OIL CONSERVATION COMMISSION
1000 Rio Brazos Road
AZTEC, NEW MEXICO 87410

NOTICE OF GAS CONNECTION

DATE January 31, 1986

THIS IS TO NOTIFY THE OIL CONSERVATION COMMISSION THAT CONNECTION FOR THE PURCHASE OF GAS FROM THE Blackwood & Nichols

OPERATOR

NE BLANCO — LEASE
#218 — WELL UNIT
16 31N 7W — S – T – R

S. LOS PINOS - FRUITLAND / PC — POOL
NORTHWEST PIPELINE CORPORATION — NAME OF PURCHASER

WAS MADE ON 1-15-86 (DATE), FIRST DELIVERY 1-15-86 (DATE)

154 mcf/D
INITIAL POTENTIAL

NORTHWEST PIPELINE CORPORATION
PURCHASER

REPRESENTATIVE

ASSOCIATE CONTRACT ANALYST
TITLE

cc: OPERATOR
BLACKWOOD & NICHOLS

RECEIVED
FEB 06 1986
OIL CON. DIV.
DIST. 3

OIL CONSERVATION COMMISSION

1000 Rio Brazos Road

AZTEC, NEW MEXICO 87410

NOTICE OF GAS CONNECTION

DATE January 31, 1986

THIS IS TO NOTIFY THE OIL CONSERVATION COMMISSION THAT CONNECTION FOR THE PURCHASE OF GAS FROM THE Blackwood & Nichols

OPERATOR

NE BLANCO

LEASE

#214

WELL UNIT

22 31N 7W

S – T – R

S. LOS PINOS - FRUITLAND / PC

POOL

NORTHWEST PIPELINE CORPORATION

NAME OF PURCHASER

WAS MADE ON 1-14-86, FIRST DELIVERY 1-14-86

DATE / DATE

995 mcf/D

INITIAL POTENTIAL

NORTHWEST PIPELINE CORPORATIO

PURCHASER

REPRESENTATIVE

ASSOCIATE CONTRACT ANALYST

TITLE

cc: OPERATOR
BLACKWOOD & NICHOLS

OIL CONSERVATION COMMISSION

1000 Rio Brazos Road

AZTEC, NEW MEXICO 87410

NOTICE OF GAS CONNECTION

(N)

DATE January 31, 1986

THIS IS TO NOTIFY THE OIL CONSERVATION COMMISSION THAT CONNECTION FOR THE PURCHASE O

GAS FROM THE Blackwood & Nichols
OPERATOR

NE BLANCO — LEASE
#213 — WELL UNIT
12 31N 7W — S – T – R

S. LOS PINOS - FRUITLAND / PC — POOL
NORTHWEST PIPELINE CORPORATION — NAME OF PURCHASER

WAS MADE ON 1-14-86 (DATE), FIRST DELIVERY 1-14-86 (DATE)

998 MCF/D
INITIAL POTENTIAL

NORTHWEST PIPELINE CORPORAT
PURCHASER

REPRESENTATIVE

ASSOCIATE CONTRACT ANALYST
TITLE

cc: OPERATOR
BLACKWOOD & NICHOLS

RECEIVED
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DIST. 3

OIL CONSERVATION COMMISSION

1000 Rio Brazos Road

AZTEC, NEW MEXICO 87410

NOTICE OF GAS CONNECTION

DATE January 31, 1986

THIS IS TO NOTIFY THE OIL CONSERVATION COMMISSION THAT CONNECTION FOR THE PURCHASE OF

GAS FROM THE Blackwood & Nichols
OPERATOR

NE BLANCO — LEASE
#212 — WELL UNIT
1 31N 7W — S – T – R

S. LOS PINOS - FRUITLAND / PC — POOL
NORTHWEST PIPELINE CORPORATION — NAME OF PURCHASER

WAS MADE ON 1-15-86 (DATE), FIRST DELIVERY 1-15-86 (DATE)

386 MCF/D
INITIAL POTENTIAL

NORTHWEST PIPELINE CORPORATION
PURCHASER

Ivan R
REPRESENTATIVE

ASSOCIATE CONTRACT ANALYST
TITLE

cc: OPERATOR
BLACKWOOD & NICHOLS

OIL CONSERVATION COMMISSION

1000 Rio Brazos Road

AZTEC, NEW MEXICO 87410

NOTICE OF GAS CONNECTION

DATE January 31, 1986

THIS IS TO NOTIFY THE OIL CONSERVATION COMMISSION THAT CONNECTION FOR THE PURCHASE OF GAS FROM THE Blackwood & Nichols
OPERATOR

N E BLANCO	#215	26 31N 7W
LEASE	WELL UNIT	S – T – R

S. LOS PINOS - FRUITLAND / PC	NORTHWEST PIPELINE CORPORATION
POOL	NAME OF PURCHASER

WAS MADE ON 1-14-86 (DATE), FIRST DELIVERY 1-14-86 (DATE)

933 MCF / D
INITIAL POTENTIAL

NORTHWEST PIPELINE CORPORATION
PURCHASER

REPRESENTATIVE

ASSOCIATE CONTRACT ANALYST
TITLE

RECEIVED
FEB 06 1986
OIL CON. DIV.
DIST. 3

cc: OPERATOR
BLACKWOOD & NICHOLS

BLACKWOOD & NICHOLS CO., LTD.
P.O. BOX 1237
DURANGO, COLORADO 81302-1237

(303) 247-0728

RECEIVED
OCT 5
OIL CONSERVATION DIVISION

OCT 5
OIL CONSERVATION DIVISION

October 3, 1988

New Mexico Oil Conservation Division
P. O. Box 2088
525 Camino De Los Marquez
Santa Fe, New Mexico 87501

Attn: Michael E. Stagner

Re: Case No. 9489
September 28, 1988 Hearing
Northeast Blanco Unit Well No. 206
Nacimiento Disposal

Gentlemen:

Blackwood & Nichols Co., Ltd. has prepared the attached, Exhibit A - Water Quality Summary, in response to your request. This summary clearly shows there have been no significant changes in the character of the produced water from the wells listed on Exhibit 6, which will initially supply the produced water that hopefully will be injected into the No. 206 well.

During the September 28, 1988 hearing I was not as explicit as I should have been. Blackwood & Nichols' does not view the No. 206 disposal well as a temporary facility; we are hopeful that it will provide some disposal capacity for an indefinite period of time, dependent on the reservoir characteristics.

By temporary, I meant the No. 206 well could currently handle Blackwood & Nichols' produced water disposal needs in this area of the Northeast Blanco Unit. However, as Blackwood & Nichols begins producing more Fruitland Coal wells in this area, then it is probable the volume of produced water will become greater than the No. 206 well's capabilities. At such time, we will need to develop additional water disposal capacity.

Blackwood & Nichols appreciates your efforts to review this case in a timely manner. If additional information is needed, please advise.

Also enclosed is a copy of a technical paper presented at the Coalbed Methane Symposium, November, 1987, which may be useful to you.

Sincerely,

BLACKWOOD & NICHOLS CO., LTD.

William F. Clark ew

William F. Clark
Operations Manager

RECEIVED
OCT 5 1988
OIL CONSERVATION DIVISION

WFC:ew

Enclosures

October 3, 1988
Case No. 9489

Exhibit A
Water Quality Summary
Northeast Blanco Unit Wells

1. Well No. 212 - Fruitland Coal

Sample Date	TDS ppm	Remarks
2-04-86	9,130	Sample while blowing well
2-04-86	9,070	Sampled from separator
2-04-86	9,410	Sampled from fiberglass pit
4-25-88	9,120	Well pumping

*No significant changes in water quality.

2. Well No. 213 - Fruitland Coals and Pictured Cliffs

Sample Date	TDS ppm	Remarks
8-27-85	10,500	Upper Coal zone, during completion
8-28-85	6,490	Middle Coal zones and Upper PC Sand, during completion
3-17-86	9,030	Coal and Sand zones
6-06-86	8,580	Coal and Sand zones
4-25-88	8,100	Coal and Sand zones

*No significant changes in water quality.

3. Well No. 214 - Fruitland and Pictured Cliffs

Sample Date	TDS ppm	Remarks
8-25-86	18,900	Coal zones and Upper PC Sand zone, during completion
2-04-86	10,600	Coal and Sand zones
6-06-86	10,800	Coal and Sand zones
4-22-88	10,700	Coal and Sand zones

*Water quality, after completion, is very stable.

4. Well No. 215 - Pictured Cliffs

Sample Date	TDS ppm	Remarks
2-04-86	760	Well only making water vaper; sampled separator
6-06-86	7,260	
4-22-88	7,820	

*Water quality stable.

5. Well No. 218 - Fruitland Coal

Sample Date	TDS ppm	Remarks
9-11-85	6,425	Initial Potential Test
2-04-86	8,630	Blowing well
6-06-86	8,600	Separator
4-22-88	8,520	Pumping well

*Water quality stable.

PROPOSED OPERATION

1. The proposed injection well will be used to dispose of produced water from the Northeast Blanco Unit wells. The maximum daily rate of disposal will be determined by the step rate injection test. The average daily rate cannot be determined at this time. Primary use of the facility will be disposal of produced water from development of Fruitland Coal gas wells. Amount of water to be disposed of will depend on this development. Blackwood & Nichols' current estimate of produced water to be disposed of is less than 500 BPD; however, this should not be the implied limit because they plan to develop more coal gas wells in the near future.

2. The proposed system will be designed and installed as a closed system.

3. The maximum injection pressure will be determined by the step rate injection test. The average pressure will be maintained at less than the maximum pressure.

4. The latest produced water analysis are: (all values in mg/l)

Well Name	Na	Ca	Mg	K	Cl	HCO_3	SO_4	CO_4	TDS
NEBU #212	3639	29	20	20	520	7970	<10	696	9,410
NEBU #213	3110	8	15	22	920	6680	11	612	8,223
NEBU #214	3950	24	23	29	2330	7860	<10	0	10,190
NEBU #215	2570	22	5	21	3310	1790	<10	0	7,260
NEBU #218	3196	27	20	24	440	8930	<10	0	8,600
								Average -	8,736

5. Water Sample Analysis (attached):

   Sampled Date: 6-27-88
   Formation: Nacimiento
   Total Dissolved Solids: 6370 ppm

6. Geologic information -

   The Nacimiento Formation was encountered at 1798' to 2290'. The proposed injection intervals are the better quality sands and have a gross interval from 1798' to 2250' (452' feet) and a net thickness (proposed perforations) of 132 feet. The Ojo Alamo (below) and Animas and San Jose (above) are the only other possible aquifers in this wellbore. There are no known aquifers below the Ojo Alamo. There are no known oil or gas reservoirs above this interval. The South Los Pinos Fruitland-Pictured Cliffs Pool is the first productive zone below the Nacimiento, starting at approximately 3140'.

EXHIBIT 6
CASE 9489

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728
MAY 19, 1988

DATE REC'D: 4/29/88
DATE SAMPLED: 4/25/88
WELL NAME: NEBU 212
LOCATION:
FORMATION: FT
SAMPLED FROM:
WELL ON/OFF:

CDS ID#: 8776

CONSTITUENT		ppm	meq/L
Sodium	Na +	3480	151.4
Potassium	K +	14.8	.4
Calcium	Ca ++	31.5	1.6
Magnesium	Mg ++	21.8	1.8
Iron Total	Fe++ & Fe+++	1	.1
POSITIVE SUB-TOTAL		3549.1	155.1769
Chloride	Cl -	600	16.9
Carbonate	CO3 =	516	17.2
Bicarbonate	HCO3-	8010	131.3
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<100	0.0
NEGATIVE SUB-TOTAL		9126	165.3867

Total Dissolved Solids	9120 ppm
pH	7.86 units
Specific Gravity	1.006 @ 73 F.
Resistivity	100 ohm-cm

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

Results are based on analysis made at the time samples are received at the laboratory.

