GEOTHERMAL BRANCH

INTER-OFFICE MEMORANDUM

SUBJECT: Hydrogeochemistry of the Animas Area, New Mexico DATE September 1, 1981

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FROM: H. D. Pilkington

The first AMAX report on the hydrogeochemistry of the Animas area was by Frank Dellechaie in 1975. Since that time, the original "hot well" sampled by Frank has been developed by Dale Burgett to provide heat for a greenhouse. Therefore, additional water samples have been collected (Table I) which represent waters sampled after several months of pumping. Burgett has drilled two new wells to supply hot water for his greenhouses which also provide additional chemical evidence of the nature of the shallow aquifer. In May of 1981 a M.S. Thesis by Mark J. Logsdon at the University of New Mexico was completed on the Aqueous Geochemistry of the Lightning Dock KGRA, Animas Valley, Hidalgo County, New Mexico was completed. A review of the geochemical data seems to be in order.

HYDROGEOCHEMICAL DATA BASE

Within the present area of the Animas property, Dellechaie (1975) reported analyses on seventeen (17) water samples. Logsdon(1981) gives analyses for a total thirty (30) samples of which seven (7) are from wells included in the 1975 AMAX study. Three of the samples from Logsdon's study represent duplicate samples collected by University of New Mexico personnel.

The chemical analyses of samples collected by AMAX are shown in Table I. The chemical analyses reported by Logsdon (1981) are shown in Table II. A hydrogeochemical map (Plate I) has been prepared based upon the total hydrogeochemical data base.

GEOCHEMICAL CHARACTERISTICS

The results of the chemical analyses are shown graphically on a trilinear diagram (Figure 1). The waters can be classified as sodium bicarbonate waters with variable proportions of sulfate and chloride. The waters shown as thermal waters on the trilinear diagram include those waters from the hot wells, and mixed waters which include some thermal water and considerable meteoric waters. Waters collected at the surface are modified by (1) mixing, (2) boiling or evaporation, and (3) water-rock reactions.

Water-Rock Reactions

Water-rock reactions are temperature dependent; therefore, it is useful to begin the discussion with an estimate of subsurface temperatures. Plate II is a contour map of subsurface temperatures based upon the silica geothermometers. Because the solubility of silica is not only temperature dependent but also may be controlled by lithologic composition, pH of fluids, and fluid flow it is useful to show a contour map of Cl/SO_4 (mole) ratios (Plate III). The Cl/SO_4 (mole) ratio reflects water-rock reactions and/or lithologic composition. The boron vs chlorine plot (Figure 2) clearly distinguishes the hot wells (Group A) from the meteoric groundwater (Ground B). The scattered analyses outside the two groups described above represent water-rock reactions in mixed waters.

Mixed Waters

In the Animas area several lines of evidence suggest the presence of mixed waters. The differences seen in the silica and alkali geothermometry (Table I and II) are suggestive of mixed waters. The contour map of Cl/HCO_3 (mole) ratios (Plate IV) suggest upwelling of thermal waters along a northeast trending structure extending from Cotton City through the hot wells. The intersection of the NE structures with the N-S trending Basin and Range structures appears to control the upwelling. The waters then spread laterally to the north along the buried fault

