Judith River Fm. UIC Policy

1044b UIC - MT EAST POPLAR OIL FIELD
ENFORCEMENT CASE SDWA 1431
Folder ID: 118378 1987 Privileged

118378 - R8 FRED

DI(MT) Program Implementation

Release in full

WATER ANALYSIS

Exhibit A.

C.T.:
Here's misc. file correspondence on
JUDITH RIVER
DE

MAY 7 1986

Ref: 8MH-DW

Ronald A. Hodge, President
Citation Oil and Gas, Ltd.
P.O. Box 1791
Bismarck, North Dakota 58502

RE: Underground Injection Control (UIC)
Clark #1 SWDW
Goings #1 SWDW
Vickers #1 SWDW

Dear Mr. Hodge:

I spoke with your associate Mr. Thompson today regarding your letter of April 30, 1986. He brought to my attention that you now operate the above mentioned wells which fall under the jurisdiction of the federally implemented UIC program in Montana.

The main purpose of my call was to make you aware that an appeal has been filed by the Fort Peck Tribes, protesting our issuance in December 1985, of the final UIC permit for the Goings #1 SWDW. The appeal process will most likely take some time to resolve, and there is a possibility that our decision to allow injection into the Judith River through the Goings #1 may be overturned. If you would like to discuss this issue in more depth, please feel free to call me at (303) 293-1416.

I am enclosing some general information regarding our authorities over salt water injection wells in Montana for your information. Since the three wells you purchased are all permitted, you should first become familiar with the requirements stated in the permits. In regard to our recent correspondence with Century concerning noncompliance, a followup letter will be sent to you after we review the situation. Another item that will have to be addressed at your earliest convenience is a demonstration of financial responsibility. Please review that part of the permit and let me know what your intentions are.

Again, please call me if I can be of any assistance.

Sincerely,

Signed

Debbie G. Ehlert, P.E.
Team Leader for Direct Implementation
Ground Water Section

Enclosures

bcc: Bill Engle, MO

0954m/DGE/5-7-86

January 28, 1986

Ref: 8HM-DW

MEMORANDUM

TO: Roger Frenette
Patrick Crotty
Andrew Lensink, ORC

FROM: Paul Osborne
Laura Clemmens, Acting DI Team Leader
Mike Liuzzi, Indian Lands Coordinator

SUBJECT: Appeal of Region VIII Judith River Policy Statement by the Fo Peck Tribal Council

This afternoon arry Wetsit of the Fort Peck R rvation came into the office to let us know that the Tribe will be submitting an appeal to EPA on the Judith River Statement of Policy and resulting final permit actions. Wetsit indicated that the appeal would be filed by the lawyers for the Tribe in Washington, and would probably be received in headquarters tomorrow.

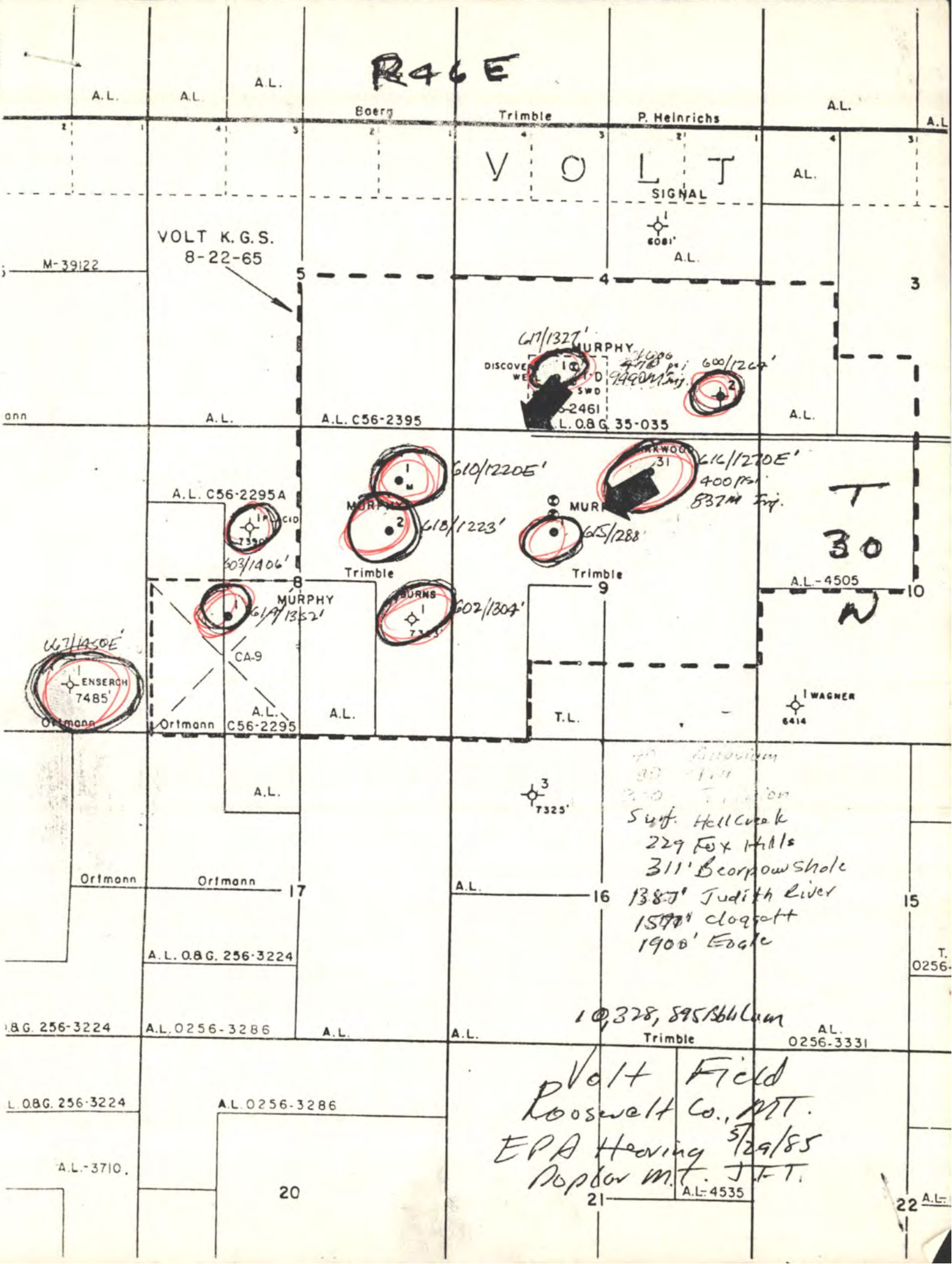
Wetsit explained that, for a number of reasons, the Tribe does not want the Judith River Formation used for injection purposes within the tribal boundries. Specifically, the Tribe wishes to protect all groundwater within tribal boundaries regardless of TDS level. Wetsit expressed interest in having EPA repeal all the aquifer exemptions for the Judith River Formation within a quarter mile radius of injection wells in operation prior to the promulgation of the UIC program in 1984. Mike Liuzzi explained to Paul and I that if portions of the Judith River do not fall within the EPA definition of an underground source of drinking water by virtue of the fact that they have a total dissolved solids level of over 10,000 mg/l, that they are outside the realm of protection afforded by the UIC program. EPA would have no authority to prohibit injection, nor to deny permits to those operators.

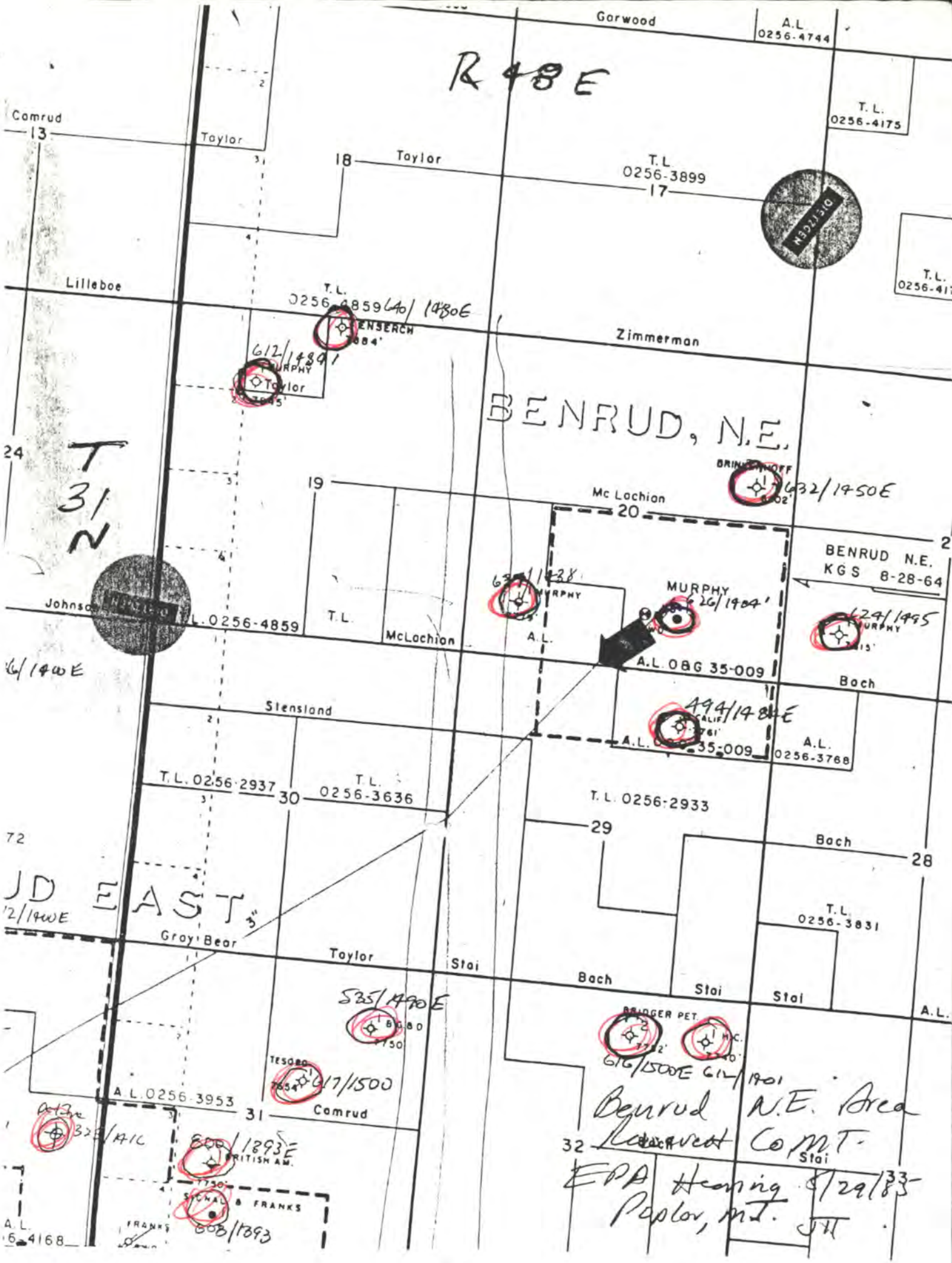
Paul contacted Eric Olsen of the Office of General Counsel, and Eric stated that any sort of appeal of the Region VIII decision on the Judith River Formation would have to be in the form of individual permit appeals for each permitted well affected by the decision. He added that the Tribe may alsohave the option of issuing a Tribal Resolution prohibiting the underground injection of brine into the Judith River if they have the legal authority to pass an enforceable statute of that nature. EPA would not be able to enforce any such law or resolution, that would be the responsibility of the Tribe.

We plan to meet with Wetsit again tomorrow. In the meantime, Paul will contact John Atcheson, so that we can arrange for John to speak with Wetsit directly. We will keep you informed of any further developments.

cc: Debra Ehlert

6405Q/1-28-86/Clemmens


R46E
A.L.
Boerg
Trimble
P. Heinrichs
VOLT
SIGNAL
6081'
VOLT K.G.S.
8-22-65
M-39122
5
4
3
MURPHY
DISCOVERY WELL
SWD
A.L. C56-2395
A.L. 0.8G. 35-035
A.L. C56-2295A
Trimble
MURPHY
BURNS
CA-9
ENSERCH
7485'
Ortmann
A.L. C56-2295
T.L.
WAGNER
6414
T 30 N
A.L.-4505
8
9
10
17
16
15
7325'
Surf. Hell Creek
229 Fox Hills
311' Bearpaw Shale
1387' Judith River
1590' Claggett
1900' Eagle
A.L. 0.8G. 256-3224
A.L. 0256-3286
A.L. 0256-3331
Volt Field
Roosevelt Co., MT.
EPA Hearing 5/29/85
Poplar MT. J.F.T.
A.L.-3710.
20
21
A.L.-4535
22


R 48 E
Garwood
A.L. 0256-4744
T.L. 0256-4175
Comrud
13
Taylor
18
Taylor
T.L. 0256-3899
17
Lilleboe
T.L. 0256-4859
640/1480E
ENSERCH
612/1480
MURPHY
Taylor
Zimmerman
BENRUD, N.E.
24
T 31 N
19
Mc Lochion
20
BRINKERHOFF
632/1450E
BENRUD N.E. KGS 8-28-64
MURPHY
626/1404
624/1495
Johnson
T.L. 0256-4859
T.L.
McLochion
A.L.
A.L. 0BG 35-009
Bach
494/1484E
Stensland
A.L. 0BG 35-009
A.L. 0256-3768
T.L. 0256-2937
30
T.L. 0256-3636
T.L. 0256-2933
29
Bach
28
JD EAST
T.L. 0256-3831
Gray Bear
Taylor
Stai
Bach
Stai
Stai
A.L.
535/1490E
BRINGER PET.
616/1500E 612/1401
TESORO
617/1500
A.L. 0256-3953
31
Comrud
32
Bach
Stai
Benrud N.E. Area
Rehearing CoMT.
EPA Hearing 8/29/83
Poplar, MT.
JH
BRITISH AM.
SIGNAL & FRANKS
FRANKS
A.L. 0256-4168

R47E

R48E

Houge | Sethre | A.L.0256-3784 | Boch | T.L. 0256-3158 | A.L 0256-2862 | A.L.0256-4487 | Dockery

HILLIARD 7728'

495/1394

BELCO 7780'

A.L.0256-4487

746/1410

Sethre 11 | 12 | Anderson 7 | A.L.0256-3825 | A.L.0256-3826 | 8 | Pat.

GRACE-FORD 620/1383

MURPHY 7772'

TULE CREEK

Houge | Sethre | Houg | Sethre | Morris | Weinber

CREEK KGS

500/400'E

PHILLIPS 7764'

PLACID

HUMBLE

575/1410

MURPHY

Anderson | Anderso

RED FOX

A.L. 56-3786

600/1408

DISCOVERY WELL

597/400E

598/1423

520/1300E 623/1300E

14 | 13 | 18

599/400E

599/400E

1433BPD

428psi

1,391,60

589/1390

611/1420

MURPHY

31 N

HUMBLE

624/1500E

608/1510

347/1422

ANSCHUTZ

A.L. 56-3771

Baracker | McKee | Herting 695/1518 | Sletvold | Zimmerman 64/1422 | A.L. 0256-4455 | A.L. 0256-2573 | A.L. 0256-

DISCOVERY WELL

KIRKW. 41 7805'

MURPHY

T.L.

770/1400E

A.L. 0256-4497

430/450E

250

950psi

3,830,468

MURPHY 7758'

5psi

2,164,863

30 N

23 | Houge 24 | Bjorgen 19 | Zimmerman

7,386,932 Bbls Com

Tule Creek

Roosevelt Co, MT.

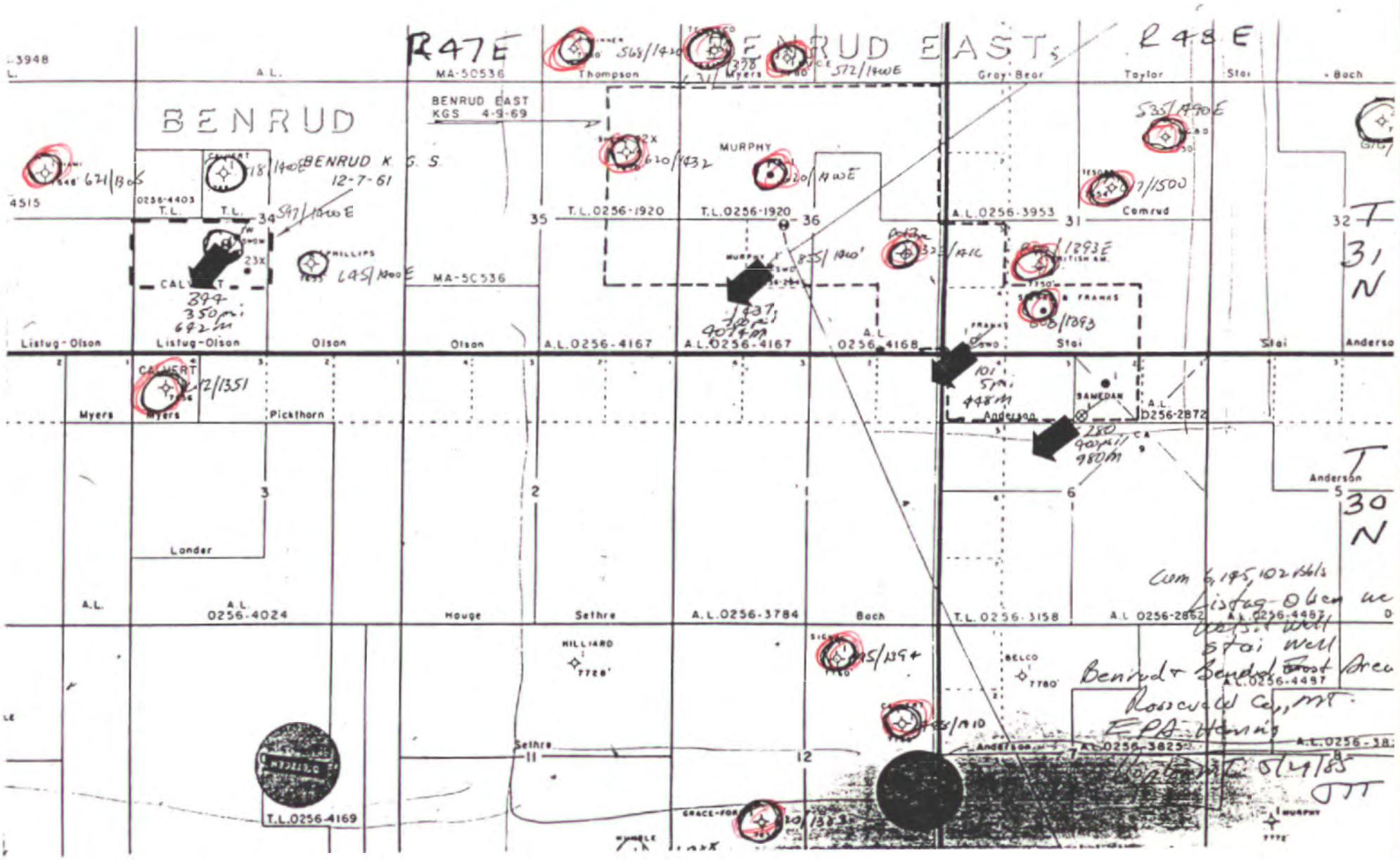
EPA Hearing

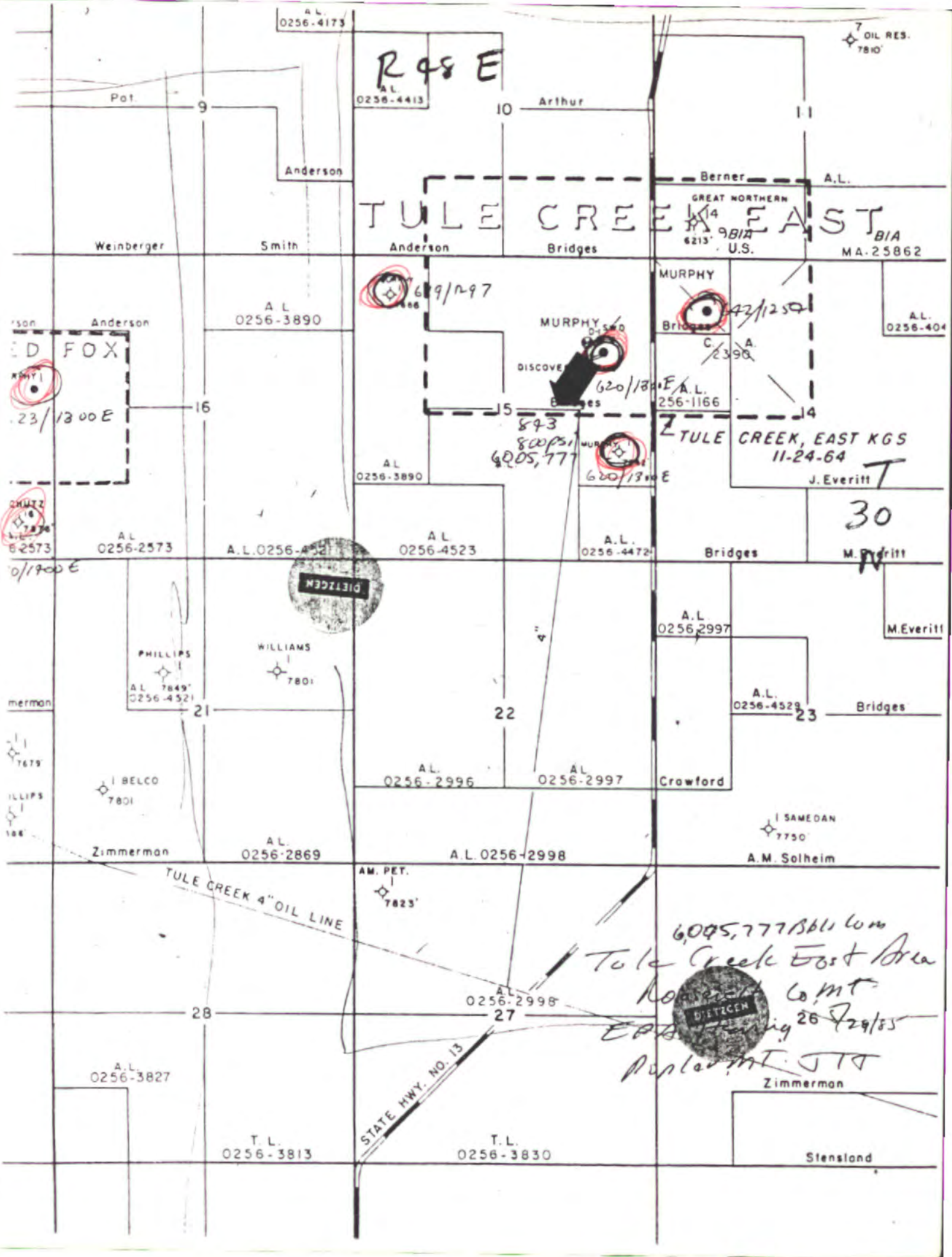
Poplar, MT. 5/29/85

IHLI 7679'

PHILLIPS

BEI 7801


R47E
BENRUD EAST
R48E
BENRUD
BENRUD EAST
KGS 4-9-69
BENRUD K.S.S.
12-7-61
MURPHY
CALVERT
PHILLIPS
FRANKS
SAMEDAN
BELCO
T.L.0256-1920
A.L.0256-3953
A.L.0256-4167
A.L.0256-4168
A.L.0256-4024
T.L.0256-3158
A.L.0256-2872
A.L.0256-3784
T.L.0256-4169
MA-5C536
Listug-Olson
Olson
Myers
Pickthorn
Lander
Hauge
Sethre
Bach
Anderson
Stai
Comrud
Gray Bear
Taylor
T 31 N
T 30 N
Cum 6,195,102 bbls
Listug-Olson
Stai well
Benrud + Benrud East Area
Roosevelt Co., MT.
EPA Hearing
Portland 5/4/85
JTT


R 48 E
TULE CREEK EAST
BIA
MA-25862
TULE CREEK, EAST KGS
11-24-64
T 30 N
Pot.
Anderson
Arthur
Berner
Weinberger
Smith
Bridges
MURPHY
GREAT NORTHERN
U.S.
A.L.
0256-3890
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A.L.
0256-4523
A.L.
0256-2997
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A.L.
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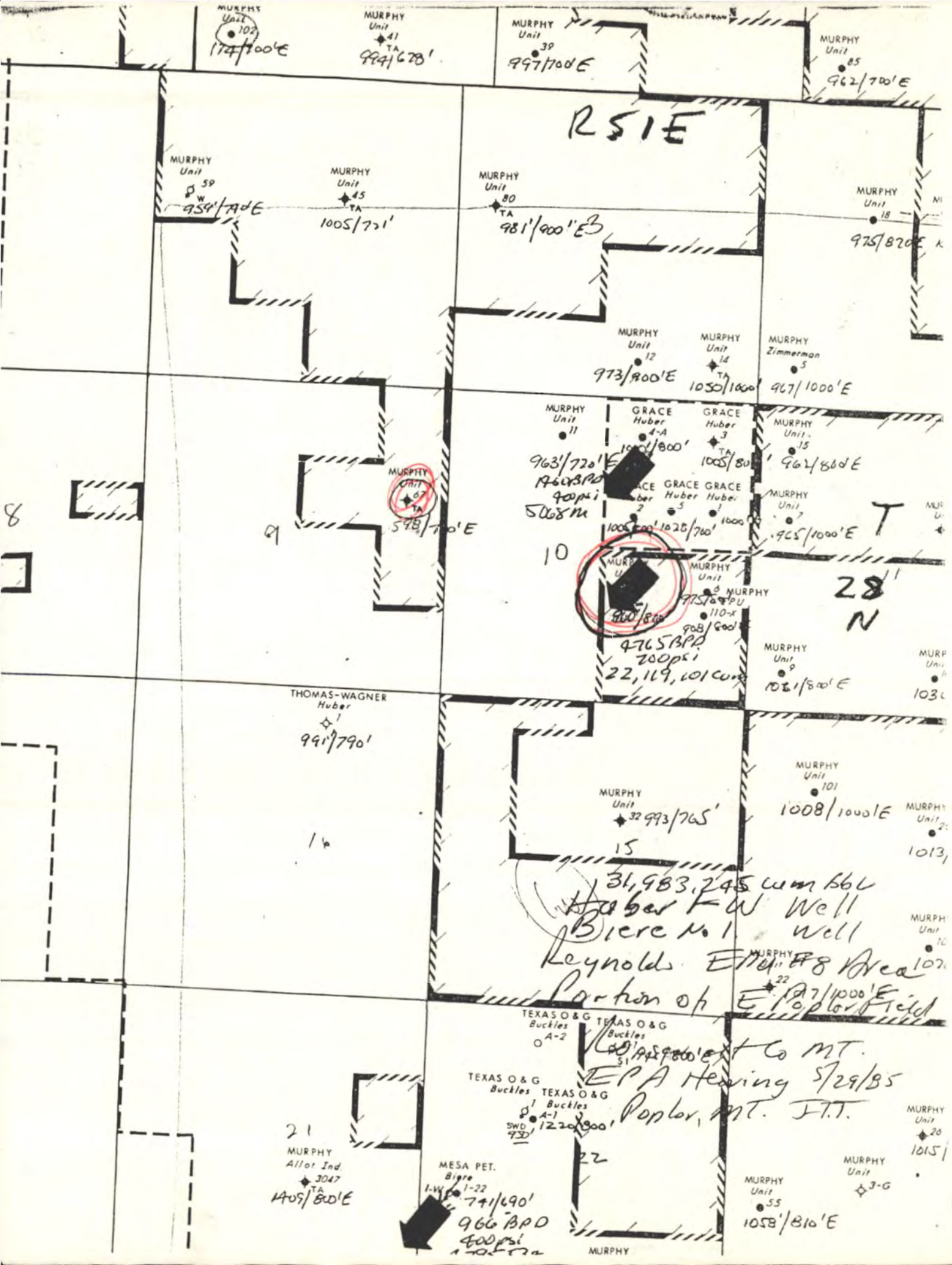
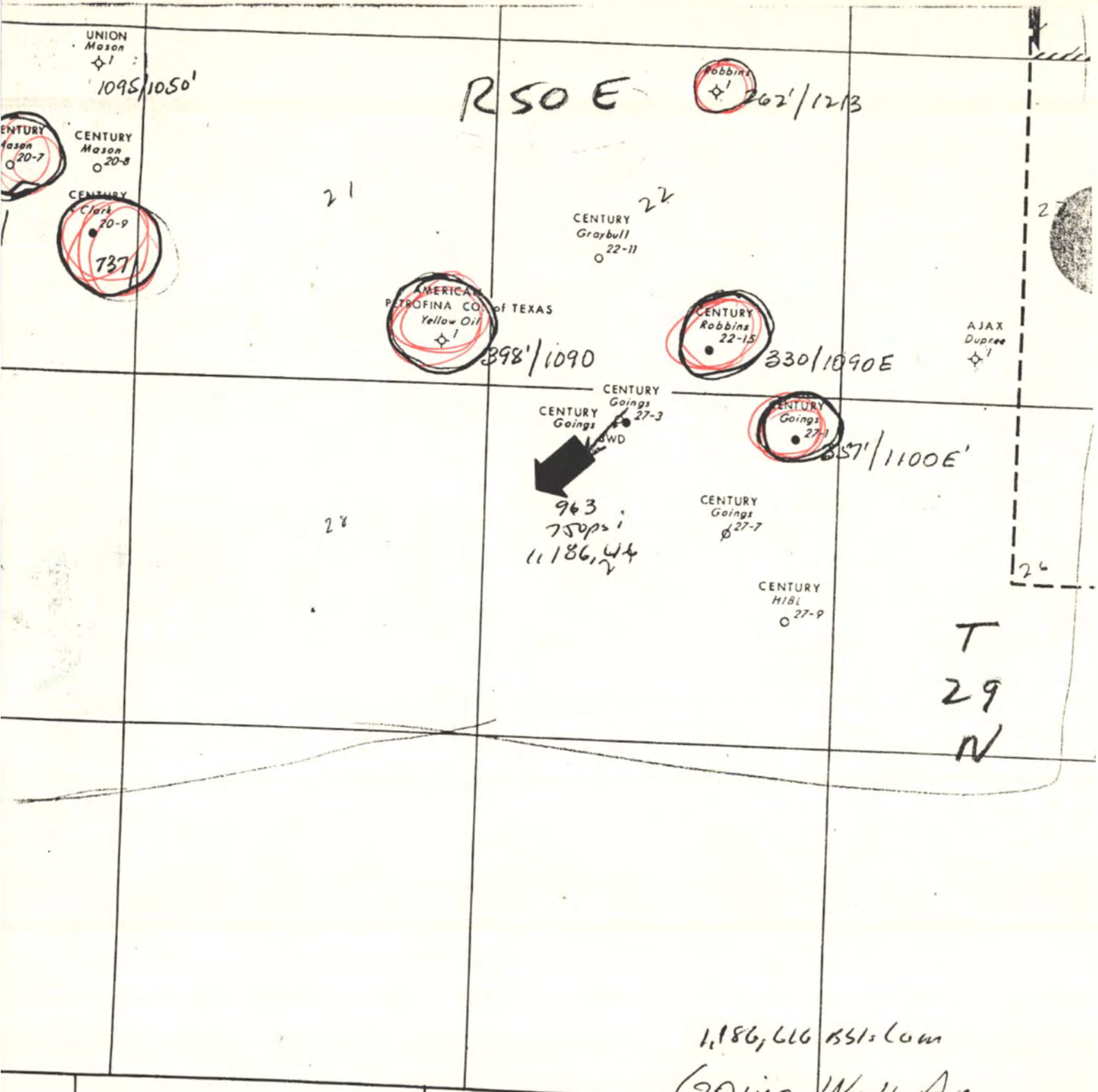
Crowford
Zimmerman
Stensland
M.Everitt
J. Everitt
A.M. Solheim
PHILLIPS
WILLIAMS
BELCO
SAMEDAN
AM. PET.
TULE CREEK 4" OIL LINE
STATE HWY. NO. 13
OIL RES.
DIETZGEN
6,095,777 Bbls Oil
Tule Creek East Area
Roosevelt Co, MT
Poplar, MT. JTT


R51E
T 28 N
MURPHY Unit 102 174/100'E
MURPHY Unit 41 TA 994/670'
MURPHY Unit 39 997/700'E
MURPHY Unit 85 962/700'E
MURPHY Unit 59 954/700'E
MURPHY Unit 45 TA 1005/721'
MURPHY Unit 80 TA 981/900'E
MURPHY Unit 18 975/820'E
MURPHY Unit 12 973/800'E
MURPHY Unit 14 TA 1050/1000'
MURPHY Zimmerman 5 967/1000'E
MURPHY Unit 11 963/720'E
GRACE Huber 4-A
GRACE Huber 3 TA 1005/800'
MURPHY Unit 15 962/860'E
MURPHY Unit 67 TA 598/700'E
GRACE Huber 2
GRACE Huber 5 1020/760'
GRACE Huber 1
MURPHY Unit 7 965/1000'E
MURPHY Unit 6 775/800 PU
MURPHY 110-X 908/800'
476 BPD 200 psi 22,169,101 cum
MURPHY Unit 9 1021/800'E
THOMAS-WAGNER Huber 1 991/790'
MURPHY Unit 32 993/765'
MURPHY Unit 101 1008/1000'E
31,983,245 cum bbl
Huber F-W Well
Biere No 1 Well
Reynolds Eng 8 Area
Portion of E Poplar Field
TEXAS O & G Buckles A-2
TEXAS O & G Buckles
TEXAS O & G Buckles A-1 1220/800'
SWD 930'
Roosevelt Co MT.
EPA Hearing 5/29/85
Poplar, MT. J.T.
MURPHY Allot Ind 3047 TA 1405/800'E
MESA PET. Biere 1-22 741/690'
966 BPD 600 psi
MURPHY Unit 55 1058'/810'E
MURPHY Unit 3-G
MURPHY Unit 26 1015'
MURPHY Unit 22 971/1000'E
MURPHY Unit 107
MURPHY Unit 1013'


UNION
Mason
1
1095/1050'
R50E
Robbins
1
262'/1213
CENTURY
Mason
20-7
CENTURY
Mason
20-8
CENTURY
Clark
20-9
737
21
22
CENTURY
Graybull
22-11
AMERICAN
PETROFINA CO. of TEXAS
Yellow Oil
1
398'/1090
CENTURY
Robbins
22-15
330/1090E
AJAX
Dupree
1
CENTURY
Goings
27-3
CENTURY
Goings
SWD
CENTURY
Goings
27-1
857'/1100E'
963
750psi
1,186,44
CENTURY
Goings
27-7
28
CENTURY
HIBL
27-9
T
29
N
1,186,666 BSL Com
Goings Well Area
Portion of Poplar NW Field
Roosevelt Co. MT.
EPA Hearing 5/29/85
Poplar, MT. JTT
STATES OIL
Hron Etux
1

JAMES T. THORNTON, CONSULTING ENGINEER
1380 GLENAIRE DRIVE
CASPER, WYOMING 82609
May 24,1985

MAXIMUM INJECTION PRESSURE

ELD NAME	STATE	WELL NAME	LOCATION	PERFERATIONS		SP GVTY	INJ PRES	PRES GRAD
lt	MT.	MURPHY Couchne 1-D	30N-46E-4-SESW	1499	1501	1.042	423	0.765
lt	MT.	KRKWD-WESCO Carlsn	30N-46E-9-NWNE	1422	1520	1.042	415	0.723
nrud	MT.	CRA List-Olsn A 1-W	31N-47E-34-NES	1463	1506	1.042	418	0.687
nrud E.	MT.	MURPHY Wetst 1	31N-47E-36-NES	1544	1600	1.042	443	0.896
nrud E.	MT.	PET INC Ltl Bgtrac 1	30N-48E-6-NWNE	1530	1550	1.042	434	0.711
Benrud	MT.	MURPHY Mule Cr. 1-D	31N-48E-20-SWS	1477	1619	1.042	436	0.858
nrud E.	MT.	SIGNAL Stai 1 SWD	31N-48E-31-SWS	1418	1560	1.042	420	0.455
le Cr.	MT.	ENERGY RES Phil-McKee	30N-47E-13-SEN	1505	1575	1.042	434	0.762
le Cr.	MT.	PETROLWS Lough 2	30N-47E-13-SES	1508	1555	1.042	432	1.071
le Cr.	MT.	MURPHY Sletvld B1	30N-48E-19-NWN	1455	1485	1.042	414	0.995
Tule Cr.	MT.	MURPHY Brdgs 1-D	30N-48E-15-SEN	1335	1395	1.042	385	0.459
Poplar	MT.	Century Goings 1	29N-50E-27-NEN	1028	1116	1.042	302	1.151
plar	MT.	Plubus Hber 1-W	28N-51E-10	735	881	1.042	228	0.946
plar	MT.	MURPHY Rynlds EPU 8	28N-51E-10-NWS	830	880	1.042	241	1.270
plar	MT.	Mesa Biere 1	28N-51E-22-NWS	1997	1999	1.042	563	0.651
plar	MT.	MURPHY Bk Elk 1	29N-51E-7-SWNW	1032	1207	1.042	315	0.808
plar	MT.	GRACE Bk Elk 2	29N-51E-7-SWNW	1149	1151	1.042	324	0.799
plar	MT.	Murphy EPU 29-D	29N-51E-28-SWS	853	887	1.042	245	1.198

JAMES T. THORNTON, CONSULTING ENGINEER
1380 GLENAIRE DRIVE
CASPER, WYOMING 82609

MAXIMUM INJECTION PRESSURE

ELD NAME	STATE	WELL NAME	LOCATION	PERFERATIONS		SP GVTY	INJ PRES	PRES GRAD
MN Coulee	MT.	RDG&BATES Hall SWD	29N-49E-29-NWN	1230	1270	1.042	352	1.171
Long Cr.	MT.	PENZL Mann 1SWD	31N-48E-25-SEN	1485	1645	1.042	441	0.643
mns Coule	MT.	RDG & BATES Hall SWD	29N-49E-29-NWN	1230	1270	1.042	352	1.171

For EPA Hearing Poplar Montana 5/29/85

[redacted]

For Month of April 19 70

Field Benrud County Roosevelt Operator TERRA RESOURCES, INC.

Unit or Lease Name LIstug-Olson Formation Injected Into Judith River

Injection Fluid (water, gas, air, LPG, etc.) Water

Source of Injection Fluid Nisku

Type of Project (Secondary Recovery, Pressure Maint., Disposal)

INJECTION DATA

INJECTION WELL INFORMATION					Monthly Inj. bbls, MCF, gals	Cumulative Inj. bbls, MCF, gals	Avg. Surfac Inj. Pressur
Name	No.	Sec.	Twp.	Rge.			
Listug-Olson "A"	1	34	31N	47E	4,905	642,238	350
				TOTALS	4,905	642,238	

JUN 1970 RECEIVED OIL & GAS CONS. COMM. STATE OF MONT. HELENA

NOTE: Mail three (3) copies to the Oil and Gas Conservation Commission of the State of Montana, Helena, Montana, o: or before the 20th day of each month following the month covered by the report. Separate report must be filed coverin each injection project.

REMARKS:

Original Signed By

By PERRY L. MITCHELL

Title Office Manager

Address P. O.Box 2250

Casper, Wyoming

Oil and Gas Conservation Commission
of the State of Montana
HELENA

REPORT OF SUBSURFACE INJECTIONS

For Month of November, 19 71

Field East Poplar County Roosevelt Operator The Columbus Corp.

Unit or Lease Name Huber Formation Injected Into Judith River

Injection Fluid (water, gas, air, LPG, etc.) Water

Source of Injection Fluid Madison - Heath - Nisku

Type of Project (Secondary Recovery, Pressure Maint., Disposal) Disposal

INJECTION DATA

INJECTION WELL INFORMATION					Monthly Inj. bbls, MCF, gals	Cummulative Inj. bbls, MCF, gals	Avg. Su Inj. Pre
Name	No.	Sec.	Twp.	Rge.			
Huber	1W	10	28N	51E	40,694	5,068,610	400
				TOTALS	40,694	5,068,610	400

REMARKS:

Huber 1 - Madison down 10 Days, Rod Parts & Working on Disposal System.
Huber 1 - Heath down 15-1/2 Days, Rod Parts & Working on Disposal Syste
Huber 2 down 19 days, Working on Disposal System and Shut In.
Huber 3 down 13-1/2 Days, Working on Disposal System.
Huber 4A down 14-1/2 Days, Working on Disposal System and plugged flow
Huber 5 down 16 days, Working on Disposal System and Shut In.
DFU 110 X down 16 days, Working on Disposal System and Shut In.

NOTE: Mail three (3) copies to the Oil and Gas Conservation Commission of the State of Montana, Helena, Monta or before the 20th day of each month following the month covered by the report. Separate report must be filed co each injection project.

REMARKS:

See Above

By Ted Nees

Title Field Supt

Address Box 1026, Poplar, Montan

FORM NO. 3

(SUBMIT IN TRIPLICATE)

TO

Board of Oil and Gas Conservation
of the State of Montana
2535 St. Johns Ave.
BILLINGS, MT 59102

ARM 36.22.307
ARM 36.22.1234

REPORT OF SUBSURFACE INJECTIONS

For Month of February 1985

Field Northwest Poplar County Roosevelt Operator Century Oil & Gas Corporation

Unit or Lease Name Goings Formation Injected Into Judith River

Injection Fluid (water, gas, air, LPG, etc.) Water

Source of Injection Fluid Charles "C" produced water

Type of Project (Secondary Recovery, Pressure Maint., Disposal) Disposal

INJECTION DATA

INJECTION WELL INFORMATION					Monthly Inj. bbls, MCF, gals	Cummulative Inj. bbls, MCF, gals	Avg. Su Inj. Pre
Name	No.	Sec.	Twp.	Rge.			
Goings	1 SWDW	27	29N	50 E	29,843	1,186,616	750
				TOTALS	29,843	1,186,616	

NOTE: Mail three (3) copies to the Board of Oil and Gas Conservation of the State of Montana, Billings, Montana, on before the 20th day of each month following the month covered by the report. Separate report must be filed covering ea injection project.

REMARKS:

By [signature]

Title Staff Engineer

Address 7887 East Belleview Avenue; Suit
Englewood, Colorado 80111

FORM NO. 5

(SUBMIT IN TRIPLICATE)

TO

Board of Oil and Gas Conservation
of the State of Montana
2535 St. Johns Ave.
BILLINGS, MT 59102

ARM 36.22.307
ARM 36.22.1234

REPORT OF SUBSURFACE INJECTIONS

For Month of January, 19 85.

Field Deadman's Coulee County Roosevelt Operator Reading & Bates Petroleum Co.

Unit or Lease Name Allotted Hall Formation Injected Into Nisku ← From to J. R.

Injection Fluid (water, gas, air, LPG, etc.) Water

Source of Injection Fluid Produced water

Type of Project (Secondary Recovery, Pressure Maint., Disposal) Disposal

INJECTION DATA

INJECTION WELL INFORMATION					Monthly Inj. bbls, MCF, gals	Cummulative Inj. bbls, MCF, gals	Avg. Surfac Inj. Pressur
Name	No.	Sec.	Twp.	Rge.			
Allotted Hall	1-29	29	29N	49E	26,927		900
Allotted Hall	2-29	29	29N	49E	12,672		
Zimmerman	1-20	20	29N	49E	30,731		
Zimmerman	2-20	20	29N	49E	5,100		
Allotted Hall	SWD	29	29N	49E			
				TOTALS	75,430	2,452,707	

Production

NOTE: Mail three (3) copies to the Board of Oil and Gas Conservation of the State of Montana, Billings, Montana, on or before the 20th day of each month following the month covered by the report. Separate report must be filed covering each injection project.

REMARKS:

By Cary L. Martinez

Title Engineering Secretary

Address 1125 17th Street, Suite 2300
Denver, CO 80202

NALCO

REPORT OF WATER ANALYSIS

Company	Murphy Oil Corporation Poplar, Montana	Date	May 21, 1985
		Analysis No.	
		Sampling Date	May 21, 1985
		Date Sample Rec'd.	May 21, 1985
Sample Marked	EPU Freshwater Station (Judith River)		

DISSOLVED SOLIDS			RESULTS AS COMPOUNDS	
Cations	mg/l	meq/l		mg/l
Sodium, Na (Calc.)	3,772	164	as NaCl	
Calcium, Ca	320	16	as $CaCO_3$	800
Magnesium, Mg	49	4	as $CaCO_3$	200
Barium, Ba	--	--	as $BaSO_4$	--
Cations Total	4,141	184		
Anions				
Chloride, Cl	6,313	178	as NaCl	10,400
Sulfate, SO_4	11	1	as Na_2SO_4	17
Carbonate, CO_3	0	0	as $CaCO_3$	0
Bicarbonate, HCO_3	317	5	as $CaCO_3$	260
Anions Total	6,641	184		
Total Dissolved Solids (Calc.)	10,782			
Total Iron, Fe	1.8		as Fe	1.8
Acidity to Phenolphthalein, CO_2	48		as $CaCO_3$	110

OTHER PROPERTIES		$CaCO_3$ STABILITY INDEX
pH	7.0	@ 70° F.
Specific Gravity		@ 120° F.
Turbidity (JTU)		@ 160° F.
		Method of Stiff & Davis

Remarks: cc: D. Kasowski
D. Brown

/mg

NALCO CHEMICAL COMPANY
VISCO CHEMICALS
P. O. BOX 87 • SUGAR LAND, TEXAS 77478

NALCO trademarks of Nalco Chemical Company.

S-16A

NALCO

REPORT OF WATER ANALYSIS

Company	Murphy Oil Corporation Poplar, Montana Fresh Water Station	Date	March 16, 1984
		Analysis No.	
		Sampling Date	March 13, 1984
		Date Sample Rec'd.	March 13, 1984
Sample Marked	Fresh Water Wellhead		

DISSOLVED SOLIDS			RESULTS AS COMPOUNDS	
Cations	mg/l	meq/l		mg/l
Sodium, Na (Calc.)	4318.02	187.74	as NaCl	
Calcium, Ca	100	5	as $CaCO_3$	250
Magnesium, Mg	12	.99	as $CaCO_3$	49
Barium, Ba	0	0	as $BaSO_4$	0
Cations Total	4430.02	193.73		
Anions				
Chloride, Cl	6450	181.89	as NaCl	10,626
Sulfate, SO_4	11.49	.24	as Na_2SO_4	17
Carbonate, CO_3	0	0	as $CaCO_3$	0
Bicarbonate, HCO_3	707.60	11.60	as $CaCO_3$	580
Anions Total	7169.09	193.73		
Total Dissolved Solids (Calc.)	11,599.11			
Total Iron, Fe	1.55		as Fe	1.55
Acidity to Phenolphthalein, CO_2	44		as $CaCO_3$	100

OTHER PROPERTIES		$CaCO_3$ STABILITY INDEX
pH	7.2	@ 70° F.
Specific Gravity		@ 120° F.
Turbidity (JTU)		@ 160° F.
		Method of Stiff & Davis

Remarks:

Sample taken at wellhead before chemical injection.

cc: S. Fox
D. Kasowski

NALCO CHEMICAL COMPANY
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DWL-461-2-A

DOWELL DIVISION OF THE DOW CHEMICAL COMPANY

LABORATORY LOCATION Casper

API WATER ANALYSIS REPORT FORM

DATE February 25, 1972

LAB NO. CL 2683

Company		Sample No.	Date Sampled
Murphy			Feb. 1972

Field	Legal Description	County or Parish	State
E. Poplar		Roosevelt	Montana

Lease or Unit	Well	Depth	Formation	Water, B/D
			Judith	

Type of Water (Produced, Supply, etc.)	Sampling Point	Sampled By
Supply	Water Plant	Getz

DISSOLVED SOLIDS

CATIONS	mg/l	me/l
Sodium, Na (calc.)	6578	286
Calcium, Ca	92	4.6
Magnesium, Mg	26	2.
Barium, Ba		

ANIONS		
Chloride, Cl	10000	285
Sulfate, SO_4	150	3.1
Carbonate, CO_3	0	
Bicarbonate, HCO_3	300	4.9

Total Dissolved Solids (calc.) 17146

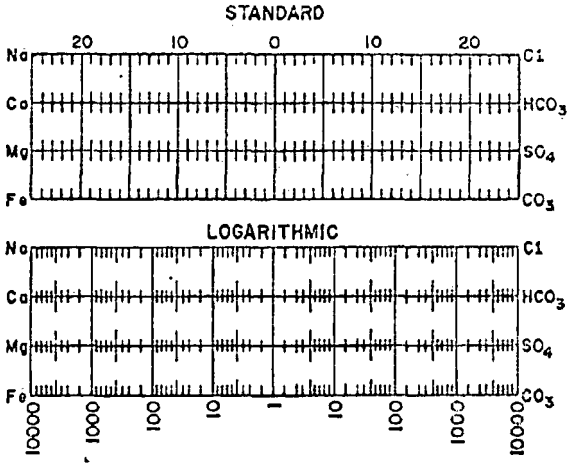
Iron, Fe (total) 1.0

Sulfide, as H_2S Trace

OTHER PROPERTIES

pH	6.75
Specific Gravity, 60/60 F.	1.015
Resistivity (ohm-meters) ____ F.	
Stability Index	+0.1
Sulfate Scaling	no

WATER PATTERNS — me/l



REMARKS & RECOMMENDATIONS: Low Solids 0.1 lb/1000 gallons suspended

ANALYSIS BASED ON API RECOMMENDED PROCEDURE

NALCO

REPORT OF WATER ANALYSIS

From Murphy Oil Corporation Analysis Date 12-29-70

Sample Marked Fresh Water, East Poplar Unit

MILLIGRAMS PER LITER

Chloride (as NaCl)	10,000
Total Hardness (as $CaCO_3$)	360
Calcium Hardness (as $CaCO_3$)	268
Total Alkalinity (as $CaCO_3$)	20 - 200
Acidity to Phenolphthalein (as $CaCO_3$)	0
Sulfate (as Na_2SO_4)	0
Total Iron (as Fe)	0.4
Suspended Solids	
Precipitated By Sulfate (as $BaSO_4$)	
Turbidity (SiO_2)	
Phosphate (PO_4)	2.5
pH	7.6
Specific Gravity	

*Estimated

Ray Green
Analyst

NALCO CHEMICAL COMPANY
VISCO DIVISION
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Form S-29

NALCO CHEMICAL COMPANY
VISCO DIVISION

P.O. Box 87 · Sugar Land, Texas 77478

Plants at Sugar Land, Texas, Anaheim, California, and Casper, Wyoming

REPORT OF WATER ANALYSIS

From Murphy Oil Corp.
Poplar, Montana

Analysis Date 4-2-69

Sample Marked L.P.U. Fresh water - suction on pump

MILLIGRAMS PER LITER

Chloride (as NaCl)	1[illegible],600
Total Hardness (as $CaCO_3$)	272
Calcium Hardness (as $CaCO_3$)	128
Total Alkalinity (as $CaCO_3$)	P-0 M-204
Acidity to Phenolphthalein (as $CaCO_3$)	47
Sulfate (as Na_2SO_4)	0
Total Iron (as Fe)	1.7
Suspended Solids	
Precipitated By Sulfate (as $BaSO_4$)	5
pH	8.4
Specific Gravity	

***ESTIMATED**

[illegible].L. Crane
ANALYST

FORM 8-39

NALCO CHEMICAL COMPANY
VISCO DIVISION
P.O. Box 87 · Sugar Land, Texas 77478
Plants at Sugar Land, Texas, Anaheim, California, and Casper, Wyoming

REPORT OF WATER ANALYSIS

From Murphy Oil Corporation

Poplar, Montana

Sample Marked EPU 5C

Date 2/28/68
Analysis No. 68-W131
Sampling Date Not Given
Date Sample Rec'd 2/22/68

	MILLIGRAMS PER LITER
Chloride (as NaCl)	13,400
Total Hardness (as $CaCO_3$)	340
Calcium Hardness (as $CaCO_3$)	250
Total Alkalinity (as $CaCO_3$)	p 50 m 290
Acidity to Phenolphthalein (as $CaCO_3$)	0
Sulfate (as Na_2SO_4)	0
Total Iron (as Fe)	55
Suspended Solids	
Precipitated By Sulfate (as $BaSO_4$)	16
Turbidity (SiO_2)	85

pH	7.8
Specific Gravity	1.008

CHEMIST

*ESTIMATED

cc: D. C. Johnson (3)
D. V. Murphy
Mr. M. T. James
Murphy Oil Corp., Mont.

mz

File

VISCO DIVISION
P. O. Box 87 • Sugar Land, Texas
NALCO CHEMICAL COMPANY

Plants at Sugar Land, Texas, and Anaheim, California

REPORT OF WATER ANALYSIS

From Murphy Corporation
E. Poplar
Poplar, Montana

Sample Marked Field Supply Water

Date 12-1-66
Analysis No. 66-W1450
Sampling Date 11-23-66
Date Sample Rec'd. 11-30-66

MILLIGRAMS PER LITER

Chloride (as NaCl)	10,800
Total Hardness (as $CaCO_3$)	330
Calcium Hardness (as $CaCO_3$)	240
Total Alkalinity (as $CaCO_3$)	180
Acidity to Phenolphthalein (as $CaCO_3$)	16
Sulfate (as Na_2SO_4)	0
Total Iron (as Fe)	1.8
Suspended Solids	-
Precipitated By Sulfate (as $BaSO_4$)	10
Turbidity (SiO_2)	0

pH	7.6
Specific Gravity	1.007

CHEMIST

*ESTIMATED

cc: D. C. Johnson (4)
D. V. Murphy
H. E. King
Harold Milam, Denver, Colo.
LeRoy Duncan, El Dorado, Ark
M. T. James, Poplar, Mont.

Case No. 56 E 50

Bradford LABORATORIES

WATER ANALYSIS RESULTS

CLIENT: MURPHY CORPORATION

Sample No.	X-35			
Date Sampled	4-26-60			
Time Sampled				
Date Received				
Time Received				
Location:	Judith River Gas sand			
Appearance When Sampled	Turbid			
Appearance After Standing				
Odor				
Taste				
Temperature °F				
pH	7.8			
Carbon Dioxide ppm CO_2				
Dissolved Oxygen ppm O_2				
Residual Chlorine ppm Cl_2				
Turbidity ppm				
Manganese ppm Mn				
Iron (Total) ppm Fe				
Alkalinity to Phenolphthalein ppm $CaCO_3$	0			
Alkalinity to Methyl Orange ppm $CaCO_3$	200			
Sulfates ppm SO_4	6			
Chlorides ppm Cl	6,750			
Total Hardness ppm $CaCO_3$	334			
Silica ppm SiO_2				
Calcium ppm Ca	96			
Magnesium ppm Mg	22			
Complex Phosphate ppm				
Total Solids ppm				
Conductivity	21,000			
Suspended Solids	15,750			

17.1 ppm equal 1 grain per U. S. gallon. - "nd" means not determined.

COMMENTS

B-4102

MURPHY CORPORATION
Gas Well #L-19
Case No. 56 E 50

Date Sampled		3-30-60	
Appearance When Sampled		Turbid	
pH		7.9	
Alkalinity to Phenolphthalein	$CaCO_3$	0	ppm
Alkalinity to Methyl Orange	$CaCO_3$	106	ppm
Sulfates	SO_4	< 5	ppm
Chlorides	Cl	6,850	ppm
Total Hardness	$CaCO_3$	322	ppm
Calcium	Ca	93	ppm
Magnesium	Mg	22	ppm
Solids, Dissolves		15,000	ppm
Conductivity		20,000	

YAPUNCICH-SANDERSON LABORATORIES
P. O. BOX 593 BILLINGS, MONTANA 5 & 9½ N. 25TH ST.

WATER ANALYSIS REPORT

Lab. No. 461-W

Field E. Poplar County Roosevelt State Montana
Well No. 4G Location SW SE 19-29N-51E
Formation Judith River Depths 850'
Operator Murphy Corporation Date Sampled 10-21-54
DST No. _____ Sample Production Sample Date Analyzed 10-25-54
Other Data Sample clear colorless water. Sample from a gas well.

Constituents	PPM	MEQ.	MEQ. %
Sodium	3057	132.95	47.16
Calcium	106	5.29	1.88
Magnesium	33	2.71	0.96
Sulfate	Trace	Trace	Trace
Chloride	6583	136.93	48.57
Carbonate	0	0	0
Bicarbonate	245	4.02	1.43

Total Solids in Parts per Million
By evaporation 10,028
After ignition 9764
Calculated 9900

pH 6.4

Specific Gravity @ 60°F 1.009

Resistivity @ 68°F ohms/meter³ 0.63

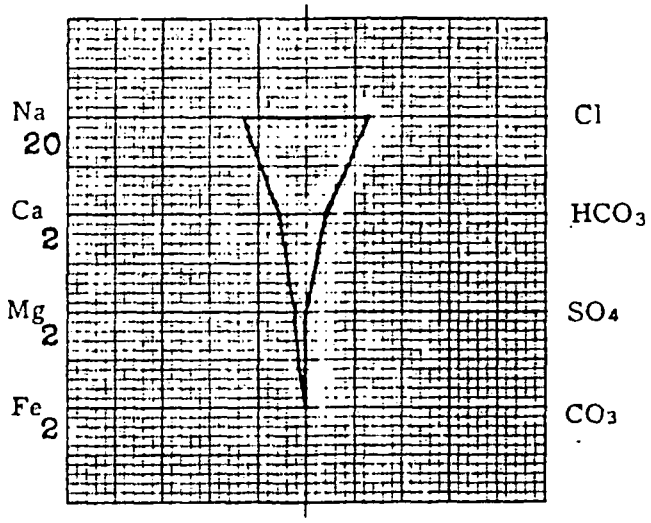
Chloride as NaCl 10,855 PPM.

Total Solids From Resistivity as NaCl 9873 PPM.

NOTE: Sodium and potassium reported as sodium. MEQ. = milliequivalents per liter PPM = parts per million (milligrams per liter) 1 PPM equivalent to 0.0001%

WATER ANALYSIS PATTERN

Scale MEQ. Per Unit



WESTERN LITHO-PRINT, INC., BILLINGS, MONT.

9-546-b
(August 1932)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Laboratory Casper, Wyoming

INFORMATION TO BE FURNISHED WITH EACH SAMPLE OF WATER

Marks on container ..... Laboratory No. 55-W 35 ..... (filled by chemist)

SOURCE OF SAMPLE

Field East Poplar (Unit), Wyoming ..... Farm or {Permit / Lease} Fort Peck Allotted No. 12974 (Serial number)

Operator Murphy Corporation ..... Operator's address .....

Well No. 4-C C SW¼SE¼ sec. 19, T. 29 N., R. 61 E., ..., P. M.

Sample taken by Mr. W. L. Jones, asst. prod. supt. Date taken 12/9/54

If known, name of sand (or formation) from which this sample is produced Judith River (If doubtful, so state)

Depth to top of sand 787' ..... Depth to bottom of sand ---

Depth well drilled 787' ..... Present depth 787'

Depths (if known) where water encountered .....

Depth at which water string is landed, cemented, mudded 8⅝" cc @ 737' w/200 sx.

METHOD OF SAMPLING

Place where sample was obtained (sump hole, lead line, flow tank, bailer, etc.) .....

Method of production (flowing, pumping, air, etc.) .....

Initial production:		Present production:	
Barrels oil		Barrels oil	
Barrels water	?	Barrels water	
Gas volume	254 MCF/day	Gas volume	
Rock pressure		Rock pressure	

REASON FOR ANALYSIS

(1) Future reference: XXXX

(2) .....

(3) Correlation: .....

(4) .....

NOTE.—A sample for analysis is of no value unless accompanied by above information. Complete information on this form is to be attached to each sample container; otherwise sample will be disregarded. Be sure to seal or tightly cork all containers immediately after sampling and label all samples so that there will be no confusion.

(OVER)

6—0174

WATER ANALYSIS

Condition of sample ..... Laboratory No. 55-W 35

Analyzed by K. P. Moore at Casper, Wyoming Date 12/15/54

REACTING VALUES

	PARTS PER MILLION	REACTING VALUE	VALUE IN PERCENT
Sodium and potassium (calculated as sodium)	4034	175.48	48.05
Calcium (Ca)	123	6.14	1.68
Magnesium (Mg)	12	0.99	0.27
Iron (Fe)	—	present	—
Sulphate (SO_4)	0		
Nitrate (NO_3)			
Chloride (Cl)	6340	178.79	48.95
Carbonate (CO_3)			
Bicarbonate (HCO_3)	233	3.82	1.05
Hydroxide (OH)			
Silica (SiO_2)			
Hydrogen sulphide (H_2S)			

TOTAL SOLIDS IN PARTS PER MILLION

By evaporation 10972

After ignition 10694

Calculated 10624

PROPERTIES OF REACTION IN PERCENT

Primary salinity 96.10

Secondary salinity 1.80

Primary alkalinity 0.00

Secondary alkalinity 2.10

Chloride salinity 100.00

Sulphate salinity 0.00

Remarks and conclusions No previous water samples from this field.

U. S. GOVERNMENT PRINTING OFFICE 6—0174

file file

YAPUNCICH, SANDERSON & BROWN LABORATORIES

P. O. BOX 593 — BILLINGS, MONTANA — 13 N. 32nd ST.

WATER ANALYSIS REPORT

Lab. No. 6733

Field _____ County ROOSEVELT State MONTANA
Well No. COURCHENE #1-D Location 30N-46E
Formation JUDITH RIVER Depths 1430-1432
Operator MURPHY OIL CORPORATION Date Sampled 3-1-65
DST No. _____ Sample _____ Date Analyzed 3-10-65
Other Data SAMPLE CLEAR, SLIGHTLY YELLOW WATER. ORGANIC MATTER PRESENT.

Constituents	PPM	MEQ.	MEQ. %
Sodium	5,558	241.76	46.99
Calcium	238	11.88	2.31
Magnesium	44	3.62	0.70
Sulfate	650	13.52	2.63
Chloride	8,140	229.55	44.61
Carbonate	0	0	0
Bicarbonate	865	14.19	2.76

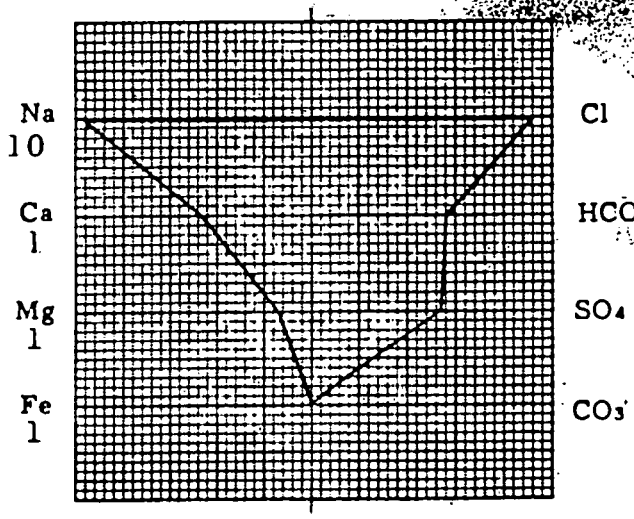
Total Solids in Parts per Million
By evaporation _____
After ignition _____
Calculated 15,056
pH 7.8
Specific Gravity @ 80°F 1.011
Resistivity @ 88°F ohms/meter³ 0.47

Chloride as NaCl 13,423 PPM. Total Solids From Resistivity as NaCl 14,608 PPM

NOTE: Sodium and potassium reported as sodium. MEQ. = milliequivalents per liter. PPM = parts per million (milligrams per liter). 1 PPM equivalent to 0.001%

WATER ANALYSIS PATTERN

Scale MEQ. Per Unit



YAPUNICH, SANDERSON & BROWN LABORATORIES

P. O. BOX 593 BILLINGS, MONTANA 13 N. 32ND ST

WATER ANALYSIS REPORT

Lab. No. 6488-2

Field _____ County _____ State MONTANA
Well No. 1 BRIDGES Location _____
Formation JUDITH RIVER Depths 1315-1411'
Operator MURPHY OIL CORPORATION Date Sampled _____
DST No. 1 Sample BOTTOM Date Analyzed 9-16-64
Other Data SAMPLE CLEAR, COLORLESS WATER.

Constituents	PPM	MEQ.	MEQ. %
Sodium	5,887	256.07	47.86
Calcium	206	10.28	1.92
Magnesium	14	1.15	0.22
Sulfate	127	2.64	0.49
Chloride	9,235	260.43	48.68
Carbonate	0	0	0
Bicarbonate	270	4.43	0.83

Total Solids in Parts per Million
By evaporation _____
After ignition _____
Calculated 15,602

pH 7.4

Specific Gravity @ 60°F 1.012

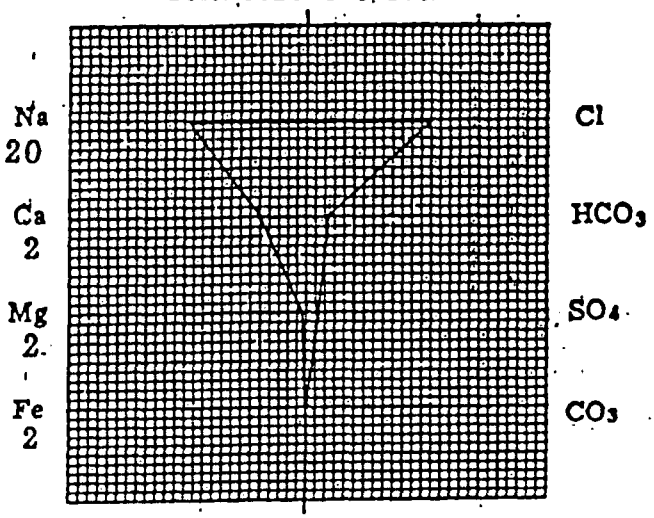
Resistivity @ 68°F ohms/meter³ 0.43

Chloride as NaCl 15,229 PPM. Total Solids From Resistivity as NaCl 15,501 PPM.

NOTE: Sodium and potassium reported as sodium. MEQ.=milliequivalents per liter. PPM=parts per million (milligrams per liter). 1 PPM equivalent to 0.0001%

WATER ANALYSIS PATTERN

Scale MEQ. Per Unit



NOT SUITABLE FOR LIVESTOCK OR DOMESTIC USE.

SPECIALIZING IN CORE, WATER, GAS AND CRUDE OIL ANALYSES

File

YAPUNCICH, SANDERSON & BROWN LABORATORIES

P. O. BOX 593 — BILLINGS, MONTANA — 13 N. 32ND ST

WATER ANALYSIS REPORT

Lab. No. 6506

Field WILDCAT — County ROOSEVELT — State MONTANA
Well No. 1 O'CONNER — Location NW NW 15-30N-49E
Formation JUDITH RIVER — Depths 1535-1600'
Operator MURPHY OIL CORPORATION — Date Sampled
DST No. 1 — Sample BOTTOM — Date Analyzed 9-30-64
Other Data SAMPLE CLEAR, COLORLESS WATER WITH MUD ON BOTTOM.

Constituents	PPM	MEQ.	MEQ. %
Sodium	6216	270.37	47.41
Calcium	253	12.62	2.21
Magnesium	26	2.14	0.38
Sulfate	558	11.61	2.04
Chloride	9050	255.21	44.75
Carbonate	370	12.32	2.16
Bicarbonate	365	5.99	1.05

Total Solids in Parts per Million

By evaporation
After ignition
Calculated 16,653

pH 9.2

Specific Gravity @ 60°F 1.012

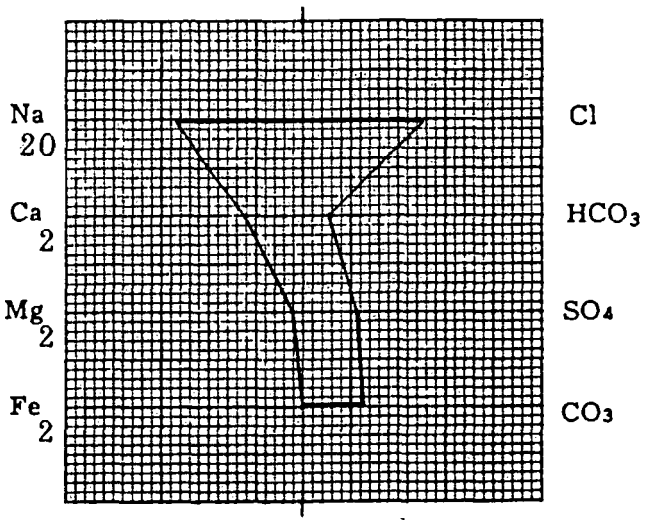
Resistivity @ 68°F ohms/meter³ 0.42

Chloride as NaCl 14,923 PPM. Total Solids From Resistivity as NaCl 16,355 PPM.

NOTE: Sodium and potassium reported as sodium. MEQ.=milliequivalents per liter. PPM=parts per million (milligrams per liter). 1 PPM equivalent to 0.0001%

WATER ANALYSIS PATTERN

Scale MEQ. Per Unit



NOT SUITABLE FOR LIVESTOCK USE.

YA[illegible]ICH, SANDERSON & BROWN [illegible]RATORIES

P. O. BOX 593 BILLINGS, MONTANA 13 N. 32ND ST.

WATER ANALYSIS REPORT

Lab. No. 1406-W

Field EAST POPLAR County ROOSEVELT State MONTANA
Well No. 93 UNIT Location C SW NW 19-29N-51E
Formation JUDITH RIVER Depths 866-877'
Operator MURPHY CORPORATION Date Sampled 3-29-57
DST No. 1 Sample Date Analyzed 4-4-57
Other Data TOOL OPEN 2 HRS. SI 20 MIN. RECOVERED 206' SALT WATER WITH GAS BUBBLES. FP 18-120 LBS., SIP 355 LBS., HP 590 LBS. SAMPLE CLEAR YELLOW COLORED WATER.

Constituents	PPM	MEQ.	MEQ. %
Sodium	7141	310.62	48.62
Calcium	135	6.69	1.05
Magnesium	26	2.14	0.33
Sulfate	69	1.44	0.23
Chloride	11,120	313.58	49.08
Carbonate	0	0	0
Bicarbonate	270	4.43	0.69

Total Solids in Parts per Million

By evaporation 18,780
After ignition 18,020
Calculated 18,623

pH 7.9

Specific Gravity @ 60°F 1.014

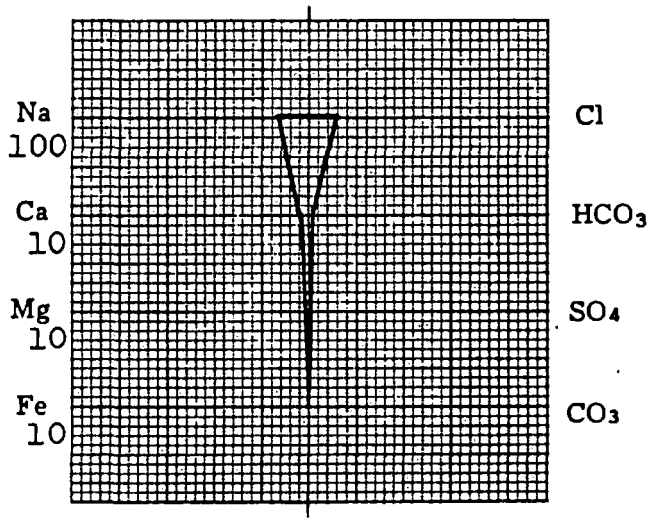
Resistivity @ 68°F ohms/meter³ 0.39

Chloride as NaCl 18,336 PPM. Total Solids From Resistivity as NaCl 18,548 PPM.

NOTE: Sodium and potassium reported as sodium. MEQ.=milliequivalents per liter. PPM=parts per million (milligrams per liter). 1 PPM equivalent to 0.0001%

WATER ANALYSIS PATTERN

Scale MEQ. Per Unit



The following is the approximate amount of water injected into the Judith River Sand and the date the wells was completed in said zone.

East Poplar Unit No. 8-D
January 29, 1978
15,975,426 BW

East Poplar Unit No. 29-D
April 27, 1981
4,075,718 BW

Sletvold B-1
June 23, 1967
4,433,262 BW

East Tule Creek No. 1-D
August 21, 1968
1,938,795 BW

Wetsit No. 1-D
October 19, 1966
4,230,004 BW

Courchene No. 1-D
March 3, 1965
9,641,002 BW

Mule Creek Allotted No. 1-D
November 17, 1967
2,164,863 BW

The following is a partial list of wells disposing into the Judith River.

Grace Petroleum
2 wells NW¼ Section 7, R29, T51
2 wells NE¼ Section 10, R28, R51

Penzoil
Section 25, T30, R48

Kirkwood
Section 9, T30, R46
874,000BW

Franks Petroleum
Section 31, T31, R48

Petroleum Inc.
Section 6, T30, R48
1,051,767 BW

Petro-Lewis
Section 13, T36, R47
2,868,818 BW

RAM Oil
Section 36, T30, R47

Olson Well
Section 34, T31, R47

Energy Reserves
Section 13, T30, R47
2,454,000 BW

Mesa Petroleum
Section 21, T28, R51

Century Oil & Gas
Section 27, T29N, R50E

THE JUDITH RIVER FORMATION BENEATH THE FORT PECK

INDIAN RESERVATION A PROVEN HIGH PLAINS

GAS RESERVOIR

325 - 340

THE JUDITH RIVER FORMATION BENEATH THE FORT PECK INDIAN RESERVATION A PROVEN HIGH PLAINS GAS RESERVOIR

by
Lawrence M. Monson
Minerals Resource Office
Fort Peck Tribes
Box 1027, Poplar Mt. 59255

ABSTRACT

As one of the transgressive-regressive cycles in the Western Interior Basin, the Judith River-Claggett sequence created potential reservoirs for shallow biogenic gas. Across the Fort Peck Reservation in northeastern Montana, a distance of 75 mi (121 km), the Judith River Formation varies in thickness form 350 ft (105 m) in the west to 130 ft (39 m) in the east.

Three distinct stratigraphic prisms are recognized in this cycle. A thick basal sandstone in the west formed in a shore environment with some deltaic sedimentation. This unit is time regressive, grading into a thin shelf sandstone, properly placed in the older, Claggett Formation. The two sandstone intervals of the main Judith River Formation are nonmarine in the west and become progressively younger as they prograde eastward into the Bearpaw (Pierre) shale. The lower unit is transitional to a shore facies and then to a shelf facies in the central reservation where it represents the maximum regression as an inner shelf ridge complex. Sand lenses reach 140 ft (43 m) in thickness. In the northeast another ridge complex formed farther out on the shelf. The upper sandstone is only a well developed shelf sand ridge in the north-central part of the reservation. Maximum sand thickness is 40 ft (12 m). At least three deltaic channel systems developed farther to the west. This unit may have signalled the last Cretaceous transgression which deposited the Bearpaw shale.

Stratigraphic traps exist in the three sandstone units due to variation in grain size, clay content, and porosity associated with the progradational facies changes. In addition, structures associated with the Poplar Dome and the Wolf Creek Nose have created local trapping mechanisms. Judith River gas has been produced in the East Poplar Field for operational use. Shows have been reported in several reservation wells, although high mud weights and deeper exploration targets have prevented adequate evaluation of the Judith River gas resource.

INTRODUCTION

The Judith River Formation in northeastern Montana has proven potential for significant shallow gas reserves. This paper will describe the stratigraphy of the Judith River-Claggett interval beneath the Fort Peck Indian Reservation (see Fig. 1). Three criteria are used to evaluate the characteristics most favorable for the accumulation of natural gas. Higher sonic porosity, lower shale content, and increased sand thickness define areas with the most potential. Local and regional structural trends may enhance that potential, especially in the Judith River Formation where a water drive may be present. Regional structural elements are shown in Figure 2. Paleotectonics played a key role in controlling Late Cretaceous sand deposition, as has been demonstrated by Shurr (1984, 1988, 1989).

Since 1915 the Judith River Formation has produced natural gas in eastern Montana along the Cedar Creek Anticline (see Fig. 2). Cumulative gas production in the Cedar Creek Field through 1986 exceeded 194 billion cubic feet (5.4 billion cubic meters), (Shurr, *et al.*, 1989), but the reservoir is currently used for storage. On the Fort Peck Reservation, Judith River gas was produced in the East Poplar Unit for operational use. Each of these gas occurrences was summarized by McRae and Swenson (1968). Gas shows in the Judith River Formation have been reported for many reservation oil wells from a fairly widespread area.

Most workers believe this stratigraphic cycle formed in an upper Cretaceous province which covered the northern Great Plains and the southern part of western Canada. This province is characterized by the potential for ubiquitous natural gas (Rice and Shurr, 1980). Reported recoverable reserves in the Suffield Block of eastern Alberta, Canada, conservatively average 2 Bcf/sq. mi (2.2 MM m^3/sq. km), (Energy Reserve Conservation Board, 1977). The Judith River Formation, known as the Belly River Group in Canada, has played a minor, yet significant role in that development of natural gas. A well on the Battle Creek Anticline in southwestern Saskatchewan tested 2.9 million cubic feet per day from the basal sand (Gilboy, 1988, personal communication).

CRETACEOUS SETTING

Figure 3 compares the relevant stratigraphic nomenclature of Upper Cretaceous rocks. In Canada, the Judith River is called the Old Man and Foremost Formations in Alberta and is known as the Belly River Group in Saskatchewan, where three separate sandstone tongues have been recognized. In Montana the Judith River has a nonmarine section overlying a marine unit. The basal Judith River section correlates with the Parkman sandstone of North Dakota and Wyoming.

Figure 4 is a paleographic generalization of the last major transgression of the North American continent. About 150 million years ago, water flooded from the north and then from the south. By the beginning of the Late Cretaceous, 100 million years ago, the two floods had joined creating an epicontinental sea.

Three main facies zones have been identified across the Cretaceous Seaway, also known as the Western Interior Basin in Canada. As Figure 5 shows, coarser clastics were deposited in a western facies formed in fluvial, deltaic, and coastal environments. A finer grained facies accumulated in a wide medial shelf environ-

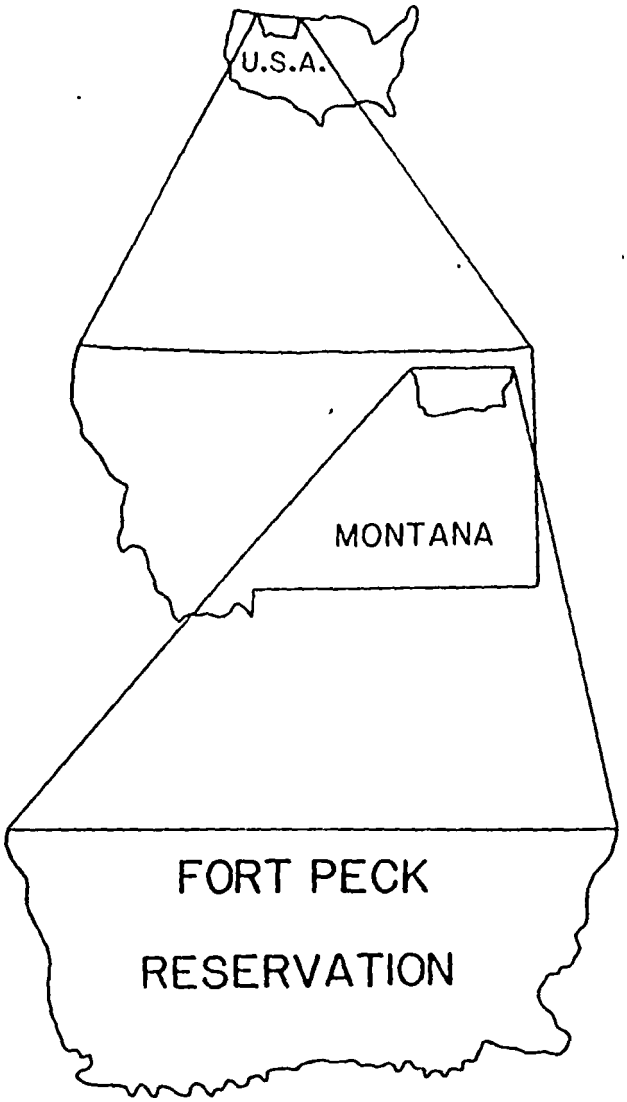


Figure 1. (left) Fort Peck Reservation index map.

Figure 3. (Facing Page)

ment. Finally, the lack of detrital sediment allowed the formation of calcareous mudrocks, especially chalk, on the eastern platform.

Figure 6 illustrates a paleogeographic model for the depositional sequence preceding the Judith River-Claggett rocks. Eagle (Milk River) sandstones formed as wave dominated deltas and inner shelf bars and in outer shelf sheet sands and sand ridges. The sediment source was in the Cordilleran highlands to the west. The Judith River Formation was deposited in a similar paleogeographic setting. Evidence is presented elsewhere in this volume for shallower water depths and a narrower shelf during Judith River time (Shurr, *et al.*, 1989).

Gill and Cobban (1973) proposed shorelines for the Judith River Formation based on ammonite fossil zones. The shoreline prograded across Montana from west to east and then reversed prior to the Bearpaw Transgression (See Fig. 7).

Illustrated in Figure 8 are the significant facies changes that characterize the Judith River Formation across northern Montana. The Fort Peck Reservation is located where the non-marine rocks pinch-out and where dramatic facies changes dominate the marine section. These facies changes can be explained by the model shown in Figure 9. The wedge shaped stacking of Cretaceous sand bodies shown is a simplified extension of the Foreland Basin Model proposed by Bally, *et al.*, (1966). The collision of exotic terranes with the North American plate produced a thrust belt that shed clastics into the Interior Seaway (Caldwell, 1982). Inactive periods allowed for subsidence and the deposition of shale. Renewed

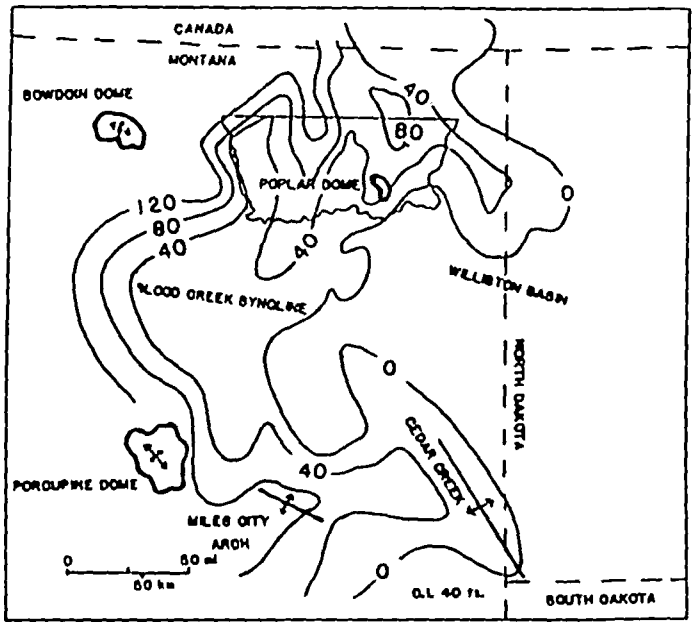


Figure 2. Judith River Sand isolith map, modified from McRae and Swenson (1968), with major structural features of eastern Montana added. Ft. Peck Reservation is outlined in northeastern Montana.

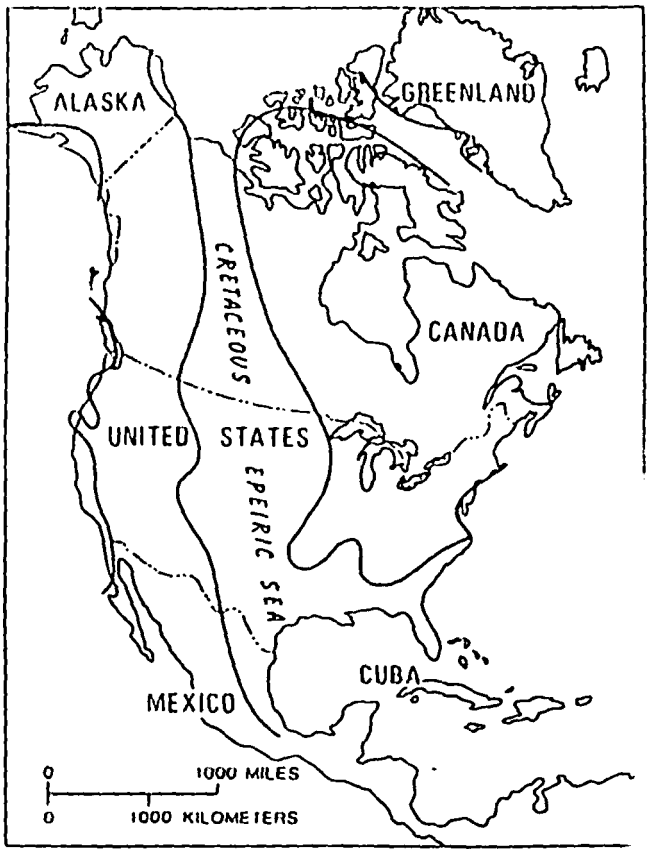


Figure 4. Paleogeologic map of North America during Late Cretaceous (Campanian) time. Modified from Gill and Cobb. (1973).

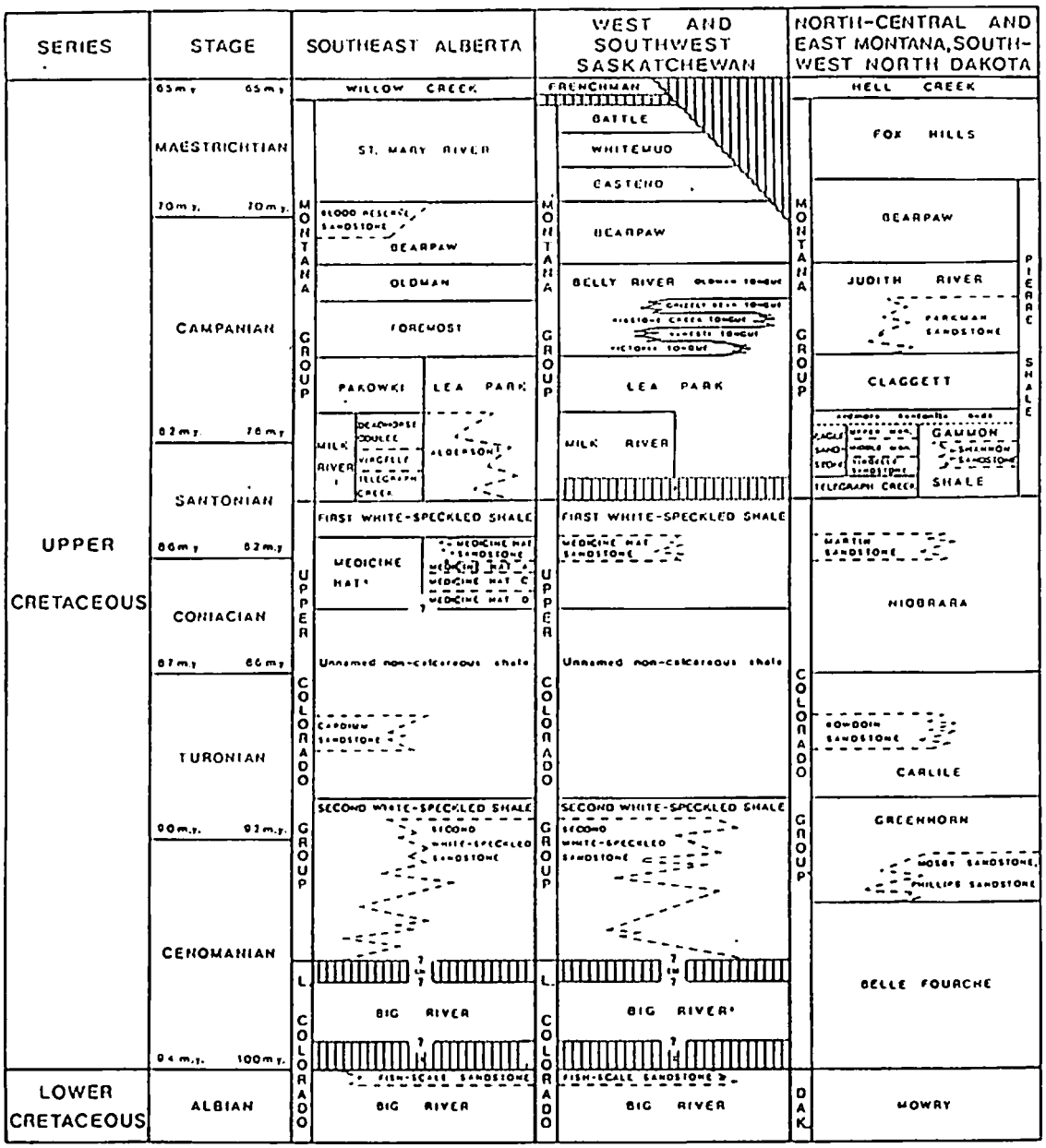


Figure 3. Summary of northern Great Plains Upper Cretaceous stratigraphic nomenclature compiled by Gilboy (1987) from several sources.

mountain building shed other coarse clastic wedges. Swift and Rice (1984), also presented a second model for the formation of Cretaceous sand bodies. Reactivation of basement tectonic elements in the Laramide Orogeny elevated submarine highs. These shelf areas of higher relief interrupted regional flow enough to cause the deposition of sandstone. The Bowdoin Dome, west of the reservation, has been identified as one of these reactivated areas (Rice and Shurr, 1983). Other models invoke worldwide sea level fluctuations (Haq, *et al.*, 1987). It is likely that more than one mechanism has influenced the deposition of Cretaceous progradational sequences.

PREVIOUS WORK

The Judith River sand thickness in eastern Montana was mapped by McCrae and Swenson (1968). Figure 2 is their isopach map of the total sand in the Judith River Formation in eastern Montana. Note the linear trends in both north-south and northwest-southeast directions in northeastern Montana. The latter trend parallels the Cedar Creek Anticline.

The sedimentary facies of the Judith River Formation have been examined recently in detail (Rice and Shurr, 1978). An obvious progradational nose is apparent in Figure 10. This "Fort Peck Nose" has a nonmarine-marine transition in the northwestern corner of the reservation. The coastal facies zone protrudes across the north-central portion of the study area. Feltis (1982), in his aquifer studies, further defined the Fort Peck Nose (see Fig. 11). The Judith River Formation in the northwestern corner of the study area has more than 150 feet (45m) of sandstone.

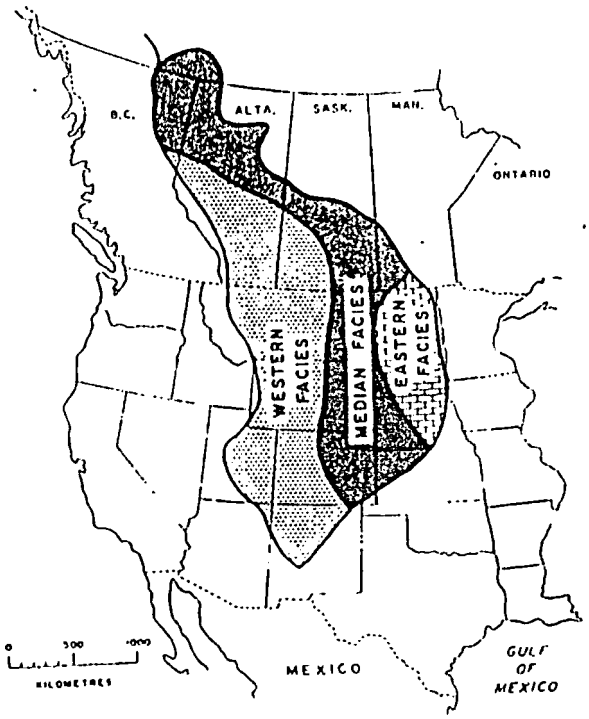


Figure 5. Campanian Age generalized facies zones of McNeil and Caldwell (1981).

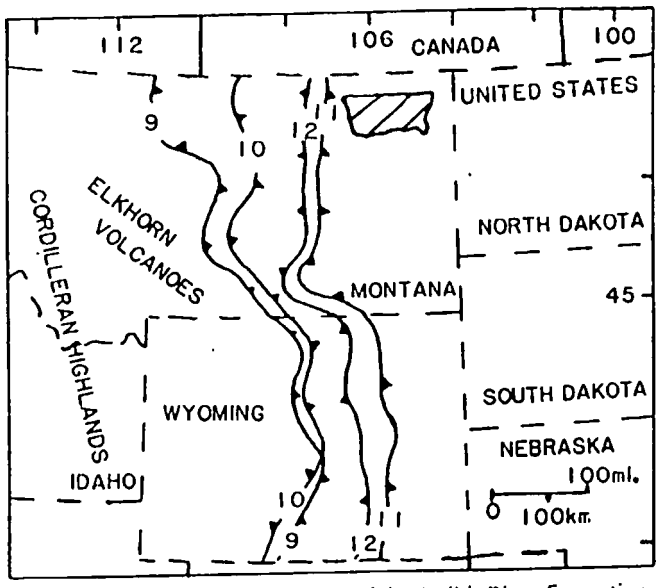


Figure 7. Approximate shorelines of the Judith River Formation, arrows showing direction of movement; based on Baculites: *9-*B. asperiformis, *10-*B. perplexus, *11-*B. gregoryensis, *12-*B. scotti. *Modified from Gill and Cobban (1973).*

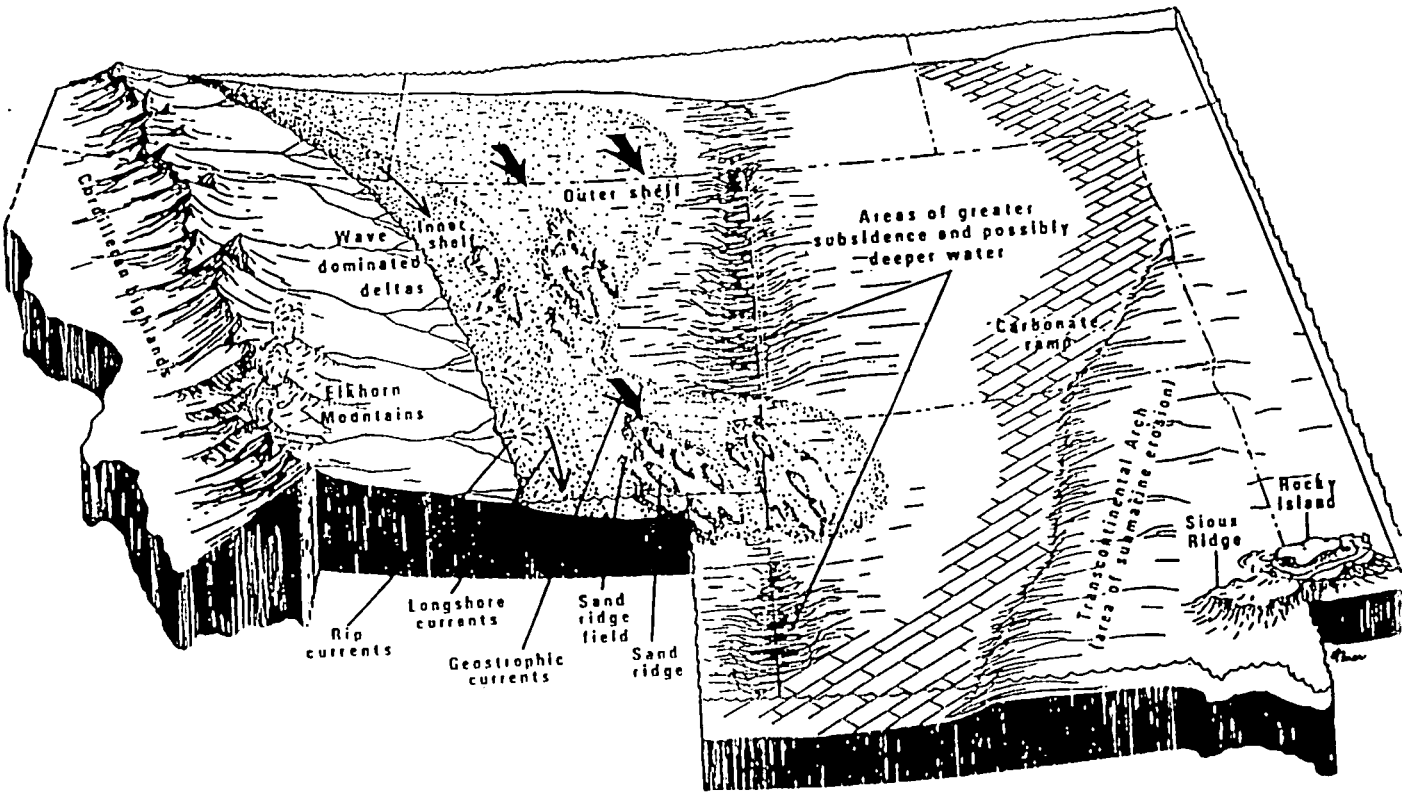


Figure 6. Paleogeographic model for deposition of Eagle Sandstone and equivalent rocks from Rice and Shurr (1983).

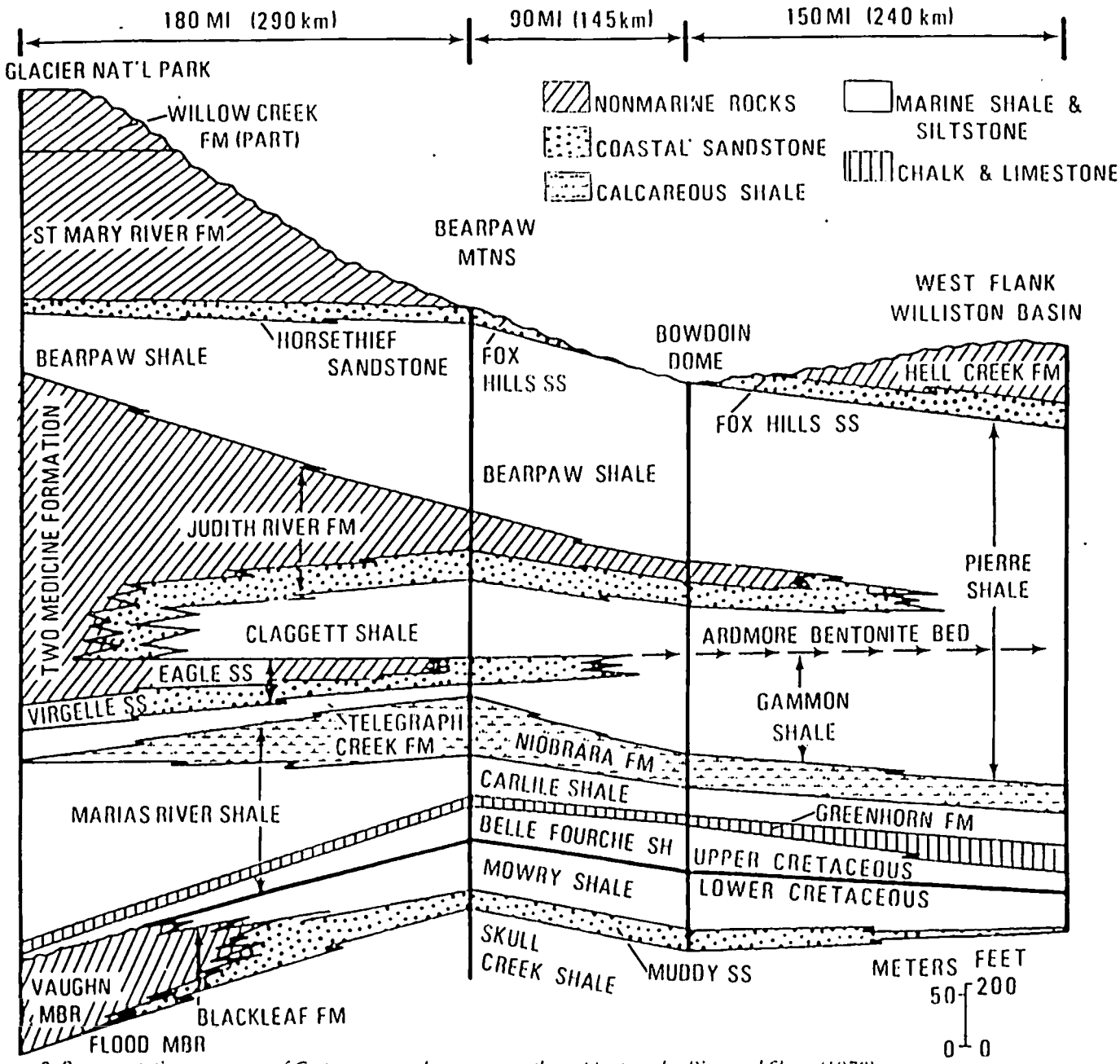


Figure 8. Representative summary of Cretaceous rocks across northern Montana by Rice and Shurr (1978).

FORT PECK RESERVATION STUDY

This study uses 146 wells from an area covering 160 townships. Logs from approximately 1100 wells were examined in order to select representative data points (See Fig. 12).

Gamma ray inflections greater than 10 A.P.I. units were used to identify sandstone intervals. Shale content was calculated using the minimum gamma ray value. The calculation was an average of an exponential equation empirically derived for pre-Tertiary clastics and a corresponding equation for Tertiary formations (Dresser Atlas, 1982). The author chose to average these two shale volume equations because of the relatively high shale volumes that were calculated using the pre-Tertiary rock equation. It is likely that the Judith River sandstones in the Fort Peck Reservation area are not highly consolidated and thus a compromise was necessary in order to determine realistic shale contents in the formation. Spontaneous potential response, when present, was helpful in correlating sandstone sections. Most wells drilled in the area used saltwater based muds so the spontaneous potential logs were usually of no value. The separation of the dual laterolog recording confirmed the sandy units. Sonic log travel time peaks were diagnostic and were averaged with the shale sonic baseline to calculate relative porosity values. These were corrected for shaliness and the apparent lack of compaction (Dresser Atlas, 1982) in order to achieve realistic results. Sonic porosities presented in this report have only relative significance.

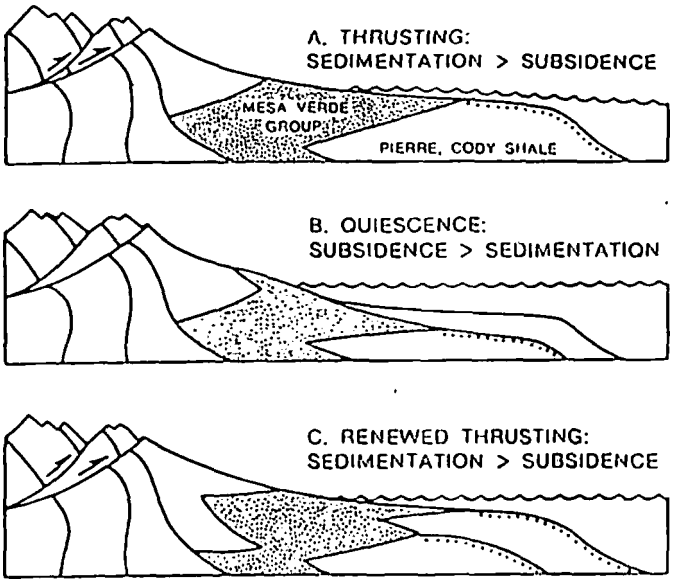


Figure 9. Model by Swift and Rice (1984) showing the development of Cretaceous progradational shelf wedges.

STRUCTURE

A structure map on the top of the Eagle formation is presented in Figure 13. In the west the curved contours reflect the edge of the Bowdoin Dome which plunges into the southeast trending, Wolf Creek Nose. This trend ends with the Poplar Anticline which plunges rapidly into the Williston Basin. The Poplar structure is flanked by the Opheim Syncline to the north and the informally designated "Wolf Point Syncline" to the south. Another small anticlinal trend is revealed in the northeastern corner of the reservation.

STRATIGRAPHY

In the center of the reservation the type well log for the Judith River-Claggett interval contains the following (See Fig. 14):

1) A thin upper sandstone.
2) A thick lower sandstone.
3) A thin basal sandstone which is actually in the Claggett Formation here.
4) Uniform shales which separate and encase each sand unit.

Within this report the three sandstone units listed above are labeled the Upper, Lower, and Basal Judith River Sandstones. They are abbreviated U.JRss, L.JRss, and B.JRss, respectively.

Two cross sections were constructed to demonstrate the stratigraphic changes in the Judith River-Claggett interval across the reservation (Fig. 15). The Judith River Formation is found at depths ranging from 400 to 2700 feet (122-824 m). Figure 15c shows the location of cross-sections A-A' and B-B'. The Upper JRss is poorly developed in the northwest (see Fig. 15a). The best sand development is in the north-central part of the reservation and no Upper JRss is found in the east or northeast, although a response can be identified in the electric logs. The Lower JRss is also poorly developed in the northwest, but maintains a relatively uniform thickness across the reservation before thickening significantly in the east. A complementary relationship describes the Basal JRss which is very thick in the west and quickly disappears in the middle of the reservation.

In the southern section, B-B', the upper sandstone thickens to the southeast, but sand content is lower as indicated by the well logs (see Fig. 15b). The lower sandstone thickens and is gas bearing in the Poplar area with two well defined benches. It divides into two separate sand units in the southeast. The basal sandstone is stratigraphically higher in the southwest than in the northwest.

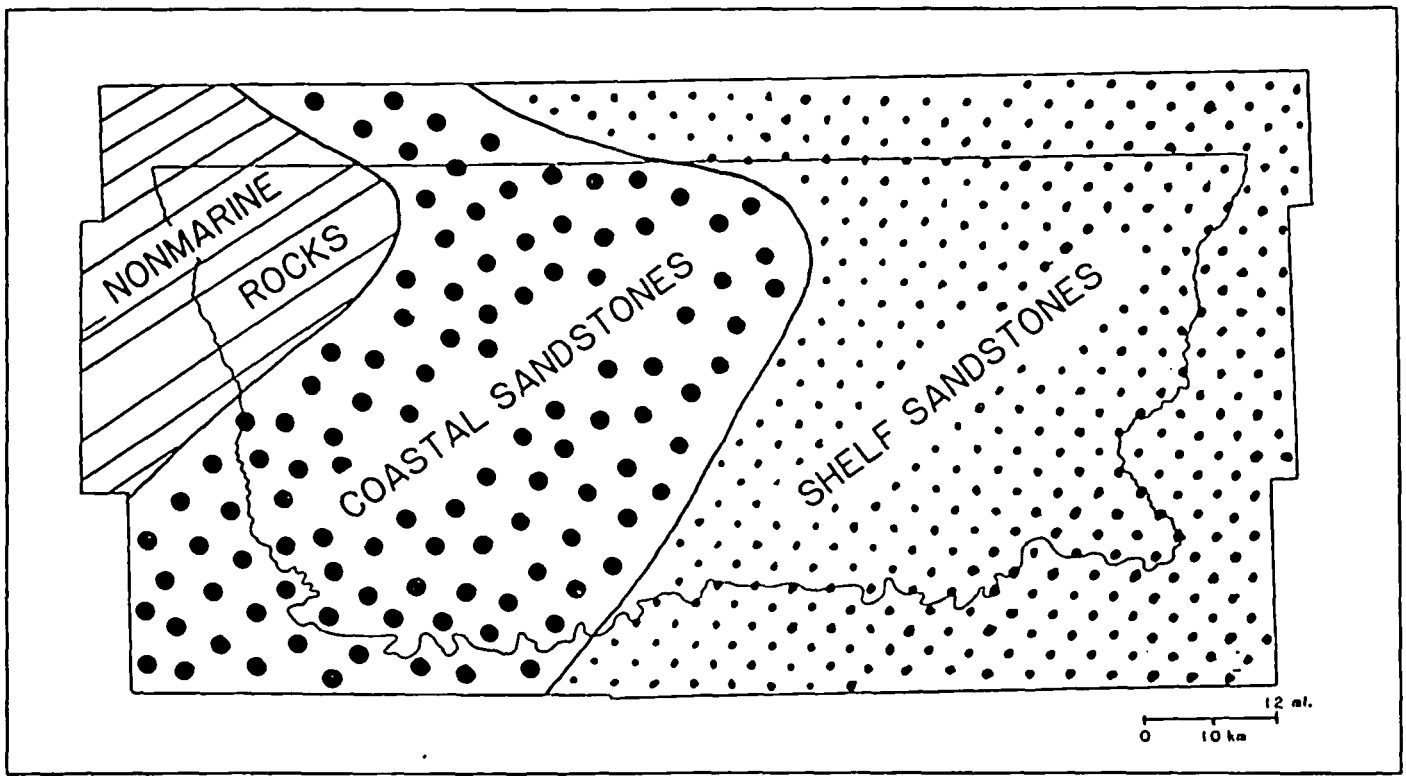


Figure 10. Modified facies map of the Judith River-Claggett interval in the Fort Peck Reservation area; scale enlarged from Rice and Shurr (1978).

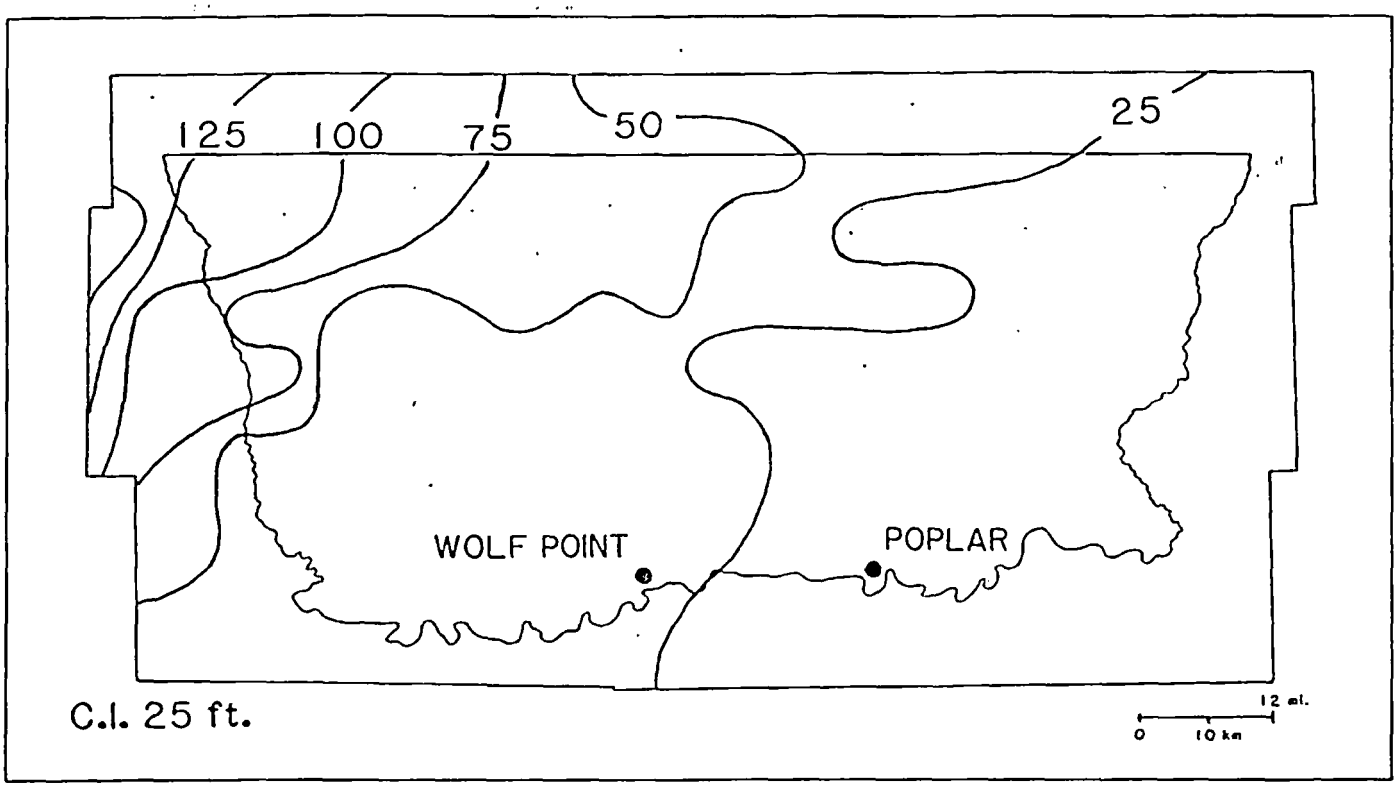


Figure 11. Total sand thickness of the Judith River Formation in the Fort Peck Reservation area; modification and enlargement of map by Feltis (1982).

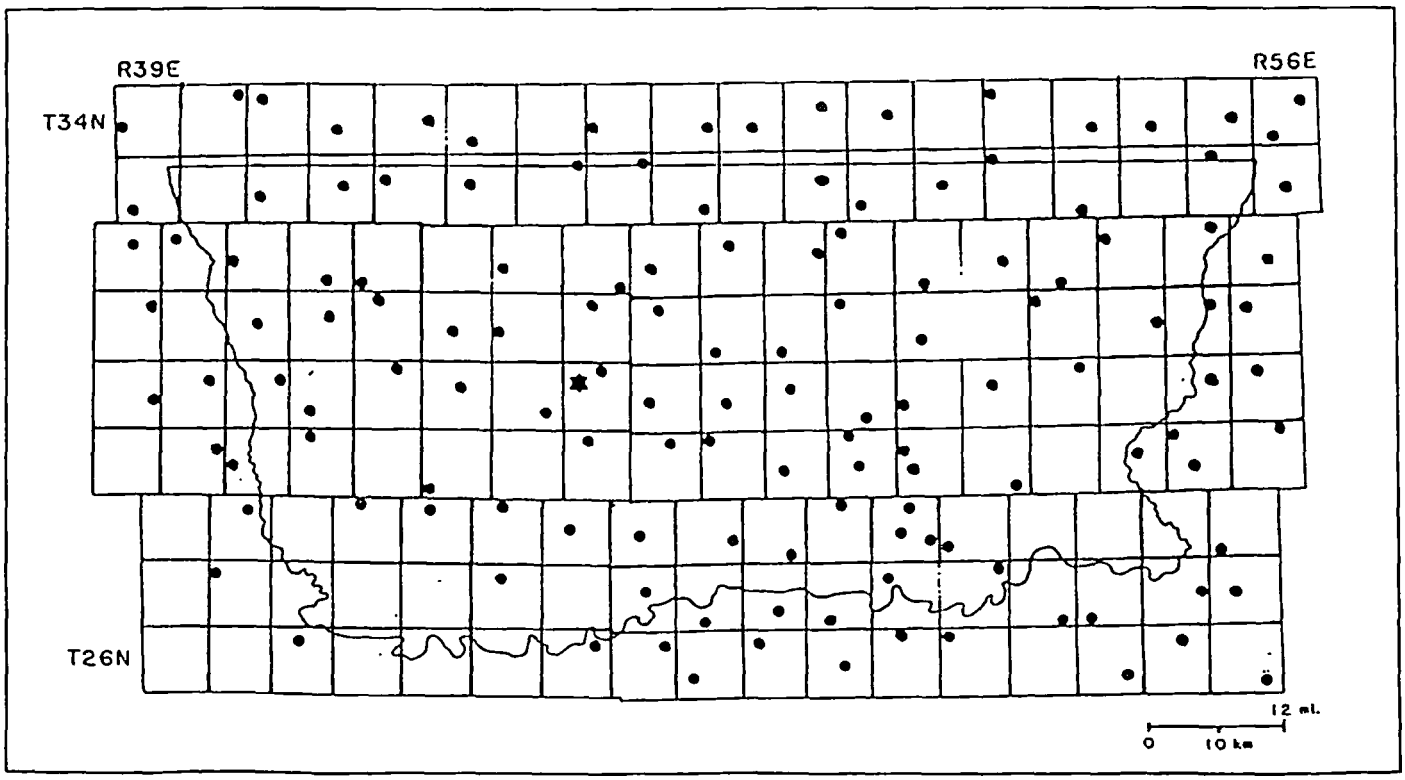


Figure 12. Selected well locations in the Fort Peck Reservation study area. Star marks the location of the type well log presented in Figure 14.

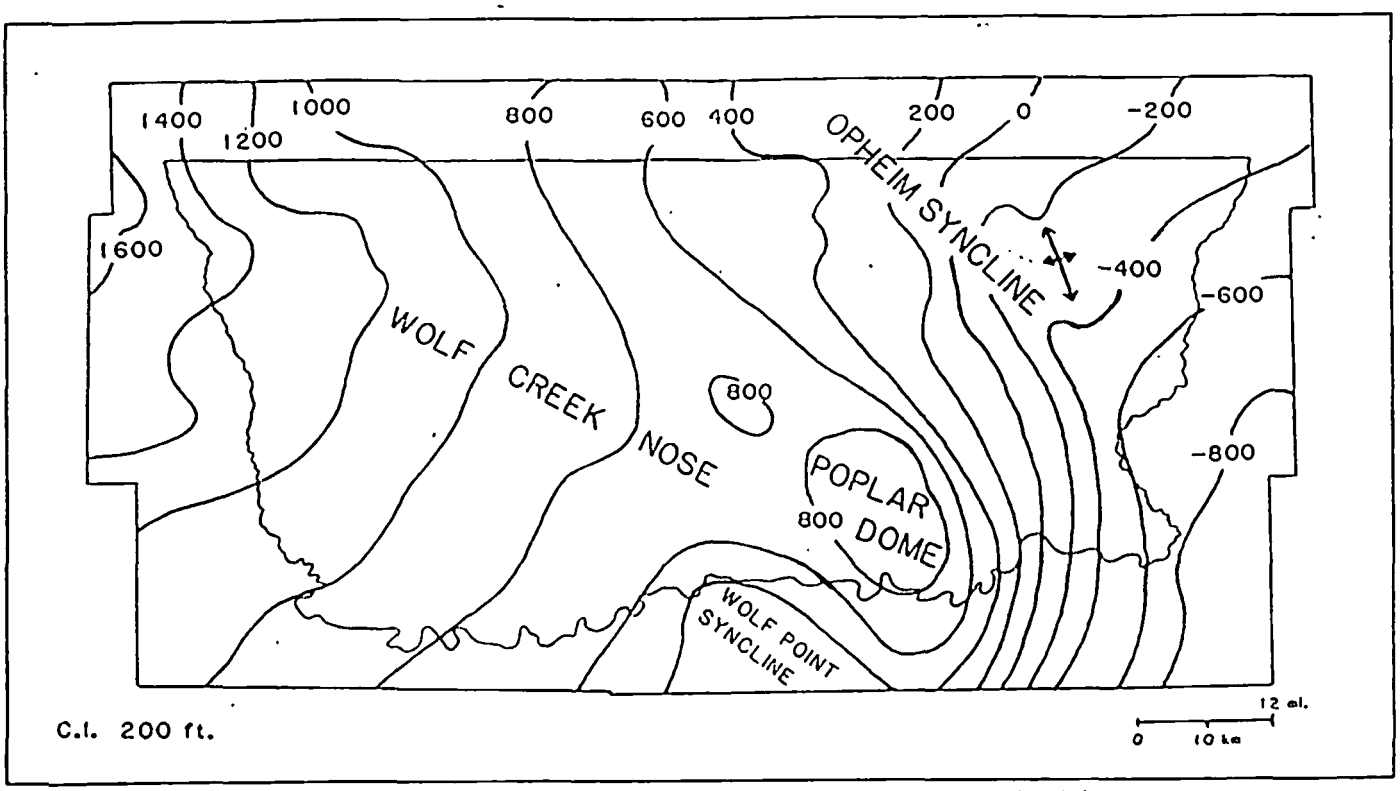


Figure 13. Structure map of the top of the Eagle Formation, for the Fort Peck Reservation area, sea level datum.

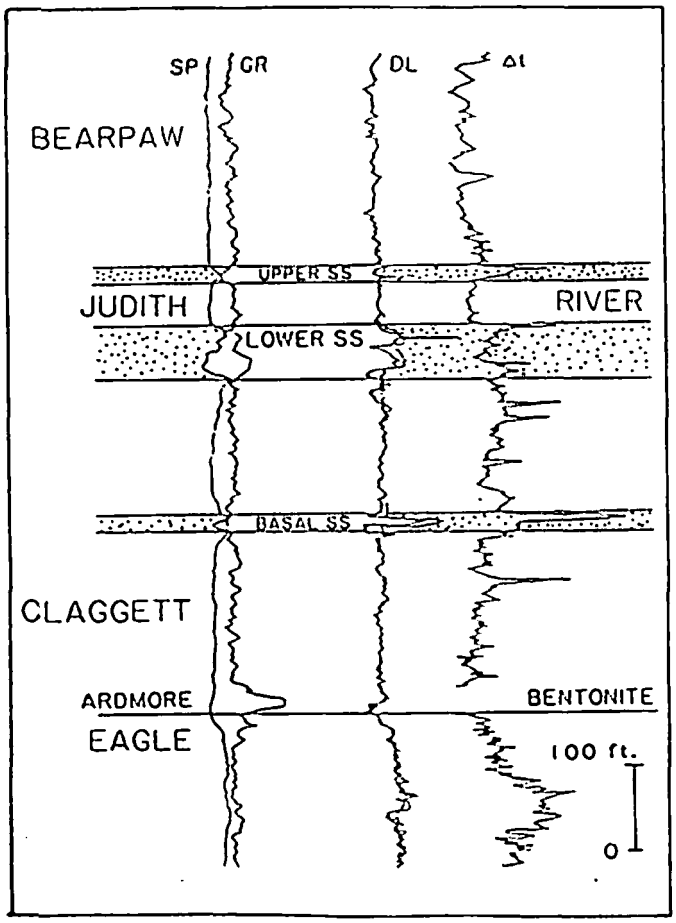


Figure 14. Representative well log of the Judith River-Claggett interval near the center of the Fort Peck Reservation, Ortmann 1-7, NW SW SE, 7-T30N-R46E.

Correlation to a Claggett sandstone is tentative due to poor well control. The sonic response can be traced to the southeast corner of the study area, but poor sandstone is indicated by the gamma ray log. Both cross-sections display genetic packages sloping to the east so that a clear progradational geometry is shown.

Three maps were constructed for each sandstone interval thickness (isopach), shale content, and porosity. In each map, areas with the best sand development are shaded with a plus (+) sign and the areas of no sand are stippled with a minus (-) sign.

Upper Judith River Sandstone

The Upper Judith River Sandstone (U.JRss) is displayed in Figures 16 a-c. Three distinct sand trends are shown in the north-central region (Fig. 16a). Shale content (Fig. 16b) is relatively high in the upper sandstone, especially in the west and in the east. The best sand development by this criteria is in the north-central area, trending east-west, and in the Wolf Point area, trending north-south. The former trend is perpendicular to the apparent thickening trend in Figure 16a, and may represent a deltaic distributary channel. The latter trend, which lies in the Wolf Point Syncline, is more likely associated with an offshore sand ridge. The best porosity development is also shown in this area (See Fig. 16c). The 10% porosity cutoff generally defines the shelf area during upper Judith River sandstone deposition. Areas with less than 10% porosity, in the west, correspond with high shale content areas and most likely define non-marine sandy mudrocks and siltstones. Areas to the east, below the 10% cutoff, define the facies transition with the Bearpaw Formation (Pierre Shale). Note the correspondence of the 0% porosity contour in Figure 16c with the 100% shale contour in Figure 16b and the 0 ft isopach in Figure 16a.

