test 7-5/8"	1.04
RUN 10-3/4" CASING	0.14	Perforate for Hydro Tests	1.44	Recement 10-3/4"	2.02
RUN 7-5/8" CASING	0.46			Condition & Mix Mud	3.73
CEMENT 10-3/4" CASING	0.38			W.O. Loggers	0.46
CEMENT 7-5/8" CASING	1.04				
DRILL OUT cement	0.22				
MAIN HOLE COT 2.24 DAYS		MAIN HOLE OST 19.25 DAYS		MAIN HOLE ODT 8.37 DAYS	

TOTAL MAIN HOLE CONST. TIME 40.29 DAYS | REMARKS:

TOTAL ELAPSED TIME

TOTAL SITE PREP TIME	____ DAYS	REMARKS:
TOTAL MAIN HOLE CONST. TIME	40.29 DAYS	
SEC. W/O CREW SITE PREP	____ DAYS	
SEC. W/O CREW MAIN HOLE CONST.	____ DAYS	
TOTAL SUSPENDED (NO RIG)	____ DAYS	
TOTAL ELAPSED TIME	40.29 DAYS	

Figure 6.--Page from driller's log showing time-breakdown data.

Table 1.--*Hole history of Northern Great Plains test well 1 provided by driller*

[CMP = corregated metal pipe; # = pounds; ft^3 = cubic feet; ST&C = short threads and couplings; psi = pounds per square inch; RTTS = retrievable test-treat-squeeze tool]

Depths for site preparation are from ground level.

A 7' diameter CMP cellar was set at 5' and cemented in place. A 40" hole was drilled to 40'. Attempted to run 30" CMP and could not get below 22'. Ran 20" CMP inside the 30" and set at 40'. Cemented annulus with 324 ft^3 of ready mix cement. 12" of cement was left inside the cellar.

Depths reported for drilling rig are from kelly bushing elevation (KB), 12' above ground level (GL) unless otherwise noted.

9-15-78	Rigged up Prairie Drilling Company's rig 1. Drilled 14-3/4" hole from 52' to 275' using mud.
9-16-78	Drilled 14-3/4" hole from 275' to 515'. Ran 10-3/4" O.D., 40.50#, H-40, ST&C casing with a Halliburton float shoe on bottom. Set casing at 497' (GL). Centralizers were placed at 433', 401' and 279', all (GL) depths. Cemented annulus using Halliburton with 556 ft^3 of 50% neat cement, 50% Pozmix, 1/4 # per sack of Flocele and 2% calcium chloride. Cement in place at 1830 hours. Cement did not circulate to surface.
9-17-78	Waited on cement to 0100 hours. Ran temperature log, cement top indicated at 126'. Perforated 10-3/4" O.D. casing at 112' with four 1/2" holes. Cemented stage #2 down the casing out the perforations with 281 ft^3 of neat cement + 3% calcium chloride with no returns. Waited on cement to 1130 hours. Ran temperature log, top of cement at 112'. Perforated casing at 97' with four 1/2" holes. Cemented stage 3 out the perforations with 115 ft^3 of neat cement + 3% calcium chloride with no returns. Placed 230 ft^3 of neat cement + 3% calcium chloride down the annulus. Cement in place at 1400 hours. Waited on cement to 1600 hours. Ran temperature log, indicated cement at surface. Cut off the 10-3/4" O.D. casing and welded on a series 900 casinghead. Top of casing at 3' below ground level. Installed and connected blow out equipment.
9-18-78	Completed connecting blow out equipment and tested to 1000 psi. Ran 9-7/8" bit in the hole, drilled out soft cement from 67' to 109'. Pressured up on casing and pressure would not hold.
9-19-78	Squeezed perforations at 97' with 58 ft^3 of neat cement + 3% calcium chloride. Cement in place at 0415 hours. Waited on cement to 1000 hours and resqueezed perforations with 58 ft^3 of neat cement + 3% calcium chloride. Cement in place at 1030 hours. Ran 9-7/8" bit in the hole and drilled cement from 55' to 80'. Ran bit to 124' and tested perforations to 1100 psi. Pulled out of the hole.

Table 1.--*Hole history of Northern Great Plains test well 1 provided by driller*--Continued

9-20-78	Made up 9-7/8" drilling assembly and ran in hole. Tagged cement at 473' and tested casing to 1000 psi. Drilled out cement and shoe and cleaned out to 515'. Drilled 9-7/8" hole from 515' to 824'.
9-21-78	Drilled 9-7/8" hole from 824' to 1100'. Raised mud weight to 9.8# gallon to stop water flow.
9-22-78	Made up 8-3/4" Christensen diamond core bit and cut core 1 from 1100' to 1125', recovered 19'. Ran 9-7/8" bit in the hole and conditioned mud to control water flow. Reamed core hole and drilled 9-7/8" hole from 1125' to 1380'.
9-23-78	Drilled 9-7/8" hole from 1380' to 1410'. Cut core 2 from 1410' to 1440', recovered 30'. Reamed core hole and drilled 9-7/8" hole from 1440' to 1784'.
9-24-78	Drilled 9-7/8" hole from 1784' to 2110'. Made up 7-7/8" Christensen diamond core bit on a rubber sleeve core barrel and cut core 3 from 2110' to 2116'.
9-25-78	Completed core 3 from 2116' to 2124', recovered 8'. Cut core 4 from 2124' to 2126', recovered 1'. Reamed core hole and drilled 9-7/8" hole from 2126' to 2422'.
9-26-78	Drilled 9-7/8" hole from 2422' to 2460'. Made up 8-3/4" Christensen diamond core bit and cut core 5 from 2460' to 2479'. recovered 16'. Reamed core hole and drilled 9-7/8" hole from 2479' to 2754'.
9-27-78	Drilled 9-7/8" hole from 2754' to 3192'.
9-28-78	Cut core 6 from 3192' to 3216', recovered 23'. Reamed core hole and drilled 9-7/8" hole from 3216' to 3541'.
9-29-78	Drilled 9-7/8" hole from 3541' to 3748'. Cut core 7 from 3748' to 3774', recovered 25'.
9-30-78	Reamed core hole and drilled 9-7/8" hole from 3774' to 4121'.
10-1-78	Drilled 9-7/8" hole from 4121' to 4159'. Cut core 8 from 4159' to 4184', recovered 25'. Reamed core hole and drilled 9-7/8" hole from 4184' to 4196'.
10-2-78	Drilled 9-7/8" hole from 4196' to 4403'.
10-3-78	Drilled 9-7/8" hole from 4403' to 4479'. Cut core 9 from 4479' to 4490'.
10-4-78	Pulled core bit, no recovery on core 9. Cut core 10 from 4490' to 4497', recovered 11.5'. Reamed core hole to 4497' and conditioned mud to log.

Table 1.--*Hole history of Northern Great Plains test well 1 provided by driller*--Continued

10-5-78	Ran Schlumberger logs. Made trip to condition mud to control water flow. Ran Birdwell logs.
10-6-78	Completed logging with Birdwell.
10-7-78	Ran in hole and conditioned mud.
10-8-78	Circulated and conditioned mud.
10-9-78	Laid down drill pipe and started running 7-5/8" O.D., 26.40#, K-55, ST&C casing for a liner.
10-10-78	Completed running liner to 4482' (GL) with the top at 419'(GL). Halliburton float shoe on bottom with a float collar at 4438' (GL) A Brown Oil Tool liner was on top and centralizers were place on every third joint. Cemented annulus using Halliburton with 1800 ft^3 of 50% neat cement, 50% Pozmix, 25# of gilsonite per sack, 2% Econolite and 5% gel. Cement in place at 0900 hours. Had circulation thru the entire job.
10-11-78	Ran 6-1/4" bit in the hole and drilled out latch-in collar in the top of the liner. Ran Birdwell temperature and bond logs, no cement indicated.
10-12-78	Perforated the 7-5/8" O.D. liner with four 1/2" holes at 2240', 2040', 1800', 1640' and 1490' using Birdwell. Ran a Halliburton retrievable packer in the hole on 2-7/8" O.D. tubing after each perforating job and tested to 500 psi, pressure held.
10-13-78	Perforated liner at 700' and 530' and tested to 500 psi, pressure held. Ran 2-7/8" O.D. tubing in the hole to the float collar and displaced mud with water.
10-14-78	Rigged up Birdwell and perforated 7-5/8" O.D. liner from 4282' to 4340' and from 4220' to 4270' with 4 holes per foot.
10-15-78	Ran Birdwell gun in the hole and operator ran off 8000' of line. Lost 21' of shots in the hole. Fished for and recovered 16' of the shots. Rigged up Gearhart - Owens, ran gamma-ray log and started perforating.
10-16-78	Completed perforating the 7-5/8" O.D. liner from 3748' to 3810', 3338' to 3352', 2460' to 2486', 2110' to 2126', 1718' to 1740', 1344' to 1400' and 774' to 806' with 4 holes per foot. Ran Halliburton test tool in the hole, could not get below 675'. Made trip with a 6-3/4" bit to 4438'. Made up test tool on 2-7/8" O.D. tubing and set the retrievable brige plug at 4350' and RTTS packer at 4210'.
10-17-78	Ran hydrological test 1 as directed.
10-18-78	Completed test at 0300 hours. Retrieved bridge plug and dressed the test tool. Picked up test tool and dropped the bridge plug in the hole, recovered same at 425'. Set the bridge plug at 3820' and the RTTS packer at 3738'. Started hydrological test 2 at 2300 hours.

Table 1.--*Hole history of Northern Great Plains test well 1 provided by driller*--Continued

10-19-78	Completed test at 1900 hours. Reset test tool from 3328' to 3362' and started hydrological test 3 at 2000 hours.
10-20-78	Completed test at 1200 hours, bridge plug was leaking. Waited on new tool.
10-21-78	Waited on new tool to 0500 hours. Set bridge plug at 3362' and packer at 3328' and continued test 3 from 0930 hours to 1700 hours. Dressed tool and reset at same depths and continued testing at 2100 hours.
10-22-78	Completed test 3 at 0330 hours. Bridge plug would not reset. Made trip and dressed same. Set bridge plug at 2496' and packer at 2450' and started hydrological test 4 at 1600 hours. Made trip at 1800 hours and set tool at same depths and continued test 4 at 2100 hours.
10-23-78	Completed test 4 at 0700 hours. Dressed tool and set bridge plug at 2136' and packer at 2100'. Ran hydrological test 5 from 0930 hours to 1630 hours. Set tool from 1708' to 1750' and started test 6 at 1930 hours.
10-24-78	Completed test 6 at 0100 hours. Reset tool from 1334' to 1410' and ran hydrological test 7 from 0215 hours to 1245 hours. Made trip and dressed tool. Set bridge plug at 816' and packer at 764' and ran hydrological test 8 from 1345 hours to 2000 hours. Retreived bridge plug and laid down test tool and tubing.
10-25-78	Completed laying down tubing. Removed blow out equipment and installed a 10" full opening valve. Released rig at 1500 hours. Hole completed.

Table 2.--*Bit record provided by driller*

Run no.	Diameter (inches)	Make	Type	Depth out (feet)	Feet drilled	Time used (hours)
			DRILLING BITS			
1	14-1/2	Smith	DSJ	515	463	24-3/4
2	9-7/8	Smith	DTJ	1,004	489	18
3	9-7/8	Smith	DTJ	2,110	1,106	29-1/2
4	9-7/8	Smith	DTJ	2,460	350	7-1/4
5	9-7/8	Smith	DTJ	3,192	732	22-1/4
6	9-7/8	Smith	DGJ	3,748	556	22-1/2
7	9-7/8	Smith	F2J	4,403	655	44-1/2
8	9-7/8	Hughes	OSC1G	4,497	94	9-1/4
			CORE BITS			
1	8-3/4	Christensen	MC-201	4,497	167	29
2	7-7/8	Christensen	MC-35	2,127	17	9

Table 3.--*Deviation surveys provided by driller*

Date	Depth (feet)	Deviation (degrees)
9-15-78	129	1/2
9-15-78	219	3/4
9-16-78	344	1/2
9-16-78	515	1/2
9-20-78	787	1/2
9-21-78	943	1/2
9-22-78	1,191	1/4
9-23-78	1,410	1/4
9-23-78	1,723	1/4
9-24-78	1,846	3/4
9-25-78	2,127	1
9-25-78	2,314	3/4
9-26-78	2,410	1/2
9-26-78	2,661	0
9-27-78	2,849	1/4
9-27-78	2,977	1/4
9-27-78	3,073	1/4
9-27-78	3,192	3/4
9-28-78	3,419	1/4
9-29-78	3,606	1/4
9-30-78	3,916	1/4
10-02-78	4,228	1/4
10-03-78	4,479	1/4
10-05-78	4,497	1/2

Table 4.--*Log index provided by driller*

Log type	Date	Run	Drill depth (feet below kelly bushing)	Logger depth (feet below kelly bushing)	Interval logged (feet)
BIRDWELL LOGS					
Acoustic	10-5-78	1	4,497	4,486	600-4,474
Caliper	10-5-78	1	4,497	4,493	478-4,485
Density	10-5-78	1	4,497	4,495	500-4,495
Epithernal neutron	10-5-78	1	4,497	4,497	500-4,497
Temperature	10-6-78	1	4,497	4,495	300-4,495
Three-dimensional velocity	10-6-78	1	4,497	4,495	450-4,488
SCHLUMBERGER LOG					
Dual induction - spherically focused	10-5-78	1	4,497	4,488	507-4,482

Table 5.--*Mud report provided by consulting geologists*

Date	Depth (feet below kelly bushing)	Weight (pounds per gallon)	Viscosity (feet squared per second)	Yield* (pounds per 100 feet squared)	pH (units)	Water loss (cubic centi-meter)	Solids (percent)
9-15-78	110	--	34	--	--	--	--
9-16-78	515	9.1	35	--	--	--	--
9-17-78	515	9.1	35	--	--	--	--
9-21-78	1,100	9.7	68	10	11.0	5.2	9
9-22-78	1,140	9.8	44	5	10.0	6.2	9
9-23-78	1,422	9.8	42	6	6.0	5.2	10
9-24-78	2,110	10.1	43	10	9.5	6.4	11
9-25-78	2,175	10.0	42	10	9.5	7.0	10
9-26-78	2,479	10.2	48	10	9.0	6.1	11.5
9-27-78	2,950	10.2	41	11	9.5	5.6	11.5
9-28-78	3,419	10.1	44	12	9.5	5.8	11.0
9-29-78	3,748	10.2	39	17	9.0	6.8	11.0
9-30-78	3,940	10.0	40	5	9.5	5.6	11.7
10-01-78	4,180	10.1	44	10	9.0	5.6	12.1
10-02-78	4,393	10.1	44	10	10.0	5.2	12.1
10-03-78	4,490	10.1	44	7	10.0	5.6	12.1
10-04-78	4,497	10.1	42	8	10.0	3.8	12.1

* A measure of the tendency of the mud to gel upon setting for 10 minutes.