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 2/24/86 CDS ID# 155
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #212
FRUITLAND CO
PIT

CONSTITUENT		ppm	epm
Sodium	Na +	3639	158.3
Potassium	K +	19.9	.5
Calcium	Ca ++	29	1.4
Magnesium	Mg ++	20	1.6
Iron Total	Fe++ & Fe+++	1.5	.1
POSITIVE SUB-TOTAL		3709.4	162.0
Chloride	Cl -	520	14.7
Carbonate	CO3 =	696	23.2
Bicarbonate	HCO3-	7970	130.6
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	<10	<.2
NEGATIVE SUB-TOTAL		9196	168.7

Total Dissolved Solids	9410	ppm
pH	8.04	units
Specific Gravity	1.008	@ 73 Deg. F
Resistivity	.95	ohm-m

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 2/24/86 CDS ID# 155
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #212
FRUITLAND CO
SEPARATOR

CONSTITUENT		ppm	epm
Sodium	Na +	3391	147.5
Potassium	K +	18.5	.5
Calcium	Ca ++	28.8	1.4
Magnesium	Mg ++	20.4	1.7
Iron Total	Fe++ & Fe+++	16.5	.9
POSITIVE SUB-TOTAL		3475.2	152.0
Chloride	Cl -	540	15.2
Carbonate	CO3 =	384	12.8
Bicarbonate	HCO3-	8150	133.6
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	<10	<.2
NEGATIVE SUB-TOTAL		9084	161.8

Total Dissolved Solids	9070	ppm
pH	7.73	units
Specific Gravity	1.008	@ 73 Deg. F
Resistivity	1.02	ohm-m

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 2/24/86 CDS ID# 1553
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #212
FRUITLAND COA
SAMPLE WHILE
BLOWING

CONSTITUENT		ppm	epm
Sodium	Na +	3508	152.6
Potassium	K +	19.7	.5
Calcium	Ca ++	31.8	1.6
Magnesium	Mg ++	20	1.6
Iron Total	Fe++ & Fe+++	5.1	.3
POSITIVE SUB-TOTAL		3584.6	156.6
Chloride	Cl -	500	14.1
Carbonate	CO3 =	1320	44.0
Bicarbonate	HCO3-	7200	118.0
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	172	3.6
NEGATIVE SUB-TOTAL		9192	179.6

Total Dissolved Solids	9130	ppm
pH	8.34	units
Specific Gravity	1.009	@ 73 Deg. F
Resistivity	.98	ohm-m

BLACKWOOD & NICHOLS CO., LTD.

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

MAY 19, 1988

DATE REC'D: 4/29/88
DATE SAMPLED: 4/25/88
WELL NAME: NEBU 213
LOCATION:
FORMATION: FT-PC
SAMPLED FROM:
WELL ON/OFF:

CDS ID#: 8777

CONSTITUENT		ppm	meq/L
Sodium	Na +	3040	132.2
Potassium	K +	21.4	.5
Calcium	Ca ++	10.6	.5
Magnesium	Mg ++	9.2	.8
Iron Total	Fe++ & Fe+++	<.5	0.0
POSITIVE SUB-TOTAL		3081.2	134.07296
Chloride	Cl -	1680	47.4
Carbonate	CO3 =	396	13.2
Bicarbonate	HCO3-	4940	81.0
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<100	0.0
NEGATIVE SUB-TOTAL		7016	141.5294

Total Dissolved Solids	8100 ppm
pH	8.46 units
Specific Gravity	1.004 @ 73 F.
Resistivity	100 ohm-cm

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

CDS ID# 2003

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 6/19/86
DATE SAMPLED: 6/6/86
WELL NAME: NEBU 213
LOCATION:
FORMATION: FT & FC ZONES
SAMPLED FROM: SEPARATOR
WELL ON/Off:

CONSTITUENT		ppm	epm
Sodium	Na +	3110	135.3
Potassium	K +	21.6	.6
Calcium	Ca ++	7.8	.4
Magnesium	Mg ++	15.3	1.3
Iron Total	Fe++ & Fe+++	1.2	.1
POSITIVE SUB-TOTAL		3155.9	137.5494
Chloride	Cl -	920	25.9
Carbonate	CO3 =	612	20.4
Bicarbonate	HCO3-	6690	109.5
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	11	.2
NEGATIVE SUB-TOTAL		8223	156.03782

Total Dissolved Solids	8580 ppm
pH	8.85 units
Specific Gravity	1.008 @ 73 F.
Resistivity	.88 ohm M

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0720

DATE: 3/25/86
DATE SAMPLED: 3/17/86
WELL NAME: NEBU #213
LOCATION:
FORMATION: FRUITLAND & FC Z
SAMPLED FROM: SEPARATOR
WELL ON/Off:

CDS ID# 1698

CONSTITUENT		ppm	epm
Sodium	Na +	3070	133.5
Potassium	K +	25.3	.6
Calcium	Ca ++	25	1.2
Magnesium	Mg ++	10.9	.9
Iron Total	Fe++ & Fe+++	4.9	.3
POSITIVE SUB-TOTAL		3136	137
Chloride	Cl -	2470	69.7
Carbonate	CO3 =	156	5.2
Bicarbonate	HCO3-	4111	67.4
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	21	.4
NEGATIVE SUB-TOTAL		6758	143

Total Dissolved Solids		9030	ppm
pH		8.13	units
Specific Gravity	1.006	@ 73	F.
Resistivity		0.85	ohm M

APPROVED BY: Susan Kay Dickinson for
DR. JOE BOWDEN, DIRECTOR

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Results are based on analysis made at the time samples are received at the laboratory.

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

CDS ID# 3711

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 9/16/85
DATE SAMPLED: 8/28/85
WELL NAME: NEBU #213
LOCATION: MIDDLE FRUITLAND COAL
FORMATION UPPER P.C.
SAMPLED FROM: SECOND STAGE FRAC.
WELL ON/OFF: BLOWING

CONSTITUENT		ppm	epm
Sodium	Na +	2370	103.1
Potassium	K +	25.3	.6
Calcium	Ca ++	39.8	2.0
Magnesium	Mg ++	11	.9
Iron Total	Fe++ & Fe+++	1,03	.0
POSITIVE SUB-TOTAL		2447	106.7
Chloride	Cl -	1920	54.1
Carbonate	CO3 =	132	2.2
Bicarbonate	HCO3-	2480	40.6
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	36	.7
NEGATIVE SUB-TOTAL		4568	97.7

Total Dissolved Solids	6490	ppm
pH	7.15	units
Specific Gravity 1.0020 @	73	DEG. F.
Resistivity	1.1	ohm - meter

APPROVED BY Bowden

DR. JOE BOWDEN, DIRECTOR

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CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 9/16/85
DATE SAMPLED: 8/27/85
WELL NAME: NEBU #213
LOCATION: UPPER FRUITLAND COAL
FORMATION: THIRD STAGE FRAC.
SAMPLED FROM: BLOWING
WELL ON/Off:

CDS ID# 3710

CONSTITUENT		ppm	epm
Sodium	Na +	4220	183.6
Potassium	K +	102	2.6
Calcium	Ca ++	12.4	.6
Magnesium	Mg ++	16.9	1.4
Iron Total	Fe++ & Fe+++	1.10	0.0
POSITIVE SUB-TOTAL		4351	188.2
Chloride	Cl -	1680	47.4
Carbonate	CO3 =	372	6.2
Bicarbonate	HCO3-	6940	113.7
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	542	11.3
NEGATIVE SUB-TOTAL		9534	178.6

Total Dissolved Solids		10,500	ppm
pH		8.21	units
Specific Gravity	1.0040 @	73	DEG. F.
Resistivity		.70	ohm - meter

APPROVED BY: ______________________________
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

CDS ID#: 8751

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728
MAY 18, 1988

DATE: 4/26/88
DATE SAMPLED: 4/22/88
WELL NAME: NEBU 214
LOCATION:
FORMATION: FT. & PC
SAMPLED FROM:
WELL ON/OFF:

CONSTITUENT		ppm	epm
Sodium	Na +	4320	187.9
Potassium	K +	22.9	.6
Calcium	Ca ++	32.7	1.6
Magnesium	Mg ++	25.2	2.1
Iron Total	Fe++ & Fe+++	.5	.0
POSITIVE SUB-TOTAL		4401.3	192.23682
Chloride	Cl -	2300	64.9
Carbonate	CO3 =	336	11.2
Bicarbonate	HCO3-	6880	112.8
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<100	0.0
NEGATIVE SUB-TOTAL		9516	188.812

Total Dissolved Solids 10700 ppm
pH 7.56 units
Specific Gravity 1.009 @ 73 F.
Resistivity 80 ohm-cm

APPROVED BY: Joe Bowden
DR. JOE BOWDEN, DIRECTOR

CDS LABORATORIES	BLACKWOOD & NICHOLS	DATE: 6/19/86
75 SUTTLE STREET	ATTEN: BILL CLARK	DATE SAMPLED: 6/6/86
PO BOX 2625	PO BOX 1237	WELL NAME: NEBU 214
DURANGO, CO 81302	DURANGO, CO 81302	LOCATION:
(303) 247-4220	(303) 247-0728	FORMATION: FT & PC ZONES
		SAMPLED FROM: SEPARATOR
CDS ID# 2804		WELL ON/Off:

CONSTITUENT		ppm	epm
Sodium	Na +	3950	171.8
Potassium	K +	29.2	.7
Calcium	Ca ++	23.6	1.2
Magnesium	Mg ++	23.1	1.9
Iron Total	Fe++ & Fe+++	4	.2
POSITIVE SUB-TOTAL		4029.9	175.8642
Chloride	Cl -	2330	65.7
Carbonate	CO3 =	0	0.0
Bicarbonate	HCO3-	7860	128.8
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<10	0.0
NEGATIVE SUB-TOTAL		10190	194.5314

Total Dissolved Solids	10,000 ppm
pH	7.82 units
Specific Gravity	1.009 @ 73 F.
Resistivity	.7 ohm M

APPROVED BY: Joe Bowden

DR. JOE BOWDEN, DIRECTOR

Results are based on analysis made at the time samples are received at the laboratory.