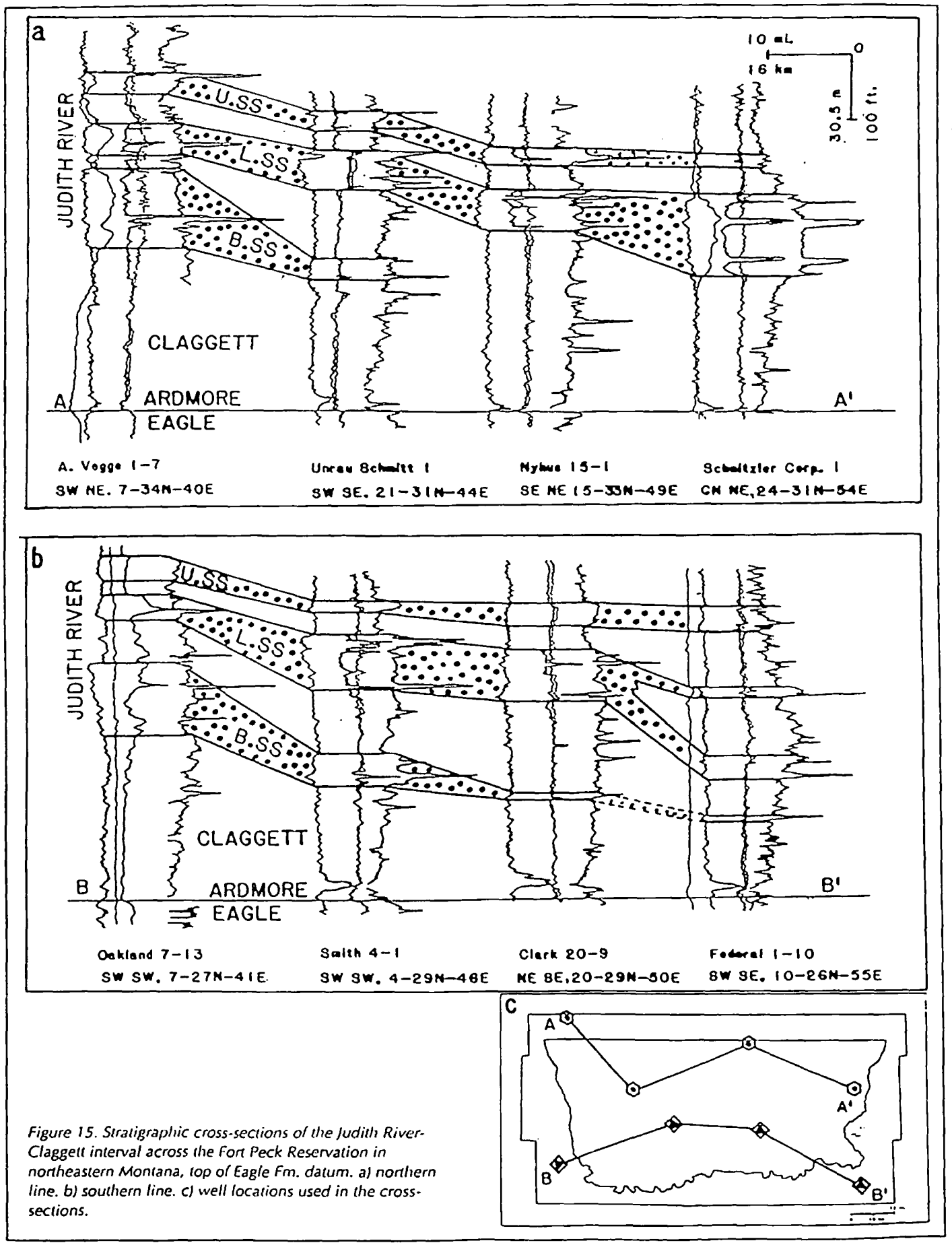


Figure 15. Stratigraphic cross-sections of the Judith River-Claggett interval across the Fort Peck Reservation in northeastern Montana, top of Eagle Fm. datum. a) northern line. b) southern line. c) well locations used in the cross-sections.

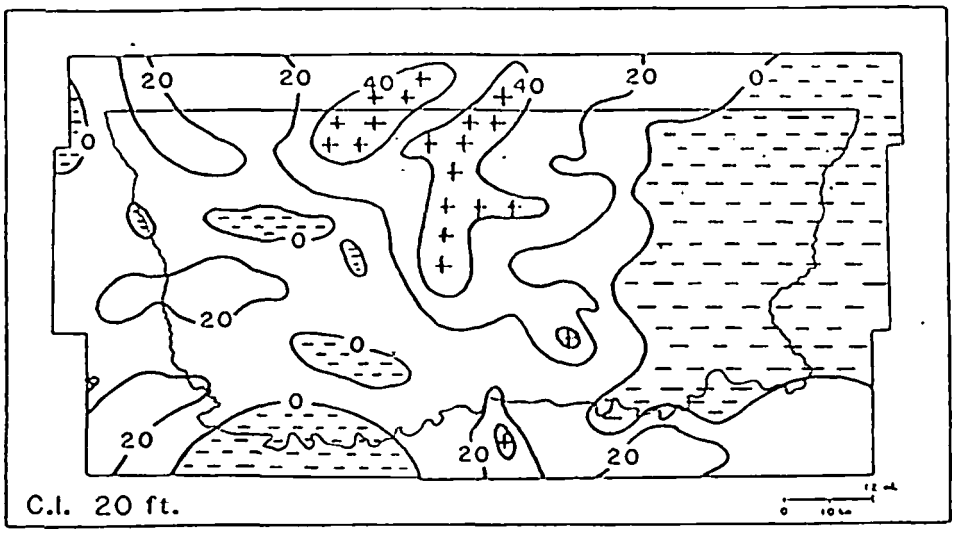


Figure 16a. Net thickness of the Upper Judith River sandstone in the Fort Peck Reservation area. + is >40 ft.

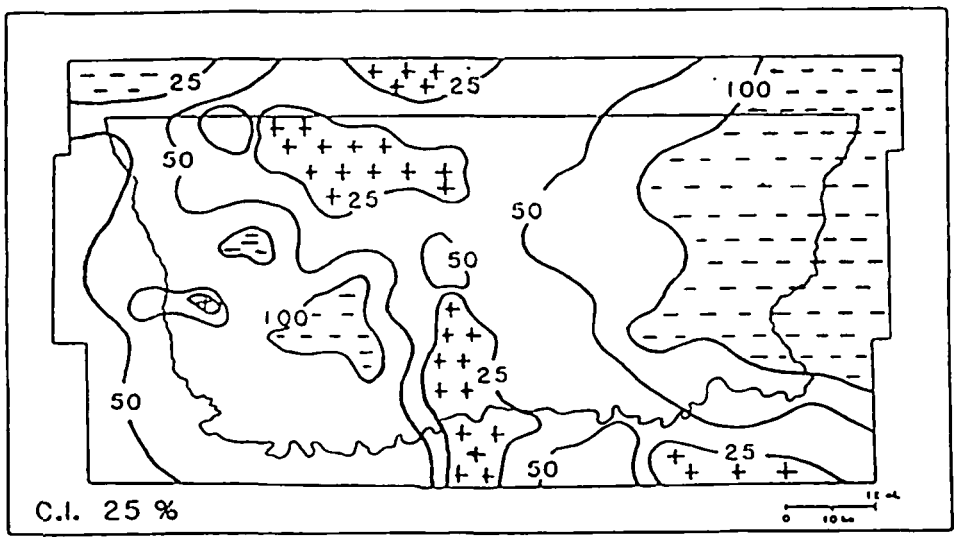


Figure 16b. Shale content of the Upper Judith River sandstone in the Fort Peck Reservation area (75% contour omitted). + is <25%.

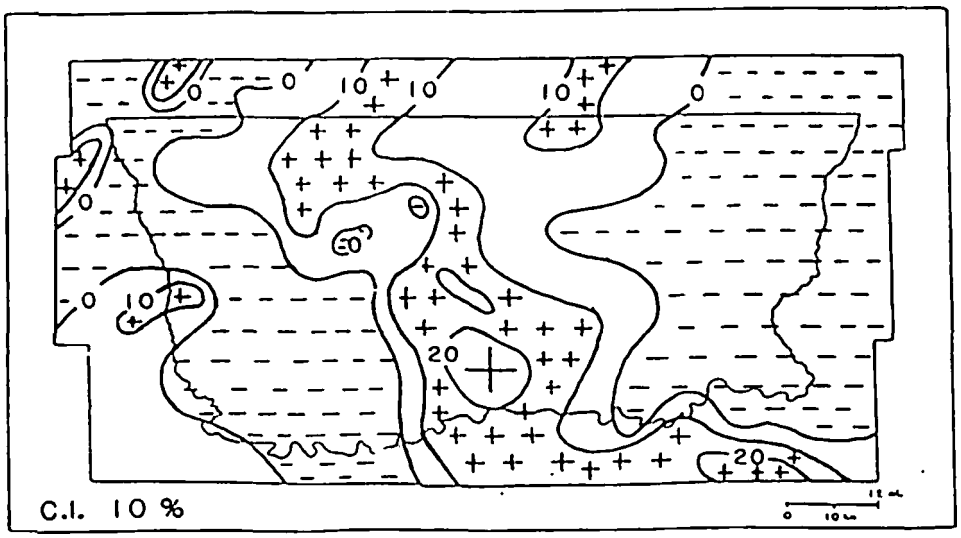


Figure 16c. Relative sonic porosity of the Upper Judith River sandstone in the Fort Peck Reservation area. + is >10%.

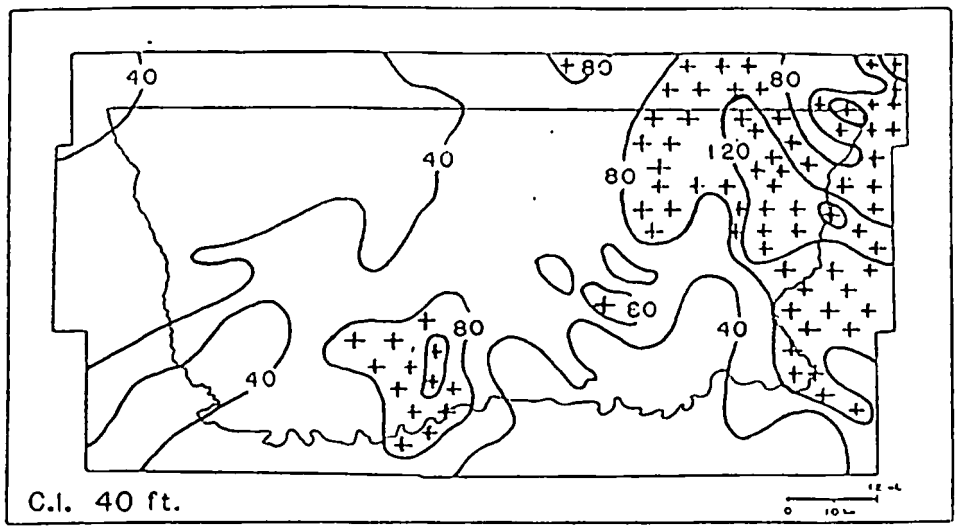


Figure 17a. Net thickness of the Lower Judith River sandstone in the Fort Peck Reservation area. + is >80 ft.

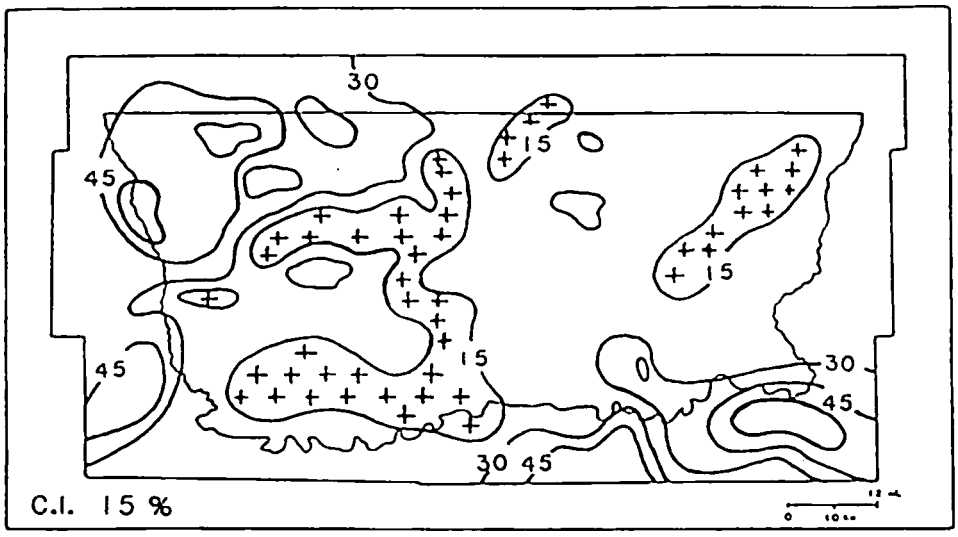


Figure 17b. Shale content of the Lower Judith River sandstone in the Fort Peck Reservation area. + is <15%.

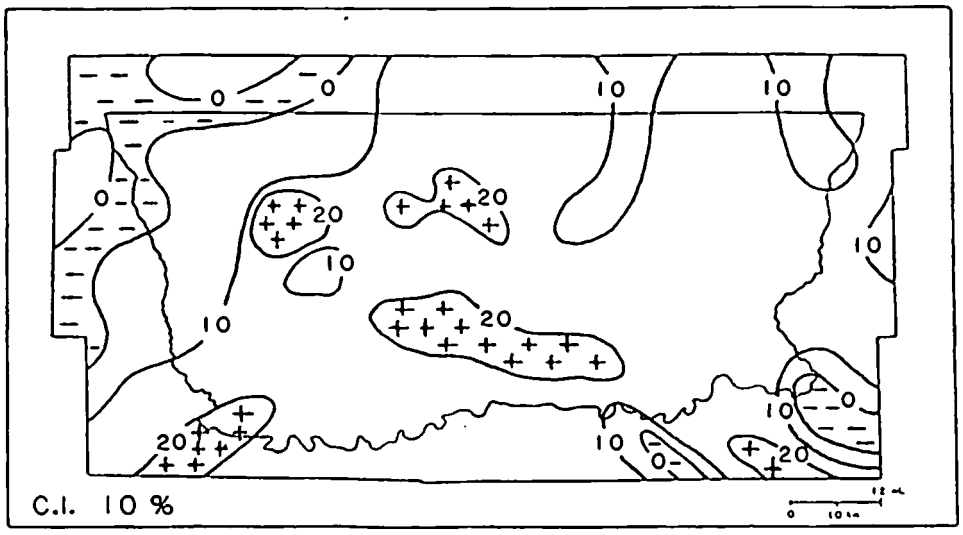


Figure 17c. Relative sonic porosity of the Lower Judith River sandstone in the Fort Peck Reservation area. + is >20%.

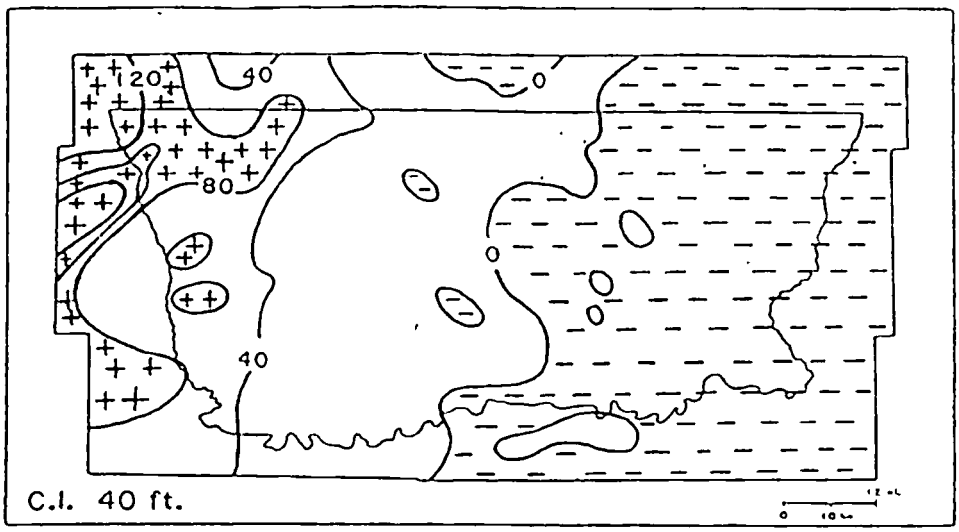


Figure 18a. Net thickness of the Basal Judith River sandstone in the Fort Peck Reservation area. + is >80 ft.

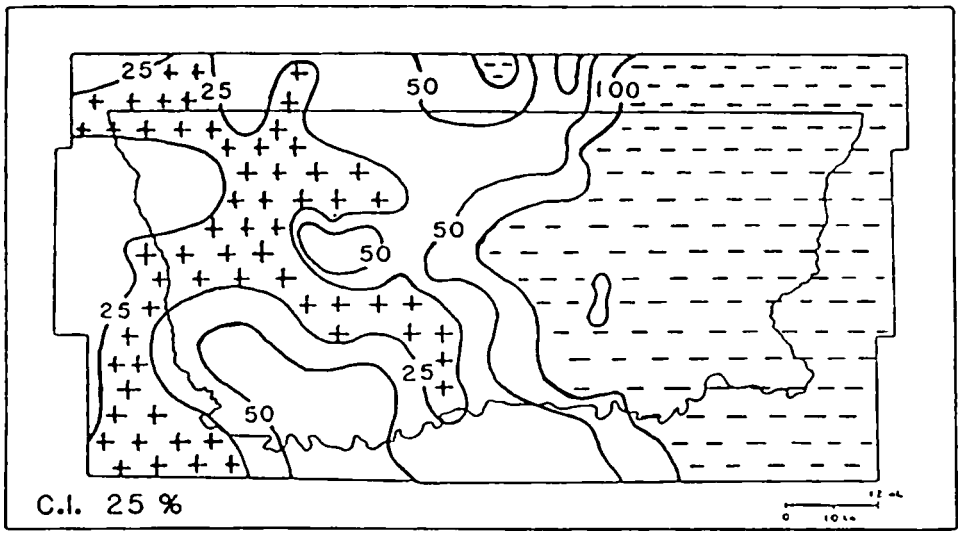


Figure 18b. Shale content of the Basal Judith River sandstone in the Fort Peck Reservation area. + is <25%.

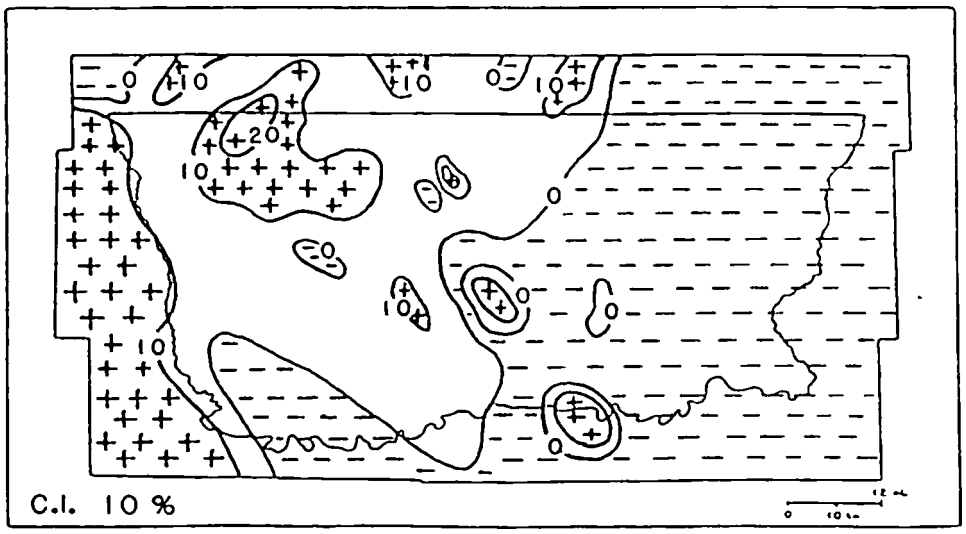


Figure 18c. Relative sonic porosity of the Basal Judith River sandstone in the Fort Peck Reservation area. + is >10%.

Lower Judith River Sandstone

The main Judith River sandstone, which is usually recognized as the basal sandstone in the center of the reservation, cannot be correlated to the thick basal sandstone which dominates the section in the west. The Lower Judith River Sandstone (L.JRss) is the best developed sand unit and is gas bearing. This is the target with the best gas potential on the reservation. Figure 17a features three thickness patterns in the L.JRss. In the west, sand thickness less than 40 ft.(12.2 m) characterizes a well defined coastal and non-marine facies. Across the center of the reservation is a north-south shelf facies which possibly has an inner shelf sand ridge developed in the Wolf Point area, slightly west of a similar buildup in the U.JRss. In the northeast, an area of thick sandstone deposition defines a possible outer or mid- shelf sand ridge which reaches a thickness of 150 ft (46 m). Shale content (Fig. 17b) in the L.JRss is relatively uniform, varying from 15% to 30% in the shelf area. Linear trends with less than 15% clay again lie at right angles to thickness trends. The 30% shale cutoff in the west suggests an area of non-marine rocks rather than a coastal environment. Porosity in the L.JRss ranges from 10-20% on the shelf (See figure 17c). Linear high porosity trends have no apparent correlation to either thickness or shale content trends and are approximately perpendicular to isopach features. There may be some relationship of higher porosity and lower shale content in the center of the reservation, especially in the Wolf Point area where thicker sandstone is found. Low porosity values in the northwest part of the reservation, confirm the previous observation that this sandstone likely formed in a non-marine, mud-rich environment.

Basal "Judith River" Sandstone

Figure 18a displays the thickness of the Basal Judith River Sandstone (B.JRss). This map resembles the isopach map of Feltis (1982, see Fig. 11). The sandstone is more than 120 ft (37 m) thick in the northwest. The center of the reservation has a wide shelf area where sand thickness varies from 40 ft (12 m) to 0 ft. The 0 contour line is at the edge of of the progradational prism. Shale content (Fig. 18b) is highest in this unit, except on the west side where the sandstone has less than 25% shale. Porosity in the Basal JRss is usually less than 10%, but does exceed 20% in the west (See Fig. 18c). The three criteria presented here suggest that a well developed delta may have existed in the northwest.

Stratigraphic Summary

A comparison of the three sandstone intervals using the three criteria presented earlier is shown in Table 1. In the selected wells, the upper sandstone varies from 0 to 55 ft (17 m) with an average shale content of 46% and only 7% average porosity. In the lower sandstone, thickness ranges from 4 to 162 ft (1 to 49 m), has much less clay content, (22%), and has an average porosity of 12%. The basal sand unit is from 0 to 185 ft (56 m) thick, and averages 35% shale content and only 7% porosity.

POROSITY DISCUSSION

Because of the unorthodox means employed to efficiently evaluate porosity in the sandstones, another log suite was used to verify sonic porosities. Neutron and density porosity logs were run through the Judith River interval in only 63 of the 1100 study area wells. An additional 50 wells had some other porosity tool run, most of them old GR/Neutron logs, from the East Poplar Unit. Of the 63 FDC/CNL logs recorded in the Judith River section, only 38 had nearby sonic logs for comparison. About 20 wells were chosen based on their location near map points and on their log quality. Using an interpretation program proposed by Elphick (1987) to calculate the effective sandstone porosity, it was found that some wells had excellent correlation with the sonic porosities. Half of the wells correlated poorly, with as much as 50 % variation. In general, from the limited number of neutron/density logs used, the Upper JRss averaged 6% porosity, the Lower JRss averaged 11% porosity, and the Basal JRss averaged only 4% porosity. The sonic porosities in these wells were 10%, 11%, and 8% respectively. The neutron/density porosities calculated from the Elphick model, do confirm that the corrections made to the sonic porosity values in

SAND UNIT	NET SAND THICKNESS (a)		SHALE CONTENT (b)		RELATIVE SONIC POROSITY (c)	
	Average	Range	Average	Range	Average	Range
Upper						
all wells	10'	0-109'	39%	0-99%	8%	0-33%
map pts.	23'	0-55'	46%	10-79%	7%	0-28%
Lower						
all wells	49'	0-185'	21%	0-99%	13%	0-32%
map pts.	62'	4-162'	22%	6-83%	12%	0-28%
Basal						
all wells	7'	0-185'	28%	0-90%	8%	0-20%
map pts.	23'	0-185'	35%	11-83%	7%	0-17%

(a) Gamma ray values greater than 10 A.P.I. units.
(b) Average of "consolidated" and "unconsolidated" equations (Dresser Atlas, 1982).
(c) Corrected for shale content and lack of compaction, average of sonic peak and shale baseline (Dresser Atlas, 1982) .

Table 1. Stratigraphic Summary of Judith River Sandstones in the Fort Peck Reservation Area.

this report, are an accurate estimation of the porosity of the shaly sandstones found in the Judith River Formation in this area. Differences can largely be explained by the shale content correction, which was much greater in the Elphick model. Average shale volumes in the three sand units were 77%, 62%, and 83% from top to bottom. These values were heavily influenced by a calculation that used the difference between the neutron and density values. The shale correction presented earlier in this paper relied upon gamma ray values only. In addition, different means of averaging the porosity readings were used. Too few neutron/density logs were available for a statistical base or correlation, but they could be valuable in local studies. Particularly important is the fact that although high shale contents were the rule on neutron/density crossplots, the presence of gas was suggested by small crossovers in many wells.

GAS POTENTIAL

One of the Cretaceous reservoirs included by Rice and Shurr (1978) in their Northern Plains gas paper, is the Judith River Formation. Currently seven fields in Montana produce gas from the Judith River Formation. These are mainly near the Bearpaw Mountains in north- central Montana and the Cedar Creek Anticline in southeastern Montana. Canadian gas production from this stratigraphic interval is overshadowed by deeper Cretaceous production, but significant tests have been reported in Saskatchewan.

Claypool and Kaplan (1974) presented a model which explains why the late Cretaceous progradational cycles have such tremendous potential for shallow gas accumulations in the Northern Plains. Conditions of rapid sedimentation in a warm, shallow sea, were ideal for the formation of biogenic methane gas. The source rock is indigenous to a low permeability reservoir rock which retains the locally generated gas. Stratigraphic control is probably more important than the Laramide structures which developed after methane generation. With this model, the gas could be everywhere that shelf sediments were deposited. However, areas of better sand development and structural enhancement should be considered first in an exploration program.

The gas resource in the Judith River Formation on the Fort Peck Reservation is summarized with the map in Figure 19. Three types of gas shows are represented:

1) Solid circles indicate where gas was found in wells drilled specifically to test the Judith River Formation. Open circles recovered no gas.

2) Solid squares indicate those wells whose gas detectors recorded gas, or gas escaped during casing attempts, or gas blew out in the Poplar Field. Open squares record wells where sample cuttings or detectors indicated no gas in the Judith River Formation.

3) Solid triangles indicate deeper exploration wells where drill stem tests recovered gas in the Judith River Formation. Open triangles are shown where DST's recovered no gas in the Judith River Formation.

The stars mark three wells in the East Poplar Unit that tested significant gas and were used on a limited basis for field operations. Initial potentials for these wells were 650, 630, and 180 MCF/day, (18.2, 17.6, 5.0 MM m^3/day) respectively. Many Poplar wells encountered gas and water flow problems in the Judith River sandstone. Some of the attempts to drill and complete gas wells in the East Poplar Field were unsuccessful because the wells were not drilled deep enough to reach the main Judith River sandstone.

Evaluating the gas potential of the Judith River Formation has not been a priority in exploration wells drilled on the reservation. Geologists and/or mud logging equipment are rarely present, and gas detector units are almost never operating if present. Most companies are only interested in a high drilling rate through the Cretaceous rocks. High mud weights and rapid drilling do not allow for proper evaluation of a shaly sandstone reservoir rock. Normal drill stem tests also do a poor job. These reservoirs may require days or even weeks to properly test with any meaning

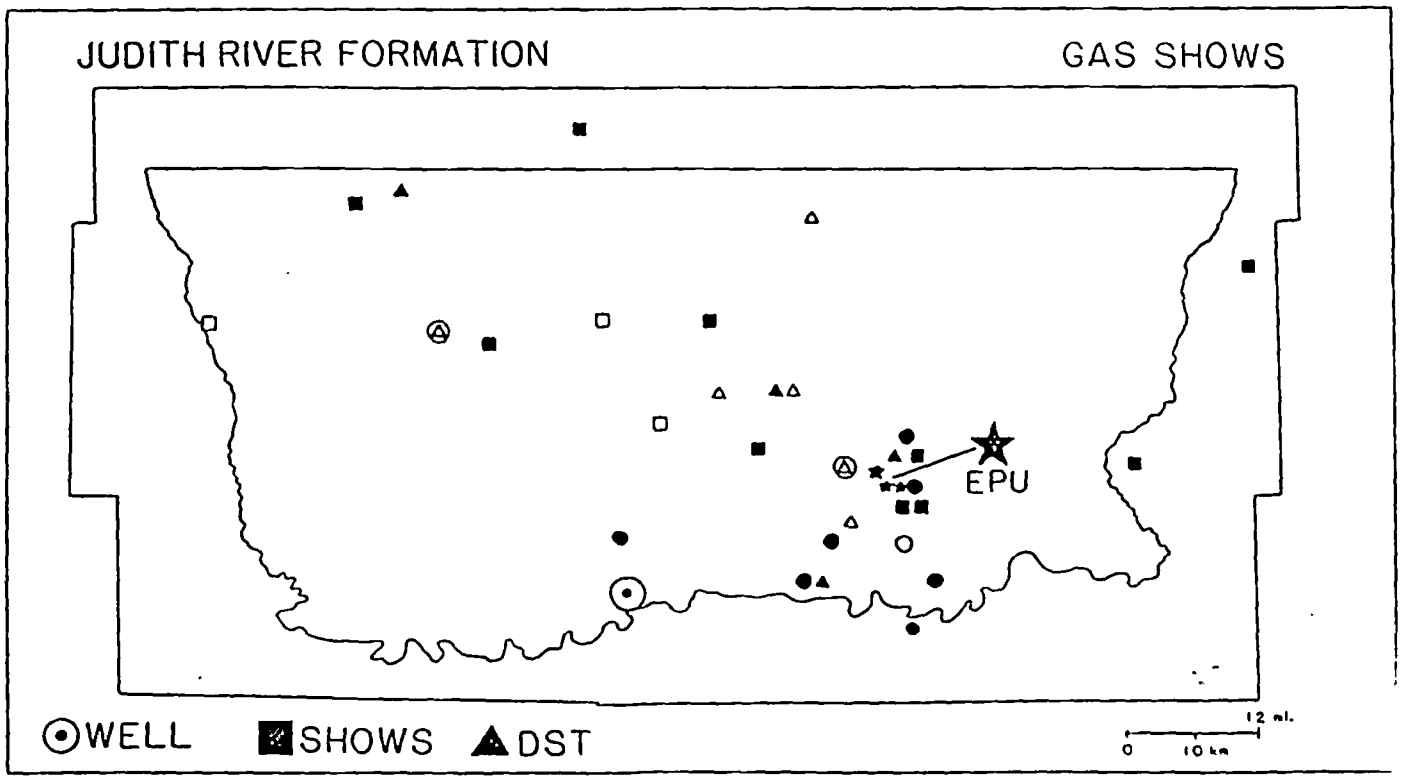


Figure 19. Gas shows in the Judith River Formation in the Fort Peck Reservation area, northeastern Montana. See text for explanation.

Wells that have been completed in the Judith River sand were drilled by operators, unfamiliar with modern techniques for drilling and completion. These techniques include the use of KCL fluids, fresh water, air, and various fracturing stimulations (Nydegger and Rice, 1979, Spencer, 1989, and Gilboy, 1987, 1988).

CONCLUSION

The Judith River Formation beneath the Fort Peck Reservation in northeastern Montana is in exciting " middle ground ". Lying approximately half-way between Cedar Creek's exhausted, yet significant gas production, and western Canada's rapid development, the Judith River sands have yielded tantalizing shows of gas in several locations. Structural entrapment appears to have been important at Cedar Creek, Battle Creek, and Poplar Dome. Stratigraphic analysis in this report suggests that even better reservoirs could exist in the north central part of the Reservation where the upper sandstone is best developed. Another favorable area is near Wolf Point, where thick sand ridges have been deposited on the Cretaceous shelf in both the upper and lower sands. In addition, the thick basal sandstone in the west, which is the main marine unit across northern Montana, is an attractive exploration target. To the northeast, a separate sand accumulation in the lower sandstone outlines a significant sand ridge farther out on the shelf.

The three progradational sequences in this area may correlate to the three recognized tongues in Saskatchewan. More work is needed to define the paleoenvironments suggested in this paper. Sample cuttings and lithologic logs, which are even scarcer than porosity logs, must be thoroughly examined and correlated to representative log signatures. Detailed mapping will reveal a more complex facies interplay in each attractive area as it has been demonstrated in the Poplar Dome locality. Understanding the paleotectonic control on deposition has been attempted regionally for the Judith River sands (see Shurr and others, 1989, this volume), but perhaps more detailed analysis can be done once the paleoenvironments and sand trends are better defined.

Only drilling and completion using appropriate modern techniques will confirm whether thicker sand trends, lower shale values, and higher porosity can produce gas. Gas economics, especially transportation requirements, will ultimately control the development of shallow gas on the Fort Peck Reservation. The intervals below the Judith River Formation produce gas in the Bowdoin Field and in the fields of southeastern Alberta and southwestern Saskatchewan. The Judith River Formation is only the top of the Cretaceous gas bearing resource waiting to be developed.

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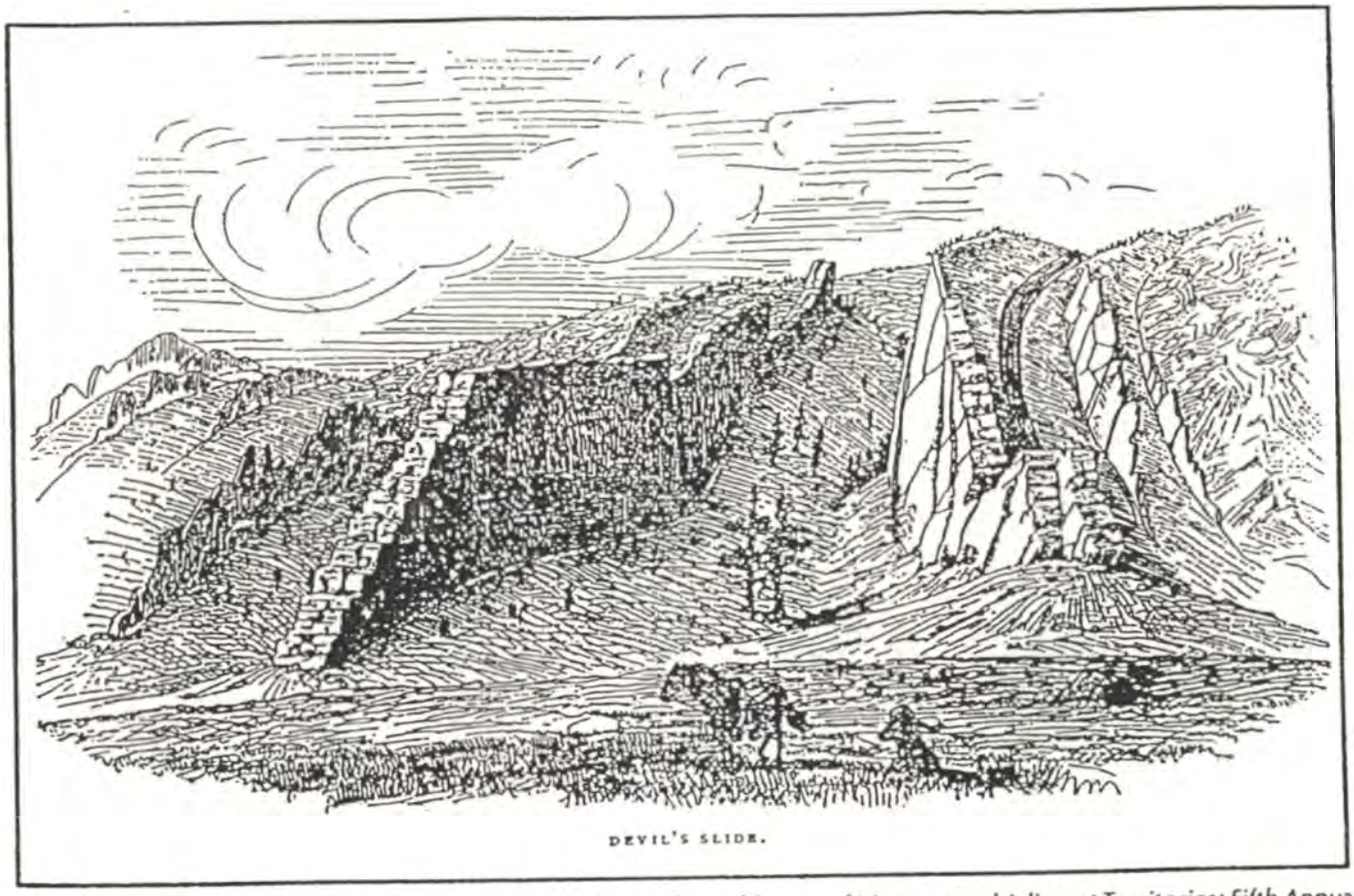

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JUDITH RIVER FORMATION IN EASTERN MONTANA-INNER

SHELF SAND RIDGES AND PALEOTECTONISM

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JUDITH RIVER FORMATION IN EASTERN MONTANA—INNER SHELF SAND RIDGES AND PALEOTECTONISM

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ABSTRACT

The Judith River Formation (Upper Cretaceous) in the Montana plains east of longitude 108°W grades laterally from nonmarine rocks and coastal sandstones into shelf sandstones and shale. The unit was deposited on a broad siliciclastic shelf that stretched along the western side of the Western Interior Seaway. The shelf was situated on the western margin of the Williston Basin and received sediments eroded from tectonic uplands in western Montana. In general, the Judith River consists of two, and locally three, sandstone sheets which display the upward increase in grain size and increased sorting, characteristic of shelf sand bodies.

Stratigraphic studies on Porcupine Dome, the Miles City Arch, Cedar Creek Anticline, and Poplar Dome document a hierarchy of shelf sandstone bodies similar to that observed in the Shannon Sandstone in southeastern Montana. Elongate lenses which show a positive correlation in width and thickness are interpreted to be sand ridges. Larger, more equidimensional lentils are interpreted to be fields of sand ridges. Sandstone sheets are interpreted to be coalesced ridge fields. Although all elements of the hierarchy are not found on each structure, the interpretation of a siliciclastic shelf setting seems inescapable. Paleotectonism on that shelf influenced deposition of the sandstone. Evidence for paleotectonic control is most clear on Porcupine Dome and Cedar Creek Anticline, where facies change perpendicular to individual mapped faults. Paleotectonic controls on shelf deposition near the Miles City Arch and Poplar Dome are less distinct; stratigraphic map patterns reflect lineaments interpreted from satellite data.

There has been extensive natural gas production from the Judith River Formation on Cedar Creek Anticline; currently the depleted sandstone reservoirs are used for gas storage. On Poplar Dome, there are numerous gas shows and some production for local field use. Near the Miles City Arch, the potential for gas production looks good, but tests have been disappointing.

INTRODUCTION

The Judith River Formation (Upper Cretaceous) is a relatively continuous stratigraphic unit throughout most of the Montana plains east of longitude 108°W. Nonmarine facies of the formation are exposed in the northwest on Bowdoin Dome and marine facies equivalent to the Judith River are exposed as portions of the Pierre Shale in the southeast on the margins of the Black Hills Uplift (Fig. 1). Between these two structures, the formation consists of predominantly coastal and shelf sandstones which are largely confined to subsurface but are exposed locally on Porcupine Dome. These shelf sandstones have produced shallow biogenic gas on Cedar Creek Anticline.

Our description of the Judith River Formation is based mainly upon investigations in the vicinity of four geologic structures (Fig. 1): 1) work on Porcupine Dome and surrounding areas of northern Rosebud County was done by Shurr; 2) work in the vicinity of the Miles City Arch covers all of Custer County and was done by Fanshawe; 3) work along the Cedar Creek Anticline was done by Wosick; and 4) work around Poplar Dome and throughout the Fort Peck Reservation was done by Monson. Data will be summarized from each of these four areas in this sequence, and then interpretations will be presented. We interpret discrete sandstone bodies in the Judith River as inner shelf sand ridges and believe that deposition was strongly influenced by tectonic elements located on the siliciclastic shelf. Finally, gas production and storage will be discussed briefly. First, however, we offer an overview of the regional stratigraphic, paleogeographic, and paleotectonic setting of the Judith River Formation in eastern Montana.

REGIONAL SETTING

The Judith River Formation is a part of a series of progradational wedges which decrease in thickness and grain size from west to

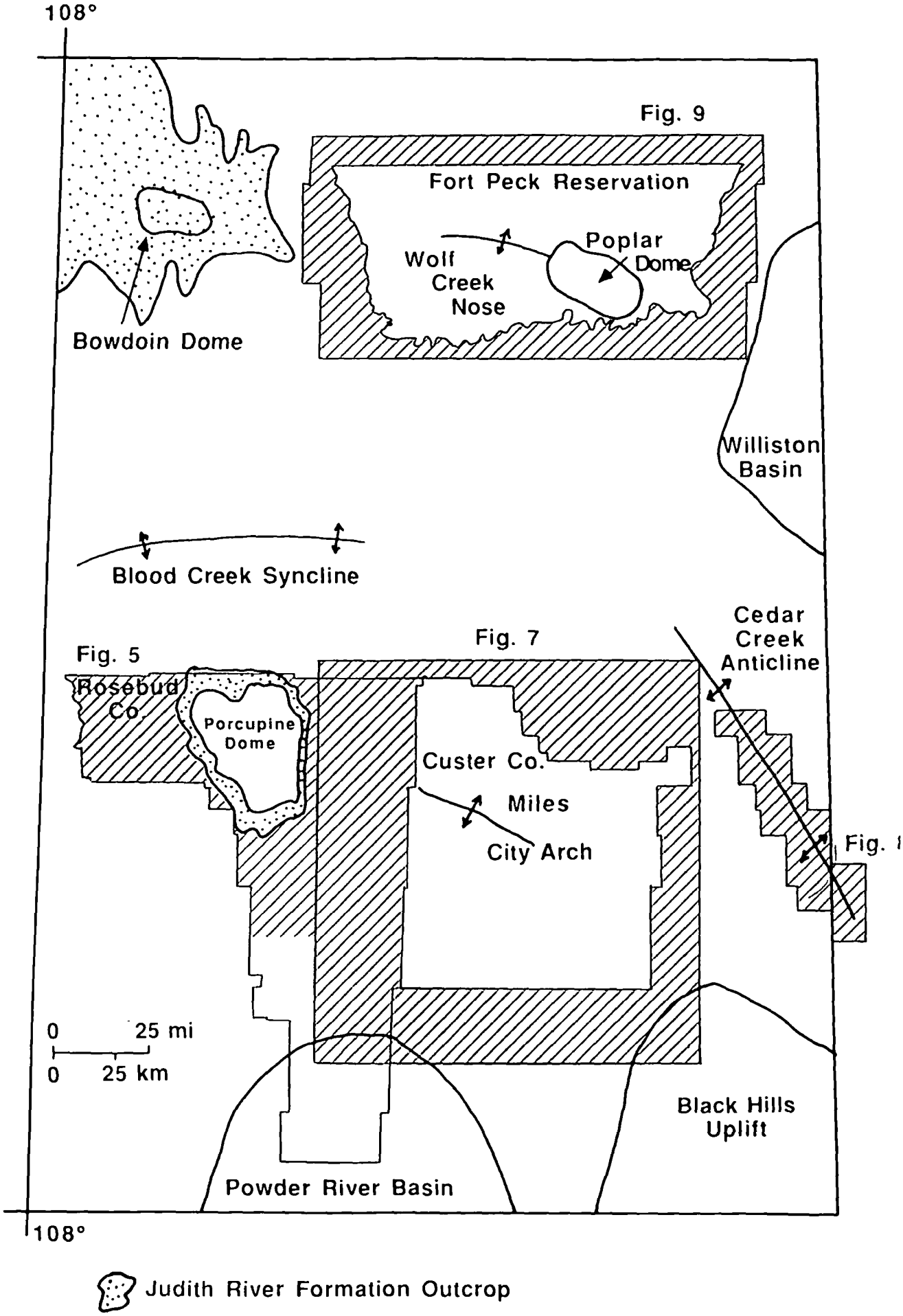

108°
Fig. 9
Fort Peck Reservation
Poplar Dome
Wolf Creek Nose
Bowdoin Dome
Williston Basin
Blood Creek Syncline
Cedar Creek Anticline
Fig. 7
Fig. 5
Rosebud Co.
Porcupine Dome
Custer Co.
Miles City Arch
Fig. 1
0 25 mi
0 25 km
Black Hills Uplift
Powder River Basin
108°
Judith River Formation Outcrop

Figure 1. Location map showing the study areas around Porcupine Dome, Miles City Arch, Cedar Creek Anticline, and Poplar Dome as well as other major tectonic elements on the Montana plains east of longitude 108°W.

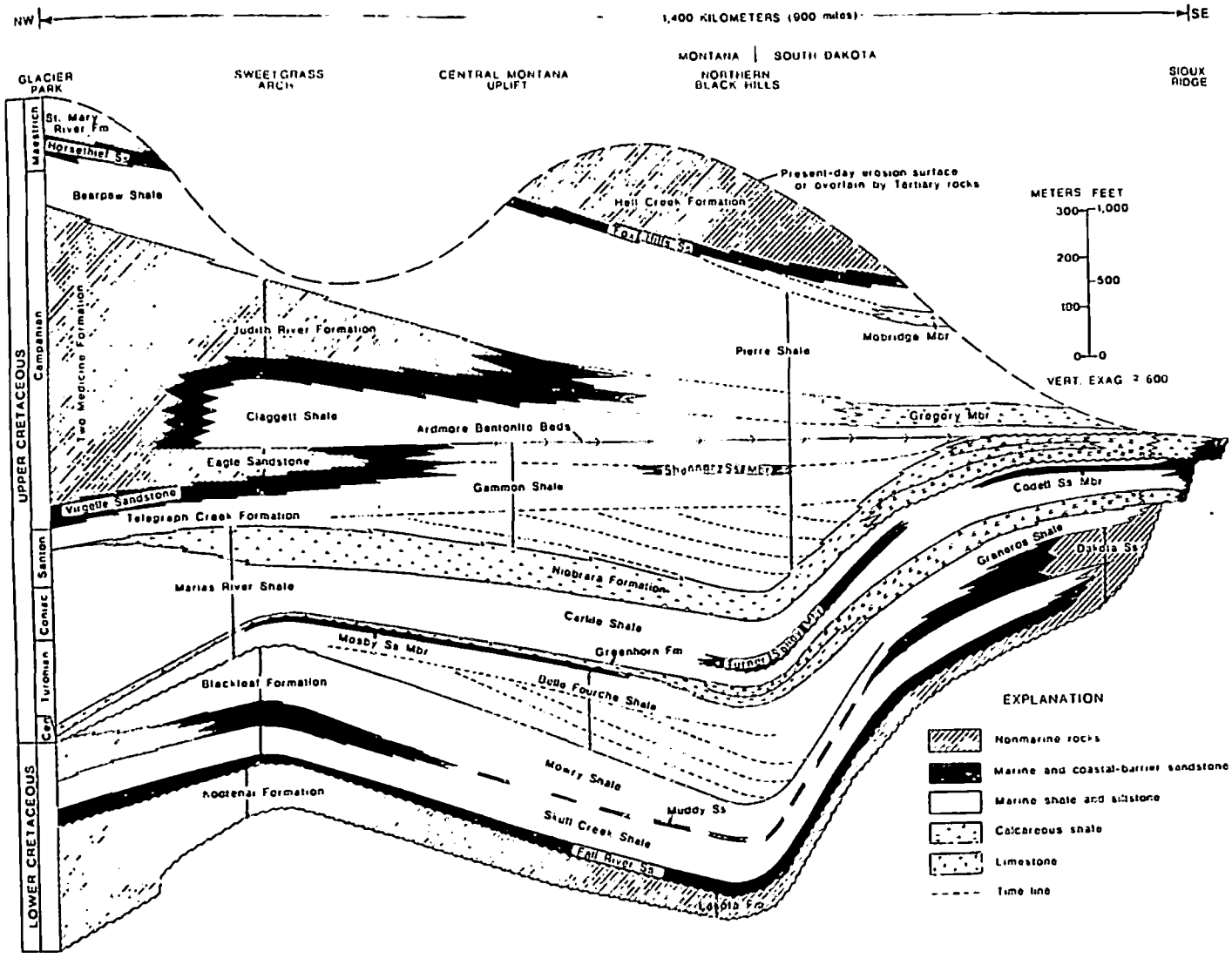


Figure 2. Regional cross section showing generalized stratigraphy of Cretaceous rocks from northwestern Montana to southeastern South Dakota. The location map shown in Figure 1 corresponds to the portion of the section between the "Central Montana Uplift" and "Northern Black Hills." From Molenaar and Rice, 1988.

east across the Western Interior Seaway (Fig. 2). The tongue of clastics which includes the Judith River was deposited during the Late Cretaceous and is of Campanian Age. The tongue consists of nonmarine Two Medicine Formation in the west and is laterally equivalent to the marine Gregory Member of the Pierre Shale to the east in South Dakota. The marine Claggett Shale which underlies the Judith River has an excellent stratigraphic marker at its base known as the Ardmore Bentonite Beds. The overlying marine Bearpaw Shale also has basal bentonite beds, but these are less useful than the Ardmore in electric log correlations.

The Judith River Formation has long been recognized to have two separate shelf sandstone sheets in eastern Montana which coalesce westward into coastal sandstone and nonmarine rocks (see, for example, Weimer, 1963). Occasionally, the unit has been referred to as the Parkman Sandstone (Gill, et al., 1972, and Shurr, 1975). Use of "Parkman" in eastern Montana can be justified in the same manner that "Shannon" has been applied to shelf sandstones (Rice, et al.,1982) in the next clastic tongue below the Judith River (Fig. 2). Specifically, the Shannon and Parkman shelf sandstones are sheets just to the east of nonmarine and coastal sandstones in the Eagle and Judith River, respectively. In this report, however, we employ the name Judith River Formation because of its long history of use in eastern Montana, because gas production is traditionally described from the Judith River, and because the Parkman Sandstone tends to be routinely confined to use in the Powder River Basin. The Eagle Sandstone does constitute a useful analogue for the Judith River Formation as we consider the paleogeographic and paleotectonic setting of eastern Montana.

Shelf sandstones of the Judith River were deposited as the upper part of a progradational package which includes the underlying Claggett Shale. Transgression during deposition of the lowermost Claggett and the subsequent progradation are a part of the global cycle Upper Zuni A-4 (Haq, et al., 1987); the cycle is termed T3 and R3 by Weimer (1960) and the Claggett cyclothem by Kauffman

(1977). Judith River sandstone in eastern Montana was deposited on a siliciclastic shelf which stretched along the western margin of the Western Interior Seaway and was very similar to the shelf which was earlier the site of Eagle and Shannon deposition (Rice and Shurr, 1978). Sediments eroded from western uplands were distributed across the adjacent coastal plain and deposited in the seaway. Inclined progradational surfaces in the Claggett and Judith River are less prominent than in the underlying Eagle and Gammon (Fig. 2), suggesting that initial water depths were shallower in the Judith River cycle than in the Eagle cycle. Areas of deeper water in eastern Montana were filled by progradation during deposition of the Gammon Shale (Rice and Shurr, 1983), and subsequent shallower water depths established during deposition of the Shannon were maintained into the time of deposition of the Claggett and Judith River. This implies that subsidence and the concomitant progradation, which took place in eastern Montana during deposition of the Belle Fourche Shale and Gammon Shale (Fig. 2), did not characterize the western siliciclastic shelf during deposition of the Judith River Formation. The regional tectonic framework for the Eagle does, however, provide a useful perspective.

During Late Cretaceous, the Western Interior Seaway was subdivided into a series of elongate paleotectonic zones which extended north and south along the seaway, parallel to the adjacent convergent plate margin in the west. From west to east these zones are termed; western foredeep, west-median trough, east-median trough, and eastern platform (McNeil and Caldwell, 1981, and Kauffman, 1977). During Eagle deposition, eastern Montana was occupied by the west-median trough (Shurr and Rice, 1986), and similarly the Judith River was also probably located in the west-median trough. This specific longitudinal zone was characterized by high sedimentation rates and included the western siliciclastic shelf and adjacent slope which prograded as basin fill. The Williston Basin did exist during deposition of the Judith River; indeed, it had expression throughout the Late Cretaceous (Shurr, et al., 1989). Marginal paleotectonic elements radiated away from the basin center (Fig. 3) which was situated in the west-median trough of the longitudinal zones. The basin and associated marginal elements thus constituted subdivisions of the longitudinal zones. The eastern Montana study area includes parts of two marginal paleotectonic elements which may have influenced Judith River deposition. In addition, the smaller Laramide structural features (Fig. 1) which deform the Judith River may have had Late Cretaceous precursors which collectively made up the marginal paleotectonic elements (Fig. 3). Our interpretations of paleotectonism are at this smaller scale; we describe the influence of constituent structural features rather than of the margin elements or of the longitudinal zones.

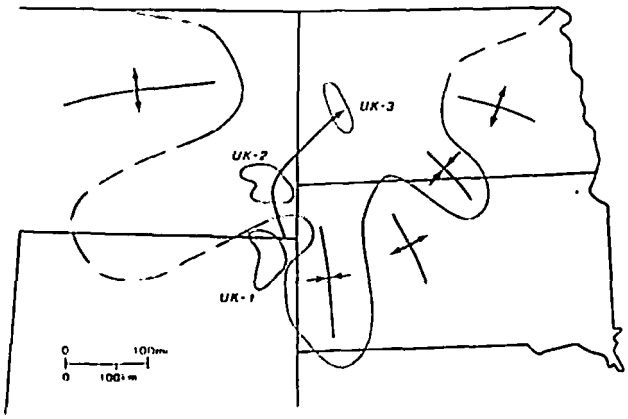


Figure 3. Paleotectonic elements surrounding the Williston Basin. Positions of depocenters associated with the Greenhorn Formation, Eagle Sandstone, and Judith River Formation (see Fig. 2) are shown by Uk-l, Uk-2, and Uk-3 respectively. From Shurr, et al., 1989.

OBSERVATIONS

The majority of the data presented in this report is based upon subsurface information documented by electric logs. However, the Judith River Formation is exposed on Porcupine Dome, and observations from this structure do include measured surface sections and outcrop data.

Porcupine Dome

Outcrops of the Judith River Formation surround Porcupine Dome in northern Rosebud County (Fig. 1). The structure is asymmetric with steep dips on the eastern flank and gentle dips on the southwest flank. A series of northeast-trending en echelon faults are located on the north flank; this zone is an eastern extension of the northwest-trending Cat Creek Fault Zone of central Montana. In general, the Judith River is poorly exposed and has little well-developed sandstone on the steep eastern flank of the dome. However, several thick sandstone units are well exposed on the southwest and also are associated with the faults on the north flank.

Overview of Formation

The sandstones and interbedded siltstone and shale of the Judith River Formation generally show a gradational contact with the underlying Claggett Shale but locally show an abrupt contact with overlying Bearpaw Shale. Bentonite beds near the base of the Claggett and Bearpaw (markers A and H, Fig. 4-A) are useful for correlation. The interval between markers B and C (Fig. 4-A) is the transition between Claggett and Judith River; markers D, E, and F are related to separate sandstone units; and marker G is the top of the Judith River. Electric log expressions of the individual sandstone units are commonly "angel wing" shapes which suggest coarsening upwards sequences. There are three separate sandstone sheets or "benches" within the formation (Fig. 4-B): the lower sheet thins to the east; the middle sheet thickens to the east and is not exposed on the dome; and the upper sheet thins to the west. At the west end of the dome a complex sandstone lithosome is exposed which generally thickens to the west.

Sandstone Sheets or "Benches"

Sections measured in rimrock exposures on the southwest flank of the dome are easily correlated with adjacent well logs (Fig. 4). This allows paleontologic and sedimentologic outcrop information to be integrated with stratigraphic subsurface data. The lower and upper sheets are well exposed on the dome and have been described by Gill et al. (1972). The middle and upper sheets extend eastward into the Miles City Arch study area (Fig. 1). Thus, the two sandstone units described in outcrop are not the same two units which are widespread in subsurface to the east. A biostratigraphic zonation (Shurr, 1975) based on identifications of ammonites made by Dr. W.A. Cobban of the United States Geological Survey, suggests that the middle and upper sheets lie within the zone of *Baculites scotti* and the lower bench is within *Baculites gregorgensis*. Maps, of the middle and upper sheets which thin to west, are presented for the Miles City study area where the sands are relatively continuous. The lower sandstone sheet is limited to the vicinity of Porcupine Dome.

Elongate Lenses

Within the lower sandstone sheet, a series of elongate lenses are shown on a map of net sandstone thickness (Fig. 5). The long axes

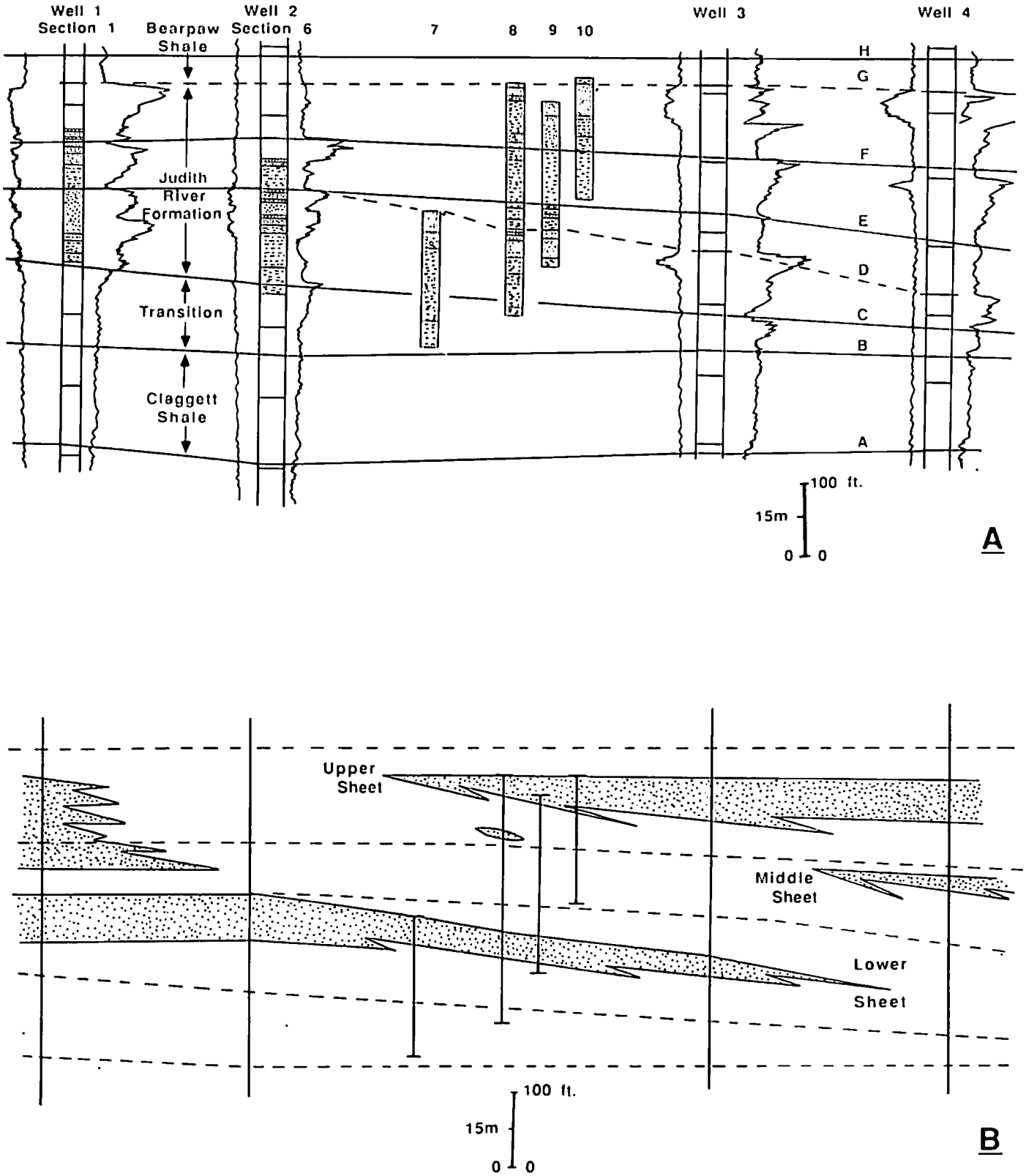


Figure 4. Correlation of measured sections and well logs in the Judith River on the southwest flank of Porcupine Dome. See Figure 5 for locations. Well 1 is Seaboard 1 N.P.R.R. in SW, SE, 1, T. 12 N., R.35 E.; well 2 is Global Enterprises 1 N.P.R.R. in NE, NE, 3, T.12 N., R.36 E.; well 3 is Bates 1 Nordquist in NE, NE, 35, T.13 N., R.37 E. ; well 4 is Anderson 31-2 Government in NW, NE, 2, T.12 N., R.40 E. See Figure 5 for locations. From Shurr, 1975. A. Correlation of subsurface markers and lithologies exposed in measured sections. B. Interpretation of sandstone sheets in the Judith River Formation.

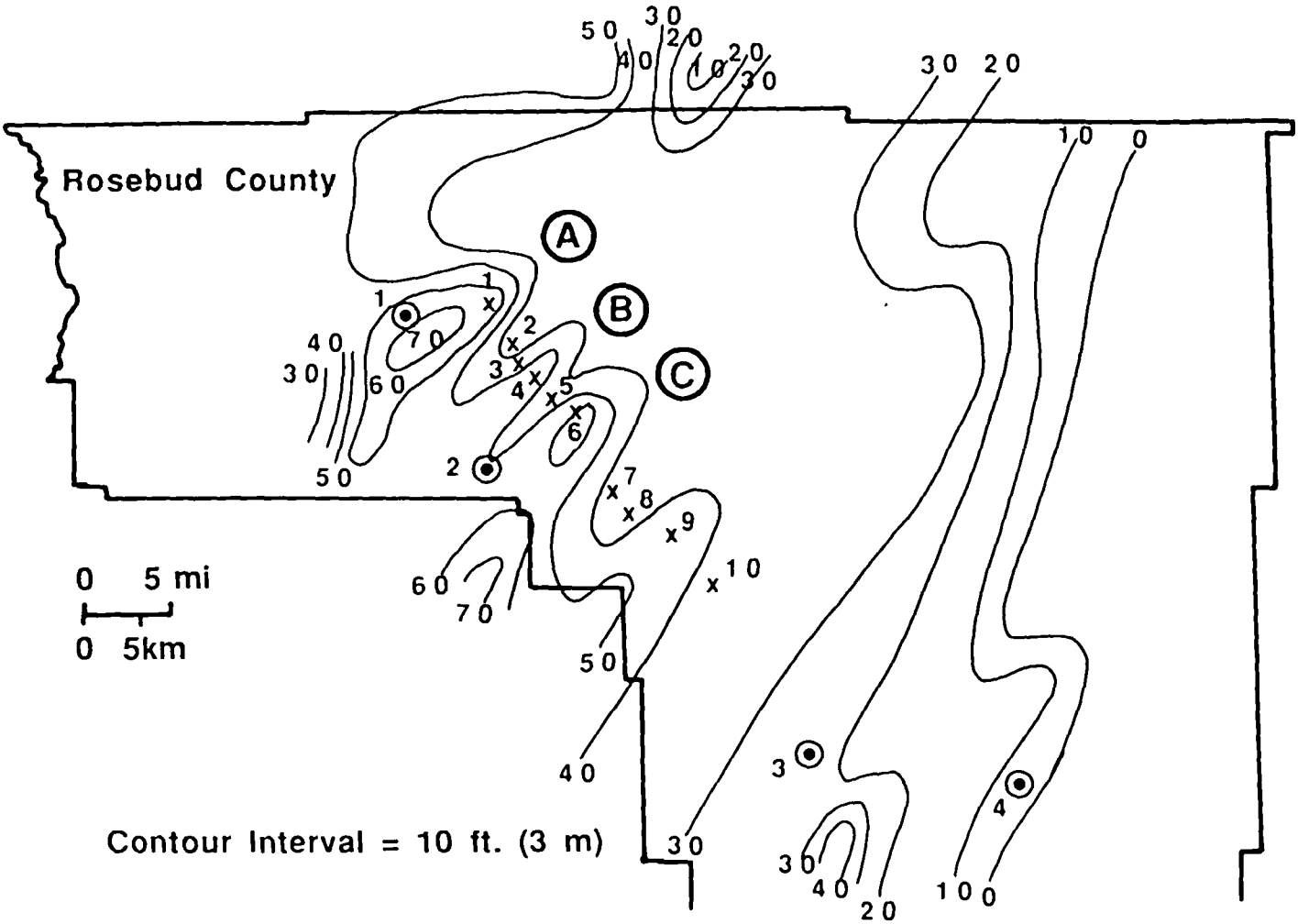


Figure 5. Net sandstone thickness in the lower sandstone sheet (see Fig. 4) in the Judith River around Porcupine Dome in northern Rosebud County. See Figure 1 for location. From Shurr, 1975.

of these lenses usually trend northeast. Maximum thickness within a lens is 75 ft (23 m) and widths range from 4.5 to 10 mi (7 to 16 km). The map shown in Figure 5 is based upon data from ten measured sections and logs from 30 oil tests. In addition to documenting discrete elongate lenses, the map shows the eastern limit of the lower sheet and a thickness of generally greater than 50 ft (15 m) in the west.

The architecture of sandstone facies within the lenses is documented in measured sections (Fig. 6) from relatively continuous exposures of the lower sheet along the southwest flank of the dome. In general, the lower part of the sandstone sheet is gradational with underlying interbedded siltstone and shale. The thickest sandstone units are friable, noncalcareous, white to tan sandstone which is burrowed and structureless, but in places the sandstone shows large-scale planar cross-bedding. Friable sandstone units are most often separated by thin, well-indurated, calcareous, tan to brown sandstone with ripple marks and planar to open trough cross-bedding. The well-indurated sandstone is usually more coarse-grained than the friable sandstone and forms continuous ledges which can be traced laterally along the rimrock. Dashed lines in Figure 6 show the resulting correlations. Relative to the top of the sandstone sheet, the ledges are inclined to the east and are more closely-spaced in the upper portion of the bench. Central portions of elongate lenses correspond with thick, friable units (section 4, lens B, Fig. 6). Ledges appear to be progradational surfaces within the lenses and show an eastward progradation which conforms with the eastward shingling of lenses, i.e. the lenses become younger to the east. In addition to the facies variations shown in Figure 6, there are lateral gradations of well-indurated, cross-bedded sandstone and friable, structureless sandstone. These small- scale facies packages generally take place over distances of less than 1,000 ft (304 m). Ripple marks and cross-bedding in the lower sheet suggest sediment transport at right angles to the trend of the elongate lenses which conforms with the eastward progradation shown in Figure 6.

Sandstone Facies Near Faults

On the north flank of Porcupine Dome, individual sandstone sheets in the Judith River coalesce and become difficult to distinguish. Thick sandstone accumulated along the trend of the en echelon fault zone; but, more specifically, sandstone units change in thickness and character away from individual fault traces. At Blacktail Butte (section 17, T.12 N., R.38 E.), small-scale facies packages are oriented with sandstone thickness decreasing away from fault traces. Ripple and megaripple crests in the sandstone trend N 59oE, an average for 20 readings, and fault traces in the en echelon fault zone average N 64oE. This suggests sediment transport at right angles to the fault, i.e. in the direction of facies variation. Six miles (9.7 km) to the west, similar relationships are

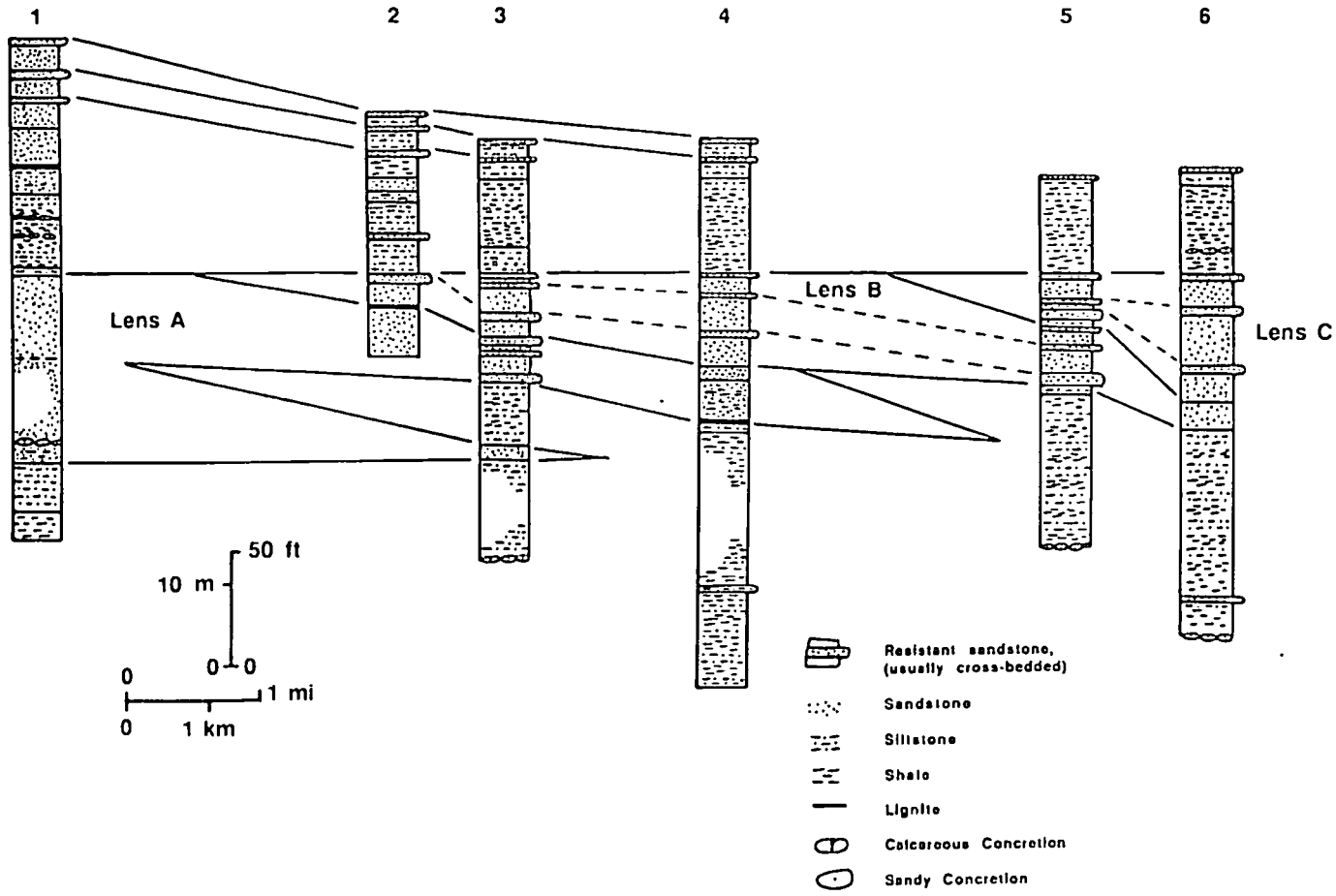


Figure 6. Correlation of measured sections in the lower sheet located between wells 1 and 2 in Figure 4. Elongate lenses A, B, and C from Figure 5 are labeled in the correlation. From Shurr, 1975.

observed in Devil's Canyon sections 5 and 6, T. 12 N., R. 37 E.). A rimrock perpendicular to a fault trace trending N 42oE, shows facies variations and progradation similar to that shown in Figure 6. Six observations yield a sediment transport direction of N 116oE which is approximately the same direction as the facies variation. At both Blacktail Butte and Devil's Canyon, faults offset the Judith River; consequently, there must have been post-depositional reactivation of structural features which also were active enough to influence Cretaceous deposition.

Miles City Arch

The Miles City Arch is a broad, low-relief structural saddle between Porcupine Dome to the west and the Black Hills Uplift to the southeast (Figure 1). The arch also constitutes a low divide between the Williston Basin to the northeast and the Powder River Basin to the south. In a general way, the middle and upper sandstone sheets in the Judith River show sandstone development in the vicinity of the arch and sandstone thickness decreases into the basins (Figure 7). The lower sandstone sheet does not extend into the Miles City Arch area, but it is confined to the area of Porcupine Dome to the west (Figures 4 and 5).

Judith River sandstones have a characteristic log expression which consists of an upward increase in resistivity and spontaneous potential (well 4, Figure 4) which is interpreted as an upward increase in grain size and increased sorting within the sandstone sheet. The base of both sandstone units is gradational, and the top is generally a sharp contact. Marine shale within the Judith River Formation separates the middle and upper sandstones; the marine Claggett Shale underlies and the marine Bearpaw Shale overlies the Judith River. The net sandstone maps shown in Figure 7 are based upon approximately 375 subsurface control points. In general, both sheets have widespread areas of less than 20 ft (6 m) thickness and more limited areas of increased sandstone thickness termed lentils. Lentils in the Miles City Arch area are generally larger and more equidimensional than elongate lenses near Porcupine Dome. The narrow axis of a lentil is 20 mi (32 km) or more, and elongate lenses can be distinguished within the outlines of at least one lentil.

The middle sandstone sheet (Figure 7-A) has a maximum thickness of more than 80 ft (24 m) in a lentil located in southwestern Custer County. The lentil has a north-northeast orientation and has several smaller elongate lenses embedded in it. Sandstone thickness decreases rapidly to the southeast, away from the lentil. On the northern margin of the sandstone sheet thickness decrease is more gradual. There are two areas of thinning within the sheet; one located at the western county boundary and one located at the eastern margin. These areas of thinning are separated by an elongate area of no sandstone which is marked by the north-south zero thickness contour extending through the center of the county.

The upper sandstone sheet (figure 7-B) has two main lentils which generally occur in the same locations as the areas of thinning in the middle sandstone. One lentil is oriented northeast and has a maximum thickness of greater than 60 ft (18 m), and the other is oriented east-west and has a maximum thickness greater than 40 ft (12 m). Neither lentil has embedded, elongate lenses. The north-south elongate area of thin middle sandstone which is prominent in the central part of the county, has no expression in the

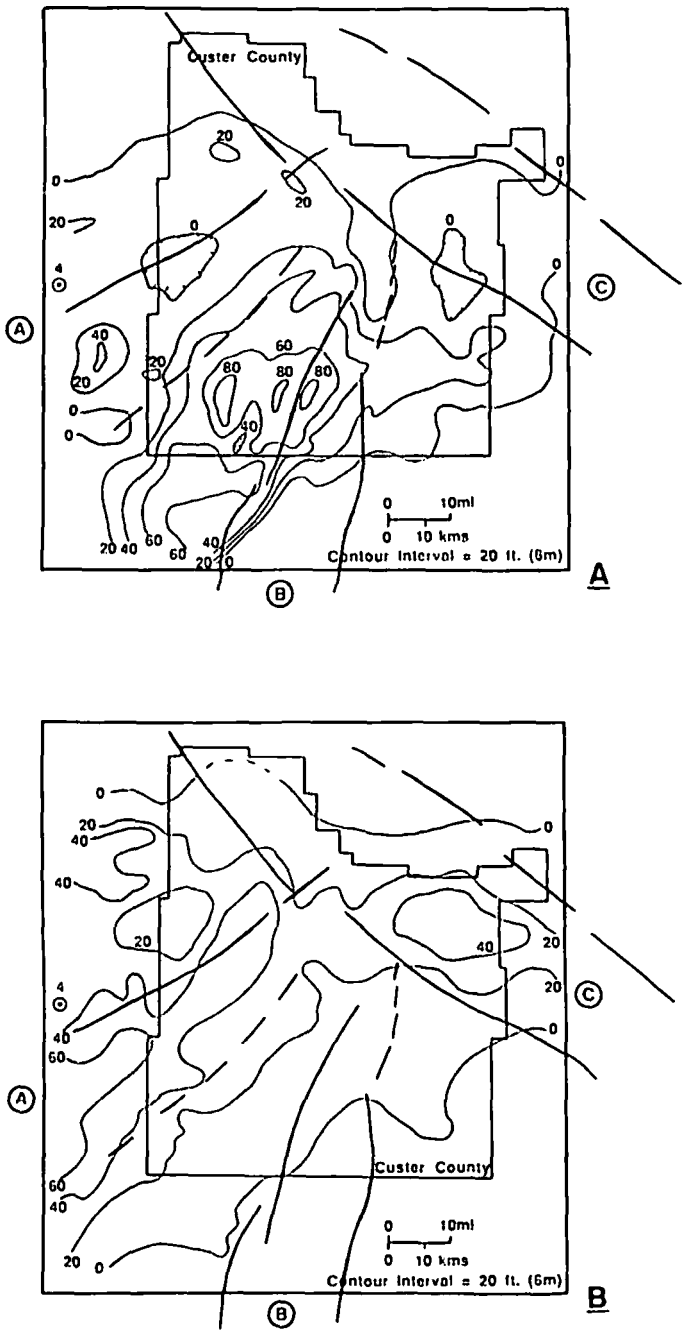


Figure 7. Sandstone thickness in Judith River sheets in the vicinity of the Miles City Arch in Custer County. Well 4 from Figures 4 and 5 is shown at the western margin of the area. Landsat lineaments are labeled A, B, and C. See Figure 1 for location. A. Sandstone thickness in the middle sandstone sheet. B. Sandstone thickness in the upper sandstone sheet.

upper sandstone sheet. Thickness variation within the upper sandstone is less extreme than in the middle sandstone and shows a generally uniform decrease to the north and south.

Cedar Creek Anticline

Cedar Creek Anticline is a northwest-trending structure located along the southwestern margin of the Williston Basin (Fig. 1). It extends from northwest of Glendive, Montana, southeast through Dawson, Prairie, Wibaux, and Fallon Counties in Montana, Bowman County in North Dakota, and into Harding County in South Dakota, for a distance of approximately 150 mi (241 km). The fold is a long, linear structure which gently plunges northwest and plunges more steeply southeast from a structural high located in T.4 N., R. 61 E. and T.4 N., R. 62 E. (Fig. 8). Cedar Creek is a forced fold draped over a fault-bound basement block and resembles the monoclines surrounding the Black Hills which have been interpreted to be forced folds (Lisenbee, 1978). The basement fault bounding Cedar Creek on the southwest is documented by seismic studies and the tilted, uplifted block has had a long paleotectonic history (Clement, 1986). Sedimentary rocks above the basement fault zone are faulted, and faults generally extend far enough up-section to offset the Judith River Formation. Stratigraphic units near the surface, however, are deformed into a highly asymmetric anticline with the steep southwest limb located over the basement fault zone and the gently-dipping northeast limb associated with the tilted block. This structure has been the site of significant gas production from the Judith River (Hoglund, 1975). The formation is currently employed for natural gas storage. Both production and storage of natural gas on Cedar Creek Anticline are reviewed in a later section of this paper.

The Judith River Formation is a series of poorly-consolidated, well-sorted quartz sandstones interbedded with siltstones and silty shales. Analyses of core indicate that porosity varies from 15 to over 30 percent, and permeability ranges from a few tens to several hundred millidarcies. Two sandstone units are present in the Judith River on Cedar Creek Anticline. Locally a third, lower sandstone is developed over the down-dropped basement block, but correlations with the lower sandstone unit found in the Porcupine Dome area are not established. We believe the two extensive sandstones on Cedar Creek do correspond with the middle and upper sandstone sheets which extend onto the Miles City Arch from Porcupine Dome. Like these sheets, the Cedar Creek sandstones show a characteristic coarsening-upward log signature and are encased in a marine shale called the Pierre Shale. The maps shown in Figure 8 are based upon more than 200 wells.

The middle sandstone is more extensive than the upper unit. Thicknesses greater than 50 ft (15 m) cover a large elongate area which extends for more than 60 mi (97 km) along crest of the tilted block, parallel to the bounding fault (figure 8-A). Thickness decreases to zero 5 to 7 mi (8 to 11 km) away from the fault and down the dip of the tilted block to the northeast. The sandstone is cut by the fault along the southwest margin of the structure.

The upper sandstone is more limited; thickness exceeds 50 ft (15 m) only at the southeast end of the anticline (Figure 8-B). As with the middle sandstone, the upper sandstone has maximum thickness developed on the uplifted edge of the basement block. The upper sandstone is elongate some 50 mi (81 km) parallel to the basement fault and extends northeast away from the fault 2 to 5 mi (3 to 8 km). On the southwest, it is cut by the fault. There is an abrupt thickness decrease to the southeast along the trend of the structure near the structural high from which the plunge changes from northwest to southeast.

Sandstone units on Cedar Creek do not really qualify as sheets or benches. Both sandstone units are distinctly elongate and have the approximate dimensions of the more equidimensional lentils described in the Miles City area. Small elongate lenses similar to those found in the vicinity of the Miles City Arch and Porcupine Dome are not documented within the Cedar Creek sandstone units. However, facies changes at right angles to the fault which offsets Judith River, are similar to the relationships described on the north flank of Porcupine Dome. Specifically, paleotectonism influenced deposition, and there was subsequent post-depositional faulting to produce offsets in the Judith River.

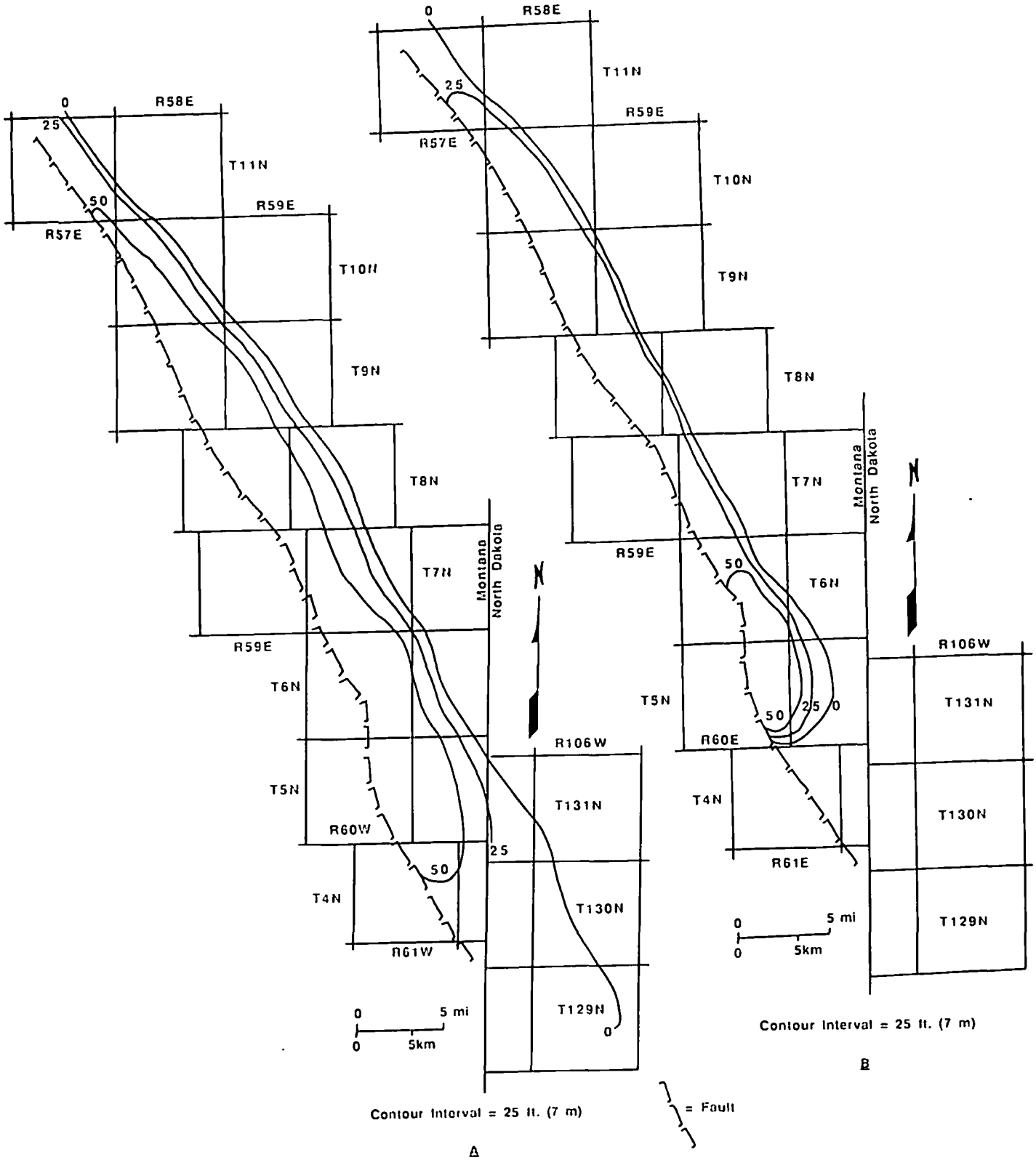


Figure 8. Sandstone thickness in Judith River sheets on Cedar Creek Anticline. See Figure 1 for location. A. Sandstone thickness in the middle sandstone sheet. B. Sandstone thickness in the upper sandstone sheet.

Poplar Dome

The Poplar Dome study area is made up of the Fort Peck Reservation and actually includes the southeastern margin of Bowdoin Dome (Fig. 1). Poplar Dome is asymmetric with steep dips on the eastern margin and is slightly elongate to the northwest. It has expression at the surface in the Bearpaw Shale, while the adjacent Bowdoin Dome exposes Judith River Formation. Poplar Dome lies along the western margin of the Williston Basin and with Bowdoin Dome, flanks the Blood Creek Syncline (Fig. 1) on the north. The stratigraphy of the Judith River and the structure of the

Fort Peck Reservation are described in detail elsewhere in this volume (Monson, 1989). The summary which follows mainly emphasizes comparisons and contrasts with the Judith River Formation on Porcupine Dome, Miles City Arch and Cedar Creek Anticline.

There are three sandstone sheets in the Judith River on the Fort Peck Reservation. In general, logs show the sandstones coarsening upward from a gradational base, i.e. the log expression is similar to that observed in the other three areas. However, the log characteristics change in the northwestern part of the reservation, and Judith River exposed on Bowdoin Dome is largely nonmarine. In correlations employing the Ardmore Bentonite Beds at the base of the Claggett Shale as a horizontal datum, the three sandstone sheets dip to the east and have the appearance of net eastward progradation. This progradational geometry is similar to that observed within the lower sandstone sheet on Porcupine Dome (see Fig. 6), but is at the scale of the total sheets (see Fig. 4). The lower sandstone sheet on the Fort Peck Reservation is similar to the lower sheet on Porcupine Dome. Specifically, the sheet is thickest (more than 120 ft or 36 m) in the extreme northwestern part of the study area and thins to a zero line about two-thirds of the way eastward across the reservation, near the position of Poplar Dome. The middle sandstone sheet is more continuous and is thicker than the upper sheet (Fig. 9). Approximately 150 of the best quality well logs were selected from a base of 1100 logs and used to construct the maps shown in Figure 9.

The middle sandstone sheet has widespread areas of greater than 40 ft (12 m) thickness, and in the northeastern part of the study area, thickness locally exceeds 120 ft (37 m) (Fig. 9-A). In the northeast, thickness variations and correlations suggest another sandstone sheet may be present. In the southeast, the middle sandstone definitely bifurcates, and locally there are four separate sandstone units. Areas on the reservation with thickness in excess of 80 ft (24 m) are generally of the same size and shape as Judith River lentils on the Miles City Arch. In addition, there are smaller elongate lenses similar to the elongate lenses on the arch and on Porcupine Dome. On the Fort Peck Reservation, elongate lenses do not appear to be constituent elements of the lentils but are found as separate entities within the sandstone sheet. In particular, elongate lenses are located in the approximate position (PD, Fig. 9-A) of the structural crest of Poplar Dome.

The upper sandstone sheet is discontinuous and thin (Fig. 9-B). Thicknesses are generally less than 20 ft (6 m), and local areas of essentially no sandstone are common within the limits of the sheet. The maximum thickness encountered is about 50 ft (15 m). The areas of greater than 40 ft (12 m) thickness have the general size and shape of lentils on the Miles City Arch. As in the upper sheet, elongate lenses are not obvious constituent elements of the larger lentils, and one of the lenses is located on the crest of Poplar Dome (PD, Fig. 9-B). The upper sheet is absent in the eastern and northeastern part of the reservation. This is the same general area in which the middle sandstone sheet increases in thickness (Fig. 9-A).

INTERPRETATION OF SHELF SANDSTONE BODIES

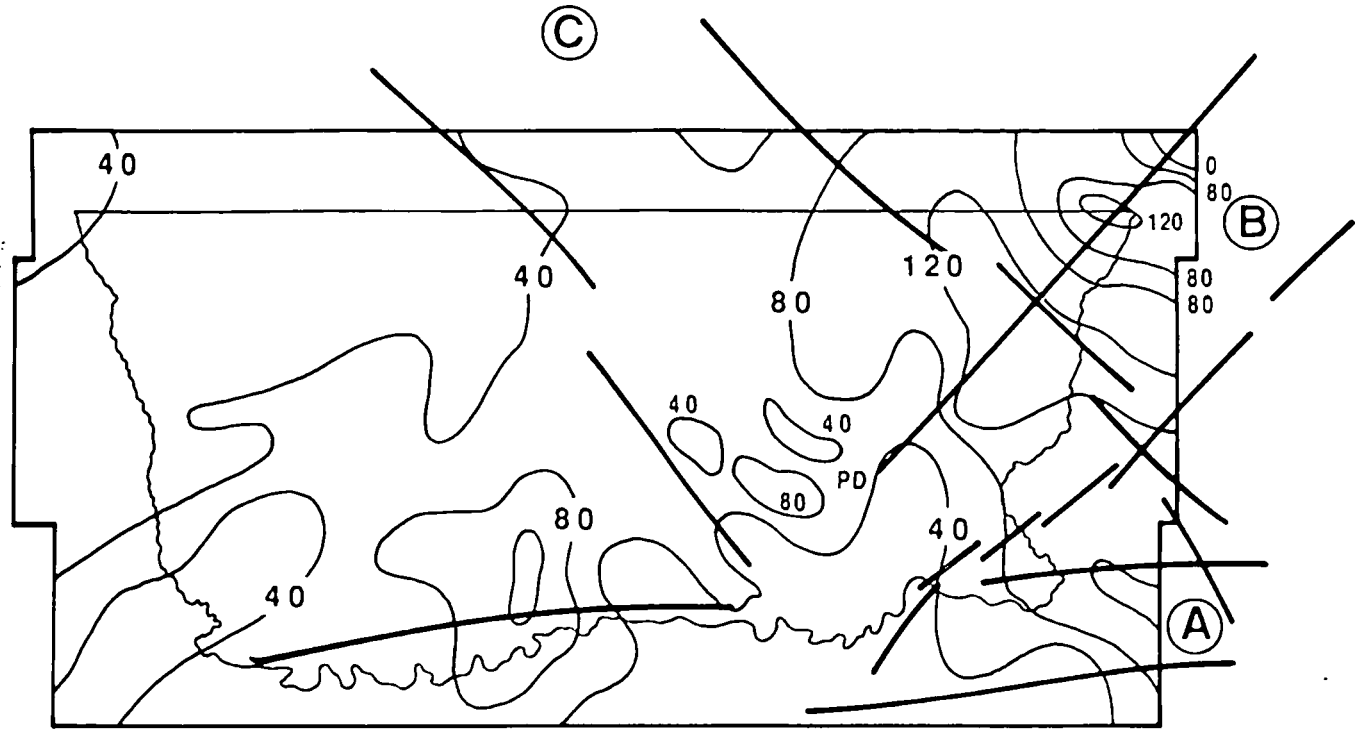
In our earlier review of Judith River paleogeographic setting in eastern Montana, the Eagle and Shannon Sandstones were used as an analogue to characterize a siliciclastic shelf on the western seaway margin. However, the similarities go beyond regional paleogeography. Individual sandstone bodies described in observations from the four study areas have exact counterparts in the Shannon Sandstone of southeastern Montana (Shurr, 1984). Figure 10 summarizes the hierarchy of shelf sandstone bodies observed in both the Shannon and Judith River: regional sheets are composed of coalesced lentils; lentils consist of progradational elongate lenses; and elongate lenses have small-scale facies packages as a part of the upper sandstones. Each level of this hierarchy is interpreted to be a specific morphologic element on a siliciclastic shelf: sheets are coalesced sand ridge fields; lentils are individual ridge fields; elongate lenses are sand ridges; and small scale facies packages are sand waves migrating on the backs of the ridges.

Sheets, lentils, elongate lenses, and small-scale facies packages have all been observed in the Judith River in eastern Montana. However, not all hierarchical levels are observed in all four study areas. For example, small-scale facies packages are observed in outcrops on Porcupine Dome, but would be difficult to document in the subsurface work in the other three areas. Another example is that lentils and elongate lenses are found on both the Miles City Arch and Poplar Dome, but only elongate lenses are described on Porcupine Dome and neither morphologic element seems to be present on Cedar Creek Anticline. Sandstone sheets are, however, found in all study areas. In addition to similarities in gross external geometry, the shelf sand bodies of the Shannon and Judith River have similar sandstone facies. Also, elongate lenses in both units display similar detailed geometries.

Sandstone geometry in the Shannon has been described in a quantitative (Shurr, et al., 1988), and there is a strong linear correlation between the width and maximum thickness in elongate lenses (Fig. 11). Elongate lenses represent sand ridges which are large-scale bedforms on the siliciclastic shelf. The lens thickness is equivalent to the ridge height and the lens width corresponds with the distance between ridges. Just as wavelength and amplitude are positively correlated for small-scale ripples, the wavelength/width and amplitude/thickness are positively correlated for large sand ridges. However, the regression lines for the Shannon and Judith River lenses are not identical (Fig. 11). The Judith River regression line is based upon 31 measurements from Porcupine Dome, Miles City Arch, and Poplar Dome. Individual elongate lenses were measured on work-scale maps contoured in more detail than the generalized, small maps of Figure 5, 7, and 9.

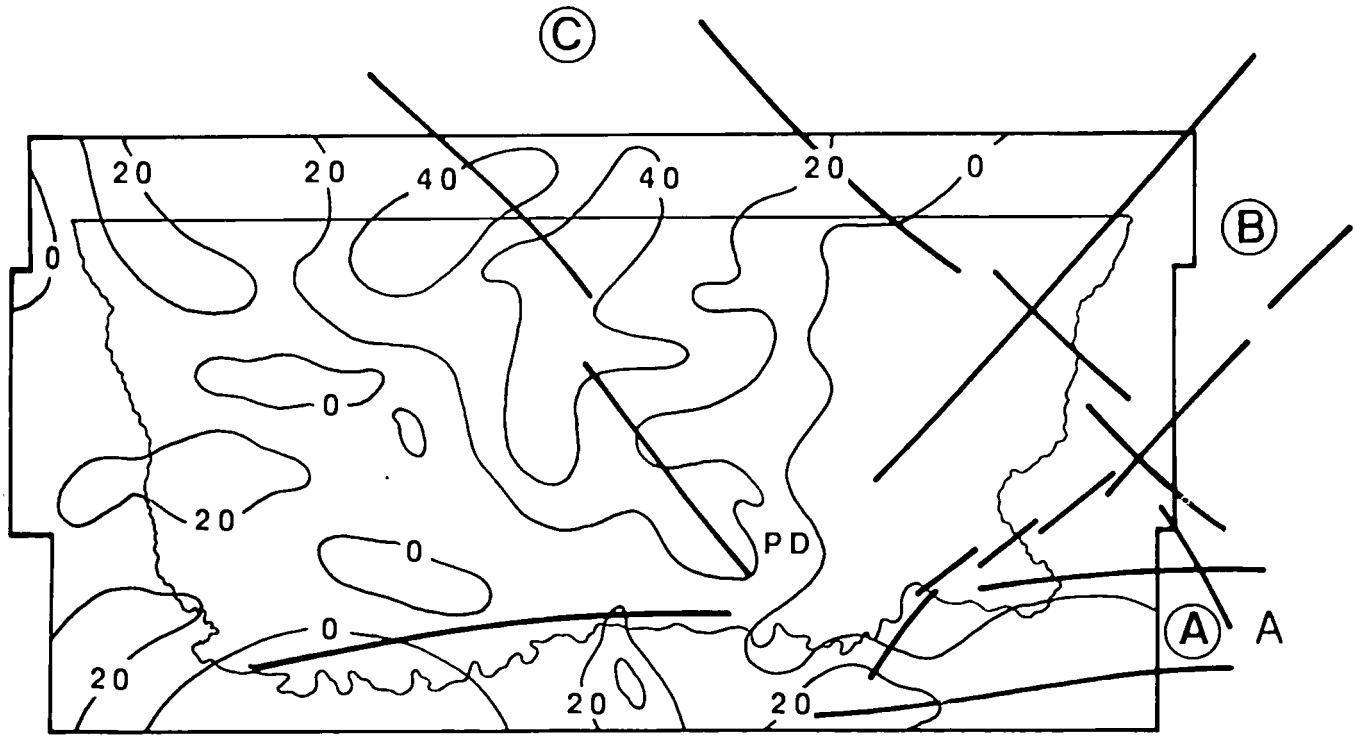
Differences between the Shannon and Judith River regression lines may reflect differences between outer and inner shelf sand ridges. Correlation between width and thickness in the Shannon data set is much higher than in the Judith River data set. There are several potential sources of variability for the Judith River data. The Judith River measurements are taken from lenses in three separate areas and based on correlations and contour maps prepared by three different workers. This could introduce variability in the data set. Alternatively, the inner shelf processes which produced the sand ridges may have been intrinsically more variable than the outer shelf processes which produced Shannon sand ridges. For example, the direction of storm wave migration may have been more variable in the inner shelf setting. It appears that sand ridges on the inner shelf during Judith River deposition were larger than the outer shelf Shannon sand ridges; Judith River lenses average 8.7 mi (14 km) in width and Shannon lenses average 6.7 mi (11 km). The geometry of modern sand ridges also varies from coastal to offshore positions on the shelf (Stubblefield, et al., 1984); specifi-

Figure 9. Sandstone thickness in Judith River sheet on the Fort Peck Reservation near Poplar Dome. Landsat lineaments labeled A, B, C. See Figure 1 for location. A. Sandstone thickness in the middle sandstone sheet. B. Sandstone thickness in the upper sandstone sheet.



A Contour Interval = 40 ft. (12m)

0 10 mi
0 10 km



B Contour Interval = 20 ft. (6m)

0 10 mi
0 10 km

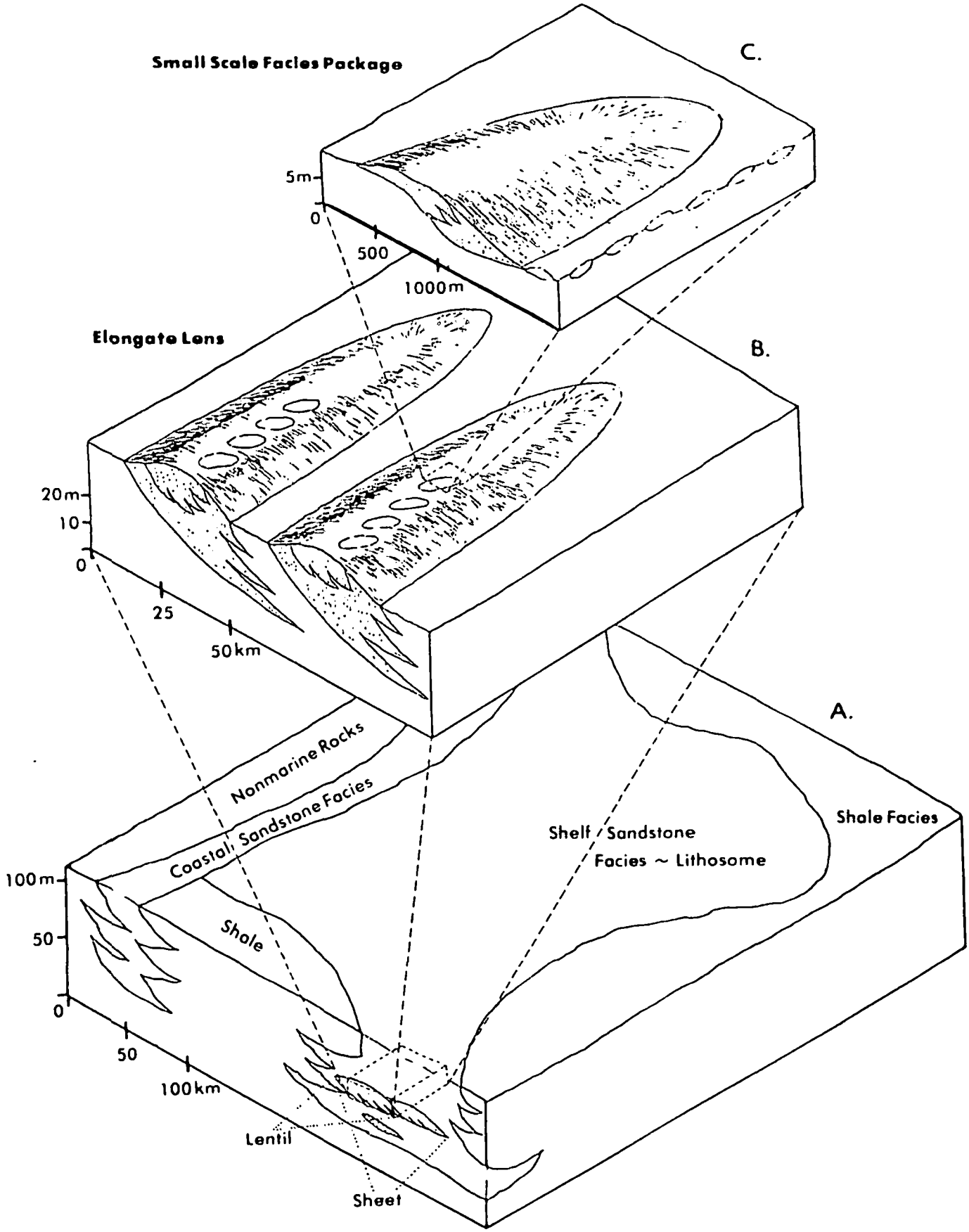


Figure 10. Hierarchy of shelf sandstone bodies recognized in the Shannon sandstone of southeastern Montana as well as in the Judith River Formation of the Montana plains. From Shurr, 1984.

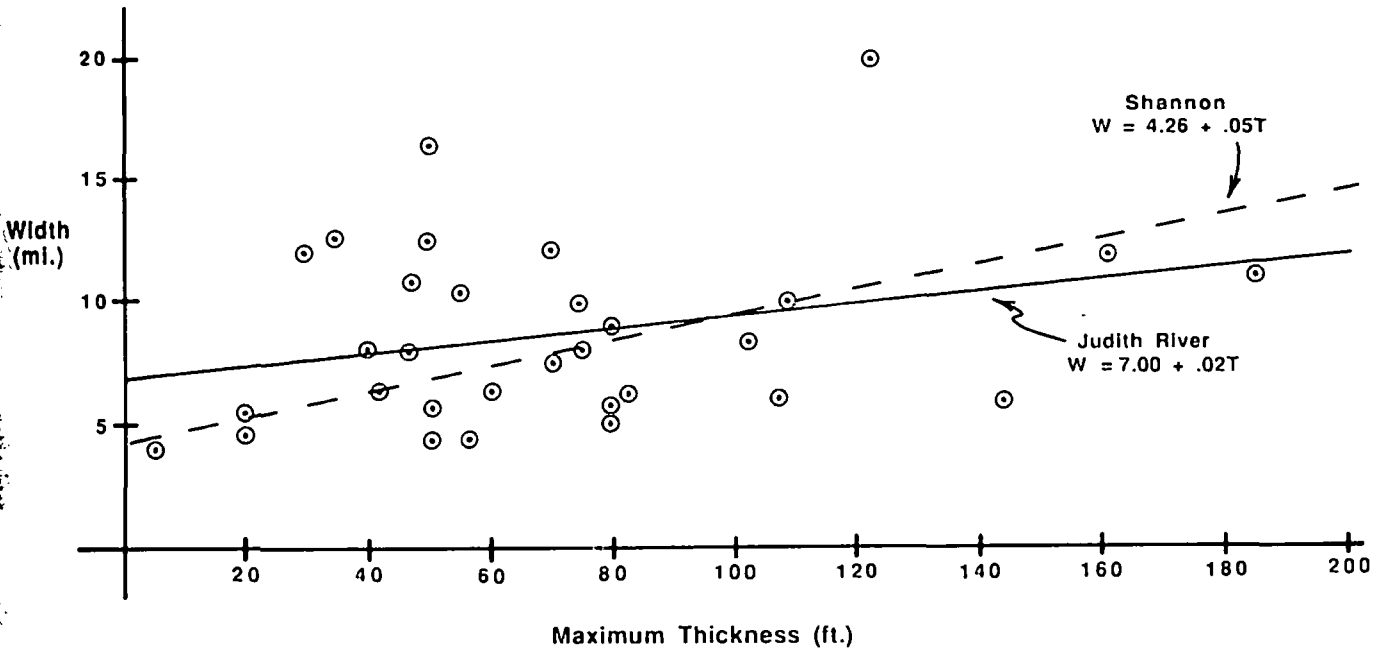


Figure 11. Scatter diagram showing correlation of width and maximum thickness in 31 elongate lenses in Judith River shelf sandstone sheets in the Montana plains. Regression line for 35 lenses in the Shannon (Shurr, et al., 1988) is also shown to emphasize differences between inner and outer shelf sand ridges.

cally, inner shelf sand ridges are smaller than outer shelf ridges. Modern ridges show exactly the opposite size variation from inner to outer shelf when compared with Judith River and Shannon ridges. This may reflect different hydrodynamic regimes on the Cretaceous and modern shelves. Modern continental shelves extending into open ocean basins may not be good analogues for the siliciclastic shelf on the western margin of the Cretaceous seaway. Perhaps the Judith River and Shannon ridges should not even be compared in an inner and outer shelf framework; they do, after all, represent two different progradational cycles. Comparisons within the Judith River population of ridges might be a more realistic way to document inner and outer shelf differences. However, the 30 measurements are distributed between three sheets in three separate areas. Comparisons of Shannon ridges on the outer shelf with possible Eagle ridges on the inner shelf (for a recent example see Hearn and Hanson, 1989, this volume) might also be instructive.

Although inner and outer shelf differences may not be distinctive, it is clear that the Judith River has a hierarchy of shelf sandstone bodies similar to that observed in the Shannon. Furthermore, like the Shannon shelf sandstones, deposition of the Judith River sandstones was influenced by paleotectonism on the siliciclastic shelf.

INTERPRETATION OF PALEOTECTONICS

Paleotectonic control of Judith River deposition is most clearly shown on Porcupine Dome and on Cedar Creek Anticline. On both structures, sand buildups are associated with individual faults, and resulting facies changes within the sandstones are oriented perpendicular to the faults. On Porcupine Dome, sediment transport directions appear to have been across the faults, i.e. in the direction of facies change. On Cedar Creek, maximum sandstone thicknesses are located along the crest of an uplifted and tilted basement block. After sandstone deposition, the structural features were reactivated so that the strata influenced by paleotectonism at the time of deposition were subsequently cut by post-depositional displacements. This syn- and post-depositional paleotectonism is less well-documented on Miles City Arch and in the Poplar Dome area.

In general, sandstone is thicker over the structural crests of the Miles City Arch and Poplar Dome, but clear relationships to specific faults are lacking. There are, however, patterns of sandstone thickness variations which appear to be related to subtle structural features. Linear features visible on satellite images have been integrated with geophysical data to interpret a mosaic of basement blocks in eastern Montana. This block mosaic is described elsewhere in this volume (Shurr, et al., 1989) and has been shown to influence Eagle and Shannon deposition (Shurr and Rice, 1986). In the Miles City area, lineament block boundaries A and B shown in Figure 7-A outline the Judith River lentil in southwestern Custer County, and lineaments A and C (Fig. 7-B) have lentils oriented along their trend. In the Poplar Dome area (Fig. 9), lineament zones are wide and specific correspondence with lentils is lacking. There are, however, general similarities in the pattern of contour lines and lineament zones.

Paleotectonism is important not only because it influenced sandstone deposition, but it also probably influenced fluid migration. Past production of and future potential for shallow gas in the Judith River of the Montana plains may thus be the result of paleotectonic controls as well as sedimentologic controls.

NATURAL GAS PRODUCTION AND STORAGE

The four separate areas described in this report each have distinctive potential for natural gas production from the Judith River Formation. The unit is exposed on Porcupine Dome and consequently any production potential is necessarily off-structure. To the east of Porcupine Dome, the Judith River has good sandstone development in the area of the Miles City Arch and is covered by a shale to act as seal. The gas potential should be excellent; however, a series of tests drilled into the Judith River were disappointing and there is no current production. It may be that gas had migrated out of the area before Laramide deformation could

produce trapping structures. In the area of Poplar Dome, the Judith River is not routinely tested, but there are encouraging shows reported (Monson, 1989, this volume). It is on Cedar Creek Anticline that the Judith River has yielded significant gas production, and it is on Cedar Creek that the unit is currently employed for gas storage.

Gas Production and Storage on Cedar Creek

The Cedar Creek Anticline has produced oil and gas continuously for almost 70 years. As the Judith River Formation gas sand reservoir neared depletion or became depleted of economically recoverable gas reserves, it was determined that it could be better utilized for the subsurface storage of natural gas. Therefore, the formation was converted, with Federal approval, to gas storage operations. Williston Basin Interstate Pipeline Company, as successor in interest to Montana-Dakota Utilities Company, now owns and operates one of the largest gas storage reservoirs in the United States. This insures a safe and adequate gas delivery potential for the company to meet peak load requirements of its integrated natural gas pipeline system, as well as to provide natural gas storage capacity for others.

Gas Discovery and Development

Gas was discovered on August 29, 1915, by a farmer drilling for water on the gumbo flats in the SW SE of Section 1, T. 7 N., R. 59 E. one mile north of Baker, Montana. In 1915, the same well blew out of control and continued to blow gas for about 7 years until 1921 when it finally was brought under control. The volume of Judith River Formation gas vented from this well has not been calculated precisely but is estimated to have been several hundred million cubic feet. The Montana Petroleum Company, a group of Miles City, Montana, businessmen continued development through 1916 and by 1917 had sufficient gas production to construct a pipeline to serve Baker, Montana.

In 1918, the Gas Products Company (Cabot Corporation of Boston) built a carbon black plant one mile east of Baker and by 1919 completed six Judith River Formation gas wells to serve the carbon black operation. The plant produced carbon black through 1929 and is estimated to have consumed approximately 10 billion cubic feet of gas during its operation. Additional natural gas was used when an electric generating plant was built in Baker, Montana in 1926 which produced electricity for two years. In 1928, Montana-Dakota Utilities Company bought this plant, shut it down and built a larger electric generating plant that remained usable until 1977 when it was retired.

Development drilling continued to expand through the late-1920's, and Montana Dakota Utilities Company, during the mid-1930's, formed Federal gas producing units 1, on the northwest, through 8B, on the southeast. The unitization included the Judith River Formation in units 1 through 7 and both the Judith River Formation and the deeper Eagle Formation in units 8A and 8B. The unit operation provided for a more conservative manner for developing the formations and a more equitable means of disbursing gas royalties to unit participants.

Total recorded and estimated gas production data, before conversion of units 2 to 8A (Montana) to storage, indicates that the Judith River Formation has produced in excess of 194 billion cubic feet of gas.

The State of Montana, Board of Oil and Gas Conservation, recognized that the Judith River Formation is used for gas storage and therefore, no longer existed as a gas producing formation on the Cedar Creek Anticline. The Board, through its Order 32-86 effective July 24, 1986, subsequently vacated Order 33-54, the prior Judith River Formation spacing order.

Gas Storage

As the Judith River Formation gas producing units neared depletion or became depleted of their native recoverable gas reserves, Williston Basin Interstate Pipeline Company systematically converted gas producing units 2 through 8A (Montana) for gas storage operations. Table 1 is a current summary of the seven former gas producing units that now comprise the total gas storage operation. Gas injection and withdrawal is accomplished through the use of up to three compressor stations as summarized in Table 2. The three compressors located within the storage field are used for either gas injection or gas transmission operations.

Storage reservoir analysis indicates that the Judith River Formation gas storage reservoir has a total reservoir capacity of approximately 252 billion cubic feet at an average stabilized shut-in wellhead pressure of 210 PSIG.

As a part of Williston Basin's gas storage operations, semiannual pressure surveys of wells in the gas storage field are conducted in the spring and fall of each year. Each well is individually shut-in for a minimum of 24 hours, and a wellhead pressure is obtained and recorded. The spring and fall pressure surveys are normally taken each year during the first three weeks of April and September, respectively. Leak surveys are conducted annually at each storage

Table 1. Summary of Gas Storage Units

Unit No.	Unit Acreage	Date of First Injec.	Number of Injec. and/or Withdrawal wells	Number of Observation wells
1	(Observation)			2
2	5,303.76	8-45	12	2
3	5,635.54	5-45	12	2
4	13,957.34	7-48	40	2
5	14,765.61	4-62	26	2
6	10,449.72	12-82	27	4
7	16,118.93	11-83	31	1
8A (Montana)	24,157.34	4-84	31	3
Total	90,388.24		179	18

Table 2. Summary of Compressor Stations

Compressor Station	Location Sec. T-R	Number of Compressors	Total Rated Horsepower
Cabin Creek	16-10N-R58E	13	13,495
Baker	12-7N-59E	7	4,780
Little Beaver	16-4N-62E	9	2,870
Total		29	21,145

well with a MSA methane gas detection unit. If a leak requiring immediate attention is discovered the well is scheduled for workover. Field development drilling data, gas production data and geologic interpretation strongly suggest that the lateral limits of the Judith River Formation gas storage reservoir clearly lie within the gas storage unit boundaries as they currently exist. Lateral migration of gas from the storage units is highly unlikely due to the following reasons:

1. Gas migration northwesterly out of unit 2 is unlikely due to the plunging nature (down strike) of the anticline axis in this area. Drilling has indicated that a "wet" formation exists north of the unit 2 boundary. The "watering out" and abandonment of unit 1 also support the wet formation concept.

2. Gas migration southeasterly out of Unit 8A (Montana) is unlikely due to the plunging nature (down strike) of the anticline axis in this area. The Judith River Formation also "shales out" and, therefore, is not developed in the southern end of Unit 8A (Montana). This has been demonstrated by data from the early gas development wells in the area.

3. Gas migration laterally to the northeast is effectively controlled by dip off of the anticlinal axis and the "shaling out" of the Judith River Formation.

4. Gas migration laterally to the southwest is effectively controlled by extreme dip, possible faulting and the "shaling out" of the Judith River Formation.

Summary

The Judith River Formation in Williston Basin's gas storage units 2-8A serves as an excellent natural gas storage reservoir for the following reasons:

1. Thick, well developed Judith River Formation sandstone.

2. Well developed natural porosity and permeability as demonstrated by the many high flow rates from unstimulated development gas wells.

3. "Shale out" or nondevelopment of the Judith River Formation laterally on the anticlinal flanks as well as in the southern end of unit 8A.

4. Excellent structural containment, or closure, on the an ticlinal flanks as well as on the south and north ends of the storage field.

5. Formation contains water down structure from the north end of unit 2.

6. Thick, impermeable shale caprock to prevent vertical migra tion of storage gas.

CONCLUSIONS

We have described the Judith River Formation in the vicinity of four structures in eastern Montana: Porcupine Dome, Miles City Arch, Cedar Creek Anticline, and Poplar Dome. Three sandstone sheets are present near Porcupine Dome, but only the middle and upper sandstone extend eastward into the area of the Miles City Arch. In exposures around Porcupine Dome, the lower sheet displays elongate lenses which appear to have prograded eastward. Also, sandstone development and facies variations are associated with individual faults. Subsurface maps of the Judith River near the Miles City Arch show that the middle and upper sandstone sheet consists of lentils as well as the smaller elongate lenses. Both sheets are fairly thick and relatively continuous. On Cedar Creek Anticline, no lentils or lenses are recognized within the two sandstone sheets, but sandstone thicknesses do decrease away from the fault which bounds the structure. In the vicinity of Poplar Dome on the Fort Peck Reservation, there are three sandstone sheets; lentils and lenses are constituents of the middle and upper sheets.

We interpret the sandstone bodies in the Judith River Formation as morphologic elements on a siliciclastic shelf similar to those interpreted for the Shannon Sandstone in southeastern Montana. Elongate lenses are individual sand ridges; lentils are ridge fields; and sheets are coalesced ridge fields. Maximum thickness and width of elongate lenses are positively correlated but do not have the same regression line as the elongate lenses in the Shannon. Deposition of the Judith River was influenced by tectonism on the siliciclastic shelf. This interpretation is most obvious on Porcupine Dome and Cedar Creek Anticline where facies variations are related to specific faults. On Miles City Arch and Poplar Dome, the paleotectonic controls on deposition are less obvious. Specifically, stratigraphic patterns reflect lineaments interpreted from satellite data.

There is potential for natural gas production in the area of the Miles City Arch and Poplar Dome. However, tests in the Miles City area have been unsuccessful, and there have only been shows and production for local field use near Poplar Dome. It is on Cedar Creek Anticline that the Judith River Formation has been an important producer of natural gas. Currently, that production activity has been replaced by a storage function. The sandstones that once produced gas now are employed to store gas.

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March 13, 1987

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EPA REGION VIII
DRINKING WATER BRANCH

Mr. Marc Herman
Environmental Protection Agency
Region VIII
Ground Water Section
One Denver Place, Suite 1300
999 - 18th Street
Denver, CO 80202-2413

Re: Underground Injection Control (UIC) Draft Permit for Courchene No. 1-D, EPA Permit #MTS 2301-0611, Roosevelt County, Montana.

Dear Mr. Herman:

Enclosed you will find my report on the Judith River sandstone porosity in the Volt Field Area.

I have also sent copies of the well logs I used in my evaluation. I tried to give reference to the material which explains the procedures used, but you may have questions. Please call me if anything is unclear. I believe I have made an excellent case to support my earlier porosity evaluation for the Judith River sandstone.

Sincerely,

Lawrence M. Monson

Lawrence M. Monson
Tribal Geologist

Enclosures

LMM/fme

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MAR 18 1987

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JR SS Porosity, Volt Field Area
Part 2 of Courchene 1D Draft Permit Protest
By Larry Monson, Geologist
Minerals Resource, Fort Peck Tribes

A. Introduction

1. Background

This report is primarily an analysis of the porosity in the Judith River sandstone in the Volt Field Area. It is a continuation of the Fort Peck Tribes' objection to the issuance of a draft permit for saltwater disposal in the Courchene 1D well which was issued by the EPA, Region VIII, in early November 1986. This author sent public comment for the Tribes through their attorneys before the December 12, 1986 deadline.

The determination of pore space in the Judith River aquifer is crucial in evaluating whether the Courchene 1D well has filled its exempted 1/4-mile radius authorized by rule. As outlined in the EPA Statement of Policy in December 1985, this well was allowed to continue saltwater disposal activities even though it was contaminating a probable USDW (underground source of drinking water). In the technical evaluation supporting that Statement Policy, Mr. Paul Osborne of the EPA, concluded that the Courchene 1D well had filled the exempted volume with saltwater. His Table 2 did not include a radius distance, but it should have been 1384 feet based on cumulative injection through January of 1985. A porosity of 15% and an aquifer thickness of 59 feet were used for that calculation. He also examined the affects of dispersion which would have filled 1382 feet of rock away from the well bore at 20% porosity. At 15% porosity, dispersion may have filled 1532 feet of radius. In summary, that report demonstrated that the Courchene 1D had filled its exempted radius.

A draft permit was issued because the operator of the well, Murphy Oil USA, showed the porosity of the rock to be considerably greater (32%) using "site specific data". The content of that data is unknown to this author, but I have been told by Marc Herman, who is evaluating this permit for the EPA, that Murphy used a sonic well log from the nearby Courchene 1 oil well. Murphy also applied a correction factor of 100/130 to the sonic porosity value, which I assume is their interpretation of the sonic travel time ratio between the sandstone and the nearby shale. This is not how shale correction is performed on sonic logs.

In the original protest report considerable material was presented as to the porosity of the Judith River sandstone in general. See that report for the expert opinions which estimated the porosity to be 15-20%. Also stressed in the earlier report was the fact that few of the best sandstone reservoirs in North America have porosities averaging more than 25%, let alone 32%.

2. Part 2 Outline

This report presents a detailed log analysis of the Judith River sandstone for the wells in the Volt Field Area. From this evaluation, it was determined that corrections were necessary in porosity values determined from the sonic logs, because of the shaly nature of the sandstone. The presence of clay impurities, found in the Judith River sandstone, was stressed by this author back in May 1985 at the original EPA public hearing concerning the Judith River.

The Judith River sandstone probably formed in a deltaic environment depositing a high volume of fine grained detritus. Well log analysis of the resistivity and gamma ray responses in this stratigraphic section has supported that observation. Mr. Herman has asked for the information that follows. From this evidence it can be concluded that the Judith River sandstone in the Volt Field Area is significantly less than 32%.

Comment will also be made on the groundwater movements in the area as they might affect the injection plume. The presence of another Judith River disposal well very nearby is also a factor which must be considered.

B. Procedure

Volt Field Area wells are listed on Table 1, and are spatially related on Map 1. See the earlier report for the location of the Volt Oil Field. Resistivity and gamma ray logs were examined for 14 of the 16 wells listed on Table 1. Logs were not available for the last two wells and sonic logs were probably not run in the Judith River anyway. Sonic logs were run through the Judith River section in 7 of the area wells. A neutron log with no scale indicated was run through the JR section in the Carlson saltwater disposal well which is not listed on Table 1. A density-neutron porosity log (FDC-CNL) was run through the Judith River Formation and calibrated to sandstone in the Schultes 3-2 well. This relatively new log supplies an important correlation tool in evaluating the sonic logs, some which were run back in the 1960's when this method was new. S.P. logs, when available, were also examined for shale content evaluation.

C. Judith River Log Data

Determination of the top of the Judith River Formation is difficult. An attempt was made to consistently pick the top based on a low resistivity response which probably represents a bentonite marker some 125 feet above the basal sandstone in the Judith River Formation. Obviously, the JR tops on the last two wells in Table 2 were chosen by someone else and merely copied from completion reports. Because the basal JR sandstone is traceable across the entire Reservation, and readily correlated in this area, it presents the best structural marker for mapping. Fortunately, this is also the zone of injection in the Courchene 1D well. The basal sandstone elevations in Table 2 are plotted on Map 1 with structural contours added. Structural elevation in this area is decreasing towards the northeast. The contour flexure on the east side is inferred from the Gess 1 well, one mile east, which lies some 20 feet lower, stratigraphically speaking. The uniformity of the aquifer is demonstrated by a standard deviation of only 4 feet in thickness. The sandstone averages 49 feet in thickness. Note that the aquifer thickness in the Courchene wells is less than the 59 feet used by Mr. Osborne in his Technical Evaluation.

Sonic and gamma ray data are summarized in Table 3 for the basal JR standstone. Values are weighted averages which consider the response peaks and troughs. Most shale correction models use the travel time values and gamma ray readings in adjacent shales as representative of the clay values that are affecting the sandstone readings in a shaly sandstone section. For this reason, shale values are also listed on Table 3. The low standard deviation in the GR values is an important point of accuracy.

D. Porosity Evaluation

Porosity values are displayed in Table 4 for the 7 wells with sonic log readings through the Judith River Formation. Values were determined from the Schlumberger Chart Por-3 for sandstone at 18,000 ft/sec. The range is from 28% to a very unlikely 51%. The average of 43% is equally impossible in a consolidated sandstone rock. If the Courchene 1 sonic porosity of 39% is multiplied by 100/130 a corrected value of 30% is arrived at. Is this Murphy's crude correction for shaliness?

Several methods exist to determine the amount of shale that is present in a shaly sandstone (see Dresser Atlas Table IV). S.P. values can be used by comparing the direct ratio between the adjacent shales and the sandstone. More correctly, resistivity values must be considered in S.P. methods to evaluate shaliness. Since only 3 of the 4 wells with S.P. logs were usable and since most of the logs had no shallow resistivity device run through the Judith River section, this method was abandoned. Resistivity was not used in calculating porosity for the same reason, although it could be a check for the newer logs. Water saturation was reasonably assumed to be 100% for this non-hydrocarbon bearing interval.