GEOLOGY PENETRATED BY TEST WELL

The following formation tops determined from electric logs (table 6) and lithology (table 7) were obtained from the report by Hegna, Kerns, and Traut. A summary of the vertical cores cut during drilling is presented in table 8. A summary of the sidewall cores obtained after drilling is presented in table 9. The sidewall-core analyses (table 10) and whole-core analyses (table 11) are from the report provided by the Core Laboratories, Inc., Denver, Colorado.

Table 6.--*Formation tops determined by consulting geologists from electric logs*

Series	Formation	Depth[1/] (feet below kelly bushing)	Feet above or below National Geodetic Vertical Datum of 1929)
	Fort Union Formation		
Paleocene	Tongue River Member	Surface	+ 3,575
Paleocene	Lebo Shale Member	1,740	+ 1,847
Paleocene	Tullock Member	2,510	+ 1,077
Upper Cretaceous	Lance Formation	3,210	+ 377
Upper Cretaceous	Foxhills Sandstone	4,213	- 626
Upper Cretaceous	Pierre Shale	4,343	- 756

[1/] Elevation of kelly bushing is 3,587 feet above National Geodetic Vertical Datum (NVGD) of 1929).

Table 7.--*Lithologic log provided by consulting geologists*

[Depths are in feet below kelly bushing; those showing an interval are from samples taken with an automatic continuous sampler or from cores; single depths are point sample or core chips; Fe = iron; Mg = magnesium; mm = millimeter]

Depth	
40- 50	60% sand, coarse and gravel, 40% claystone gray-green, silty to sandy, and sandstone, white to light gray, very fine-fine grained, silty to clayey, micaceous, carbonaceous streaks.
50- 80	Claystone, pale gray-green, silty to sandy w/sandstone, light gray, very fine-fine grained, silty to clayey, carbonaceous, scattered black Fe-Mg grains.
80- 90	As above, some carbonaceous shale, brown, silt.
100	Claystone, gray-green, silty, soft w/sandstone, very fine-fine grained, light gray, silty to clayey.
100-120	Claystone, as above, 20% shale, medium gray, carbonaceous, 30% sandstone, light gray, very fine-fine grained, silty to clayey, slightly carbonaceous.
120-130	Sandstone, clear quartz, some light orange grains, fine-medium grained, sub-angular to sub-round, loose.
130-140	Shale, medium gray, soft, silty, slightly carbonaceous.
150	Sandstone, clear quartz, fine grained, sub-angular to sub-round, loose, 30% coal, lignitic and lignitic shale, brown.
160	50% sandstone, clear, as above, 50% siltstone, light gray, sand, slightly lignitic, trace coal.
180	Siltstone, light gray-light brown, sandy, soft carbonaceous laminae and inclusions.
180-190	Siltstone, as above w/shale, brown, carbonaceous, trace coal.
200	Claystone, light gray-cream, very soft w/sandstone, fine grained, cream, very clayey, abundant, feldspar grains, cream.
200- 20	30% sandstone, white, medium-coarse grained, sub-angular to sub-round, abundant Fe-Mg grains, loose, 30% claystone, light gray and shale, medium gray, carbonaceous, trace coal.
220- 30	Sandstone, as above, increasing in carbonaceous shale and coal.
230- 40	Coal, lignitic and shale, brown, very carbonaceous, trace silt, light gray and light brown.
50	Sandstone, clear, medium-coarse grained, sub-angular to round, loose, numerous pale orange chert grains, w/30% coal and carbonaceous shale.
60	50% coal and carbonaceous shale, 50% sandstone, as above.
70	Siltstone, light gray, soft, numerous finely disseminated carbonaceous particles, 10% sandstone, light gray, very fine-fine grained, silty carbonaceous.
80	50% coal and carbonaceous shale, 30% sandstone, clear, medium-coarse grained, loose caving? 20% silt as above.
280-290	80% sandstone, clear, fine and coarse grained to conglomerate, part caving, loose, sub-angular to round, 20% carbonaceous shale and coal.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
300	80% sandstone, clear to white, fine grained, some medium grained-coarse grained, sub-angular, loose, 20% coal and carbonaceous shale.
300- 10	50% carbonaceous shale, gray-brown and coal, pyritic, 30% claystone light gray, 30% sandstone, medium-coarse grained, loose, caving?
310- 20	60% claystone, light gray, silty, soft, 40% carbonaceous shale and coal.
320- 30	60% claystone, light gray, silty, 20% silt, light gray, slightly carbonaceous, 20% carbonaceous shale, dark gray.
330- 40	80% siltstone, light gray-light brown, soft, slightly carbonaceous, 20% shale, medium-dark gray, carbonaceous.
50	As above, abundant coarse grained sand, caving?
350- 70	70% carbonaceous shale and coal, 30% claystone, light gray-light brown, silty, slightly carbonaceous.
370- 80	50% coal and carbonaceous shale, 30% silt, light gray-light brown, slightly carbonaceous, 20% claystone, light gray.
380- 90	Siltstone, light gray-light brown, slightly carbonaceous.
410	60% carbonaceous shale, dark gray and coal, 40% silt as above.
410- 20	50% claystone, light gray, 40% coal and carbonaceous shale, 10% sandstone, light gray-light brown, fine-medium grained, sub-angular, silty.
420- 50	50% carbonaceous shale and coal, 20% sandstone, light gray-light brown, fine grained, very clayey, sub-angular, 30% silt light gray.
450- 70	50% carbonaceous shale and coal, 20% claystone, light gray, 30% silt, light gray-light brown.
470-490	Sandstone, light gray, very fine, siliceous cement, hard, sub-round.
490-500	50% sandstone, as above, 30% carbonaceous shale and coal, 20% claystone, light gray.
500- 15	40% carbonaceous shale and coal, 60% claystone and silt, light gray.
515-520	Claystone, gray-green, very soft w/trace coal.
520-530	Coal.
530-540	Claystone gray-brown w/abundant fine floating sand grains, 20-30% coal.
540-550	Claystone as above.
550-560	Sandstone, very fine-fine (.0125 mm) sub-angular-sub-rounded, 2/abundant dark rock fragments, some chlorite. Very well cemented w/calcareos cement. Hard.
560-570	As above w/claystone, as above.
570-590	As above w/abundant very fine sandstone grains, loose. Very soft.
590-630	Claystone, brown-tan, very soft, silty, very finely micaceous, traces of coal.
630-640	As above w/trace very fine sand as above caving?
640-650	Coal w/very carbonaceous silty claystone.