CDS LABORATORIES
75 SUTTLE STREET
PO BOX 2605
DURANGO, CO 81302
(303) 247-4220

BLACKWOOD & NICHOLS
ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 2/24/86 CDS ID# 155
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #214
FT-PC ZONE
FROM WATER T

CONSTITUENT		ppm	epm
Sodium	Na +	3651	158.8
Potassium	K +	31.7	.8
Calcium	Ca ++	35	1.7
Magnesium	Mg ++	18.3	1.5
Iron Total	Fe++ & Fe+++	4.7	.3
POSITIVE SUB-TOTAL		3740.7	163.1
Chloride	Cl -	2980	84.0
Carbonate	CO3 =	276	9.2
Bicarbonate	HCO3-	5440	89.2
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	<10	<.2
NEGATIVE SUB-TOTAL		8706	182.6

Total Dissolved Solids	10,600	ppm
pH	7.91	units
Specific Gravity	1.008	@ 73 Deg. F
Resistivity	.81	ohm-m

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(303) 247-0728

DATE: 9/16/85
DATE SAMPLED: 8/25/85
WELL NAME: NEBU #214
LOCATION: FRUITLAND COALS
FORMATION: UPPER P.C. BLOWING
SAMPLED FROM: SECOND STAGE FRAC.
WELL ON/Off:

CDS ID# 3709

CONSTITUENT		ppm	epm
Sodium	Na +	1740	75.7
Potassium	K +	17.6	.5
Calcium	Ca ++	29.7	1.5
Magnesium	Mg ++	6.6	.5
Iron Total	Fe++ & Fe+++	.1	.0
POSITIVE SUB-TOTAL		1794	78.2
Chloride	Cl -	1020	28.8
Carbonate	CO3 =	0	0.0
Bicarbonate	HCO3-	3099	50.8
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	30	.6
NEGATIVE SUB-TOTAL		4149	80.2

Total Dissolved Solids 10,900 ppm
pH 7.56 units
Specific Gravity 1.0023 @ 73 F.
Resistivity 1.4 ohm - meter

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CDS ID#: 8752

BLACKWO[illegible] NICHOLS
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PO BOX 1237
DURANGO, CO 81302
(303) 247-0728
MAY 18, 1988

DATE: 4/26/88
DATE SAMPLED: 4/22/88
WELL NAME: NEBU 215
LOCATION:
FORMATION: P.C.
SAMPLED FROM:
WELL ON/OFF:

CONSTITUENT		ppm	epm
Sodium	Na +	3000	130.5
Potassium	K +	18.5	.5
Calcium	Ca ++	26.6	1.3
Magnesium	Mg ++	5.9	.5
Iron Total	Fe++ & Fe+++	1.3	.1
POSITIVE SUB-TOTAL		3052.3	132.8556
Chloride	Cl -	3840	108.3
Carbonate	CO3 =	60	2.0
Bicarbonate	HCO3-	1520	24.9
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<100	0.0
NEGATIVE SUB-TOTAL		5420	135.1988

Total Dissolved Solids	7820 ppm
pH	7.86 units
Specific Gravity	1.005 @ 73 F.
Resistivity	95 ohm-cm

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DURANGO, CO 81302
(303) 247-0728

DATE: 5/19/86
DATE SAMPLED: 6/6/86
WELL NAME: NEBU 215
LOCATION:
FORMATION: PC ZONE
SAMPLED FROM: SEPARATOR
WELL ON/Off:

CDS ID# 2805

CONSTITUENT		ppm	epm
Sodium	Na +	2570	111.8
Potassium	K +	21.4	.5
Calcium	Ca ++	21.9	1.1
Magnesium	Mg ++	5.2	.4
Iron Total	Fe++ & Fe+++	7	.4
POSITIVE SUB-TOTAL		2625.5	114.23891
Chloride	Cl -	3310	93.3
Carbonate	CO3 =	0	0.0
Bicarbonate	HCO3-	1790	29.3
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<10	0.0
NEGATIVE SUB-TOTAL		5100	122.6801

Total Dissolved Solids	7260 ppm
pH	7.92 units
Specific Gravity	1.005 @ 73 F.
Resistivity	.89 ohm M

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DATE: 2/24/86 CDS ID# 155
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #215
FC ZONE
SEPARATOR

Bad ?

CONSTITUENT		ppm	epm
Sodium	Na +	349	15.2
Potassium	K +	3.7	.1
Calcium	Ca ++	.5	.0
Magnesium	Mg ++	.7	.1
Iron Total	Fe++ & Fe+++	6.1	.3
POSITIVE SUB-TOTAL		360	15.7
Chloride	Cl -	33	.9
Carbonate	CO3 =	28	.9
Bicarbonate	HCO3-	676	11.1
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	20	.4
NEGATIVE SUB-TOTAL		757	13.4

Total Dissolved Solids	760	ppm
pH	8.19	units
Specific Gravity	0.997	@ 73 Deg. F
Resistivity	9.10	ohm-m

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CDS ID#: 8754

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(303) 247-0728
MAY 18, 1988

DATE: 4/26/88
DATE SAMPLED: 4/22/88
WELL NAME: NEBU 218
LOCATION:
FORMATION: FT
SAMPLED FROM:
WELL ON/OFF:

CONSTITUENT		ppm	epm
Sodium	Na +	3530	153.6
Potassium	K +	20.5	.5
Calcium	Ca ++	31.5	1.6
Magnesium	Mg ++	19.8	1.6
Iron Total	Fe++ & Fe+++	1.9	.1
POSITIVE SUB-TOTAL		3603.7	157.38166
Chloride	Cl -	430	12.1
Carbonate	CO3 =	576	19.2
Bicarbonate	HCO3-	7720	126.5
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<100	0.0
NEGATIVE SUB-TOTAL		8726	157.8376

Total Dissolved Solids	8520 ppm
pH	7.94 units
Specific Gravity	1.009 @ 73 F.
Resistivity	100 ohm-cm

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DATE: 6/19/86
DATE SAMPLED: 6/6/86
WELL NAME: NEBU 218
LOCATION:
FORMATION: FT ZONE
SAMPLED FROM: SEPARATOR
WELL ON/OFF:

CDS ID# 2008

CONSTITUENT		ppm	epm
Sodium	Na +	3196	139.0
Potassium	K +	24.3	.6
Calcium	Ca ++	27.4	1.4
Magnesium	Mg ++	19.6	1.6
Iron Total	Fe++ & Fe+++	1.6	.1
POSITIVE SUB-TOTAL		3268.9	142.71271
Chloride	Cl -	440	12.4
Carbonate	CO3 =	0	0.0
Bicarbonate	HCO3-	8930	146.4
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	<10	0.0
NEGATIVE SUB-TOTAL		9370	158.7707

Total Dissolved Solids	8600 ppm
pH	7.8 units
Specific Gravity	1.009 @ 73 F.
Resistivity	.86 ohm M

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DATE: 2/24/86
DATE SAMPLED: 2/4/86
DATE RECEIVED: 2/5/86
WELL NAME: NEBU #218
FT. COAL ZON
BLOWING WELL

CDS ID# 155

CONSTITUENT		ppm	epm
Sodium	Na +	3560	154.9
Potassium	K +	27.5	.7
Calcium	Ca ++	31	1.5
Magnesium	Mg ++	20.9	1.7
Iron Total	Fe++ & Fe+++	7.1	.4
POSITIVE SUB-TOTAL		3646.5	159.2
Chloride	Cl -	450	12.7
Carbonate	CO3 =	384	12.8
Bicarbonate	HCO3-	8100	132.8
Hydroxide	OH -	-----	0.0
Sulfate	SO4 =	<10	<.2
NEGATIVE SUB-TOTAL		8944	158.4

Total Dissolved Solids	8630	ppm
pH	7.62	units
Specific Gravity	1.008	@ 73 Deg. F
Resistivity	1.05	ohm-m

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ATTEN: BILL CLARK
PO BOX 1237
DURANGO, CO 81302
(303) 247-0728

DATE: 10/16/85
DATE SAMPLED: 9/11/85
WELL NAME: NEBU #218
FORMATION: FRUITLAND COAL
DURING I.P. TEST
WELL ON/OFF: BLOWING

CDS ID# 3825

CONSTITUENT		ppm	epm
Sodium	Na +	2020	87.9
Potassium	K +	17	.4
Calcium	Ca ++	29	1.4
Magnesium	Mg ++	15	1.2
Iron Total	Fe++ & Fe+++	156	5.6
POSITIVE SUB-TOTAL		2237	96.6
Chloride	Cl -	280	7.9
Carbonate	CO3 =	0	0.0
Bicarbonate	HCO3-	6160	101.0
Hydroxide	OH -	0	0.0
Sulfate	SO4 =	65	1.4
NEGATIVE SUB-TOTAL		6505	110.2

Total Dissolved Solids		6425	ppm
pH		7.12	units
Specific Gravity	1.003	@ 77	DEG. F.
Resistivity		1.3	ohm-m

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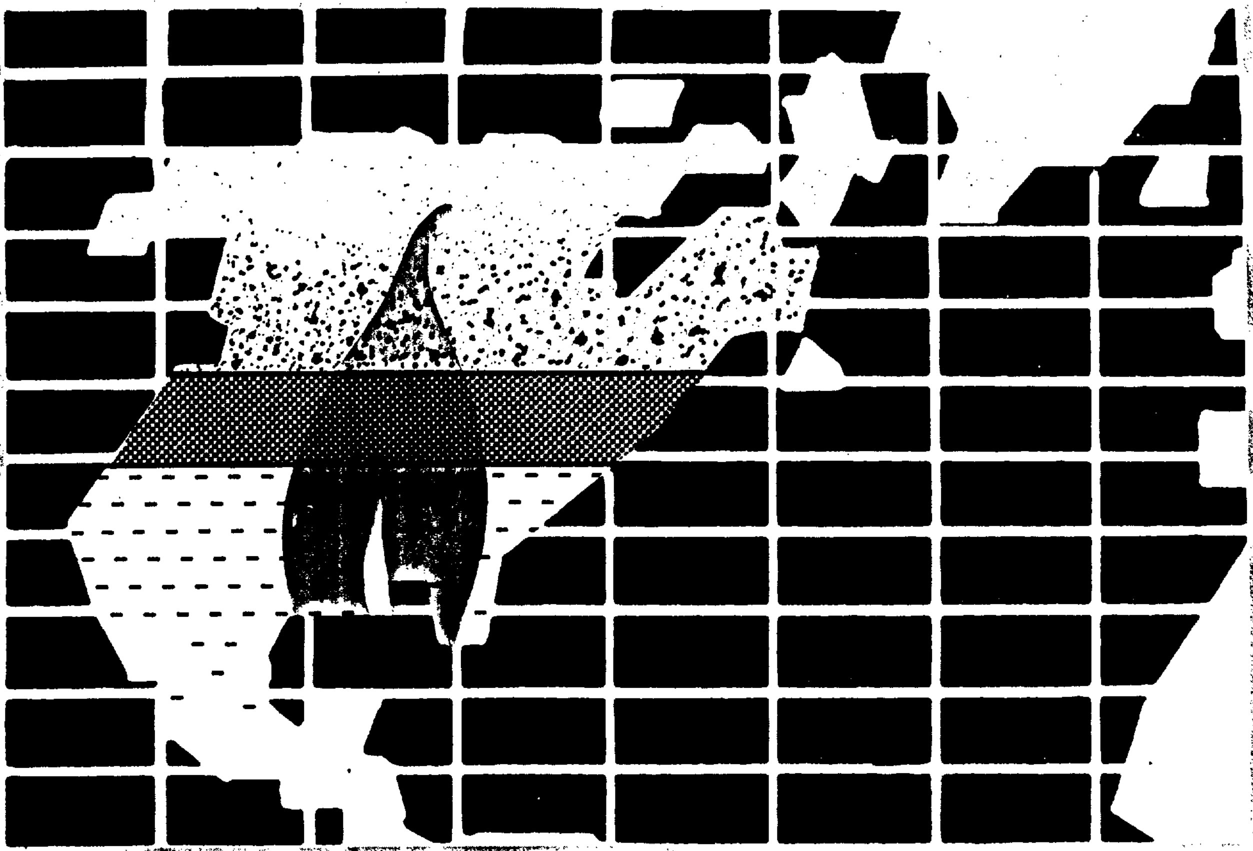
DR. JOE BOWDEN, DIRECTOR

Results are based on analysis made at the time samples are received at the laboratory.



The 1987

Coalbed Methane Symposium

Proceedings

November 16-19, 1987
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8746 Geochemical Techniques Applied to the Identification and Disposal of Connate Coal Water

A.D. Decker (Resource Enterprises, Inc.); R. Klusman (Colorado School of Mines); D.M. Horner (Gas Research Institute)

ABSTRACT

Integration of water geochemistry into a coalbed methane project in western Colorado was implemented to verify the origin of produced water, and water disposal methods. Geochemical techniques were used to identify and resolve potential water injection problems. This played an important role in the decision to produce and dispose water from fractured coal reservoirs of Tenneco's Exploration and Production 1 Cameo 20-4 coalbed methane well, Garfield County, Colorado. Fractures interconnecting the Cameo coal seams and adjacent shale and sandstone sequence, in combination with poor cement bond, raised doubts concerning the origin of produced water and water contribution from non-coal reservoirs. Well tests indicated an artesian flow rate up to 2000 barrels of water per day with present water quality below environmental standards for surface disposal. Disposal of large volumes of produced water and uncertainty of the water origin needed to be resolved before production or abandonment of the well.