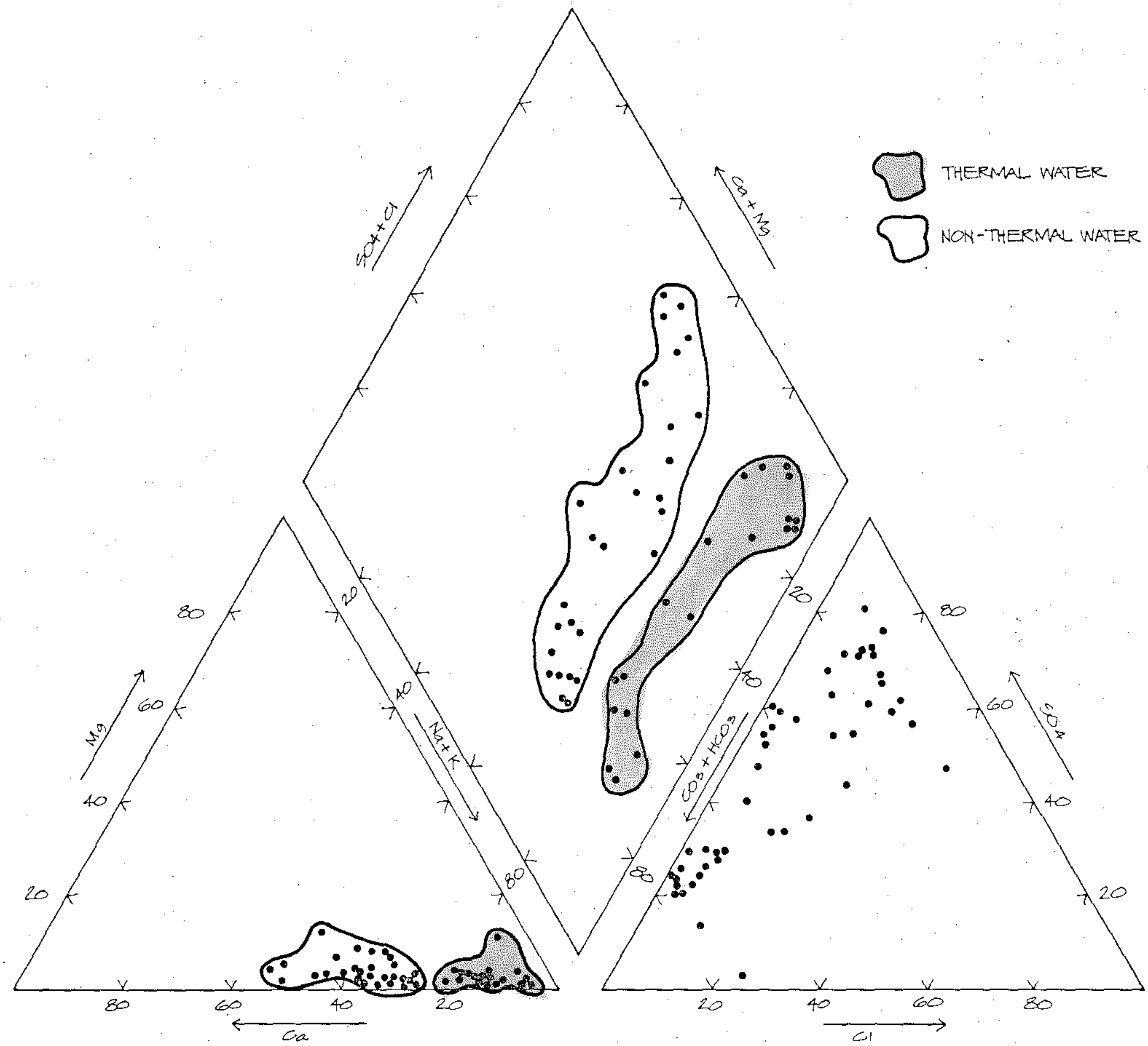

Figure 1. Trilinear diagram for Animas waters

Table I - Chemical Analyses of Water Samples Collected by AMAX

	X90433 NES12T24SR20W Cold Well	X90434 NES14T24SR20W Cold Well	X90010 NESES20T24SR19W Warm Well	X90436 NES35T24SR20W Cold Well	X90437 SESES34T24SR20W Cold Well
T^oC	19.0	19.0	23.0	18.0	18.5
pH	8.2	7.9	8.2	7.7	7.8
Cl	14.0	10.0	27.0	42.0	16.0
F	5.4	4.4	1.3	1.1	1.2
HCO_3	167.0	133.0	212.0	144.0	138.0
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	60.0	40.0	44.0	90.0	42.0
SiO_2	58.0	77.0	33.0	44.0	48.0
Na	110.0	58.0	120.0	83.0	61.0
K	2.7	4.6	1.5	2.4	2.1
Ca	10.0	33.0	20.0	48.0	36.0
Mg	2.0	3.0	2.0	4.0	3.0
Li	0.1	0.1	0.0	0.1	0.0
B	0.0	0.0	0.0	0.0	0.0
TDS	419.2	363.1	460.8	458.6	347.3
$T_qSiO_2$167.0	109.0	121.0	87.0	98.0	101.0
T_cSiO_2	80.0	95.0	52.0	66.0	70.0
TNa-K	120.0	198.0	86.0	68.0	140.0
TNa-K-Ca 1/3	114.0	147.0	86.0	107.0	111.0
TNa-K-Ca 4/3	72.0*	58.0*	43.0*	37.0*	36.0*
Cl/So_4	0.63	0.68	1.83	1.26	1.03
Cl/HCO_3	0.15	0.13	0.22	0.50	0.20

Table I - Chemical Analyses of Water Samples Collected by AMAX

	W90014 NWS12T25SR20W Cold Well	X90439 S7T2SR19W Hot Well	X90441 NWS7T25SR19W Hot Well	W90015 SWNES7T25SR19W Hot Well	W90016 SWNWS10T25SR19W Warm Well
T^oC	19.5	65.0	85.0	101.0	26.0
pH	7.5	7.0	8.1	7.8	8.0
Cl	21.0	130.0	98.0	112.0	22.0
F	1.5	7.8	13.0	15.0	0.5
HCO_3	153.0	93.0	80.0	90.0	141.0
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	115.0	700.0	460.0	400.0	500.0