Depth	
650-660	Coal w/brown clay, silty.
660-670	Coal, abundant clay as above.
670-680	Coal.
680-690	Coal, w/firm brown silty claystone.
690-710	Claystone, tan silty w/some fine coal-cave? Some firm tan silt.
710- 20	Siltstone, tan, dense, very well cemented - calcareous cement - colomitic (slow fizz) fragments of coal thru-out, 5-10% abundant soft clay as above.
720- 40	Soft clay, as above w/few pieces firm, w/dolomite cement.
740-750	Soft clay, gray as above, some w/abundant floating very fine sand, and trace sandstone, very fine-fine (.125mm+) w/abundant rock fragments, soft clay cement.
750-760	Clay, as above.
760-770	Sandstone, very fine grained (.088mm) sub-rounded well sorted, hard, well cemented w/slightly calcareous cement, clear.
770-800	Coal.
800-810	Coal w/30-40% tan soft clay.
810-820	Clay, as above w/trace of coal.
820-830	Clay w/coal as above w/some fine sand, floating grains.
830-840	Clay, soft tan as above w/some coal trace sand.
840-850	Sandstone, very fine-medium grained (.125-.35mm). Sub-rounded to angular, mostly loose grained, trace of porosity. Some w/light tan fragments (feldspar?) abundant coal and clay.
850-860	Clay, w/abundant floating - loose sand grains, very fine, w/some coal fragments, very muddy and soft.
860-870	Siltstone, gray-tan, w/some very fine sand well cemented w/calcareous cement, firm, some coal. Abundant soft clay as above.
870-880	No sample.
880-890	Siltstone and soft clay w/micro laminations of coal w/ firm w/cemented very fine grained sandstone as above.
890-900	Clay, brown, very soft, w/floating sand grains and fine coal fragments. Some coal.
900-910	Clay, gray-tan, w/abundant very fine sandstone as above floating grains. Trace of consolidated very fine sand w/chlorite and feldspar grains clay cement . Fine fragments coal.
910-920	Clay, brown, soft, very silty w/abundant coal fragments.
920-930	Siltstone, tan, brown, micaceous, w/coal.
930-950	Coal.
950- 60	Coal w/tan clay - soft.
960- 70	Clay, tan w/abundant loose very fine-medium sand grains - sub-rounded to sub-angular.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
970- 980	Siltstone, tan-brown w/tan clay as above abundant loose very fine sand.
980- 990	Sandstone, very fine, sub-rounded, sub-angular, few dark rock fragments. Abundant loose grains on dry cut w/ trace of intergranular porosity. Mostly white clay filled.
990-1000	Clay, brown.
1000-1010	As above w/abundant loose sand grains.
1010-1020	Coal, w/very fine grained sandy silt light tan.
1020-1040	Coal, w/abundant, dense hard tan siltstone and soft clay, sandy in part.
1040-1050	Shale, dark gray to black, lignitic w/tan soft clay.
1050-1090	Clay light tan, very soft, floating sand grains w/tan-gray very carbonaceous silty shale. Micro laminations of coal thruout. Interbeds of dense hard very fine grain sandstone, abundant free sand grains thruout .062mm± - almost silt in part.
1090-1100	Clay as above, w/abundant free sand grain, fine-medium grained (.25 50 .35mm) sub-angular to sub-rounded.
	Note: Sand is probably overlogged in all samples since clay is so soft it washes away.
1100'-1125'	Core #1 - cut 25' recovered 19'
	Believe that lost 6' was soft sand at bottom and lost from core catcher while coming out of hole. Description is on corrected footage.
1100-1103	Siltstone, tan-gray w/very fine floating sand grains. Carbonaceous flakes thruout. Abundant fine mica.
1103-1106	Siltstone, as above, finely laminated w/stringers of very fine sandstone laminations ½-1mm in thickness. Carbonaceous as above.
1106-1109	Siltstone as above.
1109-1112	Sandstone, tan-gray, very fine grained (.125mm). Sub-angular to sub-rounded. Well sorted w/abundant white clay cement. Slightly calcareous w/some visible inter-granular porosity.
1112-1115	As above w/tan brown - iron stain.
1115-1119	Sand as above, increase in white clay. No visible porosity abundant fine mica.
1119-1125	Sand as above (lost).
1125-1140	Sand, fine (.25mm) loose w/abundant clay, as above - fine coal fragments cave?
1140-1150	Sand as above. Increase in clay.
1150-1160	Clay, tan-gray w/floating sand increase in grain size, some to 1mm.
1160-1180	Clay, brown, w/abundant coal dragments.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
1180-1190	Coal w/abundant fine sand grains - loose.
1190-1230	Clay, very soft, some very fine sand floating, silty.
1230-1240	Sandstone, very fine (.125+) w/white clay matrix, silty, no porosity.
1240-1250	Siltstone, w/abundant clay and fine floating sand grains.
1250-1260	Clay tan-gray.
1260-1270	Coal w/brown siltstone, sandy.
1270-1290	Clay w/coal.
1290-1300	Clay.
1300-1340	Thin interbeds of coal, soft brown siltstone, and clay - some free sand grains thruout.
1340-1350	Siltstone, white, firm, very sandy, very fine sand (.88mm). Well cemented - tight.
1350-1360	As above w/abundant soft clay as above.
1360-1370	Coal and very soft brown sandy clay.
1370-1380	No sample.
1380-1390	Coal and clay as above, w/some firm white silt as above.
1390-1400	Coal. Circulating @ 1400' - 15 minutes. Coal.
1400-1410	Sandstone, fine (.35mm) loose.
1410'-1440'	Core #2 - cut 30' recovered 30'
	(Description from 3' chips)
1410	Coal.
1411	Siltstone, gray, hard carbonaceous w/abundant floating very fine sand grains.
1415	Shale, gray-green, soft.
1418	Shale as above.
1421	Sandstone, very fine (.88mm) sub-angular hard w/abundant clay cement very calcareous.
1424	Sandstone as above, slightly larger grain size, abundant clay as above.
1427	Sandstone, very fine (.88mm), very silty, very calcareous.
1430	Coal, very dirty.
1433	Siltstone, gray, abundant clay, firm but not as well lithified as above.
1436	Siltstone, gray, abundant clay very hard dense.
1439-1440	Shale, dark gray-black, conchoidal flaking, very brittle.
	10' samples - 20" carbide lag.
1440-1450	Clay, gray soft w/abundant coal.
1450-1470	Clay, dark gray to light greenish gray w/abundant coal.
1470-1490	Clay, soft light green-gray.
1490-1500	As above w/abundant coal.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
1500-1520	Clay soft as above w/some coal.
1520-1530	As above, some loose very fine-fine grained sand.
1530-1570	Clay, soft tan gray, as above, thin interbeds of coal, and few sand stringers.
1570-1590	As above, w/abundant medium grain sand - loose (.35mm).
1590-1630	Clay, w/some sand as above (thin interbeds, probably).
1630-1650	Coal, w/some very fine sand well cemented to loose. Probable good porosity in part.
1650-1660	Sandstone, very fine grained, silty, well cemented calcareous, very dolomitic.
1660-1670	As above, w/abundant soft clay and gray silt.
1670-1700	Clay, as above, very soft, w/some loose very fine sand grains.
1700-1710	Coal.
1710-1720	Clay, very silty w/some very fine sandstone as above.
1720-1730	Coal and clay as above.
1730-1750	Clay, as above, trace dense marlstone and fine coal fragments.
1750-1780	Claystone, light green, very bentonitic, w/abundant floating sand grains.
1780-1850	As above w/coal.
1850-1910	Shale and claystone, green/gray, carbonaceous, some interbeded coal, bentonite.
1910-1920	Coal.
1920-1930	Siltstone, light green, calcareous, friable.
1930-1940	Coal.
1940-1950	Sandstone, light gray/gray, very fine grained, calcareous, hard, low porosity.
1950-1960	Coal.
1960-2000	Sandstone, light greenish gray, very fine grained, calcareous, hard carbonaceous.
2000-2040	Claystone, greenish gray/brownish gray, splintery, slightly calcareous.
2040-2060	Sandstone, light gray/light green, very poor sort, abundant clay matrix w/floating grains silt/coarse, calcareous, soft, carbonaceous.
2060-2100	Claystone, green gray/brown, splintery w/local interbeds sandstone as above.
2100-2110	Claystone, green gray, soft bentonite.
<u>2110-2124'</u>	<u>Core #3 - recovered 8'</u>
2110	Claystone, dark gray, carbonaceous.
2113	Claystone, green, bentonitic, w/abundant sub-rounded/well rounded floating fine grained quartz grains (locally a sandstone) carbonaceous.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
2116	Sandstone, green very fine grained w/abundant green clay matrix, noncalcareous.
2117	Sandstone, green gray, very fine grained/fine grained, sub-rounded/well-rounded, slightly calcareous,abundant clay matrix.
2124	Claystone, green gray, carbonaceous, mottled pyritic.
2124-2126'	Core #4 - recovered 1'
2124	Sandstone, light gray, very fine grained, micaceous, carbonaceous, soft, slightly calcareous, sub-angular, abundant clay matrix, friable.
2125	Claystone, green, waxy, soft.
2125-2250	Claystone, green gray, soft, very bentonitic, w/some floating quartz sand grains.
2250-2280	As above w/slight increase sand grains.
2280-2290	As above w/trace coal.
2290-2320	Claystone, green, splintery, w/abundant bentonite.
2320-2350	Sandstone, light gray, abundant clay matrix, poor sort, low porosity, locally hard.
2350-2380	Claystone, light green gray and brownish gray, abundant bentonite, floating quartz grains, well-rounded/sub-rounded.
2380-2410	Sandstone, clear/light gray, fine grained, sub-rounded, well sorted, unconsolidated, clean, good porosity.
2410-2455	Claystone, green w/bentonite, abundant quartz grains.
2455-2460	(Circulating 60") sandstone, clear, sub-angular/sub-rounded, fine grained, unconsolidated, good porosity, good sort, 95% quartz.
2460-2479'	Core #5 - recovered 16'
2460-2462	Sandstone, light gray, fine grained, sub-angular/sub-rounded, fine grained sorted, slightly calcareous, white clay infill, fair porosity, very friable, soft.
2464	Sandstone, greenish gray, very fine grained, argillaceous, fair sorted, fair porosity, friable soft.
2467	Sandstone, light gray, fine grained, abundant white clay infill, fair/poor porosity, sub-rounded, fair sorted, calcareous.
2470	Sandstone as above fair porosity.
2473	Sandstone light gray, fine grained, sub-angular/sub-rounded, fair sorted, friable, white clay infill, fair/good porosity, noncalcareous.
2476	Sandstone as above.
2480-2490	Sandstone as above.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
2490-2500	Very fine grained, light gray, abundant pyrite, clay infill, medium hard, low porosity.
2500-2530	Claystone, greenish gray, interbeded w/sandstone light gray, very fine grained/fine grained, abundant pryite, clay infill low porosity, locally siltstone w/floating quartz grains.
2530-2550	Claystone, light gray, very bentonitic.
2550-2560	Siltstone, light green gray, bentonitic, w/floating quartz grains, thin bed, carbonaceous.
2560-2640	Sandstone/siltstone, light gray, very fine grained, clay filled, low porosity.
2640-2720	Claystone, green gray, silty, bentonitic.
2720-2770	Sandstone, light gray, sub-rounded, friable, fine grained, white clay infill fair/good porosity, fair/good sorted, calcareous.
2770-2790	Sandstone, light gray, fine grained, sub-rounded, abundant pyrite, clay infill, fair porosity.
2790-2820	Siltstone, light gray, argillaceous, w/some interbeds green gray claystone.
2820-2840	Sandstone, light gray, fine grained, well sorted, sub-angular, friable fair/good porosity, some clay infill.
2840-2870	Claystone, green gray, locally silty.
2870-2910	Sandstone, light gray, fine grained, sub-angular, friable, mostly unconsolidated, some clay infill, good porosity.
2910-2960	Claystone, green gray, very carbonaceous splintery, w/ some interbeds sandstone, very fine grained, clay filled, low porosity.
2960-2970	Coal w/interbeds claystone and siltstone green gray.
2970-2980	Sandstone, light gray, fine grained, unconsolidated friable some clay infill fair porosity.
2980-3030	Siltstone, calcareous, light gray, locally sandstone, very fine grained, hard, low porosity.
3030-3050	Sandstone, light gray, fine grained, sub-angular, friable, unconsolidated, white clay infill, good porosity, some Fe stain.
3050-3070	Shale/coal, dark gray, carbonaceous.
3070-3140	Siltstone/sandstone, very fine grained, light gray abundant white clay infill, hard, calcareous, trace pyrite, few free very coarse quartz angular grains, fair/poor porosity.
3140-3192	Sandstone, light gray, fine grained/very fine grained, abundant clay infill, some Fe stain, fair/low porosity.
3192-3216'	Core #6 - recovered 23'
3192-3200	Sandstone, light gray, very fine grained/fine grained, sub-angular, very slight calcareous, friable, mica, clay infill, fair/good porosity, medium hard.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
3200-3203	Sandstone, light gray, very fine grained, hard, very calcareous, low porosity.
3203-3214	Sandstone, light gray, fine grained, friable, sub-angular, white clay infill, fair porosity, very calcareous.
3214-3215	Shale, dark green gray, carbonaceous, thin bed.
3216-3280	Shale, light gray/green gray, splintery, carbonaceous/coaly.
3280-3290	Sandstone, light gray, fine grained, pyrite, abundant clay matrix, low porosity.
3290-3350	Claystone, gray/brownish gray, silty w/pyritic bentonite, soft, few sandstone lenses, very fine grained, low porosity.
3350-3400	Sandstone, light gray, very fine grained, clay filled, very calcareous, low porosity, w/siltstone lenses.
3400-3450	Claystone, gray/green gray, silty, soft.
3450-3460	Sandstone, light gray, abundant clay, mushy, very fine grained, sub-angular, low porosity.
3460-3480	Claystone, gray, carbonaceous, soft, bentonitic.
3480-3500	Sandstone, light gray, very fine grained, soft, clay matrix, low porosity, bentonitic, mushy.
3500-3600	Claystone, greenish gray bentonite, silty, w/occasional lenses sandstone, very fine grained, calcareous.
3600-3620	Sandstone, light gray, very fine grained, very calcareous, sub-angular, white clay infill, low/fair porosity.
3620-3640	Claystone, light gray/green gray, bentonitic.
3640-3650	Sandstone, light gray, very fine grained, calcareous, clay matrix, low porosity.
3650-3680	Siltstone, light gray, very calcareous, hard, brittle.
3680-3700	Sandstone, light gray, very fine grained, sub-angular, friable, clay filled, low porosity, calcareous.
3700-3730	Siltstone, light gray, calcareous.
3730-3748	Sandstone, light gray, fine grained, abundant clay infill, low porosity.
3748-3773'	Core #7 - recovered 25'
3748 & 50'	Sandstone, light gray, fine grained, sub-angular, calcareous, fair/good porosity.
3753	Sandstone, as above, being very calcareous, hard, fair porosity.
3756	Sandstone, light gray, very fine grained, calcareous, some clay infill, low porosity.
3759	Sandstone, light gray, fine grained, sub-angular, calcareous, fair porosity.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
3761	Shale, gray, hard.
3764	Sandstone, light gray, fine grained, sub-angular, abundant clay matrix, calcareous, low porosity.
3767	Sandstone as above, fair/low porosity.
3770	Sandstone as above.
3772	Sandstone as above, biotite mica common.
3773	Sandstone as above.
3773-3830	Sandstone, light gray, fine grained/very fine grained, clay filled, calcareous, fair/low porosity, locally coaly and silty.
3830-3880	Sandstone, light gray, fine grained, sub-rounded, calcareous, friable, good/fair porosity.
3880-3900	Claystone, gray/green gray, bentonitic.
3900-3910	Claystone, as above, w/sandstone, light gray, fine grained, sub-rounded, very clayey, poor porosity.
3910-3930	Claystone, light gray, very bentonitic, sandy.
3930-3950	Sandstone, light gray, fine-medium grained, sub-rounded, loose grains, probable good porosity, trace shale, carbonaceous, dark gray.
3950-3980	Claystone, light gray, bentonitic, sandy, soft.
3980-3990	Coal, w/claystone, gray-green.
3990-4000	Sandstone, light gray-white, fine grained, sub-rounded, consolidated interstitial clay, soft, fair porosity.
4000-4010	Sandstone, as above, becoming very clayey.
4010-4020	Sandstone, light gray, fine grained, sub-angular to sub-rounded, very clayey, trace coal.
4020-4040	Claystone, buff, bentonitic, sandy.
4040-4050	Sandstone, white, fine grained, sub-angular, abundant gray-black grains, clayey, soft.
4050-4060	Clay, buff- gray, sandy.
4060-4070	Sandstone, white-light gray, fine-medium grained, sub-angular to sub-rounded, loose, trace carbonaceous shale and coal.
4070-4090	Sandstone, white, fine grained. sub-angular to sub-rounded, loose, becoming clayey.
4090-4110	Claystone, light gray-buff, sandy, bentonitic.
4110-4120	Sandstone, light gray, fine grained, sub-angular to sub-rounded, abundant dark gray-black grains of coal and carbonaceous shale, loose, probable good porosity.
4120-4150	Claystone, light gray-buff, very bentonitic, sandy, soft sticky.
4150-4159	Siltstone, buff, grading to sandstone, buff, very fine grained, sub-angular to sub-rounded, slightly carbonaceous, abundant clay matrix, poor porosity.
4159	Circulating 15" - as above. 30" - as above, trace coal. 45" - sandstone, light gray, very fine-fine

Depth	
	grained, sub-rounded, abundant black carbonaceous grains, some clay matrix, fair-good porosity, loose.
4159-4184'	Core #8 - cut 25' recovered 24'8"
4160	Sandstone, light gray, fine grained, sub-angular to sub-rounded, abundant dark gray to black grains, some secondary quartz overgrowths, fair-good porosity.
4161	Sandstone, as above, w/claystone laminae, lenticular.
4164	Sandstone, as above, muscovite flakes.
4167	Sandstone, light gray, very fine grained, sub-rounded, micaceous, some clay infill, fair porosity.
4170	Claystone, light green-gray, carbonaceous.
4173	As above.
4176	Sandstone, light gray-white, very fine grained, clayey, sub-rounded, w/clay clasts.
4179	Claystone, light gray.
4181	Claystone, light gray, thin silty sandstone laminae.
4184	Shale, light brown, silty, carbonaceous.
4184-4190	Sandstone, white fine grained, loose, sub-rounded, caving? from reaming core hole.
4190-4210	Claystone, gray to gray green, slightly carbonaceous, slightly sandy.
4210-4220	Sandstone, white, fine grained, calcareous, sub-rounded, abundant black grains, much interstitial clay, poor porosity.
4220-4230	Sandstone, as above, w/claystone, gray-green.
4230-4280	Sandstone, white-light gray, very fine grained, silty, shale calcareous, scattered fine black grains, trace claystone, gray-green and carbonaceous shale, gray.
4280-4300	Claystone, gray-green and shale, medium grained, trace carbonaceous shale, brown, some sandstone, as above.
4300-4310	Sandstone, white-light brown, fine grained, very clayey, sub-rounded, soft, poor porosity, bentonitic.
4310-4330	Sandstone, white, fine-very fine, clayey, soft grading to silty claystone, soft, bentonitic.
4330-4350	Sandstone, white, fine grained,sub-rounded, abundant white clay infill, poor porosity, trace claystone, gray-green.
4350-4380	Decreasing sandstone, as above, claystone, light gray-green, trace carbonaceous shale and coal.
4380-4400	Shale, medium-dark gray, silty.
4400-4450	Shale, medium gray, silty streaks, w/claystone, light gray-green.
4450-4470	Shale, medium gray, slightly micaceous.

Table 7.--*Lithologic log provided by consulting geologists*--Continued

Depth	
4479-4490'	Core #9 - cut 11' recovered 0'
4490-4497'	Core #9 Run #2 cut 7' recovered 10'9" part of Run #1
	10'9" shale, medium gray, micaceous, sub-fissile, splits readily into 1" thick layers.

Table 8.--*Vertical cores cut during drilling*

[Depths are from kelly bushing (3,587 feet above National Geodetic Vertical Datum of 1929) 12 feet above land surface]

Core	Depth interval (feet)	Length cored (feet)	Length recovered (feet)	Formation or member
				Fort Union Formation
1	1,100-1,125	25	19	Tongue River Member
2	1,410-1,440	30	30	Tongue River Member
3	2,110-2,124	14	8	Lebo Shale Member
4	2,124-2,126	2	1	Lebo Shale Member
5	2,460-2,479	19	16	Lebo Shale Member
6	3,192-3,216	24	23	Tullock Member
7	3,748-3,773	25	25	Lance Formation
8	4,159-4,184	25	24.67	Lance Formation
9	4,479-4,490	11	0	Pierre Shale
10	4,490-4,497	7	10.75[1/]	Pierre Shale
	Totals	182	157.42	

[1/]Recovered part of core 9.

Table 9.--Sidewall cores taken at the end of drilling, described in the order cored

Depth (feet below kelly bushing)	Fox Hills Sandstone
4336	Sandstone, light green-white, fine grained, sub-angular-sub-rounded, micaceous, consolidated interstitial clay, scattered dark gray-black grains, fair porosity.
4328	Sandstone, as above.
4322	As above.
4316	As above.
4302	Sandstone, as above, slightly calcareous.
4294	Sandstone, white, fine-medium grained, sub-angular-sub-rounded, scattered black grains, good porosity and permeability.
4288	Sandstone, white, fine-medium grained, sub-angular-sub-rounded, scattered black grains, partly clay filled, fair porosity.
4282	Sandstone, as above, good porosity.
4274	Sandstone, white, very fine-fine grained, very clay filled.
4264	Sandstone, white, very fine grained, sub-angular-sub-rounded, part clay filled, fair porosity.
4256	Sandstone, white, fine grained, sub-rounded, slightly clay fill, good porosity.
4248	Sandstone, as above, good porosity.
4240	Sandstone, white, fine grained, sub-angular-sub-rounded, partly clay filled, fair porosity.
4232	Sandstone, as above, fair-good porosity.
4224	Sandstone, as above, fair-good porosity, thin coaly laminations.
4212	Sandstone, very fine grained, very clayey, poor porosity.
4202	Sandstone, fine grained, white, sub-angular-sub-rounded, part clay filled, fair porosity.
	Fort Union Formation: Tullock Member
2900	Sandstone, white, fine-medium grained, sub-angular-sub rounded, scattered dark gray and black grains, slightly clay filled, good porosity.
2880	Sandstone, as above, good porosity.
2746	Sandstone, as above, good porosity.
2732	Sandstone, white, fine-medium grained, sub-angular-sub-rounded, slightly calcareous, partly clay filled, fair porosity.
	Lebo Shale Member
2400	Sandstone, white, fine-medium grained, sub-angular-rounded, abundant black grains, good porosity.
	Tongue River Member
1380	Sandstone, white, fine-medium grained, sub-angular-rounded, abundant black grains, good porosity.
1360	Sandstone, white, fine grained, sub-angular-rounded, few black grains, trace clay infill, good porosity.