The availability of gamma ray logs for all the area wells made this parameter useful for shaliness estimation (see Dresser Atlas, Part VIII). A maximum value for shaliness can be determined from this simple ratio:

$$V\ shale = \frac{GR\ log\ ss - GR\ clean\ ss}{GR\ shale - GR\ clean\ ss}$$

Dresser Atlas suggests that in consolidated pre-Tertiary sandstone, the following relationship is more correct:

$$V\ shale = .33\ (2^{2(V\ shale\ max)} - 1)$$

In most cases, the gamma ray response to the shale impurities is assumed to equal the shale response in adjacent shale units. Fortunately that average response is very uniform in this stratigraphic section. Determining the radioactive response for a clean sandstone is virtually impossible in the Cretaceous rock section. The underlying Dakota sandstone is probably a cleaner unit and does reach GR values of 15. Dresser used 15 as a value in the example shown, which is similar to the case in question. Table 4 gives the range in shale volume based on the above two equations. The Courchene wells display a discouraging lack of correlation, but the Courchene 1D shaliness of 34-51% is identical to the area average of eight wells.

Both the Dresser and Schlumberger material accompanying this report present the method and rationale for correcting the sonic porosity because of shaliness. In the simplest form, the calculation is as follows:

$$\text{Porosity} = \text{Sonic Porosity} - V_{shale} \frac{(\Delta t_{shale} - \Delta t_{matrix})}{(\Delta t_{fluid} - \Delta t_{matrix})}$$

$$\text{Where Sonic Porosity} = \frac{(\Delta t_{log} - \Delta t_{matrix})}{(\Delta t_{fluid} - \Delta t_{matrix})}$$

Constants:

1. Δt matrix = 55.5 μ sec/ft Shaly SS
2. Δt fluid = 189 μ sec/ft Drilling Fluid

Corrected sonic porosity values are listed on Table 4 as well. Maximum value results from using the minimum shale volume and vice versa.

Three of the older sonic logs give surprisingly low corrected sonic porosities. The Demarrias 1 well was logged after fresh water drilling, which may have affected the results. However, the Courchene wells calculate at lower values also. GR values from the Courchene 1D well log were combined with the sonic values from the nearby Courchene 1 oil well, because of the good GR correlation mentioned earlier. Disregarding the low Courchene 1 value of 5%, the remaining 7 wells average 22% corrected sonic porosity. The Courchene 1D has no better than 15% porosity.

Formation Density - Neutron Logs are almost never run at shallow depths in the Williston Basin. If they are, they are calibrated for the limestone which is the potential pay zone at depth. The Schultes 3-2 well does have a FDC-CNL log run through the Judith River Formation and it was calibrated to a sandstone matrix.

This presents another, more modern means for evaluating the Judith River porosity. Table 5 compares various porosity values in this well for the JR basal sandstone. The FDC-CNL crossplot determined from Schlumberger Chart CP-1d is 33%. The Sonic-CNL crossplot from Chart CP-2b is only 26%. Figure 1 plots the various neutron and density porosity values taken from the peaks and troughs through the log section. The triangle represents the section weighted average. The line drawn at a 45 degree angle from the origin would be a line for clean quartz sandstone. Note that no JR values plot near the line. Neutron-Density porosity values for the adjacent shale are plotted as a square on Figure 1. Note that some of the "sandstone" values plot near the line from the origin through the shale point. This line could be loosely termed a shale line.

Schlumberger has outlined a method for calculating corrected porosity values from FDC-CNL well logs (see accompanying material). Figure 1 is scaled for shale % parallel to the clean sand line at a ratio distance along the "shale" line. The shale point is taken as 100% shale. Corrected porosity is scaled parallel to the shale line from the sand line.

The shale volume ranges from 31-85% in this shaly sandstone. Corrected porosity values range from 4-25%. The average value found at the triangle is V shale = 40% and porosity = 15%. Exact porosity correlation with the corrected sonic value for this well. Details of the SARABAND log and methodology, employed by Schlumberger in evaluating shaly rocks, is included with this report. The silt content and type of clay is important but neither can be completely evaluated in this case. There is no sand point in the log for this section because it has no clean sandstone and there are unfortunately no other logs available for comparison.

Dresser Atlas has attempted to simplify the porosity correction with two diagrams that are included (see Sections IX and X). Both are labeled Fig. 17 and are on the same page in their respective sections, p. 15. The sonic porosity of 21% on the chart would be corrected to only 5.5% according to the Dresser Atlas method.

The following parameters were used for the sonic porosity diagram:

Δt log = 92 μ sec/ft
Δt shale = 135 μ sec/ft
V shale = 21%
V fluid = 4500 ft/sec

Assuming the fluid to be invaded drilling mud would raise V fluid to 5300 ft/sec and the corrected porosity to 7.5%.

The chart for correcting density log readings gives an uncorrected porosity of 24%. Corrected porosity would be about 20%. Following parameters were used:

Bulk density = 2.25 g/cm^3 (2.247)
Density porosity = .26
Fluid density = 1.10 g/cm^3
Matrix density = 2.65 g/cm^3 (Average SS)

V shale = 21%
Shale density = 2.22 g/cm^3 (Shallow depth)
Density porosity = .28

Thus for the Schultes 3-2 well the corrected porosity values range from 15-20% based on different methods of calculation. The Dresser corrected sonic porosity is lower.

Porosity Conclusions

From the analysis of sonic logs and one FDC-CNL log in the Volt Field Area, it does not appear that the porosity in the basal sandstone of the Judith River Formation exceeds 20% on the average. The porosity may be as low as 15% in the vicinity of the Courchene 1D disposal well. That value appears to be confirmed by comparing corrected sonic values to corrected FDC-CNL values in a modern well log.

E. Groundwater Movement

Based on a structure map for the top of the Judith River presented at the May 1985 EPA hearing, and copied for the Volt Field Area in Part 1 of the earlier report, the regional direction of groundwater movement is probably to the southeast. Map 1 of this report however, shows that local flow may be to the northeast. The regional pattern probably influences, if not dominates, the local flow created by only minor differences in relief and hydraulic head.

The Carlson disposal well is located less than one-half mile to the southeast from the Courchene disposal well. (See Table 6). It also is injecting into the Judith River aquifer. The close proximity of these two wells presents two important implications. First of all, the two injection plumes may have intersected, depending on the direction of movement of the plumes and the extent of the Courchene 1D plume. If regional flow dominates the water movement then the Courchene plume is probably adding to the Carlson plume. Even with local flow patterns the two plumes could have joined to the northeast.

Table 6: Well Locations

Courchene 1	90 FSL 1740 FWL
Courchene 1D	801 FSL 2034 FWL
Carlson 31-9	660 FNL 1980 FEL
Carlson SWD	535 FNL 1980 FEL

Secondly, if Murphy is forced to abandon the Courchene 1D disposal well, another disposal site is available, nearby, in the Carlson well. The Fort Peck Tribes did not object to the Carlson well permit specifically, because of its authorization by rule status. The Tribes do object to any well disposing of saltwater into the Judith River aquifer by general principle.

F. Conclusions

Using a maximum average porosity of 20%, in an aquifer of 49 feet average thickness, and an actual cumulative injection volume of 10,580,956 barrels, as of November 30, 1986; the Courchene 1D disposal well has filled a radius of 1389 feet. As stated in the earlier report, this is in excess of a quarter mile. The effects of dispersion and regional flow would extend the plume. The rate of movement is really irrelevant since it is assumed that all of the water is entering the basal sandstone of the Judith River Formation.

The Fort Peck Tribes repeat their objection to Draft Permit #MTS2301-0611, for the disposal of saltwater into the Judith River aquifer through the Courchene 1D well. This well has exceeded the limits of its authorization by rule. The Dakota aquifer is a much better disposal horizon. The Carlson disposal well is available for injection, although the Tribes will continue to oppose any Judith River contamination.

APPENDIX

LIST OF ILLUSTRATIONS

TABLES

1 Well Summary, Volt Field Area

2 Judith River Data

3 JR Basal SS Log Data

4 Porosity Data, Basal JR SS

5 Schultes 3-2 Judith River Lower SS Porosity

6 Well Locations

MAP 1 Basal Judith River Sandstone Elevation, Volt Field Area, Montana

FIGURE 1 FDC-CNL Porosity Crossplot, Schultes 3-2 Judith River Lower Sandstone

REFERENCES

1. Schlumberger, 1972, Log Interpretation Manual, Volume I- Principles, Schlumberger Ltd., 277 Park Ave., N.Y., N.Y.

2. Schlumberger, 1972, Log Interpretation Manual, Volume II- Applications, Schlumberger Ltd., 277 Park Ave., N.Y., N.Y.

3. Schlumberger, 1972, Log Interpretation Charts Schlumberger Ltd., 277 Park Ave., N.Y., N.Y.

4. Dresser Atlas, 1982, Well Logging and Interpretation Techniques: The Course For Home Study. Dresser Industries Inc.

REFERENCE MATERIAL

A. Schlumberger

1. Charts: POR - 3, CP -1d, CP -2b
2. Vol I: page 96
3. Vol II: pages 40 - 43

B. Dresser Atlas

1. Section VIII: Gamma Ray Log pages 10 and 11
2. Section IX: Compensated Densilog pages 14 and 15
3. Section X: Acoustic Logs pages 13 -16

TABLE 1: WELL SUMMARY, VOLT FIELD AREA

	WELL	LOCATION	OPERATOR	COMPLETION	SONIC LOG	POROSITY LOG	S.P. LOG
1.	GESS 1	N S 1-30-46	NUCORP	3-05-82	YES	NO	NO
2.	SCHULTES 3-2	NW NE 3-30-46	TRICENTROL	5-29-81	YES	FDC/CNL	YES
3.	COURCHENE 1	SE SW 4-30-46	MURPHY	7-11-64	YES	NO	NO
4.	COURCHENE 1D	SE SW 4-30-46	MURPHY	3-03-65	NO	NO	NO
5.	COURCHENE 2	SE SE 4-30-46	MURPHY	7-14-65	YES	NO	NO
6.	BLUE HORSE 1	SW NE 4-30-46	SIGNAL	10-08-64	TOO DEEP	NO	NO
7.	ORTMANN 1-7	SW SE 7-30-47	ENSEARCH	8-12-77	YES	TOO DEEP	YES
8.	M. TRIMBLE 1	NE SE 8-30-46	CARDINAL	7-18-72	TOO DEEP	NO	NO
9.	DEMARRIAS 1	NE SW 8-30-46	MURPHY	8-20-65	YES	NO	YES
10.	DEMARRIAS 1	SE NW 8-30-46	PLACID	4-29-63	TOO DEEP	NO	NO
11.	TRIMBLE 2	SE NE 8-30-46	MURPHY	6-10-65	YES	NO	NO
12.	D.L. TRIMBLE 1	NE NE 8-30-46	PLACID	4-21-65	TOO DEEP	NO	NO
13.	CARLSON 31-9	NW NE 9-30-46	KIRKWOOD	5-28-74	TOO DEEP	NO	YES
14.	TRIMBLE 1	SE NW 9-30-46	MURPHY	9-24-64	TOO DEEP	NO	NO
15.	CARLSON 1	SW SW 10-30-46	WAGNER	12-15-55	N.A.	N.A.	N.A.
16.	RED DOG 3-16	NE NW 16-31-46	FARMERS UNION	12-11-74	N.A.	N.A.	N.A.

COURCHENE 10 REPORT POROSITY EVALUATION MINERALS, FPT

TABLE 2: JUDITH RIVER DATA

WELL	K.B.	DEPTH J.R. TOP	ELEVATION J.R. TOP	DEPTH TOP J.R. L.SS	EL. TOP J.R. L.SS	DEPTH BASE J.R. L.SS	THICKNESS J.R. L.SS	J.R. FM. THICKNESS
GESS 1	2647	1253	1394	1373	1274	1412	39	159
SCHULTES 3-2	2755	1332	1423	1464	1291	1508	44	176
COURCHENE 1	2726	1290	1436	1427	1299	1470	43	180
COURCHENE 10	2711	1290	1421	1410	1301	1458	48	168
COURCHENE 2	2656	1230	1426	1361	1295	1410	49	180
BLUE HORSE 1	2690	1264	1426	1396	1294	1442	46	178
ORTMANN 1-7	2766	1316	1450	1437	1329	1483	46	167
M. TRIMBLE 1	2619	1180	1439	1304	1315	1357	53	177
DEMARRIAS 1	2770	1320	1450	1440	1330	1491	51	171
DEMARRIAS 1	2718	1305	1413	1403	1315	1455	52	150
TRIMBLE 2	2623	1180	1443	1310	1313	1359	49	179
D.L. TRIMBLE 1	2626	1200	1426	1320	1306	1370	50	170
CARLSON 31-9	2672	1250	1422	1370	1302	1424	54	174
TRIMBLE 1	2688	1260	1428	1382	1306	1438	56	178
CARLSON 1	2725	1430	1295					
RED DOG 3-16	2592	1325	1267					
						AVG.	49	172
						MAX.	56	180
						MIN.	39	150
						STD. DEV.	4	8

TABLE 3: JR Basal SS, Log Data, Volt Field Area

	WELL	Avg dt ss	Avg dt sh	Avg GR ss	Avg GR sh
1.	GESS 1	116	137	40	70
2.	SCHULTES 3-2	92	135	40	85
3.	COURCHENE 1	107	150	47	65
4.	COURCHENE 1D	x	x	50	84
5.	COURCHENE 2	116	145	35	66
6.	BLUE HORSE 1	x	x	45	75
7.	ORTMANN 1-7	122	132	55	85
8.	M. TRIMBLE 1	x	x	50	80
9.	DEMARRIAS 1	108	135	52	72
10.	DEMARRIAS 1	x	x	45	78
11.	TRIMBLE 2	124	145	42	70
12.	D.L. TRIMBLE 1	x	x	48	75
13.	CARLSON 31-9	x	x	55	85
14.	TRIMBLE 1	x	x	48	70
15.	CARLSON 1	x	x	x	x
16.	RED DOG 3-16	x	x	x	x
	AVERAGE	96	140	47	76
	MAXIMUM	124	150	55	85
	MINIMUM	92	132	35	65
	STD.DEV.			6	7

(x = not available, too deep, or not run.)

TABLE 4: POROSITY DATA, BASAL JR SS, VOLT FIELD AREA

WELL	SONIC POROSITY %	VOL. SHALE MIN. %	VOL. SHALE MAX. %	CORR. SONIC POROSITY MIN. %	CORR. SONIC POROSITY MAX. %
GESS 1	46	29	45	18	28
SCHULTES 3-2	28	21	36	6	15
COURCHENE 1	39	47	65	0	5
COURCHENE 1D	x	34	51	2	15
COURCHENE 2	46	24	39	19	29
BLUE HORSE 1	x	x	x	x	x
ORTMANN 1-7	51	40	57	17	27
M. TRIMBLE 1	x	x	x	x	x
DEMARRIAS 1	39	48	65	1	11
DEMARRIAS 1	x	x	x	x	x
TRIMBLE 2	51	32	49	18	30
D.L. TRIMBLE 1	x	x	x	x	x
CARLSON 31-9	x	x	x	x	x
TRIMBLE 1	x	x	x	x	x
CARLSON 1	x	x	x	x	x
RED DOG 3-16	x	x	x	x	x
AVERAGE	43	34	51	10	20

x = not available
or not used

TABLE 5: SCHULTES 3-2, JUDITH RIVER LOWER SS POROSITY

LOG METHOD	POROSITY IN %
SONIC	28
CORR. SONIC	
MINIMUM	6
MAXIMUM	15
SONIC - FDC CROSSPLOT	26
FDC - CNL CROSSPLOT	33
CORRECTED FDC -CNL	15

Map 1: Basal Judith River Sandstone Elevation, Volt Field Area, Montana.

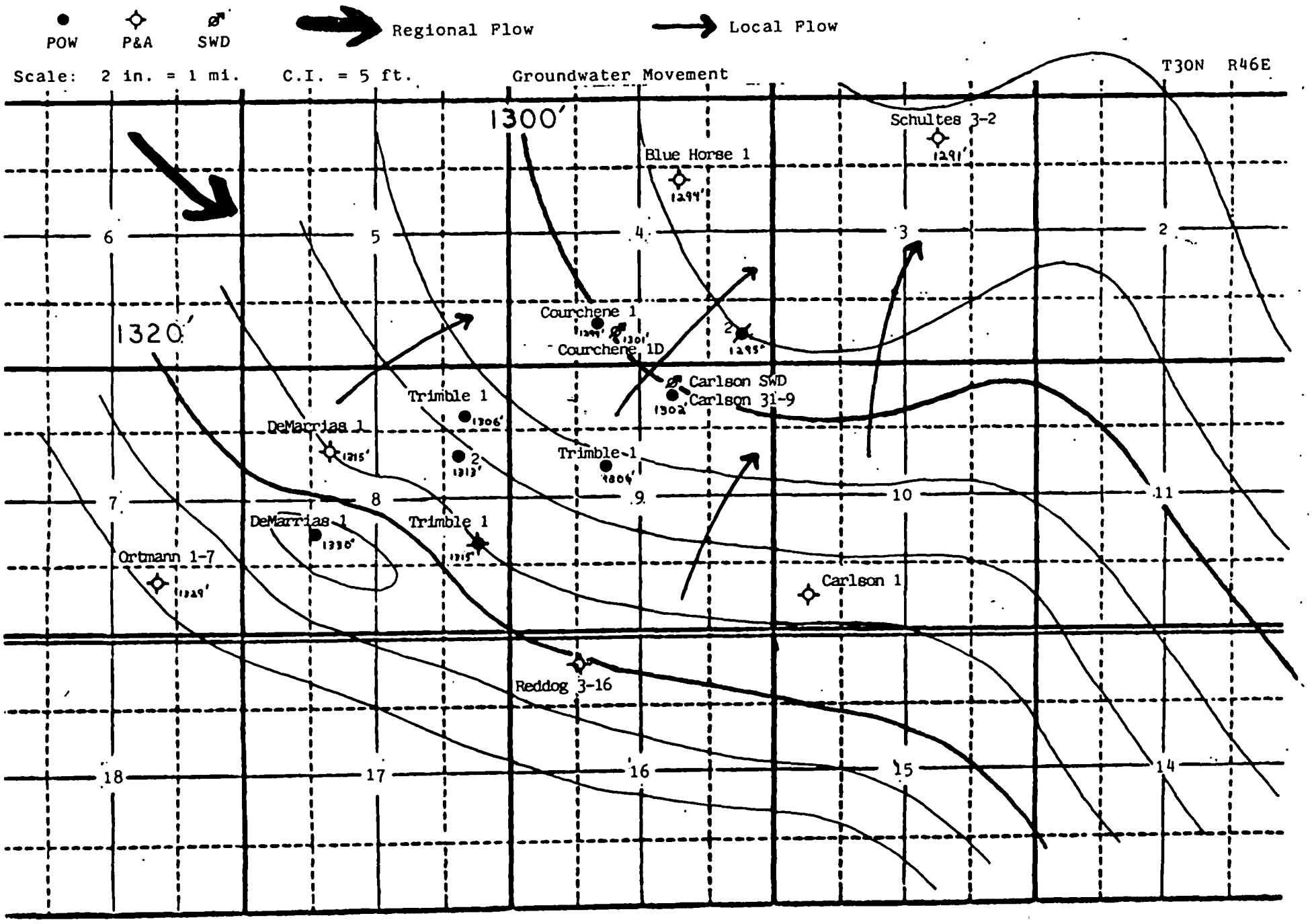
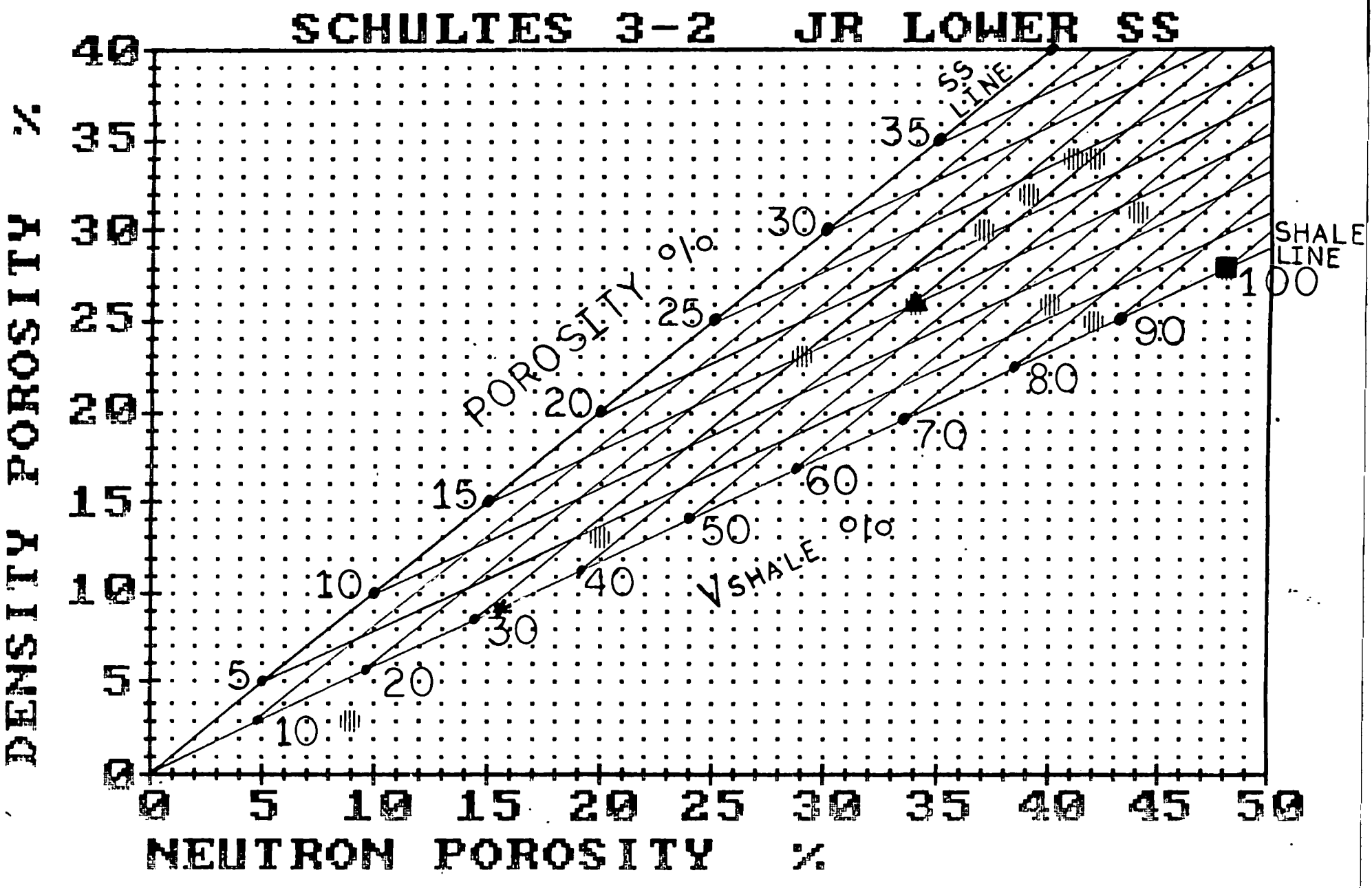


Figure 1: FDC-CNL Porosity Crossplot



DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

Form 3160-6
(November 1983)
(Formerly 9-329)

MONTHLY REPORT OF OPERATIONS

Communitization Agreement N.A.
Field Name Volt
Unit Name Courchene
Participating Area N.A.
County Roosevelt State Montana
Operator Murphy Oil USA, Inc.
☐ Amended Report

The following is a correct report of operations and production (including status of all unplugged wells) for the month of November, 19 86.

(See Reverse of Form for Instructions)

This report is required by law (30 U.S.C. 189, 30 U.S.C. 359, 25 U.S.C. 396d), regulation (43 CFR 3162.4-3), and the terms of the lease. Failure to report can result in the assessment of liquidated damages, (43 CFR 3160), penalties, shutting down operations, or basis for recommendation to cancel the lease and forfeit the bond (43 CFR 3160).

Well No	Sec & ¼ of ¼	TWP	RNG	Well Status	Days Prod	*Barrels of Oil	*MCF of Gas	*Barrels of Water	Remarks
									Accumulated
Q-D	Sec.4 SE SW	30N	46E	WDW				50,156	10,580,956

RECEIVED JAN 23 1987 Tribal Mineral Resource Poplar, Mont. 59255

RECEIVED JAN 9 1987

RECEIVED DEC 1986

*If none, so state.

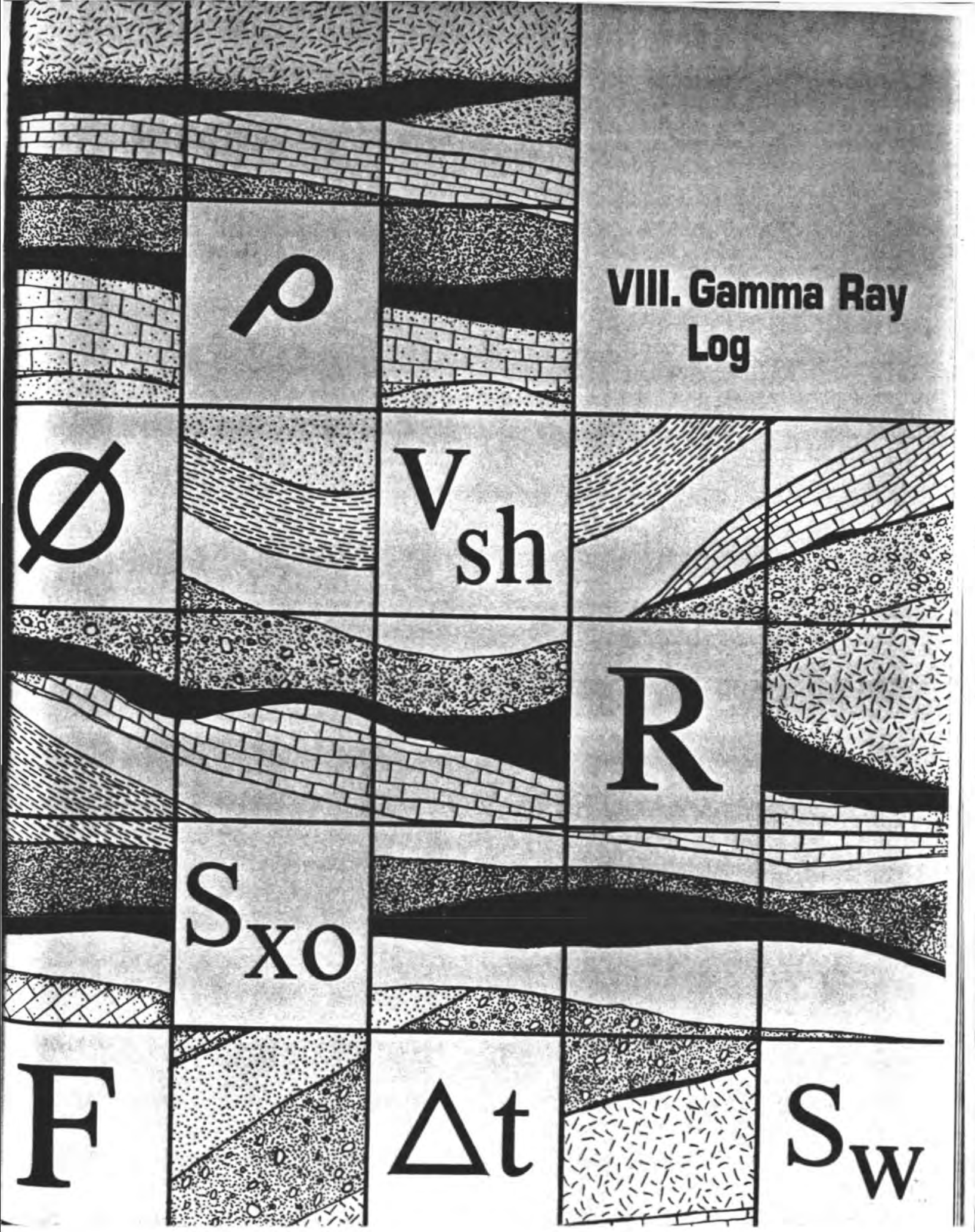
DISPOSITION OF PRODUCTION (Lease, Participating Area, or Communitized Area basis)

	Oil & Condensate (BBLS)	Gas (MCF)	Water (BBLS)
*On hand, Start of Month		XXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX
*Produced			50,156
*Sold			XXXXXXXXXXXXXXXX
*Spilled or Lost		XXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX
*Flared or Vented	XXXXXXXXXXXXXXXX		XXXXXXXXXXXXXXXX
*Used on Lease			XXXXXXXXXXXXXXXX
*Injected			50,156
*Surface Pits	XXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX	
*Other (Identify)			
*On hand, End of Month		XXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX
*API Gravity BTU Content			XXXXXXXXXXXXXXXX

Authorized Signature: Raymond Rauch Address: P.O. Box 547, Poplar, MT 59255
Title: District Superintendent Page _____ of _____

Title 18 U.S.C. Section 1001, makes it a crime for any person knowingly and willfully to make to any department or agency of the United States any false, fictitious or fraudulent statements or representations as to any matter within its jurisdiction.

VIII. Gamma Ray Log



correcting other wellbore measurements. The log is particularly useful when the SP curve cannot be recorded, such as in cased holes, nonconductive muds, or air-filled holes. Also, when the mud filtrate resistivity is close to formation water resistivity, the SP Log cannot differentiate between shales and reservoir formations, while the Gamma Ray Log can still provide good bed definition.

Nonradioactive evaporites like salt, anhydrite, and gypsum can be delineated by their markedly low radioactivity. Coal beds are also characterized by very low Gamma Ray Log response. At the same time, the Gamma Ray Log is an important part of the logging program used in the evaluation of radioactive ore beds such as potash and uranium deposits.

Applied as a through-tubing measurement, the Gamma Ray Log in conjunction with the Casing Collar Locator permits a direct correlation of depth measurements to open hole logs. This ensures the depth accuracy of related cased hole wireline services such as formation testing and perforating. The instrument is also used in radioactive tracer operations for the location of pipe leaks, thief zones, or channeling behind the casing.

Shaliness Estimation

The Gamma Ray Log has been used as one of the important shale indicators in the evaluation of shaly formations. In the quantitative evaluation of shale content, it is assumed that radioactive minerals other than shale are absent.

A gamma ray shale index has been defined as:

$$I_{GR} = \frac{GR - GR_{cl}}{GR_{sh} - GR_{cl}} \qquad (3)$$

where,

GR = log response in the zone of interest, API units

GR_{cl} = log response in clean beds, API units

GR_{sh} = log response in shale beds, API units

The gamma ray shale index has been empirically correlated with the fractional volume of shale in formations by the curves shown in Figure 11. Curve 1 is the linear relation where the shale volume equals I_{GR} and provides an upper limit of shale content in any kind of formation. Curve 2, used for pre-Tertiary formations, is defined by the exponential relation:

$$V_{sh} = 0.33\,(2^{2 \cdot I_{GR}} - 1) \qquad (4)$$

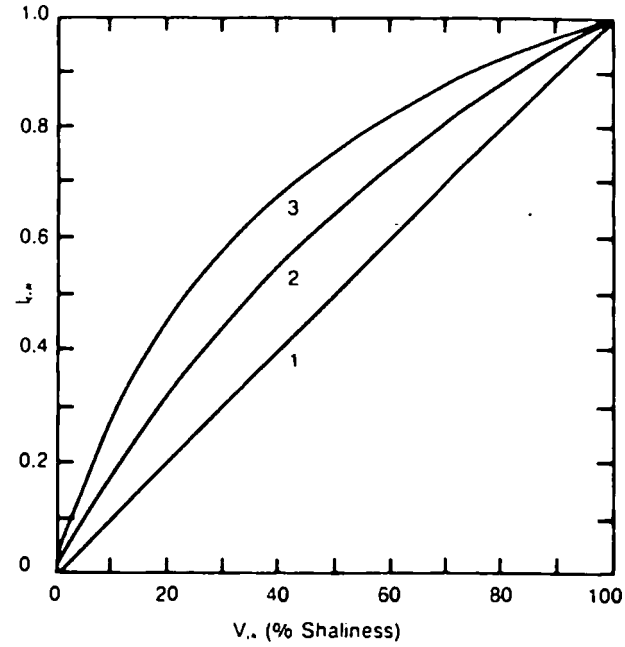


FIGURE 11
Shale content from Gamma Ray Index.

This relationship is applicable in the case of highly-consolidated Mesozoic rocks and would result in too high shale volume estimations if used in the case of younger, unconsolidated formations.

Curve 3, meant for Tertiary clastics, is defined by the equation:

$$V_{sh} = 0.083\,(2^{3.7 \cdot I_{GR}} - 1) \qquad (5)$$

If two formations of different geological age have the same amount of radioactive shale per unit volume, the Gamma Ray Log response would be lower in the case of more consolidated and dense formations. This is because the gamma ray absorption increases with the density of the medium through which it passes.

Example:

On GR Log, the responses are:
clean sand = 15 API units

shale = 90 API units

zone of interest = 40 API units

The formations are Tertiary clastic rocks.

Shaliness is determined as follows:

$$I_{GR} = \frac{40 - 15}{90 - 15} = 0.33$$

Shaliness by Curve 3 of Figure 11 is read at $I_{GR} = 0.33$ as $V_{sh} = 12\%$.

SUMMARY

The Gamma Ray Log records the amount of natural radioactivity of the formations penetrated by a borehole. Three naturally occurring radionuclides which contribute to the gamma radiations emanating from subsurface rocks are the uranium-radium series, the thorium series, and Potassium 40. The Gamma Ray Log usually reflects the shale content of sedimentary formations. Clean sandstones and carbonates normally exhibit a low level of natural radioactivity, while the clay minerals and fine particles in shales show higher levels of radioactivity due to absorption of the heavy radio-elements. Variations in the diameter of the borehole and the density of borehole fluid should be taken into consideration for correcting the log readings. The log is quantitatively used for estimation of shale volume.

The Gamma Ray Log is ideally suited for the identification of reservoir rocks as distinguished from shale beds. It can be recorded in cased holes, nonconductive borehole fluids, or air-filled holes. The log is useful in the detection of nonradioactive minerals like halite, anhydrite, gypsum, and coal, as well as in the evaluation of radioactive mineral deposits containing potash or uranium. In cased holes, the Gamma Ray Log is used for depth correlation.

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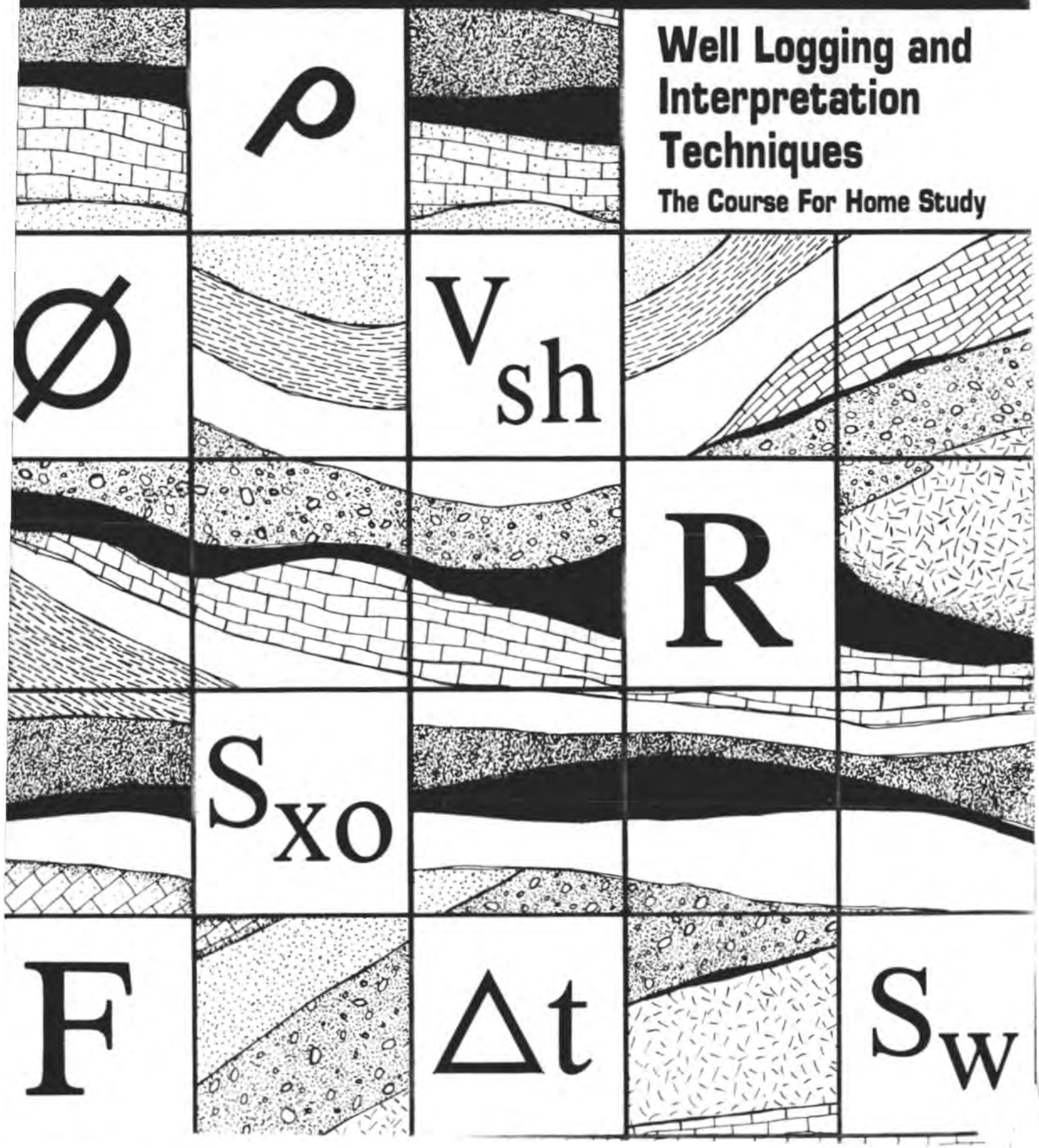
Dresser Atlas

Well Logging and Interpretation Techniques

The Course For Home Study



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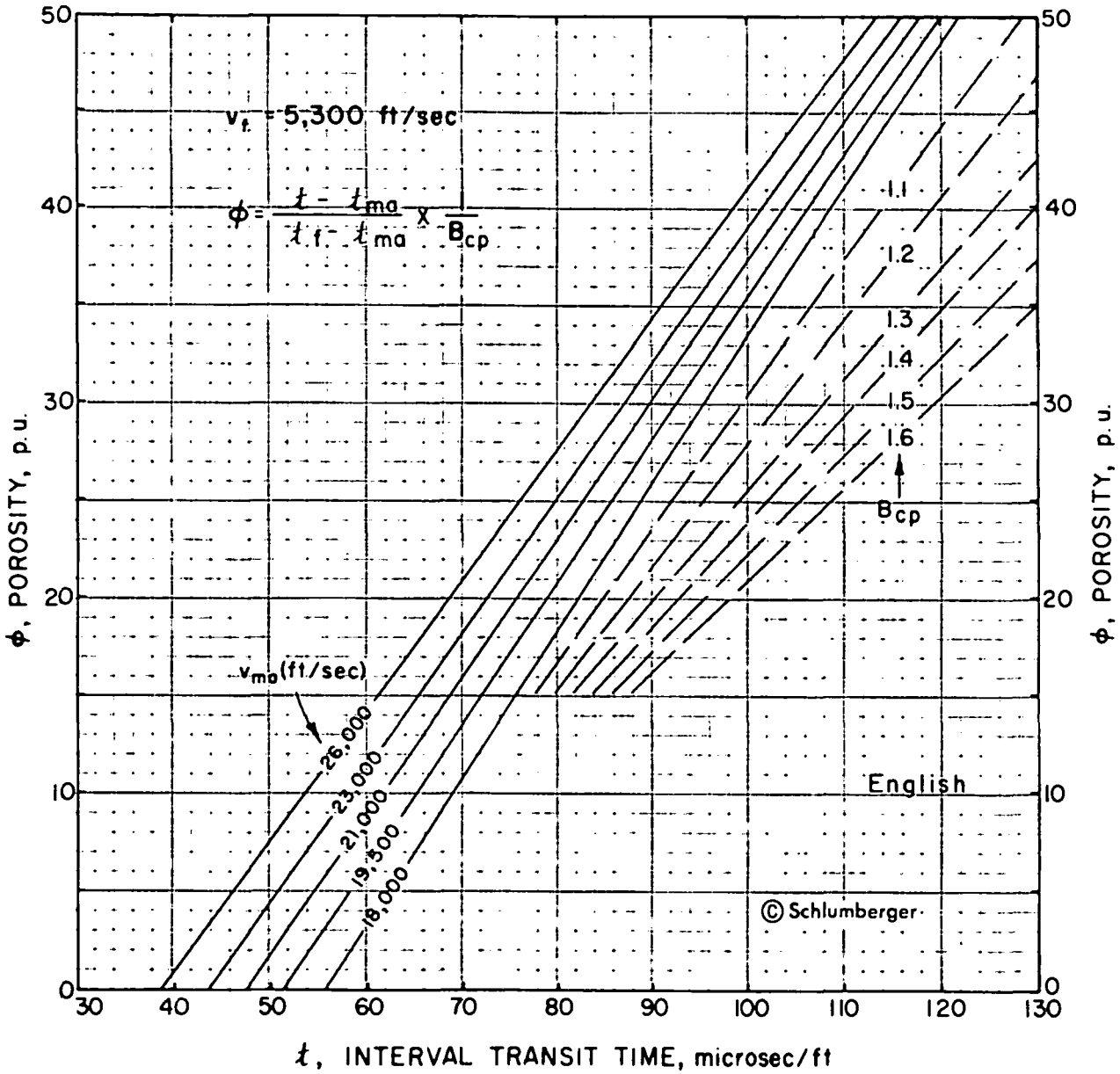
Log Interpretation Charts

English — Metric

1979 EDITION

POROSITY EVALUATION FROM SONIC



	v_{ma} (ft/sec)	t_{ma} (microsec/ft)
Sandstones	18,000-19,500	55.5-51.3
Limestones	21,000-23,000	47.6-43.5
Dolomites	23,000-26,000	43.5-38.5

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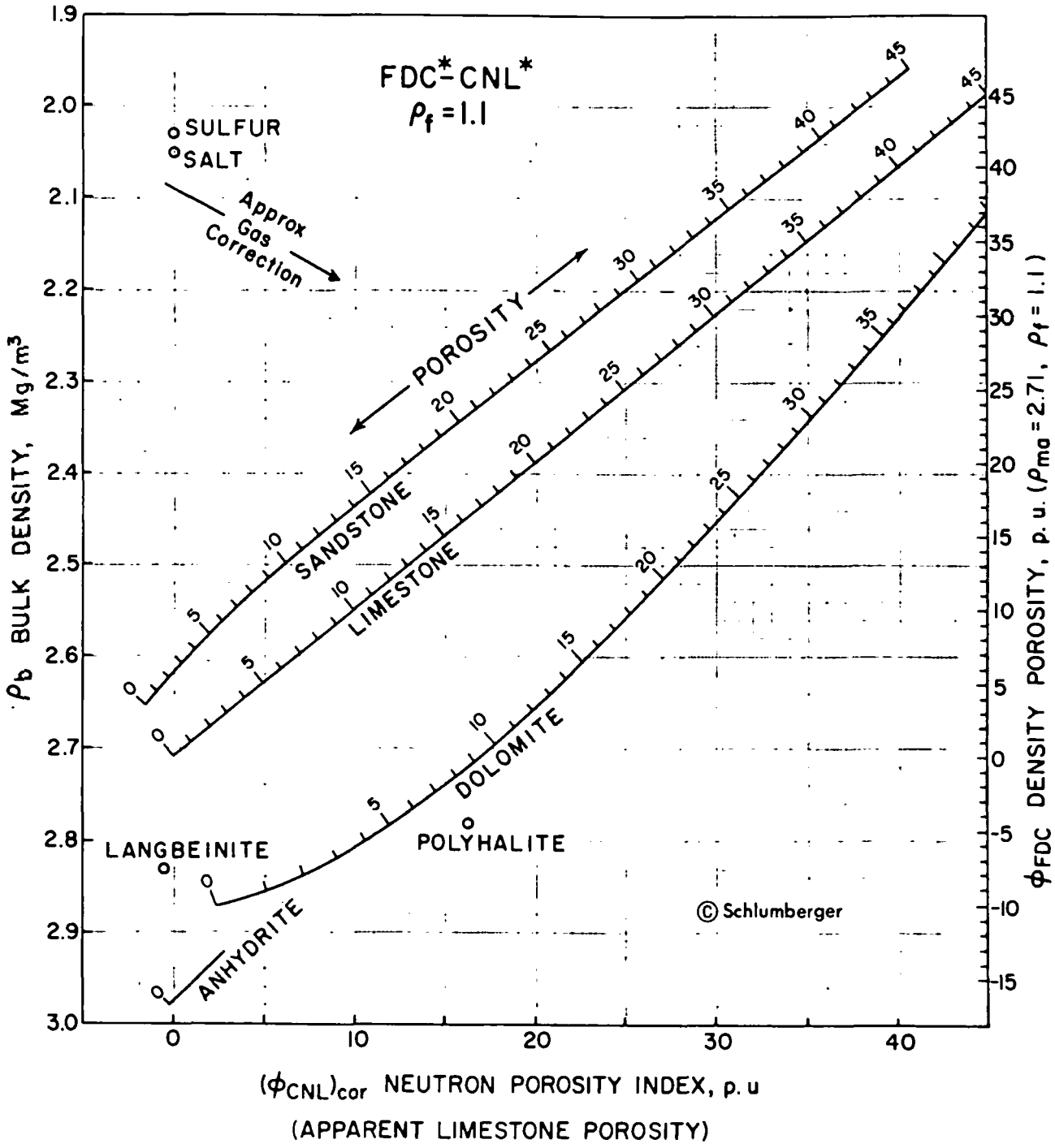
POROSITY AND LITHOLOGY DETERMINATION FROM FORMATION DENSITY LOG AND COMPENSATED NEUTRON LOG (CNL*)

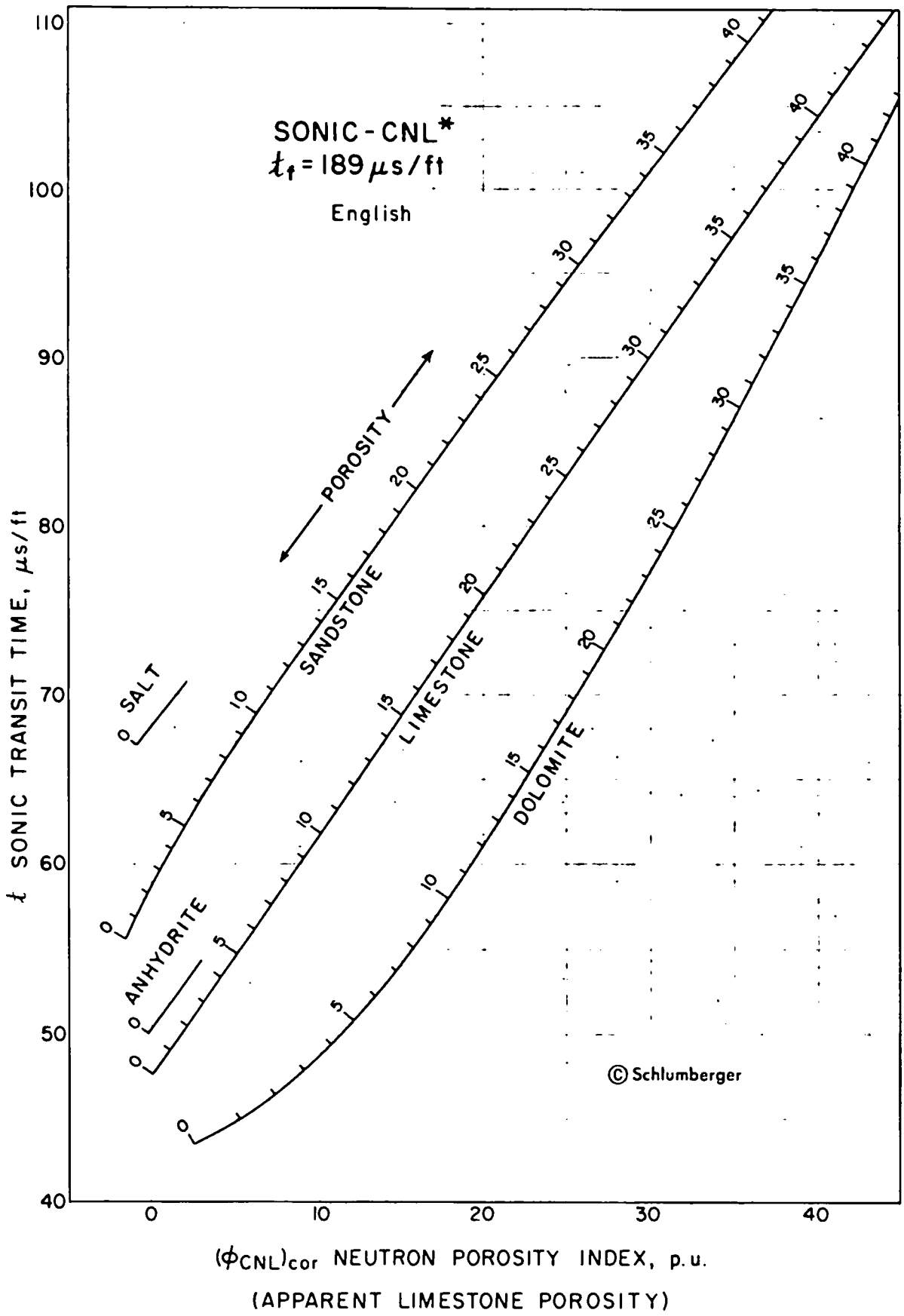
SALT WATER, LIQUID-FILLED HOLES



CP-1d

*Mark of Schlumberger

POROSITY AND LITHOLOGY DETERMINATION FROM SONIC LOG AND COMPENSATED NEUTRON LOG (CNL*)



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CP-2b

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LOG INTERPRETATION

Volume I–Principles

1972 EDITION

DOCUMENT

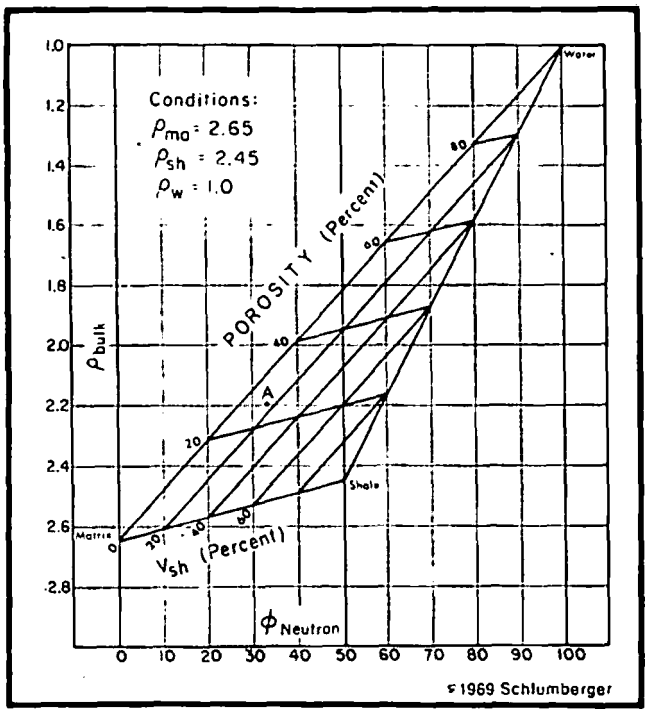

Fig. 16-4 — Neutron-Density crossplot showing matrix, water, and shale points, scaled for determination of V_{sh} and porosity.

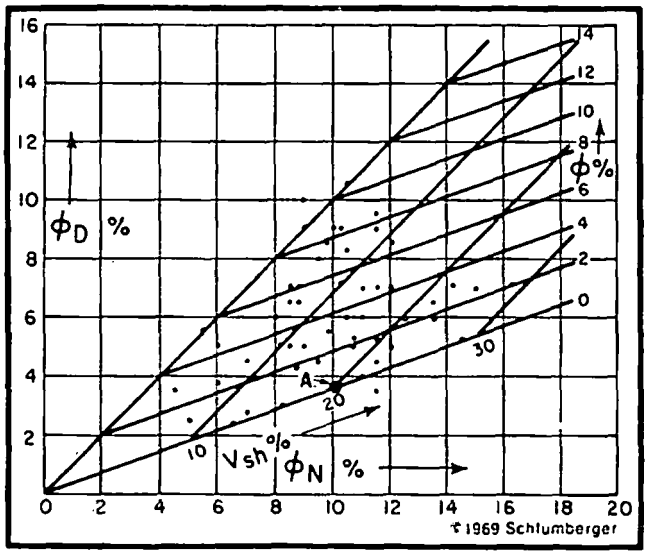

Fig. 16-5 — ϕ_D vs ϕ_N crossplot over a section of shaly limestone.

$$\phi_S = C_p\,(\phi + V_{dis}) \qquad (16\text{-}26b)$$

(in uncompacted formations)

Again in uncompacted gas sands ϕ_S may be appreciably larger than predicted by Eq. 16-26b.

In areas where, for water-bearing and filtrate-invaded formations, $\phi_D = \phi$ (i.e., $\rho_{sh} = \rho_{ma}$), we can write Eq. 16-26a.

$$\phi_S - \phi_D \approx V_{dis} = q\phi_{im} \qquad (16\text{-}27)$$

$$\frac{\phi_S - \phi_D}{\phi_S} \approx \frac{V_{dis}}{\phi_{im}} = q \qquad (16\text{-}28)$$

Eq. 16-28 is the basis of the "Q" log ($Q = (\phi_S - \phi_D)/\phi_S$), which is useful in many areas as an indicator of permeability as affected by dispersed shale.

NEUTRON-DENSITY CROSSPLOT

When the lithology is known and uniform (and the Neutron log is calibrated accordingly), and the formations investigated by the logs are water saturated, the responses of Neutron and Density logs become

$$\phi_N = \phi + V_{sh}\,\phi_{Nsh} \qquad (16\text{-}29)$$

$$\rho_b = \rho_{ma}\,(1 - \phi - V_{sh}) + \rho_{sh}\,V_{sh} + \rho_f\phi \qquad (16\text{-}30)$$

or

$$\phi_D = \phi + V_{sh}\,\phi_{Dsh} \qquad (16\text{-}31)$$

These equations are written assuming the Neutron and Density responses to laminated shale and dispersed shale are the same. This means V_{sh} is a bulk-volume total shale measurement regardless of the form of the shale. The porosity equations can be solved graphically for porosity, ϕ, and bulk-volume total shale fraction, V_{sh}, by means of a crossplot.

Fig. 16-4 shows a Neutron-Density crossplot constructed for the conditions existing in a given well or field. The triangle on the figure is defined by the "matrix" point, "water" point, and "shale" point at the respective vertices. In this particular example the matrix point is at $\phi_N = 0$ and $\rho_{ma} = 2.65$ (quartz matrix). The shale point is at $\phi_{Nsh} = 50$ p.u. and $\rho_{sh} = 2.45$, and the water point is at $\phi_{Nw} = 100$ p.u. and $\rho_w = 1.0$.

Point, A, plotted as an example, corresponds to log readings $\rho_b = 2.2$ and $\phi_N = 33\%$. Interpretation by the lines on the plot yields $\phi = 23\%$, $V_{sh} = 16\%$.

Fig. 16-5 shows a similar crossplot entered with ϕ_D and ϕ_N. Points from a thick section of shaly limestone help define the triangle. The points which fall on the line of 45 slope passing through the origin correspond to clean formations ($V_{sh} = 0$). The lowest points correspond to the lowest ϕ values. As these points fall on a line passing through the origin, we can reasonably consider that it represents the $\phi = 0$ line.

The various V_{sh} = constant lines and ϕ = constant lines may be drawn as for Fig. 16-4. The porosity and the volumetric fraction of shale can then be determined for every point on the plot.

Direct use of the crossplot assumes 100% water saturation in the zone investigated by the tools. Introduction of gas or light hydrocarbons decreases ϕ_N and decreases ρ_b (increases ϕ_D). This would cause the point to shift in a northwesterly direction. When gas or light hydrocarbons are present an additional shaliness indicator, such as Gamma Ray or SP, is needed in order to evaluate the amount of this shift. (See Clay Indicators, in a later section.)

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Volume II – Applications

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DEPTH FEET	PERM INDEX MD	POROSITY PERCENT	WATER SATUR-ATION PER-CENT	HYDRO-CARBON DENSITY GM/CC	CLAY PER-CENT	CUM. PORO-SITY FEET	CUM. HYDRO-CARBON FEET
6321.0	.0	8.5	96		42	217.19	97.06
6322.0	.6	9.4	67		38	217.10	97.04
6323.0	.1	9.4	96		39	217.00	97.02
6324.0	.1	9.6	96		46	216.91	97.01
6326.0	.1	9.1	94		44	216.75	97.01
6327.0	5	11.5	34		38	216.65	96.98
6328.0	.100	17.9	21		26	216.52	96.89
6329.0	300	22.0	21	.1	28	216.32	96.73
6330.0	100	21.8	28		19	216.10	96.56
6331.0	200	20.2	22		11	215.69	96.40
6332.0	1000	22.8	11		6	215.68	96.24
6333.0	3000	26.9	10	.2	0	215.44	96.02
6334.0	3000	29.6	12	.2	0	215.16	95.77
6335.0	4000	28.0	9	.2	0	214.87	95.51
6336.0	3000	26.6	9		1	214.59	95.26

Fig. 4-2 — SARABAND output listing over part of hydrocarbon-bearing sand in upper part of Fig. 4-1.

"Core porosity" is a computed value of porosity which usually represents more closely the value of porosity from core analysis; it is obtained by adding to ϕ the bulk volume of the water bound to the clays which are not laminated.

The dotted area in Fig. 4-1 is the difference, $\phi S_{xo} - \phi S_w$, which represents "moved hydrocarbon" (hydrocarbon displaced by mud invasion). The darkened area is the difference, $\phi - \phi S_{xo}$, which represents the unmoved hydrocarbon in the invaded zone.

5. In Track 4, a formation analysis showing the clay fraction (V_{clay}), matrix-solids fraction, and the porosity (ϕ). The matrix-solids fraction includes both the actual matrix and the non-clay materials (e.g., silt) in the shales.

Other outputs shown on the listing, Fig. 4-2, are permeability index, hydrocarbon density (when computable), cumulative porosity feet, and cumulative hydrocarbon feet.

Well logs used are:

Resistivity (for R_t determination)	— Induction Log, Dual Induction Log, Laterolog, or Dual Laterolog
Density	— FDC (Formation Density Compensated Log)
Neutron	— SNP (Sidewall Neutron Porosity Log) or CNL (Dual Spacing Neutron Log)
Sonic	— BHC (Borehole Compensated Log)
Microresistivity (for R_{xo} and S_{xo})	— Proximity Log, Microlaterolog or MicroSFL
SP, Gamma Ray and Caliper	— Run in conjunction with the above logs.

The method can still be used if some of these logs are lacking (e.g., microresistivity, Sonic, caliper, and either SP or Gamma Ray), but with less reliability on some of the results.

(General information required is: bit size, bottom-hole temperature, R_{mf} [with temperature of measurement], and R_w [if known] at formation temperature.)

THE SHALY SAND MODEL, GENERAL[1]

SARABAND uses a silty-shaly-sand model in which the shales are assumed to be of the laminated, dispersed, and structural types (Chapter I-16).

The basic model is suggested by the groupings of the plotted points in Fig. 4-3. This figure is a typical Neutron-Density frequency crossplot (explained in Chapter II-7) through an interval of a sand-shale sequence. Most of the data belong to two groups: Group A, identified from Gamma Ray or SP logs as sands and shaly sands; and Group B, identified as shales.

To explain the spread of the shale points in Group B along the line from Point Q through Point Sh_0 and Point Cl, the shales are considered to be essentially mixtures of clay minerals, water, and silt, in various proportions. Silt is fine-grained, and consists predominantly of quartz, but may also contain feldspars, calcite, and other minerals. Silt has, on the average, nearly the same Neutron- and Density-Log properties as the matrix quartz, so that ***pure quartz silt would plot on Fig. 4-3 at the "quartz point", Q*** (coordinates $\phi_N = 0$, $\phi_D = 0$).* Points near the "wet-clay" point, Point Cl, correspond to shales that are relatively silt-free. Point Sh_0 corresponds to shales containing a maximum amount of silt.

The amount of silt in a shale or shaly sand is characterized by its "silt index", I_{silt}, which is defined as the ratio, V_{silt}/V_{sh}. For a shale plotting at Point X on the "shale line",

*In sands containing other matrix minerals besides silica, and recorded with sandstone calibration, the matrix point will be shifted from the origin because of the effect of these other minerals on the matrix parameters. This can be allowed for by the matrix-lithology adjustment mentioned later.

I_{silt} is determined as the ratio: (distance of X from Cl)/(distance of origin, Q, from Cl).

The shaly sands in Group A grade from shales, on Line $\overline{Sh_{\phi}Cl}$, to clean sands at Point Sd. The shale in the shaly sands may be distributed in various ways. When all of the shale present is laminar shale, the points will fall on the Sd-Sh_{ϕ} line.* Dispersed shale causes the points to plot to the left of the line. Structural shale causes the points to plot to the right of the line. The heavy dashed curve to the right of Group A represents an empirically defined upper limit of structural-plus-laminated shale content. According to the model, all the shale in levels plotting along this line is structural and laminar; no dispersed shale is present. The thin, dash-dot line drawn through Point Sd parallel to a line (not shown) from Point Sh_{ϕ} to the Water Point, represents the limit in this case for dispersed shales. In levels plotting along this line all of the shale is dispersed.

A fairly good interpretation could be made by assuming that the shales in Group A all have the same silt index as the shale at Point Sh_{ϕ}. Another procedure for choosing the silt index will be described later.

Typically, few points plot in Area C, to the right of the heavy dashed curve and above the shale group; this is considered the "unlikely area" and points plotted here are given special treatment. (These points are not typical shaly sands or shales. They usually represent levels where either the log readings have been affected by borehole rugosity, or where shale properties have been affected by hydration of the clay in contact with the mud, or where the matrix lithology no longer corresponds to shaly sands (e.g., porous carbonates, lignite, etc. . .).

*Conversely, when the points plot on the Sd-Sh_{ϕ} line, the shale may be all laminated or a mixture of dispersed and structural.

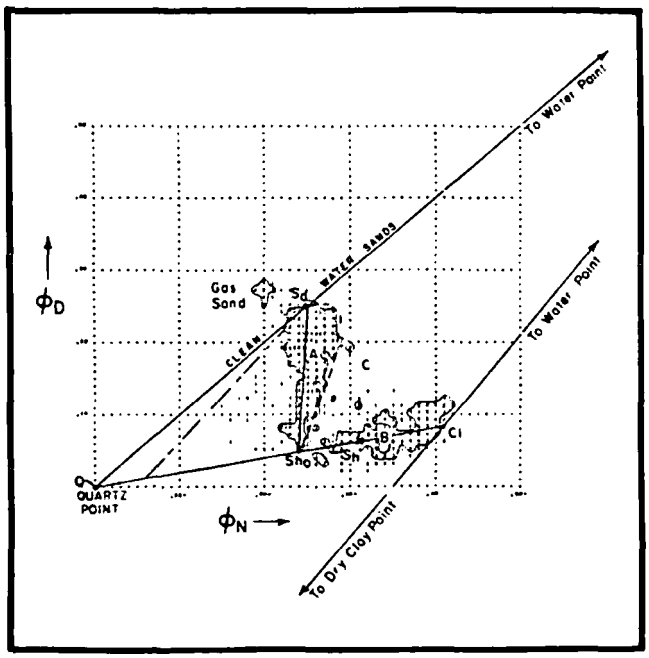


Fig. 4-3 — Neutron-Density frequency crossplot illustrating the shaly-sand model used in SARABAND. See Chapter II-7 for explanation of frequency crossplots and other types of computer-produced crossplots. (From Ref. 1, courtesy of SPE of AIME.)

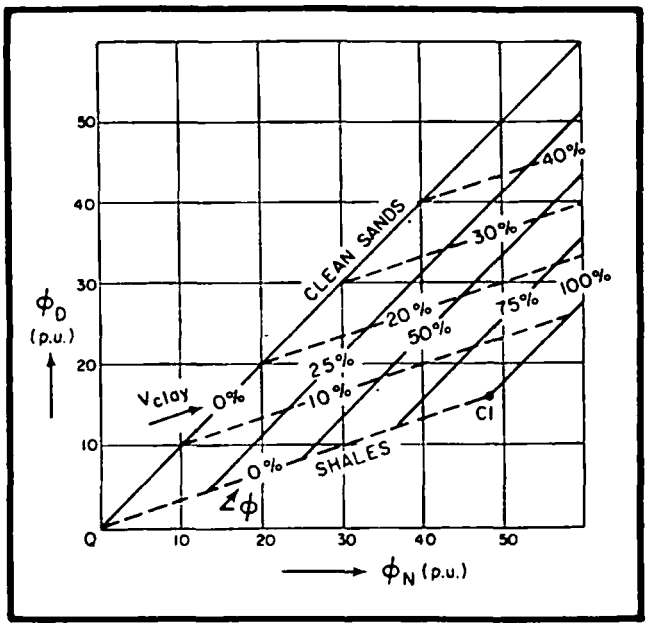


Fig. 4-4 — Neutron-Density-crossplot scalings in terms of porosity and V_{clay}.

The clean sands plotting near Point Sd have a nearly constant porosity, which is the maximum porosity in the interval (ϕ_{max}). This and the other features of this model are often encountered in recent deposition of sand-shale sequences.

SOME SPECIFICS OF THE MODEL

The following discussion pertains to water-bearing formations or to hydrocarbon-bearing formations for which the log readings have been adjusted to those of the corresponding water-bearing formations.

Once Points Sd and Cl have been determined from inspection of the crossplot, the plot may be scaled, for water-bearing sands, in terms of ϕ and V_{clay} as shown in Fig. 4-4. The lines of constant ϕ are parallel to the shale line, Q-Sh_o-Cl; they range from $\phi = 0$ on the shale line to $\phi = \phi_{max}$ on the line through Point Sd. The lines of constant V_{clay} are parallel to the clean-sand line, Q-Sd-Water Point; they range from $V_{clay} = 0$ on the clean-sand line to $V_{clay} = 100$ percent at Point Cl. A similar scaling in terms of V_{sh} is possible if the location of the laminar shale point (Point Sh) is fixed and known. In this case the silt index will be constant, and will be given by the location of the laminar shale point relative to the origin and Point Cl.

Fig. 4-5, which has been scaled in terms of ϕ and V_{sh}, illustrates the effect of different shale distributions on the plotted points (assuming a constant value of silt index). Starting at Point Sd, representing a clean, water-bearing sand,

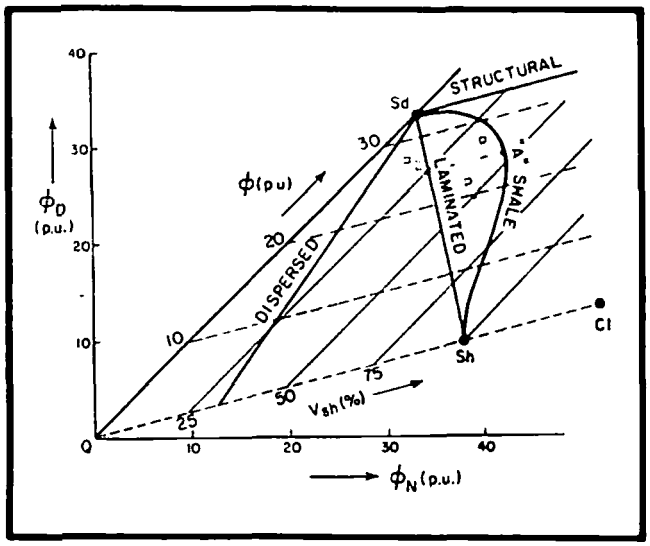


Fig. 4-5 — Illustration of effect of shale type.

addition of shale displaces the point in a direction which depends on the type of the distribution.

1) Structural shale replaces matrix, and porosity is not affected. The point is displaced along a line of constant porosity corresponding to $\phi = \phi_{Sd}$ where ϕ_{Sd} is the porosity of Point Sd.

2) Laminated shale replaces matrix and porosity in such manner that $\phi = \phi_{Sd}\,(1 - V_{lam})$. The point is displaced along the line joining Point Sd to Point Sh.

3) Dispersed shale replaces porosity. Matrix volume is not affected. The point is displaced along the straight line labeled "dispersed" such that $\phi = \phi_{Sd} - V_{dis}$. This line is drawn from Point Sd parallel to a line through Point Sh and the Water Point. For a point with no silt ($I_{silt} = 0$) this line would be parallel to the Clay Point-Water Point line.

The structural and laminar shales are similar in their log responses. It would be useful to be able to lump them together, as shown in the "A" Shale line on Fig. 4-5. Starting at Point Sd, addition of a small amount of these types of shale would hardly be expected to be sufficient to form laminae immediately. It is reasonable to expect that such shale would be structural. However, with increasing amounts of such shales, laminae will form and near the Shale Point laminar shale would be expected to predominate. The "A" Shale line has these characteristics (near structural shale line at low V_{sh} and near laminar shale line at high V_{sh}). The shape of this line was derived, for a large number of cases, from the shapes of the dashed limit lines as shown in Fig. 4-3. Empirically, this line is described by the relation

$$\phi = \phi_{Sd}\,[1 - (V_{lam} + V_{str})^2\,[2 - (V_{lam} + V_{str})]] \qquad (4\text{-}1)$$

It has been convenient to assume in this model that the dispersed shale has the same fractional silt content as the structural and laminar shales. This may not be entirely in agreement with models based on sedimentation studies. However, this assumption has negligible effect on the computation results in cases of interest, since in these cases the bulk-volume fraction of dispersed shale is generally small, being limited to a fraction of the pore space.

As already noted, Point Sd and Point Cl are determined from the groupings of the points on the crossplot (Fig. 4-3) over the interval. Then, for water-bearing levels, V_{clay} and ϕ can be found as illustrated in Fig. 4-4. The silt index is also needed for use in the saturation equation (Eq. 16-15 of Chapter I-16) and for use in determining shale composition.

The usual procedure is to determine a value of silt index for each interpreted level. The silt index chosen will determine the locations of the corresponding "A" Shale line, Point Sh, and Dispersed Shale line. Fig. 4-5 was drawn for a silt index of about 27%. Changing the silt index will shift Point Sh accordingly, as well as the "A" Shale and Dispersed Shale lines.

Choice of the silt index is usually made by use of an empirical procedure involving the coordinates of Points Sd and Cl. The black curves of Fig. 4-6 illustrate, for a particular value of ϕ_{Sd} (= 40%) and a particular location of the Clay point (ϕ_{Nclay} = 60% and ϕ_{Dclay} = 20%), how silt index is considered to vary with the position of data point, P.

Conceptually, the line of $I_{silt} = 0$ (solid curved line at upper right of Fig. 4-6) is the laminar-structural shale line for a shale consisting only of wet clay (no silt). Line $\overline{QSd}$ corresponds to I_{silt} = 100 percent; for points plotting on this line, all fines are silt. Along Line $\overline{QCl}$, silt-index values are linearly related to displacement along the line. The intermediate (dashed) I_{silt} lines are based on these boundary conditions.

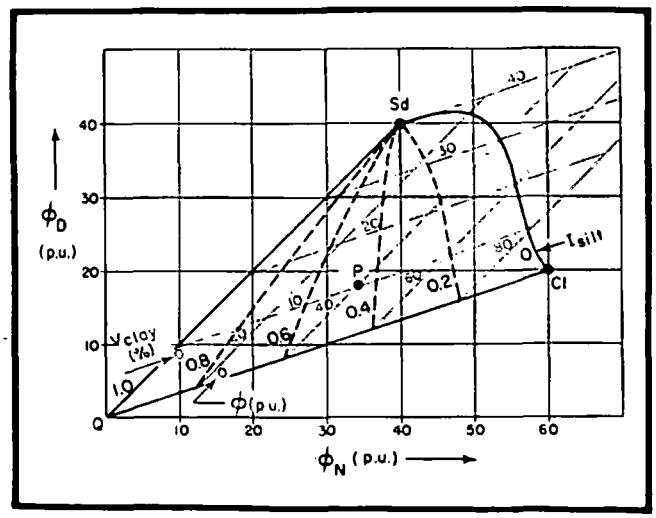


Fig. 4-6 — Empirical chart for selection of silt index for a particular Clay Point and a particular value of ϕ_{max}. V_{clay} and ϕ scalings are shown in color.

The V_{clay} and ϕ scalings are shown on Fig. 4-6, as the thin colored lines.

For Point P at $\phi_N = 34$ p.u. and $\phi_D = 18$ p.u., we would find $\phi = 10$ p.u., $V_{clay} = 0.4$, and $I_{silt} = 0.45$. We can now compute $V_{sh} = V_{clay}/(1 - I_{silt}) = 0.4/0.55 = 0.73$.

The distribution of the various types of shale, V_{dis}, V_{str}, and V_{lam}, as determined by this model, assuming a constant value of silt index, can be found according to the construction shown in colored lines on Fig. 4-5. Point P has porosity, $\phi = 20\%$, and shale fraction, $V_{sh} = 50\%$. A line from P parallel to the Dispersed line locates P_1, on the "A" Shale line. The difference, V_{sh} (at P) $- V_{sh}$ (at P_1), is V_{dis}, in this case about $50 - 45 = 5$ percent. A line from P_1 parallel to the structural shale line locates P_2 on the Laminated Shale line. The difference, V_{sh} (at P_1) $- V_{sh}$ (at P_2), is V_{str}, in this case about $45 - 25 = 20$ percent. The remaining V_{sh} at P_2 is V_{lam}, in this case about 25 percent.

REMARKS ABOUT THE METHOD

Some features of the SARABAND technique are:

1. Extensive use is made of statistical methods. The frequency crossplot and the Z-Plot™ are used to evaluate input clay and shaly-sand parameters (Chapter II-7). Other parameters (the coefficients in the clay indicators, matrix parameters, hydrocarbon density) are evaluated statistically in the program.

2. In case of caved or rugose hole, which affects the reliability of some of the logs, acceptable results are still achieved by checking against logs less affected by these conditions.

3. The quality of the interpretation is checked by reconstructing certain log values (SP, Gamma Ray, R_t) from the interpretation results and computing a figure of merit.[1]

BRIEF SKETCH OF THE INTERPRETATION PROCEDURE

For a more detailed discussion, see Ref. 1.

As explained in detail in Chapter II-7, a Pre-Interpretation Program is run in which the usual environmental corrections (for borehole, mud cake, etc.) are made to the log readings. The microresistivity log (Microlaterolog, Proximity Log, or MicroSFL) is averaged to give approximately the same vertical resolution as the Neutron and Density Logs. The Density Log is also averaged (sliding, weighted average) in order to smooth out statistical variations. SP baseline drift is removed if necessary.

Preliminary frequency crossplots and Z-Plots are used to provide such values as ϕ_{max} and the coordinates, ϕ_{Nclay} and ϕ_{Dclay}, of the Clay Point (Cl), as well as the coordinates and silt index of Point Sh_o. For example, on Fig. 4-3 the position of Point Sd yields $\phi_{DSd} = \phi_{NSd} = \phi_{max} = 0.25$. The Clay Point coordinates are $\phi_{Nclay} = 0.41$ and $\phi_{Dclay} = 0.08$. For Point Sh_o, $\phi_{No} = 0.24$, and $\phi_{Do} = 0.05$. This corresponds to a silt index, $(I_{silt})_o$, of $(0.41\text{-}0.24)/0.41 = 0.414$.

Sometimes no silt-free shale points are available; then Point Cl may have to be located to the right of the most-silt-free shale points recorded. As shown in Fig. 4-3, Point Cl should be on a line joining the water point and the dry-clay point. Although the parameters of dry clays are somewhat variable, depending on the type of clay, this consideration does provide a limit line for the left-most position of the wet-clay point, Cl.

A computer program has been developed to perform the required processing of the SARABAND method. In the actual computation three sweeps (or passes) are made through the interval to be interpreted.

On the first sweep, points plotting in the "unlikely" area (Area C of Fig. 4-3) and the obviously hydrocarbon points ($\phi_D > \phi_N$) are ignored. The remaining points are analyzed without correction for hydrocarbon or lithology effects. Because such an analysis is accurate in shales, water-bearing zones, and most oil zones, the results, treated statistically, yield good approximations of most of the coefficients needed in the clay-indicator equations. Treating the points analyzed as if they were water-bearing, ϕ and V_{clay} are found by solving the simplified equations:

$$\phi_D = \phi + V_{clay}\,\phi_{Dclay} \qquad (4\text{-}2a)$$

$$\phi_N = \phi + V_{clay}\,\phi_{Nclay} \qquad (4\text{-}2b)$$

Finally, a silt index is determined for each level using a relationship of the type indicated in Fig. 4-6.

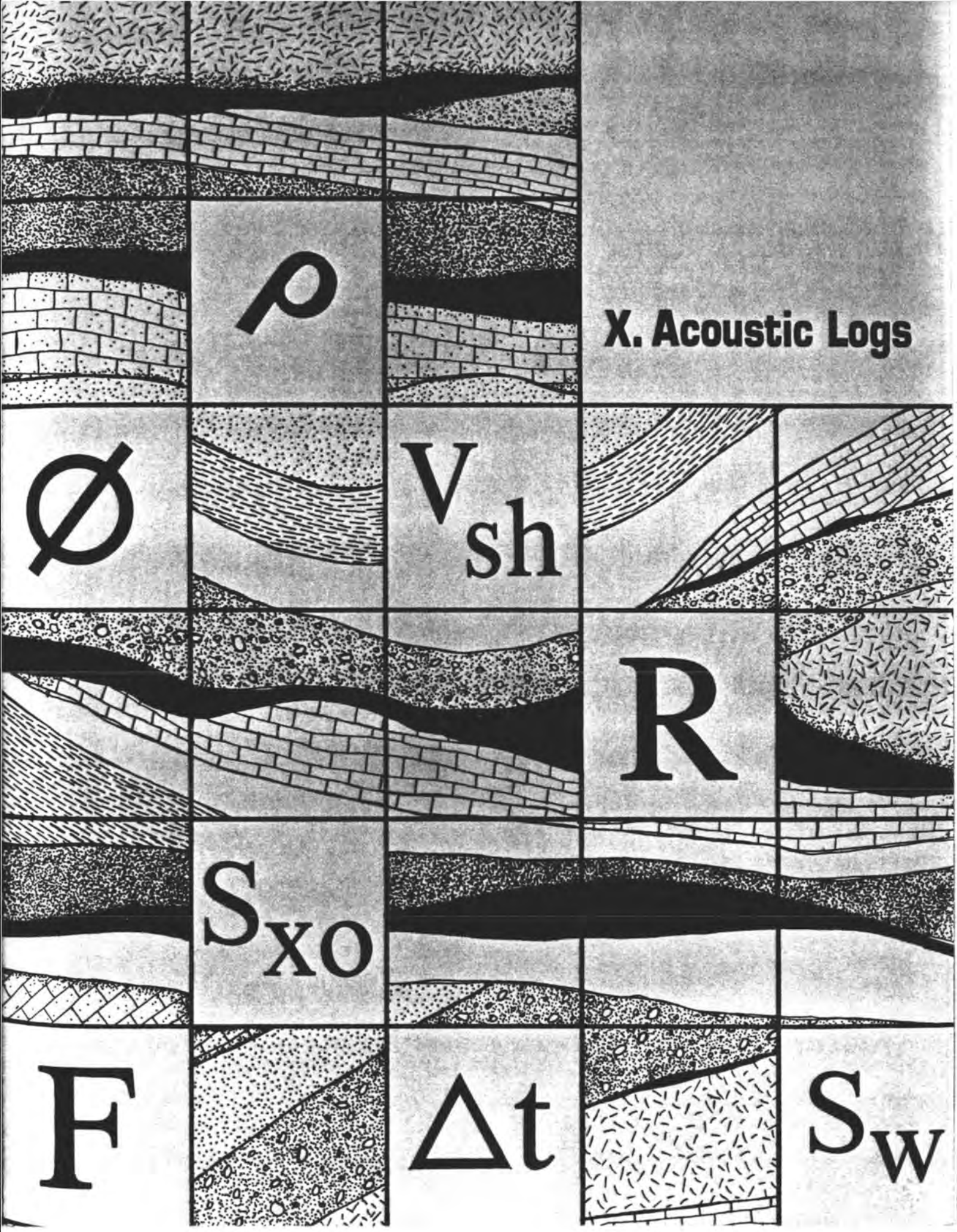
In the second sweep the approximate parameter values derived in Sweep 1 are used in the clay-indicator equations to re-evaluate V_{clay}. Then each data point is corrected for hydrocarbon or lithology effects (in the manner indicated in the next subsection) before being analyzed for improved values of ϕ, V_{clay}, and I_{silt}. From these results plus an S_{xo} value, the SP and GR are reconstructed to see which, if any, of the clay indicators should be discarded. Statistics are again made on the Gamma Ray, SP, shale resistivity, and, this time, on the Sonic data as well. A minimum value of ρ_h is selected.

In Sweep 3 all levels are interpreted. V_{clay} is again re-evaluated using the clay-indicator parameter values from Sweep 2. "Unlikely Area" points are checked for agreement with Sonic data and clay indicators, and corrected if necessary. Hydrocarbon or lithology corrections are made. Each corrected point is analyzed for silt index. S_w is computed. SP and GR are again reconstructed to obtain the final figures of merit. Shale distribution and permeability are computed.

INTERPRETATION OF ϕ AND S_w. In water zones, porosity and shaliness are computed from ϕ_D and ϕ_N. In hydrocarbon-bearing zones shaliness is evaluated using the shale indicators* (SP, GR, R_t, R_{xo}, etc.); then porosity and hydrocarbon density are computed from ϕ_N, ϕ_D, and S_{xo}.

Although the computations are actually made by use of equations (given in Ref. 1), it is easier to visualize them on the Neutron-Density crossplot of Fig. 4-7 on which Point P, at $\phi_N = 0.22$, $\phi_D = 0.20$, represents a hydrocarbon-bearing

*See discussion later in chapter, or, for more detail, see Ref. 1.


ρ
X. Acoustic Logs
Ø
Vsh
R
Sxo
F
Δt
Sw

resistivity, density or neutron logs in clean, water-filled sands.

In the resistivity method, the value of R_o in clean, water-bearing sand can be obtained from a deep resistivity log such as an induction log. Knowing formation water resistivity, R_w, from the SP curve or other sources, the porosity is calculated using the relation,

$$\varnothing = \left(\frac{a \times R_w}{R_o}\right)^{1/m} \qquad (12)$$

The coefficient, a, and porosity exponent, m, may be substituted by their accepted values in the particular field. While in some regions, values of a = 1 and m = 2 (Archie equation) may be applicable, in most cases the Humble Formula with a = 0.62 and m = 2.15 is universally accepted. Alternatively, the porosity exponent "m" may be taken as a linear function of porosity as equal to $(2.05 - \varnothing)$, and the value of "a" kept as 1 (Ref. 8). The value of the compaction correction factor is then determined as:

$$C_p = \frac{\varnothing_{AC}}{\varnothing}, \qquad (13)$$

where $\varnothing_{AC}$ is the apparent porosity from the Acoustilog® survey for the same clean, water-filled sand.

When both the Densilog® and the Acoustilog are available, a crossplot of log values in clean, water-bearing zones near the depth of interest would provide the value of C_p by using the chart in Figure 15.

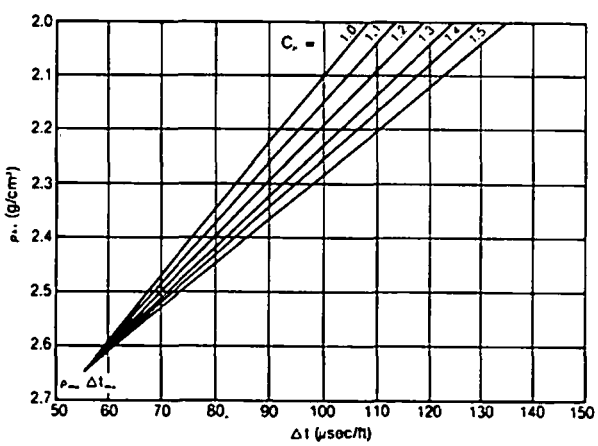


FIGURE 15
Density method for determination of C_p.

In both resistivity and density methods, it is necessary to have clean zones to estimate C_p. However, in moderately shaly sands, the Neutron Log can be used with the advantage that both the Acoustilog and the Neutron Logs are similarly affected by the presence of shale. It is still necessary for the sands to be water-filled. The porosity values in sandstone units from the Sidewall Epithermal Neutron Log or the Compensated Neutron Log are crossplotted with the Acoustilog readings to determine the value of C_p in Figure 16.

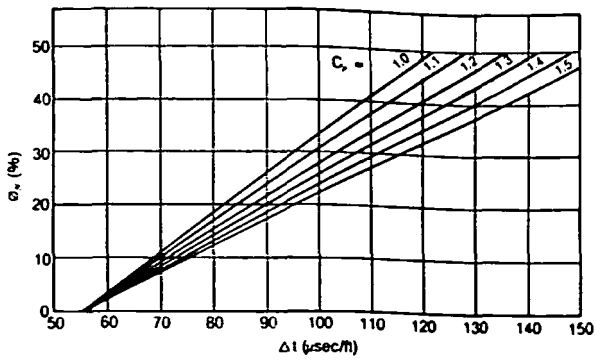


FIGURE 16
Neutron method for determination of C_p.

Shaliness Correction

Most sands, whether compacted or unconsolidated, which contain appreciable amounts of shale or clay particles will exhibit longer acoustic travel times than clean sands of identical porosity in the same borehole environment. The increase in travel time results primarily from the difference in the velocities of the shale or clay particles and the sand matrix.

When applied to the time average formula, travel time measurements in shaly sands will yield values greater than the true effective porosity of the formation. For this reason, a correction must be introduced so a more reliable porosity value may be obtained. The acoustic travel time in shale varies with the area, depending upon the type of shale and the degree of compaction. Typical values of Δt for shale range from 62.5 to 167 μsec/ft, as seen in Table II.

To correct for shaliness, it is necessary to estimate the fractional shale volume from other log readings which are strongly dependent on the shale content. Various shaliness indicators can be used, but each one of them provides an estimate which is an upper limit of the shale volume. Therefore, use of the minimum shaliness, obtained from a number of indicators, is recommended. Several of the log-derived shaliness indicators given in Table IV can be used, depending upon the availability of logs and conditions favorable for the particular indicators.

The manner in which shaliness affects the Acoustilog response not only depends upon the amount of shale present, but also upon the type of distribution of shale within the sand beds. It has been observed by studying core samples that shale may be

TABLE IV (After Ref. 9)

LOGGING CURVE	MATHEMATICAL RELATIONSHIP	FAVORABLE CONDITONS	UNFAVORABLE CONDITIONS
SPONTANEOUS POTENTIAL (SP-curve)	$V_{sh} = 1.0 - (PSP/SSP) + 1.0 - \alpha$	Waterbearing laminated shaly sands ($<R_t$)	R_{xo}/R_t approaches 1.0. Thin, $>>R_t$ zones. Hydrocarbon bearing. Large electro-kinetic and/or invasion effects
	$V_{sh} = (PSP - SP_{min})/(SSP - SP_{min})$	$c<1.0$ as function of clay type	
	$V_{sh} = 1.0 - C \times \alpha$		
	$1.0 - \alpha = \log A/\log[(A - V_{sh} \times B)/(1 - V_{sh} \times B)]$	Knowledge of several parameters required, including α, R_t, R_{mf}, R_w. Similar limitations as for straight forward SP – equations.	
	where $A = R_t/R_{mf}$; $B = R_t/R_w$		
	$1.0 - \alpha = (KV_{sh}W)/(KV_{sh}W + \phi S_{xo})$	K = log derived coefficient, W = clay porosity from bulk and matrix ρ_{sh}; S_{xo} = flushed zone water saturation; laboratory-derived, too many requirements.	
GAMMA RAY	$V_{sh} = (GR - GR_{min})/(GR_{max} - GR_{min})$	Only clay minerals are radioactive.	Radioactive minerals other than clays (mica, feldspar, silt).
	$V_{sh} = C(GR - GR_{min})/(GR_{max} - GR_{min})$	$C<1.0$, frequently approximately 0.5 when $V_{sh}<40\%$	Only potassium-deficient kaolinite present. Uranium enrichment in permeable fractured zones.
	$V_{sh} = (GR - W)/Z$	W, Z = geologic area coefficient	Radiobarite scales on casing. Severe washouts (<<GR)
	$V_{sh} = 0.33(2^{2V_{sh}} - 1.0)^*$	Highly consolidated and Mesozoic rocks	Younger, unconsolidated rocks
	$V_{sh} = 0.083(2^{3.7V_{sh}} - 1.0)^*$	Tertiary clastics	Older consolidated rocks
	*where $V_{sh} = (GR - GR_{min})/(GR_{max} - GR_{min})$		
SPECTRALOG Gamma ray spectral logging provides individual measurements of potassium (K,%) and thorium (Th, ppm) content	$V_{sh} = (A - A_{min})/(A_{max} - A_{min})$	Conditions similar to gamma ray discussion A = Spectralog readings (K in %, Th in ppm). A_{min} = minimum value (K or Th) in clean zones A_{max} = maximum values (K, Th) in essentially pure shales.	Similar to gamma ray discussion. However, uranium enrichment in permeable, fractured zones and radiobarite buildup are no limitations. If Th-curve is used, localized bentonite streaks should be ignored.
	$V_{sh} = C(A - A_{min})/(A_{max} - A_{min})$		
	$V_{sh} = 0.33(2^{2V_{sh}} - 1.0)^*$		
	$V_{sh} = 0.083(2^{3.7V_{sh}} - 1.0)^*$		
	*where $V_{sh} = (A - A_{min})/(A_{max} - A_{min})$		
RESISTIVITY If several resistivity logs are available, use the one which exhibits highest resistivity values in subject well.	$V_{sh} = (R_t/R_t)^{1/b}$	Low porosity zones (carbonate, marls), pay zones with low ($S_w - S_{xo}$).	High porosity water sand, high R_t – values.
	where b = 1.0	R_t/R_t from 0.5 to 1.0	
	b = 2.0	R_t approaches R_t.	
	$V_{sh} = \{R_{xo}(R_{max} - R_t)/[R_t(R_{max} - R_{xo})]\}^{1/b}$	In clean hydrocarbon bearing zones one calculates $V_{sh} = 0$.	
	V_{sh} = same as above, where $(1/b) = 1.0$ when $R_{xo}/R_t \geq 0.5$; $(1/b) = 0.5/(1 - R_{xo}/R_t)$ when $R_{xo}/R_t < 0.5$		
NEUTRON	$V_{sh} = \phi_N/\phi_{N,sh}$	High gas saturation or very low reservoir porosity.	$\phi_{N,sh}$ is low.
	$V_{sh} = (\phi_N - \phi_{N,cl})/(\phi_{N,sh} - \phi_{N,cl})$	$\phi_{N,cl}$ can be varied.	
PULSED NEUTRON	$V_{sh} = (\Sigma - \Sigma_{min})/(\Sigma_{max} - \Sigma_{min})$	Fresh water environment low porosity and gas bearing zones.	
	$V_{sh} = (\Sigma_f/\Sigma)(\Sigma - \Sigma_{min})/(\Sigma_{max} - \Sigma_{min})$	V_{sh} calculates zero in clean zones.	
DENSITY-NEUTRON	$V_{sh} = \dfrac{\rho_b^*(\phi_{N,sh} - 1.0) - \phi_N^*(\rho_{sh} - \rho_f) - \rho_f^*\phi_{N,sh} + \rho_{sh}}{(\rho_{sh} - \rho_f)^*(\phi_{N,sh} - 1.0) - (\phi_{N,sh} - 1.0)^*(\rho_{sh} - \rho_f)}$		Too low V_{sh} in prolific gas zones. Don't use with severe hole conditions. Lithology affected.

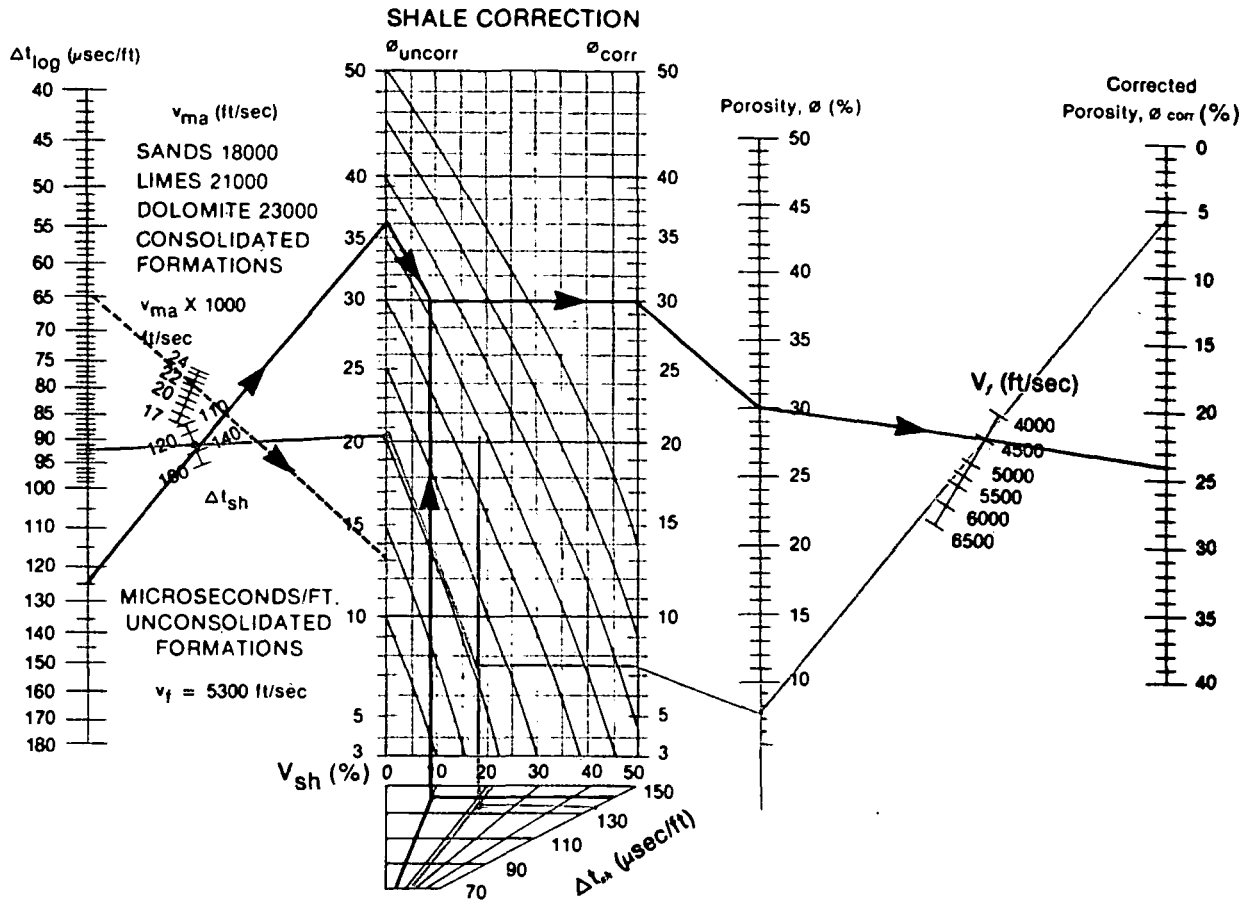


FIGURE 17
Acoustilog® porosity-shaliness and fluid corrections.

present either in the form of laminae or dispersed particles or as a part of matrix structure within the sand formations. These types of shale distribution define the limiting conditions, and a combination of different types may often be present.

In the case of laminated shale streaks, it may be assumed that these thin shale laminae have the same characteristics as the adjacent thick shale beds. The response of the shaly sand would accordingly be dependent on the shale content and shale properties.

In compacted shaly formations, the acoustic response equation can be expressed as:

$$\Delta t = (\varnothing \times \Delta t_f) + (V_{sh}\,\Delta t_{sh}) + (1 - \varnothing - V_{sh})\,\Delta t_{ma} \quad (14)$$

Solving for porosity,

$$\varnothing = \left(\frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) - V_{sh}\left(\frac{\Delta t_{sh} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) \quad (15)$$

In uncompacted shaly sands, the compaction correction factor, C_p, is introduced and the corrected porosity will be:

$$\varnothing = \left(\frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right)\left(\frac{1}{C_p}\right) - V_{sh}\left(\frac{\Delta t_{sh} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) \quad (16)$$

Equations 15 and 16 can be solved graphically by using the nomograph in Figure 17. The chart is mathematically correct when $\Delta t_{ma} = 55.5$ μsec/ft, but provides reasonably accurate corrections with other matrix values. In the nomograph, the correction factor, C_p, is approximated as $\Delta t_{sh}/100$.

Example A: In a compacted formation (limestone with $V_{ma} = 21{,}000$ ft/sec), the BHC Acoustilog reads a specific acoustic time of 64 μsec/ft.

A line is drawn from the Δt log grid at 64 μsec/ft through the matrix velocity $V_{ma} = 21{,}000$ ft/sec and is extended to the porosity grid for the clean formation to read a porosity value of 11.5%.

Example B: In a slightly shaly and unconsolidated

sand, the BHC Acoustilog® instrument reading is 125 μsec/ft. Specific acoustic time in the adjacent shale bed is 140 μsec/ft, and V_{sh} from shaliness indicators is computed at 10%. Acoustic velocity for the formation fluid is given as 4500 ft/sec.

An uncorrected porosity value of 36% is obtained by drawing a line through $\Delta t_{log} = 125$ μsec/ft and $\Delta t_{sh} = 140$ μsec/ft on the grid for unconsolidated sands. After correction for the shale content through the center grid, a porosity value of 30% is obtained, which corresponds to $V_f = 5300$ ft/sec. Correction for fluid velocity is made by drawing a line through $V_f = 4500$ ft/sec from the porosity column, so that the corrected porosity is obtained as 24%.

Equations 15 and 16 can be written in a simplified form as:

$$\varnothing = \varnothing_{AC} - V_{sh}\,\varnothing_{AC_{sh}}, \tag{17}$$

where $\varnothing_{AC_{sh}}$ is the porosity calculated for shale by the time average formula.

The effect of shaliness on the Density Log is independent of the type of shale distribution and can be similarly expressed as:

$$\varnothing = \varnothing_D - V_{sh} \times \varnothing_{D_{sh}} \tag{18}$$

where,

$$\varnothing_{D_{sh}} = \frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f} \tag{19}$$

The difference in response on the Acoustilog and the Densilog® in water-filled, shaly formations will be:

$$\varnothing_{AC} - \varnothing_D = V_{sh}(\varnothing_{AC_{sh}} - \varnothing_{D_{sh}}) \tag{20}$$

When shale is present in the form of disseminated or dispersed clay particles in the interstices of the sand matrix, the acoustic response is almost the same as if the total interstitial space were filled with water only. This is true as long as the amount of dispersed clay does not exceed about 50% of the total pore volume. The amount of dispersed clay in a shaly sand as a fraction of the total pore space is called the q factor. With the q factor greater than 50%, the acoustic velocity tends to be substantially higher than when water occupies the total pore space. In the latter case, however, the formation is no longer of commercial interest because of low permeability.

The acoustic response equation for a compacted shaly sand, when only dispersed clay is present, can be written as:

$$\Delta t = \Delta t_f(\varnothing + V_{sh}) + \Delta t_{ma}(1 - \varnothing - V_{sh}) \tag{21}$$

or,

$$\varnothing = \left(\frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) - V_{sh} \tag{22}$$

In unconsolidated sands, this should be modified by introducing the compaction correction factor, C_p.

$$\varnothing = \left(\frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right)\frac{1}{C_p} - V_{sh} \tag{23}$$

or,

$$\varnothing = \varnothing_{AC} - V_{sh} \tag{24}$$

The fraction of the total porosity occupied by disseminated clay is the q factor.

$$q = \frac{\varnothing_{AC} - \varnothing}{\varnothing_{AC}} \tag{25}$$

The q factor is indicative of the producibility of shaly reservoir rocks.

Irrespective of the type of shale distribution, it is possible to derive a pseudo q value based upon the Densilog and Acoustilog. From equations 17 and 18,

$$q = \frac{\varnothing_{AC} - \varnothing_D}{\varnothing_{AC}} = \frac{V_{sh}(\varnothing_{AC_{sh}} - \varnothing_{D_{sh}})}{\varnothing_{AC}} \tag{26}$$

Experience indicates that $\varnothing_{AC_{sh}}$ is usually larger than $\varnothing_{D_{sh}}$. On the Gulf Coast, the value of $\varnothing_{D_{sh}}$ is small, since extensive data indicate the density-derived porosity to be a close approximation of effective porosity. This is true because ρ_{sh} differs very little from ρ_{ma}, and the shaliness correction on the Densilog becomes negligible. Influence of shaliness on the Acoustilog is much larger, with values of $\varnothing_{AC_{sh}}$ ranging between 0.2 and 0.4. Of course, when the shale content is small and in the form of dispersed clay within the pore space only, $\varnothing_{AC_{sh}}$ approaches 1.

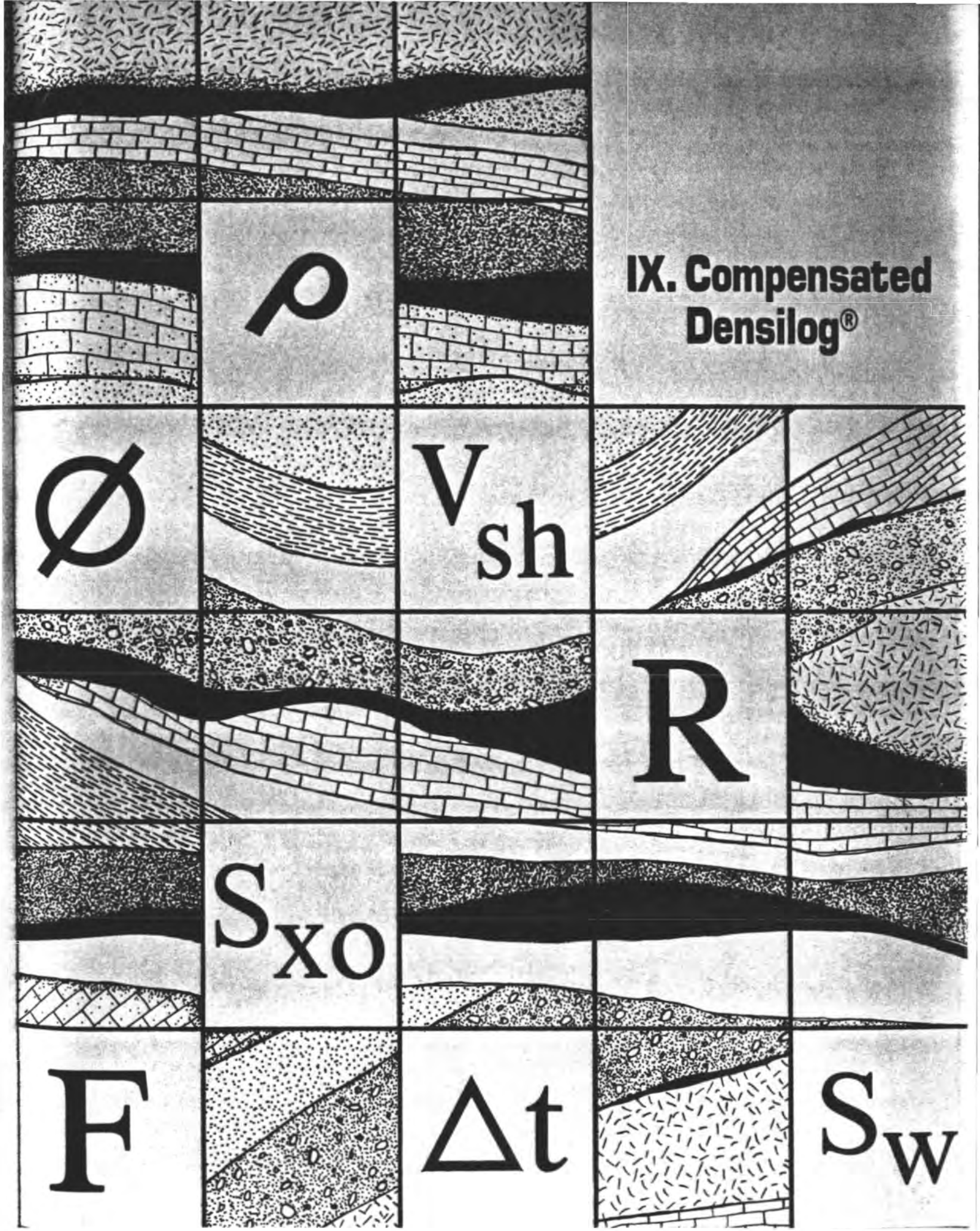
Figure 18 shows a chart based on field data from the Gulf Coast area, New Mexico, Colorado, and Wyoming. This chart can be used for predicting the producibility of shaly sands. Tentative permeability cut-offs such as $q \geq 0.4$ (or $q \geq 2\,\varnothing$) have been used.

Effect of Hydrocarbons

Invasion is generally at a minimum in highly porous formations. Occasionally in these formations, the filtrate invasion is so shallow that the measured acoustic travel time is influenced by the original formation fluids. If this occurs in a hydrocarbon-bearing section, the increased travel time in the fluid phase will cause a porosity calculation greater than that actually present.

In uncompacted formations, the porosity calculated

IX. Compensated Densilog®



formations drilled with highly saline muds, the density of mud filtrate may reach up to a maximum of about 1.15. For zones containing average residual oil saturations, the fluid density is usually close to 1.0 since the lower oil density tends to compensate for the higher density of the mud filtrate. However, for zones containing residual gas or light oil, the low hydrocarbon density appreciably affects the Densilog® response, and if not accounted for, it would result in erroneously high porosity estimates.

EFFECT OF SHALE

Porosity determination from the Densilog may be affected by the presence of shale in the formation. The density of shale varies with the area, the clay minerals present and the degree of compaction. The mineral composition of shale varies over a wide range, and shale densities are usually between 2.20 g/cm³ and 2.85 g/cm³. Density values typical for different clay minerals are shown in Table IV.

Where the shale density is close to 2.65 g/cm³, the Densilog instrument can be used with advantage to estimate the effective porosity in shaly sands. Densilog porosity can be higher or lower than the effective porosity in a formation, depending on the value of shale density, as illustrated in Figure 16.

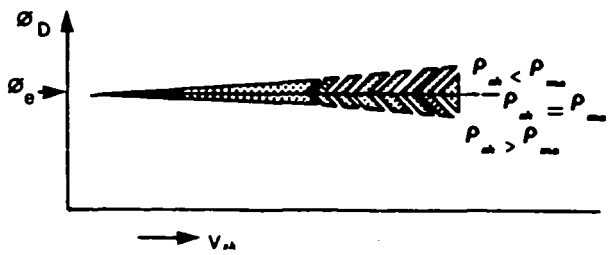


FIGURE 16:
Effect of shale on Densilog porosity (After Ref. 17)

However, it is noticed that at shallow depths, the shale densities tend to be much lower and the effect on Densilog instrument readings is greater. Also the shale disseminated in the pore space may have somewhat lower density than the adjacent shale beds or the laminar shale streaks.

Bulk density in a shaly formation is expressed as

$$\rho_b = \phi \cdot \rho_f + V_{sh} \cdot \rho_{sh} + (1 - \phi - V_{sh})\, \rho_{ma} \qquad (14)$$

Porosity is given by,

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} - V_{sh} \cdot \frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f} \qquad (15)$$

TABLE IV

DENSITIES OF CLAY MINERALS
(After Ref. 17)

	(g/cm³)	
Chlorite	2.60 - 2.96	Low water absorptive properties
Halloysite	2.55 - 2.56	Completely evacuated
	2.76 - 3.00	Muscovite
	2.70 - 3.10	Biotite
	2.642 - 2.688	No absorbed water
Kaolinite	2.609	Theoretical density
	2.60 - 2.68	Extensive literature
	2.63	Most frequently quoted
Palygorskite	2.29 - 2.36	Limited data
Sepiolite	2.08	Limited data
Smectite	2.20 - 2.70	Nontronite essentially
	2.24 - 2.30	Saponite dehydrated
	2.348	
	2.20 - 2.70	Montmorillonite
	2.53	Low-iron smectite
	2.74	3.6% iron content
Vermiculite	No precise data; oven-dried similar to biotite-mica	

The equation can be solved by the use of the nomograph in Figure 17 as illustrated in the following example. The nomograph is mathematically correct when ρ_{ma} = 2.65 g/cm³, but it provides reasonably accurate results with other matrix densities.

Example

The Densilog® survey reads 2.20 g/cm³ in a shaly sand formation at a certain level, where the shale content is estimated to be 20%. It is a waterbearing formation drilled with saline mud with density of mud filtrate as 1.15 g/cm³. The density of shale is given as 2.50 g/cm³.

A line is drawn from the ρ_b grid at the 2.20 g/cm³ point through the matrix density ρ_{ma} = 2.65 g/cm³ and is extended to the porosity grid for a clean formation (assuming ρ_f = 1 g/cm³). This gives a porosity value of 27%. In order to correct for shaliness, a diagonal line from this point is drawn up to a vertical line through the point which describes the coordinates V_{sh} = 20% and ρ_{sh} = 2.50 g/cm³ in the center bottom grid of the nomograph. Thus we obtain a shaliness corrected porosity of 25%. The correction for fluid density is made by drawing a line through the stem ρ_f = 1.15 g/cm³ to read the corrected porosity as 27.5%.

SHALE BULK DENSITY

Bulk density of shale normally increases with depth and this is usually apparent on the Densilog

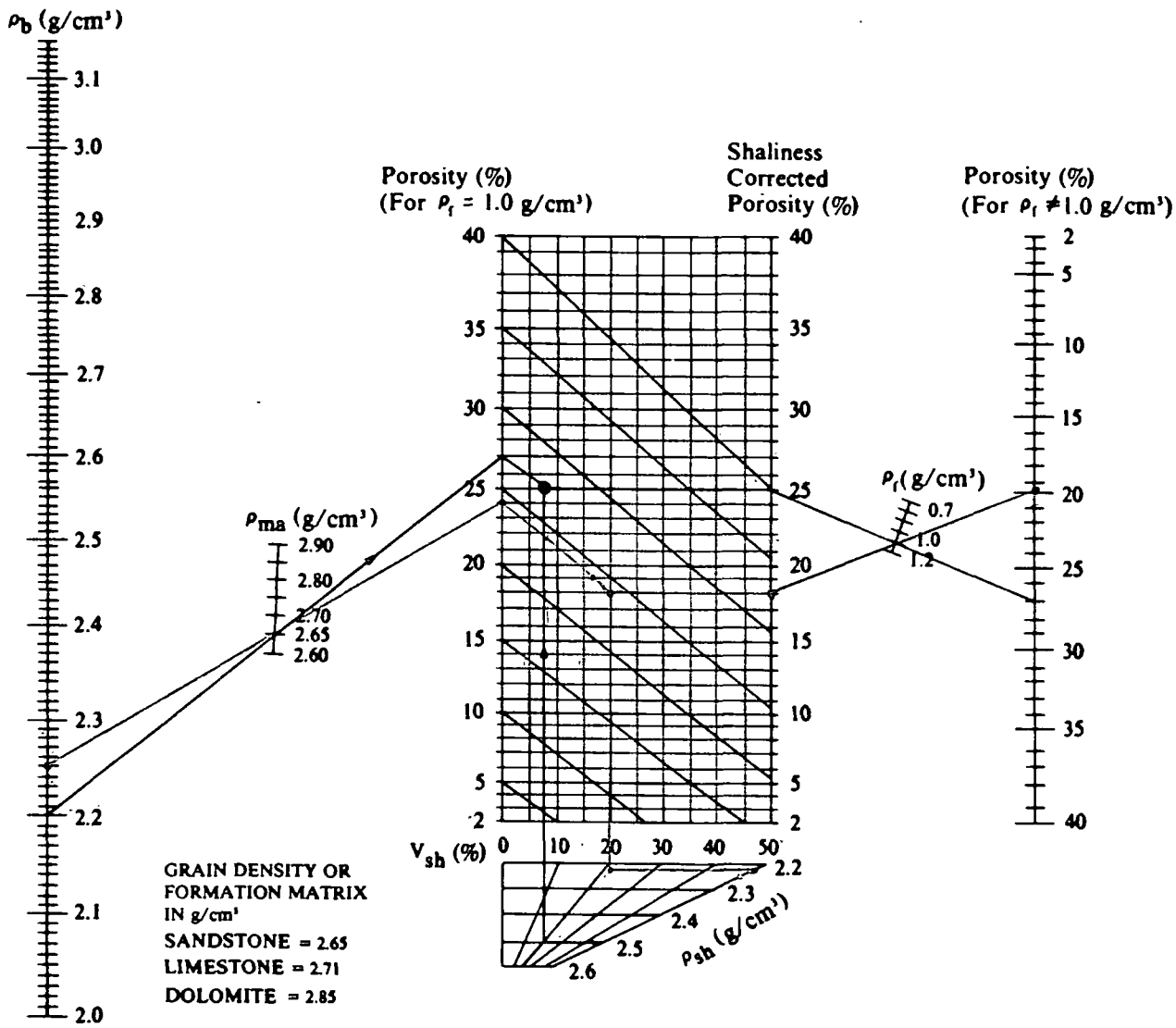


FIGURE 17:
Densilog porosity - shaliness and fluid density correction (After Ref. 16)

DUAL LATEROLOG / MICRO-SFL

CSU

COMPANY: MUCORP ENERGY INC.
WELL: 01 GESS
FIELD: WILDCAT
COUNTY: ROOSEVELT
STATE: MONTANA

RECEIVED
MAR 9 19

LOCATION: 330 FT. SOUTH OF CENTERLINE, UNDRILLED,
2310 FSL & 2640 FEL
SEC: 1 TWP: 30N RGE: 46E

PERMANENT DATUM: GL
ELEV. OF PERM. DATUM: 2630.0'
LOG MEASURED FROM: KB
17.0' ABOVE PERM. DATUM
DRLG. MEASURED FROM: KB

ELEVATIONS-
KB: 2647.0'
DF:
GL: 2630.0'

DATE: 9 MAR 02
RUN NO: 1

DEPTH-DRILLER: 7949.0'
DEPTH-LOGGER: 7946.0'
BTM. LOG INTERVAL: 7948.0'
TOP LOG INTERVAL: 787.0'

CASING-DRILLER: 791'
CASING-LOGGER: 787'
CASING: 9.625

BIT SIZE: 8.75
DEPTH: 7949'

OTHER SERVICES-
LDL/CNL/GR
INT BHC/GR
CYBERLOOK

PROGRAM
TAPE NO:
09.02
SERVICE
ORDER NO:
250996

TYPE FLUID IN HOLE: SALT GEL - STARCH
DENSITY: 10.4 LB/G
VISCOSITY: 39.0 S
PH: 4.4
FLUID LOSS: 10.0 C3
SOURCE OF SAMPLE: MUD TANK
RM: 0.064 OHMM AT 85.0 DF
RMF: 0.056 OHMM AT 85.0 DF
RMC: 0.096 OHMM AT 85.0 DF
SOURCE RMF/RMC: MEAS/CALC
RM AT BHT: 0.021 OHM AT 174. DF
RMF AT BHT: 0.019 OHM AT 174. DF
RMC AT BHT: 0.032 OHM AT 174. DF

TIME CIRC. STOPPED: 1700:09MARO2
TIME LOGGER ON BTM.: 0130:10MARO2

MAX. REC. TEMP: 174.0 DF

LOGGING UNIT NO: 8247
LOGGING UNIT LOC: WILLISTON, ND
RECORDED BY: J. BRADFORD
WITNESSED BY: RADELLA: WARMOH

REMARKS:

TENSION REFERENCE PT. = -7 IN.
CENTRALIZERS: CNEZ & CALIPER - 1 EACH
SCALE CHANGES: GR @ 9350. GR @ 787.
SALINITY = 166000 PPM (CL) LAST READING MSFL @ 5000

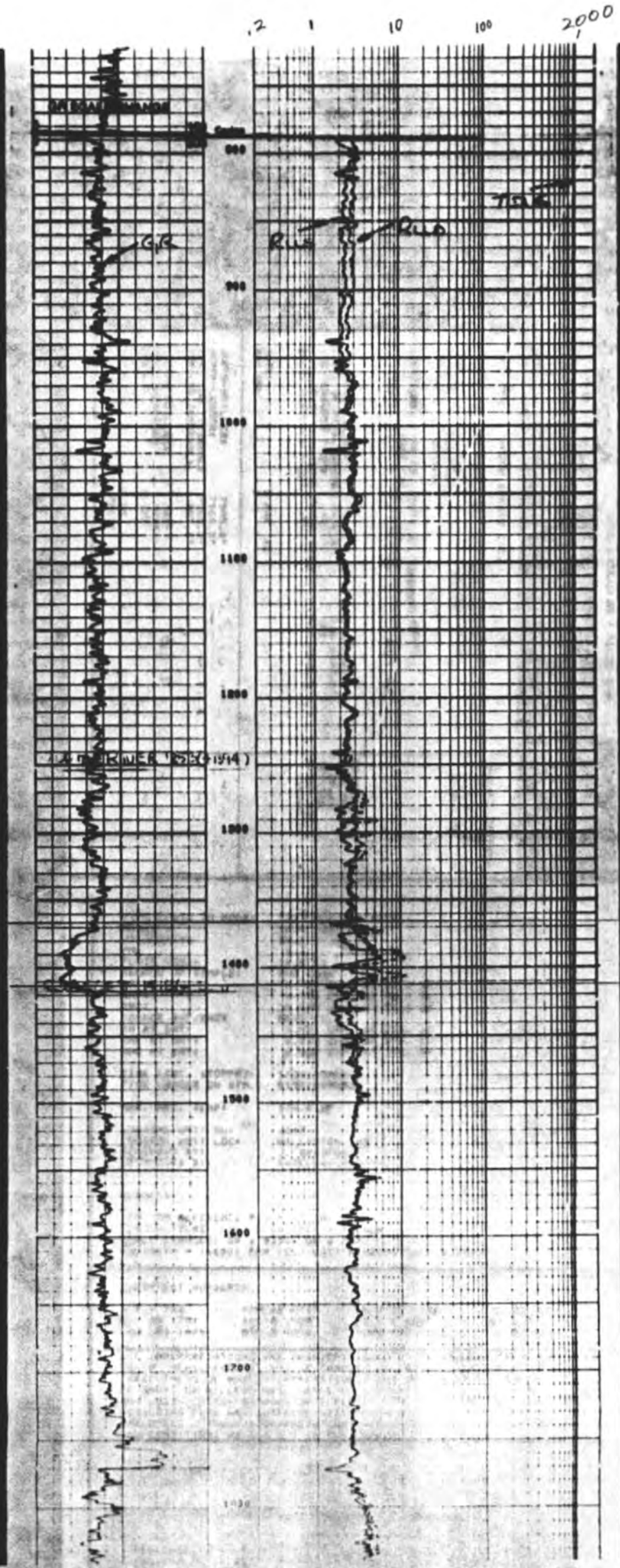
EQUIPMENT NUMBERS-

DLM B 732	MRM AB 2710	M.T BC 1128	SGC JC 3204
DLC BB 1751	SRE B 1928	DLS D 885	SRS D 713
CPU CBB 1409	MTU D 4912	OMU CBM 1001	IDM B 1972

ALL INTERPRETATIONS ARE OPINIONS BASED ON INFERENCES FROM ELECTRICAL OR OTHER MEASUREMENTS AND WE CANNOT, AND DO NOT GUARANTEE THE ACCURACY OR CORRECTNESS OF ANY INTERPRETATIONS, AND WE SHALL NOT, EXCEPT IN THE CASE OF GROSS OR WILLFUL NEGLIGENCE ON OUR PART, BE LIABLE OR RESPONSIBLE FOR ANY LOSS, COSTS, DAMAGES, OR EXPENSES INCURRED OR SUSTAINED BY ANYONE RESULTING FROM ANY INTERPRETATION MADE BY ANY OF OUR OFFICERS, AGENTS OR EMPLOYEES. THESE INTERPRETATIONS ARE ALSO SUBJECT TO OUR GENERAL TERMS AND CONDITIONS AS SET OUT IN OUR CURRENT PRICE SCHEDULE.

FILE

PERFORMED: 02 MAR 02
PROGRAM FILE: DST VERSION: 2002.2 02-MAR-02


.2
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1700

BOREHOLE COMPENSATED SONIC LOG

CSU

COMPANY:	MUSGRAVE ENERGY INC.	OTHER SERVICES- DLL/MSFL/GR LDL/CNL/GR CYBERLOOK
WELL:	#1 GESS	
FIELD:	WILDCAT	
COUNTY:	ROOSEVELT	
STATE:	MONTANA	
LOCATION:	330 FT. SOUTH OF CENTER 9 SEC 8310 FEL & 8640 FEL	
SEC:	1 TWP: 30N RGE: 44E	
PERMANENT DATUM:	GL	PROGRAM:
ELEV. OF PERM. DATUM:	2630.0'	TAPE NO: 20.22
LOG MEASURED FROM:	KB	SERVICE ORDER NO: 250996
17.0' ABOVE PERM. DATUM		
DRLG. MEASURED FROM:	KB	
DATE:	5 MAR 82	
RUN NO:	1	
DEPTH-DRILLER:	7945.0'	
DEPTH-LOGGER:	7963.0'	
BTM. LOG INTERVAL:	7960.0'	
TOP LOG INTERVAL:	770.0'	
CASING-DRILLER:	791'	
CASING-LOGGER:	787'	
CASING:	9.625	
BIT SIZE:	8.75	
DEPTH:	7945'	

ELEVATIONS- KB: 2647.0' DF: GL: 2630.0'

RECEIVED

TYPE FLUID IN HOLE:	SALT GEL - STARCH	
DENSITY:	10.4 LB/G	
VISCOSITY:	39.0 S	
PH:	6.0	
FLUID LOSS:	10.0 C3	
SOURCE OF SAMPLE:	MUD TANK	
RM:	0.064 OHMM AT 55.0 DF	
RMF:	0.056 OHMM AT 55.0 DF	
RMC:	0.096 OHMM AT 55.0 DF	
SOURCE RMF/RMC:	MEAS/CALC	
RM AT BHT:	0.021 OHM AT 180. DF	
RMF AT BHT:	0.018 OHM AT 180. DF	
RMC AT BHT:	0.031 OHM AT 180. DF	
TIME CIRC. STOPPED:	1700:05MAR82	
TIME LOGGER ON BTM.:	0930:06MAR82	
MAX. REC. TEMP:	180.0 DF	
LOGGING UNIT NO:	824.7	
LOGGING UNIT LOC:	WILLISTON: ND	
RECORDED BY:	J. BRADFORD	
WITNESSED BY:	[illegible]	

REMARKS:

TENSION REFERENCE PT 4 IN. SALINITY = 166000 PPM (CL)
CENTRALIZERS: ONE'S CALIPER - 1 EACH
SCALE CHANGES: GR @ 5300. SPHI @ 5400. DT @ 5450
LAST READING SPHI @ 4950 CALIPER MAX. READING = 15.9 IN.