SiO_2	42.0	99.0	130.0	145.0	30.0
Na	74.0	420.0	30.0	340.0	62.0
K	2.4	26.0	19.0	20.0	1.8
Ca	44.0	70.0	21.0	20.0	28.0
Mg	4.0	5.0	0.1	0.3	8.0
Li	0.0	0.8	0.4	0.5	0.0
B	0.0	0.0	0.0	0.4	0.0
TDS	456.9	1151.8	1131.6	1143.2	343.3
$T_qSiO_2$167.0	96.0	132.0	145.0	151.0	83.0
T_cSiO_2	63.0	110.0	128.0	135.0	48.0
TNa-K	136.0	179.0	178.0	175.0	130.0
TNa-K-Ca 1/3	110.0	152.0*	165.0*	165.0*	107.0
TNa-K-Ca 4/3	37.0*	123.0	140.0	145.0	36.0*
Cl/So_4	0.49	0.50	0.58	0.76	1.13
Cl/HCO_3	0.24	2.41	2.11	2.14	0.27

Table I - Chemical Analyses of Water Samples Collected by AMAX

	X90438 S13T25SR20W Cold Well	W90019 NES13T25SR20W Cold Well	W90020 SESES20T25SR20W Cold Well	W90022 SWSES27T25SR20W Cold Well	W90021 NENES25T25SR20W Warm Well
$T^{o}C$	19.5	19.0	20.0	19.0	24.0
pH	7.5	7.4	7.7	7.8	7.8
Cl	380.0	380.0	103.0	98.0	72.0
F	1.9	3.2	5.2	1.1	2.9
HCO_3	122.0	182.0	171.0	150.0	156.0
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	420.0	720.0	140.0	140.0	160.0
SiO_2	39.0	43.0	59.0	39.0	34.0
Na	190.0	340.0	160.0	87.0	120.0
K	5.8	9.5	4.8	2.8	3.4
Ca	210.0	26.0	170.0	100.0	64.0
Mg	3.0	43.0	16.0	8.0	10.0
Li	0.2	0.4	0.2	0.1	0.2
B	0.0	0.0	0.0	0.0	0.3
TDS	1372.7	1747.1	829.2	626.0	622.8
T_qSiO_2	93.0	97.0	109.0	93.0	88.0
T_cSiO_2	60.0	65.0	80.0	60.0	54.0
TNa-K	133.0	128.0	132.0	136.0	128.0
TNa-K-Ca 1/3	110.0	128.0	108.0*	107.0*	109.0
TNa-K-Ca 4/3	41.0*	107.0*	38.0	29.0	44.0*
Cl/SO_4	2.45	1.43	1.99	1.90	1.22
Cl/HCO_3	5.36	3.59	1.04	1.12	0.79