Table 10.--*Analyses of selected sidewall cores*

[Core Laboratories, Inc.]

Core no.	Depth (feet below kelly bushing)	Permeability (millidarcys)	Porosity (percent)	Grain density (expressed as specific gravity
1	1,360	153	32.3	2.65
2	1,380	375	33.0	2.63
3	2,400	262	30.2	2.65
4	2,732	57	27.4	2.67
5	2,746	71	28.6	2.69
6	2,900	117	28.6	2.70
7	4,202	27	27.1	2.66
8	4,264	12	25.7	2.69
9	4,328	12	24.9	2.67

Table 11.--*Analyses of selected whole cores*

[Core Laboratories, Inc.]

Core no.	Depth interval (feet below kelly bushing)	Permeability (millidarcys)		Bulk laboratory porosity (percent)	Fluid saturation (percent)		Specific gravity	Lithology
		Maximum	90-degree		Oil	Water		
1	1,118.3-1,119.2	Sample dried and cracked -- no analysis						
2	1,428.1-1,429.8	Sample dried and cracked -- no analysis						
3	1,431.7-1,432.9	Sample dried and cracked -- no analysis						
4	2,113.9-2,114.9	Sample dried and cracked -- no analysis						
5	2,462.0-2,463.0	655	1/	29.2	1.2	87.7	2.67	Sandstone, gray, medium grained, trace of clay, partly cemented
6	3,209.2-3,210.7	120	114	26.5	.0	93.5	2.69	Sandstone, gray, fine grained, trace of clay
7	3,748.0-3,749.0	99	95	22.3	.0	87.4	2.68	Sandstone, gray, fine grained, trace of clay
8	3,770.5-3,771.5	102	92	23.6	.0	83.2	2.68	Sandstone, gray, fine grained, trace of clay
9	4,162.3-4,163.3	74	73	22.9	2.4	89.7	2.68	Sandstone, gray, fine grained, trace of clay

1/ Not determined.

HYDROLOGIC TESTING

Drill-stem Tests

Oil-field testing equipment, used for testing and sampling, is listed in table 12. The upper packer was an RTTS (retrievable test-treat-squeeze) tool (fig. 7). Three tests were run with a cup-type bridge plug as the lower packer, before it was discovered that it would not seal. The remaining tests used a Model III packer-type bridge plug (fig. 8). Bourbon-tube recorders with 48-hour clocks were placed below the bottom packer, in the zone being tested, and above the rotation-stop valve. The procedure was to run the bridge plug and the RTTS tool into the cased hole on 2 7/8-inch tubing with the rotation-stop valve open. The bridge plug was set below the perforations in the zone to be tested and released from the rest of the string. The RTTS tool was then set above the perforation, isolating the zone to be tested. The valve was then closed, and water was swabbed from the tubing. A deep-well, water-level sensing device was set up to measure water levels, and the tubing was rotated to open the valve allowing the water level to recover for a slug-recovery test. After measuring the recovery, sufficient water was swabbed from the tubing to obtain a water sample and the valve was again closed, giving an effect similar to an oil-field, drill-stem test. If sufficient time remained on the 48-hour clocks, the valve was opened, the RTTS tool unseated, the bridge plug retrieved, the assembly moved up the hole to the next zone, and the procedure repeated. If time was insufficient for another test, the assembly was pulled from the hole, the old charts removed, a new chart installed, the clocks rewound, the string reassembled, and the procedure repeated until all zones were tested and sampled.

Table 12.--*Equipment in the testing string*

	Outside diameter (inches)	Inside diameter (inches)	Length (feet)
Tubing	2 7/8	2.441	variable
Crossover	3 7/8	?	0.60
Above packer running case	3 7/8	3.0	5.31
Rotation-stop valve	3 7/8	1.12	4.07
Crossover	3 7/8	?	0.82
Circulating valve	4 7/8	2.44	2.90
Retrievable test-treat-squeeze tool	7 5/8	2.40	4.25
Pup joint	2 7/8	?	1.76
Crossover	3 7/8	?	1.90
Above packer running case	3 7/8	3.0	6.0
Crossover	3 7/8	?	1.11
Fishtool (retrieval tool)	3 7/8	?	0.16
Perforated interval	--	--	variable
Bridge plug (cup type or model III)	7 5/8	?	6.2
Crossover	3 7/8	?	0.5
Flushjoint anchor	3 7/8	1.75	5.5
Blanked-off bourdon-tube running case	3 7/8	3.0	4.0

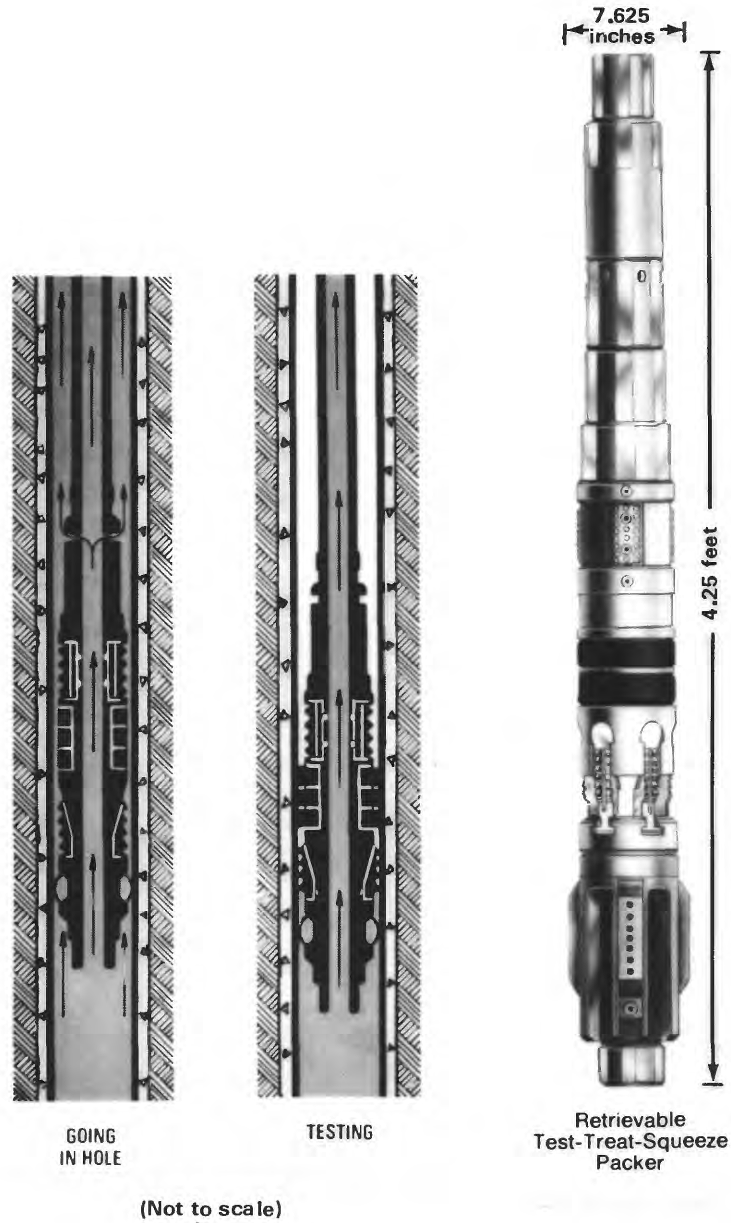
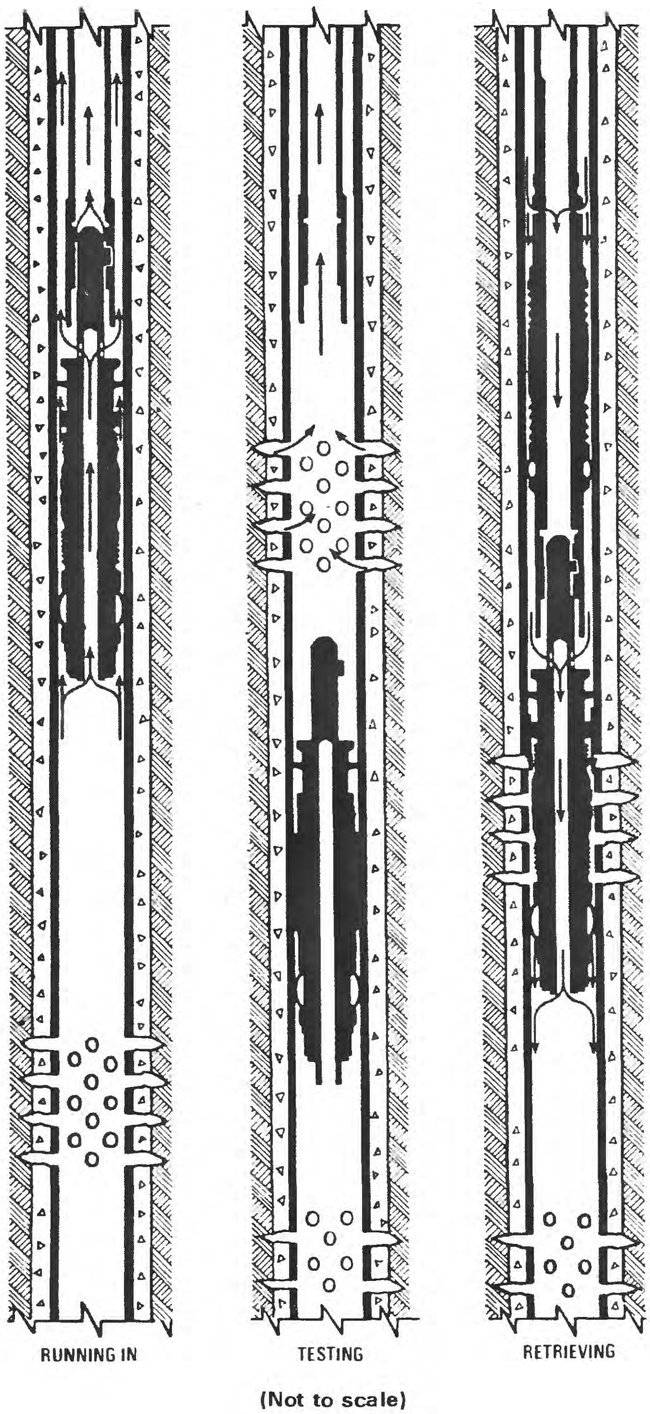


Figure 7.--Operation of upper packer (drill-stem test).



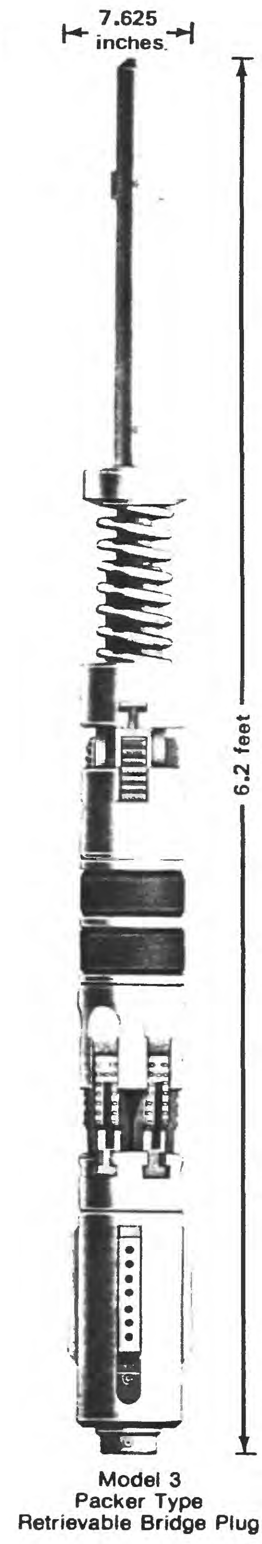


Figure 8.--Operation of bridge plug (drill-stem test).

At the end of the recovery test for zone 8, the water level rose to more than 6 feet above the kelly bushing, and the tubing was connected to gages in the water-sampling trailer to complete the test. The pressure eventually increased to about 30.75 pounds per square inch at a point 4.8 feet above ground level, equivalent to about 70.9 feet above the measuring point, or 75.7 feet above land surface. At the end of testing, a well head (fig. 5) was installed and the well turned over to the Wyoming District, U.S. Geological Survey; their personnel will be in charge of any future testing or measuring.

The drill-stem tests were not interpreted to obtain aquifer characteristics and were used mainly to determine that the packers were holding. Results of the drill-stem test are summarized in table 13.

Aquifer Tests

Aquifer tests were made for each of the zones with the drill-stem tests. The test on the Fox Hills Sandstone gave good results. The others gave reasonable estimates of transmissivity, when the packers held.

Table 13.--*Summary of drill-stem tests*

[kelly bushing was 12 feet above the surface]

Test no.	Geologic unit	Perforated interval (feet below kelly bushing)	Shut-in pressure (pounds per square inch)	Depth to pressure recorder (feet below Kelly bushing)	Remarks
1	Fox Hills Sandstone	4,220-4,340	1,817	4,216	Cap-type bridge plug leaked, but there were no perforations below the plug, so test was probably valid.
2	Lance Formation	3,748-3,810	1,620	3,744	Bridge plug leaked -- test not valid.
2a	Lance Formation	3,748-3,810	(1,622)	3,754	Test to determine if packers seated.
2b	Lance Formation	3,748-3,810	1,634	3,744	Tested to maximum pump pressure to check for leaks behind casing.
3	Lance Formation	3,338-3,352	1,447	3,334	Bridge plug leaked -- test not valid.
3a	Lance Formation	3,338-3,352	(1,442)	3,339?	Check for leaks.
3c	Lance Formation	3,338-3,352	1,438	3,344	Pressure measurements probably valid.
4	Lebo Shale Member of the Fort Union Formation	2,460-2,486	1,050	2,466	Valid pressure measurements.
5	Lebo Shale Member of the Fort Union Formation	2,110-2,126	907	2,106	Recovery was very slow; tubing was filled with water at the end of the test to approximate a static water level.
6	Tongue River Member of the Fort Union Formation	1,718-1,740	749	1,714	Valid pressure measurements.
7	Tongue River Member of the Fort Union Formation	1,344-1,400	586	1,337	Very small flow at the surface.
8	Tongue River Member of the Fort Union Formation	744-806	368	769	Maximum pressure recovery 30.75 pounds per square inch measured 4.8 feet above ground level; flowed 3 gallons in 39 seconds.

Methods of Analysis of Tests

A type-curve method for determining transmissivity of an aquifer that is applicable to testing selected intervals in deep wells was introduced by Cooper and others (1967). This analysis involves an instantaneous charge or discharge of water to or from a well. The type curves (fig. 9) are derived by plotting H/H_o versus $\beta = Tt/r_c^2$ (a dimensionless times parameter) for values of $\alpha = r_s^2 S/r_c^2$ where:

H_o = water level in tubing above or below initial hydraulic head in head immediately after discharge, in feet;

H = water level in tubing above or below initial head aquifer in feet, at time, t;

T = transmissivity, in feet squared per day per foot;

r_c = radius of injection tubing, in feet;

r_s = radius of casing, in feet; and

S = storage coefficient.