EQUIPMENT NUMBERS-

SLM IM 1231	SLC FM 1256	SLS LB 156	CPU CDB 1469
SGC JC 3204	MLM BC 1129	MCT DA 1378	MTU B 4912
DM CBM 1001	IDM B 1972		

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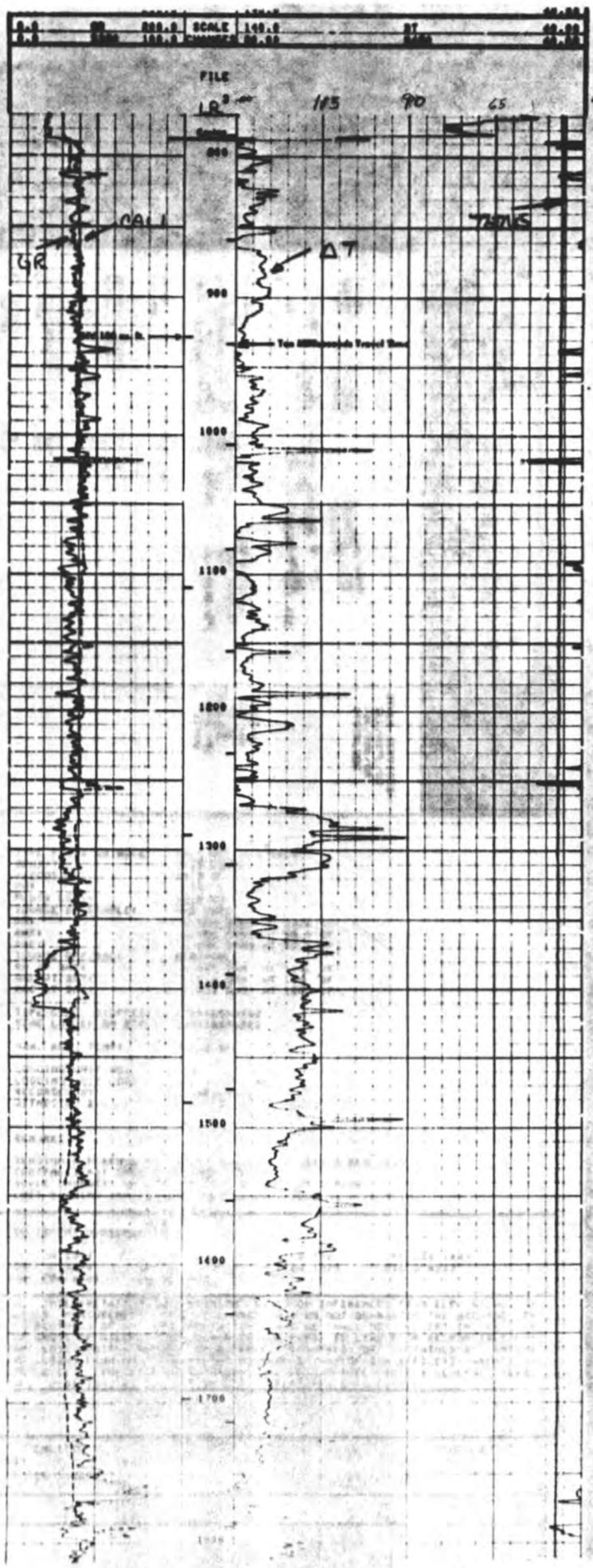
FILE

6.00	CALI(IN)	16.00	TENSLB	0.0
	GR (GAPI)	200.0	DT (US/F)	40.00
0.0				40.00
0.0	GR	200.0	DT	40.00
0.0	5350	100.0	5450	40.00

Original Retained District Office


SCALE
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1300
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1600
1700

COMPANY TRICENTROL UNITED STATES, INC.

WELL S"MATES NO.1-2

FIELD WILDCAT

COUNTY ROOSEVELT STATE MONTANA

Run No.	ONE
Service Order No.	213169
Fluid Level	FULL
Depth, Well Ck.	5860000
Logging Unit	DLM-B-867
Panel (DIP)	HRM-AB-872
Cartridge (DLC)	DLC-BB-868
Cartridge (GRS)	SRE-B-1780
Sonde (DLS)	DLS-BB-798
Sonde (GRS)	SRS-A-1769
Lower Electrode (GRS)	---
Generator Panel	CPU-CAA-1374
Tape Recorder (TTU)	MTU-D-3245
Depth Encoder (DMU)	DMU-CAA-182
Measure Wheel (CMD)	CMD-BAB-185
Calibrations Filter Series No.	CHEZ CALIPER
	ONE
Tension or Mass	E.G. Indicr ---

GR	Scale API	42
	Range API	199

GR	Sensitivity	100/200
	Scale - MM Div.	0-100/0-200
	D C FT.	1
Speed FPM		50

BOTTOM HOLE TEMPERATURE				
Time Entering Hole	0800 5/26			
Time Bottom Reached	0830 5/26			
Time Last Off Bottom	0900 5/26			
Time Out of Hole	1130			
Distance TD to Therm.	39'			
Thermometer #1	160 °F	°F	°F	°F
Thermometer #2	- °F	°F	°F	°F
Thermometer #3	- °F	°F	°F	°F

Rw FROM DRILL STEM TEST				
DST #1 Rw @ 100 °F	--- OHM	OHM	OHM	OHM
DST #2 Rw @ 100 °F	--- OHM	OHM	OHM	OHM

Type Log	Depth	Scale Up Hole	Scale Down Hole
GR	5150	0-200	0-100
GR	800	0-100	0-200
SP	5800	60 MV	SHIFT
SP	1750	40 MV	SHIFT

REMARKS:

TENSION MEASURE POINT IS -7"

MSFL & CALIPER ON 5" ONLY

02-81M12131 6-7

AFTER SURVEY TOOL CHECK SUMMARY

PERFORMED: 81/05/26
PROGRAM FILE: MILL (VERS:DM 10.2 80/08/29)

DSTB TOOL CHECK

	PLUS BEFORE	AFTER	UNITS
LLS	31.60	31.66	OHM
LLD	31.60	31.63	OHM

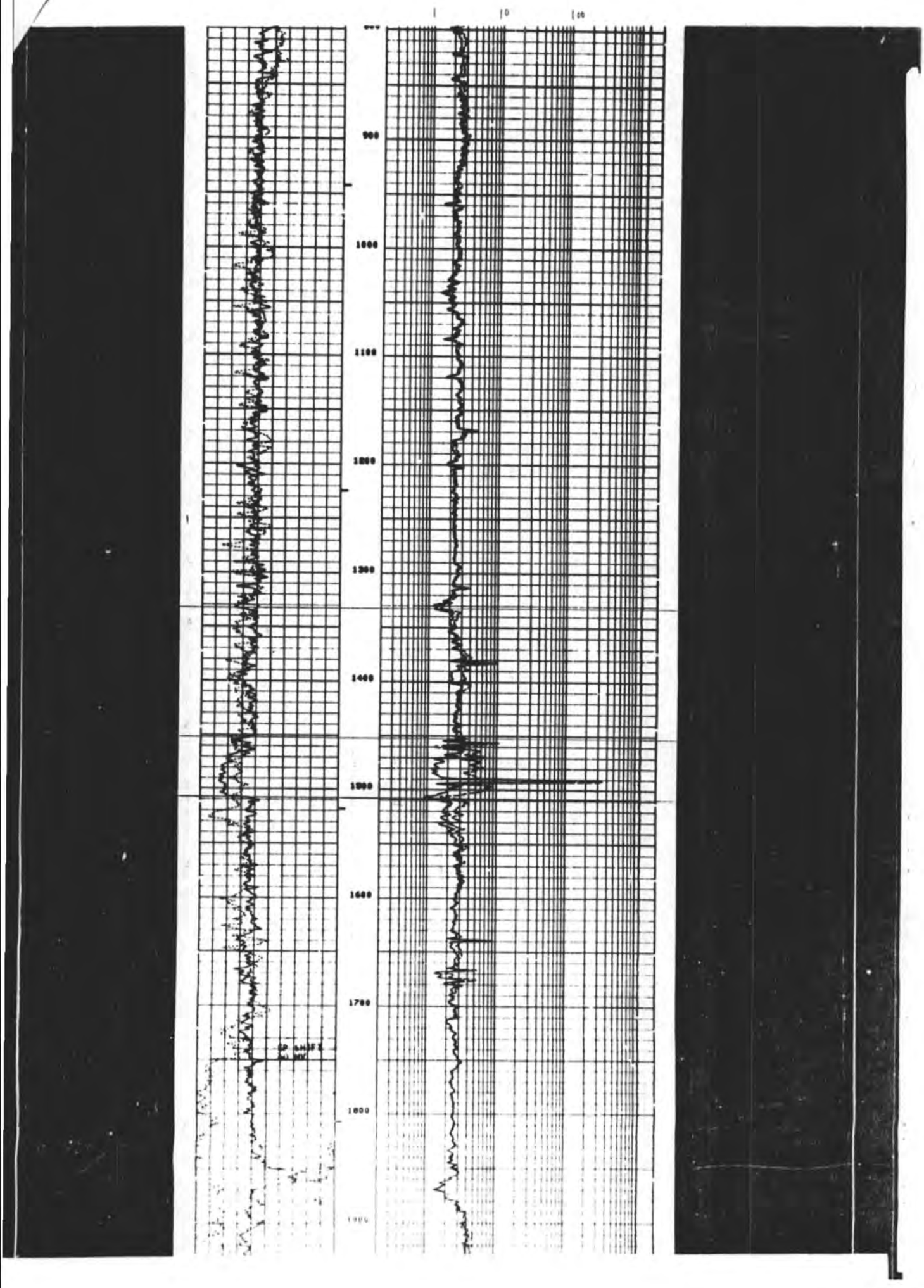
DST TOOL CHECK

	ZERO BEFORE	ZERO AFTER	PLUS BEFORE	PLUS AFTER	UNITS
CMSF	0.0	-0.1	999.9	999.4	MM.M
II	0.0	-1.0	200.0	203.5	MM/M

FILE

14

PARAMETERS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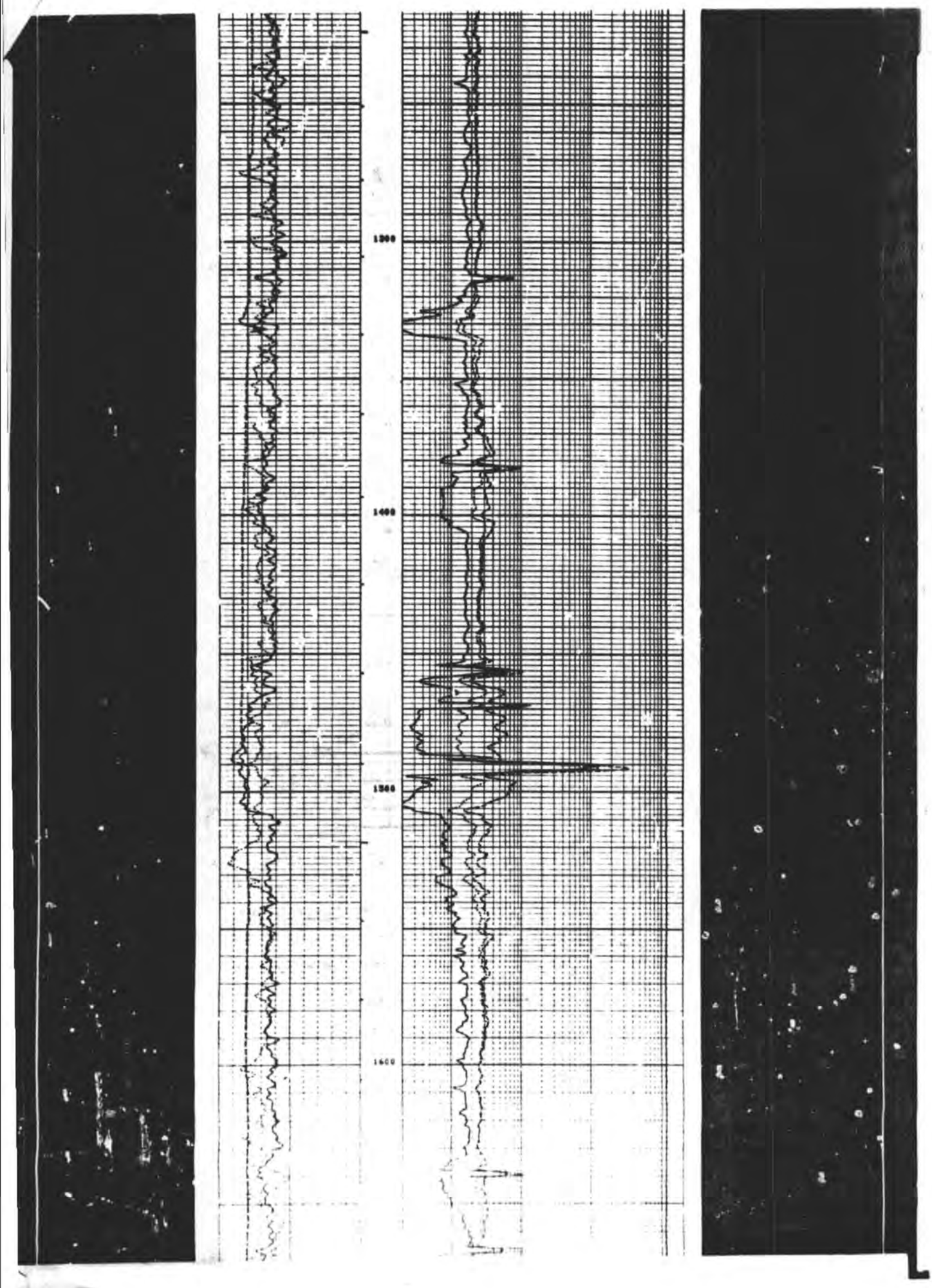
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Schlumberger

COMPENSATED NEUTRON
FORMATION DENSITY

COMPANY TRICENTROL UNITED STATES, INC.
WELL SCHULTES NO. 3-2
FIELD WILDCAT
COUNTY ROOSEVELT STATE MONTANA
LOCATION NW/NE 990' FNL 1980' FEL
Other Services DLL/MSFL/GR INT/BHC/GR

COUNTY ROOSEVELT
FIELD WILDCAT
LOCATION SEC. 3-30N-46E
WELL SCHULTES NO. 3-2
COMPANY TRICENTROL UNITED STATES, INC.

Permanent Datum GL Elev. 2261
Log Measured From KB 16 ft Above Perm. Datum
Drilling Measured From KB

Elev.: KB 2265
DF
GL 2261

Date 5-26-81
Run No. ONE
Depth Driller 2763
Depth Logger 2772
Depth Logged Int. 2774
Top Log Interval 2514
Bottom Log Interval 2774
Casing Driller 8-5/8 @ 696
Casing Logger 614
Bit Size 7-7/8
Type Fluid in Hole SALT-STARCH-GEL
Dens. Visc. 10.5 40
pH Fluid Loss 9 8 ml
Source of Sample MUD TANK
Rm @ Meas. Temp. .055 @ 66 F
Rmf @ Meas. Temp. .050 @ 66 F
Rmc @ Meas. Temp. .083 @ 66 F
Source Rmf Rmc M IC
Rm @ BHT .032 @ 166F
Circulation Stopped 0600 5/26
Logger on Bottom 1200 5/26
Max. Rec. Temp. 166 F
Equip. Location 0115 MILSTEAD
Recorded By FREBURGS-MCBAY
Witnessed By K.C. FAUN

HIGH RESOLUTION

Rm @ Meas. Temp. .055 @ 66 F
Rmf @ Meas. Temp. .050 @ 66 F
Rmc @ Meas. Temp. .083 @ 66 F
Rm @ BHT .032 @ 166F

RECEIVED
MAY 27 1981
DIVISION OF OIL & GAS
MILES CITY, MONTANA

POLY HERE

The well name, location and borehole reference data were furnished by the customer

RUN NO.	ONE			
Service Order No.	213169			
Fluid Level	FULL			
Salinity, PPM Cl.	184000			
Speed - F.P.M.	30			
INSTRUMENT DATA				
Dens. Panel	NLM-RC-439			
Dens. Cart.	PGC-G-109			
Dens. Shd.	PDH-E-219			
Dens. Sonde	PGS-EC-230			
Dens. Source	GSR-1-5076			
Dens. Calibrator	SET-106-1309			
Neut. Panel	NLM-RC-439			
Neut. Cart.	CNC-A-1339			
Neut. Source	NSR-FA-2078			
Neut. Calibrator	NSR-AB-1634			
GR Cart.	SGC-JC-2350			
Memorizer Panel	CPU-CAA-1174			
Tape Recorder (TTR)	MTU-D-2745			
Depth Encoder (DRE)	DRU-CAA-362			
Pressure Wheel (CPW)	CWO-BAB-195			
Centralizer Arm Spring	Type	ECCENTERED BOWSPRING		
	No.	---	1	
Standoffs				
In-box or None	S O Inches			
CALIBRATION DATA				
GR	BKG API	44		
	Source API	197		
	Sens Cal PC/FT	100,200		
		1		
CNC	Short Spacing Before Log	2404		
	Long Spacing Before Log	1300		
	Short Spacing After Log	2898		
	Long Spacing After Log	1300		
FDC	P+ Before Log	833		
	P+ Before Log	648		
	P+ After Log	834		
	P+ After Log	599		

SCALE CHANGE:			
Type Log	Depth	UPHOLE	DOWNHOLE
GR	5600	0-200	0-100
FD	5600	45/-15	30/-10
BN	5600	45/-15	30/-10
FD	3400	60/0	45/-15
BN	3400	60/0	45/-15

REMARKS
TENSION MEASURE POINT IS -18"

LOGGING DATA

DEPTH Top	DEPTH Bottom	CNC Porosity Scale	CNC Matrix	CNC Auto Corr. or Hole Corr. Setting	FDC Porosity Scale	FDC Grain Density	FDC Liquid Density	FDC Hole Fluid	FDC Sens Logged	D C	GR Zero Div. Left	GR Scale Per Div.
[illegible]	[illegible]	20/-10	LIME	A.1	20/-10	2.71	1.1	WATER	100	1	0	100
4600	2600	15/-15	LIME	A.1	30/-15	2.71	1.1	WATER	200	1	0	200
2400	4600	15/-15	SAND	A.1	30/-15	2.65	1.1	WATER	200	1	0	200
[illegible]	[illegible]	[illegible]	SAND	A.1	60/0	2.65	1.1	WATER	200	1	0	200

AFTER SURVEY TOOL CHECK SUMMARY

PERFORMED: 81/05/26
PROGRAM FILE: ISM (VERSION 18.2 80/08/23)

CNTA TOOL CHECK

	BEFORE	AFTER
NEAR	[illegible]	[illegible]

POROSITY CHANGE [illegible]

FDTA TOOL CHECK

	BEFORE	AFTER	UNITS
FFDC	[illegible]	[illegible]	CPS
NFDC	[illegible]	[illegible]	CPS

PERFORMED: 01/09/26
PROGRAM FILE: ISH (VERSION 10.2 06/08/03)

CNTA TOOL CHECK

	JIG BEFORE	JIG AFTER
HRAT	1.167	2.163

POROSITY CHANGE (LIME): -0.000

PGTE TOOL CHECK

	JIG BEFORE	JIG AFTER	UNITS
FFDC	336	336	CPS
NFDC	520	509	CPS

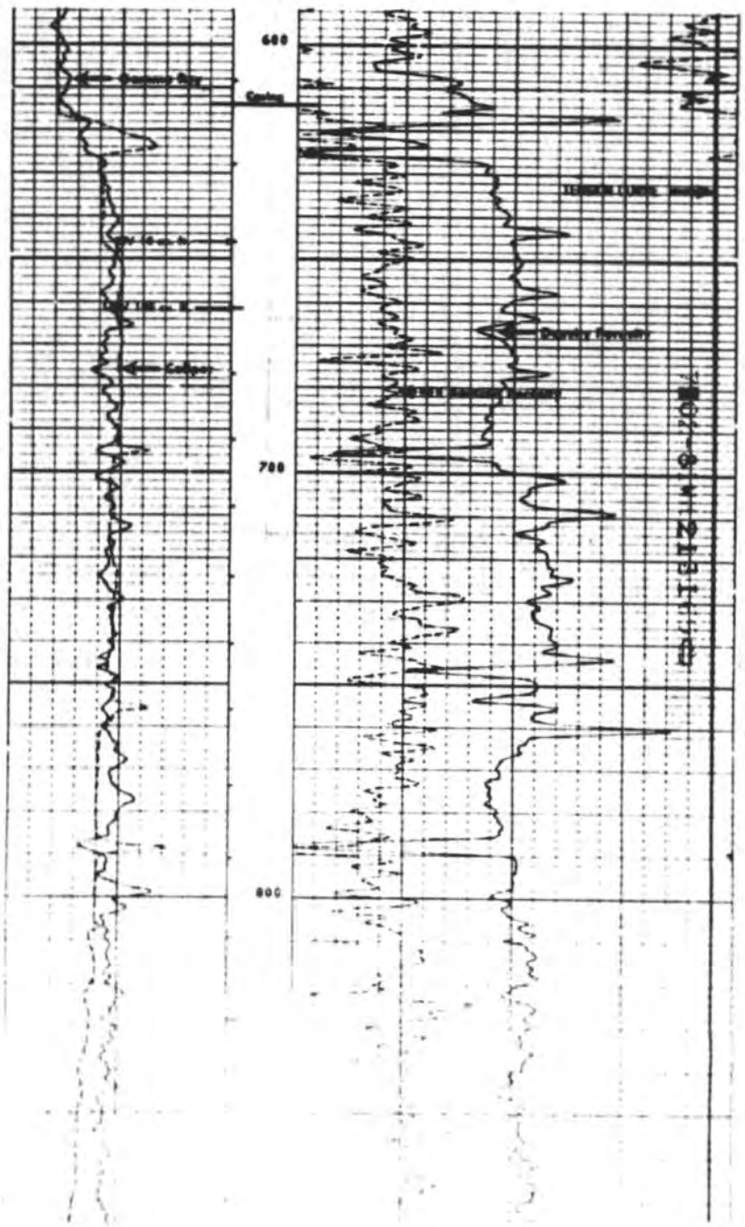
FILE 9

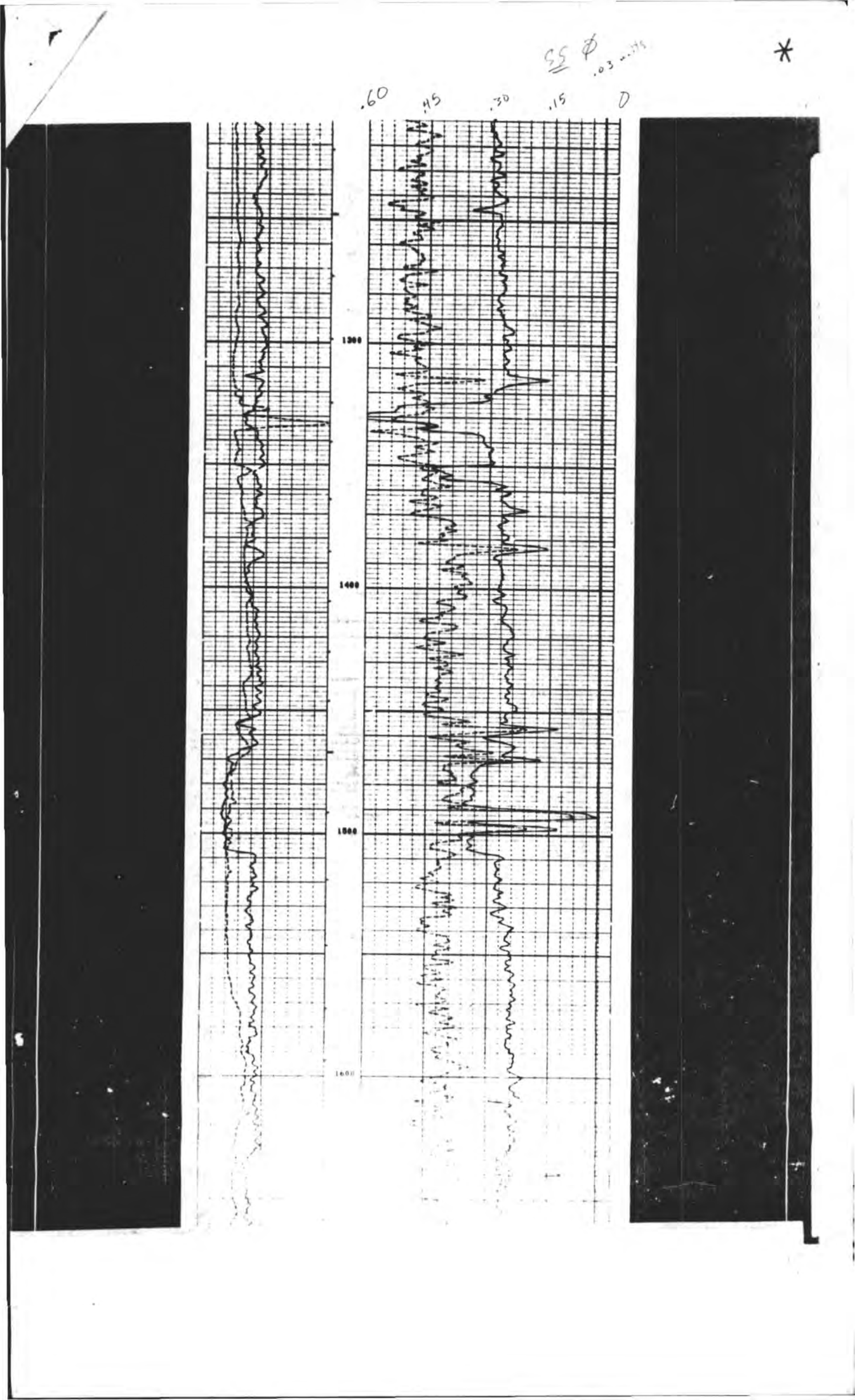
PARAMETERS

NAME	UNIT	VALUE	NAME	UNIT	VALUE	NAME	UNIT	VALUE
HC		CALI	PSNR		2.225	DS	INCH	7.875
HDEN	G/C3	7.600	FD	G/C3	1.100	MATR		SAND
DHF		WATE						
DO		0.0	DHI		OPEN	FPHI		PHIX

CALI(IN) 6.000 – 16.00		TENS(LB) 10000. – 0.0
GR (GAPI) 0.0 – 200.0		NPHI( ) SANDSTONE 0.6000 – 0.0
CALI(IN) 16.00 – 26.00		DPHI( ) SANDSTONE 0.6000 – 0.0

FILE 7

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COMPANY TRICENTROL UNITED STATES, INC.
WELL SCHULTES NO.1-2
FIELD WILDCAT
COUNTY ROOSEVELT STATE MONTANA

COMPANY TRICENTROL UNITED STATES, INC.
WELL SCHULTES NO.1-2
FIELD WILDCAT
COUNTY ROOSEVELT
LOCATION SEC. 1-30N-46E
STATE MONTANA

Permanent Datum	GL
Log Measured From	KB
Drilling Measured From	KB
Elev.	2741 ft. Above Perm. Datum
Elev. K.B.	2755
D.F.	---
G.L.	2741

Date	5-26-81
Run No.	ONE
Depth Driller	0255
Depth Logger	0255
Bottom Logged Interval	0255
Top Log Interval	0000
Casing Driller	8 5/8 @ 696
Casing Logger	8
Bit Size	7 7/8
Type Fluid in Hole	SALT-STARCH-GEL
Dens.	10.5
Visc.	40
Fluid Loss	8
Source of Sample	MUD TANK
Rm @ Meas. Temp.	.055 @ 64 F
Rmf @ Meas. Temp.	.051 @ 64 F
Rmc @ Meas. Temp.	.081 @ 64 F
Source: Rmf / Rmc	M / C
Rm @ BHT	.022 @ 168F
Time Since Circulation	10800
Time Since Logged	1730
Max. Rec. Temp.	168F
Equipment Number	5/26
Location	4
Recorded By	W. TILSA
Witnessed By	FREDONG-SAPPSL

Run No.	ONE
Other Services	DLL/MSFL/GR FDC/CNL/GR
Max. Rec. Temp.	168F
Equipment Number	5/26
Location	4
Recorded By	W. TILSA
Witnessed By	FREDONG-SAPPSL

Run No.	ONE
Bit	7 7/8
From	696
To	255
Hole Size	7 7/8
Casing Size	8 5/8
Wgt. / Ft.	24
Type Fluid in Hole	SALT-STARCH-GEL
Dens.	10.5
Visc.	40
pH	8
Fluid Loss	8
Source of Sample	MUD TANK
Rm @ Meas. Temp.	.055 @ 64 F
Rmf @ Meas. Temp.	.051 @ 64 F
Rmc @ Meas. Temp.	.081 @ 64 F
Source: Rmf / Rmc	M / C
Rm @ BHT	.022 @ 168F
Time Since Circulation	10800
Time Since Logged	1730
Max. Rec. Temp.	168F
Equipment Number	5/26
Location	4
Recorded By	W. TILSA
Witnessed By	FREDONG-SAPPSL

FIELD PRINT

FILE NONE

The well name, location and borehole reference data were furnished by the customer

Run No.	ONE
Service Order No.	213169
Fluid Level	FULL

EQUIPMENT DATA

Sonic Panel No.	SLM-DA-412
Sonic Cart No.	SLC-FA-1171
Sonic Sonde No.	SLS-BC-86
Mon. Panel No.	CPU-CAA-174
G.R. Cart. No.	SGC-JC-2750
G.R. Panel No.	NLM-BE-699
Caliper No.	HCD-DA-697
TTB No.	HTU-D-2755
Centralizers No.	1
Type	CHEZ CAL PER
Standoffs No.	---
Type	---
D.C. FT. I	1
Speed - F.P.M.	60

CALIBRATION DATA

GR	DEG API	31
	Source API	172
	D.C. FT.	1

SCALE CHANGES

Type Log	Depth	Scale Up Hole	Scale Down Hole
GR	5600	0-200	0-100
ØS	5600	45/-15	30/-10
ØT	5600	140/40	80/40
ØS	3400	60/0	45/-15
ØT	3400	160/60	140/40

LOGGING DATA

Porosity Selectors				Depth	
ΔΦm	ΔΦf	Cp	Ø Scale	From	To
47.6	189	100	30/-10	10	5600
47.6	189	100	45/-15	5600	4600
55.6	189	100	45/-15	4600	3400
55.6	189	100	60/0	3400	650

REMARKS

LET- INTEGRATED TRAVEL TIME

IHV- INTEGRATED HOLE VOLUME

POROSITY ON 5" ONLY

Velocity (ft sec) = 1,000,000 / Interval Transit Time (microseconds per foot)

All interpretations are opinions based on inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretations, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our Current Terms and Conditions as set forth in our current Price Schedule.

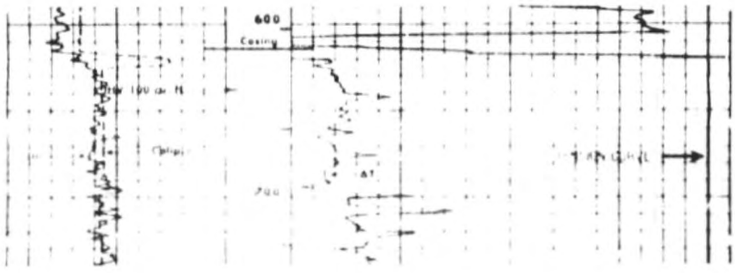
PARAMETERS

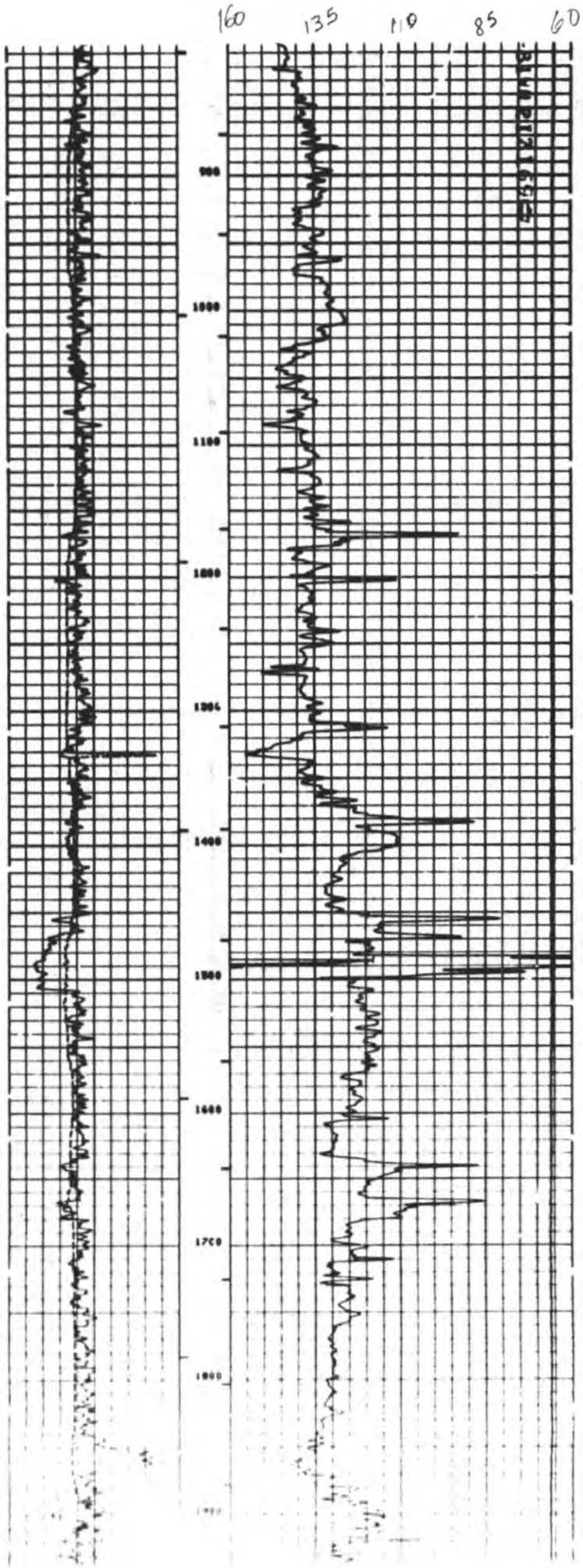
NAME	UNIT	VALUE	NAME	UNIT	VALUE	NAME	UNIT	VALUE
DTM	US/F	55.60	CDTS		100.0	BS	INCH	7.875
FPHI		PHIX	DTF	US/F	189.0			
BO		0.0	DHS		DPEM			

COLI(IN 2)		TENS(LB)
6.000 16.00		10000. 0.0
GR (GAPI)		DT (US/F)
0.0 200.0	160.0	60.00

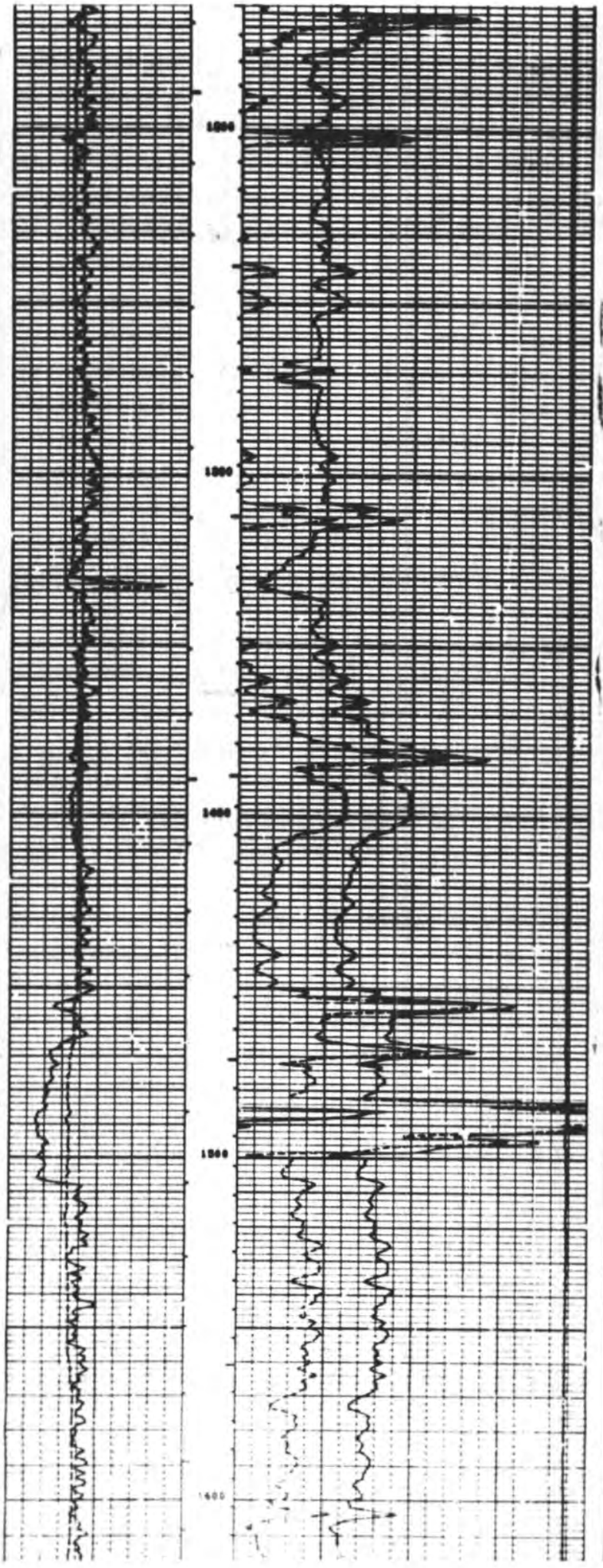
FILE

4




160
135
110
85
60
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

*


1000
1000
1000
1000
1400

REMARKS

Changes in Mud Type or Additional Samples

Type	Sample No.
Depth - Driller	
Type Fluid in Hole	

Resis.	Visc.	
pH	Fluid Loss	cc cc
Source of Sample		
Res @ Meas Temp.	@	°F
Res @ Meas Temp.	@	°F
Res @ Meas Temp.	@	°F
Source: Rmf Rmc		
Rm @ B.H.T.	@	°F
Rmf @ B.H.T.	@	°F
Rmc @ B.H.T.	@	°F

Type Log: GAMMA RAY

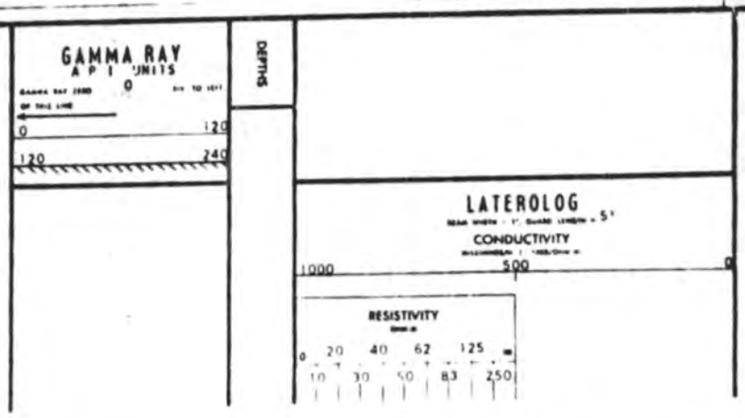
Scale	Scale Changes: Depth This Side	Depth Scale Side
5500	0 — 120	0 —

Additional Data

Run No.	Tool Type	Rad Type	Tool Position	Other

CALIBRATION: GAMMA RAY	Back ind. C.P.S.	Tool S. + Read. C.P.S.	Calib. Incr. (Division)	Seno. Top (Per Col.)	Seno. Top (Record)	Time Count.	Record Speed (ft./min.)
	70	280	8.25	500		0	
GAMMA RAY INTERVAL					500	1	90
CSG - 5500					120	2	30
5500 - TD							

HOUSTON:	Tool S. Per	Tool S. Close	Calib. Incr. (Divisions)	Seno. Top (Per Col.)	Seno. Top (Record)	Time Count.	Record Speed (ft./min.)

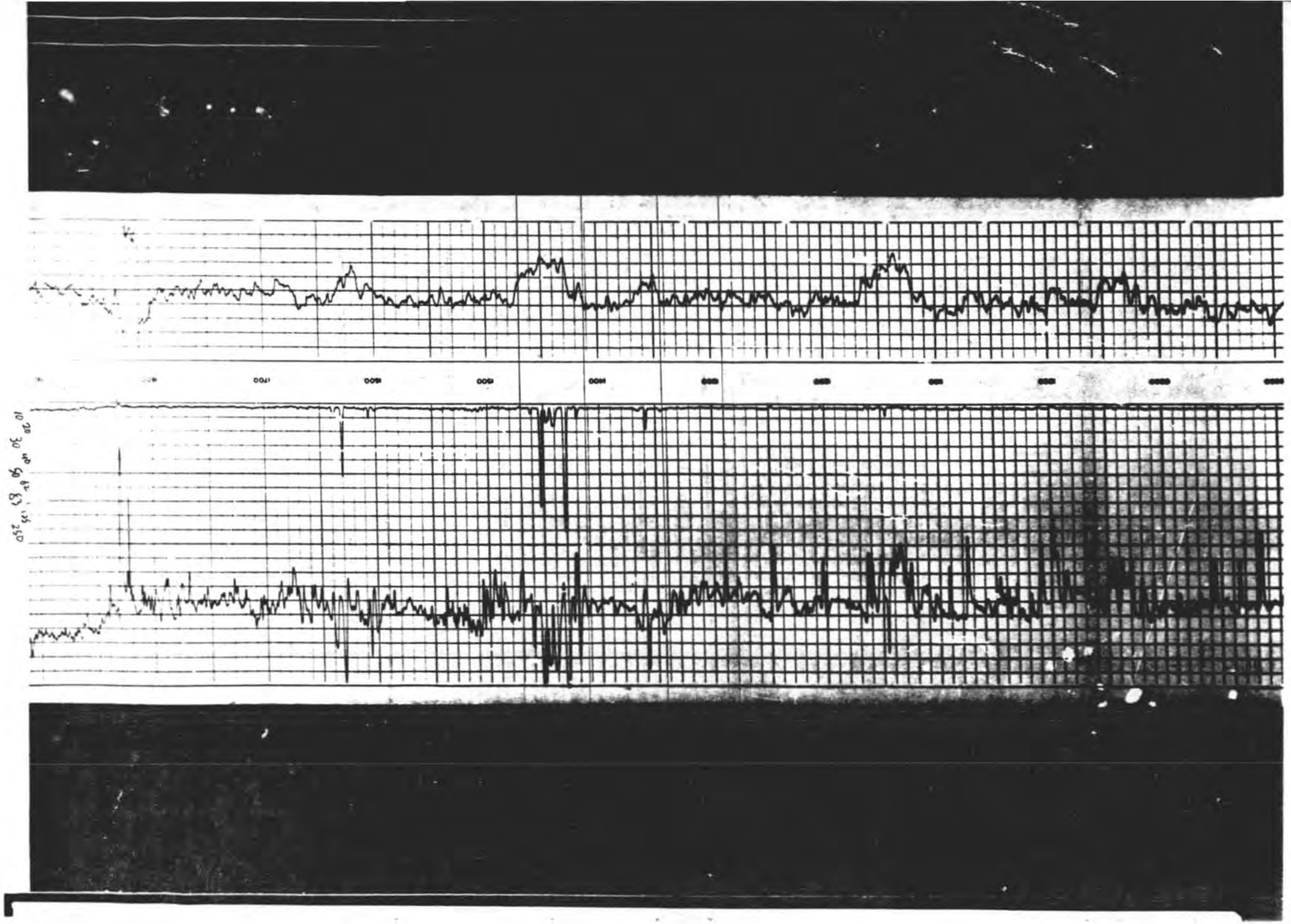


Elev. Zero

Calibration

Calibration

Meas. Zero


10 20 30 40 50 60 63 65 250

COMPANY MURPHY OIL CORPORATION

WELL CORNCREEK #1

FIELD WILDCAT

COUNTY ROOSEVELT STATE MONTANA

LOCATION SE/SW 900 N/S 1740 E/W

Sec. 6 Twp. 30N Rge. 46E

Other Services: LGR, MLL

Elev.: K.B. 2726 D.F. G.L. 2713

RECEIVED JUL 1 1964

REMARKS

Changes in Mud Type or Additional Samples		
Date / Sample No.		
Depth—Driller		
Type Fluid in Hole		
Dens. / Visc.		
ph / Fluid Loss	ml	
Source of Sample		
R_m @ Meas. Temp.	@ °F	@ °F
R_{mf} @ Meas. Temp.	@ °F	@ °F
R_{mc} @ Meas. Temp.	@ °F	@ °F
Source: R_{mf} / R_{mc}		
R_m @ BHT	@ °F	@ °F
R_{mf} @ BHT	@ °F	@ °F
R_{mc} @ BHT	@ °F	@ °F

Type Log	Depth	Scale Up Hole			Scale Down Hole		
SONIC LOG	5320	240	190	140	80	60	40

Equipment Data

Run No.	Tool Type	Tool Position	Other
ONE	VLC-B	CENTERED	

C.D.: USED S.O.: CENTERED WITH CENTER OF GRAVITY GUIDE PLUS CALIPER

Equip. Used: CART. No. VLC-B-86

PANEL No. VLP-B-108

SONDE No. VLS-J-51

GAMMA RAY TRACED FROM LATEROLOG GAMMA RAY

Velocity (feet per second) = 1,000,000 / Interval Transit Time (microseconds per foot)

A P I GAMMA RAY UNITS	DEPTHS	INTERVAL TRANSIT TIME MICROSECONDS PER FOOT
0 — 120		T2 R 1R
120 — 240		240 — 140 — 40

CALIPER

HOLE DIAM. IN INCHES

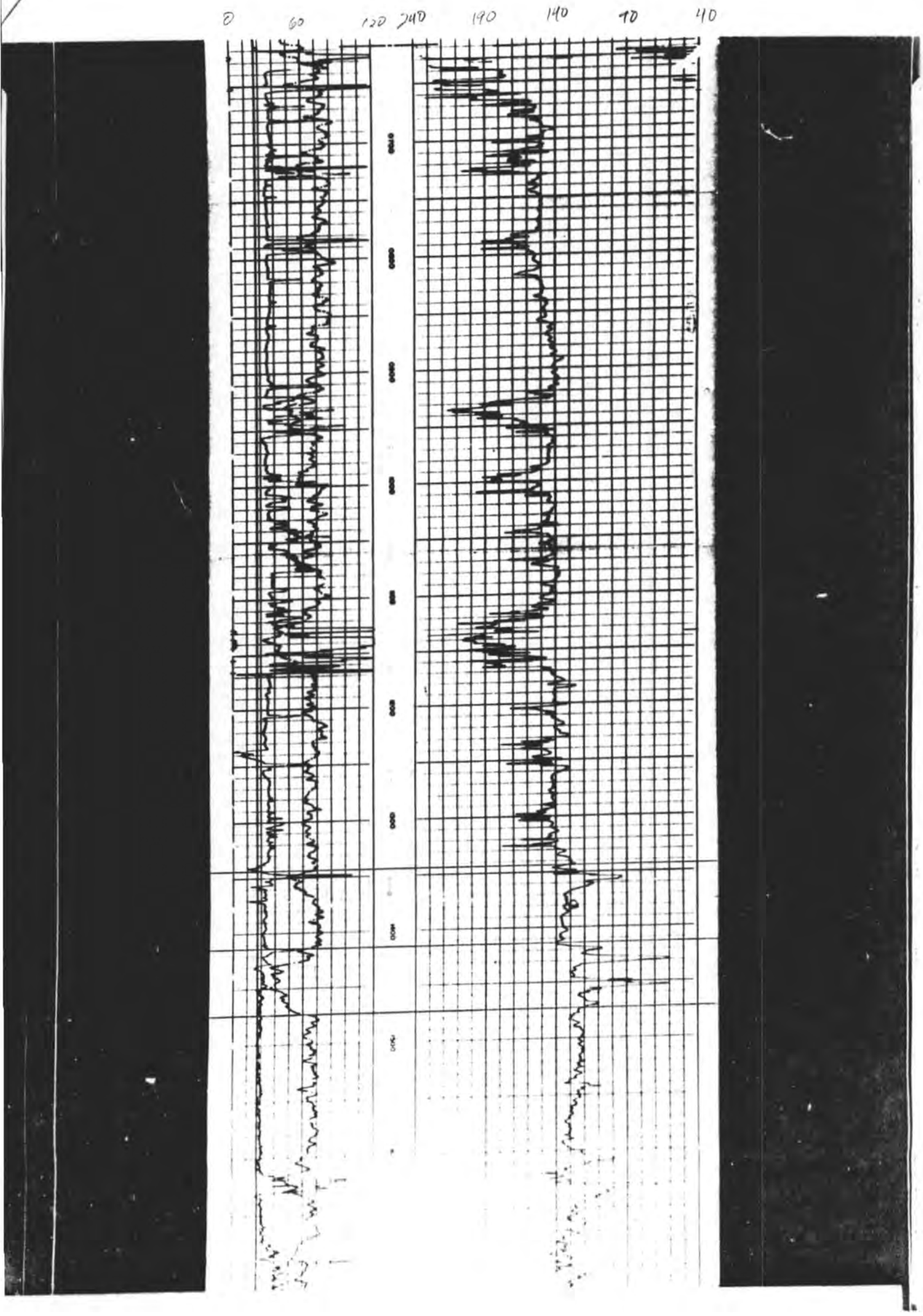
6

125 M. Sec.

100 M. Sec.

75 M. Sec.

50 M. Sec.


0
60
120
240
190
140
90
40

*

[illegible] WELL SURVEYING CORPORATION

GAMMA RAY-CALIPER LOG

COMPANY	MURPHY OIL CORPORATION
WELL	COURCHENE #1-8
FIELD	VOLT
LOCATION	SE-SW SEC. 4, TWP. 30N, RGE. 46E
COUNTY	ROOSEVELT
STATE	MONTANA

Other Surveys: FIT

Location of Well

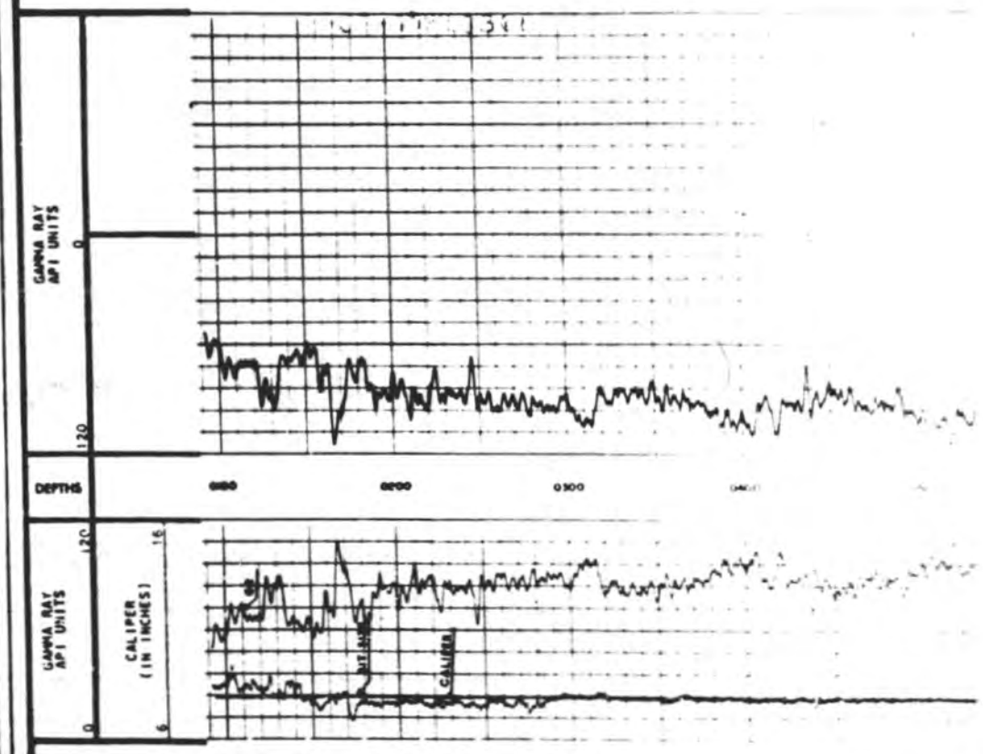
Elevation: K.B. 2710.7; D.F. or G.L. 2708.7

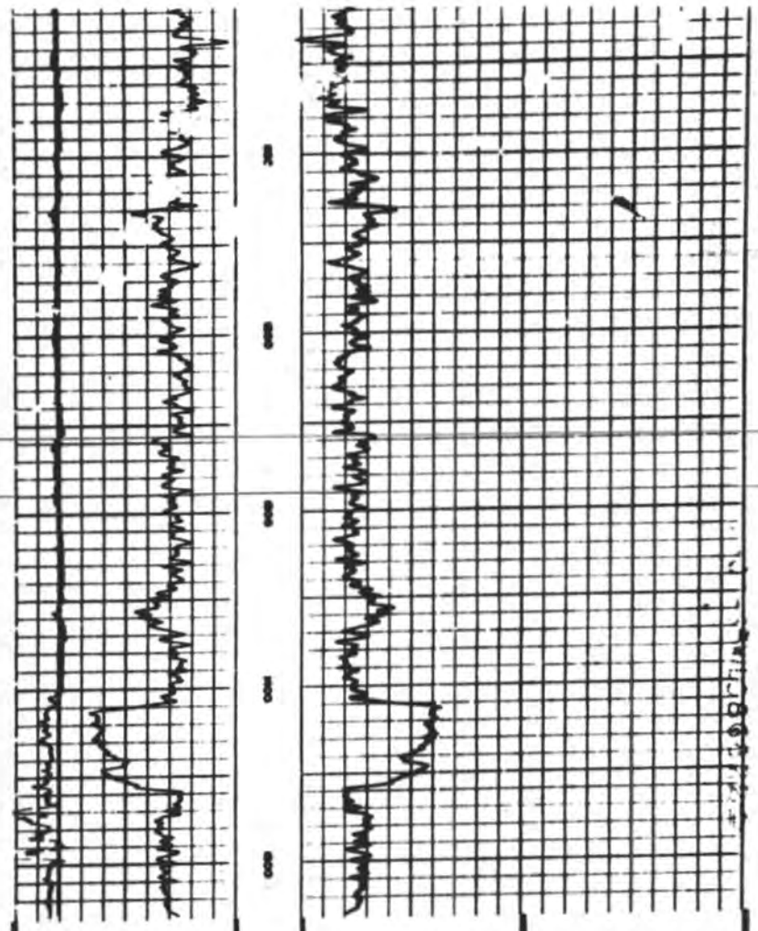
FILING No.

Elev. 2708.7

Date	2-28-65
Depth Driller	1527
Depth Logger	1526
Bottom Logged Interval	1523
Top Logged Interval	99
Type Fluid in Hole	SALT BA°C
Fluid Level	FULL
Max. Rec. Temp.	84 HOURS
Witnessed By	MR. BROWN

Size	From	To	Size	Wgt.	From	To
7-7/8	SSG	TD	8 5/8		SURF	99





6 16
CALIPER
(IN INCHES)

GAMMA RAY
API UNITS
0 120

DEPTHS

GAMMA RAY
API UNITS
120 0

COMPANY MURPHY OIL CORPORATION
WELL COURCHENE 1-D
FIELD VOLT
COUNTY ROOSEVELT STATE MONTANA

Rm --- @ -- F
Rmf --- @ -- F
Rmc --- @ -- F
BHT -- F

SWSC PR 1523
SWSC TD 1524
DRLR TD 1527
Elev:
KB 2710.7
DF
GL 2706.7

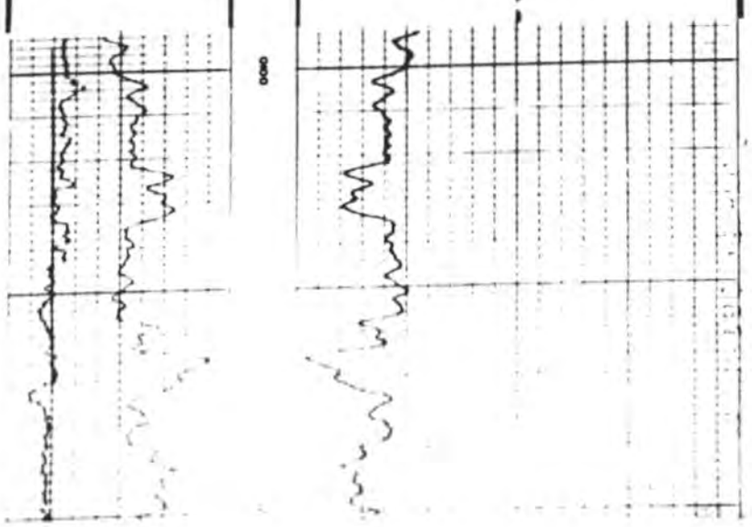
DETAIL LOG
5" = 100

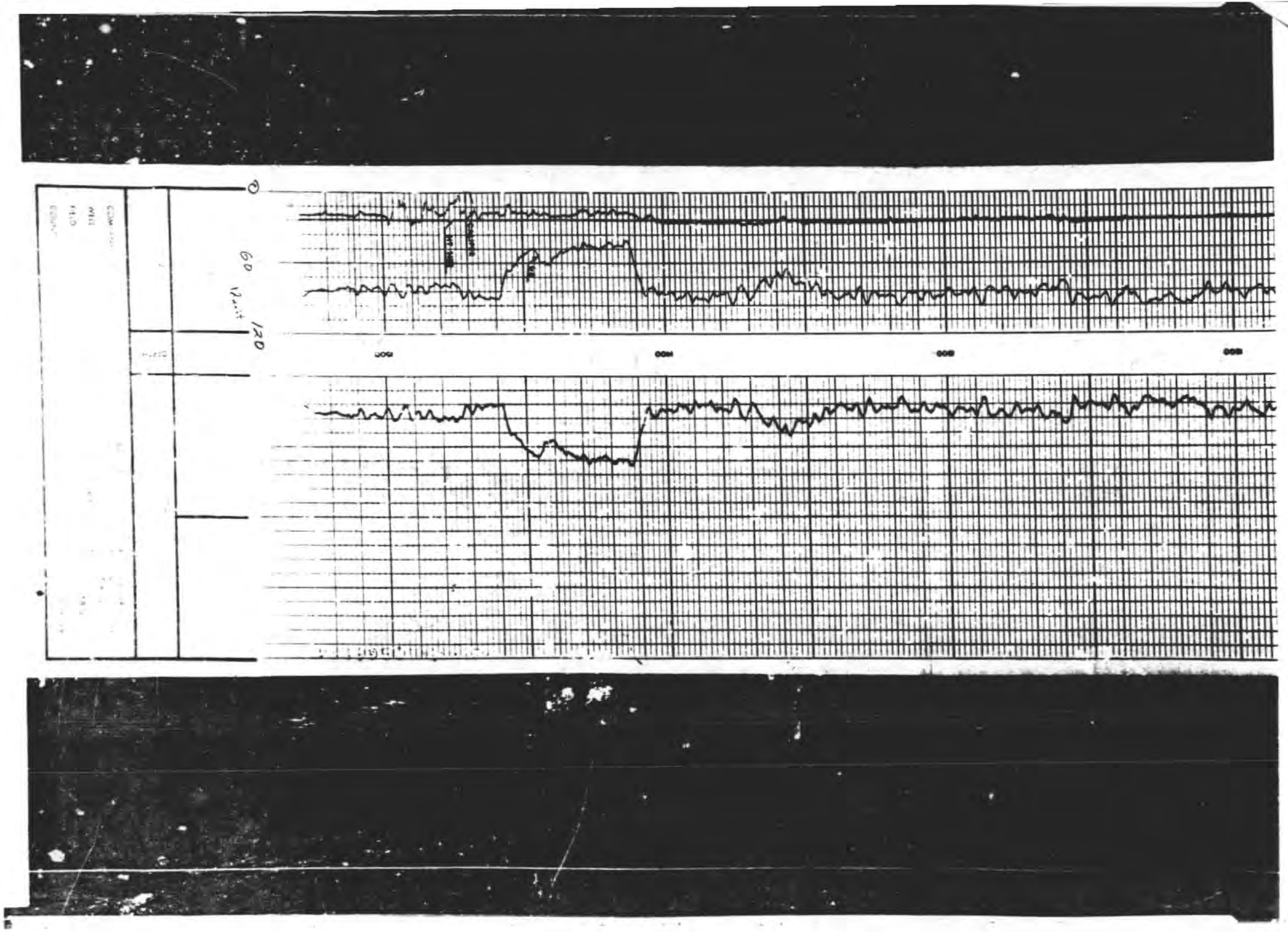
GAMMA RAY
API UNITS
0 120

DEPTHS

GAMMA RAY
API UNITS
120

CALIPER
(IN INCHES)




0
60
120

*

Copy of
LOCATION COURCHENE #1-D
WELL
COMPANY MURPHY OIL CORP.

COMPANY MURPHY OIL CORPORATION

WELL COURCHENE #1-D

FIELD VOLT

COUNTY ROOSEVELT STATE MONTANA

LOCATION SE/SW

Sec. 4 Twp. 30N Rge. 46E

Other Services: GR

Permanent Datum: GL, Elev. 2706.7

Log Measured From: KB 4 Ft. Above Perm. Datum

Drilling Measured From: KB

Elev.: K.B. 2710.7
D.F.
G.L. 2706.7

Date	2-28-65		
Run No.	ONE		
Bbl No's.	ONE		
Type of Test	Open Hole ☒ Cased Hole ☐	Open Hole ☒ Cased Hole ☐	
Type Fluid in Hole	SALT BASE		
Dens. / Visc.	9.6 / 48		
pH / Fluid Loss	9.8 CC		
Source of Sample	MUD PIT		
R_m @ Meas. Temp.	@ °F	@ °F	
R_{mf} @ Meas. Temp.	@ °F	@ °F	
R_{mc} @ Meas. Temp.	@ °F	@ °F	
Source R_{mf} / R_{mc}			
R_m @ BHT	@ °F	@ °F	
Time Since Circ.	5 HOURS		
Max. Rec. Temp.	°F	°F	
Recorded By	WALKER		
Witnessed By	BROWN		

BORE-HOLE RECORD				CASING RECORD			
BIT No.	Bit	From	To	Size	Wgt.	From	To
	7-7/8	99'	1524	8-5/8		GL	99'

Run No.	ONE
Operating Rig Time	1-1/2
Logging Truck No.	2512
P.T. Truck No.	2363
P.T. Engineer	FILBECK
P.T. Operator	
Location	Mt. STN.
REMARKS:	

PRESSURE RECORDING
PSI x 1000

Test No. 1

2.0 1.5 1.0 .5

CALIBRATION

TIME IN MINUTES

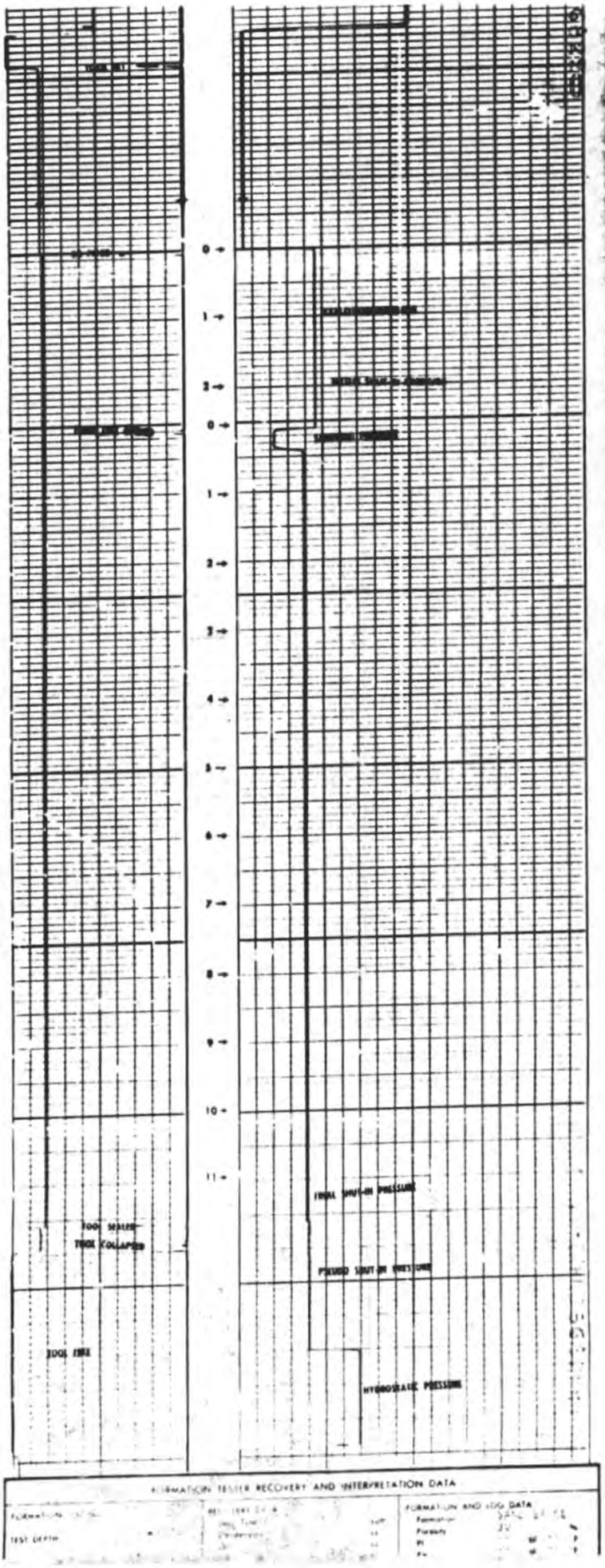
SURFACE CONTROLS

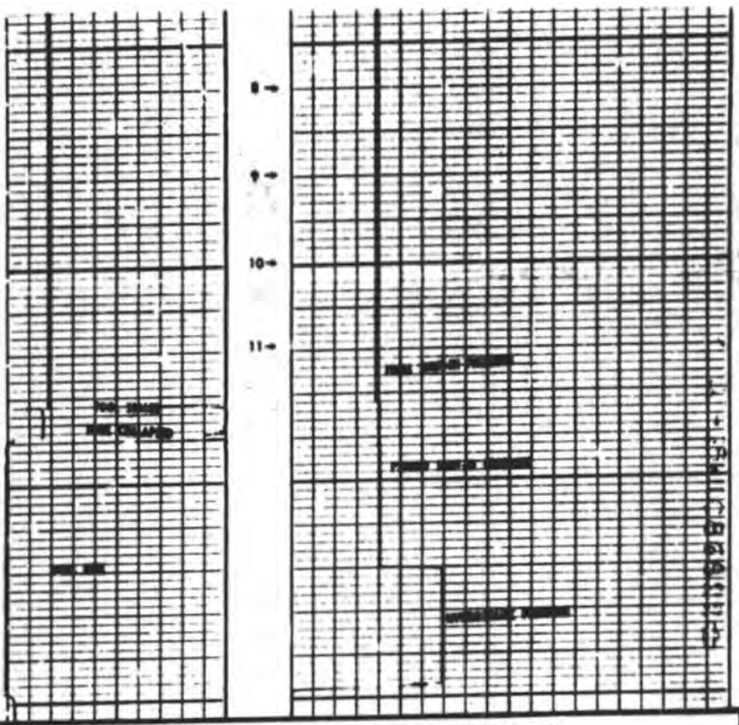
PAD ACTION

FIRING

PRESSURE INCREASE

TOOL SET


0
1
2
0
1
2
3
4
5
6
7
8
9
10
11
FINAL SHUT-IN PRESSURE
TOOL SEALED
TOOL COLLAPSED
PRIMED SHUT-IN PRESSURE
TOOL TIME
HYDROSTATIC PRESSURE
FORMATION TESTER RECOVERY AND INTERPRETATION DATA
TEST DEPTH
FORMATION AND TOOL DATA



FORMATION TESTER RECOVERY AND INTERPRETATION DATA

FORMATION TEST NO.	ONE	RECOVERY DATA		FORMATION AND LOG DATA	
TEST DEPTH	1430-32-1/2	Gas (Total)	.6 cuft	Formation	SAND STONE
OPEN HOLE TEST	X	Condensate	-- cc	Porosity	30 %
CASED HOLE TEST	☐	Oil	-- cc	Sp	-- @ -- °F
		Water	20400 cc	Sw	-- @ -- °F
		Mud	-- cc	Equivalent Cl	ppm
		Sand	-- cc	Water Saturation	%
PRESSURE DATA		RECOVERY ANALYSIS		MUD FILTRATE DATA	
Initial Shut In	460 psi	Free Gas	-- cuft	Sw	.09 @ 100 °F
Shut In Time	2-1/2 mins	Oil		Equivalent Cl	--- ppm
Sampling	220 psi	API Gravity	-- °@ -- °F		
Sampling Time	20 SEC	GOR	--	TOOL DATA	
Final Shut In	390 psi	Water		Type Tool	F-H-A 84
Shut In Time	0 mins	Sw (Filtered)	.23 @ 100 °F	Type Sample Shut	4-5/8 H.P.
Hydrostatic	700 psi	Equivalent Cl	20000 ppm	Sample Unit Size	20400 cc
Surface Chamber	200 psi	Formation Water	-- %	Choke Size	NONE

RESULTS INDICATE THAT WATER MAY BE EXPECTED AT THIS DEPTH.

REMARKS

GAS ANALYSIS		
Free Gas	--	Cuft
Sour Gas	.6	Cuft
Solution Gas	--	Cuft
Total Gas	.6	Cuft

The above interpretations represent our best judgment, and we are happy to give them to you. Nevertheless, since all interpretations are based on inferences from electrical and other measurements, we cannot and do not guarantee their accuracy or correctness, and we shall not be liable or responsible, except in the case of willful negligence on our part, for any loss, costs, damages or expenses that may be incurred or sustained from such interpretations.

COMPANY MURPHY OIL CORPORATION

WELL COURCHENE 1-D

FIELD VOLT

COUNTY ROOSEVELT STATE MONTANA

FORMATION TESTER

COMPANY MURPHY OIL CORPORATION

WELL CONCHITE #9

FIELD WILDCAT

COUNTY ROOSEVELT STATE MONTANA

LOCATION SE SE 4 Twp. 30N Rge. 44E

Other Services: SL/C

Elev.: K.B. 2856 D.F. G.L. 2842

Date 7-2-85

Type Fluid in Hole: SALT BASE

Max. Rec. Temp. 110°F

Equip. Location 1-37/46630

Recorded By

Witnessed By

RECEIVED AUG 1985

FOLD HERE

THIS RECORDING AND LOG CONFORMS TO API RP 31

REMARKS

Equipment Data

Type Log	Depth	Scale Changes
GAMMA RAY	5200	0 1200

Bit Record

Run No.	Tool Type	Bit Size	Type	Depth In	Depth Out	Footage	Hours

Borehole Record

Bit No.	From	To

Casing Record

Size	Wgt.	Grade	Type Joint	New	Used	From	To

Mud Record

Type	Viscosity	Density	Resistivity	Water Loss	Mud Resistivity	Mud Cake

Source of Sample

Rm @ Meas. Temp.

Rmf @ Meas. Temp.

Rmc @ Meas. Temp.

Source Rmf Rmc

Rm @ BHT

Rmf @ BHT

Rmc @ BHT

Max. Recd. Temp. °F

Equipment Ratings

Run No.	Tool Type	Bit Size	Type	Depth In	Depth Out	Footage	Hours

Equipment Locations

Recorded By

Witnessed By

Equipment Ratings

CASY. No.

PIPE No.

SOCKET No.

MAIN WIDTH 1"

GUARD LENGTHS 5"

GAMMA RAY

API UNITS

0 0 120 120 240

Depths

LATEROLOG

CONDUCTIVITY

1000 500 0

RESISTIVITY

0 8 16 25 50 ∞

4 12 20 33 100

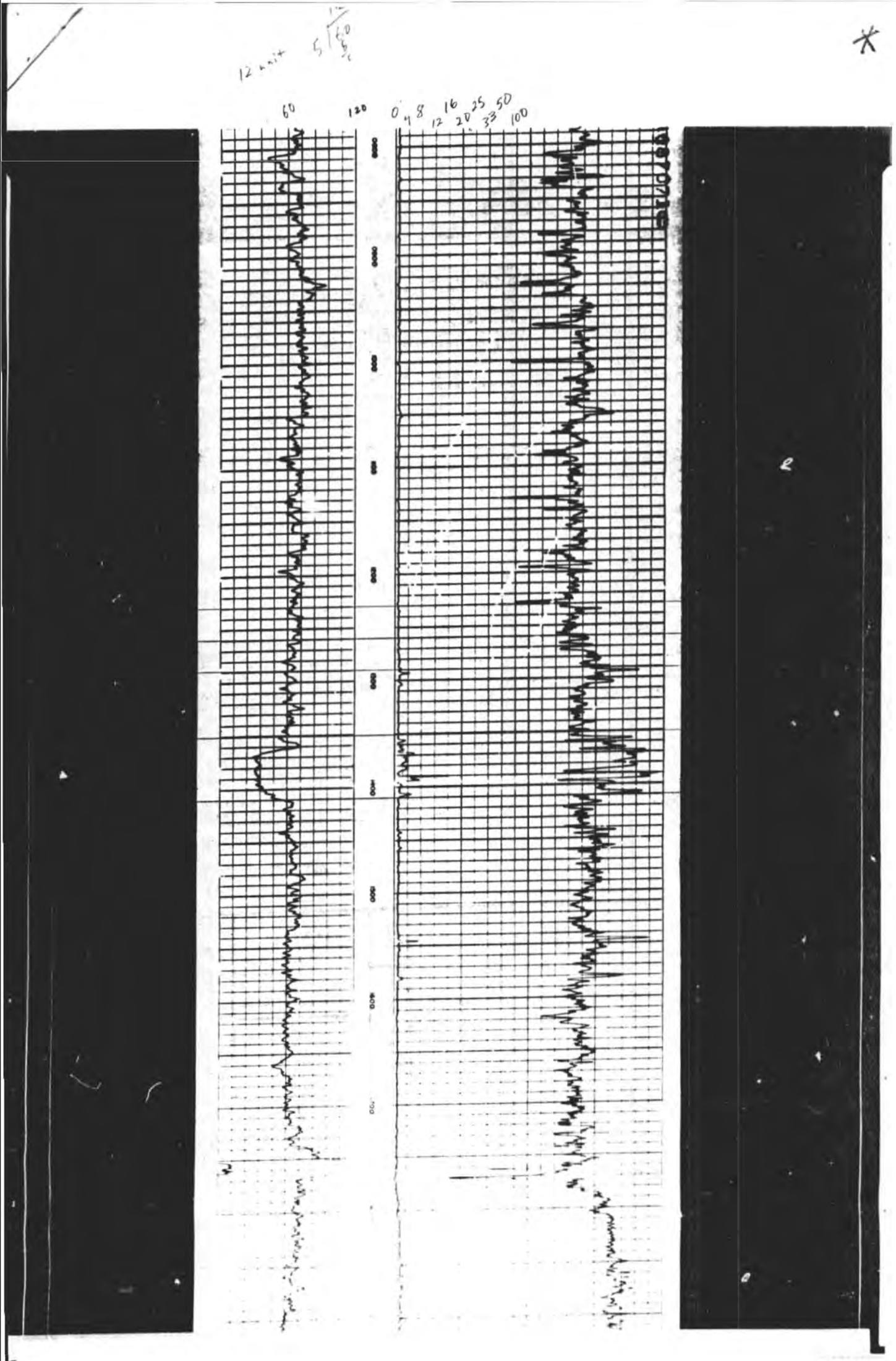
Calibration

Calibration

Elec. Zero

Mech. Zero

0000


12 unit
60
120
0
4
8
12
16
20
25
33
50
100

COMPANY MURPHY OIL CORPORATION

WELL CONGRESS #2

FIELD WILDCAT

COUNTY MINERAL STATE MONTANA

LOCATION SE SE 4 Twp. 30N Rge. 44E

Elev. K.B. 2856 D.F. G.L. 2843

Date 7-2-65

Depth Driller 10,000

Depth Logger 10,000

Bottom Log Interval 10,000

Top Log Interval 3750

Casing Driller 13 3/8 @ 1155

Casing Logger

Bit Size 12 1/4

Type Fluid in Hole SALT BASE

Dens. | Visc.

pH | Fluid Loss ml

Source of Sample

Rm @ Meas. Temp. @ °F

Rmf @ Meas. Temp. @ °F

Rmc @ Meas. Temp. @ °F

Source: Rmf | Rmc

Rm @ BHT @ °F

Rmf @ BHT @ °F

Rmc @ BHT @ °F

Time Since Circ. 5 HOURS

Max. Rec. Temp. 177 °F

Equip. Location 7-30

Recorded By KSS

Witnessed By

RECEIVED AUG 2 1965

COLD HOLE

REMARKS

Changes in Mud Type or Additional Samples

Date | Sample No.

Depth | Cause

Type Fluid in Hole

Dens. | Visc.

pH | Fluid Loss ml

Source of Sample

Rm @ Meas. Temp. @ °F

Rmf @ Meas. Temp. @ °F

Rmc @ Meas. Temp. @ °F

Source: Rmf | Rmc

Rm @ BHT @ °F

Rmf @ BHT @ °F

Rmc @ BHT @ °F

Equipment Data

Type Log	Depth	Scale Up Hole			Scale Down Hole		
SONIC	9,980	240	140	40	100	60	40

Run No.	Tool Type	Tool Position	Other

C.D. S.O.

Equip. Used: CART. No.

PAPER No.

BOTTOM No.

Velocity (feet per second) = 1,000,000 / Interval Transit Time (microseconds per foot)

DEPTHS

INTERVAL TRANSIT TIME

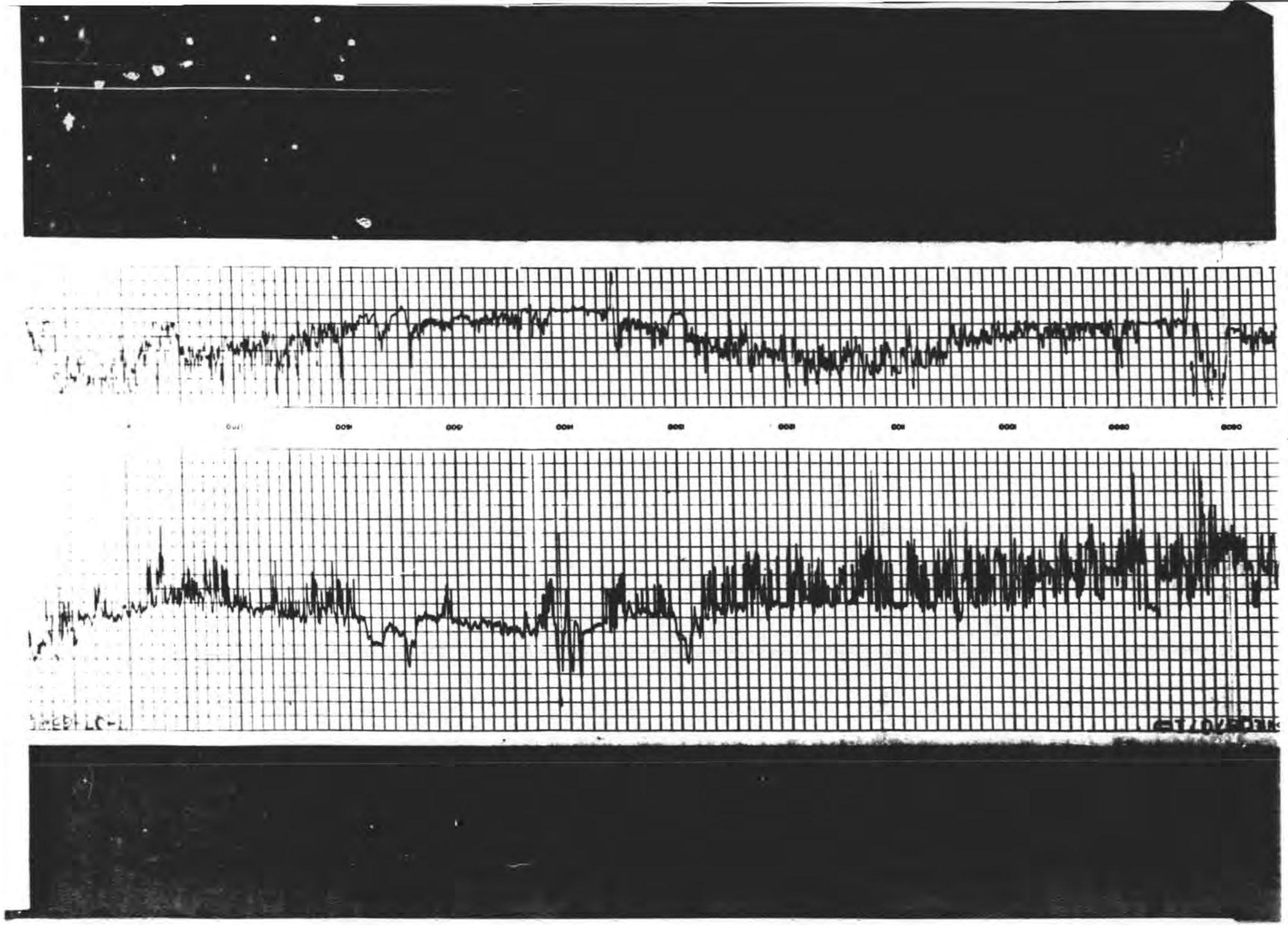
MICROSECONDS PER FOOT

240 140 40

CALIPER

HOLE DIAM. IN INCHES

6 11 16



COMPANY SIGNAL DRILLING & EXPLORATION CORP.

WELL MICHAEL BLUE HORSE # 1

FIELD VOLT

COUNTY ROOSEVELT STATE MONTANA

LOCATION 1740' S/N & W/E SE 1/4, (NE SWSE) Sec. 4 Twp. 30N Rge. 46E

Other Services: SL/C

Elev.: K.B. 2690 D.F. G.L. 2677.2

Permanent Datum: Gl. Log Measured From: KB. Drilling Measured From: KB. 12 ft. Above Perm. Datum

Date	10-7-64
Run No.	ONE
Driller	6700
Logger	6685
Bottom Log Interval	6680
Top Log Interval	4407
Casing: Driller	8-5/8" @ 406
Casing: Logger	407
Bit Size	7-7/8"
Type Fluid in Hole	SALT-OIL EMULSION
Dens. / Visc.	10.6 48
pH / Fluid Loss	9.4 1.49 ml ml
Source of Sample	P.I.T.
Rm @ Meas. Temp.	.072 @ 70
Rmf @ Meas. Temp.	.042 @ 75
Rmc @ Meas. Temp.	---- @ --
Source: Rmf / Rmc	FP
Rm @ BHT	.036 @ 145
Time Since Circ.	5 HOURS
Max. Rec. Temp.	145
Equip. Location	6553 W.S.W.
Recorded By	GIFFORD
Witnessed By	MR. RABELLA

COUNTY ROOSEVELT, MONT.
FIELD or
LOCATION VOLT
WELL MICHAEL BLUE HORSE # 1
COMPANY SIGNAL DRILLING

FOLD HERE — THIS HEADING AND LOG CONFORMS TO API RP 31

REMARKS

Changes in Mud Type or Additional Samples

Date	Sample No.			
Depth – Driller				
Type Fluid in Hole				
Dens. / Visc.				
pH / Fluid Loss		ml		
Source of Sample				
R_m @ Meas. Temp.	@	°F	@	°F
R_{mf} @ Meas. Temp.	@	°F	@	°F
R_{mc} @ Meas. Temp.	@	°F	@	°F
Source: Rmf / Rmc				
R_m @ BHT	@	°F	@	°F
R_{mf} @ BHT	@	°F	@	°F
R_{mc} @ BHT	@	°F	@	°F

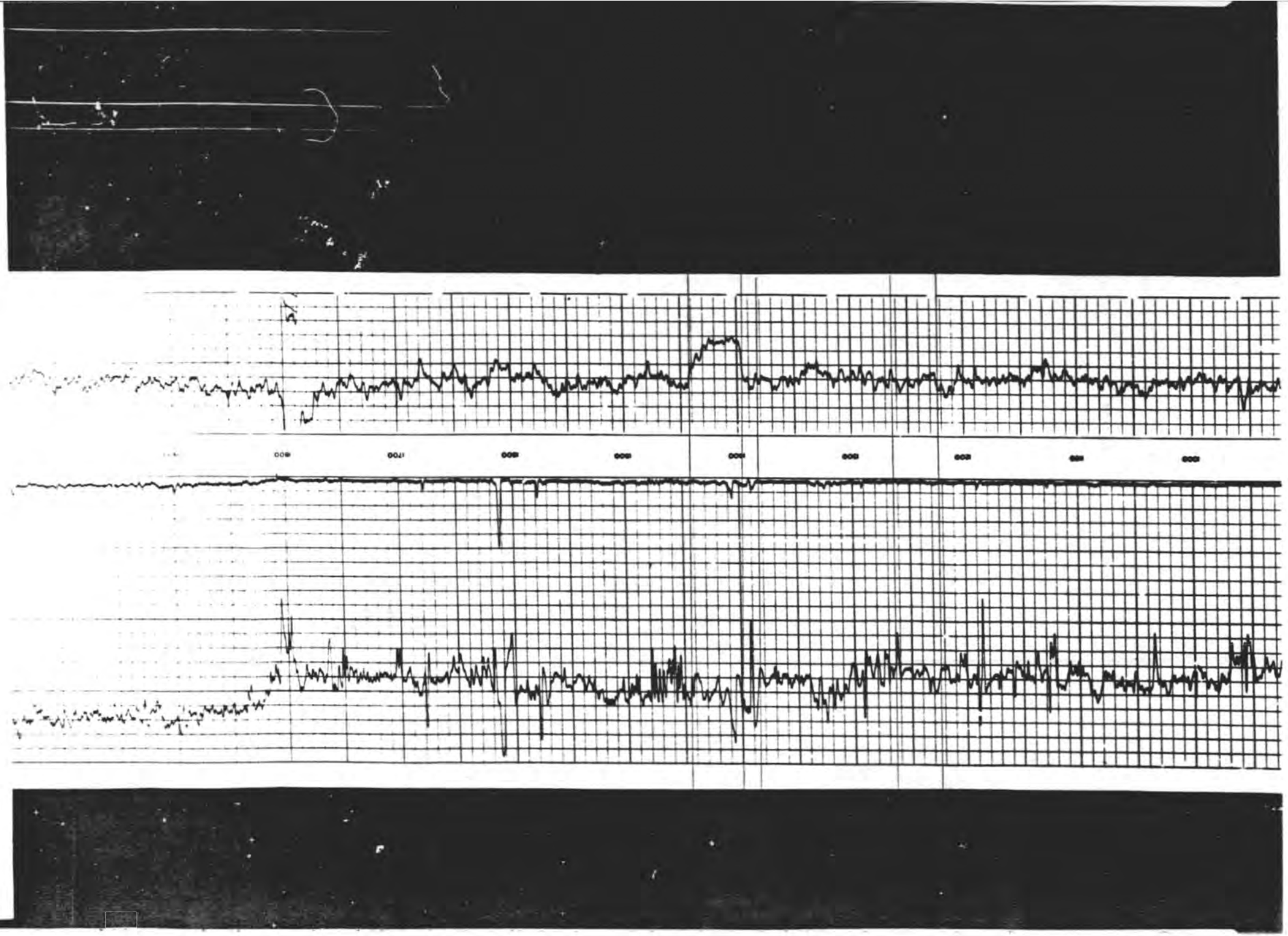
Equip. Used: CART. No. A-39
PANEL No. A-61
SONDE No. B-17
Spacing: BEAM WIDTH: 1'
GUARD LENGTH: 5'

Scale Changes

Type Log	Depth	Scale Up Hole	Scale Down Hole
GAMMA RAY	5443	0 120	0 60

Equipment Data

Run No.	Tool Type	Field Type	Tool No.	Other



COMPANY: EXPLORATION, INC.

WELL: NO. 1-2 SUNNIE ET AL

FIELD: SOUTH VALY

COUNTY: ROOSEVELT STATE: MONTANA

Elevation: G.L. 2763 Elev.: K.B. 2768 D.F. ---- G.L. 2763

Permanent Datum: G.L. Log Measured From: K.B. Drilling Measured From: K.B.

15 ft. Above Perm. Datum

Date: 12-7-77

Run No.: ONE

Depth-Driller: 1760'FTL-1160'FSL

Depth-Logger: 1760'FTL-1160'FSL

Bottom Log Interval: 1760'

Top Log Interval: SURF.

Casing-Driller: 13 3/8" @ 1007'

Casing-Logger: NONE

Bit Size: 12 1/4"

Type Fluid in Hole: WATER

Dens. / Visc.: 8.4 / 28

pH / Fluid Loss: 7 / NA

Source of Sample: PUMPED

Rm @ Meas. Temp.: .75 @ 75°F

Rmf @ Meas. Temp.: .60 @ 75°F

Rmc @ Meas. Temp.: .90 @ 75°F

Source: Rmf / Rmc: MEASURED / MEASURED

Rm @ BHT: .35 @ 150°F

Time Since Circ.: 12 HRS.

Max. Rec. Temp.: 150°F

Equip. Location: MC/GOL-48

Recorded By: BOB-GR

Witnessed By: MR. ALLEN

FOLD HERE

The well name, location and borehole reference data were furnished by the customer.

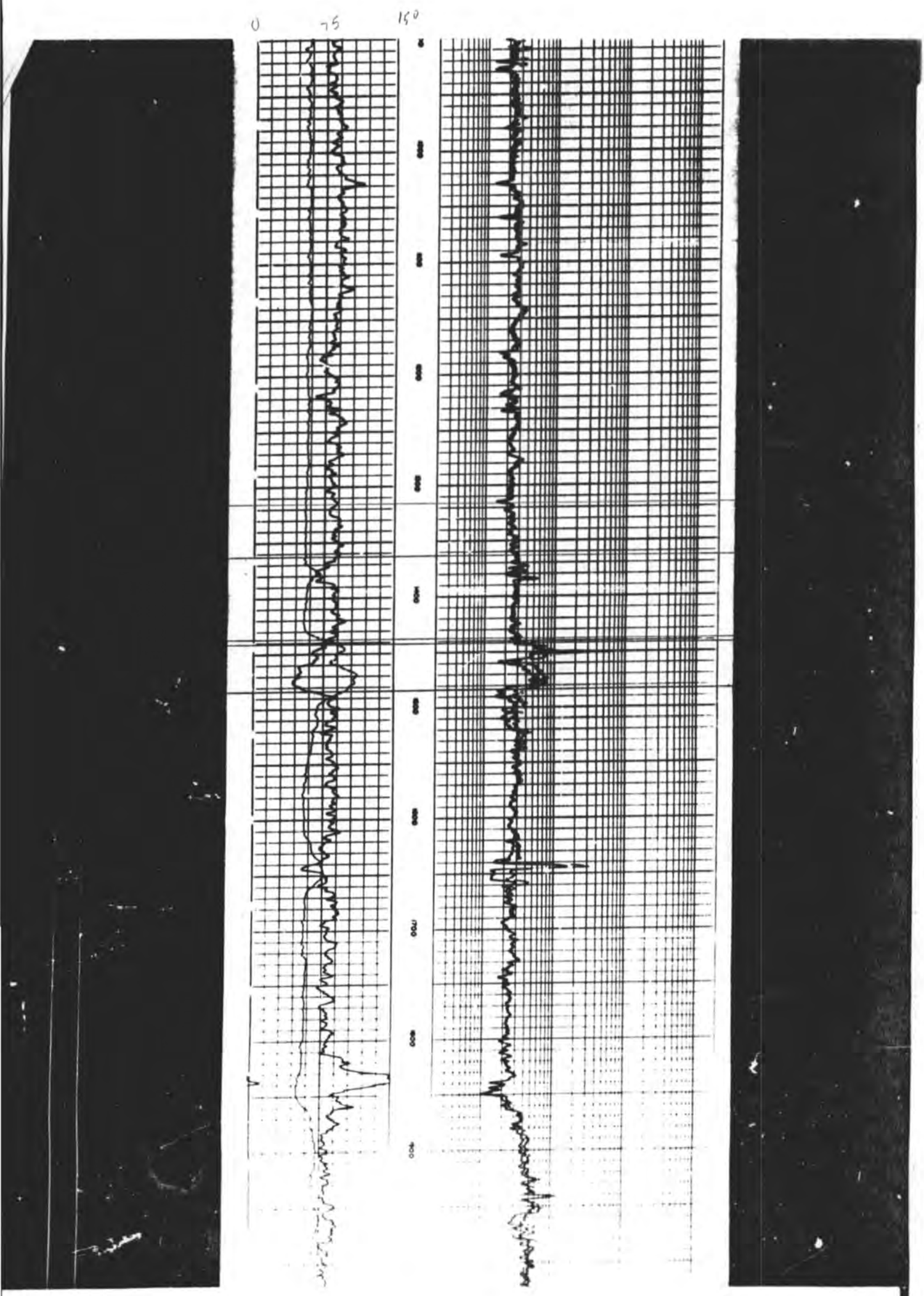
Well No.	ONE				
Service Order No.	65232				
Fluid Level	FULL				
Drilling, Wait Cl.	--				
EQUIPMENT DATA					
Panel (DIP)	DLL-B-844				
Panel (SFP)	SFL-PC-848				
Controller (DLC)	DLC-B-838				
Controller (SFC)	--				
Sonde (DLS)	DLS-B-838				
Sonde (SFS)	--				
Lower Electrode (DLE)	DLE-B-83				
Monitor Panel	MM-AB-777				
Voga Recorder (VR)	VR-PB-01-42				
Depth Recorder (DR)	DR-PC-844				
Pressure Wheel (PW)	PW-PC-1743				
Controller Inner Gating Sonde	Type	PSC-CM			
	No.	1			
	I.D. Inches	--			
DATA ENTRY DATA					
GR	Strip Chart	--			
	Source CP2	--			
RECORDING DATA					
GR	Sensitivity	100			
	Scale - 100 Div.	0-100			
	T. C. - sec	1			
Speed MM		4			
TIME ON WELL @ TERMINATION					
Time Entering Hole		1300			
Time Bottom Reached		1330			
Time Last Off Bottom		1400			
Time Out of Hole		1630			
Distance TD to Therm.		25			
Thermometer #1		155 F	F	F	F
Thermometer #2		F	F	F	F
Thermometer #3		F	F	F	F
Rw FROM DRILL STEM TEST					
DST #1 - Rw @ 100 °F		LBM	LBM	LBM	LBM
DST #2 - Rw @ 100 °F		LBM	LBM	LBM	LBM

Type Log	Depth	Scale Up Hole	Scale Down Hole
DIL	2800	0-100	0-100

REMARKS

All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretations and we shall not except in the case of gross or willful negligence on our part be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule.

unit 15



COMPANY EXXON EXPLORATION, INC.

WELL NO. 1-7 GERMAN LT AL

FIELD SOUTH WALT

COUNTY BERGEN STATE NORWAY

Permanent Datum: Log Measured From: Drilling Measured From:

Elev.: K.B. 2782 D.F. G.L. 2762

Date 8-10-77

The well name, location and borehole reference data were furnished by the customer.

Run No.	ONE
Service Order No.	22552
Fluid Level	FULL

Run No.	Bit Size	Scale Up Hole	Scale Down Hole
1	8.5	140-80-40	80-40-20
2	8.5	20-10-0	21-10-0
3	8.5	0-100	0-100

Logging Unit No.	SLP-J-662
Logging Panel No.	SLC-GA-588
Logging Console No.	SLS-GA-1182
Power Panel No.	MMS-AR-777
Log. Cont. No.	SGC-JAA-1741
Log. Panel No.	CMP-A-522
Collar No.	VCS-D-912
Log No.	TTR-KB-1842
Cassettes No.	1
Type	VCD
Sinker Bar No.	
Type	-1/2"
Time Const. Sec.	2
Speed F/M	30

Δt/m	Δt/f	Cp
7.6	100	100
6.4	100	100

Run	From	To
1	3400	5000
2	5000	6017

Rec. CPS	156
Source CPS	500
Ht F.	8

REMARKS

A SCALE CALIBRATED WRONG. THE LOG WAS RE-SCALED TO SHOW CORRECTLY. ABOVE 5000' A SCALE IS 33 TO 21. BELOW 5000' A SCALE IS 21 TO 7.

Velocity (ft/sec) = 1,000,000 / Interval Transit Time (microseconds per foot)

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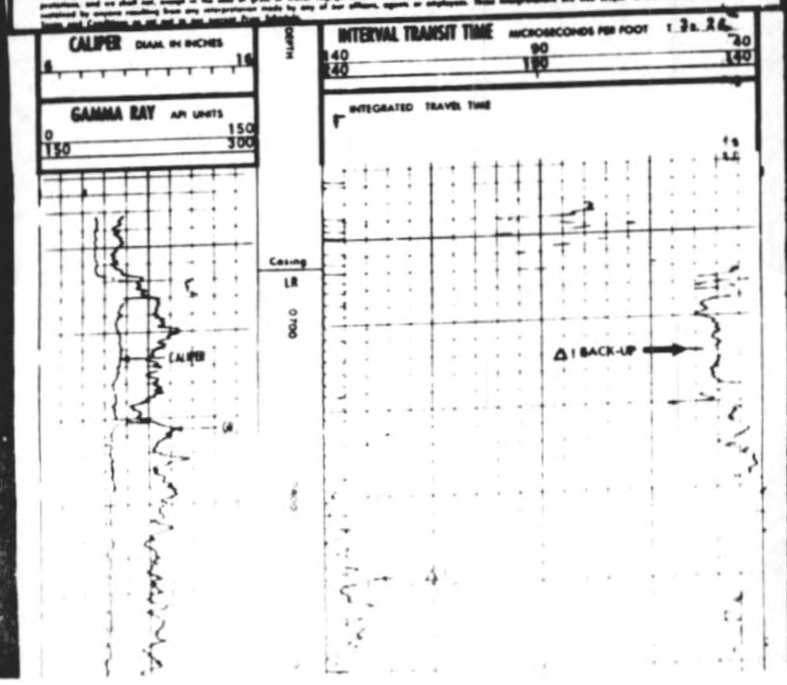
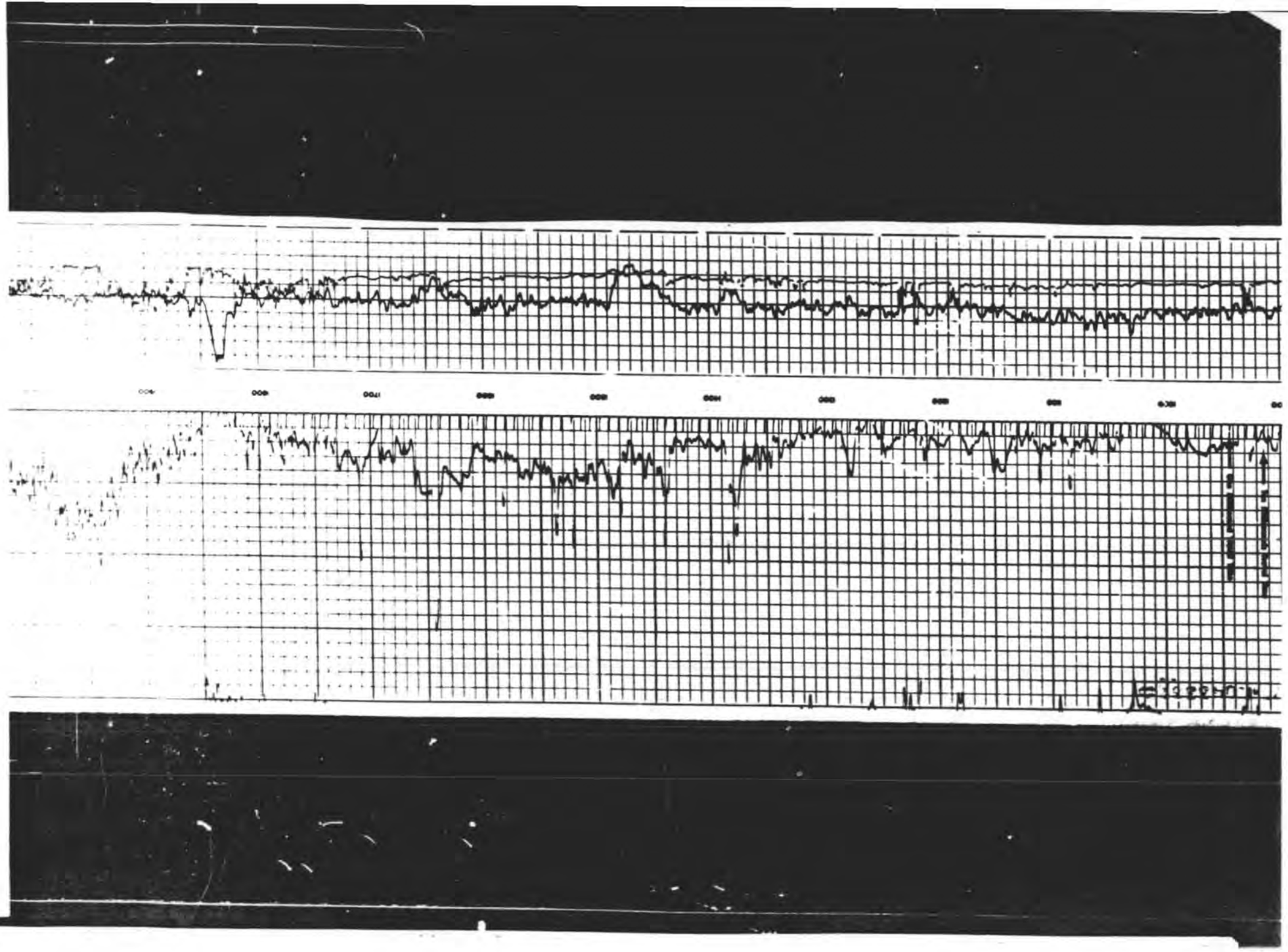




*

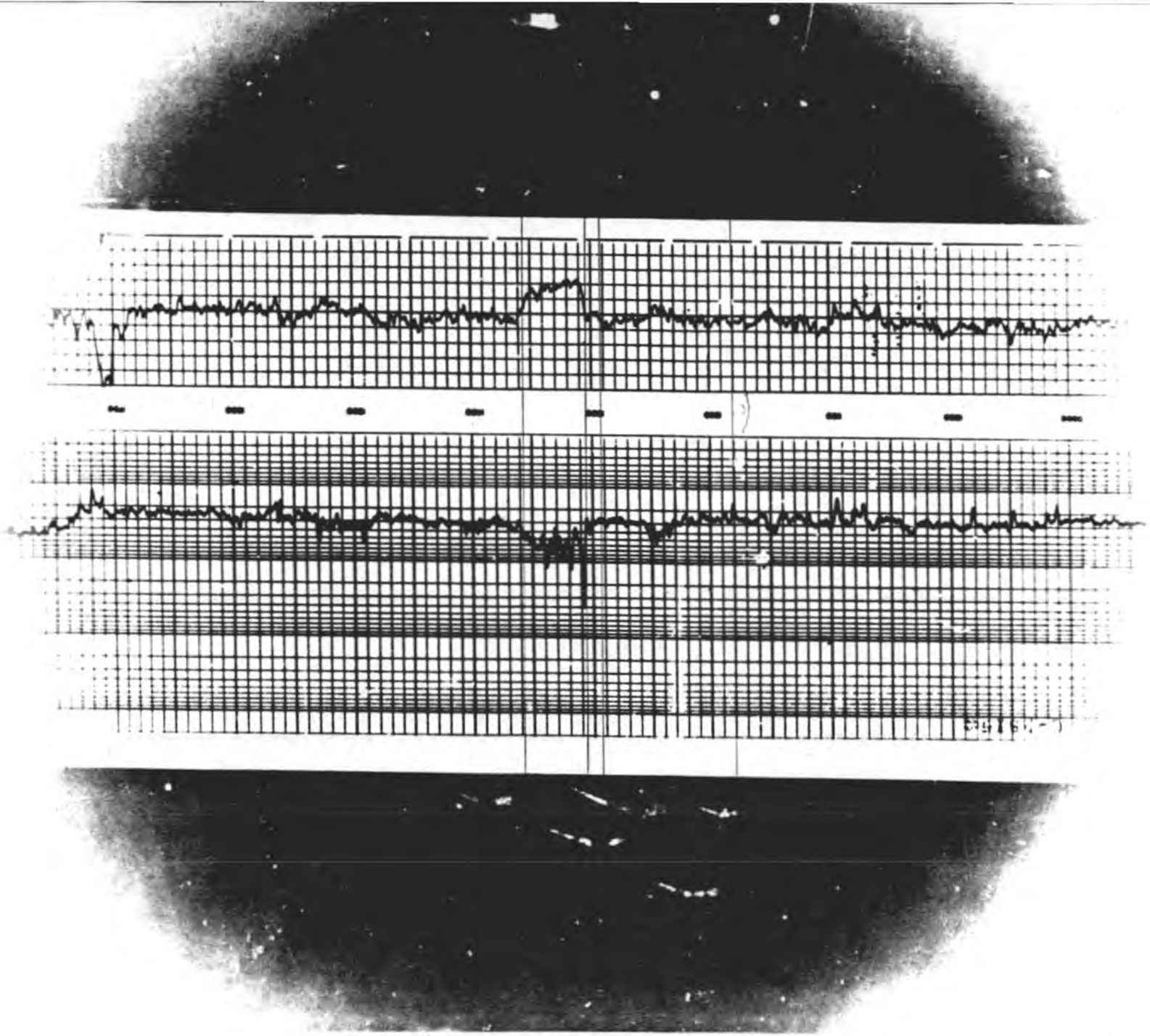
9

Reproduced By
Electrical Log Services
Midland, Texas 79701

REFERENCE K 65N

ELSI

COMPLETION RECORD



*

COMPANY MURPHY OIL CORPORATION

WELL DONAHUE, #1

FIELD WILT

COUNTY ROOSEVELT STATE MONTANA

Location SW/4 1980' FSL 1980' FWL

Sec. 8 Twp. 30N Rge. 49E

Other Services SGR-C

Elev.: K.B. 2270 D.F. G.L. 2262

Date 7-15-65

Run No. ONE

Depth-Driller 10 000

Depth-Logger 10 000

Bottom Log Interval 10 000

Top Log Interval 9500

Casing-Driller 9 5/8 @ 1265'

Casing-Logger 9 5/8 @ 1265'

Bit Size 8 3/4

Type Fluid in Hole FRESH WATER

Dens. 8.4 Visc. 60

pH 10 Fluid Loss 10 ml

Source of Sample PIT

R_m @ Meas. Temp. @ °F

R_mf @ Meas. Temp. @ °F

R_mc @ Meas. Temp. @ °F

Source: R_mf Rmc

R_m @ BHT @ °F

R_mf @ BHT @ °F

R_mc @ BHT @ °F

Max. Rec. Temp. 110-2/4hr13 °F

Equip. Location 917

Recorded By SIM

Witnessed By SIM

RECEIVED JUL 30 1965

Elev. 2268

14 Ft. Above Perm. Datum

Log Measured From KB

Drilling Measured From KB

REMARKS

Changes in Mud Type or Additional Samples

Date | Sample No.

Depth—Driller

Type Fluid in Hole

Dens. | Visc.

pH | Fluid Loss ml

Source of Sample

R_m @ Meas. Temp. @ °F @ °F

R_mf @ Meas. Temp. @ °F @ °F

R_mc @ Meas. Temp. @ °F @ °F

Source: R_mf | Rmc

R_m @ BHT @ °F @ °F

R_mf @ BHT @ °F @ °F

R_mc @ BHT @ °F @ °F

Equipment Data

Run No.	Tool Type	Tool Position	Other
ONE	6FF40	1-1/2" STANDOFF	

Equip. Used: CART. No.: IRC-F-73

PANEL No.: IRP-F-211

SONDE No.: IRS-H-241

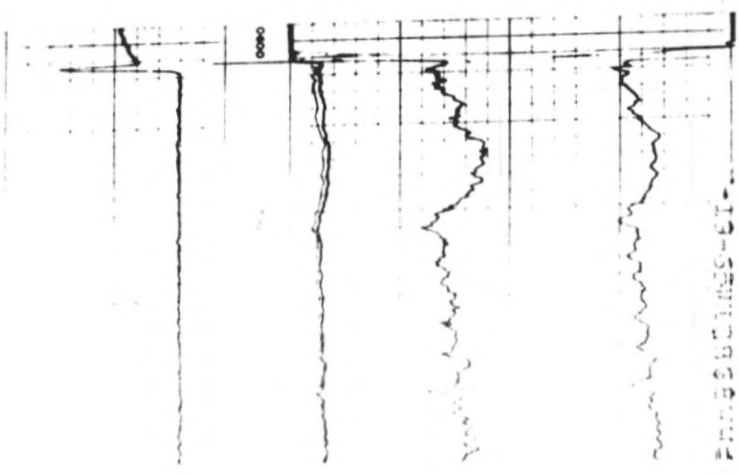
B.B.: 1

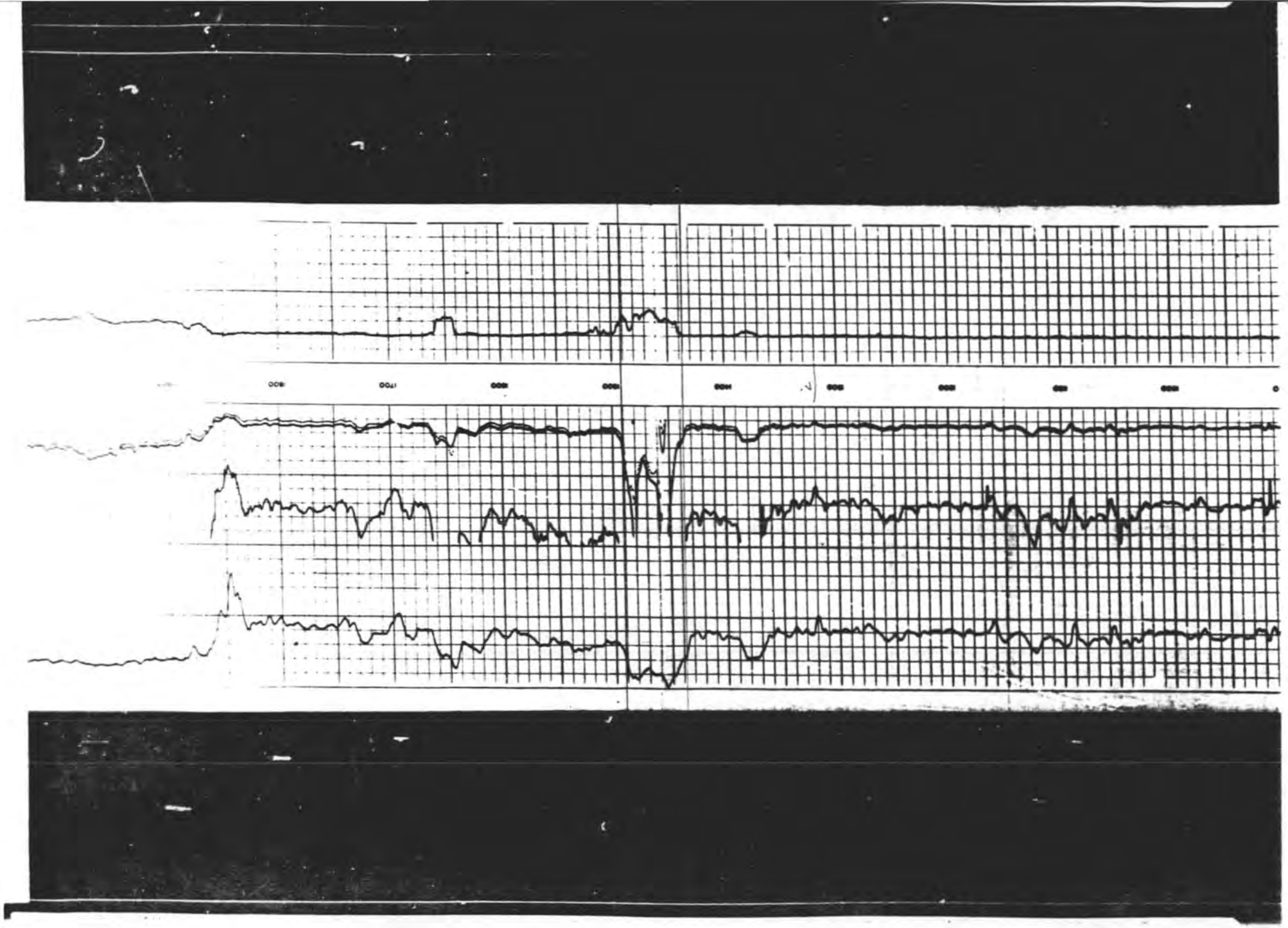
Run No.: ONE

C.O.: USED

S.O.: 1-1/2"

SPONTANEOUS POTENTIAL millivolts	DEPTHS	RESISTIVITY ohms - m²/m	CONDUCTIVITY millimhos/m = 1000/(ohms-m²/m)
- 10 +		A-16"-M SHORT NORMAL 0 – 20	6 FF40 INDUCTION 1000 – 0
		0 – 200	2000 – 1000
		INDUCTION 0 – 20	
		0 – 200	




1500
1000
500
0
20
0

RECEIVED

OIL CORPORATION

Elev.: K.B. 2770
D.F.
G.L. 2756

REMARKS RUN # 2 - GAMMA RAY TRACED FROM LATEROLOG GAMMA RAY LOG

Changes in Mud Type or Additional Samples			Scale Changes			
Date / Sample No.			Type Log	Depth	Scale Up Hole	Scale Down Hole
Depth—Driller			SONIC	5123	150-100-50	80-60-40
Type Fluid in Hole			GAMMA RAY	5400	0-120	0-60
Dens. / Visc.						
ph / Fluid Loss	ml					
Source of Sample						

			Equipment Data				
			Run No.	Tool Type	Pad Type	Tool Pos.	Other
R_m @ Meas. Temp.	@ °F	@ °F	ONE	SGC-E		CENTERED	
R_{mf} @ Meas. Temp.	@ °F	@ °F		VAC-D			
R_{mc} @ Meas. Temp.	@ °F	@ °F					
Source: R_{mf} / R_{mc}							
R_m @ BHT	@ °F	@ °F					
R_{mf} @ BHT	@ °F	@ °F					
R_{mc} @ BHT	@ °F	@ °F					

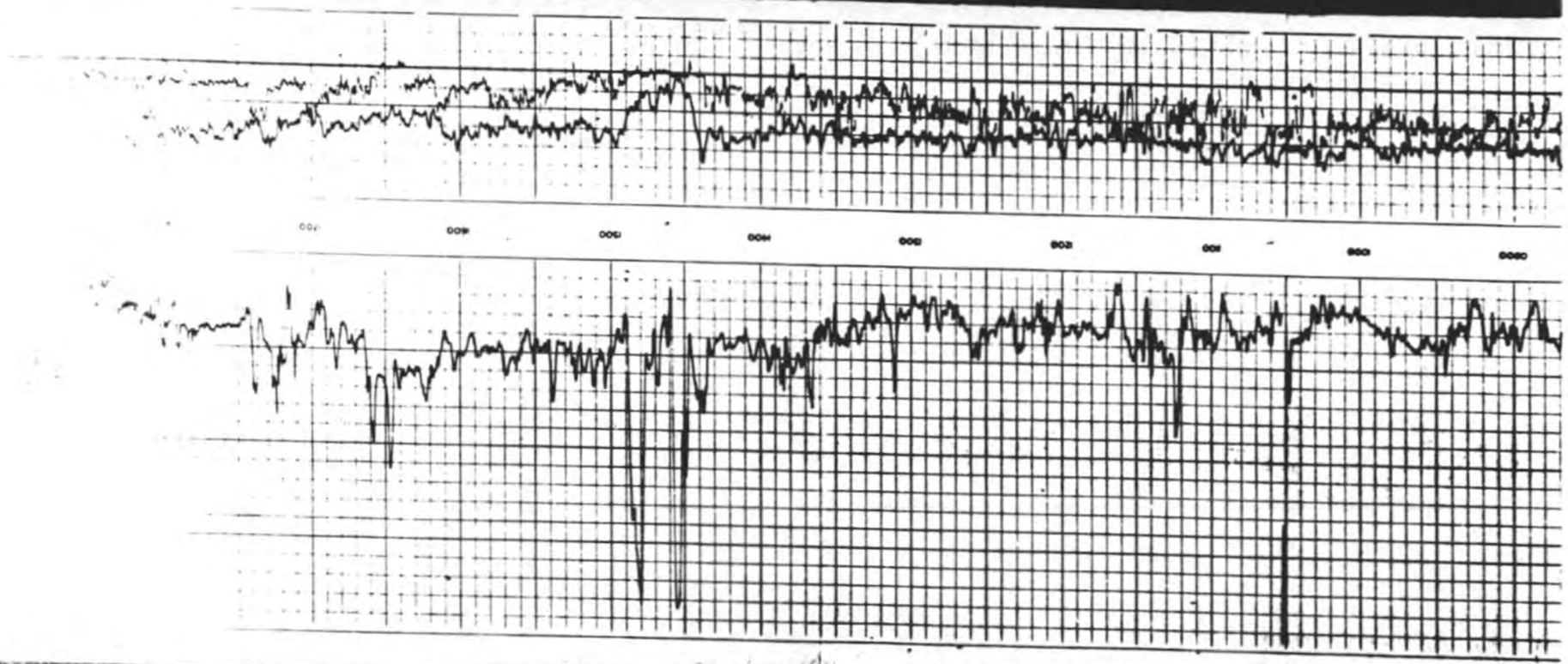
C.D. USED S.O.: CENTERED WITH CENTER OF GRAVITY GUIDE PLUS CALIPER.

Equip. Used:			
CART. No.	VAC-D-150	RUN # 2	VAC-D-150
PANEL No.	VLP-C-429		VLP-B 108
SONDE No.	VLS-J-41		VLS-J-41

CALIBRATION:	BACKGND. CPS.	SOURCE CPS.	GALV INCR. DIVISIONS	SENS. TAP (FOR CAL.)	SENS. TAP (RECORD)	TIME CONST.	RECORDING SPEED (FT./MIN.)
GAMMA RAY:	70	450	8 25	500		6	
					300	1	60
					150	2	30

$$\text{Velocity (feet per second)} = \frac{1{,}000{,}000}{\text{Interval Transit Time (microseconds per foot)}}$$

GAMMA RAY API UNITS	DEPTHS	INTERVAL TRANSIT TIME MICROSECONDS PER FOOT
0 — 120		150 — 100 — 50
120 — 240		250 — 200 — 150
CALIPER HOLE DIAM. IN INCHES		



COMPANY PLACID OIL COMPANY

WELL BC PARSONS #1

FIELD WILDCAT

COUNTY BERNALILLO STATE NEW MEXICO

Other Services SL/S

Elev.: K.B. 7218 D.F. 7200 G.L. 7200

Date 8 Twp. 20N Rge. 4W

Elev.: 7203

15 ft. Above Perm. Datum

API-30

FOLD HERE

THIS RECORD HAS BEEN CONFORMED TO API RECOMMENDED STANDARD PRACTICE RP-31

REMARKS RMF .021 @ BHT (155°F)

Changes in Mud Type or Additional Samples

Date Sample No.

Depth - Driller

Type Fluid in Hole

Dens. Visc.

pH Fluid Loss

Source of Sample

Rm @ Meas Temp. @ °F @ °F

Rmf @ Meas Temp. @ °F @ °F

Rmc @ Meas Temp. @ °F @ °F

Source: Rmf Rmc

Rm @ B. H. T. @ °F @ °F

Rmf @ B. H. T. @ °F @ °F

Rmc @ B. H. T. @ °F @ °F

Type Log	Depth	Scale Changes: Scale Up Hole		Scale Down Hole	
GAMMA RAY	6300	0	120	0	60
		120	240	60	120

Run No.	Tool Type	Background Data: Rad Type	Tool Position	Other
ONE	LGT-B			

CALIBRATION: GAMMA RAY:	Backgnd. C.P.S.	Test S. + Bkgd. C.P.S.	Galv. Incr. (Divisions)	Sens. Top (Per Cal.)	Sens. Top (Record)	Time Const.	Record. Speed (ft./Min.)
	71	410	8.25	500		0	
GR INTERVAL					300	1	90
CSG - 6300					150	2	30
6300 - TD							

NEUTRON:	Test S. Per	Test S. Close	Galv. Incr. (Divisions)	Sens. Top (Per Cal.)	Sens. Top (Record)	Time Const.	Record. Speed (ft./Min.)