Table I - Chemical Analyses of Water Samples Collected by AMAX

	W90025 SESWS35T25SR20W Warm Well	W90026 NWNES10T26SR20W Warm Well	W13458 SWNES7T22SR19W Hot Well
$T^{o}C$	25.0	28.0	102.2
pH	8.3	7.8	9.0
Cl	10.0	27.0	89.0
F	3.2	3.5	12.0
HCO_3	106.0	197.0	46.0
CO_3	0.0	0.0	28.0
SO_4	48.0	170.0	510.0
SiO_2	37.0	35.0	150.0
Na	83.0	160.0	310.0
K	1.8	5.4	23.0
Ca	12.0	35.0	22.0
Mg	0.6	5.0	0.5
Li	0.1	0.2	0.7
B	0.0	0.0	0.5
TDS	301.7	638.1	1191.7
T_qSiO_2	91.0	89.0	161.0
T_cSiO_2	57.0	55.0	0.0
TNa-K	114.0	139.0	0.0
TNa-K-Ca 1/3	105.0	124.0	174.0*
TNa-K-Ca 4/3	54.0*	72.0*	0.0
Cl/SO_4	0.56	0.43	0.47
Cl/HCO_3	0.16	0.24	3.33

Table II. Chemical Analyses of Water from Logsdon 1981.

	P-1 32° 8.7'N 108° 47.6'W Cold Well	P-2 32° 8.7'N 108° 49.9'W Hot Well	P-3 32° 8.9'N 108° 49.9'W Hot Well	P-4 32° 8.7'N 108° 50.4'W Hot Well	P-5 32° 8.1'N 108° 50.9'W Cold Well
T°C	23.0	85.0	81.0	71.0	22.0
pH	8.20	7.71	81.6	7.89	8.08
Cl	20.5	88.3	87.6	111.3	181.9
F	0.4	12.6	12.0	7.3	3.6
HCO_3	183.1	106.8	103.7	118.9	209.3
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	79.3	497.1	480.0	893.4	956.3
SiO_2	31.3	147.5	143.0	115.6	42.3
Na	68.7	333.6	338.6	493.1	231.7
K	1.9	23.5	21.1	27.8	9.0
Ca	28.0	22.0	23.2	67.3	159.3
Mg	7.3	0.5	0.5	5.3	34.9
Li	0.0	0.0	0.64	0.0	0.0
B	0.08	0.48	0.50	0.42	0.25
TDS	484.0	1116.0	1024.0	1608.0	1660.0
T_qSiO_2	85.0	152.0	150.0	140.0	96.0
T_cSiO_2	50.0	136.0	134.0	120.0	64.0
TNa-K	127.0	189.0	180.0	172.0	147.0
TNa-K-Ca 1/3	106.0	173.0*	167.0*	159.0*	124.0
TNa-K-Ca 4/3	38.0*	149.0	143.0	129.0	60.0*
$\delta^{18}O$(0/00)	-10.2	-10.5	-10.3	-10.5	-10.3
δD(0/00)	-71.0	-78.0	-78.0	-78.0	75.0
Cl/SO_4	0.07	0.48	0.49	0.34	0.52
Cl/HCO_3	0.19	1.42	1.45	1.61	1.50

Table II. Chemical Analyses of Water from Logsdon 1981.