Once a value of T is obtained, hydraulic conductivity, k, can be calculated by the equation:

$$k = T/b$$

where:

k = hydraulic conductivity, in feet per day;

T = transmissivity, in feet squared per day; and

b = thickness of tested interval, in feet.

Tests for zones 1 through 7 were interpreted using the instantaneous discharge method; results are shown in figures 10-16. The test for zone 1 matched a curve that gave a reasonable storage coefficient. The other tests could not be matched to a curve that would give a reasonable storage coefficient.

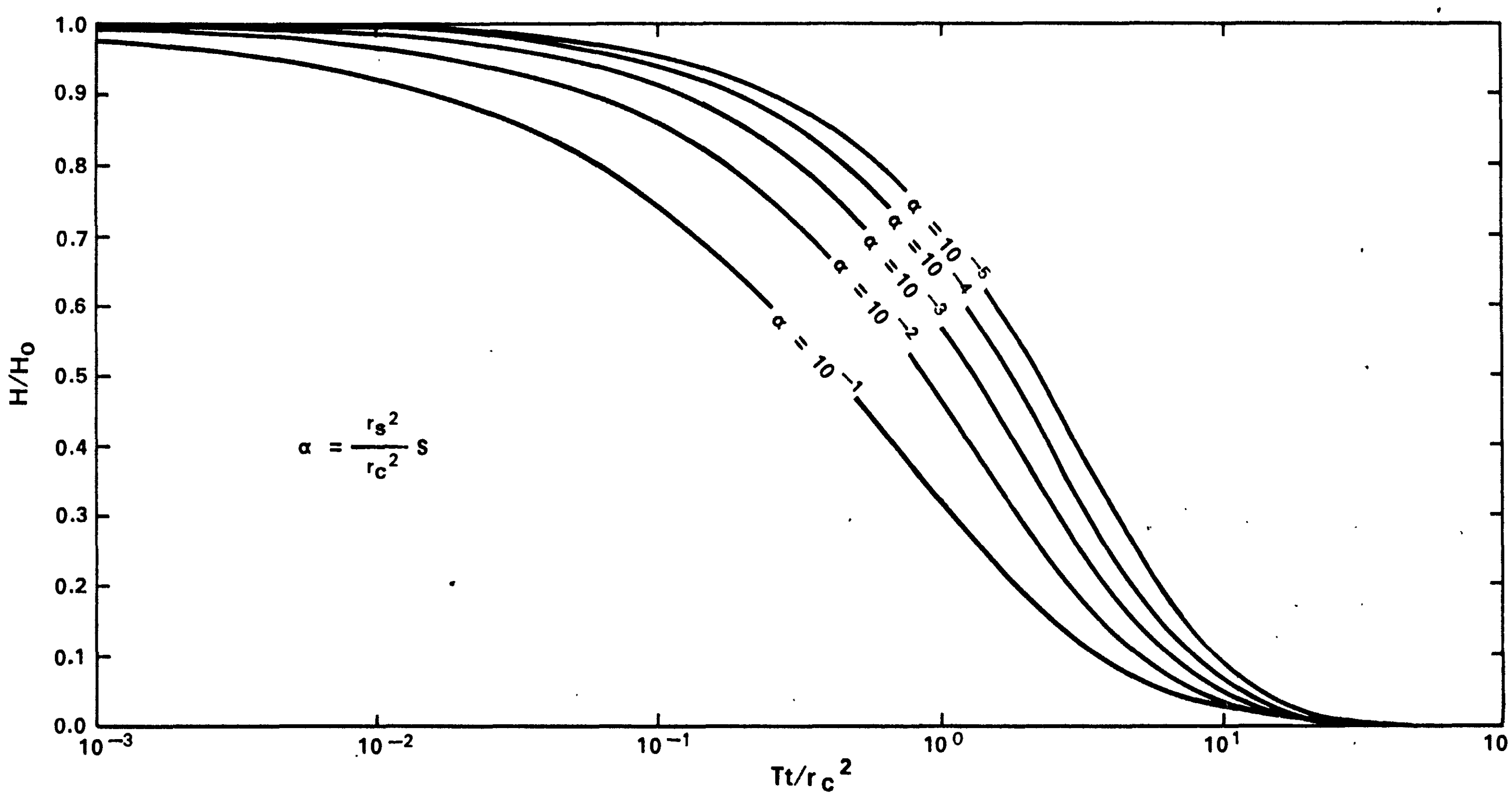


Figure 9.--Type curves for instantaneous charge in well of finite diameter (Cooper and others, 1967).

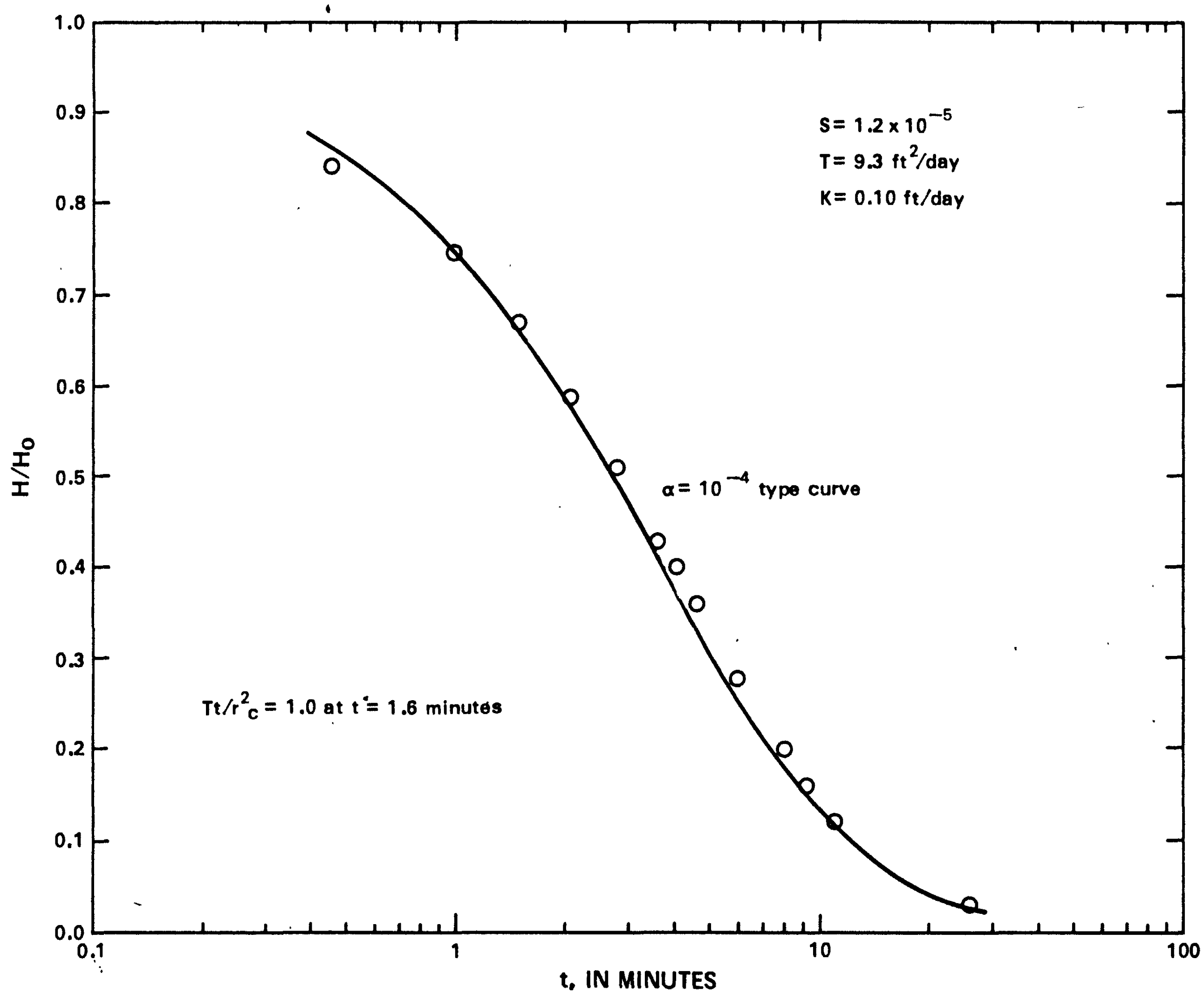


Figure 10.--Recovery after instantaneous discharge, interval 4,220 to 4,340 feet.

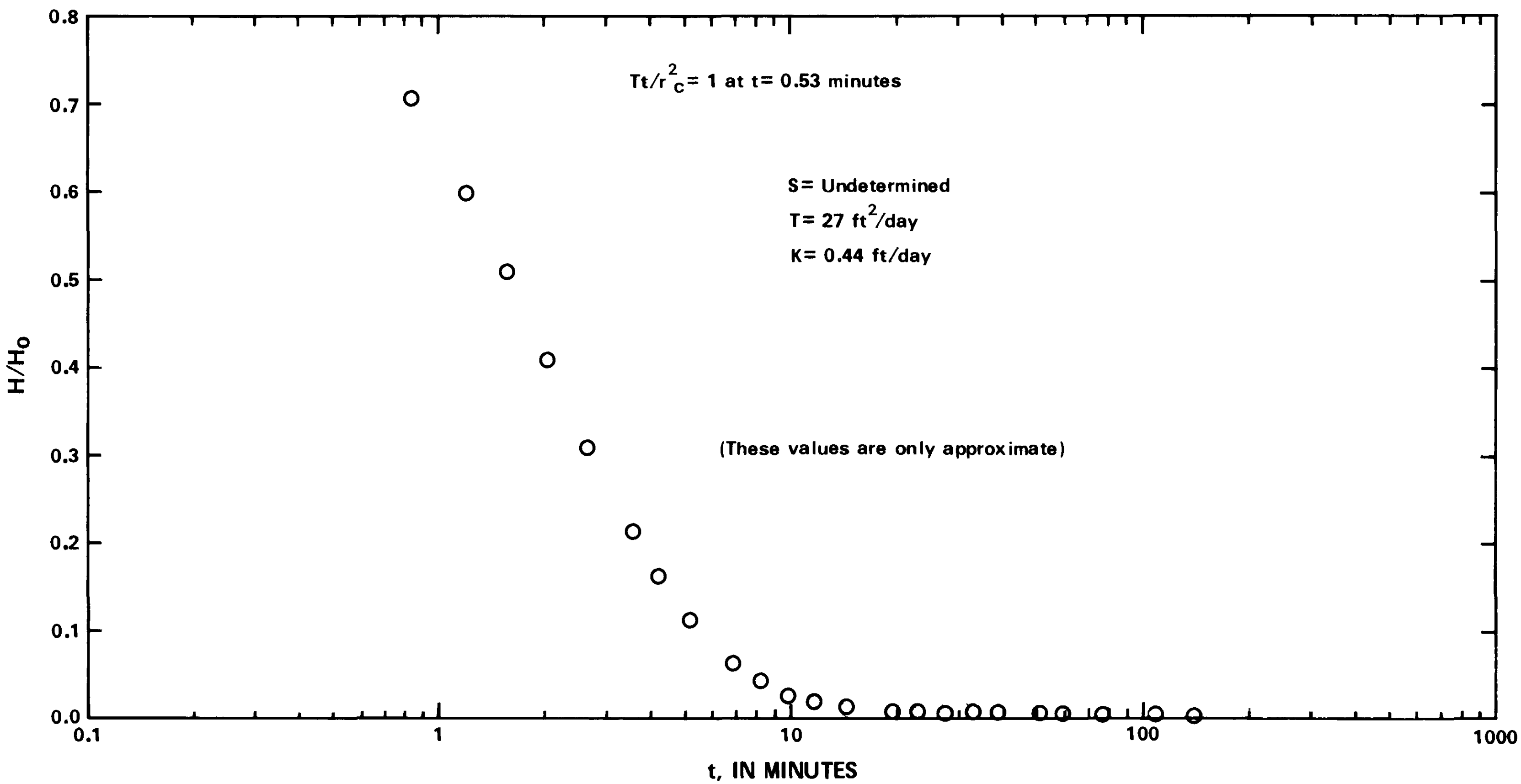


Figure 11.--Recovery after instantaneous discharge, interval 3,748 to 3,810 feet.

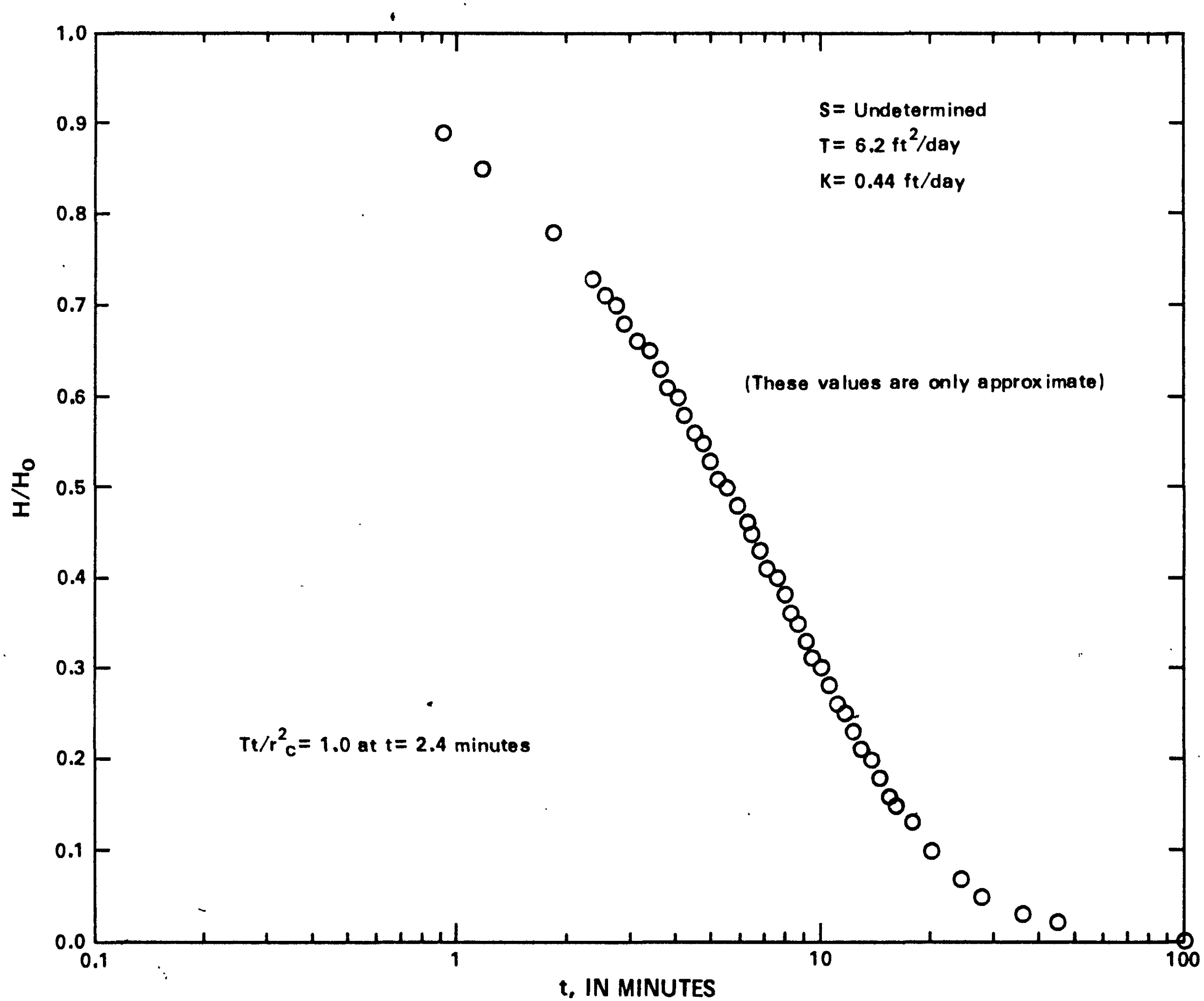


Figure 12.--Recovery after instantaneous discharge, interval 3,338 to 3,352 feet.