GAMMA RAY

API UNITS

GAMMA RAY ZERO OF THE LINE — DIV. TO LEFT

0 120

120 240

DEPTHS

LATEROLOG

BEAM WIDTH - 1", GUARD LENGTH = 5'

CONDUCTIVITY

MILLI-MHOS (1/1000/OHM M)

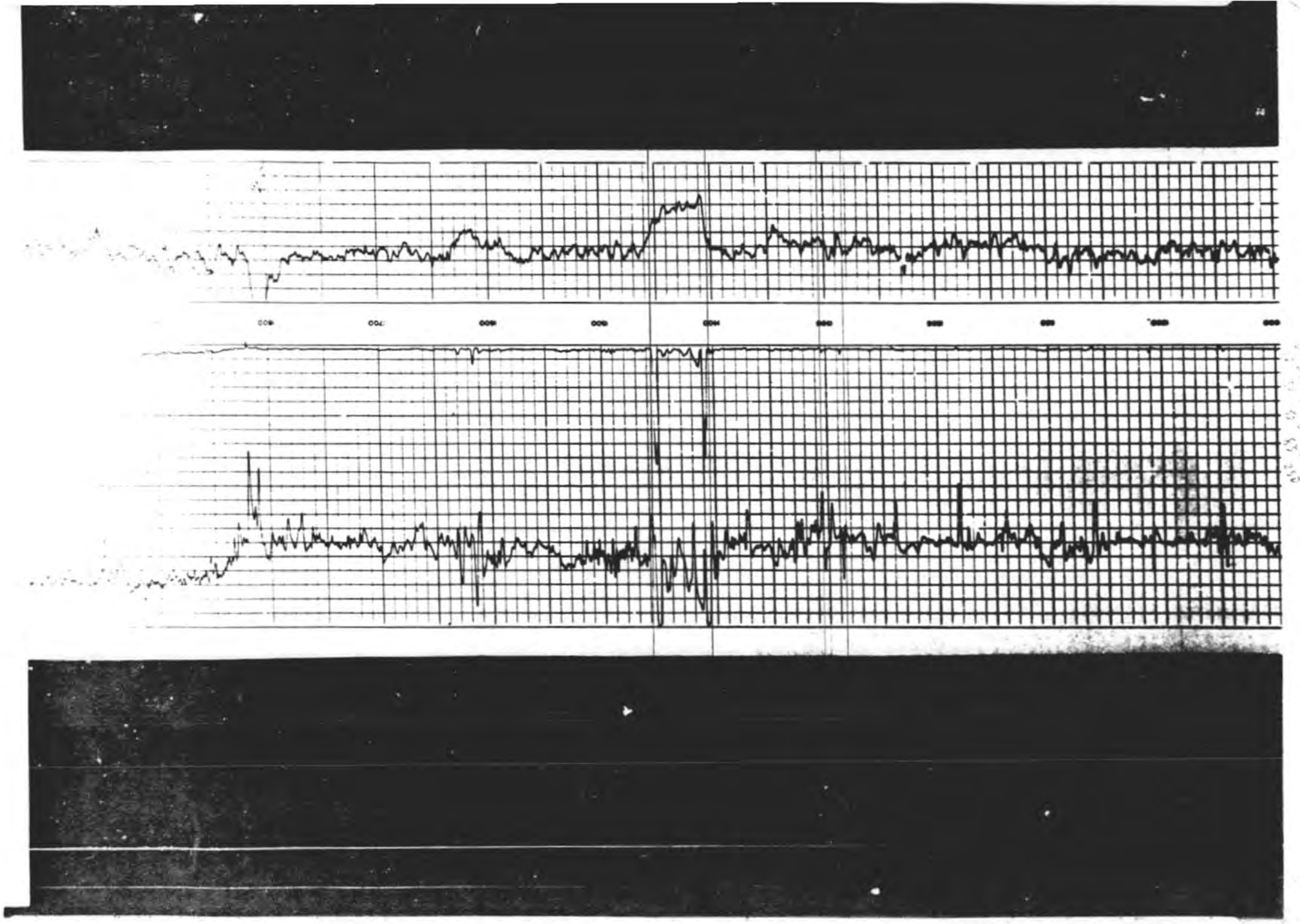
1000 500 0

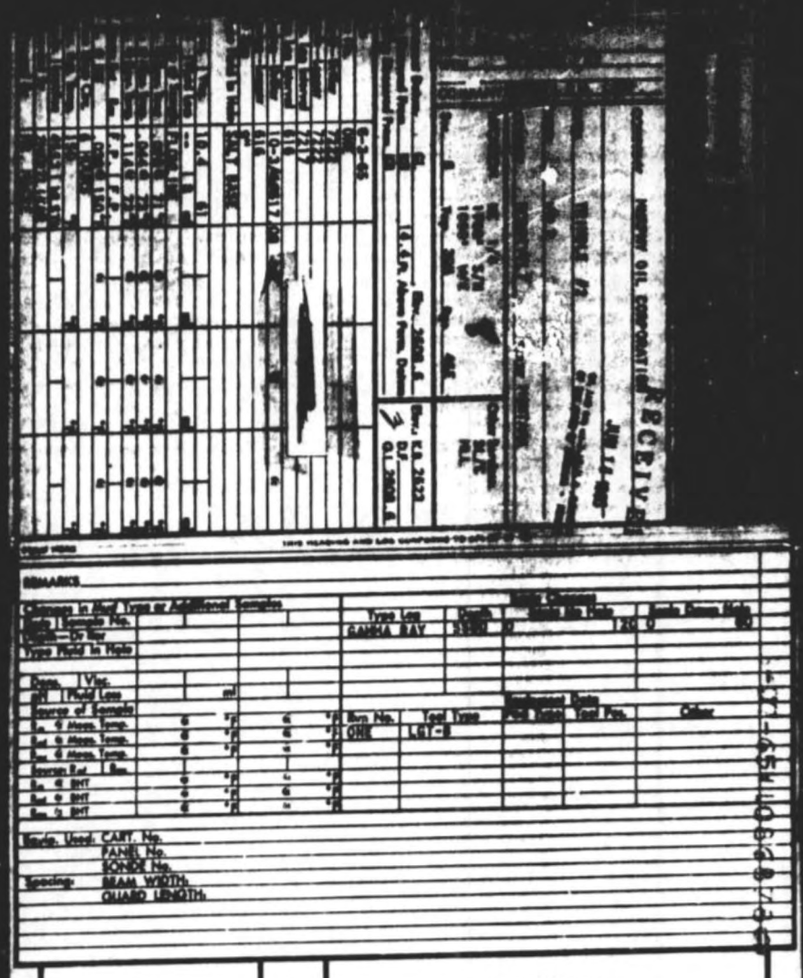
RESISTIVITY

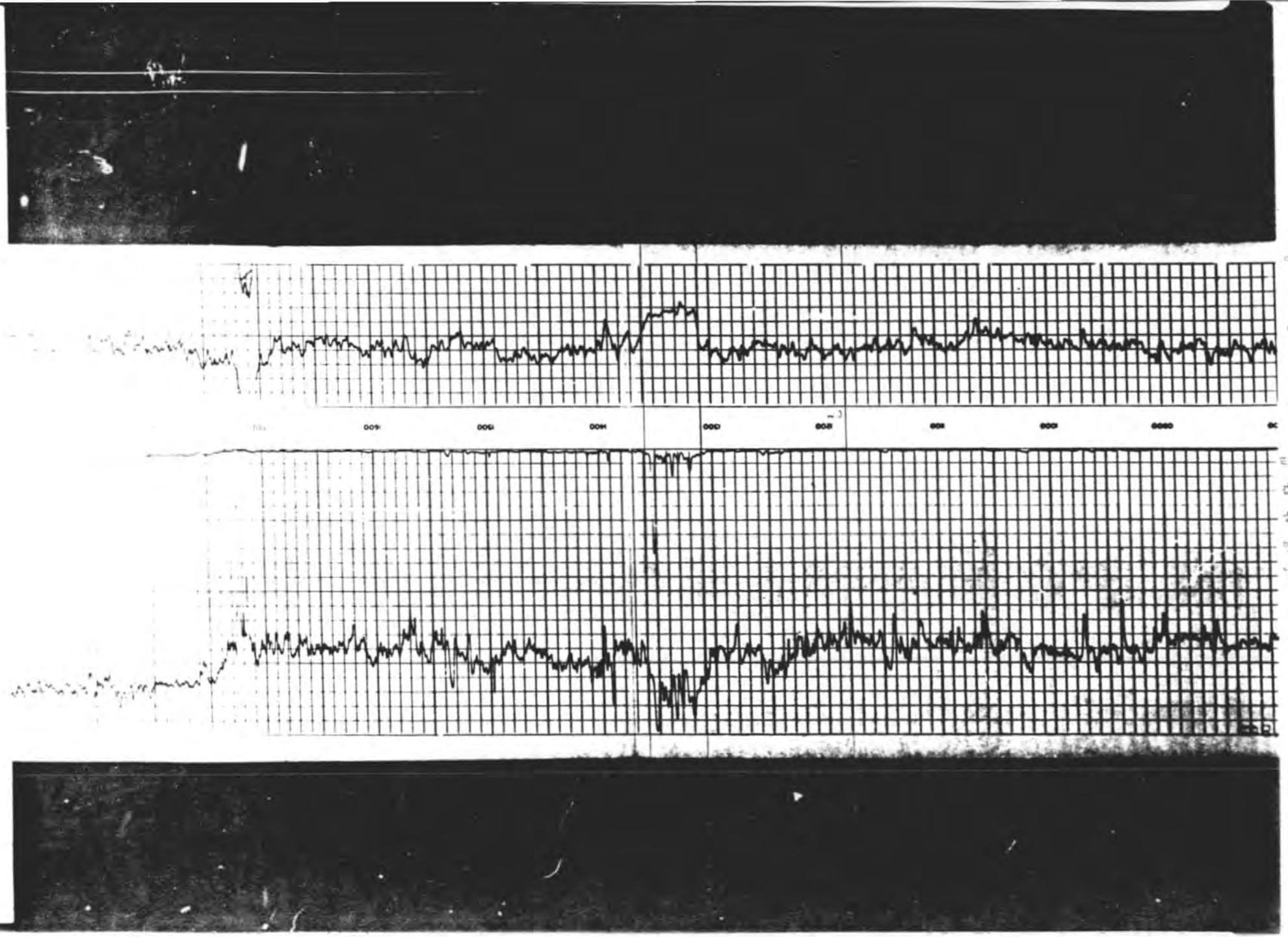
OHM-M

0 20 40 62 125 ∞

10 30 50 83 250




REMARKS
Type Log
GAMMA RAY
Run No.
ONE
Tool Type
LGT-B
Other
GAMMA RAY
API UNITS
0
120
240
Depths
LATEROLOG
CONDUCTIVITY
1000
500
0
RESISTIVITY
0
20
40
62
125
10
30
50
83
250
Calibration
Calibration
Elec. Zero
Mech Zero



COMPANY HUMBLE OIL CORPORATION

WELL TULSA 49

FIELD

COUNTY

STATE

Elev. 2608.6 K.B.

Elev. K.B. 2623

D.F.

G.L. 2608.6

Other Services: CBL TTL

Date 1-3-65

Run No. 1

Depth Driller 5280

Depth Logger 5280

Bottom Log Interval 5280

Top Log Interval 0

Casing Driller 13 3/8 @ 0

Casing Logger 13 3/8 @ 0

Bit Size 12 1/4

Type Fluid in Hole GEL

Dens. | Visc.

pH | Fluid Loss ml

Source of Sample

Rm @ Meas. Temp. @ °F @ °F

Rmf @ Meas. Temp. @ °F @ °F

Rmc @ Meas. Temp. @ °F @ °F

Source: Rmf | Rmc

Rm @ BHT @ °F @ °F

Rmf @ BHT @ °F @ °F

Rmc @ BHT @ °F @ °F

Max. Rec. Temp. 49°C

Equipment Location 3-86

Recorded by J. HUNT

Witnessed by

REMARKS

Changes in Mud Type or Additional Samples

Time | Sample No.

Depth | Reason

Time Fluid in Hole

Bit Run Changes

Type Log	Depth	Bit Run	Bit No.	Tool Type	Tool Type	Tool Pos.	Other
SONIC	5280						
GAMMA RAY	5280						

Equipment Data

Equipment Used: CBL, USED B.O.: CGG & VCD

Equip. Used: CART. No. 8-86

PANEL No. C-429

SONDE No. J-41

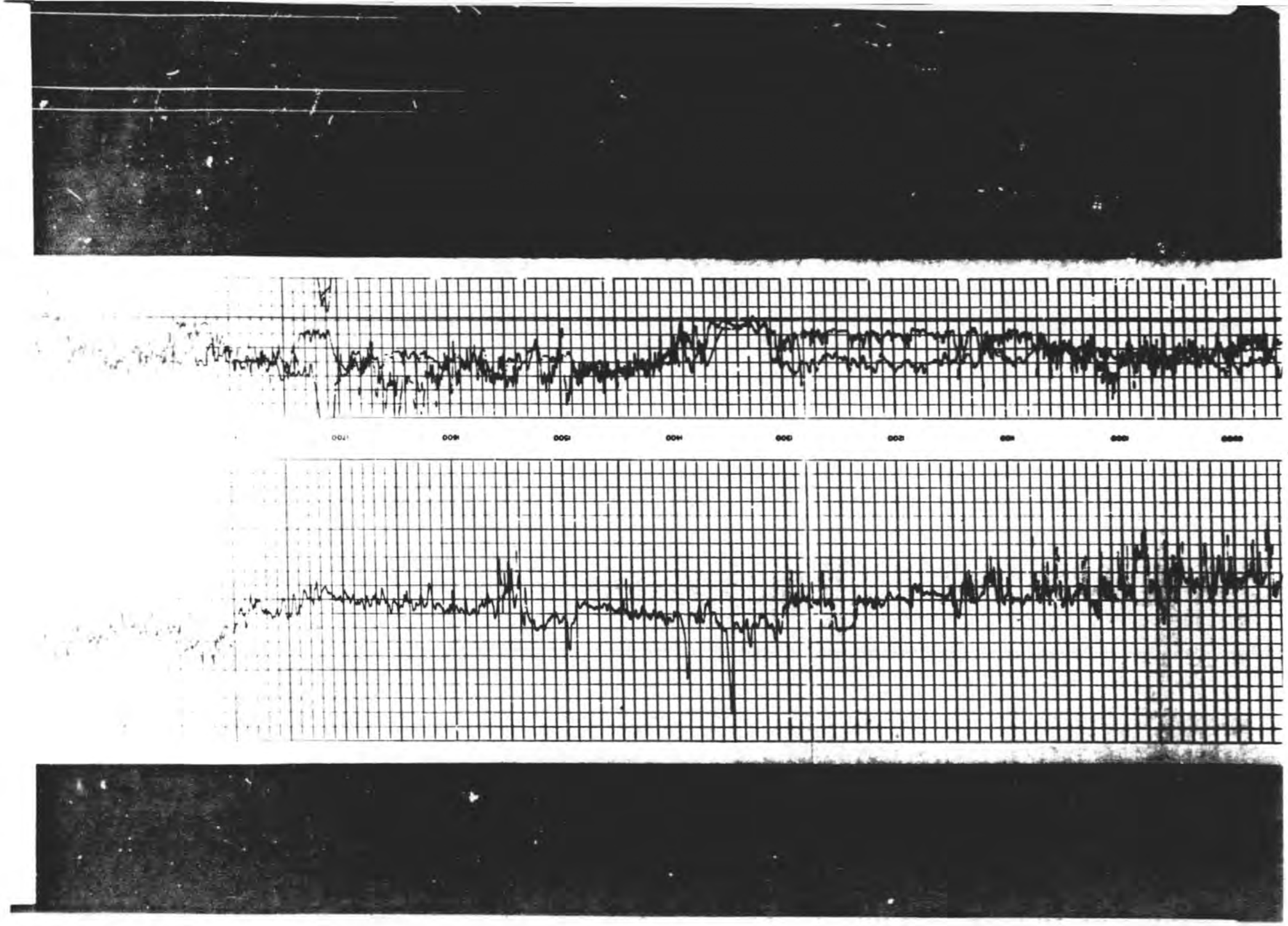
CALIBRATION	BACKGND. CPS.	SOURCE CPS.	GALV. INCR. DIVISIONS	SENS. TAP (FOR CAL.)	SENS. TAP (SECOND)	TIME CONST.	RECORDING SPEED (FT./MIN.)
GAMMA RAY:							

GAMMA RAY TRACED FROM LATEROLOG GAMMA RAY

Velocity (feet per second) = 1,000,000 / Interval Transit Time (microseconds per foot)

GAMMA RAY API UNITS	DEPTHS	INTERVAL TRANSIT TIME MICROSECONDS PER FOOT
0 — 120		τ_2 τ_1 τ_3 240 — 140 — 40
120 — 240		
CALIPER HOLE DIAM IN INCHES 6 — 16		

DC-65W LOG 1-3-65



COMPANY PLACID OIL COMPANY

WELL B. J. TRIMBLE #1

FIELD [illegible]

Elev.: K.B. 2639 D.F. 2611 G.L. 2611

Date 7-11-63

Run One

Type Log GAMMA RAY

Depth 5900

Bottom Driller 5900

Bottom Logger 5896

Top Log 0

Casing Driller 8-5/8" @ 610

Casing Logger 610

Bit Size 7-7/8"

Type Fluid in Hole WATER BASE

Max. Rec. Temp. 160°F

Est. Cement Top

Equipment No. C-[illegible]

Location [illegible]

Witnessed By [illegible]

Recorded By [illegible]

Other Services SLC

"FOLD HERE" THIS HEADING AND LOG CONFORM TO API RECOMMENDED STANDARD PRACTICE RP-33

REMARKS RMF .020 @ 160°F (BHT)

Changes in Mud Type or Additional Samples		
Date	Sample No.	
Depth - Driller		
Type Fluid in Hole		
Density	Visc.	
pH	Fluid Loss	cc cc
Source of Sample		
Rm @ Meas. Temp.	@ °F	@ °F
Rmf @ Meas. Temp.	@ °F	@ °F
Rmc @ Meas. Temp.	@ °F	@ °F
Source: Rmf / Rmc		
Rm @ B.H.T.	@ °F	@ °F
Rmf @ B.H.T.	@ °F	@ °F
Rmc @ B.H.T.	@ °F	@ °F

Type Log	Depth	Scale Changes: Scale Up Hole		Scale Down Hole	
GAMMA RAY	5900	0	120	0	60
		120	240	60	120

Equipment Data: Run No.	Tool Type	Pad Type	Tool Position	Other
NONE	LGT-B			

CALIBRATION: GAMMA RAY	Backgnd. C.P.S.	Test S. + Bkgd. C.P.S.	Calib. Incr. (Divisions)	Sens. Top (Per Cal.)	Sens. Top (Recorded)	Time Const.	Record. Speed (Ft./Min.)
GR INTERVAL	880	470	82.5	(500)		5	90
CSG-5900					300	2	30
5900-TD					150	2	30

NEUTRON:	Test S. Per	Test S. Close	Calib. Incr. (Divisions)	Sens. Top (Per Cal.)	Sens. Top (Recorded)	Time Const.	Record. Speed (Ft./Min.)

GAMMA RAY
API UNITS

Gamma Ray Zero 0 Div. to left of this line

0 — 120

120 — 240

DEPTHS

LATEROLOG

Bear Width = 1½, Guard Length = 5'

CONDUCTIVITY

Millimhos (1 = 1000/Ohm-M)

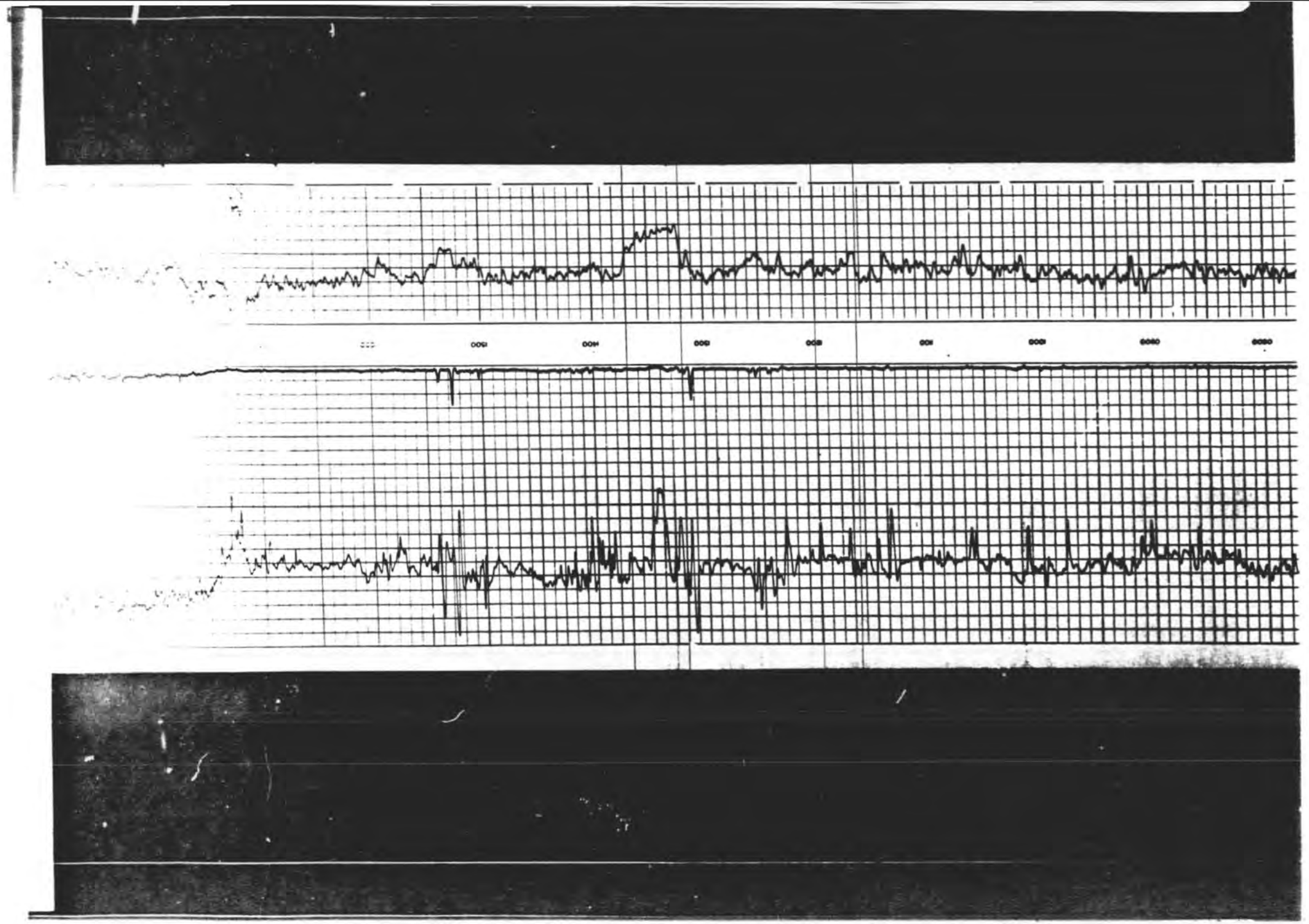
1000 — 500 — 0

RESISTIVITY

Ohm-M

0 20 40 62 125 ∞

10 30 50 83 250



Type Log	Depth	Scale Int. in Hole	Scale Above Hole
GR	9590	0-100	0-100

Sample No.				
Source: Dilter				
Type Mud in Hole				
Viss.				
Wgt.				
Mud Loss				
Source of Sample				
Rm @ Meas. Temp.				
Rmf @ Meas. Temp.				
Rmc @ Meas. Temp.				
Source Rmf Rmc				
Rm @ BHT				
Rmf @ BHT				
Rmc @ BHT				

Log No.	0006
Panel No.	---
Cart. No.	---
Blank No.	---
Meas. Panel No.	HDP.E-504
D.E. Cart. No.	SAC-E-17
D.E. Panel No.	---
VM No.	---
Speed-F.P.M.	30

REMARKS
Service Order No. - 30 - [illegible]
API Serial No. -

CALIBRATION DATA	BACKGND. CPS	SOURCE CPS	GALV. INCR. DIVISION	SENS. TAP (FOR CAL.)	SENS. TAP (RECORD)	TIME CONST.
GAMMA RAY	---	---	100		0-150	2

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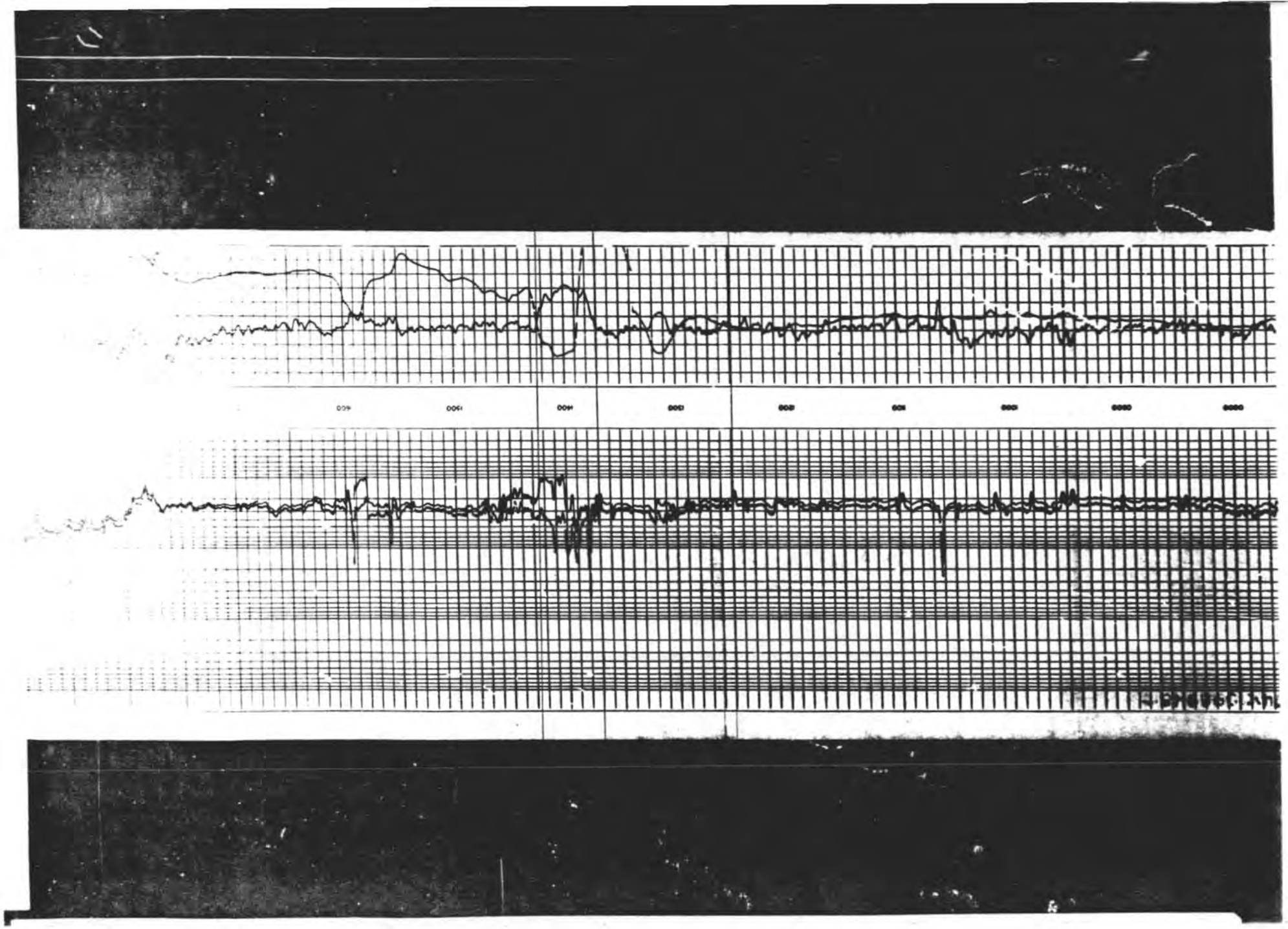
SPONTANEOUS POTENTIAL MILLIVOLTS	DEPTHS	RESISTIVITY OHMS M² M
10 MV		DEEP LATEROLOG 0.2 1.0 10 100 1000 2000 4000 10000
		SHALLOW LATEROLOG 0.2 1.0 10 100 1000 2000
GAMMA RAY		



Type Log	Depth	Scale Units		Scale Units	
GAMMA RAY	5550	0	120	0	60

Run No.	Tool Type	Equipment Data: Rad. Type	Tool Position	Other
ONE	LGT-B			

CALIBRATION: GAMMA RAY

	Background C.P.S.	Test S. + Bkgd. C.P.S.	Gain. Inc. (Divisions)	Sens. Top (Per Col.)	Sens. Top (Board)	Time Const.	Record. Speed (ft./Min.)
CSG-5550	80	440	8.25	500		5	
5550-TD					300	1	90
					150	2	30

NEUTRON:	Test S. For	Test S. Close	Gain. Inc. (Divisions)	Sens. Top (Per Col.)	Sens. Top (Board)	Time Const.	Record. Speed (ft./Min.)

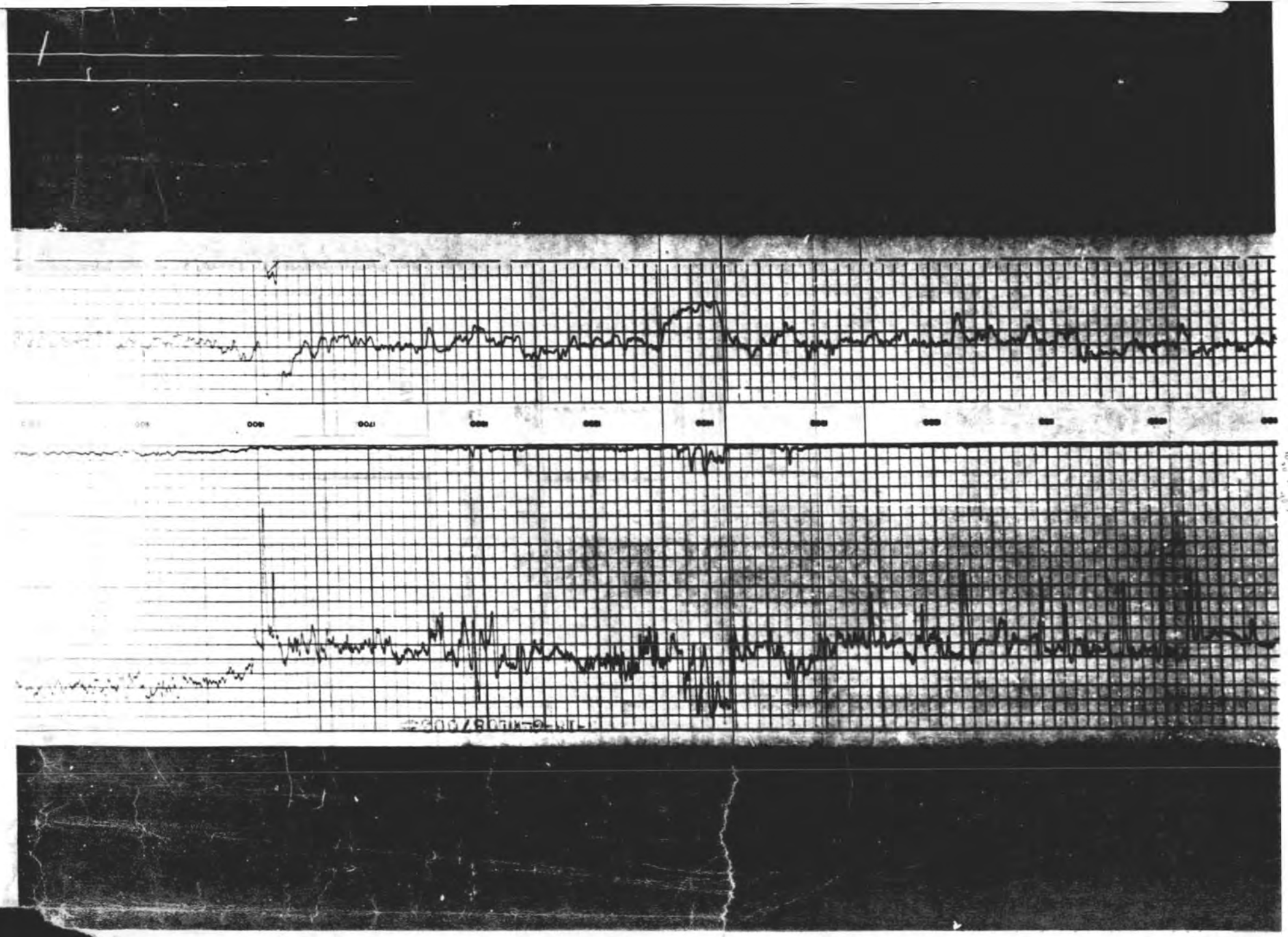
GAMMA RAY
A P I UNITS
0
0 120
120 240

DEPTHS

LATEROLOG
CONDUCTIVITY
1000 500 0

RESISTIVITY

Calibration
Calibration
Elec. Zero
Mech. Zero



Del
FYI

MAY 13 1986

Ref: 8WM-DW

Ronald L. McCallum
Chief Judical Officer
Office of the Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Attention: Alice P. Wegman

Dear Mr. McCallum:

The purpose of this letter is to confirm my phone call to Alice Wegman regarding UIC Appeal no. 86-1 (Assiniboine and Sioux Tribes). We have encountered some difficulty in obtaining material pertinent to the Petition and need until May 30, 1986 to prepare a response.

If you have any questions, please call me (FTS 564-1417).

Sincerely,

Michael J. Strieby
Acting Section Chief
Ground Water Section

Mike S./Steph/1108m/May 12, 1986/Draft
Mike S./Steph/1108m/May 13, 1986/Final

8WM-DW
Strieby
5/13/86

used in these activities is of a sufficient quantity and quality to accomplish these goals in the environment in which it is used.

The Agency is proposing that injection of salt water in a well be done through tubing and packer. Experience within the region has shown that salt water has the ability to corrode most casings in a very short period of time and the most effective way to protect casings from corrosion is to use tubing set on a packer. Use of tubing and packer will also give the operator and EPA the ability to monitor pressures in the tubing-casing annulus to detect any leaks. Owners or operators have one year from the effective date of this program to comply with this requirement. Since tubing and packer are already required by Michigan, as well as Ohio and Illinois, the proposed requirement is not considered burdensome to the regulated community in Michigan.

Area or Review

The Agency is proposing to limit the options for establishing the Area of Review for Class II wells to a fixed radius as described in §146.6 (b). The Agency is proposing this approach due in part to the potentially large number of wells involved, and the considerable delay in program implementation caused my processing requests based on many formulae.

Other Alternatives Being Considered

The Agency is considering applying plugging and abandonment requirements similar to those being proposed for Arkansas in §147.206 for all EPA-administered programs and is soliciting comment for such an approach for the State of Michigan. In addition, the Agency is considering promulgating requirements for maximum operating pressures that are similar to the approach specified in Arkansas in 40 CFR 147.204. A more detailed discussion of these requirements can be found in the preamble to the Arkansas program.

Subpart Y—Minnesota

Subpart Y proposes to require all owners and operators to comply with the UIC regulations at 40 CFR Parts 124, 144, and 146. In addition, this subpart contains regulations that supplement the UIC regulations where discretion is allowed, in order to make the Minnesota UIC program appropriate and amenable to the combination of historic practices and geology unique to Minnesota.

Because EPA is not aware of any existing Class I, II, III or IV wells in Minnesota, it is not proposing any specific provisions for existing wells authorized by rule. Class V wells will be inventoried, but no permitting or other regulatory action is proposed at this time.

All new Class I, Class II, and Class III wells in Minnesota are required to apply for permits prior to initiation of construction.

Subpart AA—Missouri

Subpart AA proposes to require all owners and operators to comply with the UIC regulations at 40 CFR Parts 124, 144, and 146. In addition, this subpart contains regulations that supplement the UIC regulations where discretion is allowed, in order to make the Missouri UIC program appropriate and amenable to the combination of historic practices and geology unique to Missouri.

These rules apply to Classes I, III IV, and V wells in Missouri. Missouri has submitted a program for Class II wells which is currently under review. Therefore, the Agency is not proposing a Class II program at this time. Because EPA is not aware of any existing Class I, III, or IV wells in Missouri, it is not proposing any specific provisions for existing wells authorized by rule. Class V wells will be inventoried, but no permitting or other regulatory action is proposed at this time.

Subpart BB—Montana

Subpart BB proposes to require all owners and operators to comply with the UIC regulations at 40 CFR Parts 124, 144, and 146. In addition, this subpart contains regulations that supplement the UIC regulations where discretion is allowed, in order to make the Montana UIC program appropriate and amenable to the combination of historic practices and geology unique to Montana.

Exempted Aquifers

EPA regulations allow the Administrator of EPA to exempt specific aquifers if the aquifer meets the criteria established in § 146.4.

The Montana Board of Oil and Gas Conservation requires that all salt water disposal wells inject either back into the producing formation or into some other salt water bearing strata.

From aquifer maps and well appropriation inventories provided by the Montana Bureau of Mines and Geology, EPA has found that many of the strata contain water with a total dissolved solids content between 4,000 and 7,000 mg/l TDS. None has been found to be less than 3,000 mg/l and none is currently being used as a source of drinking water.

EPA is proposing to exempt those portions of aquifers (within one-quarter mile of the well) into which all existing Class II wells are injecting. Commentors should note that EPA is proposing to exempt that portion of the aquifer into which wells are currently injecting. If a well owner wishes to exempt an entire field, he or she should submit a justification for such an exemption and submit the information to EPA within 45 days of publication of this proposal.

A complete listing of the proposed aquifer exemptions and their location is available for review at the EPA Regional Office in Denver as well as in the EPA office in Helena, Montana. The exemptions will apply to the injection formation only and will be applicable for Class II purposes only (all known wells are Class II wells). These limited portions of aquifers meet the criteria established in § 146.4. The vast majority of the aquifers in Montana are at a great depth (average depth of approximately 5,000 feet) and are not used now, and are not expected to be used in the future or are in a location which would economically or technologically preclude their use as a source of drinking water.

Maximum Injection Pressure

EPA is proposing for all Federally implemented programs, the use of a simple formula that will prescribe an injection pressure to be measured at the wellhead. The formula is discussed in detail in the introduction to the State-specific preambles. The 0.733 psi/ft fracture gradient proposed for Montana was from the publications listed below.

EPA is proposing this standard after reviewing industry fracturing literature ("Stimulation Fluid Friction Pressure Handbook" by the Western Company of North America, and "Fracturing Fluids: Engineering Data" by the Dowell Division of Dow Chemical), journal articles including "Step-Rate Tests Determine Safe Injection Pressures in Floods" by Martin Falsenthal, published October 28, 1974, in "The Oil and Gas Journal", "Determining Fracture Pressure Gradients from Well Logs," November 1973 by Anderson, Ingram and Zanier, and "Interpretation of Fracturing Pressures" by Kenneth G. Nolte and Michael B. Smith, September 1981, published in the "Journal of Petroleum Technology.")

It should be noted that this pressure limitation applies to wells authorized by rule. Operators may request permission to inject at higher pressures by applying for a permit and demonstrating in the application that such operations will not violate § 144.28(f)(3).

the operation will not allow movement of fluids which could pose a significant risk to the health of persons.

The Agency believes that these requirements are appropriate for wells in Michigan when a workover is necessary to bring an existing well into compliance with the requirements of 40 CFR 144.28(a) and 146.22. The requirements adopted here dictate that the Regional Administrator make a determination that the wells may not be in compliance with the above requirements. If such a determination is made he may impose requirements consistent with those adopted here, impose other appropriate requirements, or require the owner or operator to apply for a permit. In general, these requirements identify the placement of cement relative to the USDWs and the injection zone as well as the quantity and quality of cement to be used. The purpose of the requirements is to ensure that USDWs are effectively cemented off, that injection fluids are isolated in the injection zone, and the cement used in these activities is of a sufficient quantity and quality to accomplish these goals in the environment in which it is used.

EPA proposed that operators who inject salt water for disposal purposes be required to install tubing and packers on these wells. Several comments received from consultants and solution mining operators expressed opposition to the requirement of a packer and tubing in injection wells extracting minerals.

Their concerns were based on the belief that Class III wells injecting dilute mineral solutions, instead of fresh water for mineral extraction, may be technically classified as salt water injection wells. They further noted that construction practices for these wells were in ways more stringent than the requirements proposed. EPA after examining Michigan laws and prevailing practices for the solution mining industry agrees and is clarifying the tubing and packer requirement to apply only to wells which inject fluids for disposal.

Area of Review

EPA proposed that the area of review of an injection well be fixed at one-quarter mile or other fixed distance, or on the basis of the Theis' equation. EPA also welcomed public comments regarding possible alternative approaches.

EPA received no new suggestions from the commenters. However, comments generally indicated favorable acceptance of the fixed distance area of review approach. EPA will promulgate the regulation accordingly.

SUBPART Y—MINNESOTA

Subpart Y requires all owners and operators to comply with the UIC regulations at 40 CFR Parts 124, 144 and 146. Because EPA was not aware of any Class I, II, III, or IV wells in Minnesota, no supplemental regulations for these classes of wells were proposed. Class V wells would be regulated under 40 CFR Parts 124, 144, and 146.

No information was submitted during the public comment period regarding the existence of Class I, II, III or IV wells. Therefore the regulations promulgated today merely incorporate 40 CFR Parts 124, 144 and 146 in the UIC program for Minnesota.

EPA will be proposing a ban on Class I, II, III and IV wells on Indian lands in Minnesota in the near future. Until the ban is promulgated the UIC program being promulgated today applies to both Indian an non-Indian lands in Minnesota.

SUBPART AA—MISSOURI

On September 2, 1983, EPA proposed to federally implement the UIC program in Missouri (48 FR 40116). A full discussion of all actions EPA proposed is given in that notice. Pertaining to Missouri, subpart AA requires all owners and operators to comply with the UIC regulations in 40 CFR Parts 124, 144, and 146. EPA is not aware of any existing Class I, III, or IV wells in Missouri and is, therefore, not promulgating any specific provisions for existing wells authorized by rule. Class V wells will be inventoried and assessed to determine what permitting or other regulatory action is needed to protect underground sources of drinking water. EPA received no comments pertaining to the proposed rulemaking for Missouri and is now taking final rulemaking action to implement the program.

The Safe Drinking Water Act requires EPA to prescribe an Underground Injection Control program for a State if the State has not submitted an application, or if the state program either has been disapproved or no longer meets the requirements of the Act. The UIC program is designed to prevent underground injection through wells which endanger drinking water sources. On December 2, 1983, EPA granted the State of Missouri primary enforcement authority to operate a UIC Class II well program. Missouri has not received enforcement authority for Class I, III, IV, and V wells. EPA intends to operate the program for injection wells other than Class II wells, at least until such time as Missouri is granted primary enforcement authority over the remaining classes of wells.

SUBPART BB—MONTANA

Owners and operators are required to comply with the UIC regulations at 40 CFR Parts 124, 144, and 146. In addition, this Subpart BB of 40 CFR Part 147 contains supplemental regulations where discretion is allowed in order to make the Montana UIC program appropriate to the historic practices and geology specific to the State of Montana. The UIC program being promulgated today applies to both Indian and non-Indian lands in Montana.

Aquifer Exemptions

EPA regulations allow the Administrator of EPA to exempt specific aquifers if the aquifer meets the criteria established in § 146.4.

The Agency proposed to exempt those portions of aquifers within one-quarter mile of existing Class II wells in Montana for the purpose of Class II injection activities only. A listing of such aquifers was prepared and made available for review at both the EPA Regional Office in Denver and the EPA Office in Helena, Montana, beginning on September 2, 1983. There were no requests made for review of that listing. Exemptions of those aquifers or portions of aquifers included on that list are approved today. All Class II to IV injection wells which are injecting into an underground source of drinking water in Montana, as defined at § 144.3, where such aquifer has not been exempted for that Class of well, will not be legal subsequent to promulgation of this program.

Class II enhanced recovery injection well owners wishing to exempt an entire field were asked to submit a justification for such exemption within 45 days of the proposal. One owner came forward with a request to exempt seven unitized operations but did not make that request until the 59th day. Nevertheless, EPA processed this exemption request in accordance with § 144.7.

EPA recognizes that there may exist injections to USDW's that the Agency is unaware of, or that legally began during the period beginning September 2, 1983, and the effective date of these regulations.

Owners and operators of such wells are encouraged to notify Patrick A. Crotty, Chief, Ground Water Section, Drinking Water Branch, EPA Region VIII, 1860 Lincoln St., Denver, Colorado 80295, as quickly as possible to determine the status of their particular

operation. Region VIII proposes to accumulate information on these injection operations and to take such action as is appropriate. EPA will review any requests for exemption in accordance with §§ 144.7 and 146.4 and individually approve or deny the requests, as appropriate.

Maximum Injection Pressure: Existing Class I, II (Salt Water Disposal) and III Wells.

The Agency proposed to adopt a simple formula that would prescribe injection pressure measured at the wellhead. For all rule authorized wells (except enhanced recovery and hydrocarbon storage wells) that proposal has been adopted with clarification. Section 147.1353 has been reworded to make it clear that a well injection must also comply with the nonfracturing provisions of § 144.28(f)(3), notwithstanding the results of the formula calculation. The Introduction to these State-specific preambles outlines the comments received on this topic, the Agency's response to comments, and the justification for retaining the requirements as proposed. Information available to the Agency indicates that operators of such existing wells should be able to meet this requirement without significant change in current operating procedures. As pointed out in the Introduction, operators who wish to inject at higher pressures may receive authorization to do so by applying for a permit and demonstrating in that application that the increased operating pressures will not violate the performance standards in §§ 146.13, 146.23, and 146.33. If the Regional Administrator approves the application, the owner or operator may inject at the higher pressure. It should be noted that operators of Class I and III injection wells and operators of Class II salt water disposal wells must apply for a permit in any case; the former within 1 year of the effective date of the program, the later within 4 years of that date.

Maximum Injection Pressure: Existing Enhanced Recovery and Hydrocarbon Storage Wells.

The Agency received more comments on the proposed approach for limiting injection pressure than any other provision. Briefly, commenters stated that the values specified were too low, and that no single injection pressure was appropriate for an entire State; appropriate pressures being a function of formation characteristics, not political boundaries. A more complete discussion of the comments received and the Agency's response to these comments can be found in the Introduction to these state-specific preambles.

After a thorough review of the comments and other technical data, EPA has decided to promulgate a revised approach for specifying limits on injection pressure of enhanced recovery and hydrocarbon storage wells. The details of this approach are outlined below. EPA will:

1. Eliminate the proposed State-wide psi/ft fracture gradient values;

2. Require Class II enhanced recovery injection well operators to provide definitive field or formation-specific fracture-pressure data within one year of the effective date of this program;

3. Develop and specify a field or formation-specific pressure gradient based on this data and other reliable data; and

4. Require owners or operators to comply with the performance standards in § 144.28 and § 146.22 until such formation specific standards are developed.

EPA believes that the instantaneous shut-in pressure (ISIP) is an appropriate value on which to base the maximum injection pressure for a formation or field. The ISIP represents the minimum injection pressure necessary to propagate existing fractures. EPA realizes that this pressure is generally less than the pressure needed to fracture the confining zone but believes this to be appropriate when specifying a number applicable to owners or operators authorized by rule for the life of the well. In addition, EPA will allow operators who wish to operate at pressures higher than the specified limit, to do so by demonstrating to the Regional Administrator that such injection pressures are consistent with the appropriate performance standards in 40 CFR Parts 144 and 146.

EPA recognizes that there is a variety of information which may be used to establish the appropriate value for maximum injection pressures. Among the technical data that EPA believes appropriate to use in establishing the field rules are:

1. Instantaneous Shut In Pressure: ISIP is the pressure observed (recorded) at the moment the fracturing operations are discontinued. ISIP is that static pressure required to hold a fracture open to inject fluids into an established fracture system under dynamic conditions, if there were no pipe and/or perforation frictional pressure losses influencing the observed (recorded) surface pressure. Appropriate ISIP data of this quality are preferred by the Agency and are often readily available.

2. Formation "breakdown pressure": indicated values from data recorded prior to and during Squeeze Cementing (2), Acidizing and Acid-Fracturing (2), (3) jobs performed by appropriate service companies. These "breakdown pressure" values are frequently reported as the surface gauge pressure which must, through appropriate engineering calculations, be modified to reflect the corresponding sand-face pressure at which the formation fracture occurs.

3. Water (or other fluid) injection "Step-Rate" (3), (4), (5) type testing performed specifically to determine the "breakdown pressure" of the injection zone prior to the initiation of the enhanced recovery project.

4. Other reliable field tests or performance data which the operator can demonstrate as accurately reflecting the actual sand-face fracture pressure of the injection formation may also be utilized to meet the requirement.

EPA does recognize that, in certain situations, an operator may purposely inject into an enhanced recovery formation at a pressure in excess of the known formation fracture pressure. In such cases, the operator may exceed the injection formation fracture pressure so long as he can demonstrate to the Regional Administrator that the injected fluids are contained within the injection zone, i.e., the confining zone(s) have not been breached.

In no case is the operator of Class II enhanced recovery injection or hydrocarbon storage well relieved of his ultimate responsibility to assure that his injection will not endanger the safety of USDWs as provided for in § 144.12.

Casing and Cementing

The Agency is promulgating cementing requirements for existing enhanced recovery and hydrocarbon storage wells which may not be in compliance with §§ 144.28(e) and 146.22. These sections require existing wells to be cased and cemented to prevent the movement of fluids into or between underground sources of drinking water.

The requirements in § 147.1354(b) recognize that it is at best difficult to bring existing wells into compliance with a new set of construction requirements. In the June 24, 1980, promulgation of 40 CFR Part 146, the Agency outlined requirements in § 146.22 (d), (c), and (e) which were intended to relieve operators of wells in existing fields from the requirements specified in § 146.22(b), provided that the operator will not allow movement of fluids which could cause a significant risk to the health of persons.

The Agency believes that the requirements are appropriate for wells in Montana when a workover is necessary to bring an existing well into compliance with the requirements of 40

ATTACHMENT A

RESPONSE TO REQUEST FOR REVIEW

ATTACHMENT B-1

FEDERAL REGISTER - PROPOSED RULE
MONTANA AQUIFER EXEMPTIONS

ATTACHMENT B-2

FEDERAL REGISTER - FINAL RULE
MONTANA AQUIFER EXEMPTIONS

ATTACHMENT C

AUDIT OF FINAL PERMIT FOR GOINGS NO. 1 SWDW

ATTACHMENT D

STATEMENT OF POLICY - TECHNICAL EVALUATION

ATTACHMENT E-1

DRAFT PERMIT FOR THE GOINGS NO. 1 SWDW

ATTACHMENT E-2

FINAL PERMIT FOR THE GOINGS NO. 1 SWDW

ATTACHMENT F-1

STATEMENT OF BASIS FOR DRAFT PERMIT
GOINGS NO. 1 SWDW

ATTACHMENT F-2

ADDENDUM TO THE STATEMENT OF BASIS
FINAL PERMIT FOR THE GOINGS NO. 1 SWDW

ATTACHMENT G

TRANSCRIPT OF PUBLIC HEARING

PUBLIC HEARING

BEFORE THE

U. S. ENVIRONMENTAL PROTECTION AGENCY

* *

TIME: 9:00 o'clock A.M.
Wednesday, May 29, 1985

PLACE: POPLAR ACTIVITY CENTER
Poplar, Montana

HEARING CONCERNING JUDITH RIVER WATER QUALITY

HEARING PANEL:

Mr. Bill Engle, Esq., U.S. EPA, Region 8
One Denver Place
999 18th Street Suite 1300
Denver, Colo. 80202-2413

Mr. Jim Boyter, Esq., U.S. EPA, Region 8
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I N D E X

NAME OF SPEAKER	Page number
Mr. Norman Hallow	5-7
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BE IT REMEMBERED:

That this is the time and place set by public notice for a hearing before the U. S. Environmental Protection Agency, at the hour of 9:00 o'clock A.M., on the 29th day of May, 1985, in the Poplar Activity Center, Poplar, Montana.

Persons seated at the panel's head table, are shown on page one of this transcript.

The hearing is as follows:

---oOo---

MR. ENGLE: All right, I guess we are ready. This hearing will now come to order. Good morning, my name is Bill Engle from the Regional Council Office of the E.P.A., Denver, Colorado, and here before me is Debbie Ehlert, Jim Boyter and Andy Lensink, and after we have had an opportunity to hear the testimony presented this morning, there will be a time for asking questions, etc. Now I have handed out some cards, some registration cards before hand and have asked you to fill those out and then as we proceed here, we will read the names from those cards in the order they were given to me and will give you an opportunity to testify, and in the end if I have missed somebody or if someone did not have a card, there will be an opportunity to do that. Now before we get into the testimony portion I will give a synopsis of

1 the issues that are going to be submitted this morning.
2 SOMEONE IN THE AUDIENCE: Is your microphone on?
3 MR. ENGLE: Can you hear me?
4 SOMEONE IN THE AUDIENCE: No.
5 AT THIS TIME, a correction to the speaker system is
6 made by a technician, and Mr. Engle then repeated what
7 he had just previously stated in his opening remarks
8 and then laid out a general format as to the way this
9 hearing was to be conducted.
10 Following general opening remarks as stated, the
11 floor was then yielded to Mr. Norman Hollow, Chairman
12 of the Assiniboine-Sioux Tribes of the Fort Peck
13 Reservation.
14 ---oOo---
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MR. NORMAN HOLLOW: Good morning, everyone. As Chairman of the Assiniboine-Sioux Tribes of the Fort Peck Indian Reservation, I would like to extend a most hearty welcome to each of you for your attendance here this morning, especially members of the staff of the EPA office, and we appreciate the opportunity of having them come here in this matter which concerns us very much, about pollution on our reservation. As you perhaps know, the Assiniboine-Sioux Tribes who presently occupy the Fort Peck Indian Reservation at one time enjoyed a large territory of land, going into the state of North Dakota, South Dakota, Montana, Nebraska, Wyoming, and of course, a good share of Montana as a result of treaties and agreements with the federal government, we are forced to remain now on what is known as the Fort Peck Indian Reservation, and this is the reason why we are very concerned about pollution of our reservation. Just to give you an example, several years ago, some of the major oil companies and coal companies were attempting to negotiate coal leases with the Fort Peck Indian Tribes in an attempt to develop our coal resources, and we were reluctant to enter into any type of an agreement with them in fear of pollution, of polluting our atmosphere, not only our atmosphere, but the formations that we are going to discuss here this morning. As a result of being reluctant to enter into any agreement with the oil companies, the oil companies began to negotiate

with some of the local residents to apply pressure on the Tribal Council to enter into an agreement, to try to convince us to try to enter into some kind of an agreement with them. I can remember specifically, one of the local farmer-rancher that came into my office and started to pressure me into why we should go into this, going into this coal development, and after lecturing to me for about an hour, and told him that I was amazed that he was pushing for this development for the reason that you are a farmer-rancher like I am and by bringing coal development, we would be damaging not only the agricultural landbut also damaging the domestic water system and this particular farmer then grinned and looked at me and stated, "Well, you know of the potential of generating a great deal of income by going into this development and then we could take all of those resources and after that we can relocate"and let me tell you this, this turned me off. When, in the course of development, is at the cost of the environment and take advantage of the resources and then relocate, that turned me off. Maybe that is fine for him, but the Indian people can't do that; we in no way can relocate. This is the last remaining acres that we have. We have no other place to relocate. This is the reason why we are generally concerned about pollution, of our atmosphere and our land and our water. We are not technical people, like the people on the staff here of the

E.P.A. who will be making the decisions here, or of those who will be making presentations here about the concerns of the Indian people on our reservation. This is my concern, as this is the last place that we have to go and I feel strongly that we should protect it. We do appreciate the fact that these oil companies come in and develop the area of our gas and oil resources and generate a certain amount of income for our Indian people but that income will not be here forever. There is a day coming when those resources will be depleted and the only thing that we would have remaining is our land, our atmosphere and we must protect it so that the future generations to come can enjoy it. I appreciate very much the fact that you are going to discuss this here today and listen to our concerns. I thank you very much.

WITNESS RETIRES FROM the speaker's stand.

The floor is now yielded to Mr. Lawrence Wetsit.

MR. ENGLE: Lawrence Wetsit.

MR. WETSIT: Good morning, I am Lawrence Wetsit and I am with the Minerals Resources of the Fort Peck Tribes and I would like to re-enforce what I Chairman just spoke about. I, as a member of the Assiniboine-Sioux Tribes and an employee of the Tribal government am very concerned with the protection of our environment and mainly in the protection of our land. What I have been taught in the 32 years of my life is that the most important thing for the Indian people is their land. Everything that we do, religously and culturally goes back to our -- I guess there is a time coming for our people. We have been told throughout our lifetime, and the history of our people, our people's names and throughout all of the adverse conditions continues to exist and that we were pushed further and further west until we finally ended up here on the Fort Peck Reservation and like our Chairman has mentioned before me here, there is no other place for us to go. If we find it unlivable here there is no other place for us to move to. This is where my grandparents are buried, this is where my great grandparents are buried and this is where I will be buried and my children will be buried, and if my generation of people do not do what has to be done to protect what we have left, then there will be nothing left for my children, to give to our children. I am certainly fortunate that my parents and my grandparents

took the time to teach me a number of things and also to ensure that the Fort Peck Tribes will continue to exist during our lifetime and I feel that it is my obligation and my children's obligation to continue to let people know of our feelings and because of this feeling within our people in our Tribes, our Tribal Council decided that they needed to establish some system where we could protect our environment and protect our land. The Fort Peck Tribes established a Mineral Resource office to help monitor the oil and gas activites, and like Mr. Hollow has said, there was a time that we had coal spectulators coming in and asking for leases here on the Fort Peck Reservation, and at that time the Tribes no technical office to advise them and it is because of Gentlmen like Mr. Hollow we continued to hold these people off until we could get an office established where we could make decisions and perhaps then these -- allow these coal companies and oil companies come in and develop, and not on the terms of what these companies wanted but on the terms that the Fort Peck Tribes will live with. We must remember that we -- when we make decisions, we realize that we are going to be here for the rest of our lives and if we make a bad decision today, our children will have to live with it in the next thirty or forty years, and under the Tribal Mineral Resource office, our role is to protect our surface land and all of the trust land here on the Fort Peck

1 Reservation, not only tribal land but allotted deeded land.
2 We also oversee the leasing compliances on the Fort Peck,
3 on all oil and gas leases and in line with surface compliance
4 and lease compliance and follow the underground injection of
5 this produced water. Even though we do like the development
6 and the benefits of this development, we also have to look
7 on the other side of the coin and help protect our lands
8 as a result of all of this development, and because of this,
9 we continue to monitor it because of our religious and
10 cultural way of life and because of this the Fort Peck Tribes
11 did make a decision that the future of our Indian people is
12 more important at this time then the money, and I hope today
13 that after all of this evidence has been presented by the
14 Fort Peck Tribes that we could get some idea of what causes
15 us so much concern. We have had our own gas and oil
16 development here since 1951 when Murphy Corporation came in
17 and the development hasn't ceased yet. There are still new
18 wells being drilled and with each new well there is more
19 produced water to be disposed off. In the 1950s there wasn't
20 such a problem, if there was, maybe we wasn't aware of it,
21 but right now we are seeing some of the effects of this
22 disposal produced water and we can go anywhere up north of
23 here in some of the fields and we can look at some of the
24 agricultural land and look at the side of the hills where there
25 happens to be oil wells around and there is nothing growing there.

1 and because of this, it comes to our minds is what -- the
2 question in our minds is what causes it? People might be
3 able to relocate but the Fort Peck Tribes have no other
4 place to go, and if we can't make a living here, our people
5 will cease to exist. Along with the protection of our
6 lands, the Fort Peck Tribes has entered into a water
7 compact with the State of Montana and we let the State of
8 Montana know of our concern with the ground water here on
9 the Fort Peck and as you know, without water, the land has
10 no value, and if we don't do anything at this time to
11 protect our water;we now know exactly how much ground water
12 that we own and throughout the reservation as we inject this
13 salt water and if it is not done properly and not done
14 safely, we will end up damaging our underground water
15 that we have here. It is my responsibility as the Director
16 of the Tribal Mineral Resource program of the Fort Peck
17 tribe to insure that industry and other federal agencies are
18 aware of the concerns of the Fort Peck Tribes and I think
19 our number one concern through all of this is that we want
20 to leave something that our children can live with and
21 something that our children can be proud of, and hopefully,
22 we have our technical staff here, that they can show people
23 and with scientific data, that the underground injection is
24 causing us problems and is causing some concern for us and
25 that we should keep a good watch, a good look here on the

Fort Peck of this injection into the Judith River Formation, and in our estimation it should not be allowed for injection, as there are other places for this water could be injected into and I hope that after the presentation of our technical people they will have a better idea of the concerns of the Fort Peck Tribes, and I thank you for allowing me at this time to speak to you.

AT THIS TIME, this witess CONCLUDED.

AT THIS TIME, the floor is yielded to Mr. Larry Monson.

MR. LARRY MONSON: My name is Larry Monson, and I am a Geologist for the Fort Peck Tribes and all of the tables and data that we are presented have been made in duplicate and we will distribute copies to the EPA at this time, and I hope to have a written report that I will be sending to you in a week or two. This morning I would like to discuss four items, I guess, concerning the Judith River Formation. I would like to show you that these wells that are on the reservation, the various injection wells, and those that are water wells in use pertaining to the Judith River Formation. I will also go into the geology of the Judith River Formation which has been my main emphasis during the last month. I have also compiled some maps showing the nature of the Judith River Formation on the Fort Peck Reservation and specifically the Poplar Field area regarding the thickness of the sandstone formations and the structures which effects where the water moves in the Judith River Formation. I will touch briefly on the hydrology of the Judith River Formation, the aquifer and the movement of the water and will comment briefly on where the water is being discharged or moving to. Primarily, I hope to present some data regarding the quality of the water in the Judith River formation, and also I will present some analysis, some of it is very recent, and I will have to say that these analysis I suspect are not entirely correct. We are estimating what the water quality is, based

on electric logs, and I have not as yet put it into final form. It does not appear, or there is no direct evidence as yet of any surface examination around these injection wells, I don't think all of the data is in, as they are still evaluating that data, the soil and water samples. Okay, let's begin with the problem at hand. Salt water disposal on the reservation is very important and a very necessary event. The formations in this area which produces oil are heavily concentrated with sodium chloride salt. The Charles formation and the Madison group contains approximately 300,000 parts per million and there is about a maximum of 200,000 mg/l choride. They are practically super-saturated almost crystalized in that concentration. This is probably a unique problem to North America. In the middle east, the water is salty, but in North America is is very famous for its salty feature of this water. The formation that lies below the where the oil is produced on the reservation is not as quite as salty,perhaps 33 to 55 thousand mg/l and chloride perhaps 20,000 mg/l. Now this salty brine has to be disposed of, and it is coming up to the surface in tremendous quanities. There are some of the wells where there is from ten to twenty barrels of salt water per day, so there is very significant things that must be dealt with. Disposal of this salty brine is done by various means. There is the evaporation system at some places, which are still allowed in

1 Montana; there are also injection wells and we we are looking
2 now at the Judith River sandstones as a source of injection
3 today, there is the Dakota sandstone and that formation is
4 also used probably quite a bit more than the Judith River
5 formation in this area. . There are a couple of cases where
6 the water is actually put down into the that formation, and
7 this is in a way rare in Montana and is probably more
8 common in North Dakota. To begin with, I will show you the
9 wells that are currently injecting into the Judith River
10 and if I could have the lights turned off please.(so done)
11 I apologize that this is not a darker room where you could
12 perhaps see this better. It will help you if I show you
13 some of the features of this so that you will better under-
14 stand what I am talking about. The outline of the reservation
15 is shown. The various oil fields, the Poplar Field, the
16 Northwest Poplar field is here, and the Poplar Field is
17 here, the Tule Creek is here, the Benrud Field is here, and
18 the Volt, Lustre and on the maps there are three different
19 kinds of symbols, and it is not showing up too well here.
20 All of the wells shown in this area here is either injection
21 wells, there are seven in the Poplar Field, Five in the
22 Benrud Field, Three in the Tule Field, and also an injection
23 well -- two injection wells in the Volt Field and then other
24 wells that are shown -- like these here in the green -- and
25 by the way, you may examine these maps afterwards here and

I am sure that some of you cannot see this because you are sitting too far away, but they will all be available afterwards here. The green wells are drill stem wells that are wells that are being drilled to the Judith River formation. These are analysis wells and we appreciate the fact that no one would take too much time to -- for that reason the drill stem test wells are samplings not to dirty the waters in the Judith River but water that can be used in drilling, because it is quite salty, and it doesn't really amount to anything in the long run because the water that has been injected into this area -- the amount of water into this area has probably changed the quality of the Judith River considerable. Also shown are the water wells in this Judith River formation and you will notice that they are all in this area here, there are five still operating or still in use on the reservation, around Frazer and Oswego and there are two in Wolf Point that have since been abandoned, and the city of Wolf Point uses one for its municipal water supply until sometime in the 50s, I believe; the Sherman Hotel uses Judith River wells until it was remodeled in the early 70s. Other wells that are in this area, are used mostly for stock wells, although as you approach Fort Peck and the Glasgow areas, the water is used for other household uses and are used in some cases by the ranchers as they have no ther choice. There are some wells, that are off the

1 reservation, for instance the Air Force Base north of
2 Glasgow there are hundreds of Judith River wells being used
3 for water supply. Okay, now I will be breaking this table
4 up on future tables, trying to divide it up, but as to these
5 all known injection wells into the Judith River formation,
6 and there are 20 that I have located, and of these two have
7 been abandoned, five are currently on a standby status and
8 there is no record of them being abandoned, they are still
9 open holes as far as the Montana Oil and Gas commission is
10 concerned and thirteen of these Judith River wells are still
11 apparently currently injecting as of the first of the year,
12 the first of January of '85. I will point out the two Volt
13 wells here, and here the Benrud wells, and the Poplar Wells
14 and the table also shows when they began injecting and when
15 they have stopped or ended and I will break the table up
16 and I want to say that of the thirteen still operating, or
17 perhaps the possible 18 possible wells injecting, only five
18 have applied for EPA permits that we are aware of. Okay in
19 breaking the table down a little further, and again I have
20 this available if anybody wants to look at them, and on these
21 tables it shows the status of the wells, whether original
22 or converted wells, oil wells, or if they are original
23 disposal wells and currently or whether currently injecting
24 or standby or abandoned, and again, the earliest injection
25 started in the early 60s in the Poplar field and as recently

as '77 people -- and as late as 81 or '82 I believe, there were two companies that have started injecting into the Judith River Formation and so there are -- it is something that is still going on, injecting into the Judith River formation. Okay, the main point I want to show you on this table, -- shown are the well names and the intervals where the injection is occurring and it varies from about as little as 735 feet in one well in the Poplar field and some goes to about as deep as 1800 feet or 1500 feet, and there is one well right here, in the Tule Creek area. Okay the interesting thing on this is the pressure of these injecting wells, and these are largely recorded from the injection reports that the company files with the Oil and Gas Commission and I have also read some of the gauges, and some of these wells in the Volt field and these two wells, are 950 psi and this one here is 700 psi and this one is 800 psi and this Hall well here is 900 psi and the well that is the subject of this hearing is 750 psi was reported on their injection report and I read it also as being 600 psi, so you can see that it runs anywhere from 500 to 900 psi injection pressure; and it is important that this be known, these pressures. Also shown on there is the rate of injection which varies from as little as 100 barrels of salt water per day to as much as 4700 barrels of salt water per day. Also shown on here is the accumulated total and if you cannot read it here,

it varies from about 448,000,000 barrels to as much as 22,000,000 barrels going into the Judith River formation. The next thing that I would like to talk about is some of the water wells and shown on this table, listed across the table, the location of the wells, the owners if they are known and the depth of the wells, the temperature of the water if that has been measured, and whether any water samples have been done by the USGS, or Water Resources or by the Montana Bureau of Mines and some of the samples, -- many of the samples were sampled in 1947 and most recently they many were also sampled around 1977. Some as recently as 1981. I would like to show, or one point I would like to make or point out, that from the drill stem tests done on the Judith River, either in the Poplar Field or the near by Tule Creek Field area, shows a considerably higher salt content then any of the water wells. These samples range from about 10,000 to 18,000 and the water wells samples that we have range from about 1200 to as much as 4300 in dissolved salts. Now this here shows the list of water wells that are adjacent to the reservation, and this shows you those that are just west of the reservation boundary and especially in the Fort Peck area there are quite a few Judith River water wells in Valley County. There are some of these wells also south of the Missouri River, into McCone County, which is across the river to the south. Okay, this shows the well

1 locations and this has been broken up into the counties
2 they are located in and when the wells were first used and
3 its use. Most of these are stock water wells and when the
4 water was sampled in '47, either in '47, or '77 or '81, there
5 were some that were being used for domestic use, and like I
6 mentioned there were two wells in Wolf Point, one being used
7 by the Sherman Motor Inn which have since been abandoned and
8 are not being used, and also the city well, that is not in
9 use. This one here lists a few more wells adjacent to the
10 reservation and shows again its use, whether for stock use,
11 domestic use and so forth. Now then, the second set of
12 tables here that I have here, are broken off like this, shows
13 you or indicates -- the main thing that I want to show you
14 here is some of the intervals of perforating and some of
15 these wells adjacent to the reservation are shallow wells
16 as little as 400 feet in depth and across the reservation
17 into the Judith River formation as -- some of these are five
18 to six hundred feet and as much as 1800 feet in depth. The
19 other thing that this table shows is that some of these
20 wells are still flowing like the arteasan type of wells, as
21 a source of water, having a natural flow, and these wells
22 seem to have a tremendous amount of water and pressure behind
23 it. This one shows, again, some more wells again adjacent
24 to the reservation and you can see that the bottom three are
25 all flowing and also here a couple more of them that are flowing.

Now then, I would like to go into this portion a little bit, about the geology of the Judith River formation. The previous work that has been done, for instance, an article by Perry in 1934 which is a Montana Bureau of Mine & Geology memo number eleven and it concerns the arteasan sources of water resources of northeastern Montana and it expressively talks about the Judith River formation and it describes it as a great resource, a natural resource of great value to the local ranchers. He says it reaches a thickness of about 500 feet which I think is a little bit too much and it describes it as a greyish-white sandstone that is imbedded with grey sandy shale and clay. Perry spent a considerable amount of time discussing the irregular nature of the Judit River sandstone, saying that they change and saying that they are not continuous. I think that they are and there is sandstone on top of the formation and on the bottom of the formation, and sometimes in the middle of the formation. He said they were mostly non-marine deposits formed by lakes and mud plains on the land; that is true to the west in this area, where there are marine deposits. In his examination the perocerity reached a maximum of 40% and some of them reached only 15 to 20% from the samples that he looked at. It varies as you go from west to east, and there is courser sandstone in the west and becoming more and more clay fill and shaly as you go to the east. Even in that

time, in 1934, I don't know what well information he had, it must have been very minimul, Perry did construct a structure map showing this Judith River formation and it shows a inflection of the structure across the Poplar Dome area which has been seen by the more recent people that have studied this formation and generally the formation gets, from east -- or rather from west to east when it reachs the Poplar Dome area it reverses its depth and then after leaving the Poplar Dome area it changes again, and you will be able to see that on the more recent maps that I have. More recently, in 1955 one was -- a study made by Swenson, and he describes the Judith River formation as an important aquifer and states there are separate bands of sandstone and he felt that after it left Wolf Point area towards Poplar that it was mostly shale. I will show you some chemical data and one thing I want to mention is the -- in the Judith River formation is the barium content of five parts per million which distinguishes from all of the other water. He spent quite a bit of time on the domestic and stock use that the ranchers has in or from the Judith River formation. Most recently, and the next slide will show where other people have worked on this, one in '73 and more recently in '78 and the office of Water Resources in Billings have also published maps giving aquifers in the state including the Judith River. This too will also be available for you to look at after presentation.

I would like to begin with the corralation chart here, which shows the formation here. Right here, here is the Bear Paw which has been covered by a glacial gravel deposit; the Bear Paw shale has a thickness of about a thousand feet and then the Judith River formation is down here, and it is a non-marine type of deposit formation, as it goes from west to east in Montana. Underneath the Judith River formation on this side of the field, there shows some cross sections shows that on top of the Eagle formation there there is bentenite and or volcanic ash here. Now right in here there are also formations that contain sandstone which has a source of drinking water, like right in here and on different places on the reservation over here. Sometimes the Judith River is the only aquifer present. The geology here, the Judith River formation forms sort of a seaway from the artic to the Gulf of Mexico which runs the entire central part of North America. In this cross section here, which is taken from the article by Rice sometime in 1978, shows what is happening to these as it goes from Glacier Park to the Williston BAsin. You can see that these are non-marine formations and you can see non-marine rock from the Glasgow area into our area; and you can see this as this goes from Eastern Montana and throughout North Dakota and in my estimation that the water in the Judith River Formation is not a good place to inject water. I would also like to

point out these formations that exist in this area here. Now then, I don't want to keep you waiting in the dark as I do this, but on this map you can observe the rock formation in the Judith River Formation being non-marine and in this region of Montana which is shown by this band here and we are located in this area here, and this is North Dakota, that this area in here represents what is called shelf coastal deposits or sandstones, forming along the shoreline and then as you move out east it goes into deeper water and there are some off-shore sand bars that accounts for the thicker area here. These maps are maps produced by the USGSand also the Bureau of Mines and it shows the deposits in these formations and I would like to point out that these condour lines that are pointing around the Poplar Nose here, the Poplar Dome and you can see the structure here in the Judith River formation, like this. This is the structure right here as it goes through the reservation, its higher and lower elevations. Okay, on these maps concerning the thickness of the Judith River and the point that I raise here, Poplar is here and Lustre is approximately here in this area, and it varies from as much as 300 to 400 feet in thickness to as little as 200 feet of thickness throughout much of the reservation. It is very difficult to recognize once it gets on a scale like this. This shows the thickness of the sandstone and I will point out some of the things here; the

reflections in the thickness of the pattern pointing to the east in this area, and then in this area on the west end, like right here, there is 25 feet in thickness right in this area here and then right through here where it is thicker, it is perhaps 50 feet and then it goes to 75 feet to a hundred feet by the time you reach the western edge of the reservation and the shape of this rock pattern pointing to the east right here, graduating into the pure shale here. Okay, this is by way of -- this geological map shows the reservation and you can see the drainage field effecting the reservation and the Bear Paw shale being the predominate rock in this area here and the other type of rock right here. As I pointed out earlier I could show you some of the areas -- the Lustre area being here and you can also see the Poplar area over here. Does everyone see those contour lines? (Response seemed to be that they all could). Okay, this is a structural map of the top of the Judith River formation and I am showing you what looks like this is the top of the reservation, the boundaries of the reservation, the Poplar area here and the Lustre area over in here and this as you can see varies in elevation from about 18 to 1900 feet on the west to about 400 feet below sea level on the east side of the Reservation. You can see the influx of the Poplar Dome here. Okay. Because of this formation ending or coming, coming with the shale to the east, it is

not the best surface to use as a structural map, but all of you can look at these when we are through here. Okay, I would like to have the lights on for a minute. Based on the map you just saw of the Judith River going from the west end of the reservation, you can see it goes from a 2000 foot elevation to down to about 500 feet here and so you can see that the formation is dipping to the east and when you reach the Poplar Dome area, you can see what happens here, and then it goes straight past into the Williston Basis, and so that describes the way it goes, as it dips towards the Williston Basin. Now then, I also have a thickness map which shows the variation in thickness across the reservation and anyone that wants to take a look at this later on, are welcomed to do so, and the sandstone varies in thickness from about 200 feet in the western edge of the reservation, along the Glasgow Air Force Base to as little as ten or twenty feet in the region between the Volt area and the Tule Creek area and the Poplar field and in the Poplar Field it varies as much as 20 feet to as much as 80 or 90 feet of the total sandstone thickness. You can notice this area here, in 54 East and here, in 52 East, near the east end of the reservation there is no Judith River sandstone, and as I said, anyone wishing to look at this map afterwards here, are welcome to come and look at it. Now on the structural map and on the thickness

1 map that I have made for the reservation, the nose or the
2 trend of the sandstone being effected by the Poplar Dome
3 area is very obvious and you can see the ending of the
4 formation as it grades into the shale to the east. The
5 characteristics of this -- from the map and notes, indicates
6 that you can trace the sandstone across really well across
7 the bottom of the formation to the sandstone on the top of
8 the formation as it comes and goes across the reservation,
9 and the log shows the sandstone becomes quite shaly and it
10 becomes very difficult whether you can still call it sandstone
11 or not; In the Lustre area the Judith River sandstone is
12 thicker then in the west end reaching from 30 to 45 feet and
13 it is quite a bit thicker in the Volt and Tule Creek areas
14 where it reaches about a hundred feet in thickness and so
15 it is a good aquifer of sandstone in this region. The
16 structure shown by this map shows this going out from west
17 to east and rising over the top the area here, and of course
18 it controls the ground water movement. I might point out
19 that in the Poplar area -- may I have the lights off please,
20 so that it will show up better, this map covers the Poplar
21 area and this map shows the depth of the Judith River
22 Formation and this is a larger reflection here where you have
23 the Poplar River area this valley, and the higher areas to
24 the northwest of the Poplar area field but it shows the
25 Judith River formation is about within 600 feet of the surface

-- now this is the east Poplar and this is the northwest Poplar field here and it is about 695 feet in this area and reaches a thickness in the northwest Poplar field to a depth of 12 to 1300 feet. Now this map demonstrates what is seen across the reservation is that on there, it shows the thickness of the Judith River sandstone and in this area in here, and this region in here has thicker sandstone as it moves through this region here, the sandstone is somewhat thinner and as it moves across right here the sandstone again thickens to the north. This pattern of thinning and thickening of sandstone is something that shows up quite well here. I might point out a couple of things here, in the process of showing the various thickness, you should note these to the northwest, then to the south and then the north south. May I have the lights on again please? Now this one shows the cross section of the well responses according to the Judith River formation either by recent activity or gamma ray activity, and in this section here, starting with the northwest Poplar Field area, and showing the Judith River rising as it goes over the top of the field and then coming out here again on the south side, and this shows the changes in the elevation and you could see the responses here, the sandstone characteristics, that there is good sandstone on the bottom of the formation and that is where most of the water is being injected I would presume, and then as we get to the very southern part going deeper

towards the Williston Basin, there is very little sandstone left. The North-South section, shows the Judith River formation shows the sandstone changing by quite a lot, the thickness in some of the regions, but again, you can see the effect as it goes across the Poplar Dome area before it goes back down. Down below it it shows the area of the beninite on top of the Eagle, so that you do have a change in the elevation. Lights off again please.Okay, this is a structural map showing what the cross section shows, and also this is a structure map on top of the beninite which underlies the Judith River area and it shows the Poplar Dome very well. One reason the Judith River is so shallow is because the rocks are higher and the surface area here is lower, where the Poplar River runs through, about right in here. It is interesting to note though, that the structure indicates the river valley, the surface running to the north so that any water being injected into that area would be moving to the north; the overall structure of the reservation indicates that the water moves to the south. In terms of the hydrology of the Judith River Formation, the maps that I have shown here today shows to the west of Glasgow the outcrop of the Judith River and it goes all the way over to the Bowdon area in the Saco-Hinsdale area and one of the best places to see that is near the community of Vandalli which is west of Glasgow on the Milk River. This would

be the area where the Judith River probably recharges the water into the aquifer and then moves or migrates down towards the east. The sandstone in the Judith River is fine grained and is much cleaner in the west and then it becomes more and more shaly as it moves from the west. In the Poplar area, the perosity is less then -- is a maximum of 15 to 20 percent in the sandstone. I think that the logs demonstrates the continuing of the lower sandstone and sometimes the upper sandstone in the formation is much better than I have probably suggested. I would say that the flow of the water in this area here, depending on the perosity of the formation, that runs across this area would be something like five feet per day to as much as five feet per year, so that water that is passing through or across the reservation would take anywhere from a hundred years to perhaps 10,000 years to cross the reservation, and could be as much as possibly 50,000 years. Little is known as to the water communicates. The lower area like was shown on the previous map would show where the salt water is running or migrates from the higher areas and the higher area is where the fresher water would be, as the salt migrates to the lower areas. Where the water goes is really unknown, and it has been suggested that it goes probably to the south for this area and even then it would have to go through some shale but there is very little know about this, but locally some of it would go

to the north in the Poplar area. Little is know about the water quality across the reservation but we do have some for the western part, and I will try to show some of these on the next table. This table is based on an early table I showed you, and shows some of the water wells on the reservation and some of the chemistry of the water. As to the analysis of some of the water, I received some of them in '77 or '79 and the Judith River water quality as far as from the -- at least from the west end of the reservation varies from as low as a 1000 mg/l to as much as 4100 mg/l of dissolved solids and this one would be down around Frazer, Montana. The Chloride varies in the water wells from as little as 346 mg/l to as much as 2000 mg/l. You will note that the drill stem test water samples that were submitted here shows a fairly higher concentration of dissolved solids from 10,000 to 18,000 of Chloride to as much as -- here is 11,000 and so there are very different types of water in these areas. I don't believe that this type of analysis is a good method to sample the water in the aquifer and that is not an adequate way to sample the water, and a lot more work needs to be done on water quality in this area and especially in this area where this salt water injection is being done, in the various areas of this reservation. This one shows a few more water wells and the analysis and there it shows where it would be between 2000 and 3000 in this area

down to 1400 on the west end of the reservation. Okay now in conclusion here today, I hope that I have shown you a little bit as to all of this, and anyone interested in looking at these maps may do so and they will show you the nature of the formation, the Judith River formation and the structural formation, the thickness and like I told you, the water on the western side of the reservation is of a suitable nature and is being used by ranchers for stock watering and for domestic purposes and in some cases, that is all that they have to use for water and it would be a shame to see the aquifer that is being used get contaminated, to see this water get contaminated. From a geologist's point of view I feel -- and a hydrologist's point of view, that the Poplar field and the rest of the fields in the--located on this reservation is a very important thing insofar as the people who live here now and in the future. I want to thank you for the opportunity to talk to you here today, and if any of you would like to look at these maps and charts, you are welcomed to do so. Thank you.

AT THIS TIME, this speaker concluded, and a recess was called from 10:20 AM., until the hour of 10:30 AM, at which time, the speaker called to the speaker's stand, a Mr. James T. Thornton.

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MR. JAMES T. THORNTON: My name is James T. Thornton, and I am from Casper, Wyoming and I am a petroleum engineer and consultant for the Assiniboine and Sioux Tribes of the Fort Reservation and on their behalf I am presenting this evidence for this hearing. I will dwell mainly on the producing and injection mechanics for the injection into the Judith River Formation and also some potential for injection into other areas and other formations. I would like to have the first slide now, which represents a slide of casing down into the Judith River formation in the Volt Field. On this sketch, the circled wells show where the surface high is set right about the top of the Judith River formation. Now this field was built up in 1964 and the casing was set up around six hundred feed of surface casing of 10 3/4s and 9 5/8ths indicating there are potential zone between the depth of 600 feet and 1400 to 1500 average depth for the Judith River that indicates injection into these wells right here, and by moving down into other known water bearing zones. Now the potential for water moving up into the upper zone is evidenced that this could happen by corresion in the casing or leaking casings where the surface casing and the production casing always present a hazard by which contamination may result in areas up and down a hole. In the Volt field based on 45 feet of sand with an average perosity in....328,000 barrels of water injection that has the potential to fill

about a hundred and 87 acres and this would have a radius of approximately 1060 feet, if you were to spread this out around the spoke of the distribution well. As any reservoir engineer will realize, you don't have a uniform distribution away from any onjection well, you get spokes going out to lower pressure and something could happen where it would go into this area right here, rather than going out into a circular area. Now if the next thickness of sand taking the water was only one half of the 45 feet, this area of radius of injection would be extended out to approximately 3300 feet. Now the hazards of migration away from the well bore into foreign zones is always apparent. Now I would like to point out why this is apparent and is a hazard. In the discovery well in that field, 10 3/4 inch surface casing was set at 600 feet and 5 1/2 inch casing was at then set in with 340 bags of cement and assuming that an eighth and three quarters inch hole was drilled below this 10 and three quarters surface pipe and that five and a half inch long stem was run it would fill up a hundred percent without having any consideration for anything else and it would calculate to fill up at 1800 feet which would throw the cement out to about 5600 feet, now if you doubled the volume of cement we would have about 3000 feet of fill up and the cement process at 4500 feet below the surface, now the Eagle top is at 1900 feet so that the eagle sand is at a

much lower level underground source of drinking water as set out by EPA in their notice of September of 1983. Next please, the Tule Creek. Now this shows the relationship of the injection wells in the Tule Creek, and it shows here one injection well right here and with a group of wells around it and again the surface does not extend down through the Judith River formation and again the hazard of migration upwards or downwards is very emminent. Now let's look at Tule Creek East. Now the injection in the field here is 7,386,000 barrels of water. Now this is Tule creek again shown here, and the surface pipe was -- had not gone down through the Judith River. Three injection wells all of which are not active, as one is on standby and a total of 6,075,000 barrels of water injection as of February 1, 1985 of the three wells shown on this sketch. Again, the same problem through migration upward and downward exists in this particular field. Benrud next please. Benrud East and Benrud again shows injection wells here, and -- one here and three over here and the same problem as the surface casing does not extend down through the Judith River Formation with a likewise hazard being a potential and in the four wells making up this field, some 6,145,000 barrels of water has been injected into the Judith River formation. Okay the Poplar Field: This is the injection in the Poplar Field and in the center of the field, showing how much water has been injected

1 into the two wells, one being in the West Poplar Field and
2 you can thoroughly recognize the potential of the surface
3 pollution or underground pollution by setting surface casing
4 into the Bear Paw shale and on even down into the Judith
5 River because in this particular instance, there are only
6 a few wells which do not have surface casing running into
7 the Judith River. In this instance right here, and some
8 others, -- now the largest injection of water injected
9 anywhere is into this well right here, where some 22,000,000
10 barrels of salt water has been injected into that well and
11 that is one large volume of water being injected into any
12 particular well, and shows the magnitude, now the smallest
13 one is around or about 450,000 barrels into any one injection
14 well, and this is the largest one and from 76,000,000 barrels
15 of injected water has been disposed of into the Judith
16 River formation and roughly about 22 percent of it has been
17 put into this particular well right here. Taking some
18 calculations to see how far this water could migrate a well
19 in a circular distance, again assuming 15% perosity, 45 feet
20 taking water and assuming that 424 acres has been filled by
21 the 22,000,000 barrels of water injected, the radius would
22 be 2425 feet; now if the thickness of the sand is cut in
23 half, we have almost a mile of movement of water which
24 approaches 4850 feet. Now the injection into the Judith
25 River is totally unusual in that the Judith River is not an

oil and gas producing reservoir. If it is filled with anything it is water and for every barrel of water being put in we have to displace another barrel. How much gas has ever been recorded and put on the books?

SOMEONE IN THE AUDIENCE: I don't know the volume.

MR. THORNTON: Since the discovery in 1952?

SOMEONE IN THE AUDIENCE: No.

MR. THORNTON: But there is no volume that I was able to ascertain out of the Oil and Gas Commission as being produced and there are no records of any thing that gas has been produced. Now if that is fact, and until the numbers are out, no one can calculate what the bas saturation is as of today. Now let me have the Kerr on the goings Well please. This is the Goings Well that is the subject of this hearing and it is located back here and in the more recent drilling period there has been a change in the surface pipe that is set down from 300 to 600 feet and the depth of the sand for the Judith River is right around a 1000 to 1100 feet, plus or minus in there, and shows again that if pipe is set at 300 some of the upper is open for contamination due to the surface casing and long production string which is injecting into the Judith River. This is not a great problem but again it does have an adverse condition that could result in contamination of the upper potential water bearing zones. Now let me have the calculation of the injection pressures please.

Taking the data from the sheet that was presented by Mr. Monson and making the calculation for the EPA formula for maximum injection pressures where you have a factor 7.33 minus a waste...of a columm of water point four three three times the specific gravity of the injected fluid, times the depth and calculating that for the various injection wells shown, I come up with a calculation on the Volt of calculated pressure of 423 pounds and actually the wells are carrhing an injection pressure of 470 pounds and now to calculate that back what the radius is and injecting at 470 pounds psi on the surface,I calculated the same formula back and came out with a figure of .765 psi as compared to the EPA recommended pressure of .733. In the Kirkwood well number one in the Volt field, the injection is 400 pounds and the calculated maxiumm pressure of 415 psi that comes out to a 723 and in the Murphy Well in Benrud, the injection is at 350 pounds, and calculated maximum injection pressure is 418 psi and the pressure rating is 687. Now in this well over in Benrud, number one, injecting at 400 pounds, the maximum injection pressure is 434 and calculated with a rating of point 711. In the Murphy Mule Creek Number 1, you have an injection of 630 pounds and the maximum injection pressure of 436 is calculated out to 8.58 psi per foot. The largest one is on the Petro Lewis Well number 2 well, with an injection pressure of 950 pounds, calculates to a 432

1 injection pressure with a rating of 1.071 pounds per foot.
2 Likewise, Century Well here has a -- the Century Goings Well
3 I should say, had a surface pressure of injection of 750
4 pounds, calculated out to 302 pound maximum injection
5 pressure with a rating of 1.15 1 pounds per foot. Likewise
6 the Murphy Reynolds EPU number 8, operating at 780 pounds
7 of pressure, calculates to 228 pounds, maximum injection
8 pressure and a rating of 1.670 pounds per foot. These were
9 made to calculate and show how sometimes the injection
10 pressures exceeds those set by EPA and to my knowledge, none
11 of the operators have asked for an exception to the
12 prescribed .733 pounds per foot as set out by EPA. Now the
13 accumulated production of oil is 46,000,000 barrels of oil
14 and there are 114 wells that have been drilled over the
15 field and the average production is 406,000 barrels of oil
16 per well, and it is estimated by numbers from the Montana
17 Board of Oil and Gas that 25% primary recovery will be
18 obtained. The significant thing in my estimation is the
19 fact that we are only going to produce 25% of oil and we
20 are injecting with water up into the shallow zone with all
21 of the hazards and with all of the risks that accompanies
22 injection at this depth. Now true, it is the most economical
23 way is to inject, because you don't have to buy a pump, you
24 don't have to buy electricity, but with 25% of the oil in
25 place recovered, it behooves somebody to try double the
production and with the current techniques to enhance oil recovery

which are being used now in the Big Horn Basis in Wyoming, in my present work with major companies, they are first going to pulamore flooding and are going to use that in the Big Horn Basin fields, and try to pick up an additional three to five percent of the oil in place, so that with what has happened here in Poplar, in my opinion, Poplar has a prime chance to use some of the enhanced recovery methods and over in South Dakota, in depths of approximately 8000 feet it is my understanding that it is a successful operation. Volt Field has the accumulated production of two and a half million barrels, ten wells, again 250,000 barrels accumulated per well, averaging 36% of the oil in place is estimated to be the recovery. This looks like to me to be good place to put some new recovery techniques. Benrud has 11 wells, with 374,000 barrels average accumlatative production per well, and it is estimated by the Montana Oil and Gas Conservation that 50 percent of the oil in place will be recovered there and that doesn't have as good a potential for additional oil to be recovered out of the existing facilities; Tule Creek has 10,000,000 barrels of accumulative production, 20 wells, 517,000 barrels average accumulative per well and the State Board says that only 40% of the initial oil in place is going to be recovered from those wells. There is a need for enhanced recovery, particularly in Volt, Poplar, Tule Creek all of which have

a reduced recovery and they need some kind of a secondary recovery enhanced method, utilizing the produced barrels of water to supplement the reservoir pressure and push new oil back into the reservoir and then into the outlet. If the production could be doubled in the fields that I've mentioned, Poplar, Volt, Tule Creek, there would be an additional 50,000,000 to 60,000,000 barrels of oil that would be produced from these fields. Thank you.

AT THIS TIME, this speaker yielded the floor, and the floor is yielded now to a person from Murphy Oil Company, the name of whom this reporter was not made aware of.

---oOo---

1 MURPHY REPRESENTATIVE: I am Mr. Campell and
2 I am with Murphy Oil, and we've submitted a report of water
3 analysis that was taken from the East Poplar Unit primarily
4 from the Judith River that takes it all the way back to 1967
5 prior to any water injection into the Judith River, and
6 Chloride at that time from a well up in the north end of the
7 unit was a total chloride content of 18,336 parts per
8 million and another well was 14,923, which was the Number 1
9 O'Connor, and then another well up in the East Tule Creek
10 area was 15,229 parts per million in 1964 and that was
11 approximately the time of discovery; and another well up
12 in the Tule Creek area 13,423 parts per million in 1965 and
13 the sample taken from the Ford G, which was a producing gas
14 well and there were approximately five wells in the East
15 Poplar unit, and the LG, 3G, 4 and 5 G wells they did
16 produce gas for a short period of time, and the gas was
17 used primarily --- I do not know the total volume of gas
18 produced but there was very little need, the volume was
19 not being sold, all of the gas was used and the one well
20 that we do have in the Poplar field is producing in the
21 neighborhood of 200 to 300 NCF per day. The problem with
22 production was that there was water produced with the gas
23 so that you had problems producing the gas. We do have a
24 well that was later turned into a fresh water well and the
25 geologist talks about the salt saturation. It was a very

1 different problem in the late 50s and the early 60s when
2 we produced water and the salt water produced from the
3 formation into the well hole, you could see the pressure
4 drop and the temperature drop, and the result was that it
5 blocked the production; and so at that point you either go
6 in and pull the well and wash the salt water out and go
7 back into your operation or you put fresh water back in to
8 the back side of the casing in order to continually wash
9 and delute the water at the perferation to keep the salt
10 water out and that was what was done, and I don't know if
11 that was in the late 50s or early 60s, but it went to a
12 fresh water supply. What we did was to re-perferate the
13 gas well and as to this fresh water I am not talking about
14 2 or 3 thousand parts per million, we are talking about 10
15 to 12 thousand parts per million. The water injection began
16 in 1968 -- no, '78, when we converted our number 8 disposal
17 well which is our salt water station number 4 into the Judith
18 River, and I believe that volume was 15,000,000 barrels and
19 not 22,000,000 barrels. Not a lot of difference there when
20 you are it, but the one thing that you have to remember in
21 quoting the distances, or the radius from a well, when you
22 cut the sandstone in half, you don't double the radius. The
23 radius is a square formation and your radius is not that
24 much greater if you cut the sandstone in half. Also the
25 problem is not in the volume of water that is injected, when

you are talking about the migration of water up and down, the problem associated with water migration is probably within 40 to 50 feet of that particular well hole. All of your pressure drops occur within ten feet of a well, so that the migration of the water up or down is probably not used or due to the amount of water that you put in, so that something like 20,000,000 barrels of water injected into the Judith River in that particular well, when you consider the maximum of water that is in the Judith River, you are talking about a small volume, a small percentage, and you are not going to raise the pressure in the aquifer in that 200 or 300 acres more than four or five pounds, so the problem is not in the volume of water that is used, or injected, it is the near well hole conditions; that is where you are going to suffer damage if you are getting any damage. That is the only place that you have that pressure, to get the water back up to the Judith River and into the shallower water zones. The samples of water taken in 1960s from a fresh water supply well, was 15,760 parts per million and this is prior to the injection. We have a sample taken in 1966 from a supply well that had 10,800 parts per million and also you should remember there is a sampling problem and there is also an analysis problem. Sample taken in 1968 the chloride was 13,400 parts per million; sample taken in 1969 18,600 parts per million; sample taken in 1970, 10,000 parts

1 per million; sample taken in 1984, 11,600 parts per million
2 and sample taken in or on April 1st, 1985, shows 10,783.
3 As we view the Judith River, the Judith River does not fit
4 the classification in this particular area of an underground
5 drinking source of water; and as to the other evidence of
6 contamination if the Judith River is not a fresh water
7 supply source -- I would like to make a comment right here,
8 the East Poplar unit but the East Poplar unit is a water
9 dry reservoir, it is a fractured reservoir , and we started
10 in 1957 had a pressure maintenance operating in the north
11 end of the field and due to the fractured nature of the
12 reservoir we saw water going through rather quickly in the
13 wells in the north end of the unit. However, we didn't
14 stop injection and we continued on for approximately seven
15 years, on into 1964, in which time we saw no benefit at that
16 point of the pressure maintenance for water injection. The
17 idea of enchanced recovery, that is something that we are
18 still considering and will consider it for some time to come;
19 and until we find something that we have confidence in that
20 will work, under the conditions that we have. However, it
21 was suggested, it is a very viable possibility; however, the
22 problem at the current time is our temperature restriction
23 which we are operating above 200 degrees in the reservoir,
24 and others are having the same problems when operating much
25 over 125 to 150 degrees. The other problem is the use of the

-- if we could use the water that we have being produced out there at the current time. So you can see you will still have a problem with salt water disposal. The other problem is where do you get your water source for the flooding? You have to problems, you still have the problem of disposal if you can't use the disposed water; and the other problem is the water supply, and that would possibly be the Judith River. But we would still have the problem if we could use the fresh water supply in this area, and the fresh water in this area, we understand and you know and everyone knows is not in great supply. So that is the problem. Alternatives are good, but there are already problems associated with the alternatives. Number One: There is no way that you could produce the East Poplar Charles formation without producing a large amount of water. Also, even if we never put another drop of water back into the Charles formation, it continually re-supplies itself with water. Where it all comes from, we don't now know. But it is there and pressure depletion is not an extreme problem, so it does continually re-supplies itself. But when you look at the East Poplar unit, there are large volume of oil there, true, but only 25% is recoverable, and probably it is going to be a little bit lower than that. The question is how much is there to begin with? That is a question that we now don't have an answer to after 35 years of operation. So, enhanced recovery becomes a problem when

you don't know how much actually was there to start with. We have estimates that vary as much as a hundred million barrels. The other areas, I guess, that need to be discussed is whether or not the Judith River can be used for disposal. Our contention is that there will be very little damage that will occur to the Judith River itself; but we can't make the decision as to what -- there has been insofar as chloride around the well head, there is no doubt about that, but as to total contamination, as far as a guide line sent out by the EPA is 10,000 parts per million, the Judith River from the data that we have, and we believe it to be valid data, we feel that it meets the EPA requirements insofar as salt water disposal is concerned. Thank you.

AT THIS TIME, this speaker relinquished the speaker's stand. At this time, Mr. Chet Brown was yielded the speaker's stand.

MR. CHET BROWN: My name is Chet Brown and I am a Division Engineer for Century Oil and Gas Corporation located out of Colorado and our salt water disposal well I guess is the well we are talking about here today, and whether or not we can continue to dispose water into the Judith River formation, and first I would like to point out that this problem is nothing new, and it has not been since we moved in with the number one well back in 1981, and at that time, we had to secure a permit from the Montana Board of Oil and Gas and also to the BLM which also required several Judith River water analysis that we had to submit and also what type of water we were going to inject into the Judith River, and then again this problem came up in 1984, in July when the EPA required us to give them some substitute information on the Judith River in order to classify that as not being a source of drinking water. The Judith River, from what we gathered data on, does not qualify in the immediate area, and this data is the same data that Mr. Campbell from Murphy presented and what theydid, as far back as 1964, took water samples which also showed from 11,400 all the way up to 19,000 mp/l. That again, does not qualify in the USDW. We cannot find any wells in the immediate area that anybody is drinking that water today, or have they ever drank it or ever will drink it. I think that we need to go into the Judith River quality to the west and how that varys

from the immediate area and our Goings Number One, and what I have tacked up here on the board is the eastern and northeastern part of Montana and where the Murphy samples were taken way back in the early 50s, or rather late fifties and early 60s, and in going to this map, I am going to show you how the Judith River actually freshens up, and I am not a geologist here, but I am going to try to show you what we think is going on with the Judith River. What this map is, is a map of put out the Montana Bureau of Mines and Geology on salt salids in the water from the Judith River formation, and our immediate area these are the Murphy wells, the Carter Wells and some others here, samples were taken during that late 50s and 60s period and we all saw solids from 11,000 all the way up close to 19,000 mp/l. As you move west then, these numbers also -- actually you get an outcropping of the Judith River to the west, which are fed by rainwater, the Missouri River, and probably the Milk River, whatever, but this water over in that area is being used for livestock . The Judith River, in some areas, is being used today, to drink, to water livestock and also to irrigate, and as we move to the east then you are looking at outcropping to the surface and there is no way that our wells can be fed by run-offs, or by river water. The nest map please. This is a map that is put out by the USGS and what this map shows generally is some of the outcropping of

the Judith Formation in this north central Montana area. This map generally embraces this area that is shown over here, right here. I would like to point out here that the best quality of water is obtained near the outcrop of the Judith River formation that lies along the Missouri River. The discharge of ground water away from the river ....there is no doubt that people are using that water, but in our area there is no way that anybody can use that water or that they will be ever able to use that water. We do have some additional maps showing the Judith River outcrop specifically, but what I plan on doing and what Century is planning on doing, in the next couple of weeks is to present a written summary of what I am saying. Really what Murphy said is what Century is saying and that is that we believe that the samples taken from the East Poplar field from the late 50s and early 60s, from the Judith River. The Judith River today in our area contain over 10,000 milligrams per liter and nobody is capable of drinking that today, and it is not being consumed in this area that we know of by any humans, or livestock or for that matter irrigation purposes. I would like to comment on the depth of the casing that has been set in the wells we drilled ~~in the Poplar area. When we permit~~ a well in the Poplar area, we permit it for approximately five to six hundred feet of surface casing and 5 3/8th surface casing is to be run, and if it occurs on a well that

is to be on deeded land, the Montana Board of Oil and Gas Conservation approves the permit; if it occurs on Indian land, the BLM gets involved and they say, you have to set 1100 feet in order to protect the Judith River formation. We say Why? Montana disagrees with you, and they don't feel that the Judith River is a fresh water aquifer and yet you do. So the reason we set 1100 feet is simply to comply with the BLM requirements. We don't and never have believed that the Judith River is a fresh water aquifer but it is just to comply with the BLM. We don't want to pollute the fresh water aquifers in the Poplar area, and we do continue to observe the pressures on all of our wells, injection wells, and when we report these pressures to the state, for instance, a well may have 750 today, and I believe that every pumper will agree that the pressure on a given well will vary every single day of the week. They are not 750 every day, it may be 600 one day, and then the next day it may be 500 and then the day following that, you may go out and read 700, and so they do vary and so what we try to do is present to Montana and also the BLM average figures, and I guess that closes up what I have to say. I think that Century has been not only concerned with this matter, but also wants to be of any assistance in resolving this Judith River conflict that we have had since our initial well in 1981. We would like to get it finally resolved for once and for all and finally,

define what the Judith River is in this area and the extent of it and if we can or cannot inject into that formation. Thank you.

AT THIS TIME, this speaker relinquished his speaker's stand to Mr. Joe Morlin.

---oOo---

MR. JOE MORLIN: Good morning, my name is Joe Morlin and I am with the US Geological Survey from Helena, Montana and I am a hydrologist from Helena. I really don't have anything to present this morning, as Larry Munson has presented all of the reports and I feel that he has done an outstanding job of presenting the data available, but I would re-emphasize that there is not lot of data for the Judith River in this part of the state. The USGS has combed the files for several studies and there just isn't an awful lot of data that is available on the aquifer characteristics, the water quality and distribution and those kinds of things. We do have a pretty good handle on the thickness of the structure, the contours of the sandstone and those sorts of things, and the reports that Larry mentioned this morning, we do have copies of those available. As to the water quality information, several references have been made to drill stem tests and data, and the USGS Board of Resources Division has used drill stem test data to try to map the water quality distribution and the aquifers in the northern plain states, and we use that data with caution. In some cases, the drill stem tests that has been collected with proper concern given to length of time that the well has been allowed to flow and those sorts of things, and we judge each sample on its own merits. We look at the balances of the chemical analysis and what the water quality tells us and that sort of thing,

and we find that it can be from 10,000 mg/l and down to 4 to 5000, and again, drill stem tests may be useful in drilling Judith but as far as a wealth of information on finding what the water quality is like in the aquifer I are a little suspicious today. I get a little nervous when I hear things like some of the things that came up here today. Another thing that I heard today, is that perhaps we will never be able to use this water like we are using it today. The Israel uses water that is considerably more saline than the water is in this part of the state. With the modern technology that we have, we can make this water usable for industrial purposes, if not drinking water. Another thing we heard today, pertained to the water that is moving out and into the aquifer. I don't think there is anything serious of where the water is coming from, and I can see no reason why it couldn't be injected back. I guess that is about all that I have really to offer at this time, and I would caution that once we inject various high levels of salt into an aquifer, we are never going to recover it, once it is put in, it will not be coming back out. Very easy to stick it in but very difficult to take out. Thank you.

AT THIS TIME, this speaker relinquished his speaker's stand, and Mr. Whitmer was given his opportunity to present his evidence.

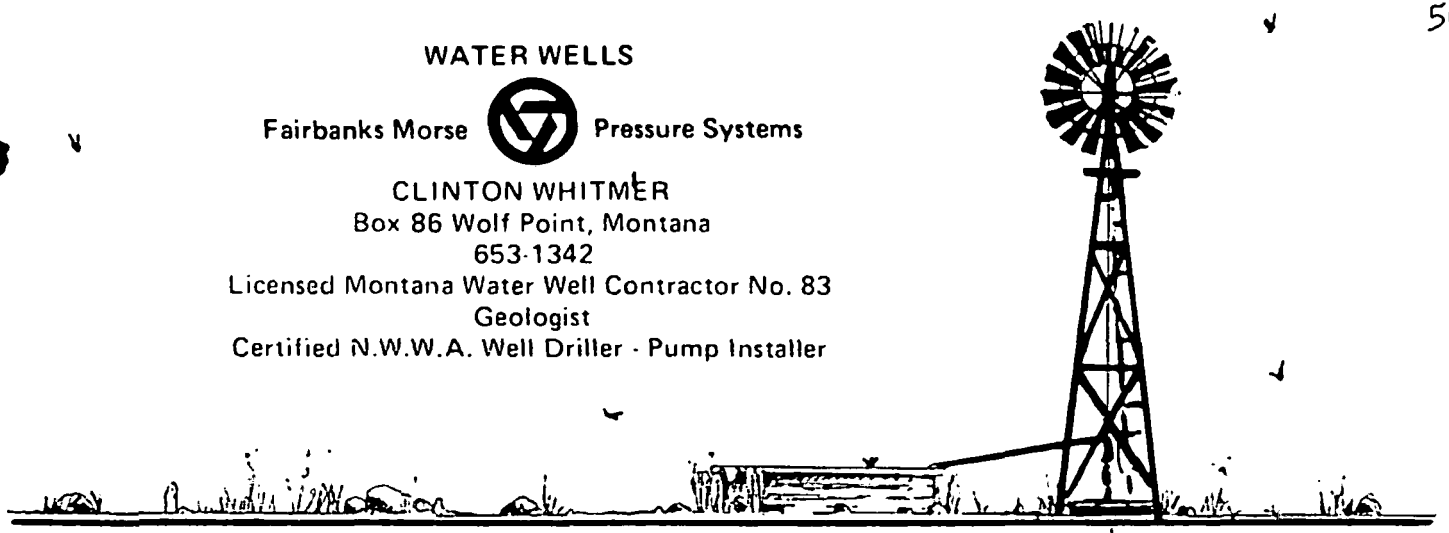
MR. CLINTON WHITMER: My name is Clint Whitmer and I am a licensed Montana well driller and I am a geologist, graduated from the University of Montana at Missoula and I have drilled hundreds of water wells in eastern Montana and one water well into the Judith River at Fort Peck, Montana. My presentation begins with "Degredation of Water in Montana".

AT THIS TIME, Mr. Whitmer read to the group, his written report, verbatim, and the same is hereby incorporated into this transcript as pages 56, 57 and 58.

WATER WELLS

Fairbanks Morse Pressure Systems

CLINTON WHITMER
Box 86 Wolf Point, Montana
653-1342
Licensed Montana Water Well Contractor No. 83
Geologist
Certified N.W.W.A. Well Driller - Pump Installer



Whitmer Drilling

Degredation of Water in Montana

1. States may have stricter guidelines than EPA
2. In Montana, there are no state guidelines for degredation that exceed EPA standards.
3. In Montana, non degredation is based upon beneficial use, i.e. if the water is not fit for beneficial use, further degredation of that water is not considered degredation.
4. Upstream states have an obligation not to pollute waters going to downstream appropriators.
5. Judith River background: the Judith River is a named member of the Cretaceous interval. It underlies much of the Williston Basin from the North Dakota border westward past central Montana. In Eastern Montana, it is overlain by Cretaceous Bear Paw shale, which itself is a thousand feet thick with no aquifers; Fox Hills sandstone, one of the most important aquifers of Montana; upper Cretaceous Hell Creek Formation, which contains intervals of alternating shales and aquifer sandstones, also an important water resource of Montana; Tertiary age Fort Union formation which has alternating intervals of shale and sandstone aquifers very important to Montana; Pleisticene Flaxville gravels; and Recent Wisconsin Glacial till and channel fill.

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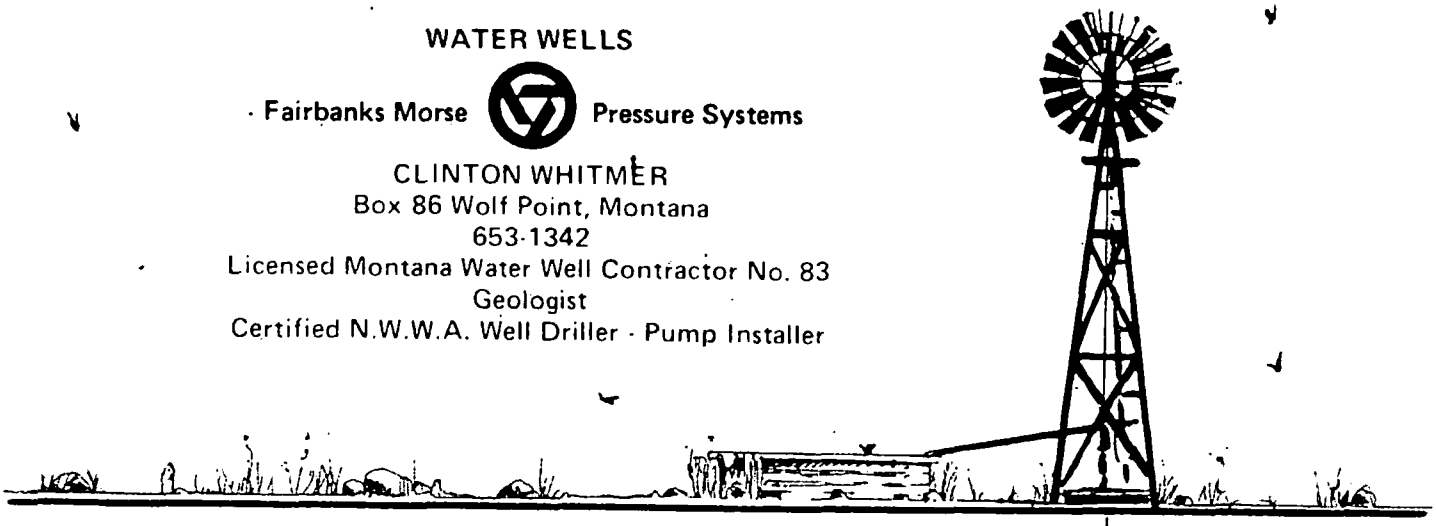

Whitmer Drilling

6. Judith River Fm in Roosevelt County
   1. Where the Bear Paw shale outcrops, the only aquifers are: The Missouri river alluvium of Recent age, glacial gravels, stream bed channels, springs, and the Judith river. The Fox Hills, Hell Creek, and Ft Union formations do also occur in Roosevelt county. Bear Paw shale outcrops on the Poplar dome, a structure near Poplar, Mt, and continues to outcrop, as this structure is the start of the North Montana uplift, westward on much of Roosevelt county and Valley county as well. Bear Paw outcrops are prominent over a large area of Valley county.
7. Judith River Sandstone geology
   1. The Judith River ss consists largely of soft sandstone beds alternating with friable shale and some coal seams. This interval can be almost 300 feet thick, with upper and lower sandstone intervals separated by a shaly sequence.
8. Judith River aquifer characteristics
   1. Static water level: The Judith River will flow freely at a rate of 10-30 gpm at an observed pressure up to 46 psi. These free flowing occurences are in the area of 2000 ft elevation.
   2. Water Quality: The Judith River contains sodium, potassium, chloride, carbonate, bicarbonate, sulfate, and nitrate. Hardness as carbonate ppm can range from 2000 to almost 3500 ppm.

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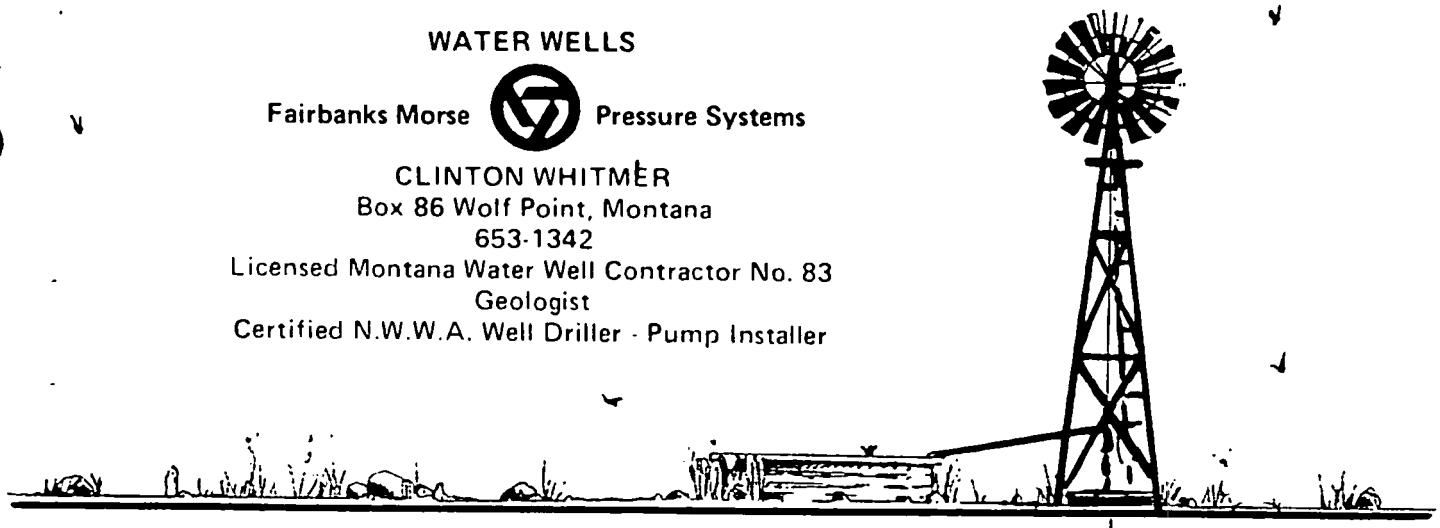

Whitmer Drilling

9. Beneficial Use of the Judith River aquifer
   1. This aquifer has been used for livestock, fire protection, household facilities, swimming pool water, industrial and business applications, and in some areas of Valley county as a source of potable water for human consumption.
10. Future use of the Judith River aquifer
   1. Modern technology such as reverse-osmosis process and distilling process are only two methods that natural state dissolved solids levels could be lowered to allow this water to be maintained as a viable resource for the people of Montana.
11. Conclusion

There are areas in Roosevelt and Valley counties that have only the Judith River sandstone aquifer as a fresh water source. It is not fair to the people of Montana to be threatened with further degredation of this aquifer.

Sources cited include: "Waters and water rights," Vol 3, Beck and Goperlud 111; "Geology and Groundwater Resources.....", Geological Survey Paper 1263, Swenson ;"Montana Water Law" Chpts 8 and 29, Jul 1, 75

AT THIS TIME, following the report given by Mr. Whitmer, Mr. John Radenberg was given an opportunity to present evidence.

MR. JOHN RADENBERG: My name is John Radenberg, and I am Chairman of the High Plains Mineral Association, Glasgow, Montana, and we are here to express our concerns about pumping salt water into the Judith River formation because that is the only source of some of our members have for fresh water. We feel it is important that we keep this as fresh as we can. It is poort water at this time, but it is useable but we would like to maintain it like that. That is all that I have to say.

AT THIS TIME, this speaker relinquished his speaker's position, and the state representative from South Valley County was given an opportunity to speak.

1 VALLEY COUNTY STATE REPRESENTATIVE: I am Ted_____
2 (The last name was not audible for this reporter) and I am
3 the State Representative fromSouth Valley County which
4 includes a third of the Fort Peck Indian Reservation and all
5 the rest of Valley County and I am also an officer in the
6 High Plains Mineral Organization or Association. I am not
7 an engineer, I am not a geologist, I am a farmer, but I feel
8 sometime that I should be able to apply for a college credit
9 for geology, but I know personally many of these people in
10 the farming business, next to me, that do use the Judith
11 River for water for domestic uses. Mostly it is for
12 livestock and a couple do drink some of it if they have to,
13 but their stock does need this water. On the south bench
14 out of Glasgow, that is all of the water that those people
15 have, as there is no other surface water had. They are all
16 very concerned about the pumping of this salt water back
17 into the Judith River basin, or formation. They look at it
18 as of right now, some of these people, they are saying right
19 now that it isn't going to last forever because they are
20 pumping into that formation, maybe five years, and at that
21 time, their cattle may not be able to drink this water, and
22 that they will not be able to use it, after all of these oil
23 companies are gone. So that is something that they are very
24 concerned about and I am, and being a farmer, I know the
25 resource of water in Montana is very very sacred and if we

do any damage to the water that we have, and I am like the man from Helena who said, many things have been said here this morning, like this is water that we don't or will never be used. He doesn't know that for sure, that this water will never be used. We don't know how fast that water is moving back and forth or what it does. That is my problem and that is the problem of a lot of people that I represent, they are real afraid of what is going to happen to some of their water. Thank you, that is all I have.

WHEREUPOn, this speaker then relinquished his speaker's stand to Mr. Paul Christiansen.

1 MR. PAUL CHRISTIANSEN: I am Paul Christiansen and I am with
2 the Bureau of Indian Affairs, the Billings Area office.
3 AT THIS TIME, this speaker read for the record,
4 a written report, which is hereto incorporated
5 into this transcript as pages 63 and 64.
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United States Department of the Interior
BUREAU OF INDIAN AFFAIRS
BILLINGS AREA OFFICE
316 NORTH 26TH ST.
BILLINGS, MONTANA 59101

IN REPLY REFER TO:
Water Resources
Code 380

MAY 29 1985

Mr. Jim Boyter
Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
Helena, MT 59626

Dear Mr. Boyter:

The following is the testimony of the Bureau of Indian Affairs, Billings Area Office, for the record of the May 29, 1985, public hearing concerning effect of brine injection into the Judith River Formation, Fort Peck Indian Reservation, Montana.

The Bureau of Indian Affairs is concerned that brine injection in the Goings No. 1 Well and other injection activity into the Judith River Formation is deteriorating what may be a useful aquifer.

Brines are extracted with petroleum in the oil fields in the central part of the Fort Peck Reservation. These brines are later injected into the Judith River Formation in this same area. Wells withdraw water from the Judith River Formation on the western edge of the reservation and also west of the reservation. The water is withdrawn mostly for stock use. The quality of water in the formation is marginal for domestic or municipal use in the western part of the reservation where total dissolved solids range from about 3,500 to 4,200 mg/l. The quality of water in the formation over the central part of the reservation is unknown, except for chemical analyses from drill-stem tests. The analyses of the drill stem tests suggest that the total dissolved solids are more than 10,000 mg/l in the area of the injection wells. If saltwater fluids were used to drill the holes where the drill stem tests were conducted, these fluids may have contaminated the formation water, perhaps rendering the results of the analysis inaccurate. The quality of water in the formation may be expected to deteriorate from the west end of the reservation to the east. The formation does not yield water to any known wells in the central and eastern part of the reservation, because of the depth to the formation below land surface or because of the presence of other aquifers at shallower depths.

The hydrology of the Judith River Formation beneath the reservation is poorly understood. The potential effects of the brine injection into the formation on the usability of the formation as an aquifer in the reservation is also unknown. The injection wells are located in a structural high. The injected brine will then migrate to structurally low areas, being much heavier than the natural water in the formation. The rate of migration is unknown.

After a period of injection, the casing of an injection well may begin to leak due to the corrosive nature of the brines. The Judith River Formation itself may reject the injection brines due to possibly low transmissivities of the formation materials.

The concerns of the Bureau of Indian Affairs are: (1) that the injected brines may be leaking into permeable geologic units shallower than the Judith River Formation, and thus might be contaminating these shallower units used as domestic and stock water supplies; (2) that the injection brines then may seep into the streams and the quality of water in the streams during low flow periods may seriously deteriorate; (3) that the quality of water in the Judith River Formation be maintained in its natural conditions for stock and any domestic use over the western part of the reservation; and (4) that the aquifer, if not contaminated, might be used as a water supply in the future.

For these reasons, BIA urges that impacts of injection activity be evaluated and that future permits be considered only when the effect is better understood.

Sincerely,

Marvin M. Sole

ACTING Area Director

MR. ENGLE: Anybody else who desires to present any testimony here today?

(No response)

MR. ENGLE: Any questions?

(No response)

MR. ENGLE: I guess then, that this wraps it up for this hearing for today.

At this time, the closing remarks by Mr. Engle stated that all written reports were to be sent to the Denver office within thirty days, and that thereafter, this

HEARING WAS CONCLUDED.

COURT REPORTER'S CERTIFICATE

I, Calmer A. Ersness do hereby certify that I was the Official Court Reporter who reported this hearing, and that it was done by shorthand, and that this transcript is a true and correct transcription of said shorthand notes, TO THE BEST OF HIS ABILITY.

Dated this 9th day of September, 1985.

Calmer A. Ersness - Court Reporter
P. O. Box 978, Wolf Point, Montana 59201
Office Phone No. (406) 653-2613

cc: Bill Cragle
Pat Crotty
Andy Lensink

RECEIVED
MAY 19 1987
Contaminated Drinking Water CH

BEFORE THE ADMINISTRATOR
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

In the Matter of:	)	
	)	
Citation Oil and Gas Company	)	UIC Appeal No. 86-1
	)	
UIC Permit No. MTS21PR-0003	)	
	)	
	)	

ORDER DENYING PETITION FOR REVIEW

EPA Region 8 issued an underground injection control (UIC) permit to Century Oil and Gas Company of Englewood, Colorado, for Goings Well #1, which injects brine brought to the surface in connection with oil production into the Judith River Formation, an aquifer in northern Montana. The well was purchased by the Citation Oil and Gas Company after issuance of the final permit. The portion of the Judith River Formation into which the well injects is not an underground source of drinking water (USDW), but USDWs exist above the Formation and in other parts of the Formation to the west. The Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation, which overlies the Judith River Formation, oppose issuance of the permit and have petitioned for review of the final permit decision pursuant to 40 CFR §124.19. For the reasons stated below, I am denying their petition for review.

Background:

The Safe Drinking Water Act and implementing regulations prohibit all underground injections that are not authorized by permit or rule, 42 U.S.C. §300h(b)(1)(A), 40 CFR §144.11; and are expressly applicable to Indian lands, 42 U.S.C. §§300j-11.[1/] Since Goings Well #1 was in existence before the underground injection control (UIC) program became effective in Montana on June 25, 1984, it became a "rule" authorized well. (The implementing regulations allow continued operation of a preexisting well, provided that the owner or operator files a timely permit application.[2/] Century Oil and Gas Company, then the owner of the well, filed such an application.)

Region 8 issued a draft permit on December 27, 1984, and a final permit decision on December 30, 1985. On the same date, the Region issued a general policy statement on existing and new wells injecting into the Judith River Formation. On February 3, 1986, petitioners filed a request for review of both the final permit decision and the policy statement.

Pursuant to 40 CFR §124.19(a), "any person who filed comments on the draft permit . . . may petition the Administrator to review any condition of the permit decision." The regulations

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1/ Phillips Petroleum Company v. EPA, 803 F.2d 545 (10th Cir. 1986).

2/ 40 CFR §144.21; 40 CFR Part 147, Subpart BB.

further provide that petitioners may not raise any issues not raised during the comment period. 40 CFR §124.13. Petitioners submitted written comments on the draft permit to EPA on January 29, 1985, and participated in the public hearing on May 29, 1985. Therefore, they have standing to petition for review.

The Safe Drinking Water Act and applicable regulations do not provide a right to obtain review of UIC permit decisions. Rather, 40 CFR §124.19 provides that petitions for review shall not be granted unless the permit determination is clearly erroneous or involves an exercise of discretion or policy that is important and should be reviewed as a discretionary matter. The preamble to the regulations states that:

> [T]his power of review should be only sparingly exercised [and] . . . most permit conditions should be finally determined at the Regional level . . . . 45 Fed Reg. 33412 (May 19, 1980).

Thus, the burden of demonstrating that a permit determination should be reviewed rests on those making the request. In this instance, the petitioners have not convinced me that review is warranted.

Discussion:

The Region contends that the petition should be dismissed, first, because it was not filed on time, and second, because petitioners have not shown that the Region erred. Although I am not persuaded by the Region's argument that the petition was not timely, I agree with the Region that petitioners have not demonstrated that this matter warrants review.

The Region issued the final permit decision on December 30, 1985. It notified petitioners by mail on the same date, and also published notice of the decision in the Billings Gazette. The petition was filed February 3, 1986. The Region maintains that the petition was due thirty days from the date of the published notice, pursuant to 40 CFR §§124.19(a) and 124.20(a), and therefore was not timely.[3/] The petitioners contend that the Region was required to notify them in person or by mail, and therefore, their filing deadline was February 3, pursuant to 40 CFR §§124.20 (c) and (d).

Since the petitioners were entitled to individual notice of the final permit decision, pursuant to 40 CFR §124.15, their petition was timely. The regulation expressly provides that the Regional Administrator shall notify the applicant "and each interested person who has submitted written comments or requested notice of the final permit decision." The legislative history of the UIC regulations for the State of Montana confirms EPA's strong concern that interested persons in the State receive individual notice of Agency actions affecting injection wells. In its Preamble to the regulations governing notice of a permit application, EPA stated that:

3/ In responding to the petition, the Region contends that the petition should have been filed no later than January 28, 1986, since it published notice of the final permit decision on December 29, 1985.

> Montana is one of those States where the rural character of the State makes it likely that notice in a newspaper will not reach those parties interested in proposed injection wells. 49 FR 20166, May 11, 1984.

According to 40 CFR §§124.19(a) and .20(d), petitioners were allowed 30 days from December 30 and an additional three days because they were notified by mail rather than in person. Since the specified time period ended on a Saturday in this instance, the deadline was the following business day, Monday, February 3. The petition was hand-delivered on February 3, and meets the deadline.

Petitioners make two requests for relief. First, they request review of the Region's decision to issue a permit for Goings Well #1. Although the well does not inject directly into a USDW,[4/] petitioners claim that its injection activities may

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4/ A USDW is defined as "an aquifer or its portion:

(1)(i) Which supplies any public water system; or

(ii) Which contains a sufficient quantity of ground water to supply a public water system; and

(A) Currently supplies drinking water for human consumption; or

(B) Contains fewer than 10,000 mg/l total dissolved solids; and

(2) Which is not an exempted aquifer." 40 CFR §146.3. (Emphasis added.)

The UIC regulations for Montana wells exempt from regulation as a USDW that portion of an aquifer within a 1/4 mile radius of an existing Class II well. 40 CFR §147.1352. Goings Well #1 qualifies for this exemption. Moreover, both the petitioners and the Region agree that the area outside the 1/4 mile radius of the well does not meet the regulatory definition of a USDW.

endanger the Formation in areas which do meet the definition of a USDW.[5/] Since the Safe Drinking Water Act prohibits any injection that endangers a USDW, petitioners claim that the permit should be denied. Second, petitioners request that the Administrator review the Region's Statement of Policy on Underground Injection Activities into the Judith River Formation on the Fort Peck Reservation, and prohibit the issuance of permits for any injections into the Formation. I am denying both requests.