	P-10 32° 13.6'N 108° 49.7'W Warm Well	P-13 32° 13.7'N 108° 52.4'W Cold Well	P-14 32° 10.1'N 108° 52.8'W Cold Well	P-15 32° 6.1'N 108° 50.7'W Warm Well	P-20 32° 4.8'N 108° 54.0'W Warm Well
T°C	23.0	19.0	20.0	24.0	22.0
pH	8.18	7.90	8.00	8.07	8.02
Cl	133.6	16.7	23.0	80.5	21.3
F	7.3	3.9	0.9	2.4	2.7
HCO_3	255.0	237.9	209.3	201.4	192.2
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	939.0	298.7	289.6	483.7	305.0
SiO_2	60.7	74.1	48.4	34.3	50.4
Na	366.2	105.5	71.0	152.2	97.0
K	6.3	3.1	2.7	5.9	2.3
Ca	67.9	38.3	47.9	78.6	43.2
Mg	17.1	2.7	4.4	12.6	4.1
Li	0.0	0.0	0.0	0.0.	0.0
B	0.51	0.1	0.06	0.18	0.10
TDS	1708.0	756.0	668.0	868.0	632.0
T_qSiO_2	111.0	119.0	101.0	88.0	103.0
T_cSiO_2	82.0	93.0	70.0	54.0	72.0
TNa-K	102.0	131.0	146.0	147.0	118.0
TNa-K-Ca 1/3	104.0*	112.0	115.0	123.0	102.0
TNa-K-Ca 4/3	71.0	49.0*	38.0*	58.0*	39.0*
$\delta^{18}O$(0/00)	-11.4	-9.8	-9.7	-10.5	-10.2
δD(0/00)	-79.0	-67.0	-67.0	-77.0	67.0
Cl/SO_4	0.39	0.15	0.22	0.45	0.19
Cl/HCO_3	0.90	0.12	0.19	0.69	0.19

Table II. Chemical Analyses of Water from Logsdon 1981.

	P-22 32° 4.1'N 108° 52.9'W Cold Well	P-23 32° 12.2'N 108° 48.8'W Warm Well	P-24 32° 10.9'N 108° 50.7'W Warm Well	P-25 32° 9.1'N 108° 52.8'W Warm Well	An-1 32° 11.7'N 108° 52.2'W Warm Well
T °C	22.0	24.0	00.0	23.0	23.0
pH	7.90	8.08	7.92	8.35	7.88
Cl	38.6	29.1	79.8	8.9	7.1
F	1.2	1.2	9.4	3.6	1.6
HCO_3	192.2	250.2	275.8	183.1	151.3
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	311.7	308.3	768.5	285.8	42.00
SiO_2	43.3	29.3	149.7	34.3	58.5
Na	111.3	120.0	321.4	78.8	54.0
K	2.7	1.6	18.0	3.5	2.0
Ca	49.3	18.6	38.5	78.1	26.2
Mg	4.4	2.4	1.8	5.7	2.2
Li	0.0	0.0	0.0	0.0.	0.0
B	0.06	0.12	0.50	0.12	0.12
TDS	600.0	640.0	1348.0	604.0	300.0
$T_q SiO_2$	97.0	82.0	153.0	88.0	109.0
$T_c SiO_2$	65.0	47.0	137.0	54.0	80.0
TNa-K	120.0	89.0	172.0	156.0	144.0
TNa-K-Ca 1/3	104.0	89.0	156.0*	125.0	115.0
TNa-K-Ca 4/3	42.0*	46.0*	121.0	50.0*	39.0*
$\delta^{18}O$(0/00)	-9.6	-9.8	-10.4	-9.0	-0.0
δD(0/00)	-67.0	-74.0	-80.0	-65.0	0.0
Cl/SO_4	0.34	0.26	0.28	0.08	0.46
Cl/HCO_3	0.35	0.20	0.50	0.08	0.08

Table II. Chemical Analyses of Water from Logsdon 1981.