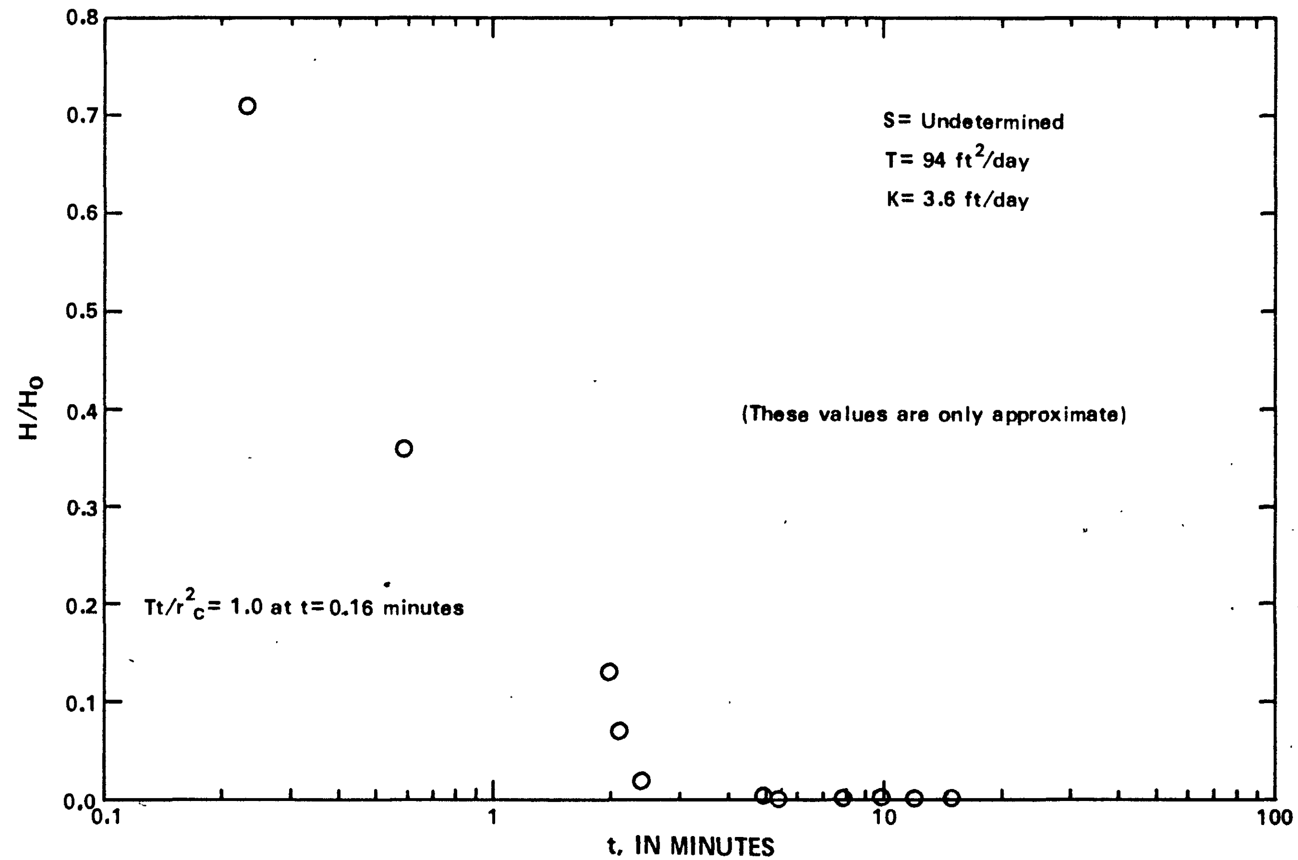


Figure 13.--Recovery after instantaneous discharge, interval 2,460 to 2,486 feet.

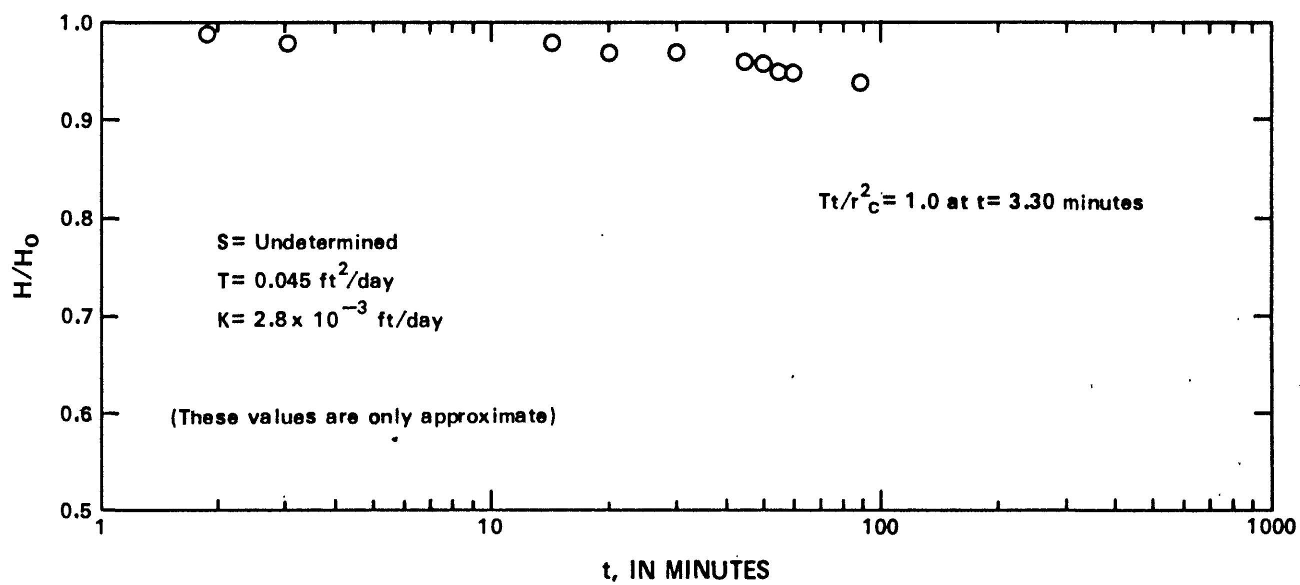


Figure 14.--Recovery after instantaneous discharge, interval 2,110 to 2,126 feet.

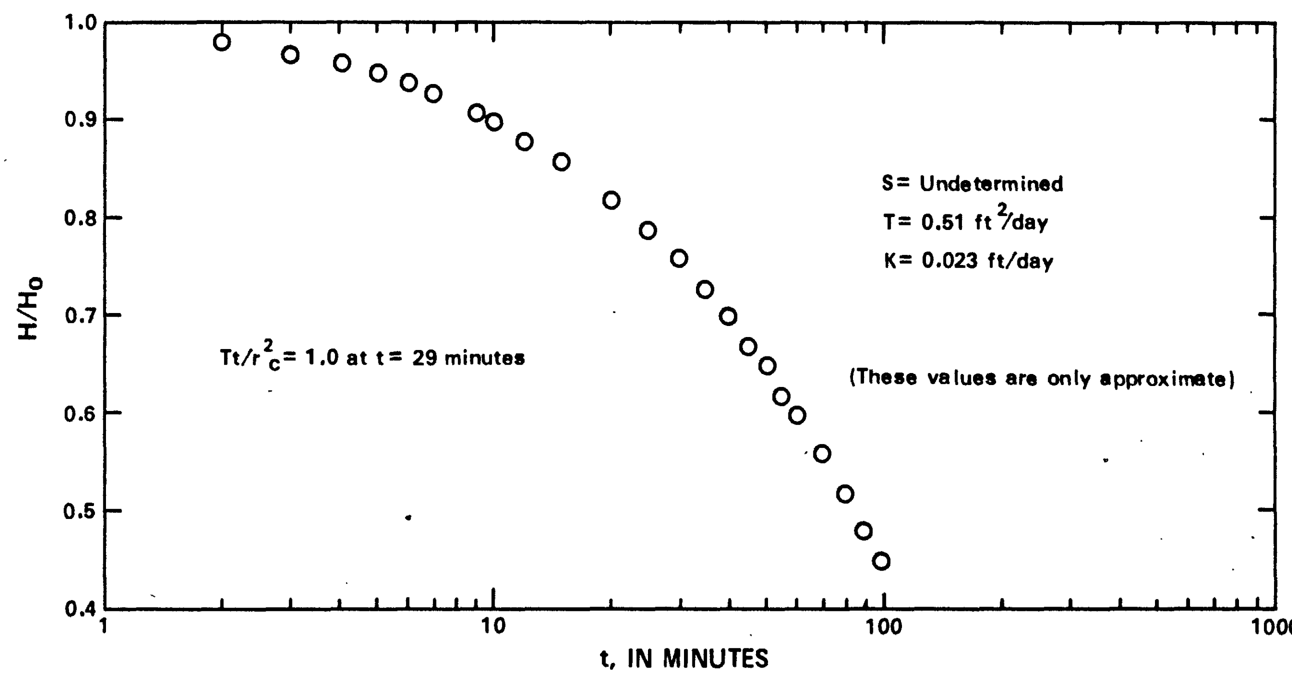


Figure 15.--Recovery after instantaneous discharge, interval 1,718 to 1,740 feet.

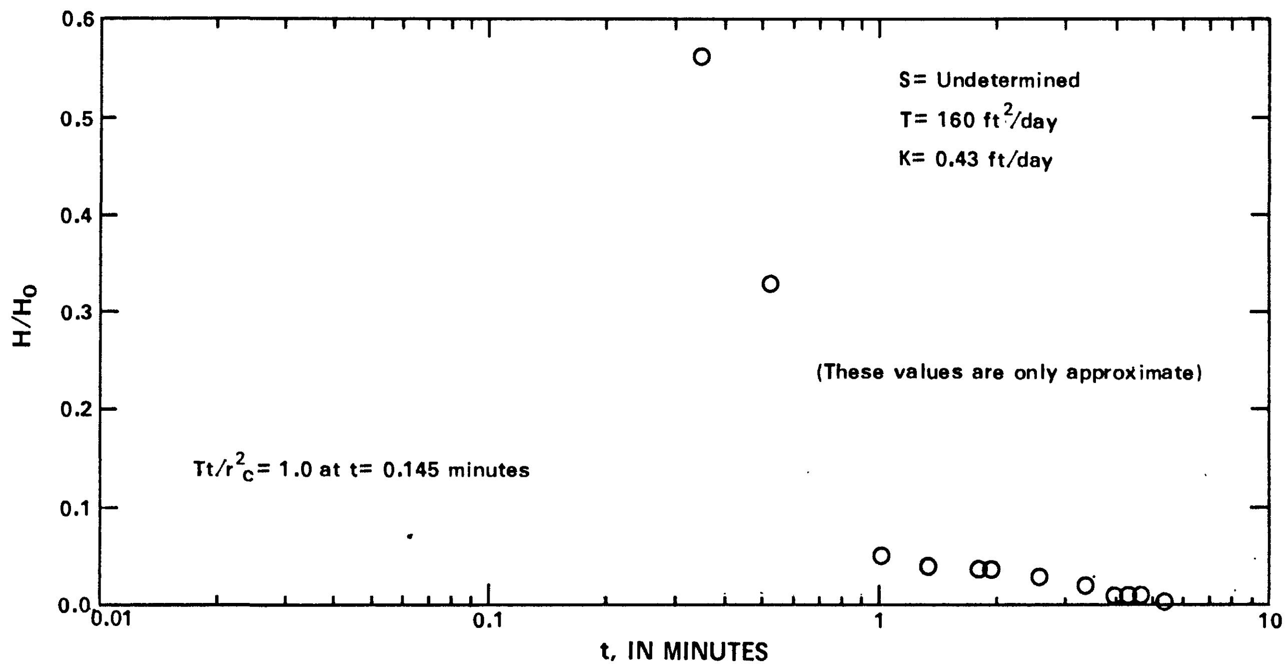


Figure 16.--Recovery after instantaneous discharge, interval 1,344 to 1,400 feet.

The test for zone 8, a coal in the Tongue River Member of the Fort Union Formation, was interpreted by the straight line method of Lohman (1972) as recovery after constant discharge (fig. 17). This zone had been flowing at the surface for at least 8 days from the time it was perforated until the test was made. An instantaneous-discharge test was attempted, but upper packers made for use with heavy drill collars would not hold with the light tubing used for the test. The tubing was then chained down, causing the packer to seal, but making it impossible to continue with the type of tests used for the other zones. The tubing was connected to gages 75 feet from the well, 4.8 feet above land surface, and the hydraulic head was allowed to recover. Problems with seating of packers cause some questions about the actual shut-off time, so the value for transmissivity is only approximate. Aquifer-test results are summarized in table 14.