Policy Statement. Petitioners request that I review Region 8's Statement of Policy, a document which provides the rationale for the Region's permit decision for Goings Well #1,[6/] and also describes the approach the Region will take with respect to other permit applications. To the extent that the Policy Statement addresses other injection wells, it falls outside the scope of matters that are normally considered in a petition for review pursuant to 40 CFR §124.19. This regulation contemplates review of permit conditions in a final permit decision issued by a Regional Administrator; it does not envision review of other

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5/ Petitioners also contend that the entire Judith River Formation should be protected as a USDW because parts of it meet the regulatory definition of a USDW. However, the regulations expressly permit the Region to treat one portion of an aquifer as a USDW and allow injection activities in another portion, provided that such activities do not endanger USDWs. See footnote 4, supra.

6/ Petitioners do not contend that the permit for Goings Well #1 is inconsistent with the Policy Statement.

matters such as a Regional memorandum intended to provide guidance to the regulated community and the public. Region 8 states that it will evaluate each permit application on an individual basis. Petitioners may, of course, comment on a proposed permit for any other well pursuant to 40 CFR §124.10.

Final Permit Decision. Petitioners have not demonstrated that the Region made an error of fact or law when it issued a final permit for Goings Well #1. The Region has determined that the well is constructed in a manner that prevents fluid migration outside the injection zone, and does not pose a threat to USDWs. The well injects into a portion of an aquifer that is exempt from regulation as a USDW pursuant to 40 CFR §147.1352. An EPA technical audit states that fluids injected to date extend less than 1/10 of a mile from the well. Based on an estimate of the radius of a cylinder representing injection formation fillup, the report states that injected fluids will not extend as far as 1/4 mile from the well for at least 18 years, long after the date when the permit will be re-examined.[7/] Moreover, the surrounding area does not meet the regulatory definition of a USDW,[8/] and is not being used for drinking water. Thus, there are no grounds to review the Region's decision unless the petitioners can show that the issuance of this permit will somehow endanger remote USDWs.

7/ The Permit expressly provides that "[t]his permit and the authorization to inject are issued for the operating life of the well but shall be reviewed at least every five years." Final Permit at p. 3.

8/ See footnote 4, supra.

Petitioners argue that injection activities at the well, together with injection activities at other existing wells and those that may be permitted in the future, will gradually degrade the Judith River Formation and reduce both its current availability and its potential as a source of drinking water. They contend that contaminated fluids from Goings Well #1 may migrate beyond the immediate injection zone toward USDWs in the western portion of the Fort Peck Reservation, which currently supply water for human and animal consumption, livestock watering and irrigation. They also claim that the Region lacked sufficient information to determine that injected brines will not migrate upward to contaminate overlying USDWs. The Region acknowledges that parts of the aquifer to the west meet the definition of a USDW. However, since fluids tend to move from west to east in the Judith River Formation, the Region concludes that brines injected into Goings Well #1 are unlikely to contaminate geographically distant USDWs to the west. The Region further concludes that any overlying USDWs are adequately protected from contamination by the Bearpaw Shale (an 800-1000 foot layer of shale) and will not be endangered by injection activities. The Region recognizes that if injection pressure is significantly above fracture pressure (in violation of UIC regulations), injected fluid may migrate upward or westward and may displace original formation fluid toward USDWs; however, in this instance,

the risk that injected fluid will migrate far enough to contaminate USDWs is too remote to provide a basis for denying this permit. 9/

I am sympathetic to petitioners' strong interest in protecting the Judith River Formation against further degradation. However, the connection between this well and the endangerment of the Formation is too speculative for me to act on at this time. At best, it suggests that future permit applications, with their potential for posing a cumulative threat to the Formation, should be scrutinized with particular care to assure protection of USDWs.

Petitioners have not demonstrated that the Region committed an error of fact or law in deciding to issue a permit for Goings Well #1, nor have they convinced me that this case involves a matter of discretion warranting review. The statute expressly provides that the federal underground injection control program may not include requirements which interfere with or impede--

> (1) the underground injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production . . .
>
> unless such requirements are essential to assure that underground sources of drinking water will not be endangered by such injection. 42 U.S.C. §300h-1(c).

9/ The Region notes that there has been "excessive injection pressure and/or volumes" at the well in the past, and states that, if the permittee cannot attain compliance, "the permit may be terminated and/or other appropriate enforcement action may be taken." Regional Response to Petition, June 2, 1986. While the Region may initiate appropriate enforcement action based on a determination that a well is injecting at excessive pressure, the regulations do not require the Region to deny a permit based on such a finding. Compare 40 CFR §§144.25(a), 144.28.

Moreover, in denying review, I am mindful of the Agency's intent that Regional Administrators exercise broad discretion in making permit decisions.

Conclusion:

For the reasons stated above, the petition is denied.

So ordered.

Lee M. Thomas
Administrator

Dated: Aug 14, 1987

CERTIFICATE OF SERVICE

I hereby certify that copies of the foregoing Order Denying Petition for Review in the matter of Citation Oil and Gas Company, UIC Appeal No. 86-1, were sent to the following persons in the following manner:

By 1st class mail, postage prepaid:

Harry R. Sachse, Esq.
Donald J. Simon, Esq.
Sonosky, Chambers & Sachse
1050 31st Street, NW
Washington, DC 20007

Alexandra Smith
Acting Regional Administrator
U.S. EPA, Region VIII
One Denver Place
999 18th Street, Suite 1300
Denver, CO 80202-2413

Max H. Dodson
Director, Water Management Division
U.S. EPA, Region VIII, 8WM
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Denver, CO 80202-2413

Debra Ehlert
Chief, Ground Water Section
U.S. EPA, Region VIII, 8WM-DW
One Denver Place
999 18th Street, Suite 1300
Denver, CO 80202-2413

Brenda H. Selden, Secretary
to the Chief Judicial Officer

Dated: MAY 18 1987

January 28, 1986

Ref: 8WM-DW

MEMORANDUM

TO: Roger Frenette
Patrick Crotty
Andrew Lensink, ORC

FROM: Paul Osborne
Laura Clemmens, Acting DI Team Leader
Mike Liuzzi, Indian Lands Coordinator

SUBJECT: Appeal of Region VIII Judith River Policy Statement by the Fort Peck Tribal Council

This afternoon, Larry Wetsit of the Fort Peck Reservation came into the office to let us know that the Tribe will be submitting an appeal to EPA on the Judith River Statement of Policy and resulting final permit actions. Wetsit indicated that the appeal would be filed by the lawyers for the Tribe in Washington, and would probably be received in headquarters tomorrow.

Wetsit explained that, for a number of reasons, the Tribe does not want the Judith River Formation used for injection purposes within the tribal boundries. Specifically, the Tribe wishes to protect all groundwater within tribal boundaries regardless of TDS level. Wetsit expressed interest in having EPA repeal all the aquifer exemptions for the Judith River Formation within a quarter mile radius of injection wells in operation prior to the promulgation of the UIC program in 1984. Mike Liuzzi explained to Paul and I that if portions of the Judith River do not fall within the EPA definition of an underground source of drinking water by virtue of the fact that they have a total dissolved solids level of over 10,000 mg/l, that they are outside the realm of protection afforded by the UIC program. EPA would have no authority to prohibit injection, nor to deny permits to those operators.

Paul contacted Eric Olsen of the Office of General Counsel, and Eric stated that any sort of appeal of the Region VIII decision on the Judith River Formation would have to be in the form of individual permit appeals for each permitted well affected by the decision. He added that the Tribe may alsohave the option of issuing a Tribal Resolution prohibiting the underground injection of brine into the Judith River if they have the legal authority to pass an enforceable statute of that nature. EPA would not be able to enforce any such law or resolution, that would be the responsibility of the Tribe.

We plan to meet with Wetsit again tomorrow. In the meantime, Paul will contact John Atcheson, so that we can arrange for John to speak with Wetsit directly. We will keep you informed of any further developments.

cc: Debra Ehlert

6405Q/1-28-86/Clemmens

DATE: January 3, 1986

SUBJECT: Pending Permits into the Judith River Formation

TO: All GWS Staff

FROM: Debbie Smith, Team Leader
Direct Implementation

Everyone should have had a chance by now to review the Judith River Formation Report that I distributed last week. Several questions have been raised about how we're going to implement the policy, so I would like to get together with everyone to discuss this. There are probably some issues that also need to be clarified. If there are no conflicts, let's try to meet for discussion after our Tuesday morning staff meeting.

The attached list shows all Judith River injection wells, which we can use for discussion. I tried to indicate the status/prognosis for each of the wells based upon what I could find. If anyone has different information, please bring it up at the meeting.

WELL, OPERATOR, & FIELD	SUMMARY
Doings #1 Century Oil Poplar Field	Final permit was issued on 12-31-85. Since it is in the Poplar Field no aquifer exemption was needed.
Buck Oil 2 Grace Pet. E. Poplar	From preliminary calculations, it appears that this well has injected beyond the 1/4 mile exemption. However, since it is in the Poplar Field, it does not need an aquifer exemption. Permit can be issued without any special limitations. Lost authorization
EPU 8-D Murphy Oil E. Poplar	No aquifer exemption needed. Check inj pressure. Permit can be issued without any special limitations.
EPU 29-D Murphy Oil E. Poplar	No aquifer exemption needed. Permit can be issued without any special limitations.
Allotted Hall Reading & Bates Deadman's Coulee	Permit application being denied due to excessive injection pressure. Operator has agreed to ultimately P&A well when replacement well is constructed.
Lough #2 Petro Lewis Tule Creek	Well shut-in April 1st for failure to submit application. Operator has permitted replacement well. This well can either be permitted (limit aquifer exemption to 1/4 mile) or, if the operator no longer wants to operator the well, must be P&A'ed. Find out if P&A'd Deleted Lough #1 now injecting
Lillian 1-D Murphy Oil E. Tule ? not certain that it is not Little River	Calculations should be repeated to demonstrate the the expected life of the well. Radius of fillup should be determined. Injection rate and volume should be checked for compatibility. Permit can be issued for a specified period of time to ensure fluids will not extend beyond 1/4 mile.
Eletvold Murphy Oil Tule Creek assigned to Dean maybe @ 1/4 mile	Preliminary calculations show that this well has already reached the 1/4 mile aquifer exemption. Permit application will have to be denied.
Mann #1 Pennzoil Long Creek	A draft permit has been issued. Calculations were shown in the SOB which verified that the 1/4 mile exemption would not be reached for 96 years. Fluid plume is only expected to extend to 0.10 mile at the end of the life of the well.

Phillips-McKee EHP Pet. Tule Creek Victoria	This well failed a MIT on 10-2-85. Operator was requested to monitor the annulus on a daily basis and report any positive pressure. From preliminary calculations, it appears that the well can be permitted for a limited period of time. Calculations should be repeated when writing the SOB. It appears that some kind of workover will need to be done to restore mechanical integrity. Operator should be contacted and informed of the approach we will be taking.
Welsit #1 Murphy Oil E. Tule	Application is being called-in. Calculations should be repeated to demonstrate the expected life of the well. Radius of fillup should be determined. Injection rate and volume should be checked for compatibility. Permit can be issued for a specified period of time to ensure fluids will not extend beyond 1/4 mile.
Stai #1 Franks Pet. E. Benrud	Permit application received December, 1985. From preliminary calculations, it appears that the well will not reach 1/4 mile exemption for sometime. Calculations should be repeated in SOB. Permit can be issued for a specified period of time.
Courchene Murphy Oil Volt worst well in field	Well has not been called-in yet. Preliminary calculations show that the radius of fillup exceeds 1/4 mile. Operator will be notified that the well will not be permitted, and that it will be P&A'ed within a specified time period. We may decide to let them find a replacement well before they are made to shut-in.
Buck Elk 1 Grace Poplar ? Lorna to check	Well was abandoned in 1967.
Bierre 1 Mesa Pet. Poplar	Well was plugged 8-13-84.
Follow-up with mgmt authorities Bigtrack Little No. 1 Petroleum Inc. E. Benrud	Well is being called-in. Operator missed 1-3-86 deadline. In addition, they ignored the June 25th, 1985, inventory submittal deadline. This is a potential enforcement case.
Mule Creek 1-D Murphy Oil N.E. Benrud	Well was called in 2-5-85. Operator responded that they were going to P&A the well if we allowed them to drill a new well (Mule Creek 2-D) into the Judith River about 40 feet away from the 1-D. It appears that a permit can be issued for the 1-D,

although there may be some operational problem with the well that makes it not advantageous to operate. The operator should be notified after a decision is made on whether a new well will be allowed.

Mule Creek 2-D
Murphy Oil
N.E. Penrud

This is an application for a new well into the Judith River, proposed to replace the 1-D. The well could only be allowed if injection pluns were limited to 1/4 mile minus 40 feet (the existing equiter exemption). We ma. not want to allow this well under any circumstances. This is a tough one.

Huber 1-W (Stdby) Lowe will check
Columbus
Poplar

Well was plugged prior to June 24, 1984.

Carlson
Kirkwood-Wesco
Volt

Kirkwood Oil & Gas Company of Casper, Wyoming, report- this well for the June 25, 1985, deadline. Well has not been called-in. Well will be called-in in the near future.

A 1-W Listug-Olson (Stdby)
Chamberlain
Benrud

Chamberlain reported this well TA'd for the June 25th deadline. Well should be called-in for application.

Bridges 1-D (Stdby)
Murphy Oil
E. Tule

Was Well plugged?

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
1860 LINCOLN STREET
DENVER, COLORADO 80295

Sent to Newspapers 4/26/85
Sent to Surface owners 4/29/85

NOTICE OF PUBLIC HEARING.

PURPOSE OF PUBLIC NOTICE

The purpose of this notice is to inform the public that the Region VIII Office of the U.S. Environmental Protection Agency (EPA) will hold a public hearing on Wednesday, May 29, 1985, at 9:00 a.m. in the Poplar Activity Center Building in Poplar, Montana. The hearing is being held for the following two reasons:

1) to obtain available hydrogeologic and water quality data concerning the Judith River Formation; and

2) to discuss the proposal by the EPA to issue permits allowing injection of fluids underground into the Judith River Formation via Class II Salt Water Disposal Wells.

BACKGROUND

EPA began implementing the Underground Injection Control (UIC) Program in Montana on June 25, 1984 under the auspices of the Safe Drinking Water Act and UIC Regulations. The overall goal of the UIC program is to protect existing and potential future underground sources of drinking water (USDW) from contamination via underground injection of fluids. If performed properly, injecting fluids underground can be a practical and environmentally safe method of ultimate disposal of unwanted waste. In some instances, injection of water is used to enhance oil production.

A USDW is defined in the regulations as an aquifer or its portion:

(a) (1) which supplies any public water system; or

(2) which contains a sufficient quantity of ground water to supply a public water system; and

(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 mg/l total dissolved solids; and

(b) which is not an exempted aquifer.

Movement of fluids into USDWs caused by underground injection activities is specifically prohibited by the UIC regulations. An aquifer exemption allows the injection of oil or gas related brines into an aquifer that is otherwise considered a USDW. All known existing wells injecting fluids at the time of the inception of the UIC program (June 25, 1984), into any underground formation (including the Judith River), were granted aquifer exemptions for a quarter mile radius of the well bore. Therefore, unless authorization to inject has been terminated for any reason, all wells currently injecting into the Judith River Formation are legally authorized to continue these activities, until a permit is issued.

EPA must permit all NEW salt water disposal wells and enhanced recovery wells BEFORE injection is authorized. In addition, EPA will permit all EXISTING salt water disposal wells within the next four years.

ISSUES

(1) Permitting Existing and/or New Injection Wells.

EPA requested permit applications from several injection well operators in the Fort Peck Reservation area on June 25, 1984 and on February 5, 1985. Many of these existing injection activities involved salt water disposal operations injecting into the Judith River Formation. EPA Region VIII is currently reviewing these permit applications, including one from Century Oil and Gas Corporation of Englewood, Colorado, regarding the proposed continuing injection of produced fluid into the Judith River Formation.

On January 15, 1985, EPA issued a public notice of its preliminary determination to issue a permit which would allow continuation of injection activities by Century Oil and Gas Corporation's Goings #1 Well into the Judith River Formation (at approximately 1,050 feet) located in the Northwest Poplar Field in the Northwest quarter of Section 27, Township 29N, Range 50E, in Roosevelt County, Montana.

The Goings #1 Well has been injecting into this formation since March of 1982. Other wells in the area have been injecting produced fluids into the formation since 1970 and possibly earlier than 1970.

In response to the January 15th public notice, the Fort Peck Tribal Council, Assiniboine and Sioux Tribes, voiced objection to issuance of this permit by letter of January 29, 1985 and, subsequently, requested a public hearing be held to discuss this proposed permit and its relationship to further degradation of ground water quality on the Fort Peck Indian Reservation by continued injection into the Judith River Formation.

(2) Judith River Formation Water Quality.

The Fort Peck Tribes plan to submit information at the public hearing concerning investigations of water quality degradation of the Judith River Formation and other aquifers in the area.

EPA is requesting that anyone having knowledge of the water quality or other hydrogeologic characteristics of the Judith River Formation, present the information in writing to the EPA prior to May 29, or verbally at the public hearing. The information will be used to resolve the issue on allowing the continuation of injection into the aquifer for both new and existing injection wells.

PUBLIC COMMENTS

EPA will hold a public hearing on Wednesday, May 29, 1985 at 9:00 a.m. in the Poplar Activities Center building in Poplar, Montana to gather further information on whether to issue the permit for continued injection by the Goings #1 Well and to continue the review of other permit applications which propose to continue injection activities into the Judith River Formation.

Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Phone: (406) 585-5486

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
1860 Lincoln Street
Denver, Colorado 80295

ATTN: Debra Ehlert
Phone: (303) 293-1415

U.S. ENVIRONMENTAL PROTECTION AGENCY.
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
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DENVER, COLORADO 80295

APR 29 1985

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(2) which contains a sufficient quantity of ground water to supply a public water system; and

(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 mg/l total dissolved solids; and

(b) which is not an exempted aquifer.

Movement of fluids into USDWs caused by underground injection activities is specifically prohibited by the UIC regulations. An aquifer exemption allows the injection of oil or gas related brines into an aquifer that is otherwise considered a USDW. All known existing wells injecting fluids at the time of the inception of the UIC program (June 25, 1984), into any underground formation (including the Judith River), were granted aquifer exemptions for a quarter mile radius of the well bore. Therefore, unless authorization to inject has been terminated for any reason, all wells currently injecting into the Judith River Formation are legally authorized to continue these activities, until a permit is issued.

EPA must permit all NEW salt water disposal wells and enhanced recovery wells BEFORE injection is authorized. In addition, EPA will permit all EXISTING salt water disposal wells within the next four years.

ISSUES

(1) **Permitting Existing and/or New Injection Wells.**

EPA requested permit applications from several injection well operators in the Fort Peck Reservation area on June 25, 1984 and on February 5, 1985. Many of these existing injection activities involved salt water disposal operations injecting into the Judith River Formation. EPA Region VIII is currently reviewing these permit applications, including one from Century Oil and Gas Corporation of Englewood, Colorado, regarding the proposed continuing injection of produced fluid into the Judith River Formation.

On January 15, 1985, EPA issued a public notice of its preliminary determination to issue a permit which would allow continuation of injection activities by Century Oil and Gas Corporation's Goings #1 Well into the Judith River Formation (at approximately 1,050 feet) located in the Northwest Poplar Field in the Northwest quarter of Section 27, Township 29N, Range 50E, in Roosevelt County, Montana.

The Goings #1 Well has been injecting into this formation since March of 1982. Other wells in the area have been injecting produced fluids into the formation since 1970 and possibly earlier than 1970.

In response to the January 15th public notice, the Fort Peck Tribal Council, Assiniboine and Sioux Tribes, voiced objection to issuance of this permit by letter of January 29, 1985 and, subsequently, requested a public hearing be held to discuss this proposed permit and its relationship to further degradation of ground water quality on the Fort Peck Indian Reservation by continued injection into the Judith River Formation.

(2) Judith River Formation Water Quality.

The Fort Peck Tribes plan to submit information at the public hearing concerning investigations of water quality degradation of the Judith River Formation and other aquifers in the area.

EPA is requesting that anyone having knowledge of the water quality or other hydrogeologic characteristics of the Judith River Formation, present the information in writing to the EPA prior to May 29, or verbally at the public hearing. The information will be used to resolve the issue on allowing the continuation of injection into the aquifer for both new and existing injection wells.

PUBLIC COMMENTS

EPA will hold a public hearing on Wednesday, May 29, 1985 at 9:00 a.m. in the Poplar Activities Center building in Poplar, Montana to gather further information on whether to issue the permit for continued injection by the Goings #1 Well and to continue the review of other permit applications which propose to continue injection activities into the Judith River Formation.

Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Phone: (406) 585-5486

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
1860 Lincoln Street
Denver, Colorado 80295

ATTN: Debra Ehlert
Phone: (303) 293-1415

Edna

Does BLM get a copy of the notice when any federal leased land? Bus.

September 1973
4 Treasury FRM 2000 Standard Form No. 1143

ADVERTISING ORDER

X5230NASA
ORDER NUMBER

DEPARTMENT OR ESTABLISHMENT, BUREAU OR OFFICE
U.S. ENVIRONMENTAL PROTECTION AGENCY, Water Management Division

DATE
April 26, 1985

The publisher of the publication named below is authorized to publish the enclosed advertisement according to the schedule below provided the rates are not in excess of the commercial rates charged to private individuals with the usual discounts. It is to be set solid, without paragraphing, and without any display in the heading unless otherwise expressly authorized in the specifications.

NAME OF THE PUBLICATION ADVERTISED IN
Wolf Point Hearald News

SUBJECT OF ADVERTISEMENT
PUBLIC NOTICE

EDITION OF PAPER ADVERTISEMENT APPEARED

NUMBER OF TIMES ADVERTISEMENT APPEARED
ONE TIME ONLY

DATE(s) ADVERTISEMENT APPEARED
April 30, 1985/As Soon As Possible prior to

SPECIFICATIONS FOR ADVERTISEMENT
Reduction may be necessary. One (1) AFFIDAVIT OF PUBLICATION AND ONE (1) COPY OF PRINTED NOTICE IN ADDITION TO THE COMPLETED REVERSE OF THIS VOUCHER SHOULD BE MAILED TO: UIC PERMITS CLERK, Drinking Water Branch, Water Management Division, 8WM-DW, U.S. Environmental Protection Agency, 1860 Lincoln St., Denver, CO 80295
Edna WALTON 303/293-1421

COPY FOR ADVERTISEMENT

COPY ATTACHED FOR PUBLIC NOTICE -

U.S. ENVIRONMENTAL PROTECTION AGENCY
NOTICE OF PUBLIC HEARING

AUTHORITY TO ADVERTISE	INSTRUMENT OF ASSIGNMENT
NUMBER EPA Delegations Manual 1-1-A(3)	NUMBER
DATE January 28, 1976	DATE 5/26/85
SIGNATURE OF AUTHORIZING OFFICIAL	TITLE Contract Specialist

INSTRUCTIONS TO PUBLISHERS

Extreme care should be exercised to insure that the specifications for advertising to be set other than solid be definite, clear, and specific since no allowance will be made for paragraphing or for display or leaded or prominent headings, unless specifically ordered, or for additional space required by the use of type other than that specified. Specifications for advertising other than solid and the advertisement copy submitted to the publisher will be attached to the voucher. The following is a sample of solid line advertisement set up in accordance with the usual Government requirements.

DEPARTMENT OF HIGHWAYS & TRAFFIC, D.C. Bids are requested for first spring 1966 cement concrete repair contract, including incidental work, Washington, D.C., Invitation No. C-6576-H, consisting of 11,000 sq. yds. PCC Class BB sidewalk repair and 2,000 cu. yds. PCC Class A pavement, alley, & driveway repair, both cut repairs only. Bidding material available from the Procurement Officer, D.C. Sealed bids to be opened in the Procurement Office at 8:00 p.m., November 15, 1965.

Your bill for this advertising order should be submitted on the "Public Voucher for Advertising" form, which is printed on the reverse of this form, immediately after the last publication of the advertisement. If copies of the printed advertisement are not available, complete the affidavit provided on the voucher. Submit the voucher and a copy of the printed advertisement to ▶.....

.....

IMPORTANT

Charges for advertising when a cut, matrix, stereotype or electrotype is furnished will be based on actual space used and no allowance will be made for shrinkage.

In no case shall the advertisement extend beyond the date and edition stated in this order.

1143-107

PUBLIC VOUCHER FOR ADVERTISING

		For Agency Use Only
DEPARTMENT OR ESTABLISHMENT, BUREAU OR OFFICE U.S. ENVIRONMENTAL PROTECTION AGENCY, Water Management Division		VOUCHER NUMBER
PLACE VOUCHER PREPARED 1860 Lincoln St., Denver, CO 80295	DATE PREPARED 4/26/85	SCHEDULE NUMBER
NAME OF PUBLICATION ~~NEWSPAPER~~ PUBLIC NOTICE		PAID BY
NAME OF PUBLISHER OR REPRESENTATIVE Wolf Point Herald News		
ADDRESS (*Street, room number, city, State, and ZIP code*) P.O. 639 Wolf Point, MT 59201		

CHARGES

TYPEFACE (*size of type*) POINT PER (*inch, square, word, or folio*)

		NUMBER OR LINES (*Indicate counted or space*)	COST PER LINE	TOTAL COST
Line Rates	FIRST INSERTION		$	$
	ADDITIONAL INSERTIONS GIVE NUMBER ▶			
	TOTAL			$
		NUMBER OF UNITS (*Indicate inch, square, word, folio*)	COST PER UNIT	TOTAL COST
Other Rates	FIRST INSERTION	9 Folios	$ 6.00	$ 54.00
	ADDITIONAL INSERTIONS GIVE NUMBER ▶			
	TOTAL			$

Attach one copy of advertisement (*including upper and lower rules*) to each copy of voucher here. If copy is not available sign the following affidavit.

TOTAL LINE RATES AND OTHER RATES	
LESS DISCOUNT AT %	
BALANCE DUE	$ 54.00
VERIFIED (*Initials*)	

AFFIDAVIT

This represents a true billing for the attached advertising order, with specifications and copy, which has been completed.

SIGNATURE OF PUBLISHER OR REPRESENTATIVE: Leulah Sutton

TITLE: Office Payroll Clerk

DATE: 5-3-85

RECEIVED MAY 7 1985 REGION VIII DRINKING WATER BRANCH

FOR AGENCY USE ONLY

ADVERTISEMENT PUBLISHED IN	DATE PUBLISHED
I certify that the advertisement described above appeared in the named publication and that this account is correct and eligible for payment.	
SIGNATURE AND TITLE OF CERTIFYING OFFICER	DATE
SIGNATURE AND TITLE OF AUTHORIZING OFFICER	DATE
ACCOUNTING CLASSIFICATION 6850200 KPN033 Order X5230 5A7108KOPN 2540 08 Est. $200.00	PAID BY CHECK NUMBER

[1] If the ability to certify and authority to approve are combined in one person enter "N/A" (*not applicable*) here.

U.S. GPO: 1974—555-598

THE HERALD-NEWS
408 MAIN STREET — P.O. LOCK BOX 639
WOLF POINT, MONTANA 59201

№ 2775

Sold to U.S. E.P.A. - Water Mgment Div

Address 1860 Lincoln St., Denver

Dept. K

Charge (✓) Credit Acct. ( ) Cash ( )

Date 5-2

Notice -	Public Hearing - 9F 1X	54	—

(2) Judith River Formation Water Quality.

The Fort Peck Tribes plan to submit information at the public hearing concerning investigations of water quality degradation of the Judith River Formation and other aquifers in the area.

EPA is requesting that anyone having knowledge of the water quality or other hydrogeologic characteristics of the Judith River Formation, present the information in writing to the EPA prior to May 29, or verbally at the public hearing. The information will be used to resolve the issue on allowing the continuation of injection into the aquifer for both new and existing injection wells.

PUBLIC COMMENTS

EPA will hold a public hearing on Wednesday, May 29, 1985 at 9:00 a.m. in the Poplar Activities Center building in Poplar, Montana to gather further information on whether to issue the permit for continued injection by the Goings #1 Well and to continue the review of other permit applications which propose to continue injection activities into the Judith River Formation.

Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Phone: (406) 585-5486

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
1860 Lincoln Street
Denver, Colorado 80295

ATTN: Debra Ehlert
Phone: (303) 293-1415

ADDITIONAL INSERTIONS
GIVE NUMBER ▶

TOTAL $

Atta ing upper and lower rules) to each
cop able sign the following affidavit.

TOTAL LINE RATES AND OTHER RATES

LESS DISCOUNT AT %

BALANCE DUE $

VERIFIED (Initials)

AFFIDAVIT

This ched advertising order, with specifications and copy, which

SIG TIVE

TITI DATE 5-3-85

U.S. ENVIRONMENTAL PROTECTION AGENCY
NOTICE OF PUBLIC HEARING

PURPOSE OF PUBLIC NOTICE

The purpose of this notice is to inform the public that the Region VIII Office of the U.S. Environmental Protection Agency (EPA) will hold a public hearing on Wednesday, May 29, 1985, at 9:00 a.m. in the Poplar Activity Center Building in Poplar, Montana. The hearing is being held for the following two reasons:

1. to obtain available hydrogeologic and water quality data concerning the Judith River Formation; and
2. to discuss the proposal by the EPA to issue permits allowing injection of fluids underground into the Judith River Formation via Class II Salt Water Disposal Wells.

BACKGROUND

EPA began implementing the Underground Injection Control (UIC) Program in Montana on June 25, 1984 under the auspices of the Safe Drinking Water Act and UIC Regulations. The overall goal of the UIC Program is to protect existing and potential future UNDERGROUND SOURCES OF DRINKING WATER (USDW) from contamination via underground injection of fluids. If performed properly, injecting fluids underground can be a practical and environmentally safe method of ultimate disposal of unwanted waste. In some instances, injection of water is used to enhance oil production.

A USDW is defined in the regulations as an aquifer or its portion:

(a) (1) which supplies any public water system; or
(2) which contains a sufficient quantity of ground water to supply a public water system; and
(i) currently supplies drinking water for human consumption; or
(ii) contains fewer than 10,000 mg/l total dissolved solids; and
(b) which is not an exempted aquifer.

Movement of fluids into USDWs caused by underground injection activities is specifically prohibited by the UIC regulations. An aquifer exemption allows the injection of oil or gas related brines into an aquifer that is otherwise considered a USDW. All know existing wells injecting fluids at the time of the inception of the UIC Program (June 25, 1984), into any underground formation (including the Judith River), were granted aquifer exemptions for a quarter mile radius of the well bore. Therefore, unless authorization to inject has been terminated for any reason, all wells currently injecting into the Judith River Formation are legally authorized to continue these activities, until a permit is issued.

EPA must permit all NEW salt water disposal wells and enhanced recovery wells BEFORE injection is authorized. In addition, EPA will permit all EXISTING salt water disposal wells within the next four years.

ISSUES

(1) Permitting Existing and/or New Injection Wells.

EPA requested permit applications from several injection well operators in the Fort Peck Reservation area on June 25, 1984 and on February 5, 1985. Many of these existing injection activities involved salt water disposal operations injecting into the Judith River Formation. EPA Region VIII is currently reviewing these permit applications, including one from Century Oil and Gas Corporation of Englewood, Colorado, regarding the proposed continuing injection of produced fluid into the Judith River Formation.

On January 15, 1985, EPA issued a public notice of its preliminary determination to issue a permit which would allow continuation of injection activities by Century Oil and Gas Corporation's Goings No. 1 Well into the Judith River Formation (at approximately 1,050 feet) located in the Northwest Poplar Field in the Northwest quarter of Section 27, Township 29N, Range 50E, in Roosevelt County, Montana.

The Goings No. 1 Well has been injecting into this formation since March of 1982. Other wells in the area have been injecting produced fluids into the formation since 1970 and possibly earlier than 1970.

In response to the January 15th public notice, the Fort Peck Tribal Council, Assiniboine and Sioux Tribes, voiced objection to issuance of this permit by letter of January 29, 1985 and, subsequently, requested a public hearing be held to discuss this proposed permit and its relationship to further degradation of ground water quality on the Fort Peck Indian Reservation by continued injection into the Judith River Formation.

(2) Judith River Formation Water Quality

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EPS is requesting that anyone having knowledge of the water quality or other hydrogeologic characteristics of the Judith River Formation, present the information in writing to the EPA prior to May 29, or verbally at the public hearing. The information will be used to resolve the issue on allowing the continuation of injection into the aquifer for both new and existing injection wells.

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Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
301 South Park
Helena, Montana 59626
ATTN: Jim Boyter
Phone: (406) 585-5486

Environmental Protection Agency

CLASSIFIED ADVERTISING

Billings Gazette

SERVING MONTANA AND NORTHERN WYOMING

P.O. BOX 2507 BILLINGS, MONTANA 59103

INVOICE

NOTICE TO ADVERTISER

The rate at which this advertising is extended is subject to possible adjustment based upon performance.

(Apply to Legal Adv.)

BILL TO

UIC PERMITS CLERK
Drinking Water Branch
Water Management Div., 8WM-DW
U.S. Env. Protection Agency
1860 Lincoln St.
Denver, CO 80295

SOLD TO

RECEIVED
MAY 6 1985
EPA REGION VIII
DRINKING WATER BRANCH

CUSTOMER NUMBER	45269	BILLING DATE	5/2/85	PAGE	

EXPIRATION DATE	DESCRIPTION	CLASS	LINES	TIMES	TOTAL LINES	RATE	AMOUNT
5/2/85	219 line legal regarding U.S. Environmental...	090	219	1	219	$1.40	$306.60
	Publication date: 5/2/85						

ast due accounts are subject to a FINANCE CHARGE of 1½% er month which is an ANNUAL PERCENTAGE RATE of 18% pplied to the previous balance.

Bills Payable 10th of Following Month

NET AMOUNT DUE ▶ $306.60

September 1973
4 Treasury FRM 2000 Standard Form No. 1143

ADVERTISING ORDER

X5234NASA
ORDER NUMBER

DEPARTMENT OR ESTABLISHMENT, BUREAU OR OFFICE
U.S. ENVIRONMENTAL PROTECTION AGENCY, Water Management Division

DATE
April 26, 1985

The publisher of the publication named below is authorized to publish the enclosed advertisement according to the schedule below provided the rates are not in excess of the commercial rates charged to private individuals with the usual discounts. It is to be set solid, without paragraphing, and without any display in the heading unless otherwise expressly authorized in the specifications.

NAME OF THE PUBLICATION ADVERTISED IN
Billings Gazette

SUBJECT OF ADVERTISEMENT
PUBLIC NOTICE

EDITION OF PAPER ADVERTISEMENT APPEARED

NUMBER OF TIMES ADVERTISEMENT APPEARED
ONE TIME ONLY

DATE(s) ADVERTISEMENT APPEARED
~~April 30,~~ 1985/As Soon as Possible prior to) May 2

SPECIFICATIONS FOR ADVERTISEMENT
Reduction may be necessary. One (1) AFFIDAVIT OF PUBLICATION AND ONE (1) COPY OF PRINTED NOTICE IN ADDITION TO THE COMPLETED REVERSE OF THIS VOUCHER SHOULD BE MAILED TO: UIC PERMITS CLERK, Drinking Water Branch, Water Management Division, 8WM-DW, U.S. Environmental Protection Agency, 1860 Lincoln St., Denver, CO 80295
Edna Wacton 303/293-1421

COPY FOR ADVERTISEMENT

COPY ATTACHED FOR PUBLIC NOTICE -

U.S. Environmental Protection Agency
NOTICE OF PUBLIC HEARING

AUTHORITY TO ADVERTISE	INSTRUMENT OF ASSIGNMENT
NUMBER EPA Delegations Manual 1-1-A(3)	NUMBER
DATE January 28, 1976	DATE 4/26/85
SIGNATURE OF AUTHORIZING OFFICIAL [illegible]	TITLE Contract Specialist

INSTRUCTIONS TO PUBLISHERS

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Your bill for this advertising order should be submitted on the "Public Voucher for Advertising" form, which is printed on the reverse of this form, immediately after the last publication of the advertisement. If copies of the printed advertisement are not available, complete the affidavit provided on the voucher. Submit the voucher and a copy of the printed advertisement to ▶.....

.....

IMPORTANT

Charges for advertising when a cut, matrix, stereotype or electrotype is furnished will be based on actual space used and no allowance will be made for shrinkage.

In no case shall the advertisement extend beyond the date and edition stated in this order.

1143-107

PUBLIC VOUCHER FOR ADVERTISING

		For Agency Use Only -
DEPARTMENT OR ESTABLISHMENT, BUREAU OR OFFICE U.S. ENVIRONMENTAL PROTECTION AGENCY, Water Management Division		VOUCHER NUMBER
PLACE VOUCHER PREPARED 1860 Lincoln St., Denver, CO 80295	DATE PREPARED 4/26/85	SCHEDULE NUMBER
NAME OF PUBLICATION PUBLIC NOTICE		PAID BY
NAME OF PUBLISHER OR REPRESENTATIVE Billings Gazette		
ADDRESS (*Street, room number, city, State, and ZIP code*) P.O. Box 2507 401 N. Broadway, Billings, Montana 59103		

CHARGES

TYPEFACE Avant Garde (*size of type*) 6 POINT PER line (*inch, square, word, or folio*)

		NUMBER OR LINES (*Indicate counted or space*)	COST PER LINE	TOTAL COST
Line Rates	FIRST INSERTION	219	$ 1.40	$ 306.60
	ADDITIONAL INSERTIONS GIVE NUMBER ▶			
	TOTAL			$ 306.60
		NUMBER OF UNITS (*Indicate inch, square, word, folio*)	COST PER UNIT	TOTAL COST
Other Rates	FIRST INSERTION		$	$
	ADDITIONAL INSERTIONS GIVE NUMBER ▶			
	TOTAL			$

Attach one copy of advertisement (*including upper and lower rules*) to each copy of voucher here. If copy is not available sign the following affidavit.

TOTAL LINE RATES AND OTHER RATES	306.60
LESS DISCOUNT AT %	
BALANCE DUE	$ 306.60
VERIFIED (*Initials*)	JMA

AFFIDAVIT

This represents a true billing for the attached advertising order, with specifications and copy, which has been completed.

SIGNATURE OF PUBLISHER OR REPRESENTATIVE Judy M. Allen

TITLE Legals Clerk DATE 5/2/85

FOR AGENCY USE ONLY

ADVERTISEMENT PUBLISHED IN	DATE PUBLISHED
I certify that the advertisement described above appeared in the named publication and that this account is correct and eligible for payment.	
SIGNATURE AND TITLE OF CERTIFYING OFFICER	DATE
SIGNATURE AND TITLE OF AUTHORIZING OFFICER	DATE
ACCOUNTING CLASSIFICATION	PAID BY CHECK NUMBER

6850200 KPN032 Order X5231 5A7108KOPN

2540 08 Est. $ 300.00

[1] If the ability to certify and authority to approve are combined in one person enter "N/A" (*not applicable*) here.

U.S. GPO: 1974—555-593

U.S. Environmental Protection Agency
Notice Of Public Hearing

Purpose of Public Notice — The purpose of this notice is to inform the public that the Region VIII Office of the U.S. Environmental Protection Agency (EPA) will hold a public hearing on Wednesday, May 29, 1985, at 9:00 a.m. in the Poplar Activity Center Building in Poplar, MT. The hearing is being held for the following two reasons:

(1) to obtain available hydrogeologic and water quality data concerning the Judith River Formation; and

(2) to discuss the proposal by the EPA to issue permits allowing injection of fluids underground into the Judith River Formation via Class II Salt Water Disposal Wells.

Background — EPA began implementing the Underground Injection Control (UIC) Program in Montana on June 25, 1984 under the auspices of the Safe Drinking Water Act and UIC Regulations. The overall goal of the UIC program is to protect existing and potential future Underground Sources of Drinking Water (USDW) from contamination via underground injection of fluids. If performed properly injecting fluids underground can be a practical and environmentally safe method of ultimate disposal of unwanted waste. In some instances, injection of water is used to enhance oil production.

The USDW is defined in the regulations as an aquifer or its portion:

(a) (1) which supplies any public water system; or

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(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 mg/l total dissolved solids; and

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Movement of fluids into USDWs caused by underground injection activities is specifically prohibited by the UIC regulations. An aquifer exemption allows the injection of oil or gas related brines into an aquifer that is otherwise considered a USDW. All known existing well injection fluids at the time of the inception of the UIC program (June 25, 1984), into any underground formation (including the Judith River), were granted aquifer exemptions for a quarter mile radius of the well bore. Therefore, unless authorization to inject has been terminated for any reason, all wells currently injecting into the Judith River formation are legally authorized to continue these activities, until a permit is issued.

EPA must permit all NEW salt water disposal wells and enhanced recovery wells BEFORE injection is authorized. In addition, EPA will permit all EXISTING salt water disposal wells within the next four years.

ISSUES

(1) Permitting Existing and/or New Injection Wells.

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Public Comments — EPA will hold a public hearing on Wednesday, May 29, 1985 at 9:00 a.m. in the Poplar Activities Center building in Poplar, MT to gather further information on whether to issue the permit for continued injection by the Goings #1 Well and to continue the review of other permit applications which propose to continue injection activities into the Judith River Formation.

Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency, Montana Office, Federal Building, Drawer 10096, 301 South Park, Helena, MT 59626, attn: Jim Boyter, 406/585-5486.

Environmental Protection Agency, Region VIII, Drinking Water Branch 8WM-DW, 160 Lincoln Street, Denver, CO 80295, attn: Debra Ehrt, 303/293-1415. 5/2

RECEIVED
MAY 6 1985
EPA REGION VIII
DRINKING WATER BRANCH

Affidavit of Publication

STATE OF MONTANA, }
County of Yellowstone, } ss.

Judy M. Allen

Being duly sworn, deposes and says:

That She is the principal clerk of The Billings Gazette, a newspaper of general circulation published daily in the City of Billings, in the County of Yellowstone, State of Montana, and has charge of the advertisements thereof.

That the 219 line legal regarding U.S. Environmental

a true copy of which is hereto annexed, was published in said newspaper on the following dates: viz:

5/2/85

making in all 1 publication

Judy M. Allen

Subscribed and sworn to before me this 2nd day of May, 19 85.

Barbara E. Meehan

NOTARY PUBLIC for the State of Montana
Residing at Billings, Montana

My commission expires 5/13/86.

(NOTARIAL SEAL)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: May 7, 1985

SUBJECT: Under estimated cost of Advertising Order X5231NASA

FROM: Edna E. Walton (8WM-DW)
UIC Permits Clerk

TO: Dee Woodling (8PM-GFM)
Accounting Tech

When Advertising Order X5231NASA was submitted, $300.00 was estimated for the cost of a public notice to be published in the Billings Gazette. However, when the actual bill for publication was received the cost was $306.60.

It is hereby authorized that Financial Management pay the difference of $6.60 to the Billings Gazette out of the UIC public notice account.

September 1973
4 Treasury FRM 2000 Standard Form No. 1143

ADVERTISING ORDER

X5234NASA
ORDER NUMBER

DEPARTMENT OR ESTABLISHMENT, BUREAU OR OFFICE
U.S. ENVIRONMENTAL PROTECTION AGENCY, Water Management Division

DATE
April 26, 1985

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Billings Gazette

SUBJECT OF ADVERTISEMENT
PUBLIC NOTICE

EDITION OF PAPER ADVERTISEMENT APPEARED

NUMBER OF TIMES ADVERTISEMENT APPEARED
ONE TIME ONLY

DATE(s) ADVERTISEMENT APPEARED
April 30, 1985/As Soon as Possible (prior to)

SPECIFICATIONS FOR ADVERTISEMENT
Reduction may be necessary. One (1) AFFIDAVIT OF PUBLICATION AND ONE (1) COPY OF PRINTED NOTICE IN ADDITION TO THE COMPLETED REVERSE OF THIS VOUCHER SHOULD BE MAILED TO: UIC PERMITS CLERK, Drinking Water Branch, Water Management Division, 8WM-DW, U.S. Environmental Protection Agency, 1860 Lincoln St., Denver, CO 80295
Edna WALTON 303/293-1421

COPY FOR ADVERTISEMENT

COPY ATTACHED FOR PUBLIC NOTICE -

U.S. Environmental Protection Agency
NOTICE OF PUBLIC HEARING

AUTHORITY TO ADVERTISE	INSTRUMENT OF ASSIGNMENT
NUMBER EPA Delegations Manual 1-1-A(3)	NUMBER
DATE January 28, 1976	DATE 4/26/85
SIGNATURE OF AUTHORIZING OFFICIAL [illegible]	TITLE Contract Specialist

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1143-107

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PLACE VOUCHER PREPARED: 1860 Lincoln St., Denver, CO 80295

DATE PREPARED: 4/26/85

NAME OF PUBLICATION: PUBLIC NOTICE

NAME OF PUBLISHER OR REPRESENTATIVE: Billings Gazette

ADDRESS (*Street, room number, city, State, and ZIP code*)
P.O. Box 2507
401 N. Broadway, Billings, Montana 59103

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U.S. ENVIRONMENTAL PROTECTION AGENCY.
NOTICE OF PUBLIC HEARING.

PURPOSE OF PUBLIC NOTICE

The purpose of this notice is to inform the public that the Region VIII Office of the U.S. Environmental Protection Agency (EPA) will hold a public hearing on Wednesday, May 29, 1985, at 9:00 a.m. in the Poplar Activity Center Building in Poplar, Montana. The hearing is being held for the following two reasons:

1) to obtain available hydrogeologic and water quality data concerning the Judith River Formation; and

2) to discuss the proposal by the EPA to issue permits allowing injection of fluids underground into the Judith River Formation via Class II Salt Water Disposal Wells.

BACKGROUND

EPA began implementing the Underground Injection Control (UIC) Program in Montana on June 25, 1984 under the auspices of the Safe Drinking Water Act and UIC Regulations. The overall goal of the UIC program is to protect existing and potential future UNDERGROUND SOURCES OF DRINKING WATER (USDW) from contamination via underground injection of fluids. If performed properly, injecting fluids underground can be a practical and environmentally safe method of ultimate disposal of unwanted waste. In some instances, injection of water is used to enhance oil production.

A USDW is defined in the regulations as an aquifer or its portion:

(a) (1) which supplies any public water system; or

(2) which contains a sufficient quantity of ground water to supply a public water system; and

(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 mg/l total dissolved solids; and

(b) which is not an exempted aquifer.

Movement of fluids into USDWs caused by underground injection activities is specifically prohibited by the UIC regulations. An aquifer exemption allows the injection of oil or gas related brines into an aquifer that is otherwise considered a USDW. All known existing wells injecting fluids at the time of the inception of the UIC program (June 25, 1984), into any underground formation (including the Judith River), were granted aquifer exemptions for a quarter mile radius of the well bore. Therefore, unless authorization to inject has been terminated for any reason, all wells currently injecting into the Judith River Formation are legally authorized to continue these activities, until a permit is issued.

EPA must permit all NEW salt water disposal wells and enhanced recovery wells BEFORE injection is authorized. In addition, EPA will permit all EXISTING salt water disposal wells within the next four years.

ISSUES

(1) Permitting Existing and/or New Injection Wells.

EPA requested permit applications from several injection well operators in the Fort Peck Reservation area on June 25, 1984 and on February 5, 1985. Many of these existing injection activities involved salt water disposal operations injecting into the Judith River Formation. EPA Region VIII is currently reviewing these permit applications, including one from Century Oil and Gas Corporation of Englewood, Colorado, regarding the proposed continuing injection of produced fluid into the Judith River Formation.

On January 15, 1985, EPA issued a public notice of its preliminary determination to issue a permit which would allow continuation of injection activities by Century Oil and Gas Corporation's Goings #1 Well into the Judith River Formation (at approximately 1,050 feet) located in the Northwest Poplar Field in the Northwest quarter of Section 27, Township 29N, Range 50E, in Roosevelt County, Montana.

The Goings #1 Well has been injecting into this formation since March of 1982. Other wells in the area have been injecting produced fluids into the formation since 1970 and possibly earlier than 1970.

In response to the January 15th public notice, the Fort Peck Tribal Council, Assiniboine and Sioux Tribes, voiced objection to issuance of this permit by letter of January 29, 1985 and, subsequently, requested a public hearing be held to discuss this proposed permit and its relationship to further degradation of ground water quality on the Fort Peck Indian Reservation by continued injection into the Judith River Formation.

(2) Judith River Formation Water Quality

The Fort Peck Tribes plan to submit information at the public hearing concerning investigations of water quality degradation of the Judith River Formation and other aquifers in the area.

EPA is requesting that anyone having knowledge of the water quality or other hydrogeologic characteristics of the Judith River Formation, present the information in writing to the EPA prior to May 29, or verbally at the public hearing. The information will be used to resolve the issue on allowing the continuation of injection into the aquifer for both new and existing injection wells.

PUBLIC COMMENTS

EPA will hold a public hearing on Wednesday, May 29, 1985 at 9:00 a.m. in the Poplar Activities Center building in Poplar, Montana to gather further information on whether to issue the permit for continued injection by the Goings #1 Well and to continue the review of other permit applications which propose to continue injection activities into the Judith River Formation.

Comments, data and references in response to this notice should be presented at the public hearing or forwarded to one of the addresses below to arrive not later than the date of the public hearing (May 29, 1985).

Environmental Protection Agency
Montana Office
Federal Building, Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Phone: (406) 585-5486

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
1860 Lincoln Street
Denver, Colorado 80295

ATTN: Debra Ehlert
Phone: (303) 293-1415

Underground Injection Activities into the Judith River Formation on the Fort Peck Reservation.

Statement of Policy &
Technical Evaluation.
December, 1985

U. S. ENVIRONMENTAL PROTECTION AGENCY
REGION VIII

One Denver Place - Suite 1300
999-18th Street
Denver, Colorado 80202-2413

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
ONE DENVER PLACE — 999 18TH STREET — SUITE 1300
DENVER, COLORADO 80202-2413

PUBLIC NOTICE
UNDERGROUND INJECTION CONTROL PROGRAM

FINAL DETERMINATION

Injection into the Judith River Formation
on the Fort Peck Reservation

PURPOSE OF PUBLIC NOTICE

The purpose of this notice is to inform interested parties that:

(1) the U.S. Environmental Protection Agency (EPA) has developed a policy regarding the issuance of Underground Injection Control (UIC) permits on the Fort Peck Reservation for disposal of fluids into the Judith River Formation; and

(2) EPA has made a determination to issue a final UIC permit for the Goings No. 1 Salt Water Disposal Well, located in the Poplar Field and operated by Century Oil & Gas.

BACKGROUND

EPA held a hearing on May 29, 1985, upon request of the Fort Peck Tribes, to gather factual information regarding hydrogeologic characteristics of the Judith River Formation, and to allow comments to be heard concerning EPA's intent to issue a UIC permit for continuation of salt water disposal into the Goings No. 1 Well. The Goings No. 1 Well is one of several disposal wells injecting fluids into the Judith River Formation. The Tribe has requested that the Judith River Formation be protected as an underground source of drinking water (USDW). The Goings No. 1 well was injecting prior to the inception of the UIC program (June 25, 1985), and is therefore classified as an existing well authorized by rule.

FINAL DECISIONS

A statement has been prepared which establishes EPA's policy on permitting existing and future wells that inject into the Judith River Formation on the Fort Peck Reservation. A copy of EPA's Statement of Policy is being sent concurrently with the publication of this notice to all attendees of the hearing as well as all persons who may be affected by the outcome of such a policy.

In addition, EPA has also made a final permit determination for the Goings No. 1 Well permit application. In the time period since the draft permit was issued in December, 1984, the Goings No. 1 Well failed a mechanical integrity test, was reworked to repair casing defects, and subsequently, passed a retesting of mechanical integrity. It has been determined that the well meets all UIC requirements and does not pose a threat to any underground source of drinking water. Therefore, a final permit is being issued on the date of publication of this notice with no changes from the draft permit. Upon issuance of the permit, authorization to inject into the Goings No. 1 Well will be transferred from rule to permit. This action is consistent with the policy mentioned above.

PERMIT APPEAL PROCESS

Within 30 days after a UIC final permit decision has been issued, any person who filed comments on that draft permit or participated in the public hearing may petition the Administrator of EPA to review any condition of the permit decision. Commentors are referred to 40 CFR 124.19 for procedural requirements of the appeal process.

FOR MORE INFORMATION

The Administrative Record for these actions contains:

(1) the Goings No. 1 permit application, draft and final permits;
(2) the official transcript of the hearing;
(3) EPA's technical evaluation of the testimony presented at the hearing; and
(4) EPA's Statement of Policy regarding injection activities and the Judith River Formation on the Fort Peck Reservation.

For further information, you may contact the following offices:

A. Concerning the Judith River Policy:

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
One Denver Place, Suite 1300
999-18th Street
Denver, Colorado 80202-2413

ATTN: Debra G. Ehlert
Telephone: (303) 293-1415

B. Concerning the Going No. 1 Permit:

Environmental Protection Agency
Montana Office
Federal Office Building
Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Telephone: (406) 449-5486

DEC 30 1985
Date of Publication

Max H. Dodson, Director
Water Management Division

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
ONE DENVER PLACE — 999 18TH STREET — SUITE 1300
DENVER, COLORADO 80202-2413

Statement of Policy

Injection activities into the Judith River Formation on the Fort Peck Reservation

BACKGROUND

EPA published a notice on December 27, 1984, in the Wolf Point Herald stating an intent to issue two Underground Injection Control (UIC) permits to Century Oil & Gas for the purpose of salt water fluid disposal. EPA encouraged public comments on the proposed actions. A notice appearing on January 15, 1985, extended the deadline for public comments on EPA's intended actions until February 15, 1985.

In a letter of January 29, 1985, the Fort Peck Tribes objected to the issuance of one of the two draft UIC permits which would allow injection through the Goings No. 1 Well. The objection was based on the Tribe's overall concern about the degradation of ground water on the Reservation. The Goings No. 1 Well is one of several injection wells which presently disposes of fluids into the Judith River Formation - an aquifer which the Tribe has requested be protected as an underground source of drinking water (USDW). The UIC regulations broadly define a USDW as an aquifer or its portion which both: 1) contains fewer than 10,000 mg/l total dissolved solids (TDS), and 2) is capable of supplying a public water system.

The Tribe subsequently requested a public hearing in order to present relevant information which would substantiate their request to preserve the Judith River Formation. The hearing was held on May 29, 1985, at the Poplar Activity Center.

CONCLUSIONS

The testimony and supporting documentation collected at the hearing were evaluated by EPA. The following discussions reflect the results of the technical evaluation and constitute EPA policy.

POLICY STATEMENT NO. 1 No new injection wells or converted wells will be allowed to dispose of fluids into the Judith River Formation where the TDS concentration is known to be less than 10,000 mg/l.

Discussion and Basis of Decision

Alternative sources of drinking water are currently available and are being used in the vicinity of the oil production. The principal sources (alluvium and glacial gravels; the Fox Hills and Fort Union aquifers) are located stratigraphically above the Judith River and have significantly higher quality water. The Judith River provides water for livestock use near the cities of Wolf Point and Glasgow. However, there are no known drinking water wells producing from the Judith River near any injection wells located in the eastern half of the Reservation.

Although there is no current domestic use of the Judith River aquifer in the eastern half of the reservation, the UIC regulations still afford protection of aquifers which exhibit fewer than 10,000 mg/l TDS. Based upon this authority, EPA adopts the policy to prohibit new injection wells into the Judith River where it is defined as a USDW. By doing so, EPA recognizes the concerns of the Tribe that the Judith River Formation be preserved for future use.

POLICY STATEMENT NO. 2

It is concluded that the Judith River Formation in the Deadman's Coulee and Poplar Fields located to the east, is not now, nor was it prior to injection activities, a USDW. The Judith River is also confined from overlying USDWs by 800 to 1,000 feet of shale. The existing injection wells in these fields will be authorized to continue injecting into the Judith River Formation as long as compliance with appropriate EPA rules and permits is maintained. The following injection wells have pending permit applications:

EPA PERMIT	WELL NAME	FIELD	OPERATOR
MTS21PR-0003	Goings No. 1	Poplar	Century Oil & Gas
MTS21PE-0009	Buck Elk No. 2	E. Poplar	Grace Petroleum
MTS21PE-0023	EPU 8-D	E. Poplar	Murphy Oil
MTS21PE-0024	EPU 29-D	E. Poplar	Murphy Oil
MTS21DM-0034	Allotted Hall	Deadman's Coulee	Reading & Bates

Discussion and Basis of Decision

Little water quality data are available for the Judith River Formation in the areas where most of the injection wells are located. However, a water analysis of a sample taken (prior to injection) from the Allotted Hall salt water disposal well, Deadman's Coulee Field, showed a TDS concentration greater than 10,000 mg/l. This sample was found to be reliable, based upon evaluation of the sampling technique. It is known that the formation downdips to the east and that TDS quality of the Judith River Formation increases from west to east. Therefore, the Judith River underlying the Poplar Field would also not qualify as a USDW.

Testimony presented by the Tribe asserted that injection fluids in the Poplar field may be forced to migrate updip and to the west (possibly to the far western edge of the Reservation) due to the fact that the Judith River Formation becomes pinched off by the Bearpaw Shale in the eastern portion of the Reservation. Pressure buildup effects, extending up to five miles, may influence the natural ground water flow pattern. However, from evaluation of the data, ground water flow reversal is not likely to exceed more that two miles from any wellbore.

A more significant impact than a reversal in ground water flow, is likely to be a flattening of the pressure gradient in the Judith River Formation. This may indirectly affect the residence time of the native fluids migrating west to east, thereby increasing the TDS concentration. However, it is not possible to estimate any direct impacts.

POLICY STATEMENT No. 3

Existing injection wells, in fields other than Deadman's Coulee and Poplar, will be allowed to continue injection activities so long as: 1) they maintain compliance with EPA rules and pending permit conditions, and 2) they do not inject more fluid than can be contained in that portion of the Judith River which has been exempted as a USDW. It is EPA's decision to limit injection in these fields to the existing 1/4-mile aquifer exemption radius. This will be done by limiting the life of individual injection wells through the permitting process.

The following wells have pending permit applications or operators have been requested to submit permit applications:

EPA PERMIT	WELL NAME	FIELD	OPERATOR
MTS21TC-0039	Lough No. 2	Tule Creek	Petro Lewis Corp.
MTS21TE-0035	Lillian 1-D	East Tule Creek	Murphy Oil
MTS21TC-0036	Sletvold	Tule Creek	Murphy Oil
MTS21LS-0038	Mann No. 1	Long Creek	Pennzoil
MTS21TC-0086	Phillips-McKee	Tule Creek	BHP Petroleum
	Wetsit No. 1	East Benrud	Murphy Oil
	Courchene 1-D	Volt	Murphy Oil
	Stai No. 1	East Benrud	Franks Petroleum

Discussion and Basis of Decision

Other fields where injection into the Judith River Formation is occurring are the Tule Creek, E. Tule Creek, Benrud, E. Benrud, Volt, and Long Creek. These fields lie west/northwest of the Deadman's Coulee and Poplar Fields and there is evidence that the Judith River Formation here may have contained fewer than 10,000 mg/l TDS before injection practices began.

The UIC regulations specifically prohibit injection into USDW's unless the aquifer is exempted. An aquifer exemption may be granted by EPA, and essentially allows injection into a formation which would otherwise be classified as a USDW but which is not likely to serve as a source of drinking water. All of the wells injecting into the Judith River Formation were granted aquifer exemptions for 1/4 mile radius from the wellbore at the inception of the UIC program in Montana on June 25, 1984. Notice of these aquifer exemptions was published in the FEDERAL REGISTER on September 2, 1983.

Using Judith River Formation characteristics and operating parameters for all the wells, calculations were done to determine the extent of formation fill-up from salt water disposal practices. These calculations are an estimate of how far the injection fluids have traveled from each wellbore. A factor of 25 percent was used in the calculations to safely accomodate uncertainty and pore volume inaccessibility to injected fluids.

In certain instances, injection wells have already surpassed the fill-up volume allowed by their authorized 1/4-mile aquifer exemptions. Permits for these wells will be denied and the operator will be required to properly plug and abandon the wells.

FOR MORE INFORMATION

EPA's technical evaluation report, the transcript of the hearing, and other pertinent documents, are available for inspection at the following locations:

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
One Denver Place, Suite 1300
999-18th Street
Denver, Colorado 80202-2413
Telephone: (303) 293-1415

Environmental Protection Agency
Montana Office
Federal Office Building
Drawer 10096
301 South Park
Helena, Montana 59626
Telephone: (406) 449-5486

Review of Data Relating to Injection of Oil Field Brines
in the Area of the Fort Peck Indian Reservation

Prepared by: Paul S. Osborne
Regional Ground Water Expert
U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation to prohibit further injections into the Judith River Formation (Fm.). The Tribe alleged that continued injection would affect the quality of water in the Judith River Fm. such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Fm.

A review of the available data (attached as appendices) pertaining to Judith River Fm. injection activities has been completed. Figure 1 shows the Fort Peck Indian Reservation and the fields which are the concern of this analysis.

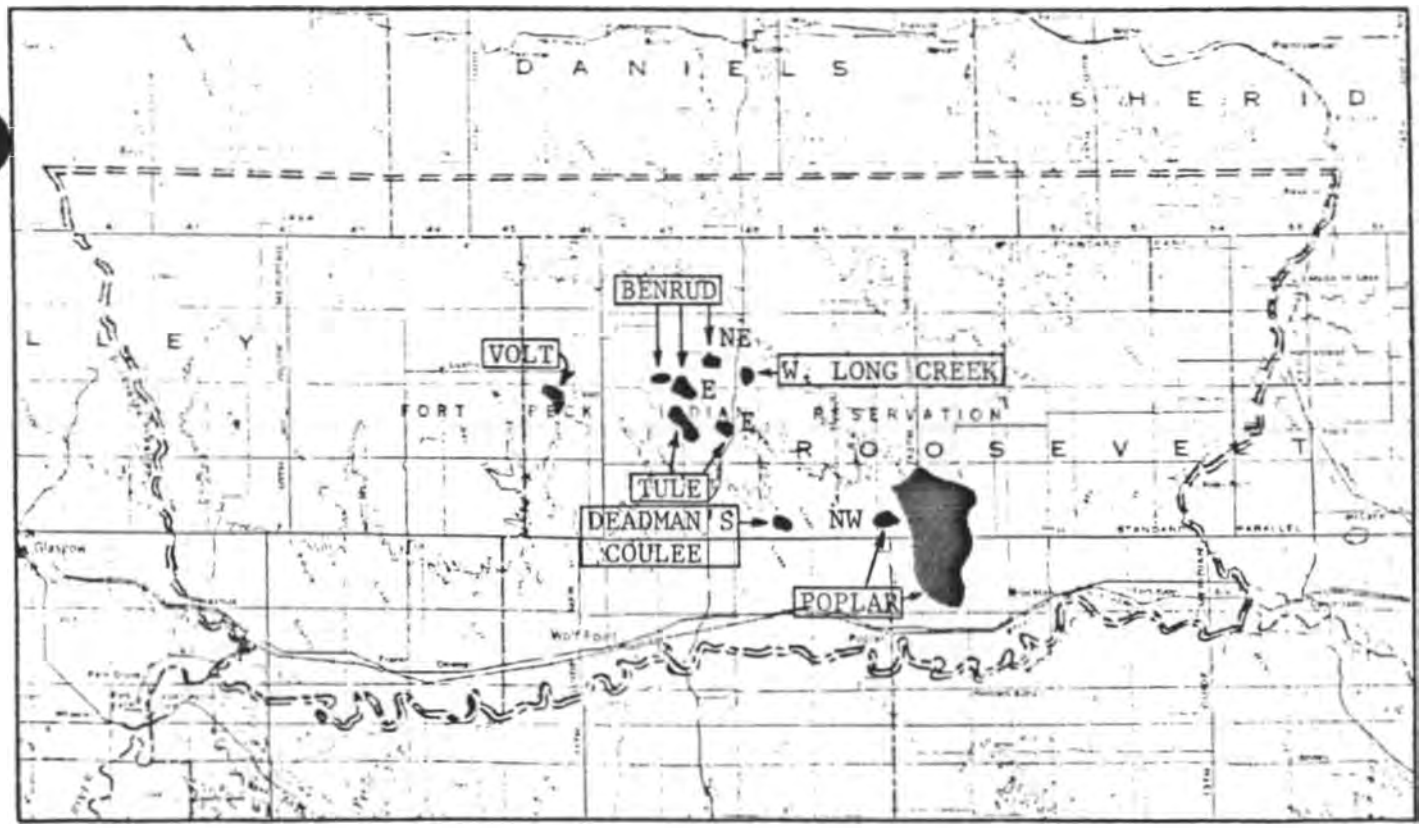


FIGURE 1. Approximate Field Locations - Fort Peck Reservation, Montana.

The data reviewed were related to the Judith River Fm. from west of Glasgow, Montana to the eastern edge of the Reservation. The review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud Fields located within the Fort Peck Reservation. The questions to be addressed by this report are the following:

1. Are the aquifer exemptions of 1/4 mile radii granted at the inception of the Underground Injection Control (UIC) program, adequate for the volumes of fluids injected?

2. What is the ambient quality of the Judith River Fm. over the entire Reservation?

3. Is the Judith River Fm. sufficiently confined to prevent contamination of overlying underground sources of drinking water (USDW's)?

4. Is fluid migration (east to west) a real possibility given that the Judith River Fm. is "pinched off" by the Bearpaw Shale on the eastern edge of the Reservation?

5. What alternative drinking water sources are there on the Reservation? Are data available so that an equal concentration (total dissolved solids (TDS)) contour map can be constructed (i.e., greater than 10,000 milligrams/liter (mg/l); less than 10,000 mg/l for other sources of drinking water)?

Conclusions relating to these issues are summarized in the following section. This is followed by a section of detailed discussions of each issue.

SUMMARY AND CONCLUSIONS

This information and other available data were used in formulating the following conclusions.

1. Using the radius-of-formation-fillup and travel-time formulas (both based on radial flow), it appears that four existing wells have exceeded or will soon exceed their 1/4-mile aquifer exemptions. In fact, one well has probably directly impacted the reservoir up to a distance of one half mile from the well. Any permits should be evaluated to determine if the 1/4 mile radius of exempted aquifer is adequate.

2. It is not possible to draw TDS contours of the ambient water quality for the Judith River Fm. over the entire Reservation. There is very little reliable data on which a contour map could be based. Data from water wells on the west side of the Reservation; a water well at Wolf Point; and a drill stem test, indicate that TDS concentrations increase from east to west. These data indicate that the Judith River Fm. was a USDW in the vicinity of the Tule Field; TDS values in the Poplar Field were always in excess of 10,000 mg/l.

3. Based on composition, thickness, and apparent low permeability of the Bearpaw Shale Fm., it appears that the Judith River Fm. is sufficiently confined to prevent fluid contamination of overlying USDW's.

4. Estimates of the radius-of-fillup indicate that even with dispersion, the direct impact of the injected water will be limited to less than a 1/2 mile for any given injection well reviewed. This will create a limited amount of east to west fluid migration due to the mounding effect caused by the injection and subsequent displacement of existing reservoir water back to the west.

5. The INDIRECT impacts of injection into the Judith River Fm. in the Poplar Field could have a significant impact to the west because of the large pressure buildup in the field since injection was initiated. Fluid pressure buildup estimates indicate that significant pressure effects could extend beyond a five mile radius. While this may not result in westward fluid migration as far as five miles, it will result in a flattening of the preinjection gradient. This will result in increased travel times of native water moving west to east, which should result in an increase in TDS.

6. Calculations using the existing injection pressures, obtained from data supplied by Larry Monson, indicate that all but seven of the 17 current and standby injection wells are operating at pressures which exceed a fracture gradient of 0.75 pounds per square inch (psi/ft).

7. The principal sources of drinking water in the vicinity of the oil fields, where injection into the Judith River Fm. is occurring, are the alluvium and glacial gravels. There are also several areas which receive supplies from bedrock aquifers of limited areal extent, such as the Fox Hills. There is insufficient data to draw either TDS contours or the extent of the aquifers in question.

8. Available data indicate that the Judith River Fm. in the vicinity of the Volt and Tule Fields was a USDW prior to injection activities. Continued injection in these fields will increase the size of the presently impacted area, therefore, limiting injection to the existing 1/4 mile aquifer exemption should be considered when establishing the expiration dates of the permits. Continued injection in the Poplar Field may have little impact on the aquifer to the west of the field, but there may be some indirect impact caused by a flattening of the gradient between the Poplar Field and the various fields to the west.

DISCUSSION

1. Are the 1/4 mile aquifer exemptions for the given injection wells, granted at the inception of the UIC program, adequate for the volumes of fluids injected?

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is a given distance, r, away. The formula, derived by integrating the equation for the average velocity through porous material, is given as:

$$t = \frac{\pi \ \emptyset \ br^2}{Q}$$

Where:

$\emptyset$ = porosity of reservoir
b = thickness of reservoir (ft)
r = distance from injection well (ft)
Q = injection rate (ft ^{3}/day)
t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;
b. the reservoir thickness is uniform;
c. the effect of the regional flow gradient on the plume is negligible;
d. the porosity is uniform; and
e. there are no dispersion effects.

The primary variables in calculating travel time are porosity and thickness of the formation. In the case of the Judith River Fm., the porosity varies from 10% to 20%, (Feltis, 1982).

A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N, R50E. This log indicated an average porosity of about 16.5%. Other experts with knowledge of the Judith River Fm., however, indicate that a porosity of less than 15% should be expected in much of the formation (Marvin Miller, Personal Communication).

The thicknesses of the sand units in the Judith River Fm. underlying the Reservation are quite variable, ranging from less than 10 feet to about 125 feet. The sandstone generally occurs in two discrete units which are separated by claystones. Analysis of a map showing cumulative thickness of sandstone in the Judith River Fm. (prepared by Larry Monson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek Fields and the Poplar Field. Spatial changes in sandstone thickness within each of the given fields, however, is small enough to base travel-time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, sand thickness was estimated using the total sum of the perforated intervals. The estimates correlate well with the map of Judith River Fm. sand thickness. In most cases the perforated intervals encompass all the available sand.

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells. This assumes that the injection rate was continuous and constant. The radii of interest are 1/4 mile (1,320') and 1/2 mile (2,640'). A 1,000 foot radius was used for the calculations, instead of 1,320 feet, to allow a margin of safety. As indicated, the travel time increases rapidly as the radius increases. Travel time is also influenced by the direct relationship with porosity; doubling of porosity will double the travel time.

The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene 1-D, the Sletvold B1, the Allotted Hall SWD, the Goings 1, the Reynolds EPU 8, the Bierre 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1-D, the Sletvold B1, and the Buck Elk 2 have already injected for at least 15 years.

An alternative means of estimating the impact of injected fluids upon a reservoir is to calculate the "radius of fillup." This value can be used to calculate the size of the cylinder of reservoir rock to be filled by the total injected fluid volume. The equation to calculate this radius is given as:

$$r_f = \sqrt{\frac{(W)\ 5.615}{(\pi)(b)(\emptyset)}}$$

Where:

r_f = radius of fillup (ft);
W = total injected volume (barrels);
$\emptyset$ = porosity;
b = sand thickness (ft); and
5.615 = conversion factor (ft^3/bbl)

TABLE 1. TRAVEL TIME FROM INJECTION WELL TO A GIVEN POINT, R

LOCATION	WELL NAME	VOLUME INJECTED PER DAY (ft^3/day)	TRAVEL TIME (days) R = 1,000 feet			R = 2,640 feet		
			ϕ = .1	ϕ = .165	ϕ = .20	ϕ = .1	ϕ = .165	ϕ = .20
SE SW 4-30-46	Courchene 1-D	7,300	2,366	3,904	4,732	16,488	27,206	32,976
NW NE 9-30-46	Carlson	1,291	7,297	23,039	14,594	50,855		
SE NE 13-30-47	Phillips-McKee	5,351	4,108	6,772	8,216	28,629		57,258
C SE SW 13-30-47	Lough 2	3,099	4,762	7,857	9,524	33,190		
NE NE SW 34-31-47	A 1-W Listug-Olson							
SW NE SW 36-31-47	Wetsit 1	3,296	6,288	10,375	12,576	43,822		87,644
NW NE 6-30-48	Bigtrack Little 1	1,259	4,988	8,230	9,976	34,765		
NW SE NE 15-30-48	Bridges 1-D	1,959	9,617	15,868	19,234	67,028		
C NW NE 19-30-48	Sletvold B1	3,694	2,550	4,208	5,100	17,773	29,325	35,546
SW SE 20-31-48	Mule Creek 1-D	1,583	27,770	45,821	55,540	193,546		
SE NE 25-31-48	Mann 1 SWD	1,645	19,470	32,125	38,940	135,697		
NW NE 29-29-49	Allotted Hall SWD	12,576	998	1,647	1,996	6,064	11,486	13,922
NE NW 27-29-50	Goings 1	6,086	2,270	3,745	4,540	15,822		31,644
SE NW NE 10-28-51	Huber 1-W	3,116	14,712	24,274	29,424	102,540		
NW SE 10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
SW NW SW 22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
SW NW 7-29-51	Buck Elk 1	3,722						
SW NW 7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
SW SW 28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
SW SW SW 31-31-48	Stai 1 SWD	465	35,886	59,212	71,772	250,109		

The use of this equation assumes that:

a. flow is radial;
b. reservoir thickness is constant;
c. existing flow gradient does not affect plume movement; and
d. there are no dispersion effects.

This equation is sensitive to both the change in volume and the change in porosity. The porosity is most important in that an increase in porosity will cause a decrease in the radius of impact. Using a high value for porosity will provide a sense of the minimum size of the area of impact. The results that appear in Table 2 were obtained by assuming a porosity of 15% and no dispersion.

As is indicated by the results, injection in several wells has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Sletvold B1, the Reynolds EPU-8, the Bierre 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a year.

As mentioned previously, the radius of fillup equation does not take into account dispersion. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972), which is given by:

$$r' = r + 2.3\sqrt{(D)(r)}$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);
r = calculated radius of fillup with no dispersion (ft);
D = dispersion coefficient (ft).

This equation estimates the point at which the injection front possesses a chemical concentration of 0.2% of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of three feet for sandstone while the value for a vuggy limestone would be 65 feet.

Table 3 shows the calculated radius of fillup with and without dispersion, assuming a higher porosity of 20%. The increase in porosity of 5% does not affect the radius of fillup estimates shown in Table 2, by more than 150 feet. Table 3 also shows calculations of the radius of the injected front using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2, which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

TABLE 2. RADIUS OF FILL-UP OF JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	NAME	FIELD	TOTAL VOLUME INJECTED (bbls)	TIME SINCE START UP (days)	RADIUS* OF FILL-UP (feet)	SAND THICKNESS (feet)
SE SW 4-30-46	Courchene 1-D	Volt	9,490,953	7,300		
NW NE 9-30-46	Carlson	Volt	837,942	3,650	577	30
SE NE 13-30-47	Phillips-McKee	Tule	1,391,601	1,460	987	70
C SE SW 13-30-47	Lough 2	Tule	3,830,468	6,935	986	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud	642,238		330	70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	4,074,613	6,935	585	66
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	980,047	4,380	764	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	2,164,863	6,205	656	60
C NW NE 19-30-48	Sletvold B1	Tule	6,005,777	9,125	1,544	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	2,164,863	7,665	429	140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	641,248	2,190	273	102
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	2,452,707	1,095	854	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,186,616	1,095	567	44
SE NW NE 10-28-51	Huber 1-W	Poplar	5,068,610	9,125	643	146
NW SE 10-28-51	Reynolds EPU 8	Poplar	15,975,426	2,555	1,952	50
SW NW SW 22-28-51	Bierre 1	Poplar	4,795,534	5,110	1,543	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,210,118	1,825		
SW NW 7-29-51	Buck Elk 2	Poplar	3,263,920	6,570	1,394	20
SW SW 28-29-51	EPU 29-D	Poplar	3,709,121	1,825	1,140	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	448,204	5,475	428	52

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,690	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 20%.

Based on the analysis of the data, it is clear that the exempted areas are not sufficient in portions of the aquifer where injection is occurring and the TDS is less than 10,000 mg/l. Given the fact that flow will not be radial because of geologic structure, fluid density differences, and existing gradient, the impacted area of aquifer may be at least 1/2 mile. Based on calculations performed during this review, there are four operating wells which impact an area of the aquifer larger than 1/4 mile and which may need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Allotted Hall SWD, and Courchene 1-D.

In summary, there are wells in the Poplar Field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, a well in the Volt Field and a well in Deadman's Coulee Field have exceeded the 1/4 mile radius. When these four wells are permitted, any exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be evaluated using radius of fillup calculations for the proposed life of the well, in order to estimate the size of impacted area.

2. <u>What is the ambient quality of the Judith River Fm. over the entire Reservation?</u>

The Judith River Fm. consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally, beds of coal and carbonaceous shale occur, such as that encountered in wells on the western edge of the Reservation near Glasgow, Montana. Individual beds of sandstone or shale are not always continuous either in thickness or character, and consequently the sequence of alternating types of rock differs laterally.

The number of sandstone beds and the distance of such beds below the top of the Judith River Fm., are not the same in all localities. Generally, there are two major sandstone layers in the Judith River Fm. on the west side of the Reservation. The Judith River Fm. (400 to 100 feet thick on the Reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the Poplar Field area. The Judith River Fm. outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a limited amount of data on the water quality and the hydrology of the Judith River Fm. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Fm., the direction of ground-water flow is most likely from the west to the east and southeast. Water quality data indicate an increase in TDS from west to east. Although Judith River Fm. water quality is marginal for drinking, it is used in the western portion of the Reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/l in a well in T34N, R40E, to more than 18,000 mg/l in a well in T29N, R51E.

Table 4. Total Dissolved Solids Content for Samples from the Judith River Formation.

LOCATION		TOTAL DEPTH (ft.)	SAMPLE DATE	TDS (mg/liter)	REMARKS
Sec. 6	T27N,R40E	495	1978	2802	
Sec. 31	T28N,R40E	555	1978	2126	
Sec. 11	T34N,R40E	405	1982	1444	
Sec. 31	T36N,R90E	1700	1971	2303	
Sec. 14	T26N,R41E	936	1947	2419	
Sec. 2	T27N,R41E	695	1978	2724	
Sec. 30	T28N,R41E	454	1978	2851	
Sec. 35	T28N,R41E	685	1978	2765	
Sec. 34	T27N,R44E	1090	1947	4133	
Sec. 15	T27N,R47E	985	1947	3862	
Sec. 22	T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15	T30N,R48E	1411	1964	15,602	DST *
Sec. 13	T28N,R50E	874	1954	11,475	DST
Sec. 19	T29N,R51E	877	1957	18,624	DST *
Sec. 15	T30N,R49E	1600	1964	16,653	DST *
Sec. 24	T36N,R52E	1940	1957	10,385	DST
Sec. 4	T30N,R46E	1432	1965	15,056	*
Sec. 29	T29N,R49E	1270	1982	11,323	DST

* Sampling methods were questionable and therefore, analytical results are considered invalid for purposes of this review.

As can be seen in the values of TDS, there is a great deal of variation within given areas. This may reflect poor "quality assurance" in either the sampling or analysis. This is especially true of the data obtained by drill stem tests. For instance, the sample from the Courchene 1-D had a calculated TDS of about 15,000 mg/l. The sample was muddy, indicating that some contamination may have been present. Additionally, this sample does not compare with the data from the wells at Wolf Point, which have TDS values of less than 4,000 mg/l.

The Wolf Point wells are about six miles east and 15 miles south of the Courchene 1-D well in the Tule Field. Given the apparent west to east flow, it is difficult to postulate why the quality would have so much variability in a north-south direction.

For purposes of this report, most of the data obtained from DST samples were considered to be questionable, except where documentation indicated a valid sample. The valid data verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29N, R48, 49, and 51E do not correlate with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the Judith River Fm.

Ignoring the samples that are questionable, it can be intimated that the TDS increases from about 4,000 mg/l in T27N, R47E to about 11,000 mg/l in T28N, R50E (a distance of 10 to 15 miles). Water quality data from the Poplar Field support a finding that the TDS has always been in excess of 10,000 mg/l.

Data from several electric logs were used to estimate the TDS in several oil wells drilled in various parts of the Reservation. These estimates were made using Archie's law:

$$R_w = R_o/F$$

Where:

R_w = resistivity of the formation water;
R_o = resistivity of the formation including the water it contains obtained from log);
F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empirical constant which depends on such formation characteristics as porosity. The Judith River Formation Factor was estimated using the electric log and the actual value of TDS from the Allotted Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follow:

R_w (at 168°F) = 0.24 (from Welex charts on salinity)
BHT = 168°F
TDS = 11,000 mg/l
R_o = 3.0 ohm-m (from log)
$F = R_o/R_w = 3.0/0.24$
F = 12.5

The Formation Factor was assumed to be constant and Archie's Law was used to estimate the TDS content of the Judith River Fm. in several locations where R_o values of the formation could be obtained from well logs. Estimates were made for several locations along an east-west line where electric logs run on production wells were available. Table 5 gives the information from the logs and the resulting estimates of TDS.

Table 5. Estimates of TDS Using Resistivity					
NAME	LOCATION	BHT	R_o	R_w	TDS
#1 Gess	Sec. 1 T30NR463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15 T31NR42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30 T31NR45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30 T31NR44E	165°F	6	0.48	5500
C. Reddig #2		165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7 T30NR46E	155°F	7.5	0.6	4400
Clark #1-MA	Sec. 4 T29NR49E	168°F	3.0	0.28	9500

* Note: It was not possible to determine which track on the log was the actual R_o value. The 2nd track had a large value of R.

These estimates indicate that the TDS content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E), which has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east, such that wells about 16 miles to the northeast have a TDS in excess of 10,000 mg/l. It is important to note, however, that calculations using the Formation Factor are questionable at best because of the lack of reliable quality data and good electric logs.

In summary, existing data indicate that the Judith River Fm. is a USDW on the western edge of the Reservation. The TDS concentration of the water in the formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Allotted Hall SWD well in Deadman's Coulee Field (supported by documentation indicating that the sample was representative) indicate that the portion of the Judith River Fm. in this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not now, and has probably never been, a USDW. The Judith River Fm. underlying the Volt, Tule, and Benrud Fields however, may have been a USDW prior to injection.

3. <u>Is the Judith River Fm. sufficiently confined to prevent contamination of overlying USDW's?</u>

The Judith River Fm. on the Fort Peck Reservation is overlain by the Bearpaw Shale, which also dips from west to east. The western margin of the Bearpaw is located west of Glasgow, Montana. The depth to the Judith River Fm. on the Reservation ranges from about 500 to about 1,300 feet. This depth

to the Judith River Fm. is dependent on the geologic structure and the surface topography. The Judith River Fm. is at shallow depths in the East Poplar Field because of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Fm. is shallowest on the western edge of the Reservation.

The Bearpaw Shale is a gray marine shale, sandy in the upper portions, and is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the fallowing practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content ranging from 5,000 to 70,000 mg/l.

Available well data indicate that the Judith River Fm. is under confined conditions such that wells flow at the surface. For instance, two wells located near Wolf Point were under flowing condtions in 1947. Surface pressures measured in the Poplar and Tule Fields are as high as 900 psi. While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection, wells in the oil fields would probably flow at the surface.

The reported injection pressures for wells injecting into the Judith River Fm. (Larry Monson, Fort Peck Mineral Resources), were used to calculate the present injection gradient for each well. These calculations indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which could exceed a fracture gradient of 0.75 psi/ft. Five wells are injecting at pressures in excess of 1.0 psi/ft. These are the Lough #2, the Allotted Hall SWD, the Goings #1, the Reynolds EPU-8, and the EPU 29-D. The Reynolds EPU-8 is injecting at the highest gradient (1.27 psi/ft).

No data on actual fracture pressure of the Judith River Fm. is apparently available. Although one operator indicated that the fracture gradient was 1.25 psi/ft, no documentation was provided to verify this claim. It is unlikely that the fracture gradient of the Judith River Fm. exceeds 0.8 psi/ft based on data from other reservoirs with similar charateristics. Even if the reservoir is fractured, the overlying shales may be of sufficient thickness to prevent fractures such that fluid will not migrate into USDW's overlying the 800 to 1,000 feet of shale. Field studies have shown that injection energy dissipates rather quickly once the fractures move out of the reservoir. The fracturing of the reservoir on the other hand could present a problem. It will provide discreet zones of high permeability which will provide avenues for injected fluid to move further from the well than estimated by the radial flow calculations. Additional data obtained from valid step rate tests should be used to justify injection pressures over 0.8 psi/ft.

Based on the thickness and low permeability of the Bearpaw Shale, combined with the evidence that the Judith River Fm. is under confined conditions, it appears that the Bearpaw Shale is adequate to prevent movement out of the injection zone. This may depend however, on the actual fracture gradient of the Judith River Fm. and the Bearpaw Shale. Although injection activities will have some impact on the pre-injection flow patterns of the Judith River Fm., there is inadequate data to develop a map to show these actual flow patterns. In order to develop such a map, it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the Reservation?

As discussed previously, the Judith River Fm. dips from west to east towards the Williston Basin. This formation outcrops at the surface near the Milk River, West of Glasgow and is considered to be a significant location for recharge to the Judith River Fm. The pre-injection flow pattern was probably west to east, with a southern component of flow, especially in the Poplar Dome area.

The dip of the Judith River Fm. increases east of the Dome due to the presence of the Williston Basin, which is a deep synclinal trough.

Available logs and cross sections indicate that the depth of the Judith River Fm. increases by 900 feet between a well in Section 29, T29N, R50E and a well in Section 35, T29N, R52E, which is a distance of about 10 miles.

The sand units in the Judith River Fm. also thin from thicknesses of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29N, R55E, however, shows a Judith River Fm. sand thickness of about 100 feet. Based on this data it is clear that the Judith River has definable sandstone layers present well out into the basin.. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River Fm. and its discharge zones.

Data on the permeability and porosity of the Judith River Fm. sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcies (md) was reasonable. Marvin Miller, of the Montana Bureau of Mines, indicated that an analysis of limited DST data indicated a range of permeabilities from 55 md to 109 md. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$P_r = P_i + (70.6)\frac{(Q)(U)(B)}{(k)(b)}\left[E\left(\frac{39.5\ (\emptyset)(U)(c)(r^2)}{(k)(t)}\right)\right]$$

where:

P_r = Pressure at a given radius (psi);
P_i = Initial pressure (psi);
Q = Constant injection rate (barrels/day);
B = Formation volume factor = 1;
c = compressibility (psi $^{-1}$) = 7.5 x 10^{-6};
U = viscosity (cp) = 1;
k = permeability (md);
b = thickness of reservoir (ft)
Ø = porosity
E = Exponential integral

For purposes of this evaluation of pressure buildup, the following is assumed:

a. flow is radial;
b. the initial pressure is zero;
c. well interference is not taken into account;
d. porosity and thickness are constant;
e. the well is fully penetrating;
f. the radius of the injection well is assumed to be 0.5 ft.; and
g. the injection rate is estimated using the total volume injected since a given well began operation and assumes the rate was constant.

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 md and a porosity of 15%. The table also lists the reported well head pressures. As indicated in the table, the calculated values of pressure buildup lie on both sides of the reported values. Generally, the calculated values were not greatly divergent from reported values.

The results provide a qualitative measure of the possible variations of permeability. The largest divergence was in the EPU-8 well and the Allotted Hall SWD well. This divergence may be caused by a higher permeability value than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed.

Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles, assuming permeabilities of 55 md and 109 md. The pressure buildups at the wells are more realistic than those estimated assuming a permeability of 25 md. This is especially true in light of the fact that there was an initial positive formation pressure in the field, which was assumed to be zero for purposes of these calculations. The important point of these estimates is that all wells are causing significant pressure increases at a distance of five miles.

TABLE 6. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of permeability of 25 millidarcies and porosity of 15%.

TABLE 7. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				permeability = 55 md		permeability = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 miles	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Permeability measured in millidarcys; porositiy assumed to be 15%.

The data presented in Tables 6 and 7 indicate that injection in the Poplar Field has created significant pressure changes around the wells, which will reach at least 5 miles to the east and west. The pressure mound will be elongated in a north and south direction because of the interference effects of several injection wells which lie in a north-south line over a distance of about 8 miles. In the author's opinion, this pressure mound has influenced the ground-water flow pattern of the Judith River Fm. This disruption will most likely cause more flow to the south, although some increased ground-water flow to the north will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this ground water flow reversal is not possible to estimate, although it is probably less than two miles.

A point of note is that the injection pressure, in feet of water, in the Tule Field is about 100 feet higher than that in the Poplar Field. This indicates that the overall gradient is still to the east. The large injection pressures in the Poplar Field will however, result in a flattening of the gradient betwen the Tule and Poplar Fields.

Any direct water quality impact due to injected water will be less than one mile to the west based on estimates for the radius of fillup. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality impact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

5. <u>What alternative water sources are there on the Reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/l, less than 10,000 mg/l for other sources of drinking water)?</u>

Although the Judith River Fm. does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Fm. The major sources are alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the TDS content of water from a representative sample of wells tapping the major water sources.

As indicated, the water quality of the alluvium and the Fox Hills is generally excellent. Note: a complete listing of wells (for which water quality data is available) is attached as Appendix 1. Some alluvial wells have TDS contents in excess of 1,000 mg/l but most have TDS contents of less than 1,000 mg/l. The TDS content of water from the Fort Union is somewhat higher, but is useable for domestic purposes.

Table 8. Total Dissolved Solids Content of Aquifers Overlying the Judith River Formation - Fort Peck Indian Reservation.

WELL LOCATION		AQUIFER	TOTAL DISSOLVED SOLIDS (mg/l)
Sec. 28	T29NR46E	Alluvium	592
Sec. 10	T29NR51E	Alluvium	809
Sec. 36	T30NR55E	Alluvium	less than 1,000
Sec. 5	T29NR51E	Alluvium	704
Sec. 32	T30N355E	Fort Union	less than 1,000
Sec. 25	T30NR45E	Fox Hills	300
Sec. 19	T28WR53E	Hell Creek	2,540
Sec. 13	T28NR58E	Fort Union	less than 500
Sec. 34	T31NR57E	Till	less than 1,000
Sec. 28	T31NR57E	Fort Union	less than 1,500
Sec. 33	T33NR44E	Alluvium	295
Sec. 29	T27NR51E	Alluvium	1503
Sec. 3	T27NR49E	Alluvium	980
Sec. 25	T28NR53E	Alluvium	2788
Sec. 2	T30NR46E	Flaxville	329

Data on the areal extent of the shallow aquifers is not available. It is apparent, however, that most of the alluvial and outwash deposits are limited in their areal extent, as are the Fort Union and Fox Hills Fms. in their subsurface extents. There are numerous alluvial aquifers throughout the Reservation, while the Fox Hills and the Fort Union Fms. are not present over the western portion of the Reservation. The Fort Union Fm. apparently extends only as far west as the Poplar Field.

Because of the absence of good maps showing the extent of the various aquifers, it is not possible to develop a map with TDS concentration contours. It is clear, however, that all of the shallow aquifers qualify as USDW's and are the major sources of drinking water in the area.

APPENDICES

1. Transcript of May 29, 1985, Public Hearing.
2. Memorandums and Correspondence relating to the Judith River Formation.
3. Summary data on the Judith River Formation compiled by Larry Monson, Fort Peck Mineral Resources.
4. Well Logs on selected wells.
5. Water Quality Data - Fort Peck Reservation.
6. Author Notes on Pressure Buildup Calculations.
7. Various Geology Reports relating to the Judith River Formation.

DATE: January 3, 1986

SUBJECT: Pending Permits into the Judith River Formation

TO: All GWS Staff

FROM: Debbie Entert, Team Leader
Direct Implementation

Everyone should have had a chance by now to review the Judith River Formation Report that I distributed last week. Several questions have been raised about how we re going to implement the policy, so I would like to get together with everyone to discuss this. There are probably some issues that also need to be clarified. If there are no conflicts, let's try to meet for discussion after our Tuesday morning staff meeting.

The attached list shows all Judith River injection wells, which we can use for discussion. I tried to indicate the status/prognosis for each of the wells based upon what I could find. If anyone has different information, please bring it up at the meeting.

WELL, OPERATOR, & FIELD	SUMMARY
Goings #1 Century Oil Poplar Field	Final permit was issued on 12-31-85. Since it is in the Poplar Field no aquifer exemption was needed.
Buck Ell 2 Grace Pet. E. Poplar	From preliminary caluclations, it appears that this well has injected beyond the 1/4 exemption. However, since it is in the Poplar Field, it does not need an aquifer exemption. Permit can be issued without any special limitations.
EFL 2-D Murhpy Oil E. Poplar	No aquifer exemption needed. Permit can be issued without any special limitations.
EFU 29-D Murphy Oil E. Poplar	No aquifer exemption needed. Permit can be issued without any special limitations.
Allotted Hall Reading & Bates Deadman's Coulee	Permit application being denied due to excessive injection pressure. Operator has agreed to ultimately P&A well when replacement well is constructed.
Lough #2 Petro Lewis Tule Creek	Well shut-in April 1st for failure to submit application. Operator has permitted replacement well. This well can either be permitted (limit aquifer exemption to 1/4 mile) or, if the operator no longer wants to operator the well, must be P&A'ed.
Lillian 1-D Murphy Oil E. Tule	Calculations should be repeated to demonstrate the the expected life of the well. Radius of fillup should be determined. Injection rate and volume should be checked for compatibility. Permit can be issued for a specified period of time to ensure fluids will not extend beyond 1/4 mile.
Sletvold Murphy Oil Tule Creek	Preliminary calculations show that this well has already reached the 1/4 mile aquifer exemption. Permit application will have to be denied.
Mann #1 Pennzoil Long Creek	A draft permit has been issued. Calculations were shown in the SOS which verified that the 1/4 mile exemption would not be reached for 9o years. Fluid plume is only expected to extend to 0.10 mile at the end of the life of the well.

Phillips-McKee SHP Pet. Tule Creek	This well failed a MIT on 10-2-85. Operator was requested to monitor the annulus on a daily basis and report any positive pressure. From preliminary calculations, it appears that the well can be permitted for a limited period of time. Calculations should be repeated when writing the SOB. It appears that some kind of workover will need to be done to restore mechanical integrity. Operator should be contacted and informed of the approach we will be taking.
Wetzel #1 Murphy Oil E. Tule	Application is being called-in. Calculations should be repeated to demonstrate the expected life of the well. Radius of fillup should be determined. Injection rate and volume should be checked for compatibility. Permit can be issued for a specified period of time to ensure fluids will not extend beyond 1/4 mile.
Stai #1 Franks Pet. E. Benrud	Permit application received December, 1985. From preliminary calculations, it appears that the well will not reach 1/4 mile exemption for sometime. Calculations should be repeated in SOB. Permit can be issued for a specified period of time.
Courchene Murphy Oil Volt	Well has not been called-in yet. Preliminary calculations show that the radius of fillup exceeds 1/4 mile. Operator will be notified that the well will not be permitted, and that it will be P&A'ed within a specified time period. We may decide to let them find a replacement well before they are made to shut-in.
Buck Elk 1 Grace Poplar	Well was abandoned in 1967.
Bierre 1 Mesa Pet. Poplar	Well was plugged 8-13-84.
Bigtrack Little No. 1 Petroleum Inc. E. Benrud	Well is being called-in. Operator missed 1-3-86 deadline. In addition, they ignored the June 25th. 1985, inventory submittal deadline. This is a potential enforcement case.
Mule Creek 1-D Murphy Oil N.E. Benrud	Well was called in 2-5-85. Operator responded that they were going to P&A the well <u>if</u> we allowed them to drill a new well (Mule Creek 2-D) into the Judith River about 40 feet away from the 1-D. It appears that a permit can be issued for the 1-D,

	although there may be some operational problem with the well that makes it not advantageous to operate. The operator should be notified after a decision is made on whether a new well will be allowed.
Mule Creek 2-D Murphy Oil N.E. Benrud	This is an application for a new well into the Judith River, proposed to replace the 1-D. The well could only be allowed if injection plume were limited to 1/4 mile minus 40 feet (the existing aquifer exemption). We may not want to allow this well under any circumstances. This is a tough one.
Huber 1-W (Stdby) Polumous Poplar	Well was plugged prior to June 24, 1984.
Carlson Kirkwood-Wesco Volt	Kirkwood Oil & Gas Company of Casper, Wyoming, report-this well for the June 25, 1985, deadline. Well has not been called-in. Well will be called-in in the near future.
A 1-W Listug-Olson (Stdby) Chamberlain Benrud	Chamberlain reported this well TA'd for the June 25th deadline. Well should be called-in for application.
Bridges 1-D (Stdby) Murphy Oil E. Tule	Was Well plugged?

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

APR 23 1987

Ref: 8WM-DW

MEMORANDUM

TO: Alfred C. Smith
Associate Regional Counsel

FROM: Debra G. Ehlert, Chief
Ground Water Section

SUBJECT: Advise on Montana House Joint Resolution #6

Attached you will find a copy of the above-referenced state resolution. There are several questions that we have:

(1) Do we need to respond?
(2) How or will this affect UIC permits or permit applications for injection wells that are completed in the Judith River?

As you might expect, there may be congressional inquiries with regard to the entire issue. Please let me know if you have any questions.

Thanks.

cc: Andy Lensink

MEHerman:kes:4/22/87

Attachment

CONCURRENCES

SYMBOL	8WM-DW							
SURNAME	MHerman							
DATE	4-22-87							

EPA Form 1320-1 (12-70)

OFFICIAL FILE COPY

*U.S. GPO : 1986-159-319

SECRETARY OF STATE
STATE OF MONTANA

Deb E. cc: Pat
rec'd in SOEA 4-15-E
Original to SMO
copy for SOEA files.

'87 APR 14 PM 3:33

Jim Waltermire
Secretary of State

Montana State Capitol
Helena, Montana 59620

RECEIVED

April 6, 1987

info cc: Max Dodson
SW 4/16

Alex Smith
SA 4/16

THE ENCLOSED COPY OF ENACTED LEGISLATION IS BEING

SENT TO YOU UPON MANDATE OF THE 1987 LEGISLATURE.

Tim Brunson
(501)
862-6411

HOUSE JOINT RESOLUTION NO. 6

INTRODUCED BY SCHYE, CODY, NATHE, E. SMITH, POFF, COMPTON

IN THE HOUSE

JANUARY 15, 1987	INTRODUCED AND REFERRED TO COMMITTEE ON NATURAL RESOURCES.
JANUARY 23, 1987	COMMITTEE RECOMMEND BILL DO PASS AS AMENDED. REPORT ADOPTED.
	PRINTING REPORT.
JANUARY 28, 1987	ON MOTION, CONSIDERATION PASSED FOR THE DAY.
JANUARY 30, 1987	SECOND READING, DO PASS.
JANUARY 31, 1987	ENGROSSING REPORT.
	THIRD READING, PASSED. AYES, 90; NOES, 3.
	TRANSMITTED TO SENATE.

IN THE SENATE

FEBRUARY 2, 1987	INTRODUCED AND REFERRED TO COMMITTEE ON NATURAL RESOURCES.
MARCH 24, 1987	COMMITTEE RECOMMEND BILL BE CONCURRED IN. REPORT ADOPTED.
MARCH 28, 1987	SECOND READING, CONCURRED IN.
MARCH 30, 1987	THIRD READING, CONCURRED IN. AYES, 50; NOES, 0.
	RETURNED TO HOUSE.

IN THE HOUSE

MARCH 31, 1987	RECEIVED FROM SENATE.
	SENT TO ENROLLING.

A JOINT RESOLUTION OF THE SENATE AND THE HOUSE OF REPRESENTATIVES OF THE STATE OF MONTANA REQUESTING THE U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION VIII, TO REVISE ITS POLICY CONCERNING UNDERGROUND SALT WATER INJECTION INTO THE JUDITH RIVER FORMATION ON THE FORT PECK RESERVATION AND TO ESTABLISH A MONITORING AND DATA COLLECTION PROGRAM.

WHEREAS, the Environmental Protection Agency (EPA) administers the Underground Injection Control (UIC) Program and has issued permits for a number of salt water disposal wells on the Fort Peck Reservation; and

WHEREAS, under present policy EPA is allowing continued injection of salt water within certain limits for a number of wells that existed prior to the UIC Program's inception in the portion of the Judith River Formation west of a line running north-south between Range 48E and 49E; and

WHEREAS, under present policy EPA will permit new salt water injection wells in the portion of the Judith River Formation east of the line between Range 48E and 49E; and

WHEREAS, the Judith River Formation is a relatively shallow aquifer, and water in the western portion of the formation qualifies as an underground source of drinking water as defined by EPA regulations; and

WHEREAS, persons living on and near the Fort Peck Reservation are presently using water from the western portion of the Judith

River Formation for livestock and domestic purposes, and technological advances may make other beneficial uses economically feasible in the future; and

WHEREAS, EPA policy concerning continued salt water injection in the Judith River Formation is based primarily on theoretical calculations and on limited or no empirical data concerning ambient water quality, hydrology and fracture gradients in the formation, the containment of injected salt water within approved limits in the vicinity of each well, and the cumulative effects of all wells injecting into the formation on beneficial use of the aquifer; and

WHEREAS, available data indicate that a number of wells have exceeded or are likely to exceed the carrying capacity of their approved disposal areas within the Judith River Formation; and

WHEREAS, pressure buildup from salt water disposal wells could cause lower quality formation water to be displaced toward portions of the formation where beneficial use of higher quality water is occurring; and

WHEREAS, EPA has not begun regulatory review of a number of existing wells disposing salt water into the Judith River Formation.

NOW, THEREFORE, BE IT RESOLVED BY THE SENATE AND THE HOUSE OF REPRESENTATIVES OF THE STATE OF MONTANA:

(1) That EPA establish a comprehensive monitoring and data

collection program on the Fort Peck Reservation to obtain reliable information concerning the ambient water quality, hydrology, and fracture gradients of the Judith River Formation and the individual and cumulative effects of salt water disposal wells on the formation's water quality.

(2) That EPA revise its policy to postpone approval of new salt water disposal wells in the eastern portion of the Judith River Formation until there is sufficient data to prove that there will be no adverse effect on existing and potential future beneficial use of formation water.

(3) That EPA revise its policy concerning existing salt water disposal wells in the western portion of the Judith River Formation to reflect the primary objectives of returning the water quality of the formation to prior ambient levels and promoting beneficial use of formation water.

(4) That EPA develop a schedule for phasing out the existing wells in the western portion of the Judith River Formation within a reasonable time.

BE IT FURTHER RESOLVED, that the Secretary of State send a copy of this resolution to the Regional Administrator, U.S. Environmental Protection Agency, Region VIII, and the Montana Congressional Delegation.

I hereby certify that the within joint resolution originated in the House.

Chief Clerk

Speaker of the House
Signed this 3 day
of April 1987.

President of the Senate
Signed this 4 day
of April 1987.

HOUSE JOINT RESOLUTION NO. 6

INTRODUCED BY SCHYE, CODY, NATHE, E. SMITH, POFF, COMPTON

A JOINT RESOLUTION OF THE SENATE AND THE HOUSE OF REPRESENTATIVES OF THE STATE OF MONTANA REQUESTING THE U.S. ENVIRONMENTAL PROTECTION AGENCY, REGION VIII, TO REVISE ITS POLICY CONCERNING UNDERGROUND SALT WATER INJECTION INTO THE JUDITH RIVER FORMATION ON THE FORT PECK RESERVATION AND TO ESTABLISH A MONITORING AND DATA COLLECTION PROGRAM.

STATE OF MONTANA
FILED
APR 6 1987
JIM WALTERMIRE
SECRETARY OF STATE
By Marian F. Cambelle
Deputy

JIM WALTERMIRE
SECRETARY OF STATE
State Capitol
Helena, Montana 59620

U.S. Environmental Protection Agency
Regional Administrator
Region VIII
1860 Lincoln Street
Denver, CO 80295

EPA 60 51105421 04/10/87
NOTIFY SENDER OF NEW ADDRESS
:EPA
999 18TH ST'500
DENVER CO 80202-2413

ASTRO-CHEM SERVICE LABORATORY

4102 2nd Ave. West Williston, North Dakota 58801 Phone 701-572-7355

P. O. Box 972

WATER ANALYSIS REPORT

SAMPLE NUMBER: W-83-0514 DATE OF ANALYSIS 2/ 3/83

COMPANY: SUPERIOR OIL COMPANY

CITY: FAIRVIEW STATE: MT

WELL NAME AND/OR NUMBER: .

DATE RECEIVED 2/ 2/83 DST NUMBER: .

SAMPLE SOURCE: 100' DOWNSTREAM FROM CREEK CROSSI

LOCATION: . OF SEC: . TWN: . RNG: .

FORMATION: . DEPTH: .

DISTRIBUTION: FAIRVIEW OFFICE
TWO COPIES

RESISTIVITY@77°F= 30.3 OHM-METERS PH= 8.58

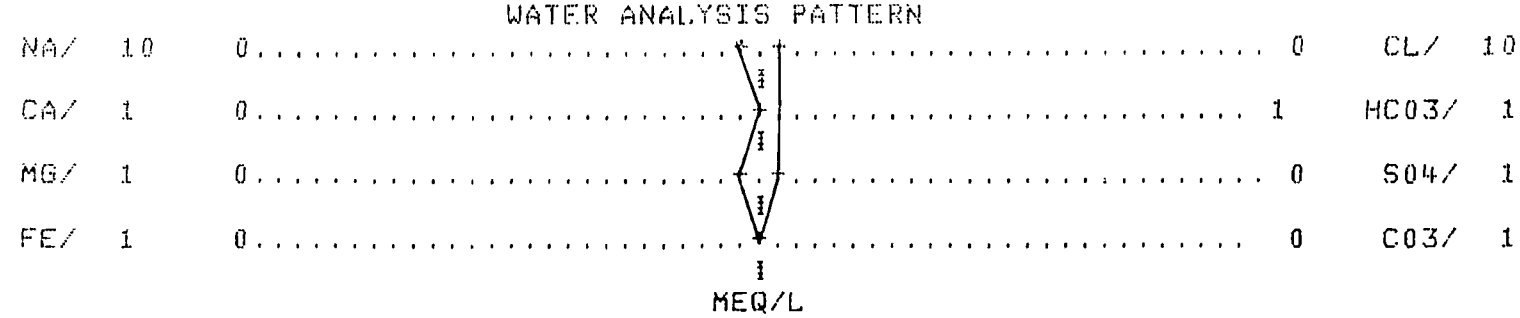
SPECIFIC GRAVITY@77°F=1.000 H2S=NEG

TOTAL DISSOLVED SOLIDS,(CALCULATED)= 150 MG/L

SODIUM CHLORIDE (CALCULATED)= 30 MG/L

CATIONS	MEQ/L	MG/L	ANIONS	MEQ/L	MG/L
CALCIUM	.4	8	CHLORIDE	.5	16
MAGNESIUM	.2	2	CARBONATE	.0	0
SODIUM	1.4	32	BICARBONATE	1.3	79
CHROMIUM	.0	.0	SULFATE	.4	17
IRON	.0	.1	NITRATE	.0	1
BARIUM	.0	.0			

WATER ANALYSIS PATTERN



REMARKS: .

ASTRO-CHEM SERVICE LABORATORY

4102 2nd Ave. West Williston, North Dakota 58801 Phone 701-572-7355

P. O. Box 972

WATER ANALYSIS REPORT

SAMPLE NUMBER:W-83-0513 DATE OF ANALYSIS 2/ 3/83

COMPANY:SUPERIOR OIL COMPANY

CITY:FAIRVIEW STATE:MT

WELL NAME AND/OR NUMBER:.

DATE RECEIVED 2/ 2/83 DST NUMBER:.

SAMPLE SOURCE:100' UPSTREAM FROM CREEK CROSSING

LOCATION:. OF SEC:. TWN:. RNG:.

FORMATION:. DEPTH:.

DISTRIBUTION:FAIRVIEW OFFICE
TWO COPIES

RESISTIVITY@77°F= 13.918 OHM-METERS PH= 8.40

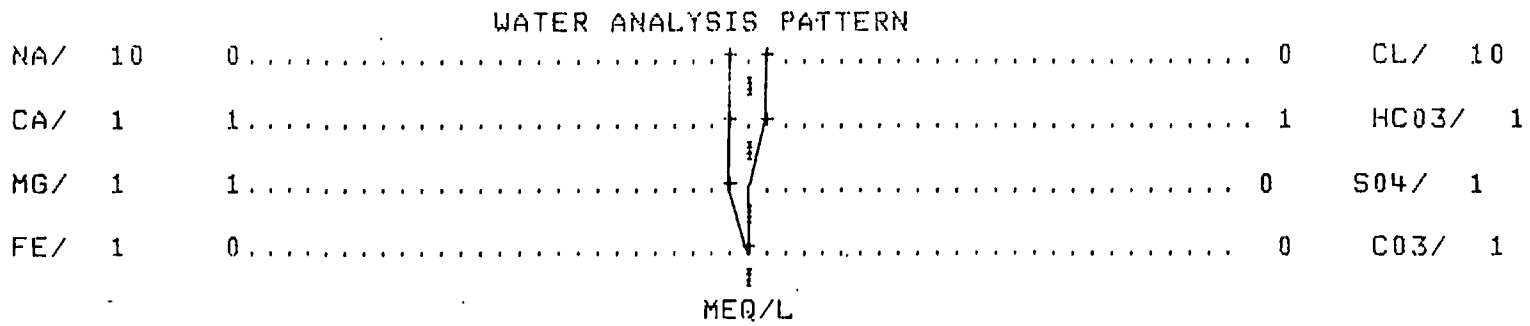
SPECIFIC GRAVITY@77°F=1.000 H2S=NEG

TOTAL DISSOLVED SOLIDS,(CALCULATED)= 180 MG/L

SODIUM CHLORIDE (CALCULATED)= 50 MG/L

CATIONS	MEQ/L	MG/L	ANIONS	MEQ/L	MG/L
CALCIUM	.6	12	CHLORIDE	.8	30
MAGNESIUM	.5	6	CARBONATE	.0	0
SODIUM	1.7	39	BICARBONATE	1.3	79
CHROMIUM	.0	.0	SULFATE	.4	17
IRON	.0	.6	NITRATE	.0	1
BARIUM	.0	.0			

WATER ANALYSIS PATTERN



REMARKS:.

Review of Data Relating to Injection of Oil Field Brines
in the Area of the Fort Peck Indian Reservation

Prepared by: Paul S. Osborne
Regional Ground Water Expert
U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation to prohibit further injections into the Judith River Formation (Fm.). The Tribe alleged that continued injection would affect the quality of water in the Judith River Fm. such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Fm.

A review of the available data (attached as appendices) pertaining to Judith River Fm. injection activities has been completed. Figure 1 shows the Fort Peck Indian Reservation and the fields which are the concern of this analysis.

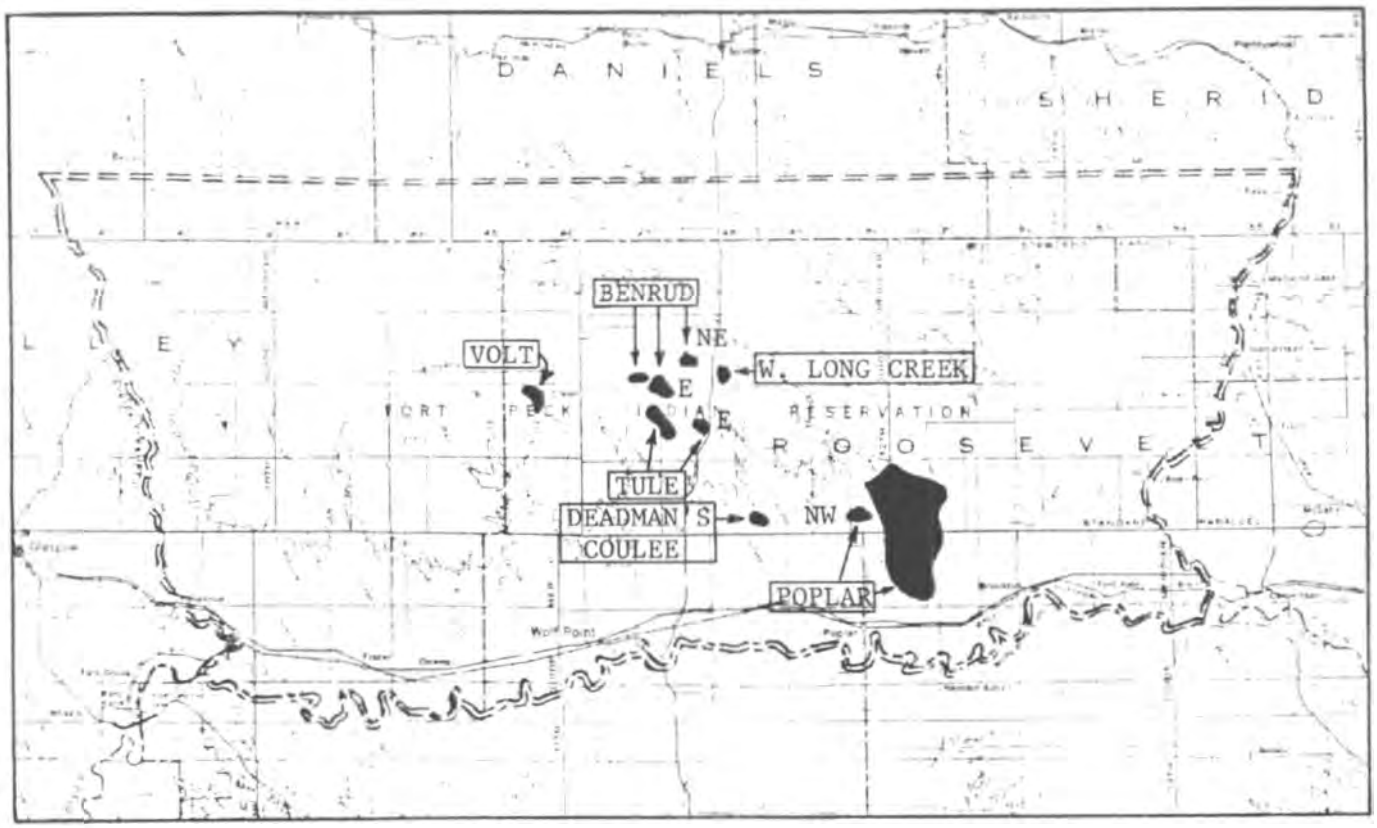


TABLE 7. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				permeability = 55 md		permeability = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 miles	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Permeability measured in millidarcys; porositiy assumed to be 15%.

TABLE 6. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of permeability of 25 millidarcies and porosity of 15%.

TABLE 7. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				permeability = 55 md		permeability = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 miles	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Permeability measured in millidarcys; porositiy assumed to be 15%.

TABLE 6. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of permeability of 25 millidarcies and porosity of 15%.

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,690	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 20%.

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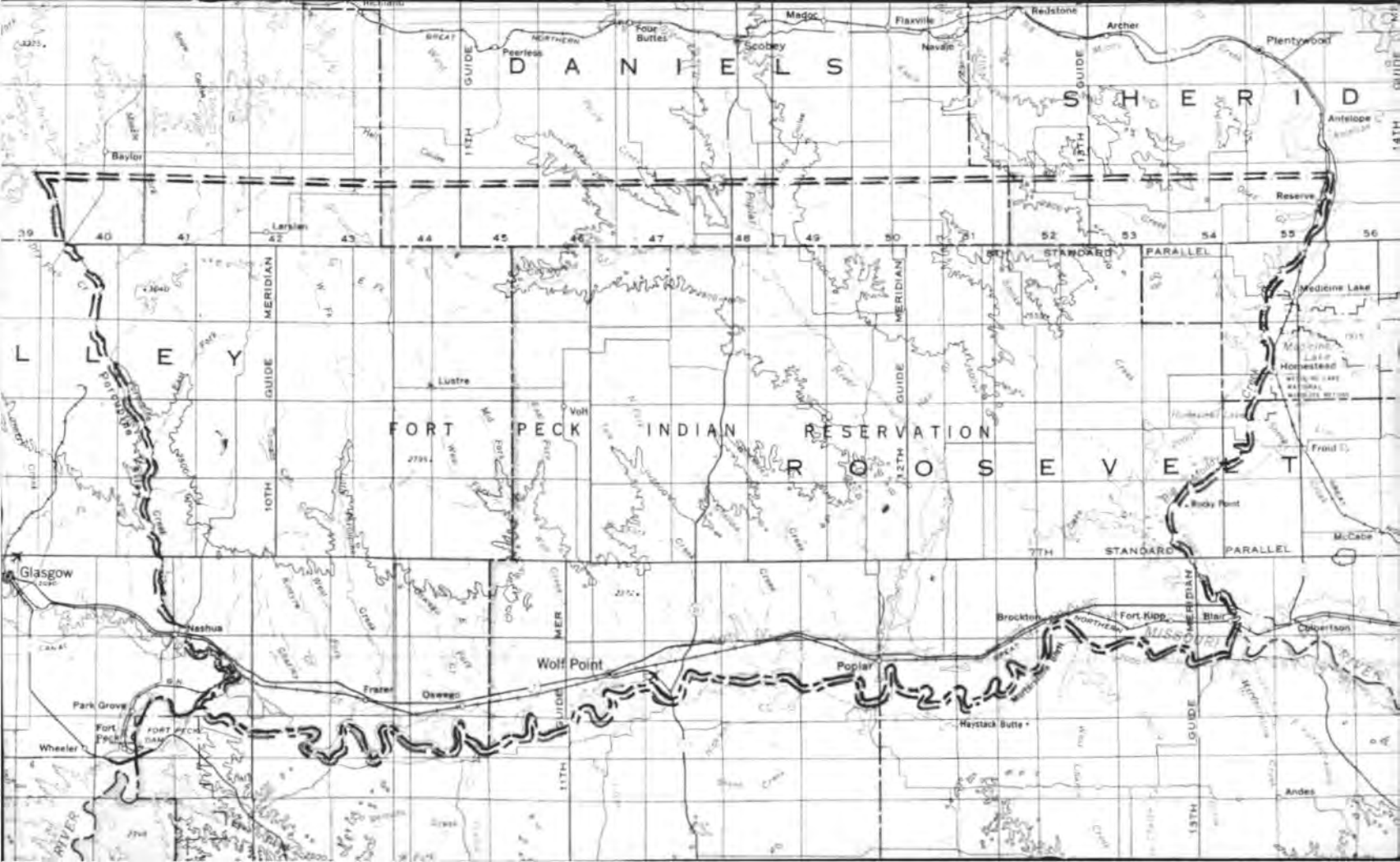

D A N I E L S
S H E R I D
L L E Y
FORT PECK INDIAN RESERVATION
R O O S E V E T
Redstone
Madoc
Flaxville
Archer
Plentywood
Four Buttes
Scobey
Peerless
Nevada
Antelope
Reserve
Baylor
Larslan
Lustre
Voll
Medicine Lake
Homestead
Froid
Rocky Point
McCabe
Glasgow
Nashua
Brockton
Fort Kipp
Blair
Culbertson
Wolf Point
Poplar
Fraser
Oswego
Park Grove
Fort Peck
Wheeler
Haystack Butte
Andes
MISSOURI RIVER
STANDARD PARALLEL
GUIDE
MERIDIAN
NORTHERN
GREAT

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,690	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 20%.

TABLE 2. RADIUS OF FILL-UP OF JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	NAME	FIELD	TOTAL VOLUME INJECTED (bbls)	TIME SINCE START UP (days)	RADIUS* OF FILL-UP (feet)	SAND THICKNESS (feet)
SE SW 4-30-46	Courchene 1-D	Volt	9,490,953	7,300		
NW NE 9-30-46	Carlson	Volt	837,942	3,650	577	30
SE NE 13-30-47	Phillips-McKee	Tule	1,391,601	1,460	987	70
C SE SW 13-30-47	Lough 2	Tule	3,830,468	6,935	986	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud	642,238		330	70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	4,074,613	6,935	585	66
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	980,047	4,380	764	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	2,164,863	6,205	656	60
C NW NE 19-30-48	Sletvold B1	Tule	6,005,777	9,125	1,544	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	2,164,863	7,665	429	140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	641,248	2,190	273	102
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	2,452,707	1,095	854	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,186,616	1,095	567	44
SE NW NE 10-28-51	Huber 1-W	Poplar	5,068,610	9,125	643	146
NW SE 10-28-51	Reynolds EPU 8	Poplar	15,975,426	2,555	1,952	50
SW NW SW 22-28-51	Bierre 1	Poplar	4,795,534	5,110	1,543	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,210,118	1,825		
SW NW 7-29-51	Buck Elk 2	Poplar	3,263,920	6,570	1,394	20
SW SW 28-29-51	EPU 29-D	Poplar	3,709,121	1,825	1,140	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	448,204	5,475	428	52

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 1. TRAVEL TIME FROM INJECTION WELL TO A GIVEN POINT, R

LOCATION	WELL NAME	VOLUME INJECTED PER DAY (ft^3/day)	TRAVEL TIME (days) R = 1,000 feet			R = 2,640 feet		
			Ø = .1	Ø = .165	Ø = .20	Ø = .1	Ø = .165	Ø = .20
SE SW 4-30-46	Courchene 1-D	7,300	2,366	3,904	4,732	16,488	27,206	32,976
NW NE 9-30-46	Carlson	1,291	7,297	23,039	14,594	50,855		
SE NE 13-30-47	Phillips-McKee	5,351	4,108	6,772	8,216	28,629		57,258
C SE SW 13-30-47	Lough 2	3,099	4,762	7,857	9,524	33,190		
NE NE SW 34-31-47	A 1-W Listug-Olson							
SW NE SW 36-31-47	Wetsit 1	3,296	6,288	10,375	12,576	43,822		87,644
NW NE 6-30-48	Bigtrack Little 1	1,259	4,988	8,230	9,976	34,765		
NW SE NE 15-30-48	Bridges 1-D	1,959	9,617	15,868	19,234	67,028		
C NW NE 19-30-48	Sletvold B1	3,694	2,550	4,208	5,100	17,773	29,325	35,546
SW SE 20-31-48	Mule Creek 1-D	1,583	27,770	45,821	55,540	193,546		
SE NE 25-31-48	Mann 1 SWD	1,645	19,470	32,125	38,940	135,697		
NW NE 29-29-49	Allotted Hall SWD	12,576	998	1,647	1,996	6,064	11,486	13,922
NE NW 27-29-50	Goings 1	6,086	2,270	3,745	4,540	15,822		31,644
SE NW NE 10-28-51	Huber 1-W	3,116	14,712	24,274	29,424	102,540		
NW SE 10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
SW NW SW 22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
SW NW 7-29-51	Buck Elk 1	3,722						
SW NW 7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
SW SW 28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
SW SW SW 31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

U.S. Environmental Protection Agency
Region VIII

PUBLIC NOTICE

UNDERGROUND INJECTION CONTROL PROGRAM

FINAL DETERMINATION

PURPOSE OF PUBLIC NOTICE

The purpose of this notice is to inform interested parties that:

(1) the U.S. Environmental Protection Agency (EPA) has developed a policy regarding the issuance of Underground Injection Control (UIC) permits on the Fort Peck Reservation for disposal of fluids into the Judith River Formation; and

(2) EPA has made a determination to issue a final UIC permit for the Goings No. 1 Salt Water Disposal Well, located in the Poplar Field and operated by Century Oil & Gas.

BACKGROUND

EPA held a hearing on May 29, 1985, upon request of the Fort Peck Tribes, to gather factual information regarding hydrogeologic characteristics of the Judith River Formation, and to allow comments to be heard concerning EPA's intent to issue a UIC permit for continuation of salt water disposal into the Goings No. 1 Well. The Goings No. 1 Well is one of several disposal wells injecting fluids into the Judith River Formation. The Tribe has requested that the Judith River Formation be protected as an underground source of drinking water (USDW). The Goings No. 1 well was injecting prior to the inception of the UIC program (June 25, 1985), and is therefore classified as an existing well authorized by rule.

FINAL DECISIONS

A statement has been prepared which establishes EPA's policy on permitting existing and future wells that inject into the Judith River Formation on the Fort Peck Reservation. A copy of EPA's Statement of Policy is being sent concurrently with the publication of this notice to all attendees of the hearing as well as all persons who may be affected by the outcome of such a policy.