Chemical components of water contained in clastic reservoirs is different from coal water. Water samples collected from the 1 Cameo 20-4 well and surrounding wells were analyzed for the cations: sodium, potassium, calcium, magnesium, and for the anions: chloride, bicarbonate, carbonate, and sulfate. The ions were expressed as a percentage of the total ionic composition and were plotted on a Piper diagram. Water from the 1 Cameo 20-4 well fell in the region of a sodium bicarbonate type coal derived water. All other water samples were located in the region of sodium chloride clastic derived water consistent with the completed intervals. Water analysis positively identified water from the 1 Cameo 20-4 well as originating from coal seams.

Rate forecasts based on measured and calculated reservoir properties indicated the 1 Cameo 20-4 well would produce 235 Mbw to 328 Mbw during the first year. A cost effective method for disposal of large volumes of water for the dewatering of the well were investigated. The levels of barium, iron, mercury and total dissolved solids (TDS) of the coal derived water exceeded environmental regulations for surface disposal. High elevations, occasional high precipitation, and large water volumes eliminated the feasibility of using evaporation ponds. A dry hole, approximately 2900 feet away, was re-entered for disposal of coal water into the Cozzette sandstone. A step rate test indicated the Cozzette sandstone could accommodate 1900 BWPD at parting pressure. Before initiation of injection, problems associated with potential plugging off the disposal zone from clay swelling, coal fines, soluble and insoluble precipitates were addressed. Geochemical modeling indicated that permanent clay stabilization processes were incompatible with water to be injected into the disposal zone. Cost considerations precluded the continuous use of potassium chloride for clay stabilization. Recognizing the inability to treat anticipated clay swelling problems, a special permit to inject water into the Cozzette sandstone above parting pressure was obtained. Filtration analysis indicated that suspended solids in the form of precipitates and coal fines could be eliminated using a 0.5 micron size filter.

Chemical equilibrium modeling indicated the absence of insoluble precipitates. A water compatibility test of the produced water and water from the injection zone was performed at a formation temperature of 180° F. A precipitate of calcium carbonate, magnesium carbonate, barium carbonate and strontium carbonate was formed. To determine the theoretical volume of potential precipitates, the equilibrium saturation for carbonate minerals was calculated, correcting for 1) temperature effects on the dielectric constant of water, 2) ionic strength, 3) activity of individual ions, and 4) temperature effects on the solubility products for each carbonate and common ion effect. The results from the theoretical approach indicated that complete precipitation of all the alkaline elements in the form of carbonates would produce approximately 123 pounds of carbonate precipitate per 1000 barrels of injected water. Calculations indicated that the addition of 740 pounds of carbon dioxide per 1000 barrels of produced water would sufficiently buffer the water, preventing the formation of precipitates.

Water analysis from Cretaceous and Pennsylvanian age coals suggests the techniques described in this paper may apply to other coalbed methane exploitation projects. As the majority of coalbed methane wells initially require long periods of dewatering, application

and implementation of coal water geochemistry will result in cost effective, environmentally acceptable water disposal techniques favorably impacting the coalbed methane industry and gas consumer by reducing the cost of gas produced from coal seams.

INTRODUCTION

Coalbed degasification projects producing from water saturated coal zones cannot proceed until water identification and disposal problems are resolved. Applied geochemical techniques are a useful tool in discriminating water types and present possible alternatives to water disposal problems for injection wells and remedial treatment of coal water for surface disposal.

A geochemical model presented hypothesizes an origin of formation water in detrital sequences and connate coal water based on chemical compositional changes caused by 1) compaction, 2) lithification, 3) maturation, and 4) hydrologic history of coal bearing intervals during basin evolution. Consistent with the model, standard analytical and geochemical techniques are then used to discriminate coal derived water from non-coal water. A two dimensional graphical plot is used to discriminate coal derived water from detrital water based on anion/cation proportions. Using these plotting techniques, shifts in water chemistry from coal water to non-coal water has been documented after hydraulic fracture stimulations of coal intervals.

When surface disposal of coal water is not permitted, produced water must be injected into a disposal zone. Problems with water incompatibility, clay swelling and fines migration, and deterioration of production equipment can be predicted and resolved using geochemical modeling techniques.

The water chemistry data base used for this paper was obtained from co-operative coal degasification projects or from the public record. Conclusions are based on case history studies performed in the Piceance, San Juan, and Black Warrior Basins.

EVOLUTION AND IDENTIFICATION OF DETRITAL AND CONNATE COAL WATER

The purpose of producing water from a coalbed completion is to reduce hydrostatic pressure below desorption pressure to initiate gas production causing a change in relative permeability from water to gas. When water originates from large non-coal aquifers, water production will be continuous with little positive effects on coal dewatering and subsequent gas production. Therefore the cost for water disposal will be incurred without realizing the benefit of gas production. Identification of coal derived water is necessary before proceeding with a dewatering operation. To establish a basis for differentiating coal and non-coal water requires a theoretical basis for the origin of both. The theoretical basis will later be documented with a data base collected from field operations.

Evolution of a Connate Water During Compaction of a Detrital Sequence

The deposition of sand-sized and finer fractions of detrital silicate material is accompanied by the inclusion of large amounts of water in the pore space, which can be as great as 80% by weight during the earliest stages of deposition. This water can range from fresh to saline depending on whether the depositional environment is marine or terrestrial. After burial a sediment interacts with the pore water modifying the sediment and in the process becoming modified itself.

In the Rocky Mountain region, a major basin was being transformed during the Cretaceous Period from a marine sequence to a terrestrial basin with a distinctive change in sediment character. The early Cretaceous seafloor was transformed into a swampy lowland in which thick intervals of peat were deposited. These alternated with fluvial sandstones of late Cretaceous age. The peat deposits became the coals which are extensively mixed in several basins of the Rocky Mountain region today.

The pore waters incorporated into these sandstones and peat deposits were fresh or locally brackish waters in some swamps. A reduction in porosity followed, resulting in the initial possible value of 80% to something less than 20% requiring a great deal of dewatering of the sediment. During compaction, waters move from the shale units into the more permeable sandstones, which can result in overpressuring. Figure 1 from Hayes[1] illustrates this in a schematic fashion. Although overpressuring is possible in detrital sequences which are dominated by fine-grained material, it is not necessary for the diagenesis process to occur. In stratigraphically isolated coal seams, overpressuring may also occur because a volume of water up to several times the volume of the present day sediment volume must be expelled. The volume of water that may be generated by coal during compaction is shown on Figure 2. Impermeable shales bounding coal seams will inhibit water expulsion leading to high fluid pore pressure. Overpressured, water saturated coal reservoirs documented in the San Juan Basin[2] might be an inherited condition from coal water generation.

The expulsion of water is not without compositional changes, in particular a selective retention/expulsion of ions occurs. A fine-grained material, particularly the three layer clay minerals associated with detrital sediments in the Cretaceous and Tertiary sediments of the Rocky Mountain region, has an electrical double layer of ions surrounding the individual particles. Electrical double layer theory was first developed in the late 1800's by Helmholtz and has been undergoing modification since that time. The details of the ion and charge distribution will be discussed to give insight to the importance of selection retention in clastic environments.

The composition and structure of clay minerals result in an excess of exposed oxygen at the edges and between layers. This surface gains a net negative charge tightly bonding cations close to the surface. There is a more diffuse, weakly bound layer of cations at increasing distance from the surface (Figure 3). At greater distances there is a free solution which is not directly influenced by particulate matter.

The distribution of ions within the electrical double layer is not the same as that of the free solution. The propensity for binding to the surface is a function of the charge and size of the ion. The ionic potential is defined as:

$$\text{Ionic potential} = \frac{\text{ion size}}{\text{ion charge}}$$

This shows that the greater the ionic potential, the more tightly bound is the ion. As a result, smaller, divalent ions such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) are held more tightly than sodium (Na^+) if concentrations are equal. Overall, the system must be electrically neutral and a statistical increase in anions at slightly greater distances can be expected. Ionic potential again applies and anions such as sulfate ($SO_4^=$) are more tightly held in the diffuse layer than a large univalent ion such as chloride (Cl^-). The sign of the surface charge can be reversed by changes in pH. This zero point of change (ZPC), or isoelectric point, is a function of the mineralogy. For silicates, it ranges from 2-4, so the surfaces are negative at ordinary pH ranges. Westall and Hohl[3] and Stumm and Morgan[4] discuss electrical double layer theory in detail.

As the sediment is compacted, it acts as a semipermeable membrane, retaining the high ionic potential ions and expelling the Na^+ and Cl^- to the more permeable sandstones. Water molecules are also preferentially expelled despite their polarity. Hanshaw and Coplen[5] and Kharaka and Berry[6] discuss the chemical fractionation processes which result as a sediment is compacted. Schmidt[7] found that connate water evolution is prevented in geopressured zones of marine sediments if compaction is prevented by insufficient permeability to expel pore fluids. Similarly retention of diagenetic coal water may also occur where overpressured, water saturated coal reservoirs resulted from the inability of coal generated water to be effectively expelled through low permeability bounding shales.

In summary, the physical processes of compaction of sediments result in both a modification of composition and an increase in total dissolved solids. Expulsion of water from the system and to the surface increases the total dissolved solids remaining over that of the original pore water. The selective retention of high ionic potential ions in the vicinity of any clays or fine grained material results in the sandstone waters becoming a Na-Cl type water.

Evolution of a Connate Water by Sulfate Reduction

A reducing environment is rapidly attained in waters containing organic-rich sediment, depleting dissolved oxygen. When molecular oxygen is not available, microbes use a series of available sources in turn, creating more reducing conditions.

The more important microbial reactions in a peat swamp and in the subsequent diagenesis to coal are $SO_4^=$ reduction and methane (CH_4) fermentation (methanation). Organic matter is a variable and complex material but is frequently represented for chemical reaction purposes as CH_2O. Using this simplified formula, sulfate reduction is coupled with organic matter and oxidation resulting in the formation of methane and bicarbonate as outlined in the Appendix (chemical reactions 1-5).

The net result of sulfate reduction is decrease of $SO_4^=$ and increase in bicarbonate (HCO_3^-) in connate waters. Methanation will produce CH_4 and HCO_3^- in connate waters.

The presence of the dissolved carbon dioxide (CO_2) as bicarbonate or HCO_3^- is supported by the C_T-pH diagram for the speciation of carbonate in aqueous systems. Carbon dioxide dissolving in water can be considered as $CO_2(aq)$ or H_2CO_3. H_2CO_3 dissociates stepwise into HCO_3^- and $CO_3^=$. These dissociation can be reversible depending on the pH of the water as shown in the Appendix (chemical reactions 6 and 7). In waters with a pH greater than 6.3 but less than 10.3, HCO_3^- will be the dominant carbonate specie.

Reactions (1-3) results in an accumulation of hydrogen sulfide (H_2S) or dissolved H_2S if there is an appreciable amount of $SO_4^=$ reduction taking place. But the presence of a trace amount of iron in the system will effectively prevent the accumulation of H_2S or HS^- in the connate water due to the precipitation of black iron sulfides which are converted to pyrite.

In summary, methanation in a highly reducing environment commonly associated with peat swamps will result in a water composed of bicarbonate as the dominant anion, contrasting with chloride as the dominant anion in the detrital section.