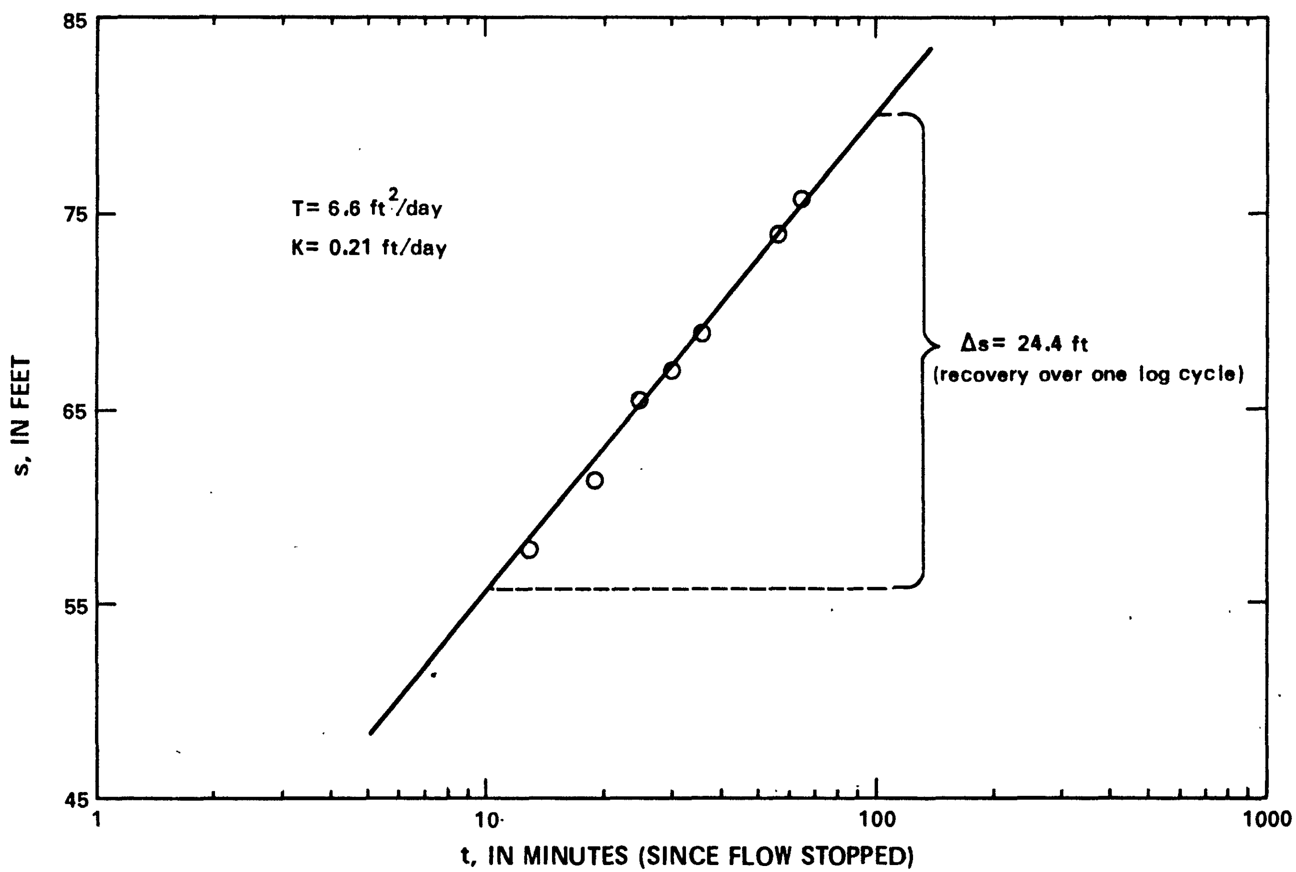


Figure 17.--Recovery after constant head discharge, interval 774 to 806 feet.

Table 14.--*Summary of aquifer tests conducted in conjunction with drill-stem tests*

[H' = static water level in feet above ground level; T = transmissivity in feet squared per day; Q/s = specific capacity in gallons per minute per foot of drawdown; Q = discharge in gallons per minute; s = drawdown in feet; t = time in minutes since pumping began (1,440 minutes for 24 hours used in calculations); r_s = radius of casing in feet (0.29 foot); S = coefficient of storage (estimated as 0.0001 where not determined); B = well-efficiency factor (0.5 used in calculations)]

Test no.	H'	T	Q/s[1/]	Estimated Q at s = 400 feet	Estimated Q for flow at the surface
1	-7.9	9.3	0.020	8.0	-0.16
2a	16.5	27.	.055	23.	.91
3c	2.46	6.2	.014	5.6	.034
4	5.7	94.	.18	73.	1.0
5	3.4	.045	.00015	.063	.00053
6	26.	.51	.0014	.60	.036
7	7.5	160.0	.30	120.	2.2
8	75.74	6.6	.015	7.1	1.1
	Totals (rounded)			237.	5.1

1/ The specific capacities shown are estimated using a formula adapted from Walton (1962); $Q/s = \{7.48T/[264 \log(7.48t/2693r_s^2S)-65.5]\}B$.

GEOCHEMISTRY

Method of Sampling

Each zone to be tested was isolated, using packers. Water samples were collected after the zone of interest was swabbed and the pH, water temperature, and specific conductance were constant between three successive swab runs.

Quality Control

Each sample container, including those comprising the duplicate samples, was numbered and randomly assigned to a sample, to minimize the effect of any determinant error in the analytical process. Duplicate samples were collected from the lower part of the Lebo Shale Member and from a coal in the Tongue River Member and submitted randomly to the U.S. Geological Survey national water quality laboratory in Denver, Colorado. Additional duplicate samples were sent to Chemical and Geological Laboratories in Casper, Wyoming as a check on the quality of the data; results of the duplicate analyses are shown in table 15. The large values of pH and carbonate in the samples submitted to the Chemical and Geological Laboratories compared to onsite values indicate that the samples analyzed by these laboratories were allowed to set for some time before analysis, allowing for outgassing of the carbon dioxide present in the sample. The bicarbonate values for these samples were recalculated, using the onsite pH and the reported sum of bicarbonate and carbonate as a measure of the total inorganic carbon in the water; values reported in the tables are recalculated values.

Table 15.--*Results of duplicate chemical analyses*

[mg/L = milligrams per liter; µg/L = micrograms per liter]

U.S. Geological Survey laboratory, Denver, Colorado				
Geologic unit	Constituents		Sample 1	Sample 2
	Major Ions		(mg/L)	(mg/L)
Lebo Shale Member of the Fort Union Formation (Depth, 2,460 to 2,486 feet below kelly bushing)	Calcium	Ca	8.0	9.2
	Magnesium	Mg	3.6	3.7
	Sodium	Na	1,100	1,200
	Potassium	K	14	14
	Bicarbonate[1/]	HCO_3	1,465	1,465
	Carbonate	CO_3	0	0
	Sulfate	SO_4	3.5	1.0
	Chloride	Cl	100	110
	Fluoride	F	2.3	2.5
	Silica	SiO_2	10	11
	Trace Cations		(µg/L)	(µg/L)
	Aluminun	Al	0	0
	Arsenic	As	1	1
	Barium	Ba	700	600
	Cadmium	Cd	3	2
	Chromium	Cr	0	0
	Copper	Cu	0	0
	Iron	Fe	40	70
	Lead	Pb	26	10
	Lithium	Li	250	250
	Manganese	Mn	70	70
	Mercury	Hg	0	0
	Molybdenum	Mo	1	1
	Selenium	Se	26	0
	Strontium	Sr	150	150
	Zinc	Zn	20	20
	Trace Anions		(mg/L)	(mg/L)
	Bromide	Br	1.5	1.4
	Iodide	I	.10	0
	Nitrogen	(As NO_2+NO_3)	.06	.03
	Phosphate	PO_4	0	0

[1/] Values calculated using onsite measurement of pH.

Table 15.--*Results of duplicate chemical analyses*--Continued

Geologic unit	U.S. Geological Survey laboratory, Denver, Colorado Constituents		Sample 1	Sample 2	Chemical and Geological Laboratories
	Major Ions		(mg/L)	(mg/L)	(mg/L)
Tongue River	Calcium	Ca	8.1	8.2	15
Member of the	Magnesium	Mg	5.4	5.3	1
Fort Union	Sodium	Na	730	760	749
Formation	Potassium	K	13	13	13
(coal)	Bicarbonate[1/]	HCO_3	1,011	1,011	1,879
(Depth, 744 to	Carbonate	CO_3	0	0	0
806 feet below	Sulfate	SO_4	2	2.3	2
kelly bushing)	Chloride	Cl	73	72	40
	Fluoride	F	3.7	3.6	2.3
	Silica	S_iO_2	13	18	
	Trace Cations		(µg/L)	(µg/L)	
	Aluminum	Al	0	0	
	Arsenic	As	1	1	
	Barium	Ba	500	400	
	Cadmium	Cd	1	2	
	Chromium	Cr	10	10	
	Copper	Ca	0	0	
	Iron	Fe	90	70	
	Lead	Pb	29	24	
	Lithium	Li	160	160	
	Manganese	Mn	90	80	
	Molybdenum	Mo	0	0	
	Selenium	Se	0	0	
	Strontium	Sr	90	80	
	Zinc	Zn	20	20	
	Mercury	Hg	0	0	
	Trace Anions		(mg/L)	(mg/L)	
	Bromide	Br	.3	.15	
	Iodide	I	0	0	
	Nitrogen	(As NO_2+NO_3)	.03	.01	
	Phosphate	PO_4	0	0	

[1/] Values calculated using onsite measurements of pH.

Analytical Results

Onsite Measurements

The pH, water temperature, specific conductance, dissolved oxygen, sulfate, sulfide, and alkalinity were measured onsite at the time of collection, following the method recommended by Wood (1976); results of these onsite analyses are reported in table 16.

The pH was measured with an Orion pH-meter combination pH-electrode. The buffers were brought to the temperature of the water, and the probe and meter were calibrated, using buffers of pH 7 and 10 before measurement of pH.

Specific conductance was measured using a Beckman RB-5 conductivity meter, and probes with cell constants of 0.1 and 1.0, depending on the specific conductance of the water. The probes and meter were calibrated at 25°C (degrees Celsius) against potassium-chloride standards.

Dissolved oxygen was measured using a Yellow Spring Instrument dissolved-oxygen meter and probe. The measurement was made by immersing the probe in the full drain line during swabbing. The meter was calibrated against an air-saturated distilled water, whose dissolved-oxygen concentration had previously been determined by a modified Winkler titration (Hach Chemical Company, 1976).

Water temperature was measured to the nearest 0.1°C by immersing a mercury-in-glass thermometer in the drain line during swabbing. The temperatures in the table are considered minimum values, not reflecting bottom-hole temperature, because of the significant temperature gradient existing between the well water and the ambient air, and the fact that the water flowed 100 feet through iron pipe before the measurement point.

Table 16.--*Results of onsite chemical analyses*

[°C = degrees Celsius; µmho = micromhos per centimeter at 25° Celsius; mg/L = milligrams per liter]

Geologic unit	Zone	Interval (feet below kelly bushing)	pH (unit)	Temperature (°C)	Specific conductance (µmho)	Dissolved oxygen[1/] (mg/L)	Alkalinity (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)
Fox Hills Sandstone	1	4,220 to 4,340	8.3	31.4	4,550	4.6	1,040	8	0.024
Lance Formation	2	3,748 to 3,810	8.5	26.1	2,975	.3	721	4	
Lance Formation	3	3,338 to 3,332	8.0	27.0		.62	763	.55	.035
			8.1	30.2	3,250	.15	847	40	1.59
			8.1	34.4	3,500	.2	892	4	.03
Fort Union Formation									
Lebo Shale Member	4	2,460 to 2,486	7.8	27.5	3,755	.20	1,460	0	.09
Tongue River Member	6	718 to 740	7.9	25.0	3,900	3.05	1,420	0	.05
Tongue River Member	7	1,344 to 1,400	7.7	26.5	775	.1	1,430	3	.09
Tongue River Member (coal)	8	774 to 806	7.8	16.6		.2	1,060	4	.087

1/ Large concentrations of dissolved oxygen are suspect due to the presence of sulfide.

Alkalinity was determined using a potentiometric titration, with a 0.01639 N sulfuric acid as the titrant. A 50-milliliter aliquot of sample was used in each determination. The end point of the titration was determined by taking the point of maximum inflection from a first derivative titration curve. Alkalinity was then calculated as milligrams per liter of calcium carbonate.

Sulfate was determined turbidimetrically using a Hach model Dr-2 spectrophotometer with Hach prepackaged reagents and a method based on standard methods for the analysis of water and wastewater (Hach Chemical Company, 1976).

Colorimetric determination of sulfide was made using a modified methylene-blue technique, using the Hach model Dr-2 colorimeter (Hach Chemical Company, 1976).

Laboratory Measurements

All samples were analyzed by the U.S. Geological Survey national water quality laboratory, Denver, Colorado, using the methods described by Brown, Skougstad, and Fishman (1970). Additional samples were submitted to Chemical and Geological Laboratories, Casper, Wyoming, where they were analyzed by proprietary methods.

Major Ions

Results of the analyses including duplicates are shown in table 17. Water-quality patterns in figure 18 show that the waters are all a sodium bicarbonate type, with pH ranging between 7.7 and 8.5, and dissolved-solids concentrations ranging between 1,806 and 3,060 milligrams per liter.

The trilinear diagram (fig. 19) shows that there is little difference in the water quality with depth, probably because there is little variation in the lithologies of the various formations tested.

Table 17.--*Chemical analyses of water samples, major ions*

[°C = degrees Celsius; µmho = micromhos per centimeter at 25° Celsius; g/mL = grams per milliliter; mg/L = milligrams per liter]

Geologic unit	Zone	Sample date	Time of day	Interval (feet below kelly bushing)	Sodium adsorption ratio	Cation-anion balance (percent)	Temperature (°C)	pH (units)	Specific conductance (µmho)	Density at 20°C (g/mL)	Hardness (mg/L as $CaCO_3$)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)	Dissolved sodium (mg/L)	Dissolved potassium (mg/L)
Fox Hills Sandstone	1	10/18/78	1400	4.220 to 4,340	134	1.19	31.4	8.3	4,802	1.000	16	4.3	1.1	1,200	11
Lance Formation	2	10/22/78	1000	3,748 to 3,810	83	2.23	26.1	8.5	2,975	1.001	39	4.0	1.1	740	7.2
Lance Formation	3	10/22/78	0100	3,338 to 3,352	89	0.26	-	8.1	3,250	-	-	4	2	849	10
Fort Union Formation															
Lebo Shale Member	4	10/22/78	1430	2,460 to 2,486	80	.39	27.5	7.8	3,775	1.000	43	8.0	3.6	1,100	14
					-	-	-	-	-	1.000	15	9.2	3.7	1,200	14
Tongue River Member	6	10/25/78	-	1,718 to 1,740	69	1.41	25.	7.9	3,450	-	-	18	0	1,069	17
Tongue River Member	7	10/24/78	0730	1,344 to 1,400	52	4.62	26.5	7.7	4,183	1.000	43	5.0	4.0	650	9.4
Tongue River Member (coal)	8	10/24/78	1830	774 to 806	51	.44	16.6	7.8	-	-	-	8.1	5.4	730	13
					-	-	-	-	2,800	1.002	30	8.2	5.3	760	12

Table 17.--*Chemical analyses of water samples, major ions*--Continued

Geologic unit	Zone	Sample date	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity as $CaCO_3$ (mg/L)	Dissolved sulfate (mg/L) (250)[1/]	Dissolved chloride (mg/L) (250)[1/]	Dissolved fluoride (mg/L) (1.4-2.4)[2/]	Bromide (mg/L)	Iodide (mg/L)	Dissolved silica (mg/L)	Dissolved nitrogen as NO_2+NO_3 (mg/L) (10)[2/]
Fox Hills Sandstone	1	10/18/78	1,007	0	1,650	40	610	3.7	5.0	1.3	13	.06
Lance Formation	2	10/22/78	824	0	1,350	5.1	250	6.0	2.7	.25	19	.01
Lance Formation	3	10/22/78	1,586	84[3/]	-	0	310	6.2	3.05	0.5	-	-
Fort Union Formation												
Lebo Shale	4	10/22/78	1,415	0	2,320	3.5	100	2.3	1.5	.10	10	.06
Member			1,440	0	2,360	32	290	5.8	4.5	.03	21	.06
Tongue River Member	6	10/25/78	2,708	48[3/]	-	24	100	5.0	-	-	-	-
Tongue River	7	10/24/78	1,427	0	2,340	1.0	110	2.5	1.4	0	11	.05
Tongue River	8	10/24/78	-	0	-	2.0	53	3.7	0.3	0	13	.03
Member (coal)			976	0	1,600	23	72	3.6	1.5	0	18	.01

1/ Recommended limit, U.S. Environmental Protection Agency, 1977.