In addition, EPA has also made a final permit determination for the Goings No. 1 Well permit application. In the time period since the draft permit was issued in December, 1984, the Goings No. 1 Well failed a mechanical integrity test, was reworked to repair casing defects, and subsequently,

passed a retesting of mechanical integrity. It has been determined that the well meets all UIC requirements and does not pose a threat to any underground source of drinking water. Therefore, a final permit is being issued on the date of publication of this notice with no changes from the draft permit. This action is consistent with the policy mentioned above.

PERMIT APPEAL PROCESS

Within 30 days after a UIC final permit decision has been issued, any person who filed comments on that draft permit or participated in the public hearing may petition the Administrator of EPA to review any condition of the permit decision. Commentors are referred to 40 CFR 124.19 for procedural requirements of the appeal process.

FOR MORE INFORMATION

The Administrative Record for these actions contains:

(1) the Goings No. 1 permit application, draft and final permits;

(2) the official transcript of the hearing;

(3) EPA's technical evaluation of the testimony presented at the hearing; and

(4) EPA's Statement of Policy regarding injection activities and the Judith River Formation on the Fort Peck Reservation.

For further information, you may contact the following offices:

A. Concerning the Judith River Policy:

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
One Denver Place, Suite 1300
999-18th Street
Denver, Colorado 80202-2413

ATTN: Debra G. Ehlert
Telephone: (303) 293-1415

B. Concerning the Goings No. 1 Permit:

Environmental Protection Agency
Montana Office
Federal Office Building
Drawer 10096
301 South Park
Helena, Montana 59626

ATTN: Jim Boyter
Telephone: (406) 449-5486

Date of Publication

Max H. Dodson, Director
Water Management Division

U.S. Environmental Protection Agency
Region VIII

Statement of Policy

Injection activities and the Judith River Formation
on the Fort Peck Reservation

BACKGROUND

EPA published a notice on December 27, 1984 in the Wolf Point Herald stating an intent to issue two Underground Injection Control (UIC) permits to Century Oil & Gas for the purpose of salt water fluid disposal. EPA encouraged public comments on the proposed actions. A notice appearing on January 15, 1985, extended the deadline for public comments on EPA's intended actions until February 15, 1985.

In a letter of January 29, 1985, the Fort Peck Tribes objected to the issuance of one of the two draft UIC permits which would allow injection through the Goings No. 1 Well. The objection was based on the Tribe's overall concern about the degradation of ground water on the Reservation. The Goings No. 1 Well is one of several injection wells which presently disposes of fluids into the Judith River Formation - an aquifer which the Tribe has requested be protected as an underground source of drinking water (USDW). The UIC regulations broadly define a USDW as an aquifer or its portion which both: 1) contains fewer than 10,000 mg/l total dissolved solids (TDS), and 2) is capable of supplying a public water system.

The Tribe subsequently requested a public hearing in order to present relevant information which would substantiate their request to preserve the Judith River Formation. The hearing was held on May 29, 1985, at the Poplar Activity Center.

CONCLUSIONS

The testimony and supporting documentation collected at the hearing were evaluated by EPA. The following discussions reflect the results of the technical evaluation and constitute EPA policy.

POLICY STATEMENT NO. 1 — No new injection wells or converted wells will be allowed to dispose of fluids into the Judith River Formation where the TDS concentration is known to be less than 10,000 mg/l.

Discussion and Basis of Decision

Alternative sources of drinking water are currently available and are being used in the vicinity of the oil production. The principal sources (alluvium and glacial gravels; the Fox Hills and Fort Union aquifers) are located stratigraphically above the Judith River and have significantly higher quality water. The Judith River provides water for livestock use near the cities of Wolf Point and Glasgow. However, there are no known drinking water wells producing from the Judith River near any injection wells located in the eastern half of the Reservation.

Although there is no current domestic use of the Judith River aquifer in the eastern half of the reservation, the UIC regulations still afford protection of aquifers which exhibit fewer than 10,000 mg/l TDS. Based upon this authority, EPA adopts the policy to prohibit new injection wells into the Judith River where it is defined as a USDW. By doing so, EPA recognizes the concerns of the Tribe that the Judith River Formation be preserved for future use.

POLICY STATEMENT NO. 2

It is concluded that the Judith River Formation in the Deadman's Coulee and Poplar Fields located to the east, is not now, nor was it prior to injection activities, a USDW. The Judith River is also confined from overlying USDWs by 800 to 1,000 feet of shale. The existing injection wells in these fields will be authorized to continue injecting into the Judith River Formation as long as compliance with appropriate EPA rules and permits is maintained. The following injection wells have pending permit applications:

EPA PERMIT	WELL NAME	FIELD	OPERATOR
MTS21PR-0003	Goings No. 1	Poplar	Century Oil & Gas
MTS21PE-0009	Buck Elk No. 2	E. Poplar	Grace Petroleum
MTS21PE-0023	EPU 8-D	E. Poplar	Murphy Oil
MTS21PE-0024	EPU 29-D	E. Poplar	Murphy Oil
MTS21DM-0034	Allotted Hall	Deadman's Coulee	Reading & Bates

Discussion and Basis of Decision

Little water quality data are available for the Judith River Formation in the areas where most of the injection wells are located. However, a water analysis of a sample taken (prior to injection) from the Allotted Hall salt water disposal well, Deadman's Coulee Field, showed a TDS concentration greater than 10,000 mg/l. This sample was found to be reliable, based upon evaluation of the sampling technique. It is known that the formation downdips to the east and that TDS quality of the Judith River Formation increases from west to east. Therefore, the Judith River underlying the Poplar Field would also not qualify as a USDW.

Testimony presented by the Tribe asserted that injection fluids in the Poplar field may be forced to migrate updip and to the west (possibly to the far western edge of the Reservation) due to the fact that the Judith River Formation becomes pinched off by the Bearpaw Shale in the eastern portion of the Reservation. Pressure buildup effects, extending up to eight miles, may influence the natural ground water flow pattern. However, from evaluation of the data, ground water flow reversal is not likely to exceed more that two miles from any wellbore.

A more significant impact, than a reversal in ground water flow, is likely to be a flattening of the pressure gradient in the Judith River Formation. This may indirectly affect the residence time of the native fluids migrating west to east thereby increasing the TDS concentration, however, it is not possible to estimate any direct impacts.

POLICY STATEMENT No. 3

Existing injection wells, in fields other than Deadman's Coulee and Poplar, will be allowed to continue injection activities so long as: 1) they maintain compliance with EPA rules and pending permit conditions, and 2) they do not inject more fluid than can be contained in that portion of the Judith River which has been exempted as a USDW. It is EPA's decision to limit injection in these fields to the existing 1/4-mile aquifer exemption radius. This will be done by limiting the life of individual injection wells through the permitting process.

The following wells have pending permit applications or operators have been requested to submit permit applications:

EPA PERMIT	WELL NAME	FIELD	OPERATOR
MTS21TC-0039	Lough No. 2	Tule Creek	Petro Lewis Corp.
MTS21TE-0035	Lillian 1-D	East Tule Creek	Murphy Oil
MTS21TC-0036	Sletvold	Tule Creek	Murphy Oil
MTS21LS-0038	Mann No. 1	Long Creek	Pennzoil
MTS21TC-0086	Phillips-McKee	Tule Creek	BHP Petroleum
?	Wetsit No. 1	East Benrud	Murphy Oil
?	Stai No. 1	East Benrud	Franks Petroleum
?	Courchene 1-D		Murphy Oil

Discussion and Basis of Decision

Other fields where injection into the Judith River Formation is occurring are the Tule Creek, E. Tule Creek, Benrud, E. Benrud, Volt, and Long Creek. These fields lie west/northwest of the Deadman's Coulee and Poplar Fields and there is evidence that the Judith River Formation here may have contained fewer than 10,000 mg/l TDS before injection practices began.

The UIC regulations specifically prohibit injection into USDW's unless the aquifer is exempted. An aquifer exemption may be granted by EPA, and essentially allows injection into a formation which would otherwise be classified as a USDW but which is not likely to serve as a source of drinking water. All of the wells injecting into the Judith River Formation were granted aquifer exemptions for 1/4 mile radius from the wellbore at the inception of the UIC program in Montana on June 25, 1984. Notice of these aquifer exemptions was published in the FEDERAL REGISTER on _____.

Using Judith River Formation characteristics and operating parameters for all the wells, calculations were done to determine the extent of formation fill-up from salt water disposal practices. These calculation are an estimate of how far the injection fluids have traveled from each wellbore. A factor of 25 percent was used in the calculations to safely accomodate uncertainty and pore volume inaccessibility to injected fluids. 15 and 20%

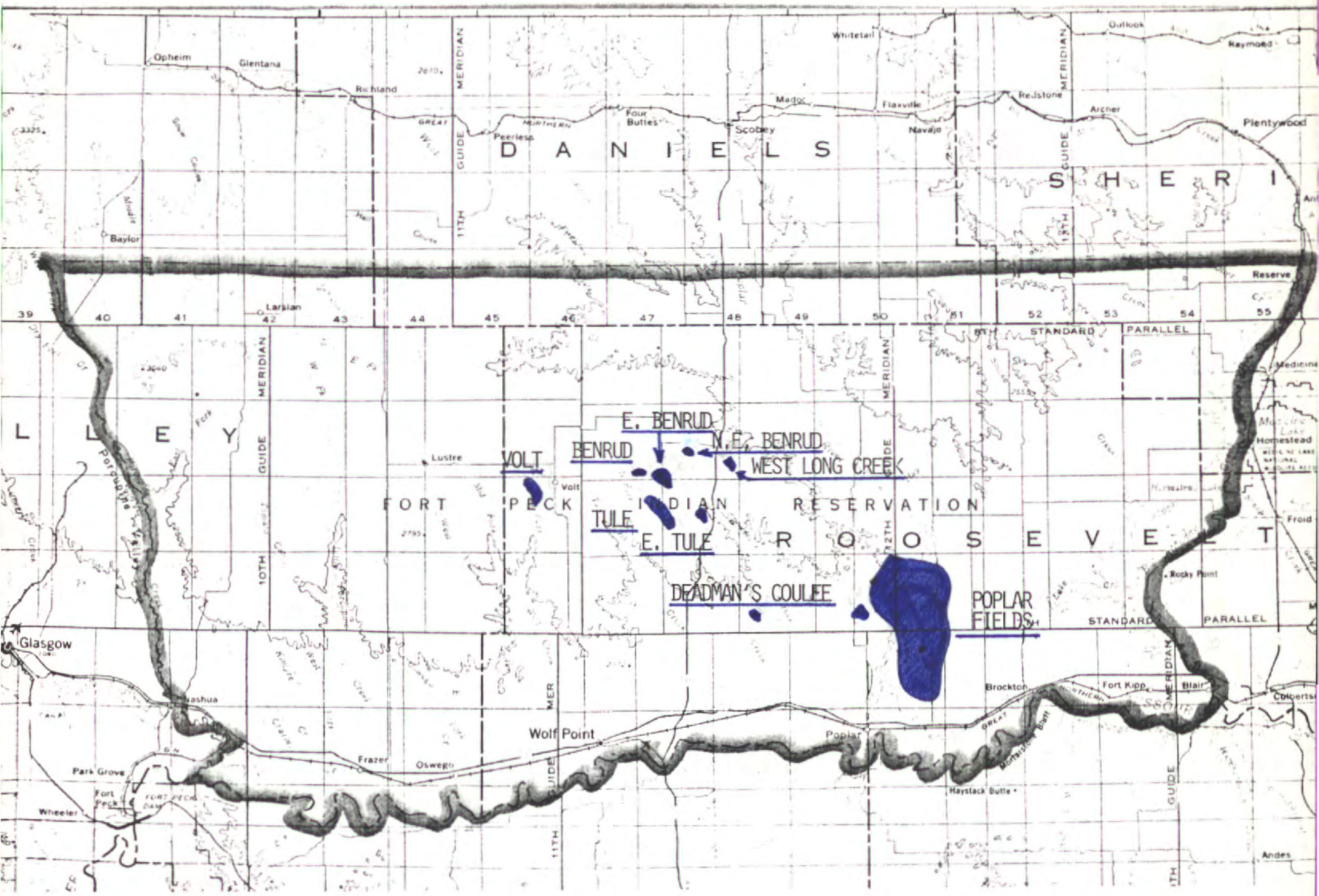
In certain instances, injection wells have already surpassed the fillup volume allowed by their authorized 1/4-mile aquifer exemptions. Permits for these wells will be denied and the operator will be required to properly plug and abandon the wells.

FOR MORE INFORMATION

EPA's technical evaluation report and the transcript of the hearing are available for inspection at the following locations:

Environmental Protection Agency
Region VIII
Drinking Water Branch 8WM-DW
One Denver Place, Suite 1300
999-18th Street
Denver, Colorado 80202-2413
Telephone: (303) 293-1415

Environmental Protection Agency
Montana Office
Federal Office Building
Drawer 10096
301 South Park
Helena, Montana 59626
Telephone: (406) 449-5486


D A N I E L S
S H E R I
L L E Y
R O O S E V E L T
FORT PECK INDIAN RESERVATION
E. BENRUD
N.E. BENRUD
BENRUD
WEST LONG CREEK
VOLT
TULE
E. TULE
DEADMAN'S COULEE
POPLAR FIELDS
Opheim
Glentana
Richland
Peerless
Four Buttes
Scobey
Madoc
Flaxville
Navajo
Whitetail
Redstone
Outlook
Raymond
Archer
Plentywood
Reserve
Baylor
Larslan
Lustre
Volt
Medicine Lake
Homestead
Froid
Rocky Point
Glasgow
Nashua
Wolf Point
Frazer
Oswego
Park Grove
Fort Peck
Wheeler
Brockton
Fort Kipp
Blair
Poplar
Haystack Butte
Andes
STANDARD PARALLEL
GREAT NORTHERN
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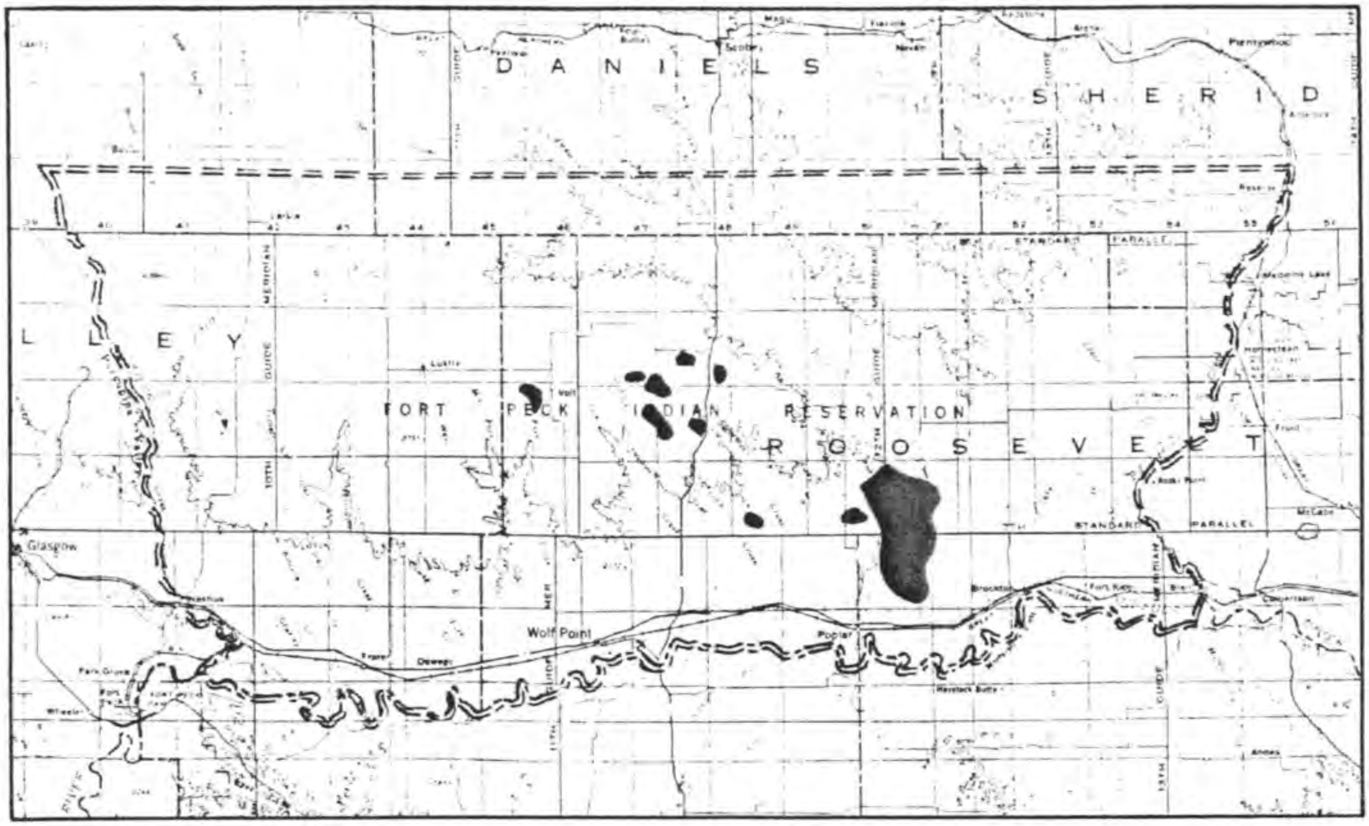
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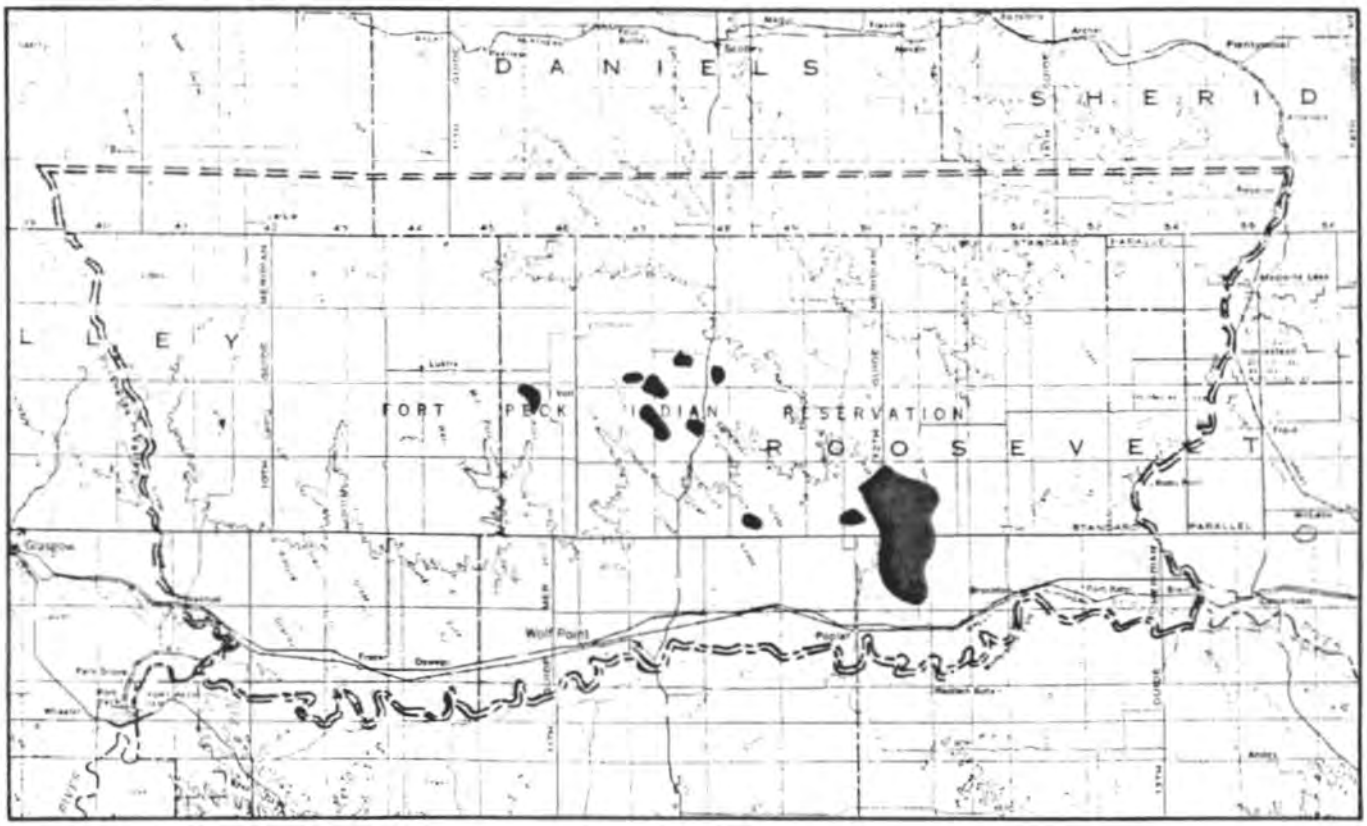
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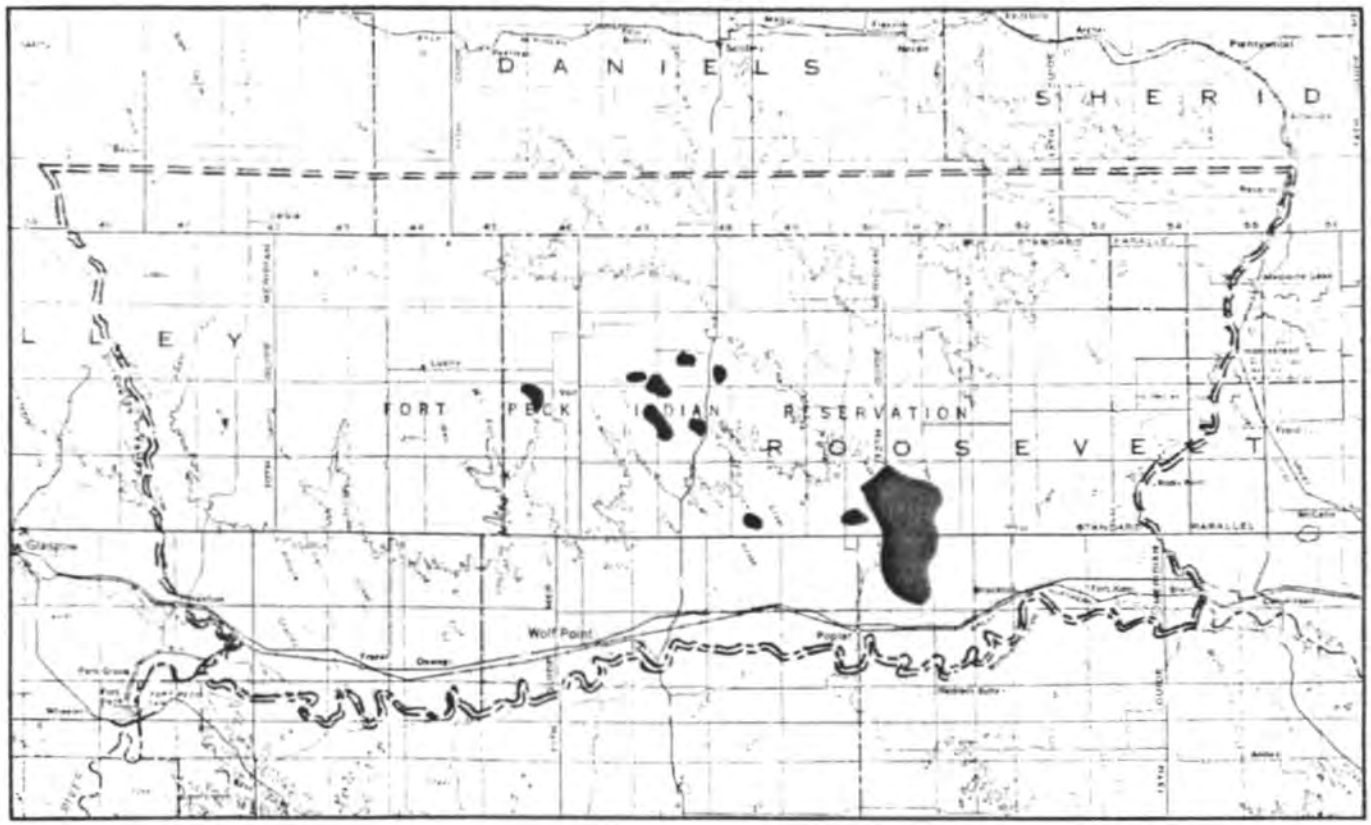
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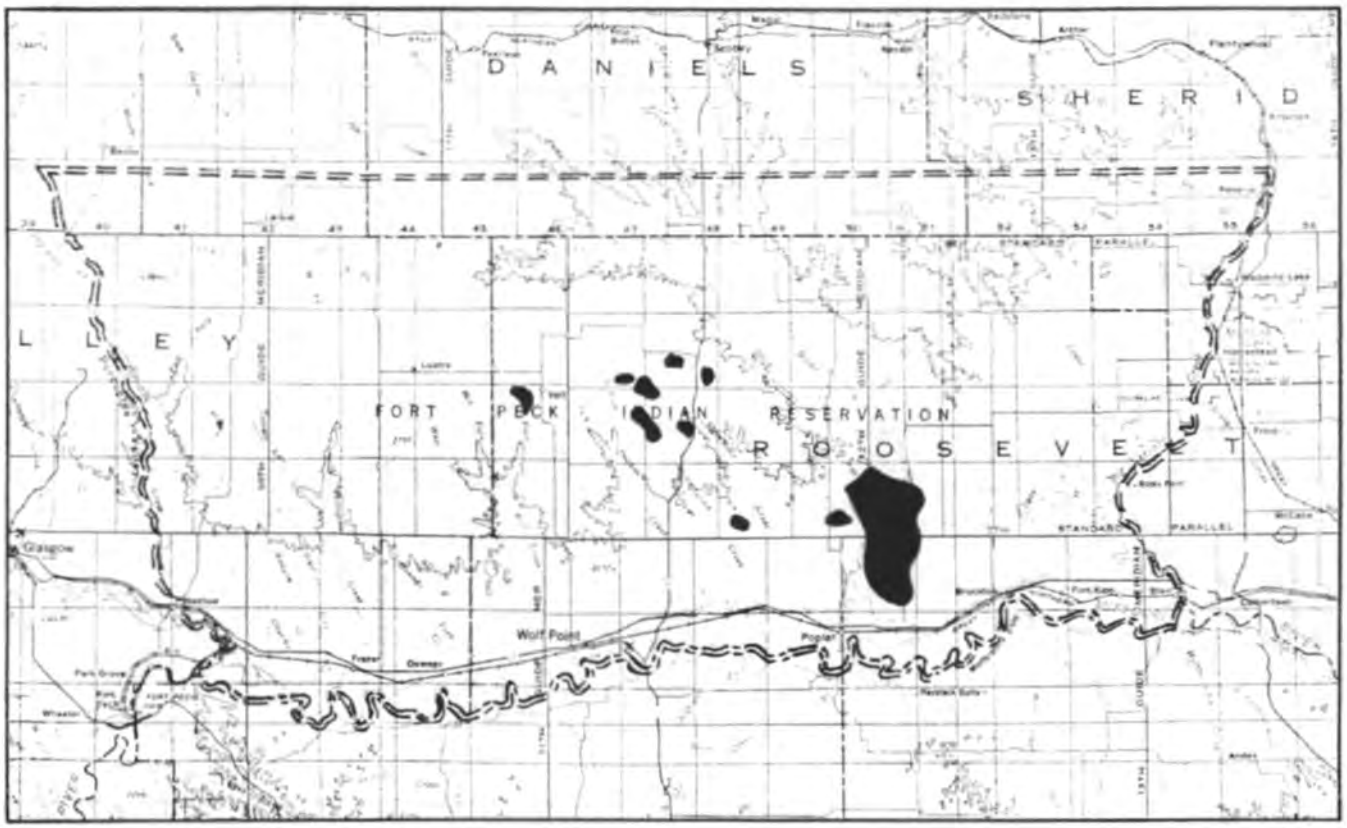
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RIVER

Review of Data Relating to Injection of Oil Field Brines
in the Area of the Fort Peck Indian Reservation

Paul S. Osborne
Regional Ground Water Expert

Debra Ehlert
Direct Implementation Team Leader

As requested, I have completed my review of the available data (attached as appendices) pertaining to Judith River injection activities. Figure 1 shows the Ft. Peck Indian Reservation and the fields which are the concern of this analysis. The data reviewed were related to the Judith River from west of Glascow, Montana to the eastern edge of the Reservation. My review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud Fields located within the Fort Peck Reservation. The questions to be addressed by my review are the following:

1. Are the aquifer exemptions of 1/4 mile radiis granted at the inception of the Underground Injection Control (UIC) program, adequate for the volumes of fluids injected?

2. What is the ambient quality of the Judith River aquifer over the entire Reservation? Is this even determinable?

3. Is the Judith River Formation sufficiently confined to prevent contamination of overlying underground sources of drinking water (USDW's)?

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is "pinched off" by the Bearpaw Shale on the eastern edge of the Reservation?

5. What alternative drinking water sources are there on the Reservation? Are data available so that an equal concentration (total dissolved solids (TDS)) contour map can be constructed (i.e., greater than 10,000 milligrams/liter (mg/l); less than 10,000 mg/l for other sources of drinking water)?

6. Based on the answers to questions 1-5, can it be concluded that the existing wells, if allowed to continue injection activities, <u>will not</u> cause future contamination problems?

My conclusions relating to the five issues are summarized in the next section followed by five sections which discuss each issue in greater detail.

<u>Summary</u>

The ~~Agency~~ U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation ~~that EPA~~ to prohibit further injections into the Judith River Formation. The Tribe alleged that continued injection would affect the

quality of water in the Judith River Formation such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Formation. This information and other available data were used in formulating the following conclusions.

1. Using the radius-of-formation-fillup and travel-time formulas (both based on radial flow), it appears that four existing wells have exceeded or will soon exceed their 1/4-mile aquifer exemptions. In fact, one well has probably directly impacted the reservoir 7 and 1/2 miles from the well. Any permits should be evaluated to determine if a 1/2 mile radius of exemption is needed.

2. It is not possible to draw TDS contours of the ambient water quality for the Judith River Formation over the entire Reservation. There is very little reliable data on which a contour map could be based. Data from water wells on the west side of the Reservation, a water well at Wolf Point, and a drill stem test, indicate that TDS concentrations increase from east to west. These data indicate that the Judith River Formation was a USDW in the vicinity of the Tule Field, TDS values in the Poplar Field were always in excess of 10,000 mg/l.

3. Based on ~~the~~ composition, thickness, and apparent low permeability of the Judith River Formation, ~~its thickness and its apparent low permeability, the~~ it appears that the Judith River is ~~appears~~ sufficiently confined to prevent fluid contamination of overlying USDW's.

4. Estimates of the radius of fillup indicate that even with dispersion, the direct impact for any given of the injected water will be limited to less than a 1/2 mile ~~of all~~ injection wells reviewed. This will create a limited amount of east to west fluid migration ~~because of~~ due to the mounding effect caused by the injection and subsequent displacement of existing reservoir water back to the west.

5. ~~The indirect impacts of~~ Injection into the Judith River Formation in the Poplar Field could have a significant impact to the west because of the far reaching pressure effects.

Fluid P~~P~~ressure buildup estimates indicate that significant ~~fluid~~ pressure effects could extend beyond a five mile radius. While this may not result in westward fluid migration as far as five miles, it will result in a flattening of the preinjection gradient. This will result in increased travel times of native water moving west to east, which should result in an increase in TDS.

6. Calculations using the existing injection pressures obtained from data supplied by Larry Monsen, indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which exceed a fracture gradient of 0.75 pounds per square inch (psi/ft). Three wells in the Poplar Field area are injecting at pressures in excess of 1.0 psi/ft.

7. The principal sources of drinking water in the vicinity of the oil fields, where injection into the Judith River Formation is occurring, are the alluvium and glacial gravels. There are also several areas which receive supplies from bedrock aquifers of limited areal extent, such as the Fox Hills. There is insufficient data to draw either TDS contours or the extent of the aquifers in question.

8. Available data indicate that the Judith River Formation in the vicinity of the Volt and Tule Fields is a USDW. Continued injection in these fields will increase the size of the presently impacted area, therefore, limiting injection to the existing 1/4 mile aquifer exemption should be considered when establishing the life of the wells. Continued injection in the Poplar Field may have little impact on the aquifer to the west of the field, but there may be some indirect impact caused by a flattening of the gradient between the Poplar Field and the various fields to the west.

1. Are the aquifer exemptions of 1/4 mile, granted ~~for existing wells~~ at the inception of the UIC program, adequate for the volumes of fluids injected?

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is a given distance, r, away. The formula, derived by integrating the equation for the average velocity through porous material, is given as:

$$t = \frac{// \; O \; br2}{Q}$$

Where:

O = porosity of reservoir
b = thickness of reservoir (ft)
r = distance from injection well (ft)
Q = injection rate (ft ^{3}/day)
t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;
b. the reservoir thickness is uniform;
c. the effect of the regional flow gradient on the plume is negligible;
d. the porosity is uniform; and
e. there are no dispersion effects.

(Feltis, 19--)

The primary variables in calculating travel time are the porosity and ~~the~~ thickness of the formation. In the case of the Judith River, the porosity varies from 10 to 20%, ~~according to Feltis.~~ ¶A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N, R5OE. This log indicated an average porosity of about 16.5%. Several other experts with knowledge of the Judith River, however, indicate that a porosity of less than 15% should be expected in much of the formation (Marvin Miller, Personal Communication).

Spatial

within

The thicknesses of the sand units in the Judith River Formation underlying the Reservation are quite variable, ranging from less than 10 feet to about 125 feet. The sandstone generally occurs in two discrete units which are separated by claystones. A analysis of a map showing cumulative thickness of sandstone in the Judith River Formation (prepared by Larry Monson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek Fields and the Poplar Field. ~~The rate of~~ changes in ~~the~~ sandstone thickness ~~in~~ each of the given fields, however, is small enough to base travel-time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, ~~the~~ sand thickness was estimated using the total sum of the perforated intervals. The values obtained correlate well with the map of Judith River sand thickness. In most cases the perforated intervals encompass all the available sand.

need paragraph

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells. This assumes that the injection rate was continuous and constant. The radii of interest are 1,000 feet and 2,640 feet. The 1,000 foot radius was chosen so that a buffer zone could be allowed. As indicated, the travel time increases rapidly as the radius increases. Travel time is also influenced by the direct relationship with porosity, doubling of porosity will double the travel time. The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene, the Svetvold B1, the Attotted Hall SWD, the Goings 1, the Reynolds EPU 8, the Biere 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1, the Svetvold B1, and the Buck Elk 2 have already injected for at least 15 years.

?

need paragraph

An alternative means of estimating ~~the extent of the reservoir which is impacted by injected fluids is to calculate the "radius of fillup"~~. This radius defines the extent of a cylinder of reservoir rock which would be filled by the fluids which have been injected to date. The equation to calculate this radius is given as:

the impact of injected fluids upon a reservoir is to calculate the "radius of fillup".

INSERT EQUATION (Page 4 of draft)

Where:

r_f = radius of fillup (ft);
W = total injected volume (barrels);
O = porosity;
b = sand thickness (ft); and
5.615 = conversion factor (ft.^{3}/bbl).

This ~~radius~~ value can be used to calculate the size of the cylinder of reservoir rock to be filled by the total injected fluid volume.

The use of this equation assumes that:

a. flow is radial;
b. reservoir thickness is constant;
c. existing flow gradient does not affect plume movement; and
d. there are no dispersion effects.

This equation is sensitive to both the change in volume and the change in porosity. The porosity is most important in that an increase in porosity will cause a decrease in the radius of impact. Using a high value for porosity will provide a sense of the minimum size of the area of impact. The results that appear in Table 2 were obtained by assuming a porosity of 15% and no dispersion.

As is indicated by the results, injection in several wells has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Svetvold B1, the Reynolds EPU-8, the Biere 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a short time.

Too vague

As mentioned previously ,the radius of reservoir fillup does not take into account dispersion. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972), which is given by:

$$r' = r + 2.3\ D \times r$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);
r = calculated radius of fillup with no dispersion (ft);
D = dispersion coefficient (ft).

This equation estimates the point at which the injection front possesses a chemical concentration of 0.2% of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of three feet for sandstone while the value for a vuggy limestone would be 65 feet.

2. Table says 15%

Table 3 shows the calculated radius of fillup with and without dispersion, assuming a porosity of 20%. This gives a reduction in the radius of fillup shown in Table 2 by a maximum of 150 feet. The table also shows the estimates for calculating the radius of the injected front using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2, which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

Based on the analysis of the data, it is clear that if portions of the aquifer, where injection is occurring, are determined to be ~~a USDW,~~ USDW's the exempted areas will need to be expanded. Given the fact that flow will not be radial because of: the geologic structure; the fluid density differences; and the existing gradient, I would recommend that the area of exemption be at least 1/2 mile. There are, however, 4 operating wells which would need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Allotted Hall SWD, and Courchene 1.

In summary, there are wells in the Poplar Field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, there is a well in the Volt Field and a well in Deadman's Coulee Field which have exceeded the 1/4 mile radius. When these four wells are permitted, any exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be ~~carefully~~ evaluated using ~~the~~ radius of fillup calculations ~~for the life of the well~~ to estimate the potential size of the exempted area.

2. What is the ambient quality of the Judith River aquifer over the entire Reservation? Is this even determinable?

laterally

The Judith River Formation consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally, beds of coal and carbonaceous shale occur, such as that encountered in wells on the western edge of the Reservation near Glascow, Montana. Individual beds of sandstone or shale are not always continuous either in thickness or character, and consequently the sequence of alternating types of rock differs ~~from place to place.~~ ¶ The number of sandstone beds and the distance of such beds below the top of the Judith River Formation is not the same in all localities. Generally, there are two major sandstone layers in the formation on the west side of the Reservation. The Judith River Formation (400 to 100 feet thick on the Reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the Poplar Field area. The Judith River Formation outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a limited amount of data on the water quality and the hydrology of the Judith River Formation. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Formation, the direction of ground-water flow is most likely from the west to the east and southeast. Water quality data indicate an increase in TDS from west to east. Although Judith River water quality is marginal for drinking, it is used in the western portion of the Reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/l in a well in T34N, R40E, to more than 18,000 mg/l in a well in T29N, R51E.

As can be seen in the values of TDS, there is a great deal of variation within given areas. This may reflect poor "quality assurance" in either the sampling or analysis. This is especially true of the data obtained by drill stem tests. For instance, the sample from the Courchene 1-D had a calculated TDS of about 15,000 mg/l. The sample was not clear, indicating that some contamination may have been present. Additionally, this sample does not compare with the data from the wells at Wolf Point, which have TDS values of less than 4,000 mg/l.

The Wolf Point wells are about six miles east and 15 miles south of the Courchene well (Tule Field). Given the apparent west to east flow, it is difficult to postulate why the quality would have so much variability in a north-south direction.

For purposes of this evaluation, the data obtained from DST samples were considered to be output, except where documentation indicated a valid sample. The apparently valid data verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29N, R48, 49, and 51E do not match with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the formation.

Ignoring the samples marked questionable, it can be intimated that the TDS increases from about 4,000 mg/l in T27N, R47E to about 11,000 mg/l in T28N,R50E (a distance of 10 to 15 miles). Water quality data from the Poplar Field support a finding that the TDS has always been in excess of 10,000 mg/l.

Data from several electric logs were used to estimate the TDS in several oil wells drilled in various parts of the Reservation. These estimates were made using Archie's law:

$$R_W = R_O/F$$

Where:

R_W = resistivity of the formation water;
R_O = resistivity of the formation including the water it contains (obtained from log);
F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empirical constant which depends on formation characteristics such as porosity. In the Judith River case the Formation Factor was estimated using the electric log and the actual value of TDS from the Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follow:

BHT = 168°F
R_W (at 168°F) - 0.24 (from Welex charts on salinity)
TDS = 11,000 mg/l
R_O = 3.0 ohm-m (from log)
F = Ro/Rw = 3.0/0.24
F = 12.5

The Formation Factor was used to estimate the TDS content of the Judith River, using logs run on several wells along an east-west line. Table 5 gives the information from the logs and the resulting estimates of total dissolved solids. These estimates indicate that the TDS content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E), which has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east, such that wells about 16 miles to the northeast have a TDS in excess of 10,000 mg/l. It is important to note, however, that calculations using the Formation Factor are questionable at best because of the lack of reliable quality data and good electric logs.

In summary, existing data indicate that the Judith River Formation is a USDW on the western edge of the Reservation and the TDS of the water in this formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Allotted Hall SWD well in Deadman's Coulee Field (supported by documentation indicating that the sample was representative) indicate that this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not a USDW. The areas underlying the Volt, Tule, and Benrud Fields however, may have been USDW's prior to injection.

3. Is the Judith River aquifer sufficiently confined to prevent contamination of overlying USDW's?

The Judith River Formation on the Fort Peck Reservation is overlain by the Bearpaw Shale, which also dips from west to east. The western margin of the Bearpaw is located west of Glascow, Montana. The depth to the Judith River Formation on the Reservation ranges from about 500 to about 1,300 feet. This depth to the Judith River is dependent on the geologic structure and the surface topography. The Judith River Formation is at shallow depths in the East Poplar Field because of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Formation is shallowest on the western edge of the Reservation.

The Bearpaw Shale is a gray marine shale, ~~which is~~ sandy in the upper portions, and ~~The Bearpaw~~ is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the fallowing practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content ranging from 5,000 to 70,000 mg/l.

Available well data indicate that the Judith River aquifer is under confined conditions such that wells flow at the surface. For instance, two wells located near Wolf Point were under flowing condtions in 1947. Surface pressures measured in the Poplar and Tule Fields are as high as 900 psi. While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection, wells in the oil fields would probably flow at the surface.

However

~~An~~ A analysis of ~~the reported~~ injection pressures, ~~contained in the information~~ submitted by Larry Monson, indicates that many of the existing wells are presently injecting at pressures which may exceed the fracture pressure of the formation. No data on actual fracture pressure of the Judith River aquifer is available. Although one operator indicated that the fracture gradient was 1.25 psi/ft, no documentation was provided to verify this claim.

It is unlikely that the fracture gradient of the Judith River exceeds 1.0 psi/ft. Even if the reservoir is fractured, the overlying shales may be of sufficient thickness to prevent fractures such that fluid will migrate into USDW's overlying the 800 to 1,000 feet of shale. Field studies have shown that injection energy dissipates rather quickly once the fractures move out of the reservoir. The fracturing of the reservoir on the other hand could present a problem. It will provide discreet zones of high permeability which will provide avenues for injected fluid to move further from the well than estimated by the radial flow calculations.

Based on the thickness and low permeability of the Bearpaw Shale, combined with the evidence that the Judith River is under confined conditions, it appears that the Bearpaw Shale is adequate to prevent movement out of the confining zone. This may depend however, on the actual fracture gradient of the Judith River Formation and the Bearpaw Shale. Although injection activities will have some impact on the pre-injection flow patterns of the Judith River Formation, there is inadequate data to develop a map to show these actual flow patterns. In order to develop such a map, it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the Reservation?

As discussed previously, the Judith River Formation dips from west to east towards the Williston Basin. This formation outcrops at the surface near the Milk River, West of Glascow and is considered to be a significant location for recharge to the Judith River. The pre-injection flow pattern was probably west to east, with a southern component of flow, especially in the Poplar Dome area.

The dip of the Judith River increases east of the Dome due to the presence of the Williston Basin, which is a deep synclinal trough.

Available logs and cross sections indicate that the depth of the Judith River increases by 900 feet between a well in Section 29, T29N,R50E and a well in Section 35, T29N, R52E, which is a distance of about 10 miles.

The sand units in the Judith River also thin from thicknesses of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29W, R55E, however, shows a Judith River Sand thickness of about 100 feet. Based on this data it is clear that the Judith River has good sand present well out into the basin. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River and its discharge zones.

Data on the permeability and porosity of the Judith River Sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcies (MD) was reasonable. Marvin Miller, of the Montana Bureau of Mines, indicated that an analysis of limited DST data indicated a range of permeabilities from 55 MD to 109 MD. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$Pr = Pi + (70.6 \times \frac{Q \times U \times B}{K \times b} \quad E \frac{39.5\ O \times U \times C \times r2}{K \times t}$$

where:

P_r = Pressure at a given radius (psi);
P_i= Initial pressure (psi);
Q = Constant injection rate (barrels/day);
B = Formation volume factor = 1;
c = compressibility (psi $^{-1}$) = 7.5×10^{-6};
U = viscosity (cp) = 1;
K = permeability (MD);
b = thickness of reservoir (ft)
O = porosity
E = Exponential integral

For purposes of this evaluation of pressure buildup, the following is assumed:

a. flow is radial;
b. the initial pressure is zero;
c. well interference is not taken into account;
d. porosity and thickness are constant;
e. the well is fully penetrating;
f. the radius of the injection well is assumed to be 0.5 ft.; and
g. the injection rate is estimated using the total volume injected since a given well began operation and assumes the rate was constant.

① should R values in table be 0.5 FT"?

what does this mean?

** Table 6 and 7 are reversed **

15%

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 MD and a porosity of ~~0.15%~~. The table also lists the current measured well-head pressure. As indicated in the table, the estimated pressure buildup lies on both sides of the measured values. Generally, the estimates were not greatly divergent from measured values.

② where is current measured well-head pressure?

The results provide a qualitative measure of the possible variations of permeability. The largest divergence was in the EPU-8 well and the Allotted Hall SWD well. This divergence may be caused by a higher permeability value than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed.

Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles, assuming permeabilities of 55 MD and 109 MD. The pressure buildups at the wells are more realistic than those estimated assuming a permeability of 25 MD. This is especially true in light of the fact that there was an initial positive formation pressure in the field, which was assumed to be zero for purposes of these calculations. The important point of these estimates is that all wells are causing significant pressure increases several miles from the well.

The data presented in Tables 6 and 7 indicate that injection in the Poplar Field has created significant pressure changes around the wells, which will reach at least 5 miles to the east and west. The pressure mound will be elongated in a north and south direction because of the interference effects of several injection wells which lie in a north-south line over a distance of about 8 miles. It is my judgement that this pressure mound has influenced the ground-water flow pattern of the Judith River. This disruption will most likely cause more flow to the ~~S~~south, although some increased ground-water flow to the North will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this ground water flow reversal is not possible to estimate, although it is probably less than one or two miles.

A point of note is that the injection pressure, in feet of water, in the Tule Field is about 100 feet higher than that in the Poplar Field. This indicates that the overall gradient is still to the east. The large injection pressures in the Poplar Field will however, result in a flattening of the gradient betwen the Tule and Poplar Fields.

Any direct water quality impact due to injected water will be less than one mile to the west based on estimates for the radius of fillup. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality impact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

Table 4

Total Dissolved Solids Content of Samples from the Judith River Formation

Location	Total Depth (ft)	Sample Date	TDS (mg/liter)	Remake
Sec. 6,T27N,R40E	495	1978	2802	
Sec. 31,T28N,R40E	555	1978	2126	
Sec. 11,T34W,R40E	405	1982	1444	
Sec. 31,T36N,R90E	1700	1971	2303	
Sec. 14,T26W,R41E	936	1947	2419	
Sec. 2,T27N,R41E	695	1978	2724	
Sec. 30,T28N,R41E	454	1978	2851	
Sec. 35,T28N,R41E	685	1978	2765	
Sec. 34,T27N,R44E	1090	1947	4133	
Sec. 15,T27N,R47E	985	1947	3862	
Sec. 22,T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15,T30N,R48E	1411	1964	15,602	DST (?)
Sec. 13,T28N,R50E	874	1954	11,475	DST
Sec. 19,T29N,R51E	877	1957	18,624	DST (?)
Sec. 15,T30N,R49E	1600	1964	16,653	DST (?)
Sec. 24,T36N,R52E	1940	1957	10,385	DST
Sec. 4, T30N,R46E	1432	1965	15,056	(?)
Sec. 29,T29N,R49E	1270	1982	11,323	DST

Table 5

Estimates of TDS Using Resistivity

need units

Name	Location	BHT	Ro	Rw	TDS
#1 Gess	Sec. 1, T30N,R463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15,T31N,R42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30T31N,R45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30T31NR44E	165°F	6	0.48	5500
C. Reddig #2	location	165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7,T30N,R46E	155 °F	7.5	0.6	4400
Clark #1-MA	Sec. 4,T29N,R49E	168 °F	3.0	0.28	9500

* Note: It was not possible to determine which track was the deep focused R value. The 2nd track had a large value of R.

what is a track?

Table 8

Total Dissolved Solids Content of Aquifers Overlying the Judith River Formation-Fort Peck Indian Reservation

Well Location	Aquifer	~~Total Dissolved Solids~~ TDS (mg/l)
Sec. 28,T29N,R46E	Alluvium	592
Sec. 10,T29N,R51E	Alluvium	809
Sec. 36, T30N,R55E	Alluvium	less than 1,000
Sec. 5, T29N,R51E	Alluvium	704
Sec. 32,T30N, 355E	Fort Union	less than 1,000
Sec. 25,T30N,R45E	Fox Hills	300
Sec. 19, T28W, R53E	Hell Creek	2,540
Sec. 13, T28N,R58E	Fort Union	less than 500
Sec. 34,T31N,R57E	Till	less than 1,000
Sec. 28,T31N,R57E	Fort Union	less than 1,500
Sec. 33,T33N,R44E	Alluvium	295
Sec. 29,T27N,R51E	Alluvium	1503
Sec. 3, T27N,R49E	Alluvium	980
Sec. 25, T28N,R53E	Alluvium	2788
Sec. 2, T30N,R46E	Flaxville	329

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5. <u>What alternative water sources are there on the Reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/l, less than 10,000 mg/l for other sources of drinking water)?</u>

Although the Judith River Formation does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Formation. The major sources are alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the TDS content of water from a representative sample of wells tapping the major water sources.

As indicated, the water quality of the alluvium and the Fox Hills is generally excellent. Note: a complete listing of wells (for which water quality data is available is attached as Appendix 1). Some alluvial wells have TDS contents in excess of 1,000 mg/l but most have TDS contents of less than 1,000 mg/l. The TDS content of water from the Fort Union is somewhat higher, but then water from the alluvial aquifers is usable for domestic purposes.

Data on the areal extent of the shallow aquifers is not available. It is apparent, however, that most of the alluvial and outwash deposits are as limited in their areal extent, as are the Fort Union and Fox Hills Formations in their subsurface extents. They are not present over the western portion of the Reservation. The Fort Union Formation apparently extends only as far west as the Poplar Field.

Because of the absence of good maps showing the extent of the various aquifers, it is not possible to develop a map with TDS concentration contours. It is clear, however, that all of the shallow aquifers qualify as USDW's and are the major sources of drinking water in the area. It is worth noting that the major threat to the shallow aquifers in the vicinity of the oil fields appears to be poor surface waste handling practices.

when writing a technical report, ~~the~~ a new topic should <u>not</u> and <u>never</u> be brought up in the last sentence of the text.

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Review of Data Relating to Injection of Oil Field Brines in the Area of the Fort Peck Indian Reservation

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U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation to prohibit further injections into the Judith River Formation (Fm.). The Tribe alleged that continued injection would affect the quality of water in the Judith River Fm. such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Fm.

A review of the available data (attached as appendices) pertaining to Judith River Fm. injection activities has been completed. Figure 1 shows the Fort Peck Indian Reservation and the fields which are the concern of this analysis.

? The data reviewed were related to the Judith River Fm. from west of Glasgow, Montana to the eastern edge of the Reservation. The review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud Fields located within the Fort Peck Reservation. The questions to be addressed by this report are the following:

1. Are the aquifer exemptions of 1/4 mile radii granted at the inception of the Underground Injection Control (UIC) program, adequate for the volumes of fluids injected?

2. What is the ambient quality of the Judith River Fm. over the entire Reservation? Is this even determinable?

3. Is the Judith River Fm. sufficiently confined to prevent contamination of overlying underground sources of drinking water (USDW's)?

4. Is fluid migration (east to west) a real possibility given that the Judith River Fm. is "pinched off" by the Bearpaw Shale on the eastern edge of the Reservation?

5. What alternative drinking water sources are there on the Reservation? Are data available so that an equal concentration (total dissolved solids (TDS)) contour map can be constructed (i.e., greater than 10,000 milligrams/liter (mg/l); less than 10,000 mg/l for other sources of drinking water)?

6. Based on the answers to questions 1-5, can it be concluded that the existing wells, if allowed to continue injection activities, <u>will not</u> cause future contamination problems?

Conclusions relating to the five issues are summarized in the following section. This is followed by a section of detailed discussions of each issue.

SUMMARY AND CONCLUSIONS

This information and other available data were used in formulating the following conclusions.

1. Using the radius-of-formation-fillup and travel-time formulas (both based on radial flow), it appears that four existing wells have exceeded or will soon exceed their 1/4-mile aquifer exemptions. In fact, one well has probably directly impacted the reservoir ~~seven~~ a distance of almost one half ~~and a half (7 & 1/2)~~ miles from the well. Any permits should be evaluated to determine if the 1/4 mile radius of exempted aquifer is adequate.

2. It is not possible to draw TDS contours of the ambient water quality for the Judith River Fm. over the entire Reservation. There is very little reliable data on which a contour map could be based. Data from water wells on the west side of the Reservation; a water well at Wolf Point; and a drill stem test, indicate that TDS concentrations increase from east to west. These data indicate that the Judith River Fm. was a USDW in the vicinity of the Tule Field; TDS values in the Poplar Field were always in excess of 10,000 mg/l.

3. Based on composition, thickness, and apparent low permeability of the Bearpaw Shale Fm., it appears that the Judith River Fm. is sufficiently confined to prevent fluid contamination of overlying USDW's.

4. Estimates of the radius-of-fillup indicate that even with dispersion, the direct impact of the injected water will be limited to less than a 1/2 mile for any given injection well reviewed. This will create a limited amount of east to west fluid migration due to the mounding effect caused by the injection and subsequent displacement of existing reservoir water back to the west.

5. The INDIRECT impacts of injection into the Judith River Fm. in the Poplar Field could have a significant impact to the west because of the large pressure buildup in the field since injection was initiated. Fluid pressure buildup estimates indicate that significant pressure effects could extend beyond a five mile radius. While this may not result in westward fluid migration as far as five miles, it will result in a flattening of the preinjection gradient. This will result in increased travel times of native water moving west to east, which should result in an increase in TDS.

6. Calculations using the existing injection pressures, obtained from data supplied by Larry Monson, indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which exceed a fracture gradient of 0.75 pounds per square inch (psi/ft).

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7. The principal sources of drinking water in the vicinity of the oil fields, where injection into the Judith River Fm. is occurring, are the alluvium and glacial gravels. There are also several areas which receive supplies from bedrock aquifers of limited areal extent, such as the Fox Hills. There is insufficient data to draw either TDS contours or the extent of the aquifers in question.

The data re

8. Available data indicate that the Judith River Fm. in the vicinity of the Volt and Tule Fields was a USDW prior to injection activities. Continued injection in these fields will increase the size of the presently impacted area, therefore, limiting injection to the existing 1/4 mile aquifer exemption should be considered when establishing the expiration dates of the permits. Continued injection in the Poplar Field may have little impact on the aquifer to the west of the field, but there may be some indirect impact caused by a flattening of the gradient between the Poplar Field and the various fields to the west.

DISCUSSION

1. Are the 1/4 mile aquifer exemptions for the given injection wells, granted at the inception of the UIC program, adequate for the volumes of fluids injected?

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is a given distance, r, away. The formula, derived by integrating the equation for the average velocity through porous material, is given as:

$$t = \frac{\pi \, \phi \, br^2}{Q}$$

Where:

ϕ = porosity of reservoir
b = thickness of reservoir (ft)
r = distance from injection well (ft)
Q = injection rate (ft ^{3}/day)
t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;
b. the reservoir thickness is uniform;
c. the effect of the regional flow gradient on the plume is negligible;
d. the porosity is uniform; and
e. there are no dispersion effects.

The primary variables in calculating travel time are porosity and thickness of the formation. In the case of the Judith River Fm., the porosity varies from 10% to 20%, (Feltis, 1982).

A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N, R50E. This log indicated an average porosity of about 16.5%. Other experts with knowledge of the Judith River Fm., however, indicate that a porosity of less than 15% should be expected in much of the formation (Marvin Miller, Personal Communication).

The thicknesses of the sand units in the Judith River Fm. underlying the Reservation are quite variable, ranging from less than 10 feet to about 125 feet. The sandstone generally occurs in two discrete units which are separated by claystones. Analysis of a map showing cumulative thickness of sandstone in the Judith River Fm. (prepared by Larry Monson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek Fields and the Poplar Field. Spatial changes in sandstone thickness within each of the given fields, however, is small enough to base travel-time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, sand thickness was estimated using the total sum of the perforated intervals. The estimates correlate well with the map of Judith River Fm. sand thickness. In most cases the perforated intervals encompass all the available sand.

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells. This assumes that the injection rate was continuous and constant. The radii of interest are 1/4 mile (1,320') and 1/2 mile (2,640'). A 1,000 foot radius was used for the calculations, instead of 1,320 feet, to allow a margin of safety. As indicated, the travel time increases rapidly as the radius increases. Travel time is also influenced by the direct relationship with porosity; doubling of porosity will double the travel time.

The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene 1-D, the Sletvold B1, the Allotted Hall SWD, the Goings 1, the Reynolds EPU 8, the Bierre 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1-D, the Sletvold B1, and the Buck Elk 2 have already injected for at least 15 years.

An alternative means of estimating the impact of injected fluids upon a reservoir is to calculate the "radius of fillup." This value can be used to calculate the size of the cylinder of reservoir rock to be filled by the total injected fluid volume. The equation to calculate this radius is given as:

$$r_f = \sqrt{\frac{(W)\ 5.615}{\pi\ )(b)(\phi)}}$$

Where:

r_f = radius of fillup (ft);
W = total injected volume (barrels);
0 = porosity;
b = sand thickness (ft); and
5.615 = conversion factor (ft^3/bbl)

The use of this equation assumes that:

a. flow is radial;
b. reservoir thickness is constant;
c. existing flow gradient does not affect plume movement; and
d. there are no dispersion effects.

This equation is sensitive to both the change in volume and the change in porosity. The porosity is most important in that an increase in porosity will cause a decrease in the radius of impact. Using a high value for porosity will provide a sense of the minimum size of the area of impact. The results that appear in Table 2 were obtained by assuming a porosity of 15% and no dispersion.

As is indicated by the results, injection in several wells has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Sletvold B1, the Reynolds EPU-8, the Bierre 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a year.

As mentioned previously, the radius of fillup equation does not take into account dispersion. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972), which is given by:

$$r' = r + 2.3\sqrt{(D)(r)}$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);
r = calculated radius of fillup with no dispersion (ft);
D = dispersion coefficient (ft).

This equation estimates the point at which the injection front possesses a chemical concentration of 0.2% of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of three feet for sandstone while the value for a vuggy limestone would be 65 feet.

Table 3 shows the calculated radius of fillup with and without dispersion, assuming a higher porosity of 20%. The increase in porosity of 5% does not affect the radius of fillup estimates shown in Table 2, by more than 150 feet. Table 3 also shows calculations of the radius of the injected front using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2, which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

Based on the analysis of the data, it is clear that the exempted areas are not sufficient in portions of the aquifer where injection is occurring and the TDS is less than 10,000 mg/l. Given the fact that flow will not be radial because of geologic structure, fluid density differences, and existing gradient, the impacted area of aquifer may be at least 1/2 mile. Based on calculations performed during this review, there are four operating wells which impact an area of the aquifer larger than 1/4 mile and which may need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Allotted Hall SWD, and Courchene 1-D.

In summary, there are wells in the Poplar Field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, a well in the Volt Field and a well in Deadman's Coulee Field have exceeded the 1/4 mile radius. When these four wells are permitted, any exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be evaluated using radius of fillup calculations for the proposed life of the well, in order to estimate the size of impacted area.

2. <u>What is the ambient quality of the Judith River Fm. over the entire Reservation? Is this even determinable?</u>

The Judith River Fm. consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally, beds of coal and carbonaceous shale occur, such as that encountered in wells on the western edge of the Reservation near Glasgow, Montana. Individual beds of sandstone or shale are not always continuous either in thickness or character, and consequently the sequence of alternating types of rock differs laterally.

The number of sandstone beds and the distance of such beds below the top of the Judith River Fm., are not the same in all localities. Generally, there are two major sandstone layers in the Judith River Fm. on the west side of the Reservation. The Judith River Fm. (400 to 100 feet thick on the Reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the Poplar Field area. The Judith River Fm. outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a limited amount of data on the water quality and the hydrology of the Judith River Fm. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Fm., the direction of ground-water flow is most likely from the west to the east and southeast. Water quality data indicate an increase in TDS from west to east. Although Judith River Fm. water quality is marginal for drinking, it is used in the western portion of the Reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/l in a well in T34N, R40E, to more than 18,000 mg/l in a well in T29N, R51E.

Table 4

Total Dissolved Solids Content
Samples from the Judith River Formation

LOCATION		TOTAL DEPTH (ft.)	SAMPLE DATE	TDS (mg/liter)	REMARKS
Sec. 6	T27NR40E	495	1978	2802	
Sec. 31	T28NR40E	555	1978	2126	
Sec. 11	T34WR40E	405	1982	1444	
Sec. 31	T36NR90E	1700	1971	2303	
Sec. 14	T26W,R41E	936	1947	2419	
Sec. 2	T27N,R41E	695	1978	2724	
Sec. 30	T28N,R41E	454	1978	2851	
Sec. 35	T28N,R41E	685	1978	2765	
Sec. 34	T27N,R44E	1090	1947	4133	
Sec. 15	T27N,R47E	985	1947	3862	
Sec. 22	T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15	T30N,R48E	1411	1964	15,602	DST *
Sec. 13	T28N,R50E	874	1954	11,475	DST
Sec. 19	T29N,R51E	877	1957	18,624	DST *
Sec. 15	T30N,R49E	1600	1964	16,653	DST *
Sec. 24	T36N,R52E	1940	1957	10,385	DST
Sec. 4	T30N,R46E	1432	1965	15,056	*
Sec. 29	T29N,R49E	1270	1982	11,323	DST

* Sampling methods were considered questionable and therefore, analytical results are invalid for purposes of this review.

As can be seen in the values of TDS, there is a great deal of variation within given areas. This may reflect poor "quality assurance" in either the sampling or analysis. This is especially true of the data obtained by drill stem tests. For instance, the sample from the Courchene 1-D had a calculated TDS of about 15,000 mg/l. The sample was muddy, indicating that some contamination may have been present. Additionally, this sample does not compare with the data from the wells at Wolf Point, which have TDS values of less than 4,000 mg/l.

The Wolf Point wells are about six miles east and 15 miles south of the Courchene 1-D well in the Tule Field. Given the apparent west to east flow, it is difficult to postulate why the quality would have so much variability in a north-south direction.

For purposes of this report, most of the data obtained from DST samples were considered to be questionable, except where documentation indicated a valid sample. The valid data verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29N, R48, 49, and 51E do not correlate with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the Judith River Fm.

Ignoring the samples that are questionable, it can be intimated that the TDS increases from about 4,000 mg/l in T27N, R47E to about 11,000 mg/l in T28N, R50E (a distance of 10 to 15 miles). Water quality data from the Poplar Field support a finding that the TDS has always been in excess of 10,000 mg/l.

Data from several electric logs were used to estimate the TDS in several oil wells drilled in various parts of the Reservation. These estimates were made using Archie's law:

$$R_w = R_o/F$$

Where:

R_w = resistivity of the formation water;
R_o = resistivity of the formation including the water it contains obtained from log);
F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empirical constant which depends on such formation characteristics as porosity. The Judith River Formation Factor was estimated using the electric log and the actual value of TDS from the Allotted Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follow:

R_w (at 168°F) = 0.24 (from Welex charts on salinity)
BHT = 168°F
TDS = 11,000 mg/l
R_o = 3.0 ohm-m (from log)
F = R $_o/R_w$ = 3.0/0.24
F = 12.5

The Formation Factor was assumed to be constant and Archie's Law was used to estimate the TDS content of the Judith River Fm. in several locations where R_o values ~~from~~ of the formation could not be obtained from well logs. Estimates were made for several location along an east-west line where electric logs run on production wells were available. Table 5 gives the information from the logs and the resulting estimates of TDS.

Table 5

Estimates of TDS Using Resistivity

NAME	LOCATION	BHT	R_o	R_w	TDS
#1 Gess	Sec. 1 T30NR463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15 T31NR42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30 T31NR45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30 T31NR44E	165°F	6	0.48	5500
C. Reddig #2		165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7 T30NR46E	155°F	7.5	0.6	4400
Clark #1-MA	Sec. 4 T29NR49E	168°F	3.0	0.28	9500

* Note: It was not possible to determine which track on the log was the actual R_o value. The 2nd track had a large value of R.

These estimates indicate that the TDS content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E), which has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east, such that wells about 16 miles to the northeast have a TDS in excess of 10,000 mg/l. It is important to note, however, that calculations using the Formation Factor are questionable at best because of the lack of reliable quality data and good electric logs.

In summary, existing data indicate that the Judith River Fm. is a USDW on the western edge of the Reservation. The TDS concentration of the water in the formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Allotted Hall SWD well in Deadman's Coulee field (supported by documentation indicating that the sample was representative) indicate that the portion of the Judith River Fm. in this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not now, and has probably never been, a USDW. The Judith River Fm. underlying the Volt, Tule, and Benrud Fields however, may have been a USDW prior to injection.

. <u>Is the Judith River Fm. sufficiently confined to prevent contamination of overlying USDW's?</u>

The Judith River Fm. on the Fort Peck Reservation is overlain by the Bearpaw Shale, which also dips from west to east. The western margin of the Bearpaw is located west of Glasgow, Montana. The depth to the Judith River Fm. on the Reservation ranges from about 500 to about 1,300 feet. This depth

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to the Judith River Fm. is dependent on the geologic structure and the surface topography. The Judith River Fm. is at shallow depths in the East Poplar Field because of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Fm. is shallowest on the western edge of the Reservation.

The Bearpaw Shale is a gray marine shale, sandy in the upper portions, and is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the fallowing practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content ranging from 5,000 to 70,000 mg/l.

Available well data indicate that the Judith River Fm. is under confined conditions such that wells flow at the surface. For instance, two wells located near Wolf Point were under flowing condtions in 1947. Surface pressures measured in the Poplar and Tule Fields are as high as 900 psi. While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection, wells in the oil fields would probably flow at the surface.

The reported injection pressures for wells injecting into the Judith River Fm. (Larry Monson, Fort Peck Mineral Resources), were used to calculate the present injection gradient for each well. These calculations indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which could exceed a fracture gradient of 0.75 psi/ft. Five wells are injecting at pressures in excess of 1.0 psi/ft. These are the Lough #2, the Allotted Hall SWD, the Goings #1, the Reynolds EPU-8, and the EPU 29-D. The Reynolds EPU-8 is injecting at the highest gradient (1.27 psi/ft).

No data on actual fracture pressure of the Judith River Fm. is apparently available. Although one operator indicated that the fracture gradient was 1.25 psi/ft, no documentation was provided to verify this claim. It is unlikely that the fracture gradient of the Judith River Fm. exceeds 0.8 psi/ft based on data from other reservoirs with similar charateristics. Even if the reservoir is fractured, the overlying shales may be of sufficient thickness to prevent fractures such that fluid will not migrate into USDW's overlying the 800 to 1,000 feet of shale. Field studies have shown that injection energy dissipates rather quickly once the fractures move out of the reservoir. The fracturing of the reservoir on the other hand could present a problem. It will provide discreet zones of high permeability which will provide avenues for injected fluid to move further from the well than estimated by the radial flow calculations. Additional data obtained from valid step rate tests should be used to justify injection pressures over 0.8 psi/ft.

Based on the thickness and low permeability of the Bearpaw Shale, combined with the evidence that the Judith River Fm. is under confined conditions, it appears that the Bearpaw Shale is adequate to prevent movement out of the injection zone. This may depend however, on the actual fracture gradient of the Judith River Fm. and the Bearpaw Shale. Although injection activities will have some impact on the pre-injection flow patterns of the Judith River Fm., there is inadequate data to develop a map to show these actual flow patterns. In order to develop such a map, it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the Reservation?

As discussed previously, the Judith River Fm. dips from west to east towards the Williston Basin. This formation outcrops at the surface near the Milk River, West of Glasgow and is considered to be a significant location for recharge to the Judith River Fm. The pre-injection flow pattern was probably west to east, with a southern component of flow, especially in the Poplar Dome area.

The dip of the Judith River Fm. increases east of the Dome due to the presence of the Williston Basin, which is a deep synclinal trough.

Available logs and cross sections indicate that the depth of the Judith River Fm. increases by 900 feet between a well in Section 29, T29N, R50E and a well in Section 35, T29N, R52E, which is a distance of about 10 miles.

The sand units in the Judith River Fm. also thin from thicknesses of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29W, R55E, however, shows a Judith River Fm. sand thickness of about 100 feet. Based on this data it is clear that the Judith River has definable sandstone layers present well out into the basin. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River Fm. and its discharge zones.

Data on the permeability and porosity of the Judith River Fm. sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcies (md) was reasonable. Marvin Miller, of the Montana Bureau of Mines, indicated that an analysis of limited DST data indicated a range of permeabilities from 55 md to 109 md. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$P_r = P_i + (70.6)\frac{(Q)(U)(B)}{(k)(b)}\left[E\left(\frac{39.5\,(O)(U)(C)(r^2)}{(k)(t)}\right)\right]$$

where:

P_r = Pressure at a given radius (psi);
P_i = Initial pressure (psi);
Q = Constant injection rate (barrels/day);
B = Formation volume factor = 1;
c = compressibility (psi $^{-1}$) = 7.5×10^{-6};
U = viscosity (cp) = 1;
k = permeability (md);
b = thickness of reservoir (ft)
O = porosity
E = Exponential integral

For purposes of this evaluation of pressure buildup, the following is assumed:

a. flow is radial;
b. the initial pressure is zero;
c. well interference is not taken into account;
d. porosity and thickness are constant;
e. the well is fully penetrating;
f. the radius of the injection well is assumed to be 0.5 ft.; and
g. the injection rate is estimated using the total volume injected since a given well began operation and assumes the rate was constant.

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 md and a porosity of 15%. The table also lists the reported well head pressures. As indicated in the table, the calculated values of pressure buildup lie on both sides of the reported values. Generally, the calculated values were not greatly divergent from reported values.

The results provide a qualitative measure of the possible variations of permeability. The largest divergence was in the EPU-8 well and the Allotted Hall SWD well. This divergence may be caused by a higher permeability value than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed.

Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles, assuming permeabilities of 55 md and 109 md. The pressure buildups at the wells are more realistic than those estimated assuming a permeability of 25 md. This is especially true in light of the fact that there was an initial positive formation pressure in the field, which was assumed to be zero for purposes of these calculations. The important point of these estimates is that all wells are causing significant pressure increases at a distance of five miles.

The data presented in Tables 6 and 7 indicate that injection in the Poplar Field has created significant pressure changes around the wells, which will reach at least 5 miles to the east and west. The pressure mound will be elongated in a north and south direction because of the interference effects of several injection wells which lie in a north-south line over a distance of about 8 miles. In the author's opinion, this pressure mound has influenced the ground-water flow pattern of the Judith River Fm. This disruption will most likely cause more flow to the south, although some increased ground-water flow to the north will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this ground water flow reversal is not possible to estimate, although it is probably less than two miles.

A point of note is that the injection pressure, in feet of water, in the Tule Field is about 100 feet higher than that in the Poplar Field. This indicates that the overall gradient is still to the east. The large injection pressures in the Poplar Field will however, result in a flattening of the gradient betwen the Tule and Poplar Fields.

Any direct water quality impact due to injected water will be less than one mile to the west based on estimates for the radius of fillup. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality impact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

5. What alternative water sources are there on the Reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/l, less than 10,000 mg/l for other sources of drinking water)?

Although the Judith River Fm. does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Fm. The major sources are alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the TDS content of water from a representative sample of wells tapping the major water sources.

As indicated, the water quality of the alluvium and the Fox Hills is generally excellent. Note: a complete listing of wells (for which water quality data is available) is attached as Appendix 1. Some alluvial wells have TDS contents in excess of 1,000 mg/l but most have TDS contents of less than 1,000 mg/l. The TDS content of water from the Fort Union is somewhat higher, but is useable for domestic purposes.

Table 8

Total Dissolved Solids Content of Aquifers Overlying the Judith River Formation-Fort Peck Indian Reservation

WELL LOCATION		AQUIFER	TOTAL DISSOLVED SOLIDS (mg/l)
Sec. 28	T29NR46E	Alluvium	592
Sec. 10	T29NR51E	Alluvium	809
Sec. 36	T30NR55E	Alluvium	less than 1,000
Sec. 5	T29NR51E	Alluvium	704
Sec. 32	T30N355E	Fort Union	less than 1,000
Sec. 25	T30NR45E	Fox Hills	300
Sec. 19	T28WR53E	Hell Creek	2,540
Sec. 13	T28NR58E	Fort Union	less than 500
Sec. 34	T31NR57E	Till	less than 1,000
Sec. 28	T31NR57E	Fort Union	less than 1,500
Sec. 33	T33NR44E	Alluvium	295
Sec. 29	T27NR51E	Alluvium	1503
Sec. 3	T27NR49E	Alluvium	980
Sec. 25	T28NR53E	Alluvium	2788
Sec. 2	T30NR46E	Flaxville	329

Data on the areal extent of the shallow aquifers is not available. It is apparent, however, that most of the alluvial and outwash deposits are limited in their areal extent, as are the Fort Union and Fox Hills Fms. in their subsurface extents. There are numerous alluvial aquifers throughout the Reservation, while the Fox Hills and the Fort Union Fms. are not present over the western portion of the Reservation. The Fort Union Fm. apparently extends only as far west as the Poplar Field.

Because of the absence of good maps showing the extent of the various aquifers, it is not possible to develop a map with TDS concentration contours. It is clear, however, that all of the shallow aquifers qualify as USDW's and are the major sources of drinking water in the area.

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editing/4th draft print pages 1-16/craig
editing/5th draft print pages 1-15/craig
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Judith River Data

Appendices

1. Transcript of public Hearing
2. memo's and correspondence relating to the Judith River
3. Summary data on the Judith River compiled by Larry Monson
4. Well logs on selected wells
5. Water Quality data / ~~on the~~ [illegible] preservation
6. Notes on pressure buildup calculations
7. Geology reports relating to Judith River

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Review of Data Relating to Injection of Oil Field Brines

in the Area of the Fort Peck Indian Reservation

Your original draft

Paul S. Osborne

Regional Ground Water Expert

Debra Ehlert

Direct Implementation Team Leader

As requested, I have completed my review of the available data pertaining to the Judith River injection activity. (Attached as separate report) My review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud fields located within the Fort Peck Reservation. The questions to be addressed by my review are the following:

1. Are the aquifer exemptions of 1/4 mile radius granted at the inception of the program for existing wells adequate for the volumes of fluids injected?

2. What is the ambient quality of the Judith River Aquifer over the entire reservation? Is this even determinable?

3. Is the Judith River sufficiently confined to prevent contamination of overlying USDW's?

4. Is fluid migration (east to west) a real possibility given that the

Judith River Formation is "pinched off" by the Bearpaw Shale on the eastern edge of the reservation?

5. What alternative drinking water sources are there on the reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e., greater than 10,000 mg/l; less than 10,000 mg/l for other sources of drinking water?

6. Based on the answers to questions 1-5, can it be concluded that the existing wells, if allowed to continue injection activities, <u>will not</u> present future contamination problems?

My recommendations and conclusions relating to the five issues are summarized in the next section followed by five sections which discuss each issue in more detail.

<u>Summary</u>

The agency received a request from the tribal government of the Fort Peck Indian Reservation that EPA prohibit further injections into the Judith River Formations. The Tribe alleged that continued injection would affect the quality of water in the Judith River Formation such that its use for irrigation purposes on the western part of the reservation would be jeopordized.

Moo to come

1. <u>Are the aquifer exemptions of 1/4 mile granted for existing wells at the inception of the program adequate for the volumes of fluids injected?</u>

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is given distance, r, away. The formula, derived by integrating the equation for the average velocity, through porous material, is given as:

$$t = \frac{\pi O b r^2}{Q}$$

Where:

O = porosity of reservoir

b = thickness of reservoir (ft)

r = distance from injection well (ft)

Q = injection rate (ft^3/day)

t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;

b. the reservoir thickness is uniform;

c. the effect of the regional flow gradient on the plume is negligible;

d. the porosity is uniform; and

e. there are no dispersion effects.

The primary variables in calculating travel time are the porosity and the thickness of the formation. In the case of the Judith River, the porosity varies from 10 to 20 percent, according to Feltis. A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N R50E. This log indicated an average porosity of about 16.5%. Several other experts with experience with the Judith River, however, indicate that a porosity of less than 15% should be expected in much of the formation.

The thickness of the sand units in the Judith River Formation underlying the reservation is quite variable ranging from less than ten feet to about one hundred and twenty five feet. An analysis of the map showing the cumulative thickness of sandstone in the Judith River Formation (prepared by Larry Munson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek fields and the Poplar field. The rate of change in the sandstone thickness in each of the given fields, however, is small enough to base travel time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, the sand thickness was estimated using the total sum of the perforated intervals. The values obtained correlate well with the map of the sand thickness. In most cases the perforated

intervals encompass all the available sand. The sandstone generally occurs in two discrete units which are separated by claystones.

will Table 1 show all wells?

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells assuming that injection was continuous and constant. The radii of interest are ? 1,000 feet and 2,640 feet. As indicated, the travel time increases rapidly as the radius increases. The travel time is also influenced by the direct relationship with porosity. The doubling of porosity will double the travel time. The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,~~340~~ 320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene, the Svetvold B1, the Hall SWD, the Goings 1, the Reynolds EPU 8, the Biere 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1, the Svetvold B1, and the Buck Elk 2 have already injected for at least 15 years.

An alternative means of estimating the extent of the reservoir which is impacted by injected fluids is to calculate the "radius of fillup". This radius defines the extent of a cylinder of reservoir rock which would be filled by the fluids which have been injected to date. The equation to calculate this radius is given as:

$$r_f = \left[\frac{(11 \times 5{,}615)}{\pi h \phi}\right]^{1/2}$$

Where:

rf = radius of fillup (ft);

W = total injected volume (barrels);

O = porosity;

b = sand thickness (ft); and

5.615 = conversion factor ($ft.^{3}/Bbl$).

The use of this equation assumes that:

a. flow is radial;

b. reservoir thickness is constant;

c. existing flow gradient does not affect plume movement; and

d. there are no dispersion effects.

The results of the fillup analysis shown in Table 2 calculations were done, assuming a porosity of 15 percent. As can be seen by the results, the injection in several wells to date has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Svetvold B1, the Reynolds EPU-8, the Biere 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a very short time frame.

As indicated, the radius of reservoir fillup does not take dispersion into account. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972) which is given by:

$$r' = r + 2.3\ D \times r$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);

r = calculated radius of fillup with no dispersion (ft);

D = dispersion coefficient (ft).

This equation was derived to estimate the point at which the injection front has a chemical concentration of 0.2 percent of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of 3 feet for sandstone while the value for a vuggy limestone would be 65 feet.

Table 3 shows the calculated radius of fillup without dispersion assuming a porosity of 20 percent. This gives a reduction in the radius

of fillup shown in Table 2 by a maximum of 150 feet. The Table also shows the estimates for calculating the radius of the injected front made using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2 which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

Based on the analysis of the data, it is clear that if portions of the aquifer where injection is occurring are determined to be a USDW, the exempted areas will need to be expanded. Given the fact that flow will not be radial because of the geologic structure, the fluid density differences, and the existing gradient, I would recommend that the area of exemption be at least 1/2 mile. There are, however, 4 operating wells which would need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Hall SWD, and Courchene 1.

In summary, there are wells in the Poplar field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, there is well in the Volt Field and a well in Deadman's Coulee Field which have exceeded the 1/4 mile radius. When these four wells are permitted, my exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be carefully evaluated using the radius of fillup for the life of the well to estimate the potential size of the exempted area.

2. <u>What is the ambient quality of the Judith River Aquifer over the entire reservation? Is this even determinable?</u>

The Judith River Formation consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally beds of coal and carbonaceous shale occur, such as that encountered in wells on the Western Edge of the reservation near Glascow, Montana. Individual beds of sandstone or shale are not continuous either in thickness or character, and consequently the sequence of alternating types of rock differ from place to place. The number of sandstone beds and the distance of such beds below the top of the formation is not the same in all localities. Generally, there are two major sandstone units in the Formation on the west side of the reservation. The Judith River Formation (400 to 100 feet thick on the reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the poplar field area. The Judith River Formation outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a very limited amount of data on the water quality and the Hydrology of the Judith River Formation. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Formation, the direction of ground water flow is most likely from the west to the east and southeast. The water quality data indicates an

increase in total dissolved solids from west to east. Although the Judith River water quality is marginal for drinking, it is used in the western portion of the reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/ in a well in T34N R40 East to more than 18,000 mg/liter in a well in T 29N, R51E. As can be seen in the values of total dissolved solids are variable data but they verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29NR 48, 49, and 51E do not match with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the Formation. Ignoring the samples marked questionable, it can be intimated that the TDS increases from about 4,000 mg/liter in T27N, R47E to about 11,000 in T28NR50E (a distance of 10 to 15 miles). Quality data in the Poplar field support a finding that the total dissolved solids has always been in excess of 10,000 mg/liter.

The data from several electric logs was used to estimate the total dissolved solids in several oil wells drilled in various parts of the reservation. These estimates were made using Archie's law:

$$Rw = R_o/F$$

Where:

Rw = resistivity of the formation water; ?

R_o = resistivity of the formation and the water it contains (obtained from log);

F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empherical constant which depends on formation characteristics such as porosity. In the Judith River case the Formation Factor was estimated using the electric log and the actual value of total dissolved solids from the Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follows:

BHT = $168^{o}F$
Rw (at $168^{o}F$) - 0.24 (from Welex charts on salinity)

TDS = 11,000 mg/l

R_o = 3.0 ohm-m (from log)

$F = R_o/Rw = 3.0/0.24$

F = 12.5

The estimate of Formation Factor was used to estimate the total dissolved solids content of the Judith River using logs run on several

wells along in an east west line. Table 5 gives the information from the logs and the resulting estimates of total dissolved solids. These estimates indicate that the total dissolved solids content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E) whcih has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east such that wells about 16 miles to the NE have a TDS in excess of 10,000 mg/l. It is important to note, however, that the calculations made using the Formation Factor are questionable at best because of the lack of otehr wells for wich reliable quality data and good electric logs are available. Another difficulty is posed by the results of an analysis from the Courchene 1 used in the T zone, R46E. This well had a TDS of about 15,000 mg/l. There is, however, no information documenting how the sample was taken.

In summary, the existing data does indicate that the Judith River Formation is a USDW on the Western edge of the Reservation and the TDS of water in the formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Hall SWD well in Deadman's Coulee (supported by documentation indicating that the sample was representative) Field indicate that this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not a USDW. The areas underlying the Volt, Tule, and Benrud Fields however, may have been a USDW prior to injection.

3. Is the Judith River Aquifer sufficiently confined to prevent contamination of overlying USDW's?

The Judith River Formation on the Fort Peck Reservation is overlain by the Bearpaw Shale which also dips from west to east. The western margin of the Bearpaw is located west of Glascow, Montana. The depth to the Judith River Formation on the reservations range from about 500 to about 1300 feet. This depth to the Judith River is dependent on the geologic structure and the surface topography. The Judith River Formation is at shallow depths in the east Poplar field as a result of the effect of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Formation is shallowest on the western edge of the reservation.

The Bearpaw shale is a gray marine shale which is sandy in the upper portions of the unit. The Bearpaw is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the following practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content

ranging from 5,000 to 70,000 mg/liter.

The available well data indicates that the Judith River aquifer is under confined conditions sufficient to cause wells to flow at the surface. Two wells located near Wolf Point are flowing. Pressures measured in the Poplar and Lustre Fields report surface pressures ~~of~~ as high as 900 psi. While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection most wells in the oil fields would probably flow at the surface.

Based on the thickness of the Bearpaw Shale, the low permeability of the shale, and the evidence that the Judith River is under confined conditions, the Bearpaw Shale appears adequate to prvent movement out of the confining zone. The injections activity will, however, have some impact on the pre-injection flow patterns of the Judith River Formation. There is however, inadequate data to develop a map showing the actual flow patterns. To develop such a map it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. <u>Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the reservation?</u>

As discussed previously, the Judith River Formation dips from west to east towards the Williston Basin. The formation outcrops at the surface near the Milk River West of Glascow. The outcrop area is

considered to be the major source of recharge. The pre-injection flow pattern was probably west to east with a southern component of flow especially in the Poplar Dome area. The dip of the Judith River increases east of the Dome due to the presence of the Williston Basin which is a deep synclinal trough. The available logs and cross sections indicate that the depth of the Judith River increases by 900 feet between a well in section 29, T29NR50E and a well in section 35, T29N R52E which is a distance of about 10 miles. The sand units in the Judith River also thin from a thickness of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29W R55E, however, shows a Judith River Sand thickness of about 100 feet. Based on this data it is clear that the Judith River has good sand present well out into the basin. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River and its discharge zones.

Data on the permeability and porosity of the Judith River Sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcy was reasonable. The Montana Bureau of Mines staff (Marvin Miller) indicated that an analysis of limited DST data indicated a range of permeability from 55 MD to 109 MD. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$Pr = Pi + (70.6 \times \frac{Q \times U \times B}{K \times b} \quad E \frac{39.5\ O \times U \times C \times r2}{K \times t}$$

where:

Pr = Pressure at a given radius (psi);

Pi = Initial pressure (psi);

Q = Constant injection rate (barrels/day);

B = Formation volume factor = 1;

c = compressibility (Psi $^{-1}$) = 7.5×10^{-6};

U = viscosity (cp) = 1;

K = permeability (MD);

b = thickness of reservoir (ft)

O = porosity

For purposes of this evaluation of pressure buildup the following assumed:

a. flow is radial;

b. the initial pressure was zero;

c. well interference was not taken into account;

d. porosity and thickness are constant;

e. the radius of the injection well was assumed to be 0.5 ft.; and

f. the injection rate was estimated using the total volume injected since a given well began operation and assuming the rate was constant.

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 MD and a porosity of 0.15. The Table also lists the currently measured well head pressure. As indicated in the table, the estimated pressure buildup lies on both sides of measured values. Generally, the estimates were not greatly divergent from measured value. The results provide a qualitative measure on the variation of permeability possible. The largest divergence was in the EPU-8 well and the Hall SWD well. This divergence may be caused by a higher permeability unit than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed. Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles assuming a permeability of 55 MD and 109 MD. The pressure buildup at the wells are more realistic than those estimated assuming a permeability of 25 MD. This is especially true in light of the fact that there was an initial positive formation pressure in the field which was assumed to be zero for purposes of these calculations. The important point to these estimates is the fact that all wells are causing significant pressure increases several miles from the well.

The data presented in Tables 6 and 7 indicate that injection in the Poplar field has created significant pressure changes around the wells which will reach at least 5 miles to the east and west. The pressure mound will be enlongated in a north and south direction because of the intererence effects of several injection wells which lie in a north-south

line over a distance of about 8 miles. It is my judgement that this pressure mound has influenced the flow pattern of the Judith River. This disruption will most likely cause more flow to the South, although some increased flow to the North will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this flow reversal is not possible to estimate although it is probably less than one or two miles. Any direct water quality impact due to injected water will be less than 1 mile to the west? based on the estimates of the radius of fillup calculations. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality inpact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

Table 4

Total Dissolved Solids Content of Samples from the Judith River Formation

Location	Total Depth	Sample Date	TDS (mg/liter)	Remake
Sec. 6,T27N,R40E	495	1978	2802	
Sec. 31,T28N,R40E	555	1978	2126	
Sec. 11,T34W,R40E	405	1982	1444	
Sec. 31,T36N,R90E	1700	1971	2303	
Sec. 14,T26W,R41E	936	1947	2419	
Sec. 2,T27N,R41E	695	1978	2724	
Sec. 30,T28N,R41E	454	1978	2851	
Sec. 35,T28N,R41E	685	1978	2765	
Sec. 34,T27N,R44E	1090	1947	4133	
Sec. 15,T27N,R47E	985	1947	3862	
Sec. 22,T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15,T30N,R48E	1411	1964	15,602	DST (?)
Sec. 13,T28N,R50E	874	1954	11,475	DST
Sec. 19,T29N,R51E	877	1957	18,624	DST (?)
Sec. 15,T30N,R49E	1600	1964	16,653	DST (?)
Sec. 24,T36N,R52E	1940	1957	10,385	DST

Sec. 4, T30N,R46E	1432	1965	15,056	(?)
Sec. 29,T29N,R49E	1270	1982	11,323	DST

Table 5

Estimates of TDS Using Resistivity

Name	Location	BHT	Ro	Rw	TDS
#1 Gess	Sec. 1, T30N,R463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15,T31N,R42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30T31N,R45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30T31NR44E	165°F	6	0.48	5500
C. Reddig #2		165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7,T30N,R46E	155	7.5	0.6	4400
Clark #1-MA	Sec. 4,T29N,R49E	168	3.0	0.28	9500

* Note: It was not possible to determine which track was the deep focused R value. The 2nd track had a large value of R.

Table 8

Total Dissolved Solids Content of Aquifers Overlying the

Judith River FormationFort Peck Indian Reservation

Well Location	Aquifer	Total Dissolved Solids
Sec. 28,T29N,R46E	Alluvium	592
Sec. 10,T29N,R51E	Alluvium	809
Sec. 36, T30N,R55E	Alluvium	less than 1,000
Sec. 5, T29N,R51E	Alluvium	704
Sec. 32,T30N, 355E	Fort Union	less than 1,000
Sec. 25,T30N,R45E	Fox Hills	300
Sec. 19, T28W, R53E	Hell Creek	2,540
Sec. 13, T28N,R58E	Fort Union	less than 500
Sec. 34,T31N,R57E	Till	less than 1,000
Sec. 28,T31N,R57E	Fort Union	less than 1,500
Sec. 33,T33N,R44E	Alluvium	295
Sec. 29,T27N,R51E	Alluvium	1503
Sec. 3, T27N,R49E	Alluvium	980
Sec. 25, T28N,R53E	Alluvium	2788
Sec. 2, T30N,R46E	Flaxville	329

5. What alternative water sources are there on the reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/liter, less than 10,000 mg/liter for other sources of drinking water?

Although the Judith River Formation does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Formation. The major sources are the alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union Formation aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the total dissolved solids content of water from a representative sample of wells tapping the major water sources. As indicated, the water quality of the alluvium and the Fox Hills is a complete listing of wells (for which quality data is available is attached as appendix one), ? generally excellent some alluvial well have a TDS in excess o fl,000 mg/l but most have a TDS of less than 1,000 mg/l. The total dissolved solids content of water from the Fort Union is somewhat higher but then the alluvial aquifers water is usuable for domestic purposes. Data on the areal extent of trne shallow aquifers is not available. It is apparent, however, that most of the alluvial and outwash deposits are limited in their areal extent. The extent of the Fort Union and Fox Hills Formations is also limited. They are not present over the western

portion of the reservation. The Fort Union Formation apparently extends only as far west as the Poplar Field. Because of the absence of good maps showing the extent of the various aquifers, it is not possible to develop a map with TDS concentration contours. It is clear, however, that all of the shallow aquifers qualify as USDW's and are the major source of drinking water in the area. It is worth noting that the major threat to the shallow aquifers in the vicinity of the oil fields appears to be poor surface waste handling practices.

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editing/3rd draft print pages 1-14/craig

Review of Data Relating to Injection of Oil Field Brines
in the Area of the Fort Peck Indian Reservation

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The U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation to prohibit further injections into the Judith River Formation. The Tribe alleged that continued injection would affect the quality of water in the Judith River Formation such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Formation.

A review of the available data (attached as appendices) pertaining to Judith River injection activities has been completed. Figure 1 shows the Ft. Peck Indian Reservation and the fields which are the concern of this analysis.

The data reviewed were related to the Judith River from west of Glasgow, Montana to the eastern edge of the Reservation. The review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud Fields located within the Fort Peck Reservation. The questions to be addressed by this report are the following:

1. Are the aquifer exemptions of 1/4 mile radii granted at the inception of the Underground Injection Control (UIC) program, adequate for the volumes of fluids injected?

2. What is the ambient water quality of the Judith River ~~aquifer~~ Form. over the entire Reservation? Is this even determinable?

3. Is the Judith River Formation sufficiently confined to prevent contamination of overlying underground sources of drinking water (USDW's)?

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is "pinched off" by the Bearpaw Shale on the eastern edge of the Reservation?

5. What alternative drinking water sources are there on the Reservation? Are data available so that an equal concentration (total dissolved solids (TDS)) contour map can be constructed (i.e., greater than 10,000 milligrams/liter (mg/l); less than 10,000 mg/l for other sources of drinking water)?

6. Based on the answers to questions 1-5, can it be concluded that the existing wells, if allowed to continue injection activities, will not cause future contamination problems?

Conclusions relating to the five issues are summarized in the following section. This is followed by a section of detailed discussions of each issue.

SUMMARY AND CONCLUSIONS

This information and other available data were used in formulating the following conclusions.

1. Using the radius-of-formation-fillup and travel-time formulas (both based on radial flow), it appears that four existing wells have exceeded or will soon exceed their 1/4-mile aquifer exemptions. In fact, one well has probably directly impacted the reservoir seven and a half (7 & 1/2) miles from the well. Any permits should be evaluated to determine if a 1/2 mile radius of exemption is appropriate.

2. It is not possible to draw TDS contours of the ambient water quality for the Judith River Formation over the entire Reservation. There is very little reliable data on which a contour map could be based. Data from water wells on the west side of the Reservation, a water well at Wolf Point and a drill stem test, indicate that TDS concentrations increase from east to west. These data indicate that the Judith River Formation was a USDW in the vicinity of the Tule Field, TDS values in the Poplar Field were always in excess of 10,000 mg/l.

3. Based on composition, thickness, and apparent low permeability of the Judith River Formation, it appears that the formation is sufficiently confined to prevent fluid contamination of overlying USDW's.

4. Estimates of the radius of fillup indicate that even with dispersion, the direct impact of the injected water will be limited to less than a 1/2 mile for any given injection well reviewed. This will create a limited amount of east to west fluid migration due to of the mounding effect caused by the injection and subsequent displacement of existing reservoir water back to the west.

5. The indirect impacts of injection into the Judith River Formation in the Poplar Field could have a significant impact to the west because of the far reaching pressure effects.

   Fluid pressure buildup estimates indicate that significant pressure effects could extend beyond a five mile radius. While this may not result in westward fluid migration as far as five miles, it will result in a flattening of the preinjection gradient. This will result in increased travel times of native water moving west to east, which should result in an increase in TDS.

6. Calculations using the existing injection pressures, obtained from data supplied by Larry Monson, indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which exceed a fracture gradient of 0.75 pounds per square inch (psi/ft). Three wells in the Poplar Field area are injecting at pressures in excess of 1.0 psi/ft.

7. The principal sources of drinking water in the vicinity of the oil fields, where injection into the Judith River Formation is occurring, are the alluvium and glacial gravels. There are also several areas which receive supplies from bedrock aquifers of limited areal extent, such as the Fox Hills. There is insufficient data to draw either TDS contours or the extent of the aquifers in question.

8. Available data indicate that the Judith River Formation in the vicinity of the Volt and Tule Fields is a USDW. Continued injection in these fields will increase the size of the presently impacted area, therefore, limiting injection to the existing 1/4 mile aquifer exemption should be considered when establishing the life of the permit ~~wells~~. Continued injection in the Poplar Field may have little impact on the aquifer to the west of the field, but there may be some indirect impact caused by a flattening of the gradient between the Poplar Field and the various fields to the west.

DISCUSSION

1. Are the aquifer exemptions of 1/4 mile, granted at the inception of the UIC program, adequate for the volumes of fluids injected?

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is a given distance, r, away. The formula, derived by integrating the equation for the average velocity through porous material, is given as:

$$t = \frac{\pi O b r^2}{Q}$$

Where:

O = porosity of reservoir
b = thickness of reservoir (ft)
r = distance from injection well (ft)
Q = injection rate (ft ^{3}/day)
t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;
b. the reservoir thickness is uniform;
c. the effect of the regional flow gradient on the plume is negligible;
d. the porosity is uniform; and
e. there are no dispersion effects.

The primary variables in calculating travel time are ~~the~~ porosity and thickness of the formation. In the case of the Judith River, ~~the~~ Formation porosity varies from 10 to 20%, (Feltis, 19__).

A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N, R50E. This log indicated an average porosity of about 16.5%. Several other experts with knowledge of the Judith River, however, indicate that a porosity of less than 15% should be expected in much of the formation (Marvin Miller, Personal Communication).

The thicknesses of the sand units in the Judith River Formation underlying the Reservation are quite variable, ranging from less than 10 feet to about 125 feet. The sandstone generally occurs in two discrete units which are separated by claystones. Analysis of a map showing cumulative thickness of sandstone in the Judith River Formation (prepared by Larry Monson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek Fields and the Poplar Field. Changes in sandstone thickness

within each of the given fields, however, is small enough to base travel-time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, sand thickness was estimated using the total sum of the perforated intervals. The values obtained correlate well with the map of Judith River sand thickness. In most cases the perforated intervals encompass all the available sand.

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells. This assumes that the injection rate was continuous and constant. The radii of interest are 1,000 feet and 2,640 feet. The 1,000 foot radius was chosen so that a buffer zone could be allowed. As indicated, the travel time increases rapidly as the radius increases. Travel time is also influenced by the direct relationship with porosity, doubling of porosity will double the travel time. The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene, the Sletvold B1, the Attotted Hall SWD, the Goings 1, the Reynolds EPU 8, the Biere 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1, the Sletvold B1, and the Buck Elk 2 have already injected for at least 15 years.

An alternative means of estimating the impact of injected fluids upon a reservoir is to calculate the "radius of fillup." This value can be used to calculate the size of the cylinder of reservoir rock to be filled by the total injected fluid volume. The equation to calculate this radius is given as:

INSERT EQUATION (Page 4 of draft)

Where:

r_f = radius of fillup (ft);
W = total injected volume (barrels);
O = porosity;
b = sand thickness (ft); and
5.615 = conversion factor ($ft.^3/bbl$).

The use of this equation assumes that:

a. flow is radial;
b. reservoir thickness is constant;
c. existing flow gradient does not affect plume movement; and
d. there are no dispersion effects.

This equation is sensitive to both the change in volume and the change in porosity. The porosity is most important in that an increase in porosity will cause a decrease in the radius of impact. Using a high value for porosity will provide a sense of the minimum size of the area of impact. The results that appear in Table 2 were obtained by assuming a porosity of 15% and no dispersion.

As is indicated by the results, injection in several wells has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Sletvold B1, the Reynolds EPU-8, the Biere 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a short time.

As mentioned previously, the radius of fillup equation does not take into account dispersion. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972), which is given by:

$$r' = r + 2.3\ D \times r$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);
r = calculated radius of fillup with no dispersion (ft);
D = dispersion coefficient (ft).

This equation estimates the point at which the injection front possesses a chemical concentration of 0.2% of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of three feet for sandstone while the value for a vuggy limestone would be 65 feet.

Table 3 shows the calculated radius of fillup with and without dispersion, assuming a porosity of 20%. This gives a reduction in the radius of fillup shown in Table 2 by a maximum of 150 feet. The table also shows the estimates for calculating the radius of the injected front using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2, which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

Based on the analysis of the data, it is clear that the exempted areas will need to be expanded, if portions of the aquifer where injection is occurring are determined to be USDW's. Given the fact that flow will not be radial because of geologic structure, fluid density differences, and existing gradient, I would recommend that the area of exemption be at least 1/2 mile. There are, however, four operating wells which would need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Allotted Hall SWD, and Courchene 1-D.

In summary, there are wells in the Poplar Field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, there is a well in the Volt Field and a well in Deadman's Coulee Field which have exceeded the 1/4 mile radius. When these four wells are permitted, any exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be evaluated using radius of fillup calculations for the proposed life of the well, in order to estimate the potential size of the exempted area.

2. What is the ambient quality of the Judith River aquifer over the entire Reservation? Is this even determinable?

The Judith River Formation consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally, beds of coal and carbonaceous shale occur, such as that encountered in wells on the western edge of the Reservation near Glasgow, Montana. Individual beds of sandstone or shale are not always continuous either in thickness or character, and consequently the sequence of alternating types of rock differs laterally.

The number of sandstone beds and the distance of such beds below the top of the formation is not the same in all localities. Generally, there are two major sandstone layers in the Judith River Formation on the west side of the Reservation. The Judith River Formation (400 to 100 feet thick on the Reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the Poplar Field area. The Judith River Formation outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a limited amount of data on the water quality and the hydrology of the Judith River Formation. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Formation, the direction of ground-water flow is most likely from the west to the east and southeast. Water quality data indicate an increase in TDS from west to east. Although Judith River water quality is marginal for drinking, it is used in the western portion of the Reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/l in a well in T34N, R40E, to more than 18,000 mg/l in a well in T29N, R51E.

Table 4

Total Dissolved Solids Content
Samples from the Judith River Formation

LOCATION		TOTAL DEPTH (ft.)	SAMPLE DATE	TDS (mg/liter)	REMARKS
Sec. 6	T27NR40E	495	1978	2802	
Sec. 31	T28NR40E	555	1978	2126	
Sec. 11	T34WR40E	405	1982	1444	
Sec. 31	T36NR90E	1700	1971	2303	
Sec. 14	T26W,R41E	936	1947	2419	
Sec. 2	T27N,R41E	695	1978	2724	
Sec. 30	T28N,R41E	454	1978	2851	
Sec. 35	T28N,R41E	685	1978	2765	
Sec. 34	T27N,R44E	1090	1947	4133	
Sec. 15	T27N,R47E	985	1947	3862	
Sec. 22	T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15	T30N,R48E	1411	1964	15,602	DST (?)
Sec. 13	T28N,R50E	874	1954	11,475	DST
Sec. 19	T29N,R51E	877	1957	18,624	DST (?)
Sec. 15	T30N,R49E	1600	1964	16,653	DST (?)
Sec. 24	T36N,R52E	1940	1957	10,385	DST
Sec. 4	T30N,R46E	1432	1965	15,056	(?)
Sec. 29	T29N,R49E	1270	1982	11,323	DST

As can be seen in the values of TDS, there is a great deal of variation within given areas. This may reflect poor "quality assurance" in either the sampling or analysis. This is especially true of the data obtained by drill stem tests. For instance, the sample from the Courchene 1-D had a calculated TDS of about 15,000 mg/l. The sample was not clear, indicating that some contamination may have been present. Additionally, this sample does not compare with the data from the wells at Wolf Point, which have TDS values of less than 4,000 mg/l.

The Wolf Point wells are about six miles east and 15 miles south of the Courchene 1-D well in the Tule Field. Given the apparent west to east flow, it is difficult to postulate why the quality would have so much variability in a north-south direction.

For purposes of this report, the data obtained from DST samples were considered to be output, except where documentation indicated a valid sample. The apparently valid data verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29N, R48, 49, and 51E do not match with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the Judith River Formation.

Ignoring the samples that are questionable, it can be intimated that the TDS increases from about 4,000 mg/l in T27N, R47E to about 11,000 mg/l in T28N, R50E (a distance of 10 to 15 miles). Water quality data from the Poplar Field support a finding that the TDS has always been in excess of 10,000 mg/l.

Data from several electric logs were used to estimate the TDS in several oil wells drilled in various parts of the Reservation. These estimates were made using Archie's law:

$$R_w = R_o/F$$

Where:

R_w = resistivity of the formation water;
R_o = resistivity of the formation including the water it contains obtained from log);
F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empirical constant which depends on such formation characteristics as porosity. In the Judith River case the Formation Factor was estimated using the electric log and the actual value of TDS from the Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follow:

R_w (at 168°F) = 0.24 (from Welex charts on salinity)
BHT = 168°F
TDS = 11,000 mg/l
R_o = 3.0 ohm-m (from log)
F = R $_o/R_w$ = 3.0/0.24
F = 12.5

The Formation Factor was used to estimate the TDS content of the Judith River, using logs run on several wells along an east-west line. Table 5 gives the information from the logs and the resulting estimates of total dissolved solids.

Table 5

Estimates of TDS Using Resistivity

NAME	LOCATION	BHT	R_o	R_w	TDS
#1 Gess	Sec. 1 T30NR463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15 T31NR42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30 T31NR45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30 T31NR44E	165°F	6	0.48	5500
C. Reddig #2		165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7 T30NR46E	155°F	7.5	0.6	4400
Clark #1-MA	Sec. 4 T29NR49E	168°F	3.0	0.28	9500

* Note: It was not possible to determine which track was the deep focused R value. The 2nd track had a large value of R.

These estimates indicate that the TDS content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E), which has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east, such that wells about 16 miles to the northeast have a TDS in excess of 10,000 mg/l. It is important to note, however, that calculations using the Formation Factor are questionable at best because of the lack of reliable quality data and good electric logs.

In summary, existing data indicate that the Judith River Formation is a USDW on the western edge of the Reservation. The TDS concentration of the water in the formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Allotted Hall SWD well in Deadman's Coulee Field (supported by documentation indicating that the sample was representative) indicate that the portion of the Judith River Formation in this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not a USDW. The Judith River Formation underlying the Volt, Tule, and Benrud Fields however, may have been a USDW prior to injection.

3. Is the Judith River aquifer sufficiently confined to prevent contamination of overlying USDW's?

The Judith River Formation on the Fort Peck Reservation is overlain by the Bearpaw Shale, which also dips from west to east. The western margin of the Bearpaw is located west of Glascow, Montana. The depth to the Judith River Formation on the Reservation ranges from about 500 to about 1,300 feet. This depth to the Judith River is dependent on the geologic structure and the surface topography. The Judith River Formation is at shallow depths in the East Poplar Field because of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Formation is shallowest on the western edge of the Reservation.

The Bearpaw Shale is a gray marine shale, sandy in the upper portions, and is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the fallowing practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content ranging from 5,000 to 70,000 mg/l.

Available well data indicate that the Judith River aquifer is under confined conditions such that wells flow at the surface. For instance, two wells located near Wolf Point were under flowing condtions in 1947. Surface pressures measured in the Poplar and Tule Fields are as high as 900 psi.

While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection, wells in the oil fields would probably flow at the surface.

No data on actual fracture pressure of the Judith River Formation is available. However, analysis of injection pressures, reported by Larry Monson, indicates that many of the wells are presently injecting at pressures which may exceed the fracture pressure of the formation. Although one operator indicated that the fracture gradient was 1.25 psi/ft, no documentation was provided to verify this claim.

It is unlikely that the fracture gradient of the Judith River exceeds 1.0 psi/ft. Even if the reservoir is fractured, the overlying shales may be of sufficient thickness to prevent fractures such that fluid will not migrate into USDW's overlying the 800 to 1,000 feet of shale. Field studies have shown that injection energy dissipates rather quickly once the fractures move out of the reservoir. The fracturing of the reservoir on the other hand could present a problem. It will provide discreet zones of high permeability which will provide avenues for injected fluid to move further from the well than estimated by the radial flow calculations.

Based on the thickness and low permeability of the Bearpaw Shale, combined with the evidence that the Judith River is under confined conditions, it appears that the Bearpaw Shale is adequate to prevent movement out of the confining zone. This may depend however, on the actual fracture gradient of the Judith River Formation and the Bearpaw Shale. Although injection activities will have some impact on the pre-injection flow patterns of the Judith River Formation, there is inadequate data to develop a map to show these actual flow patterns. In order to develop such a map, it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the Reservation?

As discussed previously, the Judith River Formation dips from west to east towards the Williston Basin. This formation outcrops at the surface near the Milk River, West of Glascow and is considered to be a significant location for recharge to the Judith River. The pre-injection flow pattern was probably west to east, with a southern component of flow, especially in the Poplar Dome area.

The dip of the Judith River increases east of the Dome due to the presence of the Williston Basin, which is a deep synclinal trough.

Available logs and cross sections indicate that the depth of the Judith River increases by 900 feet between a well in Section 29, T29N,R50E and a well in Section 35, T29N, R52E, which is a distance of about 10 miles.

The sand units in the Judith River also thin from thicknesses of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29W, R55E, however, shows a Judith River Sand thickness of about 100 feet. Based on this data it is clear that the Judith River has good sand present well out into the basin. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River and its discharge zones.

Data on the permeability and porosity of the Judith River Sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcies (MD) was reasonable. Marvin Miller, of the Montana Bureau of Mines, indicated that an analysis of limited DST data indicated a range of permeabilities from 55 MD to 109 MD. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$Pr = Pi + (70.6 \times \frac{Q \times U \times B}{K \times b}) \quad E \frac{39.5\ O \times U \times C \times r2}{K \times t}$$

where:

P_r = Pressure at a given radius (psi);
P_i = Initial pressure (psi);
Q = Constant injection rate (barrels/day);
B = Formation volume factor = 1;
c = compressibility (psi $^{-1}$) = 7.5 x 10^{-6};
U = viscosity (cp) = 1;
K = permeability (MD);
b = thickness of reservoir (ft)
O = porosity
E = Exponential integral

For purposes of this evaluation of pressure buildup, the following is assumed:

a. flow is radial;
b. the initial pressure is zero;
c. well interference is not taken into account;
d. porosity and thickness are constant;
e. the well is fully penetrating;
f. the radius of the injection well is assumed to be 0.5 ft.; and
g. the injection rate is estimated using the total volume injected since a given well began operation and assumes the rate was constant.

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 MD and a porosity of 15%. The table also lists the current measured well head pressure. As indicated in the table, the estimated pressure buildup lies on both sides of the measured values. Generally, the estimates were not greatly divergent from measured values.

The results provide a qualitative measure of the possible variations of permeability. The largest divergence was in the EPU-8 well and the Allotted Hall SWD well. This divergence may be caused by a higher permeability value than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed.

Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles, assuming permeabilities of 55 MD and 109 MD. The pressure buildups at the wells are more realistic than those estimated assuming a permeability of 25 MD. This is especially true in light of the fact that there was an initial positive formation pressure in the field, which was assumed to be zero for purposes of these calculations. The important point of these estimates is that all wells are causing significant pressure increases several miles from the well.

The data presented in Tables 6 and 7 indicate that injection in the Poplar Field has created significant pressure changes around the wells, which will reach at least 5 miles to the east and west. The pressure mound will be elongated in a north and south direction because of the interference effects of several injection wells which lie in a north-south line over a distance of about 8 miles. It is my judgement that this pressure mound has influenced the ground-water flow pattern of the Judith River. This disruption will most likely cause more flow to the south, although some increased ground-water flow to the north will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this ground water flow reversal is not possible to estimate, although it is probably less than one or two miles.

A point of note is that the injection pressure, in feet of water, in the Tule Field is about 100 feet higher than that in the Poplar Field. This indicates that the overall gradient is still to the east. The large injection pressures in the Poplar Field will however, result in a flattening of the gradient betwen the Tule and Poplar Fields.

Any direct water quality impact due to injected water will be less than one mile to the west based on estimates for the radius of fillup. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality impact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

5. What alternative water sources are there on the Reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/l, less than 10,000 mg/l for other sources of drinking water)?

Although the Judith River Formation does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Formation. The major sources are alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the TDS content of water from a representative sample of wells tapping the major water sources.

Table 8

Total Dissolved Solids Content of Aquifers Overlying the Judith River Formation-Fort Peck Indian Reservation

WELL LOCATION		AQUIFER	TOTAL DISSOLVED SOLIDS (mg/l)
Sec. 28	T29NR46E	Alluvium	592
Sec. 10	T29NR51E	Alluvium	809
Sec. 36	T30NR55E	Alluvium	less than 1,000
Sec. 5	T29NR51E	Alluvium	704
Sec. 32	T30N355E	Fort Union	less than 1,000
Sec. 25	T30NR45E	Fox Hills	300
Sec. 19	T28WR53E	Hell Creek	2,540
Sec. 13	T28NR58E	Fort Union	less than 500
Sec. 34	T31NR57E	Till	less than 1,000
Sec. 28	T31NR57E	Fort Union	less than 1,500
Sec. 33	T33NR44E	Alluvium	295
Sec. 29	T27NR51E	Alluvium	1503
Sec. 3	T27NR49E	Alluvium	980
Sec. 25	T28NR53E	Alluvium	2788
Sec. 2	T30NR46E	Flaxville	329

As indicated, the water quality of the alluvium and the Fox Hills is generally excellent. Note: a complete listing of wells (for which water quality data is available is attached as Appendix 1). Some alluvial wells have TDS contents in excess of 1,000 mg/l but most have TDS contents of less than 1,000 mg/l. The TDS content of water from the Fort Union is somewhat higher, but then water from the alluvial aquifers is usable for domestic purposes.

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,590	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 6. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				conductivity = 55 md		conductivity = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 MILES	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Conductivity measured in millidarcys; porositiy assumed to be 15%.

TABLE 7. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of hydraulic conductivity of 25 millidarcies and porosity of 15%.

Review of Data Relating to Injection of Oil Field Brines
in the Area of the Fort Peck Indian Reservation

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The U.S. Environmental Protection Agency (EPA or Agency) received a request from the tribal government of the Fort Peck Indian Reservation to prohibit further injections into the Judith River Formation (Fm.). The Tribe alleged that continued injection would affect the quality of water in the Judith River Fm. such that its use for irrigation purposes on the western part of the Reservation would be jeopordized. A public hearing was held in Poplar, Montana on May 29, 1985, to collect information relating to existing injection into the Judith River Fm.

A review of the available data (attached as appendices) pertaining to Judith River Fm. injection activities has been completed. Figure 1 shows the Fort Peck Indian Reservation and the fields which are the concern of this analysis.

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The data reviewed were related to the Judith River Fm. from west of Glasgow, Montana to the eastern edge of the Reservation. The review included an inspection of several wells in the Poplar, Volt, Tule, and Benrud Fields located within the Fort Peck Reservation. The questions to be addressed by this report are the following:

1. Are the aquifer exemptions of 1/4 mile radii granted at the inception of the Underground Injection Control (UIC) program, adequate for the volumes of fluids injected?

2. What is the ambient quality of the Judith River Fm. over the entire Reservation? Is this even determinable?

3. Is the Judith River Fm. sufficiently confined to prevent contamination of overlying underground sources of drinking water (USDW's)?

4. Is fluid migration (east to west) a real possibility given that the Judith River Fm. is "pinched off" by the Bearpaw Shale on the eastern edge of the Reservation?

5. What alternative drinking water sources are there on the Reservation? Are data available so that an equal concentration (total dissolved solids (TDS)) contour map can be constructed (i.e., greater than 10,000 milligrams/liter (mg/l); less than 10,000 mg/l for other sources of drinking water)?

6. Based on the answers to questions 1-5, can it be concluded that the existing wells, if allowed to continue injection activities, <u>will not</u> cause future contamination problems?

Conclusions relating to the five issues are summarized in the following section. This is followed by a section of detailed discussions of each issue.

SUMMARY AND CONCLUSIONS

This information and other available data were used in formulating the following conclusions.

1. Using the radius-of-formation-fillup and travel-time formulas (both based on radial flow), it appears that four existing wells have exceeded or will soon exceed their 1/4-mile aquifer exemptions. In fact, one well has probably directly impacted the reservoir seven and a half (7 & 1/2) miles from the well. Any permits should be evaluated to determine if a 1/2 mile radius of exemption is appropriate.

2. It is not possible to draw TDS contours of the ambient water quality for the Judith River Fm. over the entire Reservation. There is very little reliable data on which a contour map could be based. Data from water wells on the west side of the Reservation, a water well at Wolf Point and a drill stem test, indicate that TDS concentrations increase from east to west. These data indicate that the Judith River Fm. was a USDW in the vicinity of the Tule Field, TDS values in the Poplar Field were always in excess of 10,000 mg/l.

3. Based on composition, thickness, and apparent low permeability of the Judith River Fm., it appears that the Judith River Fm. is sufficiently confined to prevent fluid contamination of overlying USDW's.

4. Estimates of the radius of fillup indicate that even with dispersion, the direct impact of the injected water will be limited to less than a 1/2 mile for any given injection well reviewed. This will create a limited amount of east to west fluid migration due to the mounding effect caused by the injection and subsequent displacement of existing reservoir water back to the west.

5. The INDIRECT impacts of injection into the Judith River Fm. in the Poplar Field could have a significant impact to the west because of the far reaching pressure effects. Fluid pressure buildup estimates indicate that significant pressure effects could extend beyond a five mile radius. While this may not result in westward fluid migration as far as five miles, it will result in a flattening of the preinjection gradient. This will result in increased travel times of native water moving west to east, which should result in an increase in TDS.

6. Calculations using the existing injection pressures, obtained from data supplied by Larry Monson, indicate that all but 7 of the 17 current and standby injection wells are operating at pressures which exceed a fracture gradient of 0.75 pounds per square inch (psi/ft). Three wells in the Poplar Field area are injecting at pressures in excess of 1.0 psi/ft.

7. The principal sources of drinking water in the vicinity of the oil fields, where injection into the Judith River Fm. is occurring, are the alluvium and glacial gravels. There are also several areas which receive supplies from bedrock aquifers of limited areal extent, such as the Fox Hills. There is insufficient data to draw either TDS contours or the extent of the aquifers in question.

8. Available data indicate that the Judith River Fm. in the vicinity of the Volt and Tule Fields is a USDW. Continued injection in these fields will increase the size of the presently impacted area, therefore, limiting injection to the existing 1/4 mile aquifer exemption should be considered when establishing the expiration dates of the permits. Continued injection in the Poplar Field may have little impact on the aquifer to the west of the field, but there may be some indirect impact caused by a flattening of the gradient between the Poplar Field and the various fields to the west.

DISCUSSION

1. Are the 1/4 mile aquifer exemptions for the given injection wells, granted at the inception of the UIC program, adequate for the volumes of fluids injected?

There are several methods which can be used to estimate the extent of movement of injected fluids away from a well. It is possible to calculate the time for fluid to move from an injection well to a point which is a given distance, r, away. The formula, derived by integrating the equation for the average velocity through porous material, is given as:

$$t = \frac{0\ br^2}{Q}$$

Where:

0 = porosity of reservoir
b = thickness of reservoir (ft)
r = distance from injection well (ft)
Q = injection rate (ft ^{3}/day)
t = travel time (days)

This equation assumes the following:

a. flow from the well is radial;
b. the reservoir thickness is uniform;
c. the effect of the regional flow gradient on the plume is negligible;
d. the porosity is uniform; and
e. there are no dispersion effects.

The primary variables in calculating travel time are porosity and thickness of the formation. In the case of the Judith River Fm., the porosity varies from 10 to 20%, (Feltis, 19__).

A compensated neutron and formation density log was available for the Goings 27-3 in Section 27, T29N, R50E. This log indicated an average porosity of about 16.5%. Several other experts with knowledge of the Judith River Fm., however, indicate that a porosity of less than 15% should be expected in much of the formation (Marvin Miller, Personal Communication).

The thicknesses of the sand units in the Judith River Fm. underlying the Reservation are quite variable, ranging from less than 10 feet to about 125 feet. The sandstone generally occurs in two discrete units which are separated by claystones. Analysis of a map showing cumulative thickness of sandstone in the Judith River Fm. (prepared by Larry Monson, Fort Peck Mineral Resources) indicates a thinner sandstone layer between the Benrud-Tule Creek Fields and the Poplar Field. Changes in sandstone thickness within each of the given fields, however, is small enough to base travel-time estimates on the sand thickness encountered at each individual well. For purposes of these calculations, sand thickness was estimated using the total sum of the perforated intervals. The values obtained correlate well with the map of Judith River Fm. sand thickness. In most cases the perforated intervals encompass all the available sand.

Table 1 shows the travel times assuming three different porosities, 10%, 16.5%, and 20%. The injection rates were estimated using the total volume injected since injection started in each of the wells. This assumes that the injection rate was continuous and constant. The radii of interest are 1,000 feet and 2,640 feet. The 1,000 foot radius was chosen so that a buffer zone could be allowed. As indicated, the travel time increases rapidly as the radius increases. Travel time is also influenced by the direct relationship with porosity, doubling of porosity will double the travel time. The analysis indicates that even if porosity in some of the reservoir approaches 20%, fluids from several wells will have traveled close to or greater than 1/4 of a mile (1,320 feet) after 15 years of injection (5,475 days). The wells in question are the Courchene, the Sletvold B1, the Attotted Hall SWD, the Goings 1, the Reynolds EPU 8, the Bierre 1 (plugged in 1984), the Buck Elk 2, and the EPU 29-D. Of these wells, the Courchene 1, the Sletvold B1, and the Buck Elk 2 have already injected for at least 15 years.

An alternative means of estimating the impact of injected fluids upon a reservoir is to calculate the "radius of fillup." This value can be used to calculate the size of the cylinder of reservoir rock to be filled by the total injected fluid volume. The equation to calculate this radius is given as:

INSERT EQUATION (Page 4 of draft)

Where:

r_f = radius of fillup (ft);
W = total injected volume (barrels);
O = porosity;
b = sand thickness (ft); and
5.615 = conversion factor ($ft.^3/bbl$).

TABLE 1. TRAVEL TIME FROM INJECTION WELL TO A GIVEN POINT, R

LOCATION	WELL NAME	VOLUME INJECTED PER DAY (ft^3/day)	TRAVEL TIME (days) R = 1,000 feet			R = 2,640 feet		
			Ø = .1	Ø = .165	Ø = .20	Ø = .1	Ø = .165	Ø = .20
SE SW 4-30-46	Courchene 1-D	7,300	2,366	3,904	4,732	16,488	27,206	32,976
NW NE 9-30-46	Carlson	1,291	7,297	23,039	14,594	50,855		
SE NE 13-30-47	Phillips-McKee	5,351	4,108	6,772	8,216	28,629		57,258
C SE SW 13-30-47	Lough 2	3,099	4,762	7,857	9,524	33,190		
NE NE SW 34-31-47	A 1-W Listug-Olson							
SW NE SW 36-31-47	Wetsit 1	3,296	6,288	10,375	12,576	43,822		87,644
NW NE 6-30-48	Bigtrack Little 1	1,259	4,988	8,230	9,976	34,765		
NW SE NE 15-30-48	Bridges 1-D	1,959	9,617	15,868	19,234	67,028		
C NW NE 19-30-48	Sletvold B1	3,694	2,550	4,208	5,100	17,773	29,325	35,546
SW SE 20-31-48	Mule Creek 1-D	1,583	27,770	45,821	55,540	193,546		
SE NE 25-31-48	Mann 1 SWD	1,645	19,470	32,125	38,940	135,697		
NW NE 29-29-49	Allotted Hall SWD	12,576	998	1,647	1,996	6,064	11,486	13,922
NE NW 27-29-50	Goings 1	6,086	2,270	3,745	4,540	15,822		31,644
SE NW NE 10-28-51	Huber 1-W	3,116	14,712	24,274	29,424	102,540		
NW SE 10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
SW NW SW 22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
SW NW 7-29-51	Buck Elk 1	3,722						
SW NW 7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
SW SW 28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
SW SW SW 31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

The use of this equation assumes that:

a. flow is radial;
b. reservoir thickness is constant;
c. existing flow gradient does not affect plume movement; and
d. there are no dispersion effects.

This equation is sensitive to both the change in volume and the change in porosity. The porosity is most important in that an increase in porosity will cause a decrease in the radius of impact. Using a high value for porosity will provide a sense of the minimum size of the area of impact. The results that appear in Table 2 were obtained by assuming a porosity of 15% and no dispersion.

As is indicated by the results, injection in several wells has been of sufficient quantity to cause the 1/4 of a mile radius to be exceeded. These wells are the Courchene 1-D, the Sletvold B1, the Reynolds EPU-8, the Biere 1 (plugged), and the Buck Elk 2. Well EPU 29-D will exceed the 1/4 mile radius within a short time.

As mentioned previously, the radius of fillup equation does not take into account dispersion. The dispersion mechanism can cause the plume of injected water to be significantly larger than a plume with no dispersion. The dispersion effect can be estimated using an equation developed by Bear (1972), which is given by:

$$r' = r + 2.3\ D \times r$$

Where:

r' = radial distance of contaminant movement with dispersion (ft);
r = calculated radius of fillup with no dispersion (ft);
D = dispersion coefficient (ft).