Interpretation of the Composition of Connate Waters from the Piceance, San Juan, and Warrior Basins

A group of formation waters from three coal-bearing basins were analyzed for major chemical constituents. In most cases, the interval being sampled is known. The general hypothesis is that connate waters derived from coal will be chemically distinct from those connate waters derived from sandstones. The objectives were to: 1) examine the data from a geochemical perspective to determine if the waters from the two sources are distinctive; 2) determine if the data are consistent with the theory presented in the previous section.

Most waters have four cations and four anions that may be present in significant quantities. These include the cations, Na^+, K^+, Ca^{2+}, Mg^{2+} and the anions Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}. Due to electroneutrality requirements, the number of equivalents of cations must be equal to the number of equivalents of anions. Diagnostic plotting techniques require examining the relative proportion of these ions. Unless pH is unusually high, CO_3^{2-} is minor and is combined with HCO_3^- for plotting purposes. Potassium (K^+) is also minor in most waters and is combined with Na^+ for plotting.

The original chemical data for the Piceance and San Juan Basin connate waters are tabulated in Table 1. The data are converted to meq/L in Table 1 which can be plotted on triangular diagrams to show the proportion of cations and anions separately (Figure 4). The pairs of points can be projected onto a quadrilateral diagram. The sandstone-derived connate waters are NaCl type waters and the coal-derived connate water samples are primarily a Na-HCO_3 type water. The Cameo 20-4 well connate waters are also clearly Na-HCO_3 type, indicating a "coal-type" water.

Distinctive chemical characteristics which allow differentiation of coal-derived and sandstone-derived waters are shown on Figure 4. The sandstone-derived waters are a Na-Cl type and generally of higher TDS than the coal-derived waters. This is consistent with the observation in other basins that compaction selectively expels Na^+ and Cl^- to the more permeable sandstones. The expulsion of water during volume reduction also increases the total dissolved solids well above that expected for a freshwater aquifer.

The processes of sulfate reduction and methanation illustrated in equations (1) to (5) support the in-situ conversion of connate waters to a Na-HCO_3 type.

Note that Ca^{2+} is depleted in the coal-derived waters of Table 1. The CO_3^{2-} concentration can be estimated from HCO_3^- concentration and pH using Figure 5 or calculated ionization fractions for the carbonate system. Calcium and CO_3^{2-} data are then used to compute the ion concentration product for $[Ca^{2+}][CO_3^{2-}]$. Ionic strength corrections and activity coefficient determination were not made, but both the coal-derived and sandstone-derived waters seem to be saturated with calcite ($CaCO_3$). This is shown in Figure 6, where if the concentration product of $[Ca^{2+}][CO_3^{2-}]$ exceeds $10^{-8.34}$, $CaCO_3$ is stable.

If the waters were at or near $CaCO_3$ saturation early in the deposition process, later diagenetic production of HCO_3^- will result in additional precipitation of $CaCO_3$, depleting Ca^{2+} from the connate water. These data are supportive of a late diagenetic and perhaps continuing process.

Special Laboratory Procedures for High Bicarbonate Water

Some specific problems with the analysis of high bicarbonate water may be encountered. The chloride determination by mercuric nitrate titration (Standard Methods 407B, and ASTM D512 method A) cannot be used in a routine manner, using the mixed acid buffer and indicator (diphenylcarbazone). The acid added to the sample is insufficient to achieve the required pH of 2.5 (Standard Methods). If the sample is first adjusted to the proper pH before the titration, the correct result is obtained. The Mohr method API RP45 section 2.8, using silver nitrate as a titrant gives correct results, but should also be preceded by a pH adjustment, since carbonate ions interfere.

The sulfate determination by precipitation of barium sulfate API RP45, section 2.71, does not include sufficient hydrochloric acid to prevent precipitation of barium carbonate, and a preliminary pH adjustment to 4.5 (Standard Methods 426A) is necessary. The turbidimetric methods API RP45, section 2.72 and Standard Methods 426C, ASTM D516B suffer from the same problem.

Though these problems are rather simple chemically, laboratories may view these determinations as rather routine, and base quality control judgments on accompanying, less alkaline, reference samples. There is also inadequate concern for anion-cation balances, resulting in data containing errors outside the expected statistical error limits.

Monitoring Water Chemistry During Production Operations

The 1 Cameo 20-4 well is being produced in an effort to dewater the coal seams. The current problem is whether there is significant change in the composition of produced waters indicating tapping of sandstone-derived waters during production.

Case History Study, 1 Cameo 20-4

Table 2 includes the chemical analyses of water from the 1 Cameo 20-4 East Divide Creek Unit, Piceance Basin, Colorado for the period 05-14-85 to 06-23-87. The Piper diagram was used to determine if there is a systematic change in composition with time from the point of initiation of water production through 6-23-87 or a total production of 54,000 barrels of water.

Figure 7 is a Piper diagram for the 1 Cameo 20-4 samples. Since the waters are from a single source and are all Na-HCO_3 type waters, only that region of the Piper diagram is plotted. The 95-100% Na-HCO_3 region is expanded to enable the detection of time-related trends. Successive daily samples are connected with arrows to show change with time. The cluster of points in the anion triangle is so tight not all of the points are connected with arrows.

There are two reasons for variation in this type of data set; true change in composition and a combination of sampling and analytical error. The magnitude of sampling and analytical error can be determined by replicate sampling and replicate analysis. Data which exhibits reasonably tight clusters and time-connected points which go in all directions in a random walk fashion suggest only random error, which in this case appears to be of an acceptable magnitude.

A systematic change in one direction or a simultaneous change in several components is suggestive of a real change in water composition. The Piper diagram suggests a systematic change on 6-11-87 or possibly beginning on 6-09-87. The composition changes again on 6-13-87. The changes are relatively small but are significantly different from a random walk pattern.

The waters sampled from 5-14-87 through 6-8-87 are $NaHCO_3$ type waters typical of coal seam derivation. There may be a small sandstone Na-Cl type component. On 6-09 or 6-10 there is a systematic increase in both Mg^{2+} and SO_4^{2-}. This is hypothesized to be from a $MgSO_4$-rich fracture but still within the coal seam. The fracture is small and is drained by 6-13-87. Subsequent to 6-13-87, the water returns to a purer $Na\text{-}HCO_3$ type with even less sandstone component as Cl^- decreases to a very low concentration.

Saturation indices were calculated using MINTEQ for several minerals for three of the samples: 5-15-87, 6-11-87 and 6-23-87. Saturation indices are an indication of whether a given mineral will precipitate under equilibrium conditions, which may be of concern during disposal or injection. A value of 0.00 is exactly saturated and values greater than 0.00 indicate supersaturation. The scale is logarithmic so a value of 1.00 is ten times the saturation value. Table 3 is a brief listing of saturation indices for some carbonate and sulfate species.

In summary, the temporal variance in the composition of 1 Cameo 20-4 waters has been examined using Piper diagrams. The data suggests no change from a $Na\text{-}HCO_3$ water typical of a coal seam. A slight increase in Mg^{2+} and SO_4^{2-} may suggest draining of a $Mg\text{-}SO_4$ rich fracture but then returns to a nearly pure $Na\text{-}HCO_3$ type water.

Determination of Water Compositional Changes Caused by Vertical Fracture Growth from Artificial Stimulation or Introduction of Drilling Fluids, and Load Water

Figure 8 is a Piper diagram for seven waters from the Piceance Basin, nine waters from the San Juan Basin and two waters from each of the three coal bearing intervals in the Black Warrior Basin prior to hydraulic fracturing. This diagram is used to examine and quantify the influence of 1) non coal water draining through artificially induced fractures originating in coal seams but grown out of zone and 2) drilling fluid, load water, and fracture fluids introduced into the coal reservoirs.

Produced Water from Coalbed Methane Wells having a Mixed Character, Piceance and San Juan Basin

Coal-derived waters plot in the lower left of the anion triangle and lower right of the quadrilateral. Sandstone-derived waters plot in the lower right of the anion triangle and center-right of the quadrilateral. Divide Creek #21 has a mixed character. By determining the center of the locus of points for Piceance Basin coal-derived and sandstone-derived waters one can estimate the proportion of coal water and sandstone water. This can be done mathematically or graphically. Measuring the total distance between coal waters and sandstone water on the anion triangle or quadrilateral allows proportioning of relative mix using the lever rule. The Divide Creek #21 sample is approximately 84% coal water and 16% sandstone water. The Glover #1 sample and San Juan 30-6 #400 well are mixed character waters from the San Juan Basin. Utilizing a similar graphical procedure yields 56% coal water and 44% sandstone water for the Glover #1 and the San Juan 30-6 #400 well is composed of approximately 81% coal water and 19% sandstone water. All three wells were stimulated open hole in coal seams within close vertical proximity of low permeability sandstones. The Glover well was drilled and completed in a co-operative program between Gas Research Institute and Tiffany Oil and Gas Co. Fracture diagnostics indicated fracture extension down to the Pictured Cliffs sandstone. Water analysis techniques supports that communication with coal seams and sandstones are a result of fracture growth during hydraulic stimulation for all three wells.

The influence of drilling fluid on initial composition can be estimated using data from the 1 Cameo 20-4 well in the Piceance Basin. Figure 9 is a plot of water production versus dissolved solids and bicarbonate. Note the initial increase in bicarbonate levels which stabilizes after 10,000 barrels of produced water. Geochemistry modeling was applied to determine possible effects lost circulation occuring during drilling of the well might have on formation water composition. A combination of drilling fluid and load water of very low bicarbonate content were used with an estimated 1,000 barrels lost in circulation. The first 10,000 barrels of production averages 5,000 mg/L HCO_3^- with subsequent connate water averaging 5,500 mg/L HCO_3^-. If one assumes the first 10,000 barrels of production is a mixture of 1,000 barrels of drilling fluid and 9,000 barrels of connate water, a mass balance equation can be written as:

$$9{,}000 \text{ bbls} \times 5{,}500 \text{ mg/L} + 1{,}000 \text{ bbls} \times 0 \text{ mg/L} = 4.95 \times 10^7$$

This number agrees with the measured volumes and concentrations for the first 10,000 barrels:

$$10{,}000 \text{ bbls} \times 5{,}000 \text{ mg/L} = 5.00 \times 10^7$$

Pre-Stimulation and Post-stimulation Coal Water Analysis Pratt, MaryLee-Blue Creek and Black Creek Coal Groups, Rock Creek Site

Pre-stimulation and post-stimulation water samples were collected and analyzed from the produced waters from three wells penetrating the Pratt Coal Group (P1A), Mary Lee-Blue Creek Coal Group (P1B) and Black Creek Coal Group (P1C) in the Warrior Basin at the Rock Creek Coal Degasification Site for the period 5/2/87 through 7/1/87. The study also contains data for miscellaneous surface and groundwaters of the area.

The first observation in the cation-anion balance is rather poor for many of the Black Warrior Basin samples suggesting there is an analytical problem. The presence of both positive and negative directions of imbalance indicates there is not a major constituent that is not being analyzed. Imbalance in only one direction indicates a major constituent is being missed.

Interpretation of the Warrior Basin wells is reasonably clear for the samples taken prior to hydraulic fracturing. P1A and P1B are clearly sodium bicarbonate type coal waters. P1C is relatively high in sulfate. Using the anion triangle as the primary interpretative tool, the P1C water is mostly sandstone-derived. Not having a typical sandstone water available hinders the estimation by graphical means. The combination of sulfate and chloride on the same quadrilateral axis precludes using this for estimation of the mix of waters.

Piper diagrams were used to monitor water composition with time. The interpretations which follow are made not knowing the connate water production history of the wells but only that hydraulic fracturing took place in the course of the sampling program. The data set contains 28 or 29 samples from each well, collected over a period of approximately 14 months.