2/ Mandatory limit, U.S. Environmental Protection Agency, 1976. Limit for fluoride is air temperature dependent, see reference.

3/ Reported by laboratory.

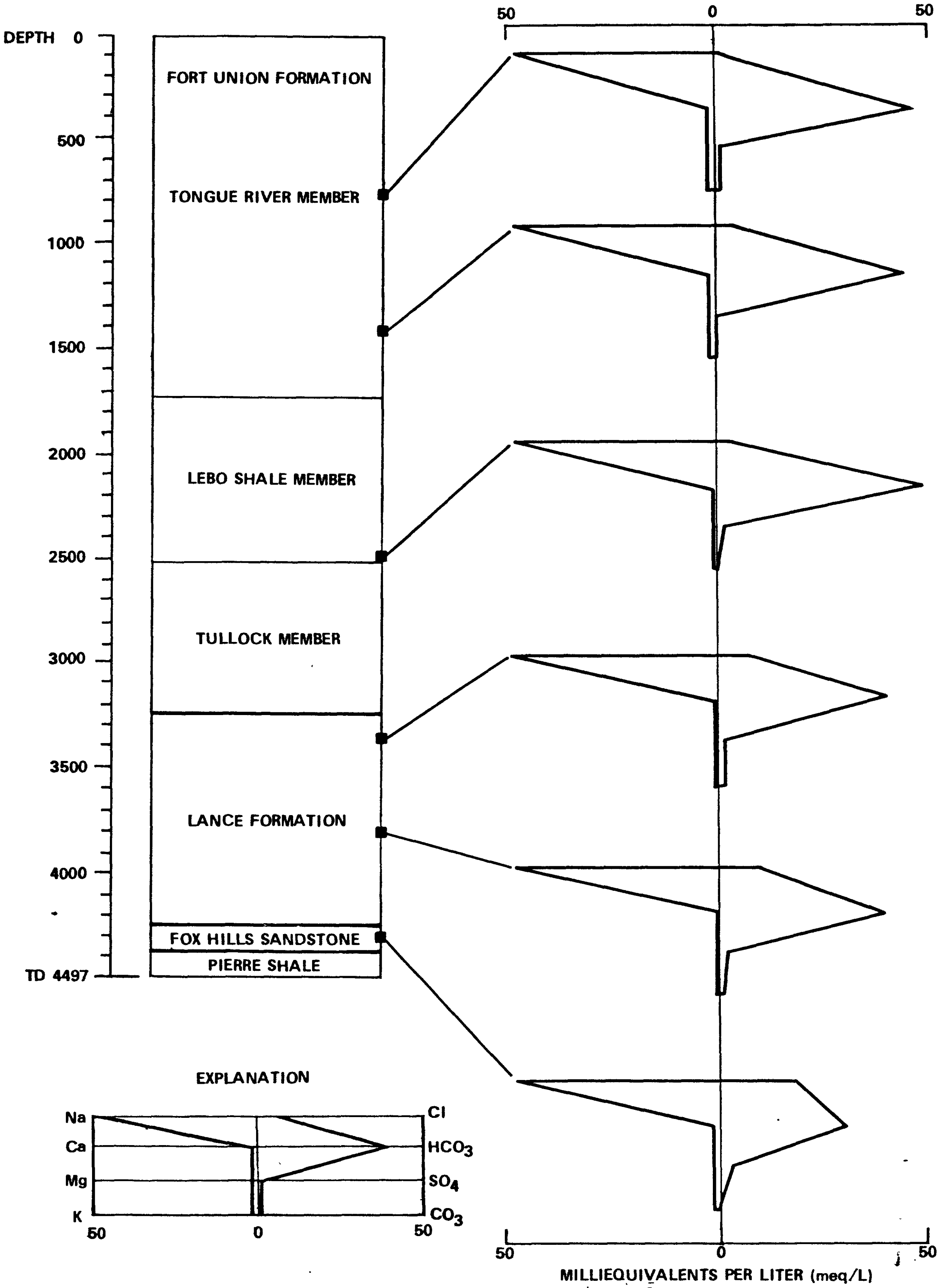
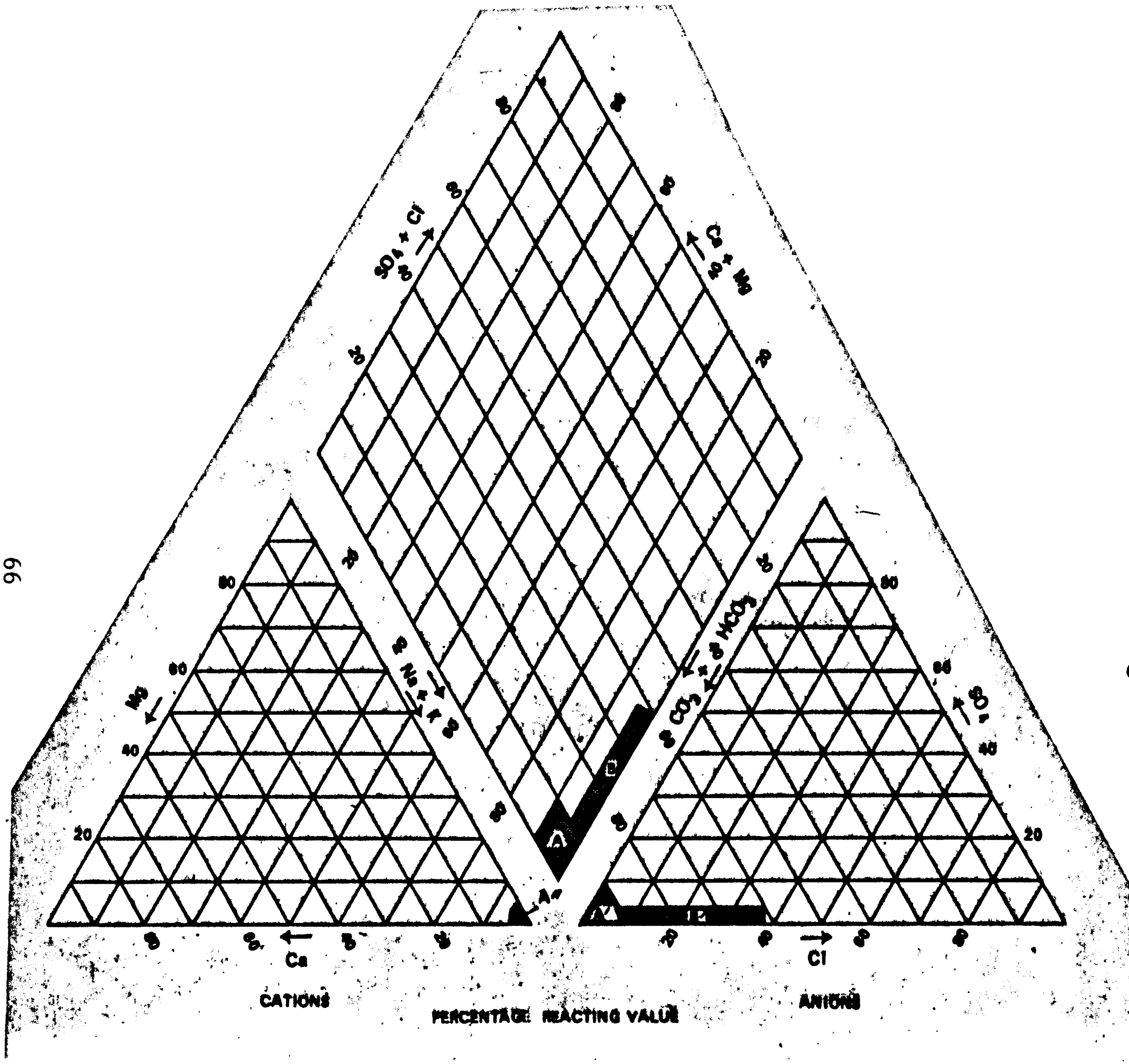


Figure 18.--Water-quality patterns of water from geologic units in Northern Great Plains test well 1.



EXPLANATION

SAMPLE NUMBER	AQUIFER
1	Fox Hills Sandstone
2	Lance Formation
3	Lance Formation
	Fort Union Formation
4	Lebo Shale Member
7	Tongue River Member
8	Tongue River Member (coal)
9	Fox Hills Sandstone
10	Fox Hills Sandstone
	Fort Union Formation
11	Lebo Shale Member
12	Tongue River Member
13	Lebo Shale Member
14	Tongue River Member (coal)

SAMPLE CLUSTER	SAMPLE NUMBERS
A	4, 8, 13, 14
A'	4, 8, 13, 14
A''	all samples
B	1, 2, 3, 7, 9, 10, 11, 12
B'	1, 2, 3, 7, 9, 10, 11, 12

Figure 19.--Trilinear diagram showing analytical results.

Trace Elements

Concentrations of the trace elements are summarized in table 18. A comparison of the trace-element concentrations with the most recent limits for drinking water (U.S. Environmental Protection Agency, 1976, 1977), shown at the bottom of each column in the table, indicates that none of the trace-element concentrations are in excess of the mandatory limits.

Calculation of Sodium Adsorption Ratio and Alkalinity

The value of the sodium adsorption ratio (SAR) is used as a measure of the suitability of a water for irrigation (U.S. Department of Agriculture Salinity Laboratory, 1954). The values of the SAR were computed using the formula:

$$SAR = \frac{(Na^{+})}{\sqrt{\frac{(Ca^{++}) + (Mg^{++})}{2}}}$$ where

SAR is the sodium adsorption ratio;

(Na^{+}) is the concentation of sodium, in milliequivalents per liter;

(Ca^{++}) is the concentration of calcium, in milliequivalents per liter; and

(Mg^{++}) is the concentration of magnesium, in milliequivalents per liter.

SAR values calculated for each formation and the description of the salinity hazard are presented in table 19. All waters were in the C-4, S-4 class of very high salinity hazard and generally are unsuitable for irrigation.

It also was necessary to calculate the alkalinity for the analyses from Chemical and Geological Laboratories; this was done by substituting the onsite value of the pH and the sum of the analytical carbonate and bicarbonate into a equation derived from the mass balance, charge balance, and equilibrium relationships, and by calculating the bicarbonate and carbonate values at the onsite pH.

Table 18.--*Chemical analyses of water samples, trace elements*

[All values in micrograms per liter]

Geologic unit	Dis-solved aluminum	Dis-solved arsenic	Dis-solved barium	Dis-solved boron	Dis-solved cadmium	Dis-solved chromium	Dis-solved copper	Dis-solved iron	Dis-solved lead	Dis-solved lithium	Dis-solved manganese	Dis-solved mercury	Dis-solved molydenum	Dis-solved selenium	Dis-solved strontium	Dis-solved zinc
Fox Hills Sandstone	140	1	700	220	1	10	30	300	4	120	70	-	4	0	390	20
Lance Formation	30	1	700	910	2	0	1	70	9	60	40	0	6	0	130	20
Fort Union Formation																
Lebo Shale Member	0	1	700	790	3	0	0	40	26	250	70	0	1	0	150	20
	0	1	600	820	2	0	0	70	10	250	70	0	1	0	150	20
Tongue River Member (coal)	0	1	500	210	1	10	0	90	29	160	90	0	0	0	90	20
	0	1	400	210	2	10	0	70	24	160	80	0	1	0	80	20
Tongue River Member	60	2	500	220	3	0	3	70	17	70	30	0	12	0	150	10
	No limit established	1/ 50	1/ 1,000	No limit established	1/ 10	2/ 50	2/ 1,000	2/ 300	1/ 50	No limit established	2/ 50	1/ 2	No limit established	1/ 10	No limit established	2/ 5,000

1/ Mandatory limit, U.S. Environmental Protection Agency, 1976.

2/ Recommended limit, U.S. Environmental Protection Agency, 1977.

Table 19.--*Sodium adsorption ratios and salinity hazard for determining the suitability of water for irrigation*

[USGS = U.S. Geological Survey; C & G Lab = Chemical and Geological Laboratories]

Geologic unit	Analysis performed by:	Sodium adsorption ratio		Salinity hazard description
Fox Hills Sandstone	USGS	134		Very high
Fox Hills Sandstone	C & G Lab	129		Very high
Fox Hills Sandstone	C & G Lab	143		Very high
Lance Formation	C & G Lab	83		Very high
Lance Formation	USGS	89		Very high
Fort Union Formation				
Lebo Shale Member	USGS	80		Very high
Lebo Shale Member	C & G Lab	84	(Duplicate)	Very high
Tongue River Member	C & G Lab	69		Very high
Tongue River Member	USGS	52		Very high
Tongue River Member (coal)	USGS	48		Very high
Tongue River Member (coal)	C & G Lab	51	(Duplicate)	Very high

PRELIMINARY RESULTS AND FUTURE TESTING PLANS

Preliminary analysis of some of the information obtained for this site during the drilling, coring, and testing of Northern Great Plains test well 1 follows:

1. Based on the drill-stem tests, all significant water-bearing units except the Fox Hills Sandstone have sufficient hydraulic head to cause the water in them to flow at the land surface.

2. Chemical-quality tests indicate that no fresh water (less than 1,000 milligrams per liter of dissolved solids) is in the zones tested. All of the water samples are a sodium bicarbonate type with the upper-most zone, a coal in the Tongue River, yielding water with 3,060 milligrams per liter of dissolved solids. Quality did not vary consistently with depth.

3. The well might yield as much as 240 gallons per minute as it is now perforated. More perforations opposite water-yielding zones might increase the yield.

4. No further tests on the well are planned at this time; however, well construction allows for further testing.

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