This equation estimates the point at which the injection front possesses a chemical concentration of 0.2% of the injected fluid. The dispersion coefficient varies according to the composition of the aquifer. Experiments indicate a dispersion coefficient of three feet for sandstone while the value for a vuggy limestone would be 65 feet.

Table 3 shows the calculated radius of fillup with and without dispersion, assuming a porosity of 20%. This gives a reduction in the radius of fillup shown in Table 2 by a maximum of 150 feet. The table also shows the estimates for calculating the radius of the injected front using Bear's dispersion equation. The dispersion coefficient was assumed to be 3 feet. The results of the calculations further support the data on Tables 1 and 2, which indicate that several wells already have plumes in excess of 1/4 mile, even when assuming a high value for porosity.

TABLE 2. RADIUS OF FILL-UP OF JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	NAME	FIELD	TOTAL VOLUME INJECTED (bbls)	TIME SINCE START UP (days)	RADIUS* OF FILL-UP (feet)	SAND THICKNESS (feet)
SE SW 4-30-46	Courchene 1-D	Volt	9,490,953	7,300		
NW NE 9-30-46	Carlson	Volt	837,942	3,650	577	30
SE NE 13-30-47	Phillips-McKee	Tule	1,391,601	1,460	987	70
C SE SW 13-30-47	Lough 2	Tule	3,830,468	6,935	986	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud	642,238		330	70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	4,074,613	6,935	585	66
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	980,047	4,380	764	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	2,164,863	6,205	656	60
C NW NE 19-30-48	Sletvold B1	Tule	6,005,777	9,125	1,544	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	2,164,863	7,665	429	140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	641,248	2,190	273	102
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	2,452,707	1,095	854	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,186,616	1,095	567	44
SE NW NE 10-28-51	Huber 1-W	Poplar	5,068,610	9,125	643	146
NW SE 10-28-51	Reynolds EPU 8	Poplar	15,975,426	2,555	1,952	50
SW NW SW 22-28-51	Bierre 1	Poplar	4,795,534	5,110	1,543	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,210,118	1,825		
SW NW 7-29-51	Buck Elk 2	Poplar	3,263,920	6,570	1,394	20
SW SW 28-29-51	EPU 29-D	Poplar	3,709,121	1,825	1,140	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	448,204	5,475	428	52

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,590	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 15%.

Based on the analysis of the data, it is clear that the exempted areas will need to be expanded, if portions of the aquifer where injection is occurring are determined to be USDW's. Given the fact that flow will not be radial because of geologic structure, fluid density differences, and existing gradient, it is recommended that the area of exemption be at least 1/2 mile. There are, however, four operating wells which would need a slightly larger exemption (if an exemption is required), because of the large volume of fluids already injected. The wells in question are EPU 29-D, Reynolds EPU-8, Allotted Hall SWD, and Courchene 1-D.

In summary, there are wells in the Poplar Field which have injected sufficient quantities of water to impact reservoir water beyond the 1/4 of a mile radius. Additionally, there is a well in the Volt Field and a well in Deadman's Coulee Field which have exceeded the 1/4 mile radius. When these four wells are permitted, any exemption deemed necessary should be for a minimum of 1/2 mile to a mile. Any other wells which are permitted should be evaluated using radius of fillup calculations for the proposed life of the well, in order to estimate the potential size of the exempted area.

2. <u>What is the ambient quality of the Judith River Fm. over the entire Reservation? Is this even determinable?</u>

The Judith River Fm. consists of approximately 500 feet of grayish-white sandstone and light to dark gray sandy shale and clay. Locally, beds of coal and carbonaceous shale occur, such as that encountered in wells on the western edge of the Reservation near Glasgow, Montana. Individual beds of sandstone or shale are not always continuous either in thickness or character, and consequently the sequence of alternating types of rock differs laterally.

The number of sandstone beds and the distance of such beds below the top of the Judith River Fm., are not the same in all localities. Generally, there are two major sandstone layers in the Judith River Fm. on the west side of the Reservation. The Judith River Fm. (400 to 100 feet thick on the Reservation) thins from west to east. The sand layers inter-tongue from east to west and only one layer is present in the Poplar Field area. The Judith River Fm. outcrops west of the Reservation and plunges to the east. There is also a steep plunge to the southeast off the Poplar Dome.

There is a limited amount of data on the water quality and the hydrology of the Judith River Fm. Based on the structural geology of the Fort Peck area and the location of the outcrop of the Judith River Fm., the direction of ground-water flow is most likely from the west to the east and southeast. Water quality data indicate an increase in TDS from west to east. Although Judith River Fm. water quality is marginal for drinking, it is used in the western portion of the Reservation for livestock purposes. Table 4 gives the location of wells for which TDS information is available. As indicated, the TDS ranges from less than 2,000 mg/l in a well in T34N, R40E, to more than 18,000 mg/l in a well in T29N, R51E.

Table 4

Total Dissolved Solids Content
Samples from the Judith River Formation

LOCATION		TOTAL DEPTH (ft.)	SAMPLE DATE	TDS (mg/liter)	REMARKS
Sec. 6	T27NR40E	495	1978	2802	
Sec. 31	T28NR40E	555	1978	2126	
Sec. 11	T34WR40E	405	1982	1444	
Sec. 31	T36NR90E	1700	1971	2303	
Sec. 14	T26W,R41E	936	1947	2419	
Sec. 2	T27N,R41E	695	1978	2724	
Sec. 30	T28N,R41E	454	1978	2851	
Sec. 35	T28N,R41E	685	1978	2765	
Sec. 34	T27N,R44E	1090	1947	4133	
Sec. 15	T27N,R47E	985	1947	3862	
Sec. 22	T27N,R47E	1100	1947	3552	City of Wolf Point
Sec. 15	T30N,R48E	1411	1964	15,602	DST (?)
Sec. 13	T28N,R50E	874	1954	11,475	DST
Sec. 19	T29N,R51E	877	1957	18,624	DST (?)
Sec. 15	T30N,R49E	1600	1964	16,653	DST (?)
Sec. 24	T36N,R52E	1940	1957	10,385	DST
Sec. 4	T30N,R46E	1432	1965	15,056	(?)
Sec. 29	T29N,R49E	1270	1982	11,323	DST

As can be seen in the values of TDS, there is a great deal of variation within given areas. This may reflect poor "quality assurance" in either the sampling or analysis. This is especially true of the data obtained by drill stem tests. For instance, the sample from the Courchene 1-D had a calculated TDS of about 15,000 mg/l. The sample was not clear, indicating that some contamination may have been present. Additionally, this sample does not compare with the data from the wells at Wolf Point, which have TDS values of less than 4,000 mg/l.

The Wolf Point wells are about six miles east and 15 miles south of the Courchene 1-D well in the Tule Field. Given the apparent west to east flow, it is difficult to postulate why the quality would have so much variability in a north-south direction.

For purposes of this report, the data obtained from DST samples were considered to be output, except where documentation indicated a valid sample. The apparently valid data verify that quality does change from west to east. The TDS information obtained from the samples in T28 and 29N, R48, 49, and 51E do not match with the samples taken on T26N, R52E, and T29N, R49E. This may be related to sampling error. The sample taken in T36N, R52E had sufficient documentation to show that it was representative of the Judith River Fm.

Ignoring the samples that are questionable, it can be intimated that the TDS increases from about 4,000 mg/l in T27N, R47E to about 11,000 mg/l in T28N, R50E (a distance of 10 to 15 miles). Water quality data from the Poplar Field support a finding that the TDS has always been in excess of 10,000 mg/l.

Data from several electric logs were used to estimate the TDS in several oil wells drilled in various parts of the Reservation. These estimates were made using Archie's law:

$$R_W = R_O/F$$

Where:

R_W = resistivity of the formation water;
R_O = resistivity of the formation including the water it contains obtained from log);
F = Formation factor which depends on the porosity and other characteristics of the unit.

The Formation Factor is an empirical constant which depends on such formation characteristics as porosity. In the Judith River Fm. case the formation factor was estimated using the electric log and the actual value of TDS from the Hall #1 SWD well in Section 29, T29N, R49E. The calculations are as follow:

R_W (at 168°F) = 0.24 (from Welex charts on salinity)
BHT = 168°F
TDS = 11,000 mg/l
R_O = 3.0 ohm-m (from log)
F = R $_O/R_W$ = 3.0/0.24
F = 12.5

The Formation Factor was used to estimate the TDS content of the Judith River Fm., using logs run on several wells along an east-west line. Table 5 gives the information from the logs and the resulting estimates of total dissolved solids.

Table 5

Estimates of TDS Using Resistivity

NAME	LOCATION	BHT	R_o	R_w	TDS
#1 Gess	Sec. 1 T30NR463	179°F	10.1	0.81	3000
#1 Rodger	Sec. 15 T31NR42E	158°F	6.5	0.52	5300
Franz #1	Sec. 30 T31NR45E	140°F	15	1.2	2500
C. Reddig #2	Sec. 30 T31NR44E	165°F	6	0.48	5500
C. Reddig #2		165°F	8.5*	0.68	3800
#1-7 Bectman	Sec. 7 T30NR46E	155°F	7.5	0.6	4400
Clark #1-MA	Sec. 4 T29NR49E	168°F	3.0	0.28	9500

* Note: It was not possible to determine which track was the deep focused R value. The 2nd track had a large value of R.

These estimates indicate that the TDS content from wells west of the Poplar Field is less than 10,000 mg/l. This information provides some support to the data from the well in Wolf Point (Section 22,T27N,R47E), which has a TDS of about 3,500 mg/l. This would indicate that a gradual increase in TDS occurs as water moves from west to east, such that wells about 16 miles to the northeast have a TDS in excess of 10,000 mg/l. It is important to note, however, that calculations using the Formation Factor are questionable at best because of the lack of reliable quality data and good electric logs.

In summary, existing data indicate that the Judith River Fm. is a USDW on the western edge of the Reservation. The TDS concentration of the water in the formation increases towards the east such that the aquifer is not a USDW in the Poplar Field. Data from the Allotted Hall SWD well in Deadman's Coulee Field (supported by documentation indicating that the sample was representative) indicate that the portion of the Judith River Fm. in this area was not a USDW prior to any injection. There is insufficient data available to delineate the actual boundary of the USDW, but it is possible to state that the Poplar Field is not a USDW. The Judith River Fm. underlying the Volt, Tule, and Benrud Fields however, may have been a USDW prior to injection.

3. Is the Judith River Fm. sufficiently confined to prevent contamination of overlying USDW's?

The Judith River Fm. on the Fort Peck Reservation is overlain by the Bearpaw Shale, which also dips from west to east. The western margin of the Bearpaw is located west of Glasgow, Montana. The depth to the Judith River Fm. on the Reservation ranges from about 500 to about 1,300 feet. This depth

to the Judith River Fm. is dependent on the geologic structure and the surface topography. The Judith River Fm. is at shallow depths in the East Poplar Field because of the Poplar Dome and the presence of the Poplar River Valley. Generally, however, the Judith River Fm. is shallowest on the western edge of the Reservation.

The Bearpaw Shale is a gray marine shale, sandy in the upper portions, and is gradational with the overlying Fox Hills Sandstone. The total thickness of the Bearpaw is about 1,200 feet. The shale is tight except in the upper part or in places where it has been deeply weathered, and it generally will not yield water to a well. Any water that might be obtained from permeable zones in the shale probably would be too highly mineralized for domestic or stock use. This is evidenced by the presence of numerous saline seeps (associated with the fallowing practices used in some dry/land farming). Water from saline seeps has been found to have a total dissolved solids content ranging from 5,000 to 70,000 mg/l.

Available well data indicate that the Judith River Fm. is under confined conditions such that wells flow at the surface. For instance, two wells located near Wolf Point were under flowing condtions in 1947. Surface pressures measured in the Poplar and Tule Fields are as high as 900 psi. While much of this pressure is in response to the existing injection activity, initial shut-in pressures indicate that even without injection, wells in the oil fields would probably flow at the surface.

No data on actual fracture pressure of the Judith River Fm. is available. However, analysis of injection pressures, reported by Larry Monson, indicates that many of the wells are presently injecting at pressures which may exceed the fracture pressure of the formation. Although one operator indicated that the fracture gradient was 1.25 psi/ft, no documentation was provided to verify this claim.

It is unlikely that the fracture gradient of the Judith River Fm. exceeds 1.0 psi/ft. Even if the reservoir is fractured, the overlying shales may be of sufficient thickness to prevent fractures such that fluid will not migrate into USDW's overlying the 800 to 1,000 feet of shale. Field studies have shown that injection energy dissipates rather quickly once the fractures move out of the reservoir. The fracturing of the reservoir on the other hand could present a problem. It will provide discreet zones of high permeability which will provide avenues for injected fluid to move further from the well than estimated by the radial flow calculations.

Based on the thickness and low permeability of the Bearpaw Shale, combined with the evidence that the Judith River Fm. is under confined conditions, it appears that the Bearpaw Shale is adequate to prevent movement out of the confining zone. This may depend however, on the actual fracture gradient of the Judith River Fm. and the Bearpaw Shale. Although injection activities will have some impact on the pre-injection flow patterns of the Judith River Fm., there is inadequate data to develop a map to show these actual flow patterns. In order to develop such a map, it would be necessary to shut in all of the injection wells and measure the shut-in pressure.

4. Is fluid migration (east to west) a real possibility given that the Judith River Formation is pinched off by the Bearpaw Shale on the eastern edge of the Reservation?

As discussed previously, the Judith River Fm. dips from west to east towards the Williston Basin. This formation outcrops at the surface near the Milk River, West of Glasgow and is considered to be a significant location for recharge to the Judith River Fm. The pre-injection flow pattern was probably west to east, with a southern component of flow, especially in the Poplar Dome area.

The dip of the Judith River Fm. increases east of the Dome due to the presence of the Williston Basin, which is a deep synclinal trough.

Available logs and cross sections indicate that the depth of the Judith River Fm. increases by 900 feet between a well in Section 29, T29N, R50E and a well in Section 35, T29N, R52E, which is a distance of about 10 miles.

The sand units in the Judith River Fm. also thin from thicknesses of about 80 feet to about 10 feet. Some experts have indicated (Larry Monson, personal conversation, 1985) that the sand unit is not present further out in the Williston Basin. A well in Section 28, T29W, R55E, however, shows a Judith River Fm. sand thickness of about 100 feet. Based on this data it is clear that the Judith River has good sand present well out into the basin. It is not possible without looking at well logs from holes in North Dakota, to speculate on the full extent of the Judith River Fm. and its discharge zones.

Data on the permeability and porosity of the Judith River Fm. sandstone is not readily available but Feltis indicated that a porosity of 10 to 20% and a permeability of 25 millidarcies (MD) was reasonable. Marvin Miller, of the Montana Bureau of Mines, indicated that an analysis of limited DST data indicated a range of permeabilities from 55 MD to 109 MD. This data can be used to estimate the pressure buildup at a given radius from injection using the following equation:

$$Pr = Pi + (70.6 \times \frac{Q \times U \times B}{K \times b}) \quad E \frac{39.5\ 0 \times U \times C \times r2}{K \times t}$$

where:

P_r = Pressure at a given radius (psi);
P_i = Initial pressure (psi);
Q = Constant injection rate (barrels/day);
B = Formation volume factor = 1;
c = compressibility (psi $^{-1}$) = 7.5×10^{-6};
U = viscosity (cp) = 1;
K = permeability (MD);
b = thickness of reservoir (ft)
0 = porosity
E = Exponential integral

For purposes of this evaluation of pressure buildup, the following is assumed:

a. flow is radial;
b. the initial pressure is zero;
c. well interference is not taken into account;
d. porosity and thickness are constant;
e. the well is fully penetrating;
f. the radius of the injection well is assumed to be 0.5 ft.; and
g. the injection rate is estimated using the total volume injected since a given well began operation and assumes the rate was constant.

Table 6 gives the estimated pressure buildup at the injection wells assuming a permeability of 25 MD and a porosity of 15%. The table also lists the current measured well head pressure. As indicated in the table, the estimated pressure buildup lies on both sides of the measured values. Generally, the estimates were not greatly divergent from measured values.

The results provide a qualitative measure of the possible variations of permeability. The largest divergence was in the EPU-8 well and the Allotted Hall SWD well. This divergence may be caused by a higher permeability value than was assumed; a larger thickness of reservoir than assumed; or an over estimation of the volume disposed.

Table 7 lists estimates of pressure buildup at the well and at a radius of 5 miles, assuming permeabilities of 55 MD and 109 MD. The pressure buildups at the wells are more realistic than those estimated assuming a permeability of 25 MD. This is especially true in light of the fact that there was an initial positive formation pressure in the field, which was assumed to be zero for purposes of these calculations. The important point of these estimates is that all wells are causing significant pressure increases several miles from the well.

The data presented in Tables 6 and 7 indicate that injection in the Poplar Field has created significant pressure changes around the wells, which will reach at least 5 miles to the east and west. The pressure mound will be elongated in a north and south direction because of the interference effects of several injection wells which lie in a north-south line over a distance of about 8 miles. In the author's opinion, this pressure mound has influenced the ground-water flow pattern of the Judith River Fm. This disruption will most likely cause more flow to the south, although some increased ground-water flow to the north will occur.

There will be some westerly flow in the immediate vicinity of the injection wells, but the extent of this ground water flow reversal is not possible to estimate, although it is probably less than one or two miles.

TABLE 7. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of hydraulic conductivity of 25 millidarcies and porosity of 15%.

TABLE 6. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				conductivity = 55 md		conductivity = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 MILES	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Conductivity measured in millidarcys; porositiy assumed to be 15%.

A point of note is that the injection pressure, in feet of water, in the Tule Field is about 100 feet higher than that in the Poplar Field. This indicates that the overall gradient is still to the east. The large injection pressures in the Poplar Field will however, result in a flattening of the gradient betwen the Tule and Poplar Fields.

Any direct water quality impact due to injected water will be less than one mile to the west based on estimates for the radius of fillup. The pressure mound will have an indirect impact on water quality in that it will increase the length of the flow path. This will probably result in an increase in total dissolved solids. There will also be an indirect water quality impact caused by the displacement of the original formation water towards the west where the water quality was better (lower TDS).

5. What alternative water sources are there on the Reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e. greater than 10,000 mg/l, less than 10,000 mg/l for other sources of drinking water)?

Although the Judith River Fm. does supply water for livestock use on the western edge of the Fort Peck Reservation, most of the ground water used for domestic purposes is supplied from geologic units which overlie the Judith River Fm. The major sources are alluvial aquifers, terrace deposits, glacial outwash deposits and sand lenses in the glacial till. The Fox Hills, the Hell Creek and the Fort Union aquifers supply some water in areas east of Poplar, Montana. Table 8 shows the TDS content of water from a representative sample of wells tapping the major water sources.

Table 8

Total Dissolved Solids Content of Aquifers Overlying the Judith River Formation-Fort Peck Indian Reservation

WELL LOCATION		AQUIFER	TOTAL DISSOLVED SOLIDS (mg/l)
Sec. 28	T29NR46E	Alluvium	592
Sec. 10	T29NR51E	Alluvium	809
Sec. 36	T30NR55E	Alluvium	less than 1,000
Sec. 5	T29NR51E	Alluvium	704
Sec. 32	T30N355E	Fort Union	less than 1,000
Sec. 25	T30NR45E	Fox Hills	300
Sec. 19	T28WR53E	Hell Creek	2,540
Sec. 13	T28NR58E	Fort Union	less than 500
Sec. 34	T31NR57E	Till	less than 1,000
Sec. 28	T31NR57E	Fort Union	less than 1,500
Sec. 33	T33NR44E	Alluvium	295
Sec. 29	T27NR51E	Alluvium	1503
Sec. 3	T27NR49E	Alluvium	980
Sec. 25	T28NR53E	Alluvium	2788
Sec. 2	T30NR46E	Flaxville	329

As indicated, the water quality of the alluvium and the Fox Hills is generally excellent. Note: a complete listing of wells (for which water quality data is available is attached as Appendix 1). Some alluvial wells have TDS contents in excess of 1,000 mg/l but most have TDS contents of less than 1,000 mg/l. The TDS content of water from the Fort Union is somewhat higher, but then water from the alluvial aquifers is usable for domestic purposes.

Data on the areal extent of the shallow aquifers is not available. It is apparent, however, that most of the alluvial and outwash deposits are as limited in their areal extent, as are the Fort Union and Fox Hills Fms. in their subsurface extents. They are not present over the western portion of the Reservation. The Fort Union Fm. apparently extends only as far west as the Poplar Field.

Because of the absence of good maps showing the extent of the various aquifers, it is not possible to develop a map with TDS concentration contours. It is clear, however, that all of the shallow aquifers qualify as USDW's and are the major sources of drinking water in the area. It is worth noting that the major threat to the shallow aquifers in the vicinity of the oil fields appears to be poor surface waste handling practices.

9/26/85

Summary of Judith River Decision

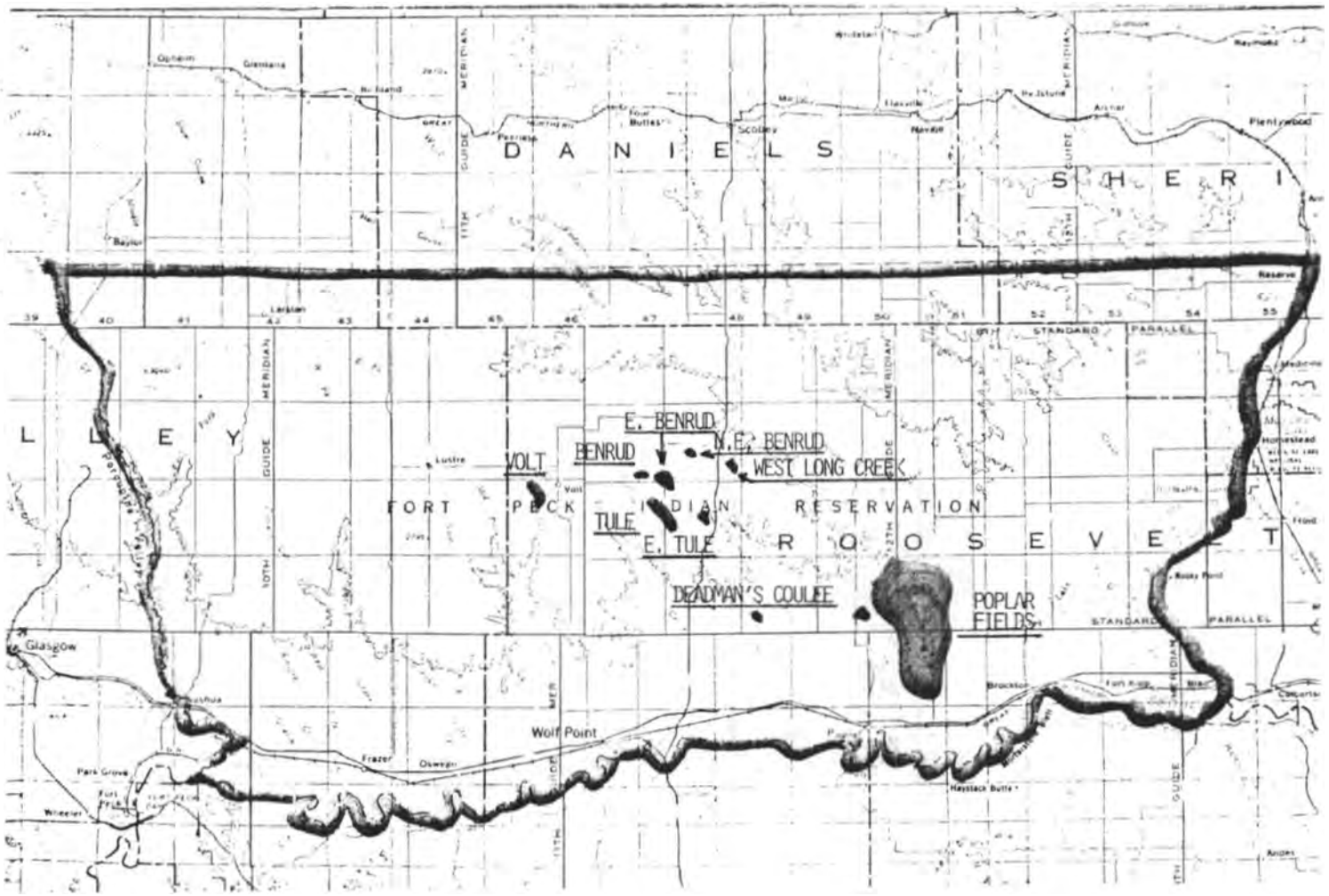
1) The Poplar/NW Poplar was ~~determined~~ probably never a USDW. ~~so injection~~ Also, water sample from Hall SWD in Deadman's Coulee Field was very reliable and also shows J.R. not a USDW.

2) Other Fields (Tules, Beauruds, Volt, Long Creek) probably were USDWs. ~~Therefore~~ Therefore, continuance of Injection should be limited to the original 1/4 mile ag. exemp area. When wells are permitted, this will be reviewed and permits will have limited injection periods.

3) No new injection wells will be allowed into the J.R. when TDS < 10,000 mg/l.

4) ~~It~~ was determined fluid migration east to west from Poplar Field is not likely.

5) Alternative sources of water supply are currently available and are being used.


D A N I E L S
S H E R I
L E Y
FORT PECK INDIAN RESERVATION
R O O S E V E L T
E. BENRUD
N.E. BENRUD
BENRUD
WEST LONG CREEK
VOLT
TULE
E. TULE
DEADMAN'S COULEE
POPLAR FIELDS
Glasgow
Wolf Point
Frazer
Oswego
Park Grove
Wheeler
Fort Peck
Haystack Butte
Brockton
Fort Kipp
Scobey
Plentywood
Opheim
Glentana
Baylor
Larslan
Lustre
Reserve
Medicine Lake
Homestead
STANDARD PARALLEL
GUIDE MERIDIAN
10TH
11TH
12TH
17TH

		(t calc. days) Exceed 1/4 mile	radius of fill up	USDW
T	Conchene	✓	✓	
T	Suetvold B1	✓	✓	
DC.	Hall SWD	✓		No
P	Goings 1	✓		No
P	Reynolds EPN 8	✓	✓	No
	Biere 1 (PA)	✓	✓	
P	Bulk Elk 2	✓	✓	No
P	EPU 29-D.	✓		No

Flow pattern of J.R. will change due to pressure build up – will increase TDS more time in situ

Direct effects will be rather localized
Indirect effects (Native water TDS increasing) will be somewhat to the west but prob. not very far

THE FOLLOWING PERMIT APPLICATIONS WILL BE AFFECTED

BY THE OUTCOME OF THE FORT PECK PUBLIC HEARING HELD MAY 29th.

ALL INJECT INTO THE JUDITH RIVER FORMATION.

		Permit No.	Well Name	Owner/Operator	Assigned to:
Lustre 2	1.	MTS21LS-0038	Mann #1	Pennzoil	not assigned yet
Tule Cr.	2.	MTS21TC-0039	Lough #2	Petro Lewis	not assigned yet
Poplar	3.	MTS21PR-0003	Goings #1	Century Oil & Gas	Boyter
Deadman's Coulee	4.	MTS21DM-0034	Allotted Hall SWD	Reading & Bates	Herman
E. Poplar	5.	MTS21PE-0024	E. Poplar 29-D	Murphy Oil	Campbell
E. Poplar	6.	MTS21PE-0023	E. Poplar 8-D	Murphy Oil	Liuzzi
E. Tule	7.	MTS21TE-0035	Lillian 1-D	Murphy Oil	~~Strieby~~
Tule Creek	8.	MTS21TC-0035	Sletvold B-1	Murphy Oil	~~Strieby~~
E. Poplar 10/2/85	9.	MTS21PE-0009	Buck Elk	Grace	Clemmens
	**	MTS21PE-0025	E. Poplar 59-D	Murphy Oil	Campbell

(Note: This well shut-in; Murphy wanted to withdraw application but were told they could not.)

Called in. 10. — Tract #2 Ptm

TABLE 1. TRAVEL TIME FROM INJECTION WELL TO A GIVEN POINT, R

LOCATION	WELL NAME	VOLUME INJECTED PER DAY (ft^3/day)	TRAVEL TIME (days) R = 1,000 feet			R = 2,640 feet		
			Ø = .1	Ø = .165	Ø = .20	Ø = .1	Ø = .165	Ø = .20
SE SW 4-30-46	Courchene 1-D	7,300	2,366	3,904	4,732	16,488	27,206	32,976
NW NE 9-30-46	Carlson	1,291	7,297	23,039	14,594	50,855		
SE NE 13-30-47	Phillips-McKee	5,351	4,108	6,772	8,216	28,629		57,258
C SE SW 13-30-47	Lough 2	3,099	4,762	7,857	9,524	33,190		
NE NE SW 34-31-47	A 1-W Listug-Olson							
SW NE SW 36-31-47	Wetsit 1	3,296	6,288	10,375	12,576	43,822		87,644
NW NE 6-30-48	Bigtrack Little 1	1,259	4,988	8,230	9,976	34,765		
NW SE NE 15-30-48	Bridges 1-D	1,959	9,617	15,868	19,234	67,028		
C NW NE 19-30-48	Sletvold B1	3,694	2,550	4,208	5,100	17,773	29,325	35,546
SW SE 20-31-48	Mule Creek 1-D	1,583	27,770	45,821	55,540	193,546		
SE NE 25-31-48	Mann 1 SWD	1,645	19,470	32,125	38,940	135,697		
NW NE 29-29-49	Hall SWD	12,576	998	1,647	1,996	6,064	11,486	13,922
NE NW 27-29-50	Goings 1	6,086	2,270	3,745	4,540	15,822		31,644
SE NW NE 10-28-51	Huber 1-W	3,116	14,712	24,274	29,424	102,540		
NW SE 10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
SW NW SW 22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
SW NW 7-29-51	Buck Elk 1	3,722						
SW NW 7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
SW SW 28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
SW SW SW 31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

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TABLE 1
TRAVEL TIME FROM INJECTION WELL
TO A GIVEN POINT

LOCATION	WELL NAME	VOLUME INJ.* PER DAY (FT^3/DAY)	TRAVEL TIME (DAYS) R = 1000 ft. Ø = .1	Ø = .165	Ø = .20	R = 2640 ft. Ø = .1	Ø = .165	Ø = .2
4-30-46	Courchene 1	7300	2366	3904	4732	16,488	27206	32,976
9-30-46	Carlson	1291	7297	12,039	14594	50,855		
13-30-47	Phillips-McKee	5351	4108	6,772	8216	28,629		57,258
13-30-47	Lough 2	3099	4762	7,857	9524	33,190		
34-31-47	A 1-W Listug-Olsen							
36-31-47	Wetsit 1	3296	6288	10,375	12,576	43,822		87,644
6-30-48	Bigtrack Little 1	1259	4988	8,230	9,976	34,765		
15-30-48	Bridges 1-D	1959	9617	15,868	19,234	67,028		
19-30-48	Sletvold B1	3694	2550	4,208	5,100	17,773	29,325	35,546
20-31-48	Mule Creek A11 1D	1583	27770	45,821	55,540	193,546		
25-31-48	Mann 1 SWD	1645	19470	32,125	38,940	135,697		
29-29-49	Hall SWD	12576	998	1,647	1,996	6,964 69,61	11,486	13,922
27-29-50	Goings 1	6086	2270	3,745	4,540	15,822		31,644
10-28-51	Huber 1-W	3116	14,712	24,274	29,424	102,540		
10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
7-29-51	Buck Elk 1	3,722						
7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

TABLE 1
TRAVEL TIME FROM INJECTION WELL
TO A GIVEN POINT

LOCATION	WELL NAME	VOLUME INJ.* PER DAY (FT^3/DAY)	TRAVEL TIME (DAYS) R = 1000 ft. Ø = .1	Ø = .165	Ø = .20	R = 2640 ft. Ø = .1	Ø = .165	Ø = .2
4-30-46	Courchene 1	7300	2366	3904	4732	16,488	27206	32,976
9-30-46	Carlson	1291	7297	12,039	14594	50,855		
13-30-47	Phillips-McKee	5351	4108	6,772	8216	28,629		57,258
13-30-47	Lough 2	3099	4762	7,857	9524	33,190		
34-31-47	A 1-W Listug-Olsen							
36-31-47	Wetsit 1	3296	6288	10,375	12,576	43,822		87,644
6-30-48	Bigtrack Little 1	1259	4988	8,230	9,976	34,765		
15-30-48	Bridges 1-D	1959	9617	15,868	19,234	67,028		
19-30-48	Sletvold B1	3694	2550	4,208	5,100	17,773	29,325	35,546
20-31-48	Mule Creek All 1D	1583	27770	45,821	55,540	193,546		
25-31-48	Mann 1 SWD	1645	19470	32,125	38,940	135,697		
29-29-49	Hall SWD	12576	998	1,647	1,996	69,61	11,486	13,922
27-29-50	Goings 1	6086	2270	3,745	4,540	15,822		31,644
10-28-51	Huber 1-W	3116	14,712	24,274	29,424	102,540		
10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
7-29-51	Buck Elk 1	3,722						
7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

TABLE 2
RADIUS OF FILL UP OF JUDITH
RIVER INJECTION WELLS
FT. PECK INDIAN RESERVATION

LOCATION		NAME	FIELD	VOLUME DISPOSAL (BBLS)	TIME SINCE START UP (DAYS)	RADIUS* OF FILL UP	SAND THICK
SE SW	4-30-46	Courchene 1-D	Volt	9,490,953	7300		
NW NE	9-30-46	Carlson	Volt	837,942	3650	577	30
SE NE	13-30-47	Phillips - McKee	Tule	1,391,601	1460	987	70
C SE SW	13-30-47	Lough 2	Tule	3,830,468	6935	986	47
NE NE SW	34-31-47	A 1-W Listug-Olsen	Benrud	642,238		330	70
SW NE SW	36-31-47	Wetsit 1	E. Benrud	4,074,613	6935	585	66
NW NE	6-30-48	Bigtrack Little 1	E. Benrud	980,047	4380	764	20
NW SE NE	15-30-48	Bridges 1-D	E. Tule	2,164,863	6205	656	60
C NW NE	19-30-48	Sletvold B1	Tule	6,005,777	9125	1544	30
SW SE	20-31-48	Mule Creek All 1D	N. E. Benrud	2,164,863	7665	429	140
SE NE	25-31-48	Mann 1 SWD	W. Long Creek	641,248	2190	273	102
NW NE	29-29-49	Hall SWD	Deadman's Coulee	2,452,707	1095	854	40
NE NW	27-29-50	Goings 1	N.W. Poplar	1,186,616	1095	567	44
SE NW NE	10-28-51	Huber 1-W	Poplar	5,068,610	9125	643	146
NW SE	10-28-51	Reynolds EPU 8	Poplar	15,975,426	2555	1952	50
SW NW SW	22-28-51	Biere 1	Poplar	4,795,534	5110	1543	24
SW NW	7-29-51	Buck Elk 1	Poplar	1,210,118	1825		
SW NW	7-29-51	Buck Elk 2	Poplar	3,263,920	6570	1394	20
SW SW	28-29-51	EPU 29-D	Poplar	3,709,121	1825	1140	34
SW SW SW	31-31-48	Stai 1 SWD	E. Benrud	448,204	5475	428	52

* The radius of fill up calculation assumed a porosity of 15%

TABLE 2
RADIUS OF FILL UP OF JUDITH RIVER
INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	NAME	FIELD	VOLUME DISPOSAL (BBLS)	TIME SINCE START UP (DAYS)	RADIUS* OF FILL UP	SAND THICKNESS
SE SW 4-30-46	Courchene 1-D	Volt	9,490,953	7,300		
NW NE 9-30-46	Carlson	Volt	837,942	3,650	577	30
SE NE 13-30-47	Phillips-McKee	Tule	1,391,942	1,460	987	70
C SE SW 13-30-47	Lough 2	Tule	3,830,468	6,935	986	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud	642,238		330	70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	4,074,613	6,935	585	66
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	980,047	4,380	764	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	2,164,863	6,205	656	60
C NW NE 19-30-48	Sletvold B1	Tule	6,005,777	9,125	1,544	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	2,164,863	7,665	429	140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	641,248	2,190	273	102
NW NE 29-29-49	Hall SWD	Deadman's Coulee	2,452,707	1,095	854	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,186,616	1,095	567	44
SE NW NE 10-28-51	Huber 1-W	Poplar	5,068,610	9,125	643	146
NW SE 10-28-51	Reynolds EPU 8	Poplar	15,975,426	2,555	1,952	50
SW NW SW 22-28-51	Biere 1	Poplar	4,795,534	5,110	1,543	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,210,118	1,825		
SW NW 7-29-51	Buck Elk 2	Poplar	3,263,920	6,570	1,394	20
SW SW 28-29-51	EPU 29-D	Poplar	3,709,121	1,825	1,140	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	448,204	5,475	428	52

TABLE 3
RADIAL DISTANCE OF INJECTION FRONT
WITH AND WITHOUT DISPERSION

LOCATION	NAME	SAND THICKNESS	TOTAL VOLUME INJECTED	RADIUS OF* FILL UP (FT.)	RADIUS OF FILL UP** WITH DISPERSION
4-30-46	Courchene 1-D	59	9,490,953	1242	1382
9-30-46	Carlson	30	837,942	499	587
13-30-47	Phillips - McKee	70	1,391,601	421	502
13-30-47	Lough 2	47	3,830,468	853	969
34-31-47	A 1-W Listug-Olsen	70	642,238	286	353
36-31-47	Wetsit 1	66	4,074,613	742	850
6-30-48	Bigtrack Little 1	20	980,047	661	763
15-30-48	Bridges 1-D	60	2,164,863	567	662
19-30-48	Sletvold B1	30	6,005,777	1338	1483
20-31-48	Mule Creek All 1D	140	2,164,863	371	447
25-31-48	Mann 1 SWD	102	641,248	237	298
29-29-49	Hall SWD	40	2,452,707	740	848
27-29-50	Goings 1	44	1,186,616	491	579
10-28-51	Huber 1-W	146	5,068,610	557	651
10-28-51	Reynolds EPU 8	50	15,975,426	1690	1853
22-28-51	Biere 1	24	4,795,534	1336	1482
7-29-51	Buck Elk 1		1,210,118		
7-29-51	Buck Elk 2	20	3,263,920	1208	1346

TABLE 3 CONT'D

LOCATION	NAME	SAND THICKNESS	TOTAL VOLUME INJECTED	RADIUS OF* FILL UP (FT)	RADIUS OF FILL UP** WITH DISPERSION
28-29-51	EPU 29-D	34	3,709,121	988	1113
31-31-48	Stai 1 SWD	52	448,204	277	343

* The radius of fill up calculation assumed a porosity of 20%

TABLE 3
RADIAL DISTANCE OF INJECTION FRONT
WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS	TOTAL VOLUME INJECTED	RADIUS OF* FILL UP (FT.)	RADIUS OF FILL UP** WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,690	1,853
SW NW SW 22-28-51	Biere 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

TABLE 6
PRESSURE BUILDUP

LOCATION		NAME	FIELD	DAYS SINCE INITIAL INJECT. (DAYS)	ESTIMATED PRESSURE * BUILDUP (PSI) R = 0.5 FT.	R = 5 MILES	ESTIMATED PRESSURE ** BUILDUP R = 0.5 ft.	R = 5 MILES	SAND THICKNESS
SE SW	4-30-46	Courchene 1-D	Volt	7300					
NW NE	9-30-46	Carlson	Volt	3650	246	32	118	10	30
SE NE	13-30-47	Phillips - McKee	Tule	1460	422	43	201	11	70
C SE SW	13-30-47	Lough 2	Tule	6935	377	59	185	20	47
NE NE SW	34-31-47	A 1-W Listug-Olsen	Benrud						70
SW NE SW	36-31-47	Wetsit 1	E. Benrud	6935	334	40	1654	18	56
NW NE	6-30-48	Bigtrack Little 1	E. Benrud	4380	363	50	172	15	20
NW SE NE	15-30-48	Bridges 1-D	E. Tule	6205					60
C NW NE	19-30-48	Sletvold B1	Tule	9125	737	119	339	40	30
SW SE	20-31-48	Mule Creek All 1D	N.E. Benrud	7665					140
SE NE	25-31-48	Mann 1 SWD	W. Long Creek	2190					102
NW NE	29-29-49	Hall SWD	Deadman's Coulee	1095	1708	155	831	37	40
NE NW	27-29-50	Goings 1	N.W. Poplar	1095	1106	101	359	16	44
SE NW NE	10-28-51	Huber 1-W	Poplar	9125					146
NW SE	10-28-51	Reynolds EPU 8	Poplar	2555	5814	709	1894	140	50
SW NW SW	22-28-51	Biere 1	Poplar	5100	1275	182	601	60	24
SW NW	7-29-51	Buck Elk 1	Poplar	1825					
SW NW	7-29-51	Buck Elk 2	Poplar	6570					20

TABLE 6 CONT'D
PRESSURE BUILDUP

LOCATION		NAME	FIELD	DAYS SINCE INITIAL INJECT. (DAYS)	ESTIMATED PRESSURE * BUILDUP (PSI) R = 0.5 FT	R = 5 MILES	ESTIMATED PRESSURE ** BUILDUP R = 0.5 FT	R = 5 MILES	SAND THICKNESS
SW SW	28-29-52	EPU 29-D	Poplar	1825			1010	62	34
SW SW SW	31-31-48	Stai 1 SWD	E. Benrud	3650					52

* Uses estimated hydraulic conductivity of 55 Md, ϕ = 0.15

** Uses estimated hydraulic conductivity of 109 Md, ϕ = 0.15

TABLE 6.
PRESSURE BUILDUP

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION	ESTIMATED PRESSURE * BUILDUP (PSI) R = 0.5 FT.	ESTIMATED PRESSURE * BUILDUP (PSI) R = 5 MILES	ESTIMATED PRESSURE ** THICKNESS R = 0.5 ft.	ESTIMATED PRESSURE ** THICKNESS R = 5 MILES
SE SW 4-30-46	Courchene 1-D	Volt	7,300				
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Hall SWD	Deadman's	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Biere 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

TABLE-7

PRESSURE BUILDUP ESTIMATE FOR
JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION		NAME	FIELD	DAYS SINCE INITIAL INJECTION	VOLUME INJECTED* PER DAY	PBU AT WELL**	REPORTED PRESSURE
SE SW	4-30-46	Courchene 1	Volt	7300	1300	0	470
NW NE	9-30-46	Carlson	Volt	3650	230	482	400
SE NE	13-30-47	Phillips-McKee	Tule	1460	953	820	478
C SE SW	13-30-47	Lough 2	Tule	6935	552	759	950
NE NE SW	34-31-47	A 1-W Listug-Olsen	Benrud				350
SW NE SW	36-31-47	Wetsit 1	E. Benrud	6935	587	575	700
NW NE	6-30-48	Bigtrack Little 1	E. Benrud	4380	224	709	400
NW SE NE	15-30-48	Bridges 1-D	E. Tule	6205	349	374	WR
C NW NE	19-30-48	Sletvold B1	Tule	9125	658	1435	800
SW SE	20-31-48	Mule Creek All 1D	N.E.	7665	282	131	630
SE NE	25-31-48	Mann 1 SWD	W. Long Creek	2190	293	176	300
NW NE	29-29-49	Hall SWD	Deadman's Coulee	1095	2240	3327	900
NE NW	27-29-50	Goings 1	N.W. Poplar	1095	1084	1465	750
SE NW NE	10-28-51	Huber 1-W	Poplar	9125	555	249	400
NW SE	10-28-51	Reynolds EPU 8	Poplar	2555	6253	7727	700
SW NW SW	22-28-51	Bierre 1	Poplar	5110	938	2494	400
SW NW	7-29-51	Buck Elk 1	Poplar	1825	663		400
SW NW	7-29-51	Buck Elk 2	Poplar	6570	497	1602	400
SW SW	28-29-51	EPU 29-D	Poplar	1825	2032	3640	650
SW SW SW	31-31-48	Stai 1 SWD	E. Benrud				

* The injection volume per day estimate is based on the assumption that injection has been continuous.
** The calculations of pressure build up at the well is based on the assumption of 25 and a porosity of 15%.

TABLE 7
PRESSURE BUILDUP ESTIMATE FOR
JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION	VOLUME INJECTED * PER DAY	PBU AT WELL**	REPORTED PRESSURE
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Biere 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

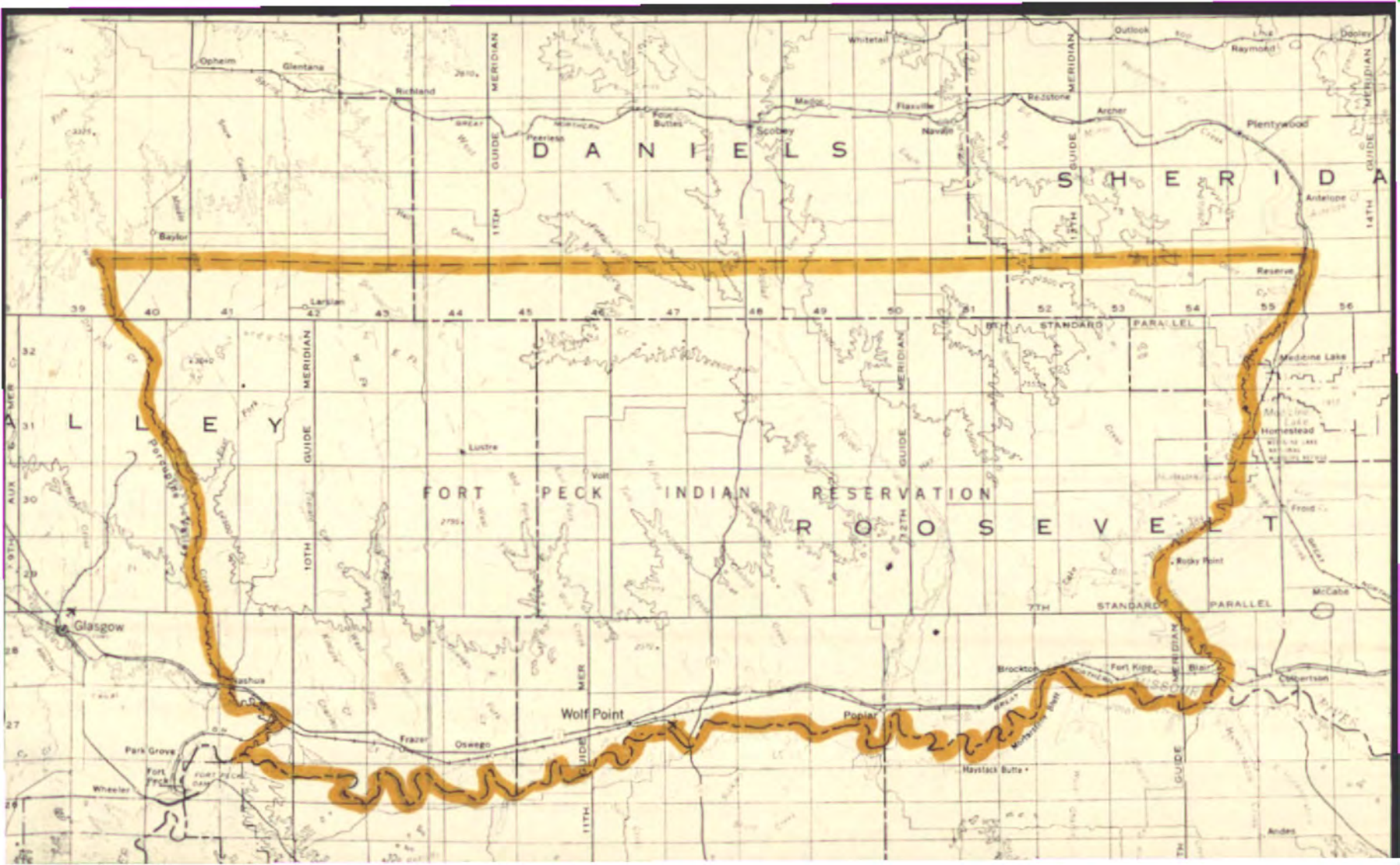
DANIELS
SHERIDA
ALLEY
FORT PECK INDIAN RESERVATION
ROOSEVELT
Opheim
Glentana
Richland
Peerless
Scobey
Flaxville
Westby
Outlook
Raymond
Dagney
Plentywood
Antelope
Baylor
Larslan
Lustre
Volt
Medicine Lake
Homestead
Froid
Rocky Point
McCabe
Glasgow
Nashua
Wolf Point
Frazer
Oswego
Poplar
Brockton
Fort Kipp
Blair
Park Grove
Fort Peck
Wheeler
Haystack Butte
Anders
Reserve
GREAT NORTHERN
MISSOURI RIVER
STANDARD PARALLEL
GUIDE MERIDIAN
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TABLE 7. PRESSURE BUILDUP ESTIMATE FOR JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	VOLUME * INJECTED PER DAY (bbls)	PRESSURE BUILDUP ** AT WELL (psi)	REPORTED PRESSURE (psi)
SE SW 4-30-46	Courchene 1-D	Volt	7,300	1,300	0	470
NW NE 9-30-46	Carlson	Volt	3,650	230	482	400
SE NE 13-30-47	Phillips-McKee	Tule	1,460	953	820	478
C SE SW 13-30-47	Lough 2	Tule	6,935	552	552	759
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud				350
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	587	575	700
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	4,380	224	709	400
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205	349	374	WR
C NW NE 19-30-48	Sletvold B1	Tule	9,125	658	1,435	800
SW SE 20-31-48	Mule Creek 1-D	N.E.	7,665	282	131	630
SE NE 25-31-48	Mann 1 SWD	W. Long	2,190	293	176	300
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	1,095	2,240	3,327	900
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,084	1,465	750
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125	555	249	400
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	6,253	7,727	700
SW NW SW 22-28-51	Bierre 1	Poplar	5,110	938	2,494	400
SW NW 7-29-51	Buck Elk 1	Poplar	1,825	663		400
SW NW 7-29-51	Buck Elk 2	Poplar	6,570	497	1,602	400
SW SW 28-29-51	EPU 29-D	Poplar	1,825	2,032	3,640	650
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud				

* Injection volume per day estimates based on assumption that injection has been continuous.

** Calculations of pressure buildup at the well are based on assumption of hydraulic conductivity of 25 millidarcies and porosity of 15%.

TABLE 6. PRESSURE BUILDUP AT A GIVEN DISTANCE, R

LOCATION	WELL NAME	FIELD	DAYS SINCE INITIAL INJECTION BEGAN	ESTIMATED PRESSURE BUILDUP * (psi)				SAND THICKNESS
				conductivity = 55 md		conductivity = 109 md		
				R=0.5 ft	R=5 miles	R=0.5 ft	R=5 MILES	
SE SW 4-30-46	Courchene 1-D	Volt	7,300					
NW NE 9-30-46	Carlson	Volt	3,650	246	32	118	10	30
SE NE 13-30-47	Phillips-McKee	Tule	1,460	422	43	201	11	70
C SE SW 13-30-47	Lough 2	Tule	6,935	377	59	185	20	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud						70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	6,935	334	40	1,654	18	56
NW NE 6-30-48	Bigtrack Little	E. Benrud	4,380	363	50	172	15	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	6,205					60
C NW NE 19-30-48	Sletvold B1	Tule	9,125	737	119	339	40	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	7,665					140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	2,190					102
NW NE 29-29-49	Allotted Hall SWD	Deadman's C.	1,095	1,708	155	831	37	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,095	1,106	101	359	16	44
SE NW NE 10-28-51	Huber 1-W	Poplar	9,125					146
NW SE 10-28-51	Reynolds EPU 8	Poplar	2,555	5,814	709	1,894	140	50
SW NW SW 22-28-51	Bierre 1	Poplar	5,100	1,275	182	601	60	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,825					
SW NW 7-29-51	Buck Elk 2	Poplar	6,570					20
SW SW 28-29-51	EPU 29-D	Poplar	1,825			1,010	62	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	3,650					52

* Conductivity measured in millidarcys; porositiy assumed to be 15%.

TABLE 3. RADIAL DISTANCE OF INJECTION FRONT WITH AND WITHOUT DISPERSION

LOCATION	WELL NAME	SAND THICKNESS (feet)	TOTAL VOLUME INJECTED (bbls)	RADIUS OF FILL-UP * (feet)	
				WITHOUT DISPERSION	WITH DISPERSION
SE SW 4-30-46	Courchene 1-D	59	9,490,953	1,242	1,382
NW NE 9-30-46	Carlson	30	837,942	499	587
SE NE 13-30-47	Phillips-McKee	70	1,391,601	421	502
C SE SW 13-30-47	Lough 2	47	3,830,468	853	969
NE NE SW 34-31-47	A 1-W Listug-Olson	70	642,238	286	353
SW NE SW 36-31-47	Wetsit 1	66	4,074,613	742	850
NW NE 6-30-48	Bigtrack Little 1	20	980,047	661	763
NW SE NE 15-30-48	Bridges 1-D	60	2,164,863	567	662
C NW NE 19-30-48	Sletvold B1	30	6,005,777	1,338	1,483
SW SE 20-31-48	Mule Creek 1-D	140	2,164,863	371	447
SE NE 25-31-48	Mann 1 SWD	102	641,248	237	298
NW NE 29-29-49	Allotted Hall SWD	40	2,452,707	740	848
NE NW 27-29-50	Goings 1	44	1,186,616	491	579
SE NW NE 10-28-51	Huber 1-W	146	5,068,610	557	651
NW SE 10-28-51	Reynolds EPU 8	50	15,975,426	1,690	1,853
SW NW SW 22-28-51	Bierre 1	24	4,795,534	1,336	1,482
SW NW 7-29-51	Buck Elk 1		1,210,118		
SW NW 7-29-51	Buck Elk 2	20	3,263,920	1,208	1,346
SW SW 28-29-51	EPU 29-D	34	3,709,121	988	1,113
SW SW SW 31-31-48	Stai 1 SWD	52	448,204	277	343

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 2. RADIUS OF FILL-UP OF JUDITH RIVER INJECTION WELLS
FORT PECK INDIAN RESERVATION

LOCATION	NAME	FIELD	TOTAL VOLUME INJECTED (bbls)	TIME SINCE START UP (days)	RADIUS* OF FILL-UP (feet)	SAND THICKNESS (feet)
SE SW 4-30-46	Courchene 1-D	Volt	9,490,953	7,300		
NW NE 9-30-46	Carlson	Volt	837,942	3,650	577	30
SE NE 13-30-47	Phillips-McKee	Tule	1,391,601	1,460	987	70
C SE SW 13-30-47	Lough 2	Tule	3,830,468	6,935	986	47
NE NE SW 34-31-47	A 1-W Listug-Olson	Benrud	642,238		330	70
SW NE SW 36-31-47	Wetsit 1	E. Benrud	4,074,613	6,935	585	66
NW NE 6-30-48	Bigtrack Little 1	E. Benrud	980,047	4,380	764	20
NW SE NE 15-30-48	Bridges 1-D	E. Tule	2,164,863	6,205	656	60
C NW NE 19-30-48	Sletvold B1	Tule	6,005,777	9,125	1,544	30
SW SE 20-31-48	Mule Creek 1-D	N.E. Benrud	2,164,863	7,665	429	140
SE NE 25-31-48	Mann 1 SWD	W. Long Creek	641,248	2,190	273	102
NW NE 29-29-49	Allotted Hall SWD	Deadman's Coulee	2,452,707	1,095	854	40
NE NW 27-29-50	Goings 1	N.W. Poplar	1,186,616	1,095	567	44
SE NW NE 10-28-51	Huber 1-W	Poplar	5,068,610	9,125	643	146
NW SE 10-28-51	Reynolds EPU 8	Poplar	15,975,426	2,555	1,952	50
SW NW SW 22-28-51	Bierre 1	Poplar	4,795,534	5,110	1,543	24
SW NW 7-29-51	Buck Elk 1	Poplar	1,210,118	1,825		
SW NW 7-29-51	Buck Elk 2	Poplar	3,263,920	6,570	1,394	20
SW SW 28-29-51	EPU 29-D	Poplar	3,709,121	1,825	1,140	34
SW SW SW 31-31-48	Stai 1 SWD	E. Benrud	448,204	5,475	428	52

* Radius of fill-up calculations assume a porosity of 15%.

TABLE 1. TRAVEL TIME FROM INJECTION WELL TO A GIVEN POINT, R

LOCATION	WELL NAME	VOLUME INJECTED PER DAY (ft^3/day)	TRAVEL TIME (days) R = 1,000 feet			R = 2,640 feet		
			Ø = .1	Ø = .165	Ø = .20	Ø = .1	Ø = .165	Ø = .20
SE SW 4-30-46	Courchene 1-D	7,300	2,366	3,904	4,732	16,488	27,206	32,976
NW NE 9-30-46	Carlson	1,291	7,297	23,039	14,594	50,855		
SE NE 13-30-47	Phillips-McKee	5,351	4,108	6,772	8,216	28,629		57,258
C SE SW 13-30-47	Lough 2	3,099	4,762	7,857	9,524	33,190		
NE NE SW 34-31-47	A 1-W Listug-Olson							
SW NE SW 36-31-47	Wetsit 1	3,296	6,288	10,375	12,576	43,822		87,644
NW NE 6-30-48	Bigtrack Little 1	1,259	4,988	8,230	9,976	34,765		
NW SE NE 15-30-48	Bridges 1-D	1,959	9,617	15,868	19,234	67,028		
C NW NE 19-30-48	Sletvold B1	3,694	2,550	4,208	5,100	17,773	29,325	35,546
SW SE 20-31-48	Mule Creek 1-D	1,583	27,770	45,821	55,540	193,546		
SE NE 25-31-48	Mann 1 SWD	1,645	19,470	32,125	38,940	135,697		
NW NE 29-29-49	Allotted Hall SWD	12,576	998	1,647	1,996	6,064	11,486	13,922
NE NW 27-29-50	Goings 1	6,086	2,270	3,745	4,540	15,822		31,644
SE NW NE 10-28-51	Huber 1-W	3,116	14,712	24,274	29,424	102,540		
NW SE 10-28-51	Reynolds EPU 8	35,107	447	738	894	3,117	5,143	6,234
SW NW SW 22-28-51	Bierre 1	5,266	1,442	2,379	2,884	9,974	16,457	19,948
SW NW 7-29-51	Buck Elk 1	3,722						
SW NW 7-29-51	Buck Elk 2	2,790	2,250	3,712	4,500	15,688		
SW SW 28-29-51	EPU 29-D	11,409	935	1,543	1,870	6,522	10,761	13,044
SW SW SW 31-31-48	Stai 1 SWD	455	35,886	59,212	71,772	250,109		

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
ONE DENVER PLACE — 999 18TH STREET — SUITE 1300
DENVER, COLORADO 80202-2413

July 11, 1985

MEMORANDUM

TO: Paul Osborne, Regional Expert

FROM: Deb Ehlert, UIC DI Team Leader

THRU: Pat Crotty, Chief, Ground Water Section

SUBJECT: Request for Technical Review
Testimony Presented at Public Hearing - Judith River

A Public Hearing was held on May 29th in Poplar, Montana to gather data and other testimony which would allow EPA to make a decision concerning continued/future injection of oil field brines into the Judith River Aquifer on the Fort Peck Reservation. As you may know, the Fort Peck Tribe requested the hearing based on a notice we published of our intent to issue a permit to Century Oil and Gas for continuation of injection into the Judith River. The bulk of the testimony is comprised of data submitted by the Tribe or its consultants.

I have attached a file containing the pertinent information for your review. Included are:

(a) Technical data - Fort Peck Tribal Mineral Resources;

(b) EPA in-house report of available water quality data for the Judith River Formation; and

(c) A letter from the Montana Bureau of Mines and Geology.

We have not received the official transcript of the hearing but I believe we have most of the technical data in the above documents. I have asked Larry Monson, consultant to the Tribe, to loan us some maps and schematics that he used at the hearing. When they come in, I'll make sure you get them.

I would appreciate your technical review by July 29th. Specific questions that should be addressed are:

(1) Are the aquifer exemptions of 1/4 mile granted at the inception of the program for existing wells adequate for the volumes of fluids injected?

(2) What is the ambient quality of the Judith River Aquifer over the entire reservation? Is this even determinable?

(3) Is the Judith River Aquifer sufficiently confined to prevent contamination of overlying USDWs?

(4) Is fluid migration (east to west) a real possibility given that the Judith River Formation is "pinched off" by the Bearpaw Shale on the eastern edge of the reservation?

(5) What alternative drinking water sources are there on the reservation? Is data available so that an equal concentration (TDS) contour map can be constructed (i.e., greater than 10,000 mg/l; less than 10,000 mg/l) for other sources of drinking water?

(6) Based on the answers to questions 1 - 5, can it be concluded that the existing wells, if allowed to continue injection activities, will not present future contamination problems?

Thanks for your help! ! !

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: July 15, 1985

SUBJECT: SPMS (FY85 3RD QTR) AMENDMENT

FROM: D. Ehlert

TO: P. Crotty.

I spoke with Jentai this morning about amending our SPMS report - increasing # of MITs performed by 5. He said it was too late to pull back the report now, but that we could comment/edit the report when they asked for verification. If we don't do that, we can always add it in for next quarter's report. It doesn't seem like such a big deal either way. ?!

EPA Form 1320-6 (Rev. 3-76)

RECORD OF COMMUNICATION

☒ PHONE CALL ☐ DISCUSSION ☐ FIELD TRIP ☐ CONFERENCE
☐ OTHER (SPECIFY)

(Record of item checked above)

Bill Engle	FROM: Marvin Sonosky, Attorney for Fort Peck Tribe, Offices - Wash, D.C. 202-342-9131	DATE 5-3-85 TIME 11:25 AM

SUBJECT
Public Hearing - May 29, 1985 in Poplar

SUMMARY OF COMMUNICATION
I returned Mr. Sonosky's call from 5-2-85. He was knowledgeable on the situation @ Fort Peck as far as injection into the Judith River goes (i.e., no. of wells, depth of Judith River, no new wells allowed into Judith River by BIA or BLM). He was aware that we were dealing with old existing injection wells. He wanted to know what the Tribe had to approve about the Judith River formation & where water quality information was available. I told him basically it was up to the Tribe to prove that (1) the Judith River was a drinking water aquifer now except in the contaminated areas immediately around the injection wells, (2) historically the Judith River had been a drinking water aquifer and that (3) the Judith River aquifer could possibly eventually return to its previous potability in the contaminated areas if it had historically been a drinking water aquifer. I gave him the name of Marv Miller @ the Bureau of Mines & Geology as possibly someone to contact for Judith River quality information. He intimidated that he or someone from his firm might be at the public hearing

CONCLUSIONS, ACTION TAKEN OR REQUIRED
I get a little nervous when a high power attorney from Washington representating an Indian Tribe gets involved in a public hearing. I suggest we think about having our attorney at the public hearing also.

RECEIVED
MAY 6 1985
EPA REGION VIII
DRINKING WATER BRANCH

INFORMATION COPIES TO: Roger, Pat

EPA Form 1300-6 (7-72) REPLACES EPA HQ FORM 5300-3 WHICH MAY BE USED UNTIL SUPPLY IS EXHAUSTED.

PN's sent to the following companies
RE: Judith River Hearing

OIL COMPANIES OPERATING ON
FORT PECK RESERVATION

Petroleum, Inc. *
P. O. Box 367
Mohall, ND 58761

Murphy Oil Company *
200 Peach Street
El Dorado, Arkansas 71730

Grace Petroleum Corporation *
143 Union Blvd, Suite 760
Lakewood, CO 80228

Century Oil *
7887 East Belleview Ave.
Englewood, CO 80111

Petro-Lewis Corporation *
P. O. Box 2250
717 17th St
Denver, CO 80201

Reading & Bates Petroleum Company
1125 17th St., Suite 2300
Denver, CO 80202

Ajax Oil Company
Box 1584
Billings, MT 59103

Terry Schagunn *
N.S.R. Box 2032
Poplar, MT 59255

Mobil Oil Corp.
P. O. Box 5444, Mail Stop 90
Denver, CO 80217

Pennzoil Company *
P. O. Box 1139
Denver, CO 80201

Murphy Oil Company
P. O. Box 547
Poplar, MT 59255

P & M Petroleum Mgt.
1600 Broadway, Suite 1700
Denver, CO 80202

Energy Reserves Group, Inc.
P. O. Box 3280
Casper, WY 82602

Roosevelt Disposal
Box 1081
Wolf Point, MT 59201

Exxon Corporation
P. O. Box 1600
Midland, TX 79702

Sun Exploration & Petroleum Company
P. O. Box 5940 TA
Denver, CO 80217

Larslan Water Disposal
Box 35
Larslan, MT 59244

Phillips Oil Company
P. O. Box 939
Cut Bank, MT 59427

Sam Picard
1643 Lewis Ave., Suite 200
Billings, MT 59102

* Known or suspected injection into Judith River formation.

Paul

For your review

Will this data & conclusions stand if contested?

Pat

3/15

May 29th Public Hearing - Judith River Aquifer

Speakers - Testimony.

1. NORMAN HOLLOW - TRIBAL CHAIRMAN.
2. LAURENCE VETSITT - DIRECTOR - FT. PK. MINERALS OFFICE
3. LAURENCE MONSON (GEO.)
   - J.R. bounded on East by Shale -
   - Fluid migration likely to be up gradient to the West.

4. JAMES T. THORTON - Consultant Pet. Eng -> Tribe.
   discussed calculated MIP vs. actual op. pressures
   radius of influence - could be greater than 1/4 mile

5. Sid Campbell - Murphey Oil Corp.
   - claims J.R. is gaseous - early production 30-200 mcf/day for on site facility use.
   - has virgin water quality data - most > 10,000 claims not USDW.
   - History of Unit. (E. Poplar)

6. Ted Brown

Land Operations

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF INDIAN AFFAIRS

P. O. BOX 637
FORT PECK AGENCY
POPLAR, MONTANA 59255

February 27, 1984

Bureau of Land Management
Miles City Dist. Office
P.O. Box 940
Miles City, Montana 59301

Dear District Manager:

The Bureau of Indian Affairs along with the Ft. Peck Tribes is concerned with all possible fresh water aquifers.

The Judith River is considered a possible fresh water aquifer. For this reason, we will no longer consider the Judith River as a saltwater disposed zone. We are also requiring the use of surface casing for all new wells, through the Judith River.

We propose the Lakota, Dakota or deeper formations for all new saltwater disposal wells.

Sincerely,

Superintendent

File

ENVIRONMENTAL PROTECTION AGENCY.

REGION VIII.

March 17, 1985

SUBJECT: My Trip to Poplar, Montana

FROM: Pat Crotty

TO: Ground Water Section Staff
Roger Frenette

This trip was a good one for both Bill Engle and me. We met with BLM, BIA and the Fort Peck Tribes; and visited several wells in the East Poplar field.

The meeting was led by Dave Allison, a supervisor with the Fort Peck Agency. He had three main topics: (1) injection into the Judith River formation, (2) surface disposal in pits, and (3) Tribal eligibility for the UIC program. Bill and I were not told of these latter two issues; so we had to respond in generalities that EPA had no current jurisdiction over pits, and that the Tribe was not eligible for primacy under the SDWA.

Others in attendence were:

- Larry Wetsit, Minerals Director for the Tribes
- Jackie Miller, Tribal Environmental Protection Director
- Warren Barton, BLM
- Several other BIA and Tribal representatives.

As discussion progressed, it became evident that concerns span the entire subject of salt water disposal, not just injection. People are concerned that fixing problems in one area only leads to problems in others. I likened it to the arcade game where you try to "bop" ground squirrels as they pop their heads out of the ground. Once you take aim on one, it disappears, only to be replaced by another.

The end result of the discussion was that the Tribe should assemble all parties that have regulatory authority over salt water disposal, and define both where gaps exist in coverage and how the agencies can best work together to close loopholes. It will not be good if operators switch to pit disposal because we are too tough in implementing the UIC program. Similarly it will not be good, on this land of checkerboarded ownership, if the BIA and BLM establish an effective pit program if the operators can simply move to land outside federal jurisdiction. The need for

State involvement was apparent; but, based upon past performance, the BIA and Tribe do not expect much help from the State. (I also suggested that the Tribe begin working both with the Southern Ute Agency in Colorado, and the State of North Dakota (OGCC) because both of these groups have a headstart in solving the same problem.)

Injection into the Judith River was discussed at some length. The Tribe would like us to hold a public hearing on the draft Century permit in order to present data their consultant has that will show native quality of the JR is from 500 to 1500 TDS. Coupled with a report prepared by the USGS to show contamination of the shallow alluvial aquifer in the East Poplar field, they are convinced that injection into the JR should be eliminated ASAP. (Aside: Paul, in your review of this report, please evaluate whether we might have authority over the pits under NPDES if there is connection to the Poplar River (which is tributory to the Missouri River.))

The Tribe thought that their comment letter on the Century well would lead to a public hearing. I told them to supplement it with a specific request telling of the new information, and suggesting a date for the hearing. I also told them we would probably hold one, and that <u>no permits would be issued for injection into the JR until they had an opportunity to present that information</u>. Permit writers should keep this in mind and advise applicants that they can avoid the delay by going deeper to the Dakota formation.

The Tribe also asked that we provide them with copies of all draft permits for injections within the Ft. Peck Reservation. Bill and I agreed that this can be done. The permit writer should make a note of this so that adequate copies of the the permit and statement of basis are made when implementing GWSG # 2. The copies should be sent to:

Mr. Lawrence Wetsit
Fort Peck Mineral Resource Dept.
P.O. Box 595
Poplar, Montana 59255

Mr. Wetsit can be phoned at (406) 768-5331.

We discussed, briefly, that the hearing, if held, could be no sooner than late May. If a hearing is held, Mr. Allison will try to arrange for the interagency meeting on salt water disposal to be held during the same week. (Aside: If we hold this hearing, we need to ask the Tribe to provide the Resolution to Ban Injection Into the Judith River Formation. This was promised Bill by Mr. Wetsit last Summer, but has never been received.)

One final issue raised by the Tribe is over the pressure we use for mechanical integrity testing. Mr. Wetsit does not think it is high enough. I said we would review it. Then I began to wonder whether this was established by regulation. Deb, please check.

Bill and I spent a few hours in the wind and dust of the East Poplar field. We visited all three Grace wells and found that all were physically disconnected. In speaking with Grace's hired help, we found that they had been shut in for some time. The Ajax facility, on the other hand, was operating. I use the work facility because we never located the actual well. It is probably buried. I have slides of all four sites being developed. The permit writer originally assigned to the Ajax permit should initiate compliance follow-up immediately.

Bill and I discussed the following and want the DI Team to recommend whether and how we can implement or resolve each issue.

- Housekeeping at the sites was not good. Pits contained substantial quantities of crude. Wells are in pits. Trash was being burned, in a pit that contained substantial petroleum products at the Ajax well site. Should we be requiring photos or slides of all existing well sites when we call them in for permits? Full site pictures, from each cardinal direction, and of each major component of the site, might help you decide whether you have received sufficient information for deciding the permit issue.

- Most of the sites in this field can be hazardous due to hydrogen sulfide presence. Gus should arrange with Jim Baker for training of our staff on these hazards. The DI Team should decide how we implement safety precautions during trips to the field. All this should be done by the end of April.

- We should tie down the source of injected fluids going to permitted wells. Grace did shut in. But, they are hauling from two producing wells to the Century Goings well. This is the well that the Tribe is requesting a public hearing on because it injects into the Judith River.

- Is there any way we can include surface restoration of the site in plugging plans? Paul Osborne should research this and report back to me on our authority and appropriate methods, by April 30.

ROUTING AND TRANSMITTAL SLIP

Date 5-29-85

TO: (Name, office symbol, room number, building, Agency/Post)	Initials	Date
1. Jack Hoffbuhr		
2. 8EOM-DW		
3. Roger Frenette		
4.		
5.		

	Action		File		Note and Return
	Approval		For Clearance		Per Conversation
	As Requested		For Correction		Prepare Reply
	Circulate	X	For Your Information		See Me
	Comment		Investigate		Signature
	Coordination		Justify		

REMARKS

DO NOT use this form as a RECORD of approvals, concurrences, disposals, clearances, and similar actions

FROM: (Name, org. symbol, Agency/Post)	Room No.—Bldg.
M. White 8PM-RS	Phone No. X1710

5041-102

OPTIONAL FORM 41 (Rev. 7-76)
Prescribed by GSA
FPMR (41 CFR) 101-11.206

☆ GPO : 1983 O - 381-529 (308)

ROUTING AND TRANSMITTAL SLIP

Date 7-19-85

TO: (Name, office symbol, room number, building, Agency/Post)	Initials	Date
1. Deb		
2.		
3.		
4.		
5.		

	Action		File		Note and Return
	Approval		For Clearance		Per Conversation
	As Requested		For Correction		Prepare Reply
	Circulate	✓	For Your Information		See Me
	Comment		Investigate		Signature
	Coordination		Justify		

REMARKS

As Captain D.I., I ~~[illegible]~~ thought you'd like to see the materials I prepared for the DOT briefing.

DO NOT use this form as a RECORD of approvals, concurrences, disposals, clearances, and similar actions

FROM: (Name, org. symbol, Agency/Post)	Room No.—Bldg.
Laura	Phone No.

5041-102

☆ GPO : 1983 O - 381-529 (308)

OPTIONAL FORM 41 (Rev. 7-76)
Prescribed by GSA
FPMR (41 CFR) 101-11.206

JUL 19 1985

ENFORCEMENT CASE: GRACE PETROLEUM CORPORATION

THE UIC PROGRAM: Mandate and Objectives

The UIC program was promulgated under Part C of the Safe Drinking Water Act - Protection of Underground Sources of Drinking Water (USDWs). As a preventive program, the UIC program protects USDWs by controlling avenues of contamination resulting from the underground injection of fluids. Region VIII implements the UIC program in Montana.

Key to the UIC program is the concept of mechanical integrity, a demonstration of the absence of significant leaks in the casing, tubing or packer of a well, and that there is no significant fluid movement into a USDW outside the casing through vertical channels adjacent to the well bore. The absence of leaks is confirmed by the performance of a successful mechanical integrity test.

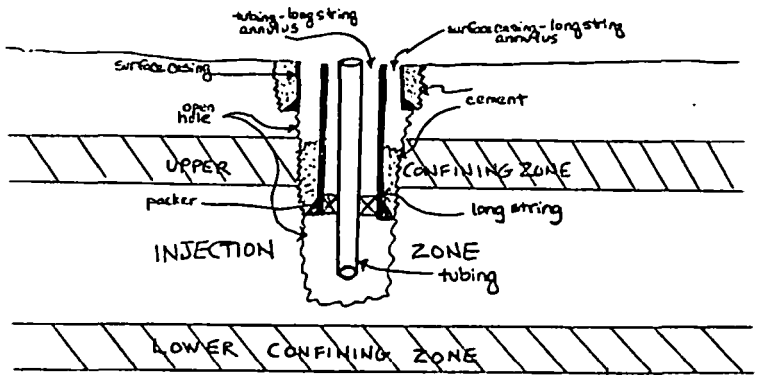

Figure 1. Well Bore Diagram

BACKGROUND:

The UIC program began on June 25, 1984. As of that date, no underground injection is allowed unless authorized by permit or by rule. All injection wells in operation prior to that date were automatically granted authorization to inject by rule, which meant they were allowed to inject while maintaining compliance with certain requirements, unless they were required to obtain a permit.

Salt water disposal (SWD) wells are wells which dispose of brine extracted in conjunction with oil, injecting it through a well into a suitable formation. All SWD wells authorized by rule are required to be permitted within five years of the commencement of the UIC program. Accordingly, EPA decided to begin the permitting process immediately upon the start of the program. SWD wells are Region VIII's number one permitting priority. Within that priority, areas where contamination of USDWs is known or suspected are the most urgent permitting priority. EPA had received complaints of contamination from only the Poplar field, consequently, that field became Region VIII's top priority for permitting.

In letters mailed June 25, 1985, EPA notified all well operators in the field to submit a permit application by July 31, 1985. The letters warned that if they failed to submit such application within the time frame referenced in the notice that they would lose their authorization to inject. The letters also provided the operators with the names of two EPA contacts, and phone numbers to call with questions.

Of the six operators in the Poplar field, Grace Petroleum and Ajax Oil were the only ones that did not submit an application on time, or request an extension. Both lost their their authorization to inject on July 31, 1984 and were so advised by phone and by certified letter. Shortly thereafter, an EPA representative from the Montana Operations Office inspected both the Grace and Ajax wells. He found the Grace wells to be injecting, and the Ajax well to be shut-in. Grace continued to inject illegally for 60 days after the deadline, at which time they shut-in their wells.

The Safe Drinking Water Act does not give EPA Administrative Order authority, so EPA was not able to order Grace to stop injection. EPA could only advise Grace to shut-in the wells until they received authorization to recommence injection via a permit. During the 60 days of illegal injection, Grace received two oral and two written warnings that they were without authorization to inject, and that continued injection was a violation of the SDWA, and subjected them to the penalties and/or fines prescribed therein.

ISSUES OF REGIONAL/NATIONAL SIGNIFICANCE:

1. This is the first UIC civil enforcement case in the nation.

2. This is a landmark case because it is representative of the very essence of the most basic UIC objective; to prevent the contamination of USDWs by assuring compliance with the proper construction, operating and monitoring requirements. EPA cannot ascertain such compliance unless well operators comply with permitting requirements so EPA can examine the wells.

3. EPA is asking for a significant penalty amount. Settlement of this case will establish a point of reference for setting penalties in future cases.

4. This case is precedential because it does not rest on documented environmental harm, but instead relies on the preventative nature of the statute.

RECORD OF COMMUNICATION	☒ PHONE CALL ☐ DISCUSSION ☐ FIELD TRIP ☐ CONFERENCE ☐ OTHER (SPECIFY) (Record of item checked above)	
TO: Marc Herman	FROM: Randy Nordwick Box 482 Wolfpoint, MT 59201	DATE 8-29-85 TIME 11:00 AM

SUBJECT
Injection into the Judith River Formation

(406) 653-3243 farmer/rancher

SUMMARY OF COMMUNICATION

He is considering drilling some irrigation wells (to be completed in the Judith River) in the vicinity of Section 25, T31N, R47E. He wants to know what is going on with our moratorium on injection into the Judith River, specifically he asked about the Pennzoil wells.

He is concerned about:

1. Judith River ground-water quality and his children's future dependency on such water.
2. Because of the droughts, he is considering using poorer quality water. (ie. Judith River)
3. Making the operators drill + inject deeper (ie Dakota) and leave the upper water-bearing zones to the farmers/ranchers.
4. Would like to be kept informed of what happens with the Judith River investigation.
5. Can we give him any information right now on the water quality?

CONCLUSIONS, ACTION TAKEN OR REQUIRED

He wants us to make the operators inject into deeper zones.

Send him a letter containing any useful info.

INFORMATION COPIES
TO: Deb, Paul

EPA Form R8 1300.1 (11-84) REPLACES EPA HQ FORM 5300-3 WHICH MAY BE USED UNTIL SUPPLY IS EXHAUSTED.

Bureau of Land Management
Division of Minerals
Miles City District Office
Miles City, MT 59301

Jeff Burkman
Petroleum Engineer
P.O. Drawer 1139
Denver, CO 80201

Rep.: Pennzoil Co.

William F. Baswell, III
Operations Engineer
143 Union Blvd., Suite 760
Lakewood, CO 80227

Rep.: Grace Petroleum Corp.

Jack A. Toth
District Superintendent
P.O. Box 21497
Billings, MT 59104

Rep.: Petro Lewis Corp.

Norman Hollow
Tribal Chairman
Box
Poplar, MT 59255

Rep.: Fort Peck Tribes

Lawrence Wetsit
Minerals Director
P.O. Box 595
Poplar, MT 59255

Rep.: Fort Peck Tribes

Lawrence Monson
Geologist
P.O. Box 595
Poplar, MT 59255

Rep.: Fort Peck Tribal Minerals Office

James T. Thornton
Consulting Petroleum Engineer (Tribes)
1380 Glenaire Drive
Casper, WY 82609

Paul K, Christensen
Hydrologist
316 N. 26th Street
Billings, MT 59103

Rep.: Billings Area Office- Bureau of Indian Affairs

Ray Reede
Prod. Supt
Box 547
Poplar, MT

Rep.: Murphy Oil USA

Sidney W. Campbell
Senior Petroleum Engineer
200 Peach Street
El Dorado, AR 71730

Rep.: Murphy Oil USA, Inc.

Ted D. Brown
Division Engineer
7887 E. Belleview
Englewood, CO 80111

Rep.: Century Oil & Gas Corp.

T. Bruce Petitt
Division Engineer
1125 17th St. #2300
Denver, CO 80127

Rep.: Reading & Betas Petroleum Co.

Joe A. Moreland
Acting District Chief
301 S Park, Drawer 10076
Helena, MT 59626

Rep.: U.S. Geological Survey

Clinton C. Whitmer
Box 86
Wolf Point, MT

Rep.: Whitmer Drilling

Dan Sallee
Petroleum Engineer
Box 3280
Casper, WY 82602
Energy Reserves Group, Inc.

John Rabenberg
President
South Route
Fort Peck, MT 59223

Rep.: Hi-Plains Land & Mineral Asso.

Ted Schye
North Star Rt.
Glasgow, T+MT 59230

Rep.: State Rep. House Dist 18

Ref:

1

re: EPA public hearing
of May 29, 1985 concerning
injection into the Judith
River Formation

Dear _____ :

Our records show that you attended a ~~hearing~~ public hearing held by EPA at the Poplar Community Center in Poplar, Montana, on May 29 of this year. The subject of the hearing was the issue whether EPA should allow injection into the Judith River formation, specifically, whether the Goings No. 1 well should be allowed to continue injection.

EPA scientists have been close to rendering a decision on the issue for some time but have had some problems with what appears to be an

inaccurate record of the oral comments made at the hearing. Unfortunately, the transcript is difficult to understand in some places and, in others, doesn't seem to reflect ~~the~~ what was actually said at the hearing.

Though there appear to be problems with the transcript, we nevertheless feel we can make a fair decision on the issues ~~per~~ discussed at the hearing. Most of the information presented was in written form, and was simply mailed to EPA offices for closer scrutiny by our scientists. This information more or less duplicated what was said at the hearing also, ~~as~~ our scientists were present at the hearing and took their own notes. Thus, we feel there is no problem considering a

a fair decision.

So that we can be sure that we have all the comments submitted to us at the hearing, we ~~$~~ are asking those who attended ~~the hearing~~ to review the transcript, a copy of which is enclosed, and ~~let~~ forward to us ~~know whether you have~~ any ~~objections~~ comments as to ~~the~~ its wording. We would also like to know if you object to ~~any~~ a decision rendered based on this transcript.

Please get to us by December 15 with your comments. If we haven't heard from you by then, we ~~as~~ will assume you have no objection and will go forward with our decision.

Sincerely,
AJL

REGISTRATION RECORD

NAME (Please Print)
Sidney W. Campbell

TITLE
Senior Petroleum Engineer

ADDRESS (Street, City, State, ZIP Code)
200 Peach Street El Dorado, AR 71730

REPRESENTING (Organization)
Murphy Oil USA, Inc

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [X] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 10 min.
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [ ] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
TED D. BROWN

TITLE
DIVISION ENGINEER

ADDRESS (Street, City, State, ZIP Code)
7887 E. BELLEVIEW ENGLEWOOD, COLO 80111

REPRESENTING (Organization)
CENTURY OIL + GAS CORP

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 20-30 MIN
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
T. Bruce Petitt

TITLE
Division Engineer

ADDRESS (Street, City, State, ZIP Code)
1125 17th St. #2300
Denver, Colorado 80127

REPRESENTING (Organization)
Reading + Bates Petroleum Co.

DO YOU INTEND TO PRESENT A STATEMENT? [ ] YES [X] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
JOE A. MORELAND

TITLE
ACTING DISTRICT CHIEF

ADDRESS (Street, City, State, ZIP Code)
301 S PARK, DRAWER 10076
HELENA, MT 59626

REPRESENTING (Organization)
U.S. GEOLOGICAL SURVEY

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 5 MIN
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
Clinton C Whitmer

TITLE
Box 86 WOLF POINT MT

ADDRESS (Street, City, State, ZIP Code)

Whitmer Drilling

REPRESENTING (Organization)

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 5 min
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
DAN SALLEE

TITLE
PETROLEUM ENGINEER

ADDRESS (Street, City, State, ZIP Code)
Box 3280
CASPER, WY. 82602

REPRESENTING (Organization)
ENERGY RESERVES GROUP, INC.

DO YOU INTEND TO PRESENT A STATEMENT? [ ] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
Lawrence Monson

TITLE
Geologist

ADDRESS (Street, City, State, ZIP Code)
P.O. Box 595 Poplar, MT 59255

REPRESENTING (Organization)
Fort Peck Tribal Minerals Office

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 40 min

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
James T. Thornton

TITLE
Consulting Petroleum Engineer (Tribes)

ADDRESS (Street, City, State, ZIP Code)
1380 Glenaire Drive Glenaire Drive Casper Wyo 82609

REPRESENTING (Organization)
Assiniboine & Sioux Tribes of Fort Peck Reservation MT.

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 15 min

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
Ray Reede

TITLE
Prod Supt

ADDRESS (Street, City, State, ZIP Code)
Box 547 Poplar Mont.

REPRESENTING (Organization)
Murphy Oil USA

DO YOU INTEND TO PRESENT A STATEMENT? [ ] YES [X] NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

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REGISTRATION RECORD

NAME (Please Print)
JACK A Toth

TITLE
District Superintendent

ADDRESS (Street, City, State, ZIP Code)
P.O. Box 21497, Billings, MT 59104

REPRESENTING (Organization)
Petro Lewis Corp.

DO YOU INTEND TO PRESENT A STATEMENT? ☐ YES ☒ NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

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REGISTRATION RECORD

NAME (Please Print)
Norman Hollow

TITLE
Tribal Chairman

ADDRESS (Street, City, State, ZIP Code)
Box Poplar, MT 59255

REPRESENTING (Organization)
Fort Peck Tribes

DO YOU INTEND TO PRESENT A STATEMENT? ☒ YES ☐ NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 10 min.

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

REGISTRATION RECORD

NAME (Please Print)
Lawrence Wetsit

TITLE
Minerals Director

ADDRESS (Street, City, State, ZIP Code)
P.O. Box 595 Poplar, MT 59255

REPRESENTING (Organization)
Fort Peck Tribes Minerals Office

DO YOU INTEND TO PRESENT A STATEMENT? ☒ YES ☐ NO

IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 5 min

DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

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REGISTRATION RECORD

NAME (Please Print)
Bureau of Land Management, Div of Minerals

TITLE
Miles City District Office, Miles City MT 59301

ADDRESS (Street, City, State, ZIP Code)

REPRESENTING (Organization)

DO YOU INTEND TO PRESENT A STATEMENT? ☐ YES ☒ NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

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REGISTRATION RECORD

NAME (Please Print)
Jeff Burkmad

TITLE
Petroleum Engineer

ADDRESS (Street, City, State, ZIP Code)
P.O. Drawer 1139 Denver, Colo. 80201

REPRESENTING (Organization)
Pennzoil Co.

DO YOU INTEND TO PRESENT A STATEMENT? ☐ YES ☒ NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

REGISTRATION RECORD

NAME (Please Print)
William P. Baswell III

TITLE
Operations Engineer

ADDRESS (Street, City, State, ZIP Code)
Suite 760 143 Union Blvd. Lakewood Co. 80227

REPRESENTING (Organization)
Grace Petroleum Corp.

DO YOU INTEND TO PRESENT A STATEMENT? ☐ YES ☒ NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED?
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? ☒ YES ☐ NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

REGISTRATION RECORD

NAME (Please Print)
John Rabenberg

TITLE
President.

ADDRESS (Street, City, State, ZIP Code)
South route Fort Peck MT 59223

REPRESENTING (Organization)
Hi-Plains Land + Mineral Ass.

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 2 Min.
DO YOU WANT TO BE PLACED ON our MAILING LIST? [X] YES [ ] NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

REGISTRATION RECORD

NAME (Please Print)
Ted Schye
Schye

TITLE

ADDRESS (Street, City, State, ZIP Code)
North Star RT Glasgow MT 59230

REPRESENTING (Organization)
State Rep House Dist 18

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 3 Min.
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [X] YES [ ] NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

REGISTRATION RECORD

NAME (Please Print)
Paul K. Christensen

TITLE
Hydrologist

ADDRESS (Street, City, State, ZIP Code)
316 N. 26th Street
Billings MT 59103

REPRESENTING (Organization)
Billings Area Office - Bureau of Indian Affairs

DO YOU INTEND TO PRESENT A STATEMENT? [X] YES [ ] NO
IF SO, APPROXIMATELY HOW MUCH TIME DO YOU NEED? 3 minutes
DO YOU WANT TO BE PLACED ON OUR MAILING LIST? [ ] YES [ ] NO

EPA Form 2660-1 (Rev. 6-75) PREVIOUS EDITION MAY BE USED

Ref: 8WM-DW

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Mr. Jeff Burkman
Petroleum Engineer
Pennzoil Corporation
P.O. Box Drawer 1139
Denver, Colorado 80201

Re: EPA Public Hearing of May 29, 1985:
Underground Injection into the
Judith River Formation.

Dear Mr. Burkman :

Our records show that you attended a public hearing held by EPA at the Poplar Activity Center in Poplar, Montana, on May 29th of this year. The subject of the hearing was the issue of whether EPA should allow injection to occur into the Judith River Formation; specifically, whether the Goings No. 1 salt water disposal well should be issued a permit which would allow continuation of injection activities.

EPA has been close to rendering a decision on the issue for some time, but has had some problems with what appears to be an inaccurate record of the oral comments made at the hearing. Unfortunately, the transcript is difficult to understand in some places and in others, doesn't seem to reflect what was actually said at the hearing.

Though there appear to be problems with the transcript, EPA nevertheless feels that a fair decision can be made on the issues discussed at the hearing. Most of the informatin presented was in written form, and was simply mailed to EPA offices for closer scrutiny by the technical staff. This information more or less duplicated what was said at the hearing. Also, the hearing panel was comprised of three EPA staff members, who were able to witness the testimony firsthand. Thus, EPA feels there is no problem rendering a fair decision.

So that we can be sure that we have all the comments submitted to us at the hearing, we are asking those who attended to review the transcript, a copy of which is enclosed, and that they forward to us, any comments as to its wording. We would also like to know if you object to a decision rendered based on this transcript.

Please respond with any comments by December 10, 1985, to the following address:

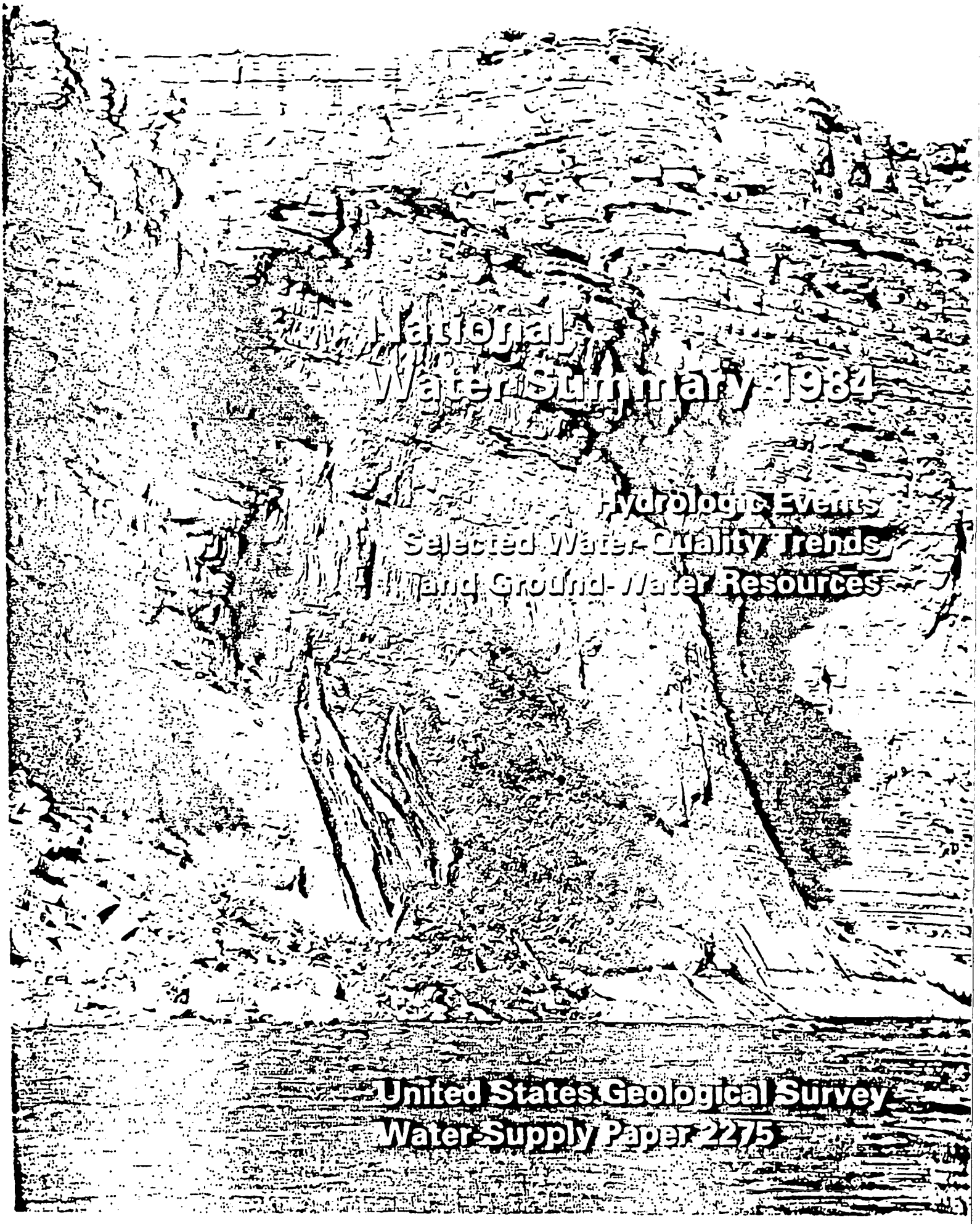
U.S. Environmental Protection Agency
Region VIII
Office of Regional Counsel
ATTN: Andrew J. Lensink
One Denver Place - Suite 1300
999 18th Street
Denver, Colorado 80202-2413

If we have not heard from you by then, we will assume you have no objections and will go forward with our decision.

Sincerely yours,

Andrew J. Lensink, Esquire
Office of Regional Counsel

bcc: Bill Engle
Montana Office



National Water Summary 1984

Hydrologic Events, Selected Water-Quality Trends, and Ground-Water Resources

United States Geological Survey
Water-Supply Paper 2275

MONTANA
Ground-Water Resources

Ground water is available in nearly every part of Montana but constitutes less than 2 percent of the total water withdrawals. However, 424,000 people, or about one-half of the State's 786,000 population, are supplied with water for domestic purposes from ground-water sources—230,000 people through public water-supply systems and 194,000 people through rural water-supply systems. The quantity of ground water withdrawn for public and rural-domestic supplies (68 million gallons per day) is about 0.5 percent of total statewide surface- and ground-water withdrawals (Montana Department of Natural Resources and Conservation, 1985). About one-half of the fresh ground-water withdrawals in the State is used for irrigation (Solley and others, 1983). Recent statistics related to withdrawals of ground water and its various uses are given in table 1.

Table 1. Ground-water facts for Montana

[Withdrawal data rounded to two significant figures and may not add to totals because of independent rounding. Mgal/d = million gallons per day; gal/d = gallons per day. Sources: Montana Department of Natural Resources and Conservation, 1985; irrigation data from Solley, Chase, and Mann, 1983]

Population served by ground water, 1980	
Number (thousands)	424
Percentage of total population	54
From public water-supply systems:	
Number (thousands)	230
Percentage of total population	29
From rural self-supplied systems:	
Number (thousands)	194
Percentage of total population	25
Freshwater withdrawals, 1980	
Surface water and ground water, total (Mgal/d)	11,000
Ground water only (Mgal/d)	200
Percentage of total	2
Percentage of total excluding withdrawals for thermoelectric power	2
Category of use	
Public-supply withdrawals:	
Ground water (Mgal/d)	54
Percentage of total ground water	27
Percentage of total public supply	39
Per capita (gal/d)	235
Rural-supply withdrawals:	
Domestic:	
Ground water (Mgal/d)	14
Percentage of total ground water	7
Percentage of total rural domestic	94
Per capita (gal/d)	72
Livestock:	
Ground water (Mgal/d)	9
Percentage of total ground water	4
Percentage of total livestock	38
Industrial self-supplied withdrawals:	
Ground water (Mgal/d)	29
Percentage of total ground water	14
Percentage of total industrial self-supplied:	
Including withdrawals for thermoelectric power	20
Excluding withdrawals for thermoelectric power	52
Irrigation withdrawals:	
Ground water (Mgal/d)	94
Percentage of total ground water	48
Percentage of total irrigation	1

GENERAL SETTING

Montana has two distinct hydrogeologic regimes. The first, which is in western and south-central Montana (Northern and Middle Rocky Mountains physiographic provinces, fig. 1), generally consists of a series of structurally complex mountain ranges separated by downfaulted intermontane valleys containing as much as 16,000 feet (ft) of Cenozoic basin-fill sediments. Annual precipitation ranges from 8 inches (in.) in the valleys to about 120 in. along the higher mountain crests. The second, which is in eastern and north-central Montana (Great Plains physiographic province, fig. 1), generally consists of moderately dissected plains underlain by Cenozoic and Mesozoic sedimentary rocks locally interrupted by small mountain ranges. Annual precipitation ranges from 12 to 30 in. on the plains.

Recharge to the ground-water system in Montana is derived mainly from precipitation. Recharge ranges from less than 1 in. per year in parts of the eastern plains to several inches in parts of the western mountains.

PRINCIPAL AQUIFERS

Aquifers in Montana consist of unconsolidated alluvial, glacial, and basin-fill deposits, and consolidated sedimentary rocks. The aquifers are described below and in table 2; their areal distribution is shown in figure 1.

CENOZOIC AQUIFERS

Alluvial, Glacial, and Basin-Fill Aquifers

Most ground water used in western and south-central Montana is derived from Cenozoic aquifers that consist of alluvial, glacial, and basin-fill deposits of unconsolidated to semiconsolidated gravel, sand, silt, and clay (fig. 1, table 2). In these areas, where the mountain snowpack provides an adequate supply of fresh surface water for most purposes, ground-water supplies generally are not well developed. However, an adequate water supply generally can be obtained at shallow depths in alluvium bordering major rivers.

Water in the alluvial aquifer is unconfined at most locations. Materials deposited by meltwater from mountain glaciers provide variable yields depending on the silt and clay content. Basin-fill deposits can yield an adequate water supply, usually within 200 ft of land surface, for stock and domestic purposes. Yields to wells completed in the alluvial and basin-fill deposits may be adequate for irrigation, public supply, or industrial purposes; such deposits supply water to the cities of Bozeman (Gallatin County), Missoula (Missoula County), Dillon (Beaverhead County), Kalispell (Flathead County), and Townsend (Broadwater County). Water in the glacial and basin-fill deposits usually is unconfined near the land surface and confined at deeper levels by layers of silt and clay.

In eastern and north-central Montana, ground water is the most reliable source of supply, except along the major rivers and streams where a fairly dependable supply of surface water can be obtained. Ground-water supplies in this region are available from Cenozoic alluvial and glacial deposits and from deeper aquifers (fig. 1, table 2).

Table 2. Aquifer and well characteristics in Montana

[Ft = feet; gal/min = gallons per minute; est. = estimated; mg/L = milligrams per liter. Sources: Davis and Rogers (1984); Levings (1982a, b, c, d); Noble and others (1982a, b); Feltis (1980c)]

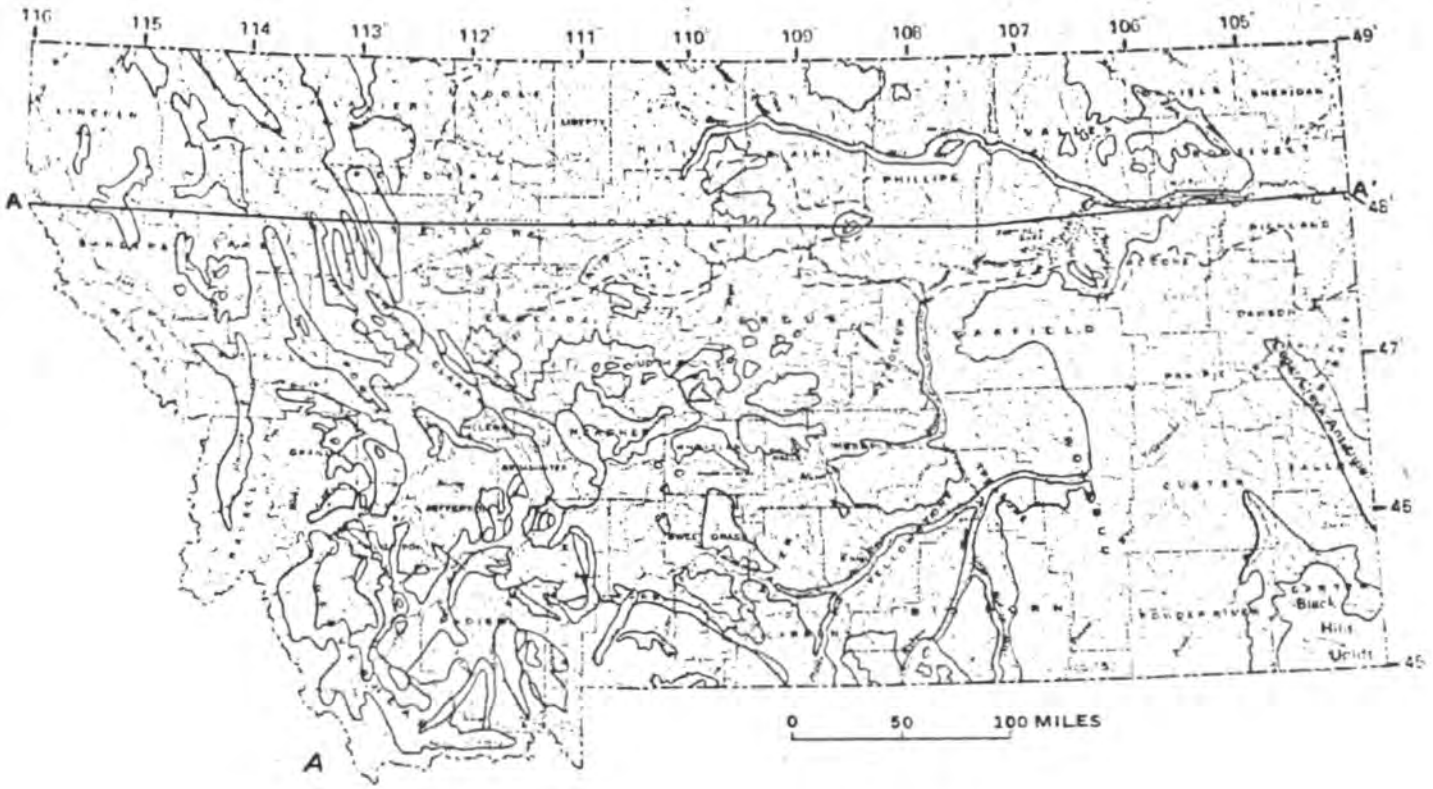
Aquifer name and description	Well characteristics				Remarks
	Depth (ft)		Yield (gal/min)		
	Common range	May exceed	Common range	May exceed	
Cenozoic aquifers:					
Western alluvial and basin-fill deposits: Unconsolidated sand, gravel, silt, and clay. Generally unconfined.	20 - 40	250	5 - 50 est.	1,500	Dissolved-solids concentration generally less than 300 mg/L near Helena and Missoula. Water quality in other areas probably similar.
Western glacial deposits: Unconsolidated sand, gravel, silt, and clay. Unconfined to confined.	50 - 300	900	5 - 50 est.	3,500	Dissolved-solids concentration generally less than 200 mg/L in northwestern Montana. Water quality in other areas probably similar.
Eastern alluvial deposits and terrace gravels: Unconsolidated sand, gravel, silt, and clay. Generally unconfined.	20 - 50	250	5 - 50 est.	1,000	Dissolved-solids concentration generally less than 2,000 mg/L.
Eastern glacial deposits: Unconsolidated sand, gravel, silt, and clay. Unconfined to confined.	20 - 60	200	5 - 10	1,000	Dissolved-solids concentration generally less than 2,200 mg/L.
Fort Union Formation: Moderately consolidated and interbedded shale, siltstone, sandstone, and coal. Unconfined to confined.	50 - 300	1,000	15 - 25	100	Dissolved-solids concentration generally less than 1,800 mg/L.
Mesozoic aquifers:					
Hell Creek Formation and Fox Hills Sandstone: Sandstone with some siltstone and shale. Confined except near outcrop areas.	150 - 500	1,000	5 - 20	200	Dissolved-solids concentration generally less than 1,200 mg/L. Includes Fox Hills-lower Hell Creek aquifer.
Judith River Formation: Sandstone with shale, siltstone, lignite, and coal. Confined except near outcrop areas.	200 - 600	1,000	5 - 15 est.	100	Dissolved-solids concentration generally less than 2,300 mg/L in central Montana. Water quality in other areas of Montana relatively unknown.
Eagle Sandstone: Interbedded sandstone and shale. Confined except near outcrop areas.	100 - 800	2,000	10 - 20 est.	200	Dissolved-solids concentration generally less than 2,300 mg/L in central Montana Water quality in other areas of Montana relatively unknown.
Kootenai Formation: Sandstone, siltstone, and shale. Confined except near outcrop areas.	100 - 900	3,000	10 - 30 est.	100	Dissolved-solids concentration generally less than 500 mg/L near outcrop areas in central Montana. Water quality in other areas of Montana relatively unknown.
Ellis Group: Sandstone, shale, limestone, and dolomite. Confined except near outcrop areas.	300 - 2,000	5,000	-	100	Dissolved-solids concentration generally less than 600 mg/L near outcrop areas. Water quality in other areas of Montana relatively unknown.
Paleozoic aquifer:					
Madison Group: Limestone, dolomite, anhydrite, and halite. Confined except near outcrop areas.	500 - 3,000	7,000	-	1,000	Dissolved-solids concentration generally less than 5,000 mg/L, but may exceed 300,000 mg/L in northeastern Montana.

Alluvial deposits are present mainly along the major river valleys. Water from these deposits is used for public and rural-domestic supplies near population centers along these river valleys. Locally, terrace gravel is developed for water, although supplies are affected by the generally limited saturated thickness and storage capabilities of the aquifer. One such deposit is exposed throughout large areas in Blaine, Valley, and Daniels Counties where it is a source of water for irrigation.

Pleistocene glacial debris deposited by a continental ice sheet forms a veneer over much of the plains of Montana north of 47°30′N. latitude and east of 112°W. longitude. The ice sheet also was responsible for altering river courses and subsequently burying ancient stream gravels with glacial drift. Recently discovered buried stream gravels in Roosevelt and Sheridan Counties are very productive aquifers, yielding sufficient quantities of water to wells for irrigation. The glacial deposits commonly yield adequate water supplies for stock and domestic needs. Water in the glacial deposits may be either confined or unconfined depending on their depth below the land surface and the silt and clay content of the overlying material.

Fort Union Aquifer

The Fort Union Formation consists primarily of moderately consolidated continental shale, siltstone, fine sand, sandstone, and coal. Well yields are sufficient for rural-domestic and livestock needs. Larger yields are sometimes



EXPLANATION

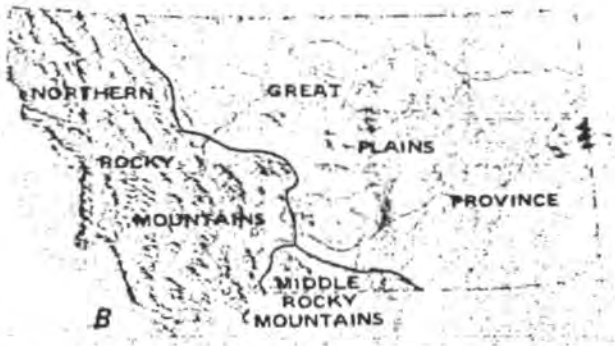
PRINCIPAL AQUIFER GROUPS

- Cenozoic
- Mesozoic
- Paleozoic
- Not a principal aquifer

Fault– Dashed where approximately located. Arrows show direction of displacement

A—A' Trace of cross section

- - - Southern border of continental glaciation



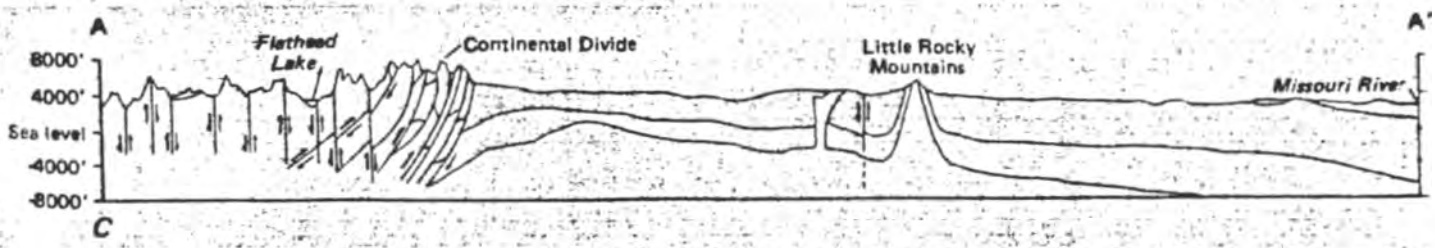


Figure 1. Principal aquifers in Montana. *A*, Geographic distribution. *B*, Physiographic diagram and divisions. *C*, Generalized cross section (A-A'). (See table 2 for more detailed description of the aquifers. Sources: *A*, Ross and others, 1955. *B*, Fenneman, 1931; Raisz, 1954. *C*, American Association of Petroleum Geologists, 1972.)

available in clinker, which is rock that has been baked, fused, and fractured from the burning of underlying coal beds. Generally, shallow ground water flows from topographically high areas toward local surface drainages, and deeper ground water flows toward major surface drainages. Shallow ground water may be either confined or unconfined; deeper ground water generally is confined.

MESOZOIC AQUIFERS

Fox Hills-Lower Hell Creek Aquifer

The lower part of the Hell Creek Formation consists of lenticular sandstone with intertonguing siltstone and shale. Where present, the underlying Fox Hills Sandstone, which is of marine origin, is connected hydraulically to the Hell Creek. Together, these two units compose the Fox Hills-lower Hell Creek aquifer. This aquifer is used most extensively in Carter, Custer, Prairie, and Fallon Counties on the flanks of the Cedar Creek anticline and Black Hills uplift or along major streams and rivers where drilling depths are minimized (Levings, 1982c). Yields generally are adequate for stock and rural-domestic purposes and for public supply in some areas. Water in this aquifer is confined except near its outcrop.

Judith River, Eagle, Kootenai, and Ellis Aquifers

Beneath the Fox Hills Sandstone is a series of aquifers that consist mainly of sandstone separated by shale confining layers. The aquifers commonly yield adequate supplies for most stock and rural-domestic needs and, at places, may yield adequate water for public supplies. Most of the wells are drilled near the outcrop area of the aquifers or where a satisfactory shallower source of supply is not available. The Judith River Formation is developed most extensively in Phillips, Blaine, Hill, and Valley Counties (Levings, 1982a); the Eagle Sandstone in Hill, Liberty, Choteau, Glacier, and Fergus Counties (Levings, 1982d); and the Kootenai Formation and the Ellis Group in Cascade, Judith Basin, Fergus, and Petroleum Counties near the flanks of mountain ranges (Levings, 1982b, and Levings, 1983). Water in these aquifers is confined except along their outcrop areas.

PALEOZOIC AQUIFERS

Madison Aquifer

The Madison Group is the lowermost widespread aquifer in eastern and central Montana. It consists mainly of limestone with some dolomite, anhydrite, and halite. Rocks of the Madison Group crop out mostly in mountain ranges but dip steeply away from the mountains and lie deeply buried in most of the eastern part of the State. Precipitation is the primary source of recharge in outcrop areas. Several large perennial springs issue from rocks of the Madison Group in Cascade, Fergus, and Carbon Counties. The Madison Group has not been used extensively for water supplies because of the generally deep drilling needed, but its subsurface configuration and potentiometric surface are well known because of regionwide oil exploration drilling (Feltis, 1980a, b). In areas where permeability is enhanced by fracturing and solution, large yields are possible. Water in the Madison is confined except near outcrop areas. The water is fresh near outcrops but increases in salinity with depth and distance from the outcrop (Feltis, 1980c).

GROUND-WATER WITHDRAWALS AND WATER-LEVEL TRENDS

Major areas of ground-water withdrawals are listed and trends in ground-water levels near selected locations are shown in figure 2. Most of the withdrawals are from the near-surface unconsolidated Cenozoic aquifers.

Water levels in wells throughout the State have been monitored since the 1950's. Presently, water levels are measured at least annually in about 220 observation wells statewide. In the western part of the State, 64 observation wells tap Cenozoic aquifers. In the eastern part, 76 wells are completed in Cenozoic aquifers, 78 in Mesozoic aquifers, and 4 in Paleozoic aquifers. Data from the measurements are stored in computer files and are available to the public upon request. The data can be used to evaluate naturally fluctuating water levels as a result of climatic patterns and the effects of man's activities on the hydrologic system.

Water levels generally decline in response to increases in withdrawals or decreases in recharge and recover with increased recharge or as withdrawals are decreased. Hydrographs (locations 1, 2, 8, fig. 2) from Beaverhead, Missoula, and Blaine Counties show that the overall trend is no net change; declines in water levels are seasonal. These unconsolidated aquifers are all unconfined.

The hydrograph from Fallon County (location 6, fig.2) shows a long-term decline in water level from 1962 to 1973 for the Fox Hills-lower Hell Creek aquifer. The declines resulted from large water withdrawals for industrial, public supply, rural domestic, and stock uses. Decreases in withdrawals since the mid-1970's have resulted in a rise in water levels, although the present water level is still about 60 ft lower than the 1962 level at the location shown. The Fox Hills-lower Hell Creek aquifer is confined in this area.

GROUND-WATER MANAGEMENT

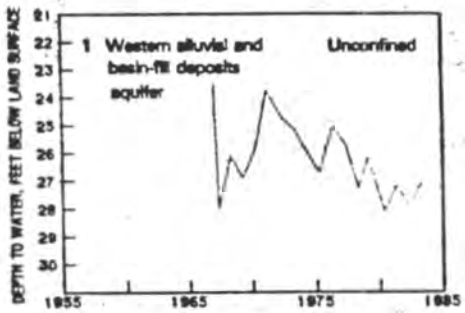
The 1973 Montana Water Use Act established a uniform central system for the acquisition, administration, and determination of all water rights. The Act also mandated the adjudication of all existing rights. To date, 10,500, or about 5 percent, of the State's existing water rights applications have been adjudicated, all in the Powder River Basin.

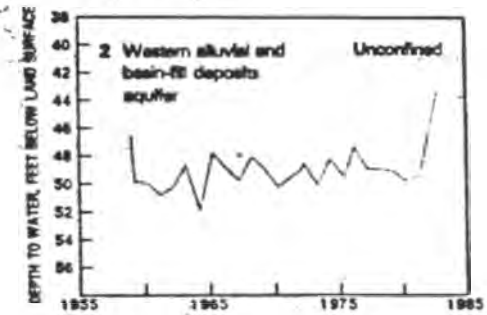
Appropriation of ground-water supplies for domestic, agricultural, or livestock purposes does not require a water-right permit if the maximum appropriation from the source well is less than 100 gallons per minute (gal/min). The only requirement is completion of a form within 60 days after completion of the well.

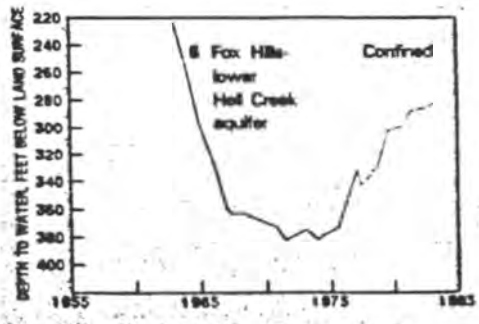
Appropriation of ground-water supplies requires a water-right permit if the maximum yield of the well is 100 gal/min or more or if the well is in a controlled ground-water area. Controlled ground-water areas can be established to protect water rights, an entire water resource, or public health in areas subject to pollution of water supplies.

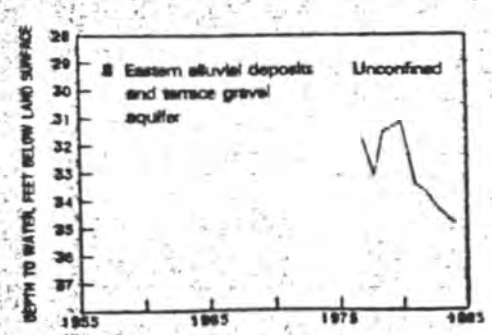
Requirements to be met before issuance of a water-right permit are:

1. Unappropriated waters exist that the applicant can use in the quantity and at the time proposed in the application.
2. The rights of prior appropriators will not be adversely affected.
3. The proposed means of construction are adequate.
4. The proposed use is deemed a beneficial use.
5. The proposed use will not interfere unreasonably with other permitted, planned uses or developments or with water previously reserved for other uses.









WITHDRAWAL SITES

No. on map	Geographic area	Aquifer	Principal uses
1	Beaverhead County	Western alluvial and basin-fill deposits.	Irrigation.
2	Missoula County	....do	Industrial, public supply, irrigation.
3	Broadwater County	....do	Irrigation.
4	Gallatin County	....do	Do.
5	Yellowstone County.	Eastern alluvial deposits and terrace gravel.	Irrigation, public supply, rural domestic.
6	Fallon County	Fox Hills-lower Hell Creek aquifer.	Public supply, industrial (in previous years).
7	Sheridan County	Eastern glacial deposits.	Irrigation.
8	Blaine County	Eastern alluvial deposits and terrace gravel.	Do.

Figure 2. Areal distribution of major ground-water withdrawals and graphs of annual greatest depth to water in selected wells in Montana. (Sources: Withdrawal data from Montana Department of Natural Resources and Conservation, 1985, and Solley and others, 1983; water-level data from U.S. Geological Survey files.)

6. The applicant proposing to use in excess of 10,000 acre-feet per year (15 cubic feet per second) must prove by clear and convincing evidence that the rights of prior appropriators will not be adversely affected.

Several State agencies implement most of the planning, regulatory, and research programs mandated by legislation in Montana. The Montana Department of Natural Resources and Conservation has the responsibility for administering water-resources and water-right programs and assists in the organization and operation of water-conservation districts. The Montana Department of Health and Environmental Sciences has the responsibility for regulating the quality of Montana's streams, lakes, and ground-water resources, including public-water supplies and wastewater management. The Montana Department of State Lands applies for and claims water for use on school-trust lands, maintains records of water rights attached to the State school-trust lands, and has indirect responsibility for water through various mining-reclamation acts. The Montana Universities Joint Water Resources Research Center, as the center of academic-oriented water research in Montana, conducts and coordinates specialized water studies, sometimes at the specific request of water-resource-management agencies.

The Montana Bureau of Mines and Geology is a nonregulatory agency responsible for conducting applied research projects on all aspects of the State's ground-water resources, maintaining a statewide ground-water information center and data base, and assisting governmental organizations and private citizens with water-related problems and requests. In addition, the Bureau has an active ground-water cooperative program with the U.S. Geological Survey to conduct local and regional hydrogeological investigations throughout the State. The research, data collection, and analyses provided through the program form an information base that helps regulating agencies make ground-water-management decisions and recommendations.

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Prepared by Julianne F. Levings, Robert E. Davis, and Charles Parrett

For further information contact District Chief, U.S. Geological Survey, Federal Building, Room 428, 301 South Park Avenue, Drawer 10076, Helena, MT 59626

United States
Environmental Protection
Agency

Region 8, Montana Office
Federal Building
301 S. Park, Drawer 10096
Helena, Montana 59626-0096

EPA

REF: 8MO

July 16, 1987

Debra Schmidt
Executive Director
Environmental Quality Council
State Capitol
Helena, Montana 59620

RE: Joint Resolution of the Senate and House on EPA Policy for the Judith River Formation

Dear Debra:

This letter is in response to the Montana House Joint Resolution No. 6 regarding the permitting of injection wells into the Judith River Formation on the Fort Peck Reservation. We are sympathetic to the concerns expressed in the Joint Resolution regarding protection of underground sources of drinking water (USDW's), which is the principal goal of the Underground Injection Control Program as authorized by the Safe Drinking Water Act. The Joint Resolution requests that EPA initiate a comprehensive monitoring and data collection effort on the Fort Peck Reservation and revise its policy on "Underground Injection Activities into the Judith River Formation on the Fort Peck Reservation, December 1985." Unfortunately, EPA Region VIII does not have sufficient funding to undertake a study of the scope suggested in the resolution.

The Region's policy on injection into the Judith River Formation describes the basic approach which will be used in reviewing permit applications. The policy statement is based on a general evaluation of injection activities on the Fort Peck Reservation. This general policy has since been used as guidance when issuing and denying permits with the basic concern being potential for endangerment of USDW's. Permits determinations are only made after evaluation of individual permit applications measured against specific requirements of the regulations.

As you may already be aware, the Assiniboine and Sioux Tribes filed a petition with the Administrator requesting review of a permit decision and the policy statement. After considering the merits of the petition, the Administrator denied the petition for review. (See attached document.)

The decision by the Administrator stated that the ". . . Petitioners have not demonstrated that the Region made an error of fact or law when it issued a final permit for Goings Well #1." In addition, the decision noted that the Policy Statement was beyond the scope of the review process established in 40 CFR 124.19.

As is always the case, any interested party can comment on a proposed permit action. Notices of permit actions are published in local newspapers and are sent directly to landowners that may be affected by the action. The burden of proof that a proposed injection activity will not endanger a USDW is on the permit applicant. If an interested party has evidence to suggest that a USDW may be endangered by the proposed injection activity, then that evidence should be provided to EPA during the comment period.

If I can be of further assistance on this issue, please call me at (406) 449-5414.

Sincerely,

John F. Wardell

John F. Wardell, Director
Montana Office

cc: Max H. Dodson

ROUTING AND TRANSMITTAL SLIP

Date 7-17-87

TO: (Name, office symbol, room number, building, Agency/Post)	Initials	Date
1. Debbie Ehlert 8WM-DW		
2. Drinking Water Branch		
3.		
4.		
5.		

	Action		File		Note and Return
	Approval		For Clearance		Per Conversation
	As Requested		For Correction		Prepare Reply
	Circulate		For Your Information		See Me
	Comment		Investigate		Signature
	Coordination		Justify		

REMARKS

RECEIVED
[redacted] 2n [redacted]
EPA REGION VIII
DRINKING WATER BRANCH

DO NOT use this form as a RECORD of approvals, concurrences, disposals, clearances, and similar actions

FROM: (Name, org. symbol, Agency/Post)	Room No.—Bldg.
Bill Eyk	Phone No.

5041-102 ★U.S.GPO:1986-0-491-247/20047

OPTIONAL FORM 41 (Rev. 7-76)
Prescribed by GSA
FPMR (41 CFR) 101-11.206

Land Operations

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF INDIAN AFFAIRS

P. O. BOX 637
FORT PECK AGENCY
POPLAR, MONTANA 59255

February 27, 1984

MAR 1984
Bureau of Land Management
Miles City, Montana

Bureau of Land Management
Miles City Dist. Office
P.O. Box 940
Miles City, Montana 59301

Dear District Manager:

The Bureau of Indian Affairs along with the Ft. Peck Tribes is concerned with all possible fresh water aquifers.

The Judith River is considered a possible fresh water aquifer. For this reason, we will no longer consider the Judith River as a saltwater disposed zone. We are also requiring the use of surface casing for all new wells, through the Judith River.

We propose the Lakota, Dakota or deeper formations for all new saltwater disposal wells.

Sincerely,

Superintendent