Figure 10 is a Piper diagram for Well P1A from the Rock Creek site in the Warrior Basin. The 28 sequential samples are connected with arrows where practical to indicate changing composition. The first two samples may indicate production of some mixture of connate water and load water. If this is the case, the load fluid is probably a nearby surface water of moderately high SO_4^{2-} content.

The samples 3-8 show declining SO_4^{2-} and increasing HCO_3^- indicating a return to more normal coal water. The hydraulic fracturing appears to be in a direction which enhances production of a coal water. There is an anomaly with respect to sample number 25. There is a brief interval of production of a mixed sandstone and coal water or alternatively, an analytical error. Sample 25 is also considerable higher in total dissolved solids than the other samples from this well.

Figure 11 is the Piper diagram for Well P1B from the Rock Creek site. The 29 sequential samples are also connected by arrows where practical. The first two samples also suggest a mixture of connate coal water and a load fluid. In this well, the proportion of coal water is initially higher than P1A. The composition shifts to a typical coal water in samples 3-7. The data suggest the hydraulic fracturing occurred after sample 7. The production of coal water increases and remains steady through 19. An influx of sandstone type water occurs in samples 20-21, then returns to a predominantly coal water. A second influx of sandstone type water occurs with sample 25, but returns to a coal water with samples 26-29. A reason for these pulses is not known.

Figure 12 is the Piper diagram for well P1C for the Rock Creek site. There seems to be a large amount of load water being produced initially, similar to the surface water, and no clear indication of whether the water is coal- or sandstone-derived. Samples 8-10 indicate the load water is flushed out and a sandstone type water is being produced. The well is fractured after 10 with the injection of more water of a lesser total dissolved solids and a mixed anion character. As this mixed water is produced in samples 11-14, composition drifts back to a sandstone type water. Samples 19-28 are clearly sandstone type waters.

In summary, the Pratt and MaryLee-Blue Creek Coal Groups at the Rock Creek Site produce a sodium bicarbonate type coal water as found in Cretaceous age coals. Water produced from the Black Creek Coal Group is a NaCl type water and is likely to be originally derived from a sandstone source over geologic time.

Role of Water Chemistry in Disposal Operations

Total dissolved solids (TDS) in produced waters from the Cameo well were in excess permitted for surface disposal. On gas lift, the well would produce 2600 BWPD which reduced the dilution factor for discharge into the nearest drainage which flows only intermittently through the year. A combination of long cold winters and wet springs in conjunction with large volumes of produced waters eliminated use of evaporation ponds as a disposal method. Remedial surface treatment of the water to reduce TDS for acceptable surface disposal was investigated. The amount of lime ($CaCl_2$) additives and subsequent calcite precipitate necessary to reduce the high bicarbonate water to environmentally acceptable levels was not economically feasible or practical to implement.

The only remaining practical method of water disposal was an injection well system. A dry hole located approximately 2900 feet away was re-entered with the objective of using the blanket Cozzette sandstone as a disposal zone. The Cozzette interval was perforated, acidized and then a step rate test was performed to determine the injectivity of the zone. Water and gas samples from the Cozzette were collected and analyzed. Pressure tests indicated the disposal zone was 600 pounds above hydrostatic pressure.

After reviewing all data it was determined that long-term injectivity would be limited by:

1. Massive $CaCO_3$ precipitation due to water incompatibility.
2. Clay swelling and clay fines migration.
3. Low porosity, permeability and overpressured reservoir conditions limiting legal injection rates below production rates.
4. Plugging of formation by coal fines.

A geochemical approach was implemented to evaluate potential precipitation problems from incompatible waters. Parameters to be measured during water analysis, listed in Table 4, were determined from the standpoint of potential precipitate problems with sensitivity to possible insoluble sulfate precipitation. Particular attention was given to well site sampling to avoid sample contamination and retention of heavy metals in solution. Analysis of water from the disposal zone and injection water were then used to evaluate precipitate problems.

The state of saturation for $CaCO_3$, $MgCO_3$, $BaCO_3$, $SrCO_3$ was calculated. Corrections were made for:

1. Temperature on dielectric constant of water.
2. Ionic strength.
3. Activity of individual ions.
4. Common ion effect (calcite only).

Both waters are saturated to supersaturated with respect to the carbonates. The 1 Cameo 20-4 water may be slightly under-saturated with respect to calcite. A 50:50 mix of the waters was corrected for the above effects and is expected to be saturated with respect to all four carbonates.

A 50:50 mix of the waters will produce a precipitate that is approximately five parts $CaCO_3$: 1 part $MgCO_3$; 1 part $SrCO_3$, 1 part $BaCO_3$. If there were complete precipitation of all the alkaline earths as carbonates there would be approximately 123 pounds of precipitate per 1000 barrels of injected water. The mixed waters are approximately 4-fold saturated with calcite. Water compatibility tests performed at formation temperatures under bench conditions confirmed a massive precipitate problem.

Calcite precipitate could be prevented by the addition of acid to the injected water or buffer the coal water with CO_2. It was determined that 2 1/2 gallons of 7 1/2 percent solution of HCl per 1000 barrels of injected water would be adequate for dissolution of calcite precipitate. Safety considerations, implementation problems and corrosion of downhole tubulars were reasons for not using HCl. A buffer of 1.03 ft^3 CO_2/bbl produced water was the final solution to the calcite precipitate problem.

A potassium hydroxide (KOH) clay stabilizer treatment to prevent clay swelling and clay fines migration was proposed. The KOH solution would drive the high sodium bicarbonate water to maximum levels of precipitation and therefore could not be used. A pad of 2 percent KCl to temporarily stabilize clays in advance of injection was the preferred clay treatment.

Laboratory tests indicated that filtration of coal fines would be necessary. A 0.45 micron filtration system was added to the water disposal network. To overcome low permeability and high reservoir pressure, a special permit to inject water 1000 pounds over parting pressure was obtained from the Colorado State Oil and Gas Commission.

Integration of geochemistry into field water disposal operations has contributed to the successful disposal of 150,000 barrels of water into the Cozzette sandstone with no indication of injectivity problems.

DISCUSSION

A method of verifying the origin of bicarbonate coal water during sulfate reduction and possible compositional changes occurring in connate coal water through geologic time are worth further investigation.

Methanation and sulfate reduction are not unique to coal seams. Microbial activity in the subsurface over geologic time has been documented in many basins. The Gulf Coast region is a marine basin with high SO_4^{2-} marine sediment. Piercement type salt domes with halite (NaCl) and anhydride ($CaSO_4$) are presently undergoing microbial SO_4^{2-} reduction to H_2S and native sulfur. Native S is likely at high SO_4^{2-} concentrations in connate waters. The carbon source was not available initially, but was provided much later as petroleum seeped into the uplifted flanks of the salt domes.

If S isotope ratios are measured on both the SO_4^{2-} and the S, it is found there is a fractionation consistent with a biological reduction of the SO_4^{2-}. The S is isotopically lighter than the coexisting SO_4^{2-}.

This leads to the possibility of an analysis which might verify the theoretical origin of $NaHCO_3$ coal water. If the proposed process is correct, the pyrite (FeS_2) associated with the coal should be approximately 30 parts per mil lighter than the associated SO_4^{2-} in the connate water. This is a determination that may be considered for the future which could be considered a final confirmation for the origin of coal derived bicarbonate water.

In theory, water originating from coal should be of a universal composition with little bearing on age or geographic distribution.

However, 1) the total amount of sodium bicarbonate found in coal water varies, 2) connate coal water may be replaced with clastic water during cross formational fluid flow. An understanding of the relation between fluid flow and its impact on connate water is best summarized by To'th[8].

1. Contents of dissolved minerals are know to increase with the water's subsurface residence time. Consequently, the mineral content of groundwater is expected to be relatively low at shallow depths of the recharge areas and in short and active systems.

2. Conversely, TDS will be high at great depths in discharge areas and in extensive sluggish systems.

Shallow, Pratt and MaryLee-Blue Creek coals examined at the Rock Creek Site are consistent with Case 1. Low mineral content groundwater could dilute the TDS of coal water without changing proportion of the ions. However, the deeper Black Creek Coals would be subject to high chloride sandstone water which would alter proportion of ions and increase TDS.

High TDS bicarbonate coal water of the San Juan and Piceance Basin appears to be of the type (2) where impermeable barriers cause a "sluggish system" inhibiting cross formational flow that would change connate coal water composition.

Specific conclusions regarding variability of coal water bicarbonate levels and concentrations can only be verified through water geochemistry on a basin level evaluation. Identification of coal reservoirs housing low levels of TDS acceptable for surface disposal may results from such a study.

CONCLUSIONS

Development of coalbed methane resources in water saturated coal reservoirs will in part be sensitive to the cost of water production and disposal. Water geochemistry techniques described in this paper are an inexpensive technique to reduce production costs by timely abandonment of coal wells producing from non-coal reservoirs. Water chemistry also played an integral role in the successful injection of coal water into a disposal horizon containing incompatible water. Demonstrating that a blanket sandstone underlying 84 Tcf of coalbed methane within the Piceance Basin as an acceptable horizon for the disposal of coal water will increase the ability of operators to reach commercialization of the coalbed methane resource.

Under certain water compositions, remedial treatment of coal water for surface disposal may be a preferred disposal method. Economic incentives for surface disposal methods suggest further investigation using applied geochemistry would be appropriate.

Conclusions reached in this paper are consistent with a theoretical approach to connate water evolution and documented with analysis of 96 water samples from 11 sedimentary sections in 3 basins from coal and clastic horizons. Statistical verification is still dependent on a larger coal water data base.

SUMMARY

Coal-derived waters were found to be primarily a sodium bicarbonate type water and sandstone-derived waters are a sodium chloride type water. While a genetic process relating to diagenesis in the peat stage seems to be the primary control of connate coal water, sodium chloride type water originates from a process of selective retention. The basin or origin does not seem to be critical in controlling the gross composition. Coal water and sandstone type water can be distinguished by use of a Piper diagram.

In cases where hydraulic stimulation have grown out of zone, compositional analysis can be used to approximate relative contribution of coal and non-coal waters. Basic geochemical modeling should be applied to determine potential water incompatibility problems in advance of injection operations into a disposal zone. Remedial treatment of the water may prevent permanent loss of a disposal zone.

Water geochemistry is a practical tool that can be used to reduce production costs to coalbed methane operators. Effective use of techniques presented in this paper require that operators obtain water samples before stimulation and continue water sampling over the life of a producing well. Cost benefits can be realized during production and disposal operations.