	An-2 32^{o} 12.2'N 108^{o} 48.8'W Cold Well	An-3 32^{o} 10.1'N 108^{o} 52.8'W Cold Well	An-4 32^{o} 9.7'N 108^{o} 50.7'W Warm Well	An-5 32^{o} 8.1'N 108^{o} 50.9'W Cold Well	An-6 32^{o} 7.3'N 108^{o} 51.2'W Cold Well
$T^{o}C$	18.0	16.0	24.0	19.0	19.0
pH	8.00	8.29	7.59	7.82	8.00
Cl	7.1	15.6	122.7	144.3	117.0
F	1.6	0.7	2.9	3.5	2.0
HCO_3	151.3	207.4	228.8	172.1	83.6
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	42.0	64.8	492.8	351.9	369.00
SiO_2	15.5	68.5	97.5	50.5	30.0
Na	115.4	66.9	353.3	178.6	161.4
K	2.0	2.7	14.1	8.2	6.6
Ca	13.0	39.7	79.7	122.0	125.2
Mg	1.6	8.8	8.3	25.3	14.6
Li	0.0	0.0	0.0	0.0.	0.0
B	0.17	0.02	0.59	0.18	0.78
TDS	360.0	380.0	1372.0	1184.0	1020.0
T_qSiO_2	61.0	115.0	132.0	103.0	83.0
T_cSiO_2	22.0	87.0	109.0	72.0	48.0
TNa-K	102.0	150.0	149.0	158.0	138.0
TNa-K-Ca 1/3	372.0	118.0	136.0*	129.0*	115.0*
TNa-K-Ca 4/3	58.0*	41.0*	94.0	60.0	47.0
$\delta^{18}O$(0/00)	0.0.	0.0	0.0	0.0	0.0
δD(0/00)	0.0	0.0	0.0	0.0	0.0
Cl/SO_4	0.46	0.36	0.67	1.11	0.86
Cl/HCO_3	0.08	0.13	0.92	1.44	2.41

Table II. Chemical Analyses of Water from Logsdon 1981.

	An-7 32° 6.3'N 108° 50.8'W Cold Well	An-8 32° 7.7'N 108° 53.2'W Cold Well	An-9 32° 4.8'N 108° 52.8'W Cold Well	An-12 32° 4.2'N 108° 54.0'W Cold Well	An-15 32° 4.3'N 108° 51.2'W Warm Well
T°C	20.0	0.0	18.0	21.0	24.0
pH	7.52	7.83	7.85	7.73	7.93
Cl	68.1	3.5	59.2	8.5	6.4
F	2.3	1.1	0.8	2.3	0.6
HCO_3	195.2	170.8	81.1	185.5	139.1
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	167.0	51.6	107.3	74.8	38.4
SiO_2	29.5	33.5	0.95	45.0	30.0
Na	134.3	55.6	98.2	77.9	49.6
K	4.3	2.3	3.1	2.7	2.0
Ca	60.5	28.8	19.8	34.5	18.2
Mg	9.7	2.7	4.7	3.0	2.5
Li	0.0	0.0	0.0	0.0.	0.0
Cu	0.0	0.0	0.0	0.0	0.0
B	0.17	0.05	0.01	0.0	0.0
Mo	0.0	0.0	0.0	0.0	0.0
Hg	0.0	0.0	0.0	0.0	0.0
TDS	624.0	272.0	384.0	384.0	240.0
Ec	0.0	0.0	0.0	0.0	0.0
T_qSiO_2	82.0	88.0	0.0	98.0	83.0
T_cSiO_2	47.0	53.0	0.0	67.0	48.0
TNa-K	136.0	151.4	135.0	140.0	150.0
TNa-K-Ca 1/3	115.0	119.0	118.0	115.0	119.0
TNa-K-Ca 4/3	52.0*	41.0*	61.0*	45.0*	44.0*
Cl/SO_4	1.10	0.18	1.50	0.31	0.45
Cl/HCO_3	0.60	0.04	1.26	0.08	0.08

Table II. Chemical Analyses of Water from Logsdon 1981.