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APPENDIX

$$SO_4^{2-} + 2\text{"}CH_2O\text{"} + 2H^+ \rightleftharpoons H_2S + 2H_2O + 2CO_2 \qquad (1)$$

This reaction occurs at pH < 7.0. At a pH > 7.0, the reaction can be written as:

$$SO_4^{2-} + 2\text{"}CH_2O\text{"} + H^+ \rightleftharpoons HS^- + 2H_2O + 2CO_2 \qquad (2)$$

An alternative way of writing reaction (2) is:

$$SO_4^{2-} + 2\text{"}CH_2O\text{"} \rightleftharpoons HS^- + 2HCO_3^- + H^+ \qquad (3)$$

Methanation can be represented by:

$$2\text{"}CH_2O \rightleftharpoons CH_4 + CO_2 \qquad (4)$$

An alternative form is:

$$2\text{"}CH_2O\text{"} + H_2O \rightleftharpoons CH_4 + HCO_3^- + H^+ \qquad (5)$$

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \qquad \log K = -6.3 \qquad (6)$$

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+ \qquad \log K = -10.3 \qquad (7)$$

TABLE 1

	Well	Formation	Na+ (PPM)	Cl- (PPM)	HCO_3^- (PPM)	TDS (PPM)	Na+K (Meq/M)	Ca (Meq/M)	MG (Meq/M)	CL (Meq/M)	SO_4 (Meq/M)	HCO_3+CO_3 (Meq/M)
Piceance Basin	1 Cameo 20-4	Cameo Coal Gp.	2,070	4	5,250	5,230	99.4	0.9	0.0	0.5	0.2	99.3
	Divide Ck.#21	Cameo Coal Gp.	2,673	600	6,612	8,328	98.8	0.8	0.3	13.2	2.2	84.6
	Federal 6-27	Rollins SS.	—	6,746	1,693	18,850	68.9	23.1	8.0	90.7	0.0	9.8
	Rifle Bolton	Corcoran SS.	—	7,156	709	14,500	96.0	2.1	1.9	93.8	0.0	6.2
	Hoff/Rogers	Cozzette SS.	6,690	10,850	1,590	20,146	96.4	2.9	0.7	92.2	0.0	7.9
San Juan Basin	Cahn #1	Fruitland Coal	5,734	869	13,095	17,059	98.6	1.2	0.2	10.6	0.1	89.4
	Schneider #15	Fruitland Coal	5,399	783	12,305	18,913	99.0	0.9	0.1	8.9	0.1	91.0
	State BW	Fruitland Coal	5,939	684	12,593	19,392	98.5	1.4	0.1	10.3	0.1	89.6
	SJ 30-6 #400	Fruitland Coal	5,463	1,620	12,224	13,690	96.3	2.4	1.3	18.5	0.2	81.3
	SJ 30-6 #402	Fruitland Coal	5,825	668	14,701	13,748	97.5	1.5	1.1	7.3	0.0	92.8
	Glover #1	Fruitland Coal	3,674	2,499	6,083	10,667	99.2	0.2	0.6	40.6	2.0	57.4
	Gardner #1	Pictured Cliffs SS.	5,883	7,601	2,743	15,881	100.0	0.0	0.0	82.7	0.0	17.3
	Leeper C-1	Pictured Cliffs SS.	5,771	7,781	2,446	15,741	100.0	0.0	0.0	84.6	0.0	15.4
	Compton #1	Pictured Cliffs SS.	5,080	6,107	3,276	13,223	100.0	0.0	0.0	76.2	0.0	23.8

To determine Meq/M, Expressed as a percentage of total sample

$$\text{Meq} = \frac{Mq/\rho}{\text{Equiv. wt.}}$$

Mq/ρ = From water analysis, Approximatly equal to PPM when water density is nearly one

$$\text{Equiv. wt.} = \frac{\text{Molecular Wt.}}{\text{Charge of Ion}}$$

Table 2

1 CAMEO 20-4

WATER ANALYSIS

DATE	TIME	CUM BW	PH	SODIUM	CALCIUM	MAGNESIUM	POTASSIUM	CHLORIDE	SULFATE	TDS	IRON	BARIUM	BICARBONAT
07-12-1985	17:00:00	0	7.4	1810	14.7	0	10.6	13.0	8.5	4530		34	4930
01-07-1987	17:00:00		7.35	2070	9	0	14.8	4	5	5230			5250
05-14-1987	17:00:00	778	8.00	1890	21	0	15.80	9.0	15	5580	0.005	4.9	4880
05-15-1987	17:00:00	2524	7.95	1880	17	2	15.20	5.0	19	5700	1.170	5.1	4990
05-18-1987	18:30:00	4608	7.95	1810	13	4	10.00	6.0	32	5600	1.490	5.2	5010
05-21-1987	18:21:00	8169	8.45	1870	12	4	13.00	6.0	36	5840	1.150	5.3	4950
05-22-1987	20:09:00	9246	8.10	1440	16	1	14.80	10.0	27	5440	1.740	5.3	5080
05-23-1987	18:01:00	10238	8.35	1940	14	3	8.20	10.0	30	6030	1.740	5.4	5040
05-24-1987	20:18:00	10633	8.00	2010	14	3	8.80	15.0	28	5850	1.420	4.9	5460
05-25-1987	19:57:00	11705	8.35	2010	19	0	8.80	11.0	24	5830	1.420	5.9	5040
05-26-1987	20:26:00	12952	7.95	1920	16	3	9.40	12.0	22	5790	0.930	5.4	5520
05-27-1987	18:35:00	14594	7.85	1800	14	13	9.60	12.0	16	5820	1.020	5.4	5280
05-28-1987	19:35:00	16304	7.95	1920	26	0	16.20	12.0	30	6170	7.500	5.7	5730
05-29-1987	17:18:00	17773	7.85	1900	12	7	14.20	10.0	21	5810	0.790	5.4	5430
05-30-1987	17:54:00	19368	8.00	1970	12	4	1.40	13.0	20	5820	1.070	5.6	5460
05-31-1987	19:35:00	21052	7.95	2130	15	3	21.00	9.0	20	6070	1.960	5.3	5760
06-01-1987	18:17:00	22356	7.95	2260	20	3	31.20	10.0	24	6000	1.170	5.6	5580
06-02-1987	18:01:00	23887	7.95	2080	17	2	28.20	10.0	30	6290	1.890	5.3	5880
06-03-1987	17:59:00	25399	8.35	1880	23	7	27.00	7.0	23	4850	1.700	5.9	4740
06-04-1987	17:59:00	26880	7.95	2110	13	5	27.20	8.0	31	5950	1.430	5.7	5550
06-05-1987	17:59:00	28430	8.00	2190	10	6	27.00	7.0	23	6090	1.390	4.9	5520
06-06-1987	18:05:00	29980	7.95	2330	9	8	24.80	8.0	30	6110	1.470	5.3	5610
06-07-1987	17:59:00	31514	8.50	1920	10	6	30.00	8.0	33	6080	1.150	5.4	5040
06-08-1987	18:00:00	32997	8.00	1800	10	12	24.00	8.0	24	5800	0.992	5.4	5580
06-09-1987	18:00:00	34530	7.85	1900	20	16	18.60	8.0	27	5860	6.250	5.60	5490
06-10-1987	18:00:00	36001	7.95	1920	10	20	27.00	7.0	32	5860	1.570	5.7	5640
06-11-1987	18:00:00	37547	8.05	2240	10	60	22.20	7.0	46	5970	1.740	5.3	5580
06-13-1987	10:00:00	39803	8.10	2020	0	9	13.4	0.4	15	6200	0.300	6.6	5170
06-17-1987	10:40:00	45782	8.10	2080	0	20	12.7	0.4	19	6650	0.000	7.2	5690
06-23-1987	10:00:00	54356	8.20	2170	0	15	12.00	0.4	30	6730	0.360	6.7	5620

Table 3

Saturation Indices for 1 Cameo 20-4 Waters

Sample	Aragonite $CaCO_3$	Barite $BaSO_4$	Calcite $CaCO_3$	Dolomite $CaMg(CO_3)_2$	Witherite $BaCO_3$
5-15-87	1.15	0.14	1.27	1.91	0.23
6-11-87	0.97	0.48	1.09	3.28	0.33
6-23-87	0.04	0.42	0.18	1.88	0.57

Table 4

Analysis to determine water Compatibility 1 Cameo 20-4, Hoffmeister/Rogers 15-20

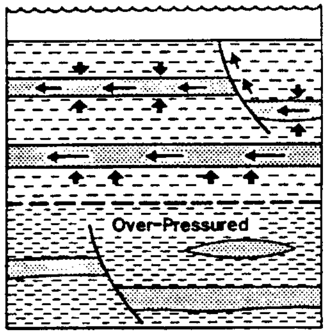
Calcium
Sodium
Magnesium
Potassium
Barium
Strontium

Carbonate
Bicarbonate
Chloride
Sulfate
Ferrous Iron
PH

Ferric Iron
Manganese
Copper
Zinc
Sulfide
Silica

Figure 1

Shale Dewatering



Fluid Flow, Over-Pressuring during Basin Evolution, Hayes, 1979

Figure 2

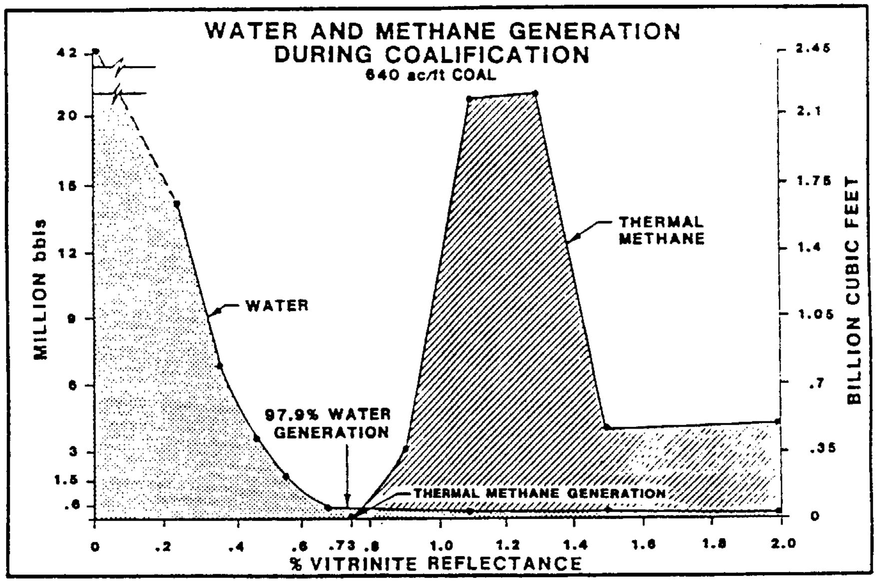


Figure 3

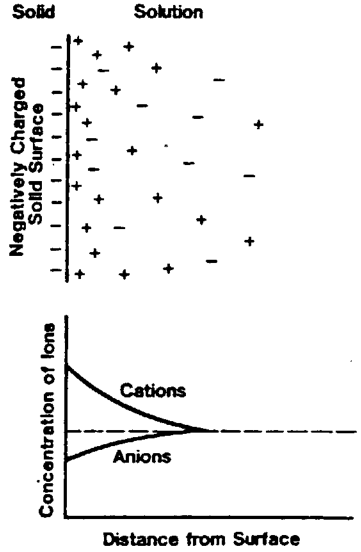


Figure 4

Piper Diagram for Water Samples from

Piceance Basin, San Juan Basin

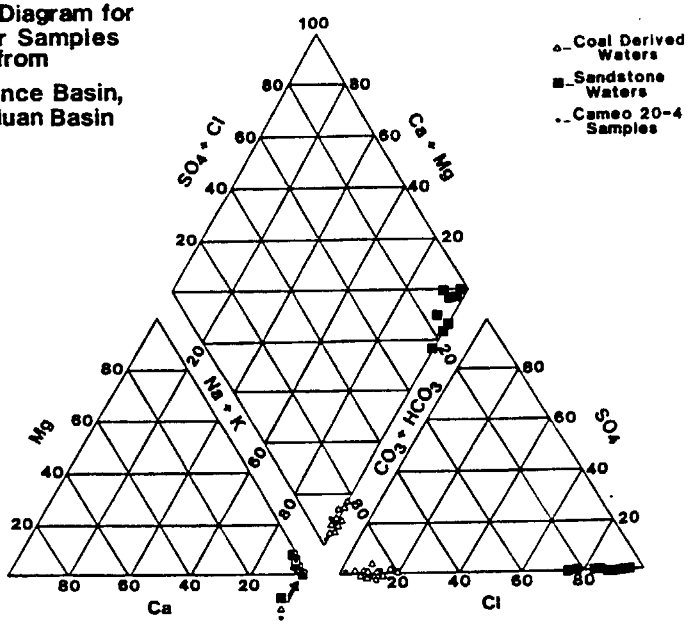
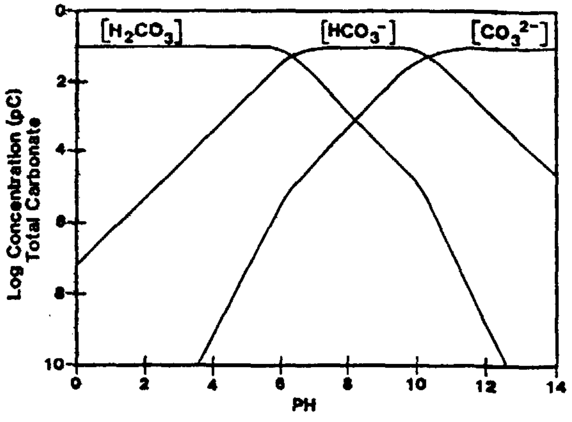
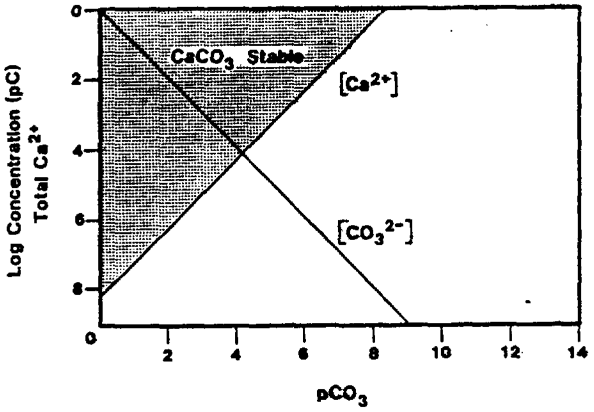


Figure 5



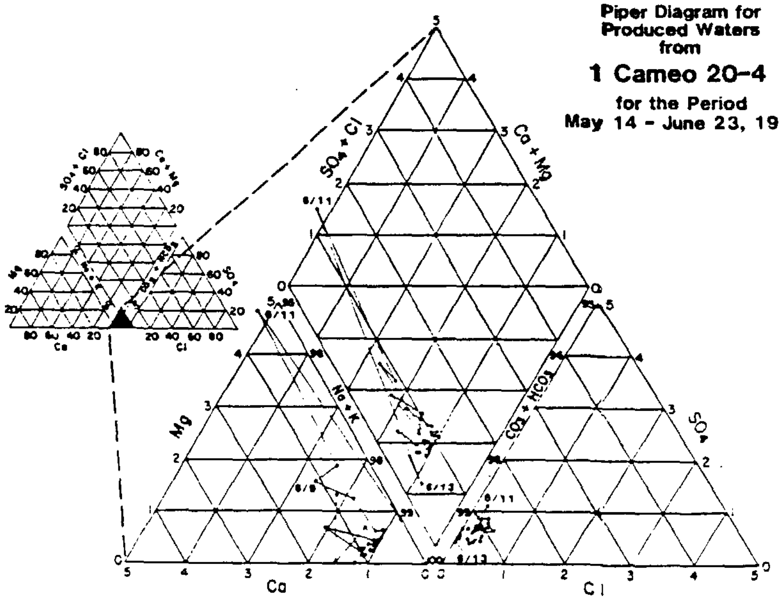
Aqueous Carbon Speciation at C_t, $C=10^{-1}$

Figure 6



Solubility Diagram for CaCO$_3$

Figure 7



Piper Diagram for Produced Waters from

1 Cameo 20-4

for the Period May 14 - June 23, 1987

Figure 8

Piper Diagram for Connate Waters from

Piceance Basin, San Juan Basin, Warrior Basin

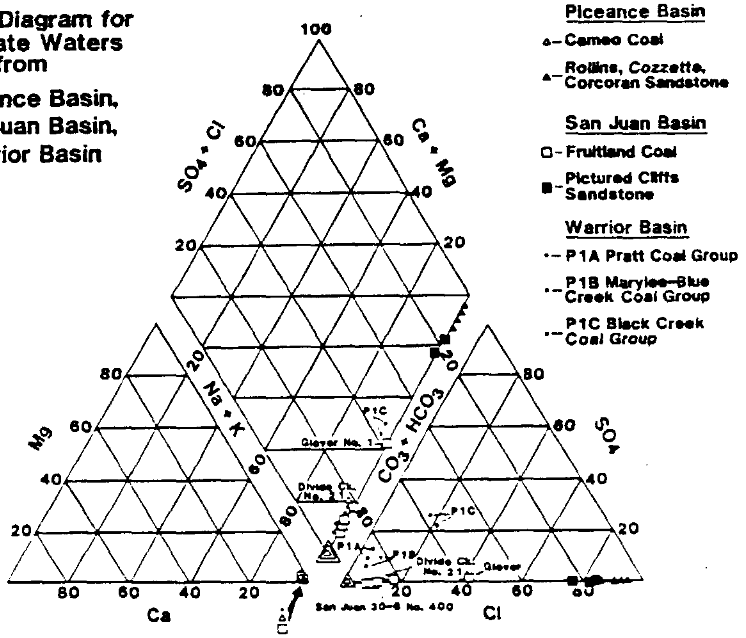


Figure 9

Cameo Water Analysis

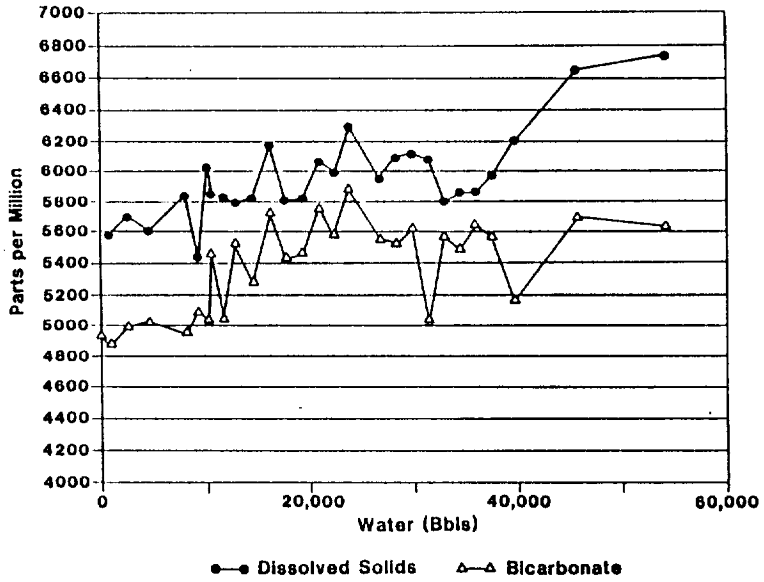


Figure 10

Piper Diagram for Produced Waters from

Rock Creek Site
Well : P1A

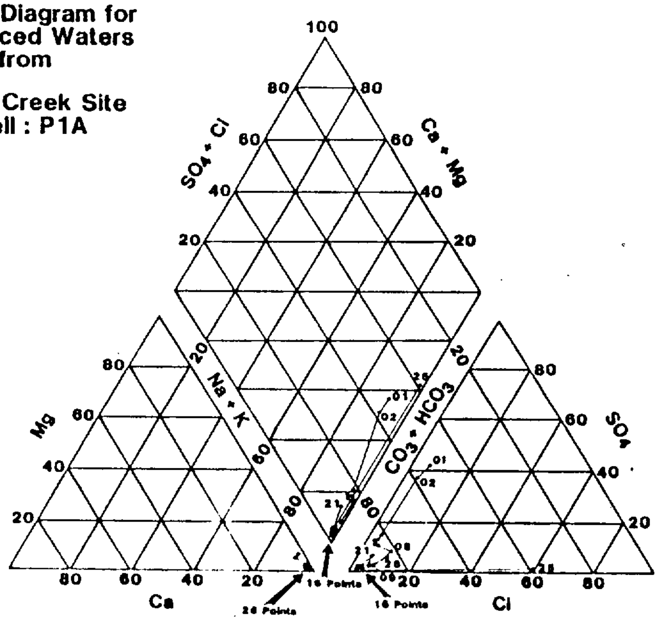


Figure 11

Piper Diagram for Produced Waters from

Rock Creek Site
Well : P1B

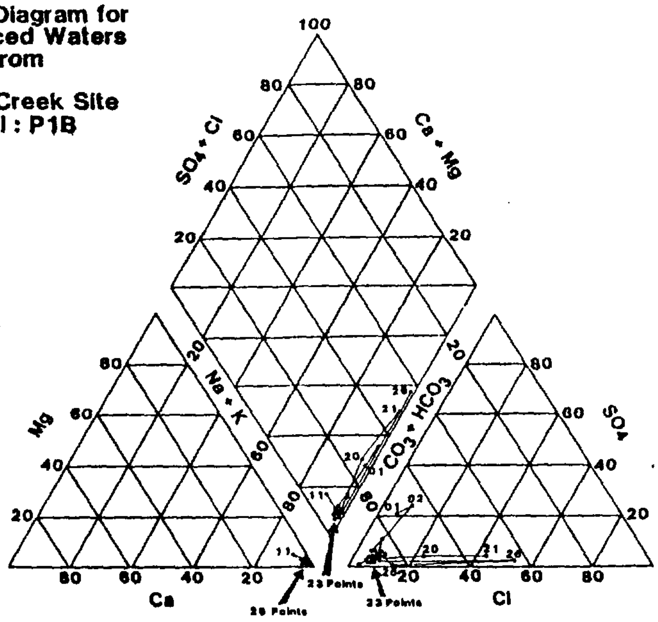
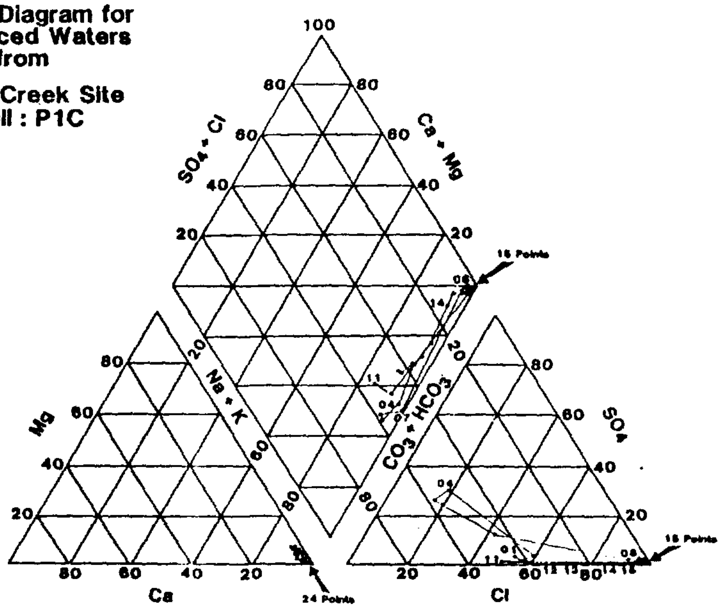


Figure 12

Piper Diagram for Produced Waters from

Rock Creek Site
Well : P1C



STATE OF NEW MEXICO
ENERGY AND MINERALS DEPARTMENT
OIL CONSERVATION DIVISION

GARREY CARRUTHERS
GOVERNOR

POST OFFICE BOX 2088
STATE LAND OFFICE BUILDING
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(505) 827-5800

October 13, 1988

Mr. William F. Carr
Campbell & Black
Attorneys at Law
Post Office Box 2208
Santa Fe, New Mexico

Re: CASE NO. 9489
ORDER NO. R-8763

Applicant:

Blackwood & Nichols Co., Ltd.

Dear Sir:

Enclosed herewith are two copies of the above-referenced Division order recently entered in the subject case.

Sincerely,

Florene Davidson

FLORENE DAVIDSON
OC Staff Specialist

Copy of order also sent to:

Hobbs OCD x
Artesia OCD x
Aztec OCD x

Other