	An-17 32° 4.8'N 108° 52.7'W Cold Well	An-18 32° 5.6'N 108° 52.2'W Cold Well	An-20 32° 5.2'N 108° 53.6'W Cold Well	An-22 32° 6.3'N 108° 51.7'W Cold Well	An-23 32° 9.1'N 108° 52.7'W Cold Well
T^oC	22.0	21.0	20.0	19.0	18.0
pH	8.17	8.43	7.41	8.41	8.44
Cl	29.4	27.3	64.2	20.9	2.1
F	4.0	1.7	0.7	2.2	0.9
HCO_3	237.4	157.4	187.9	172.1	148.0
CO_3	0.0	0.0	0.0	0.0	0.0
SO_4	113.3	58.8	124.9	76.4	51.6
SiO_2	30.0	37.5	49.5	32.5	37.0
Na	129.2	67.8	91.7	93.8	53.4
K	7.0	2.7	3.5	2.3	2.0
Ca	30.7	31.3	76.1	25.4	22.0
Mg	5.7	3.2	7.2	2.5	2.1
Li	0.0	0.0	0.0	0.0.	0.0
Cu	0.0	0.0	0.0	0.0	0.0
B	0.13	0.18	0.05	0.05	0.0
Mo	0.0	0.0	0.0	0.0	0.0
Hg	0.0	0.0	0.0	0.0	0.0
TDS	524.0	352.0	628.0	396.0	384.0
Ec	0.0	0.0	0.0	0.0	0.0
T_qSiO_2	83.0	91.0	102.0	86.0	91.0
T_cSiO_2	48.0	58.0	71.0	52.0	57.0
TNa-K	170.0	149.0	146.0	120.0	145.0
TNa-K-Ca 1/3	142.0	119.0	116.0*	106.0	116.0
TNa-K-Ca 4/3	80.0*	45.0*	39.0	48.0*	42.0*
Cl/SO_4	0.70	1.26	1.39	0.74	0.11
Cl/HCO_3	0.21	0.30	0.59	0.21	0.02

blocks and also down the hydrologic gradient which is to the northwest. The strong northeast trends of upwelling thermal waters are also shown on the Cl/SO_4 (mole) ratio map (Plate III). The mixing of thermal and nonthermal waters is also apparent on a plot of SiO_2 vs Cl/HCO_3 (mole) ratio as seen in Figure 3.

The isotopic analyses of hydrogen and oxygen (Table II) as reported by Logsdon (1981) are plotted in Figure 4 and compared to the meteoric water line of Craig (1961). The waters within Group B are thought to be representative of modern meteoric recharge water (δD=-67 per mil and $\delta^{18}O$=9.6 per mil). The principal source of recharge is the winter rains. The water from the hot wells averages δD of -97 per mil and $\delta^{18}O$ of -13.4 per mil. The small oxygen shift is similar to that reported for Wairakei and Long Valley (Mariner and Welley, 1976) and may indicate that the Animas geothermal system is old. Figure 5 is a contour map of the $\delta^{18}O$ values for the Animas waters after Logsdon (1981). The NE trend intersects the N-S buried ridge at the hot wells and some leakage spreads northward.

GEOTHERMAL RESERVOIR

The geochemical data suggests the waters in the near surface, low temperature, reservoir tapped by the hot wells is a mixed water. If the water is mixed, what is the nature of the deep reservoir fluid? Figure 6 is a plot of silica concentration versus temperature using an average groundwater value from Table I and II and the hot wells from AMAX analyses (Table I). A line from the groundwater point (GW) through the hot wells to the quartz solubility line give the silica concentration and temperature of a possible reservoir fluid, i.e. silica concentration of 340 ppm and temperature of 195°C or 223°C based upon the solubility of quartz. The fact that all the "Hot Wells" fall into a single line adds some credibility to the concept of mixed waters. The solubility of silica is controlled by enthalpy rather than temperature; however, for temperatures up to 250°C the enthalpy and temperatures are nearly identical. From Figure 6 the graphical mixing proportion for the deep reservoir component is 39% for C, 30% for B and 21% for A.

Another method of analysis of the thermal history of the geothermal reservoir fluids is to plot the enthalpy against chloride concentration (Figure 7). The four hot wells (Table I) are represented by the letters A,B,C, and D. If we take the water with maximum chloride content, well A and project to the enthalpy of water at 100°C, point R then represents a possible parent fluid with a reservoir temperature of 220°C which agrees well with the reservoir temperature predicted from the

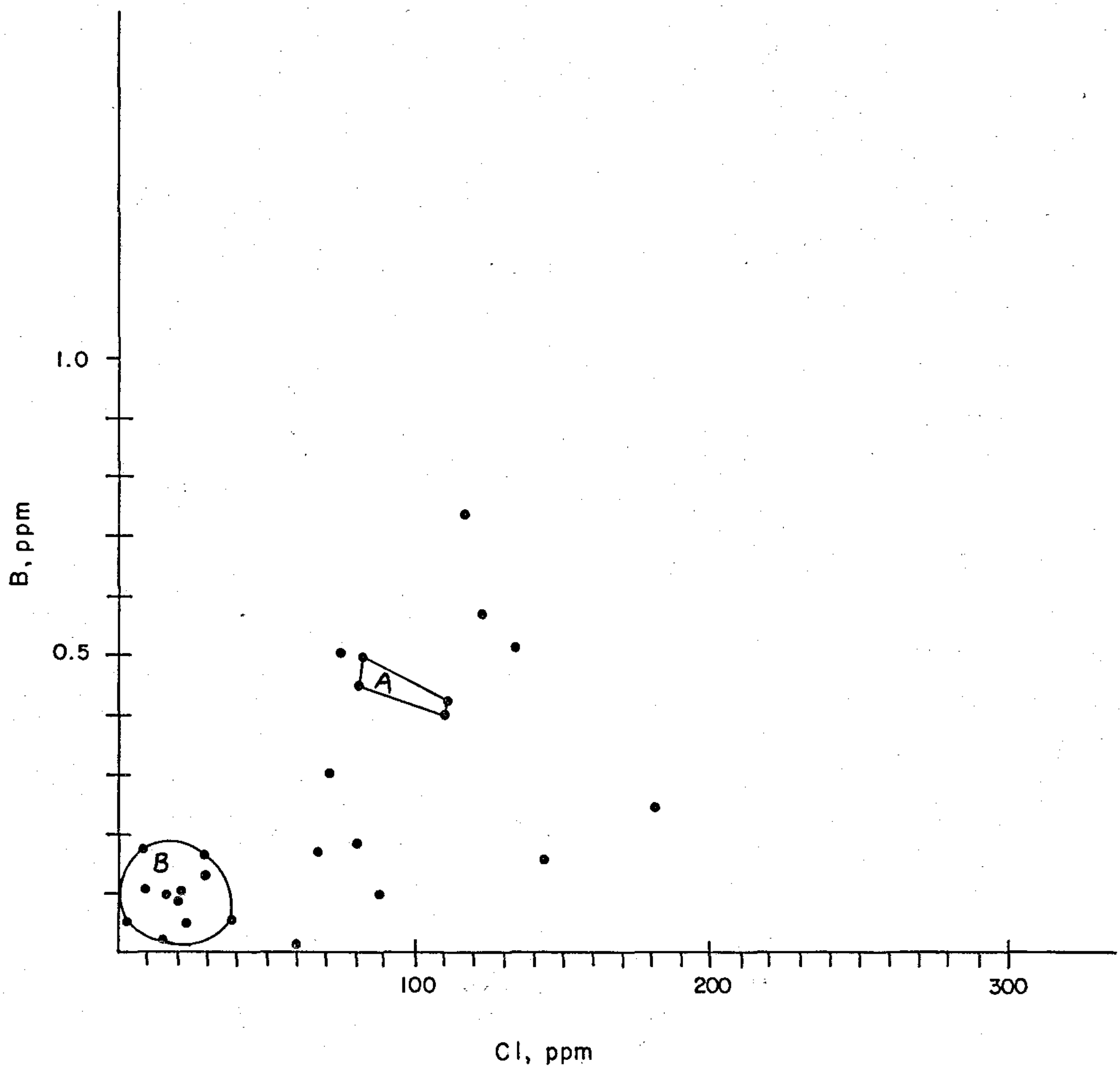

Figure 2. Boron vs chlorine plot for meteoric groundwaters (Group B), the hot wells (Group A) and mixed waters.

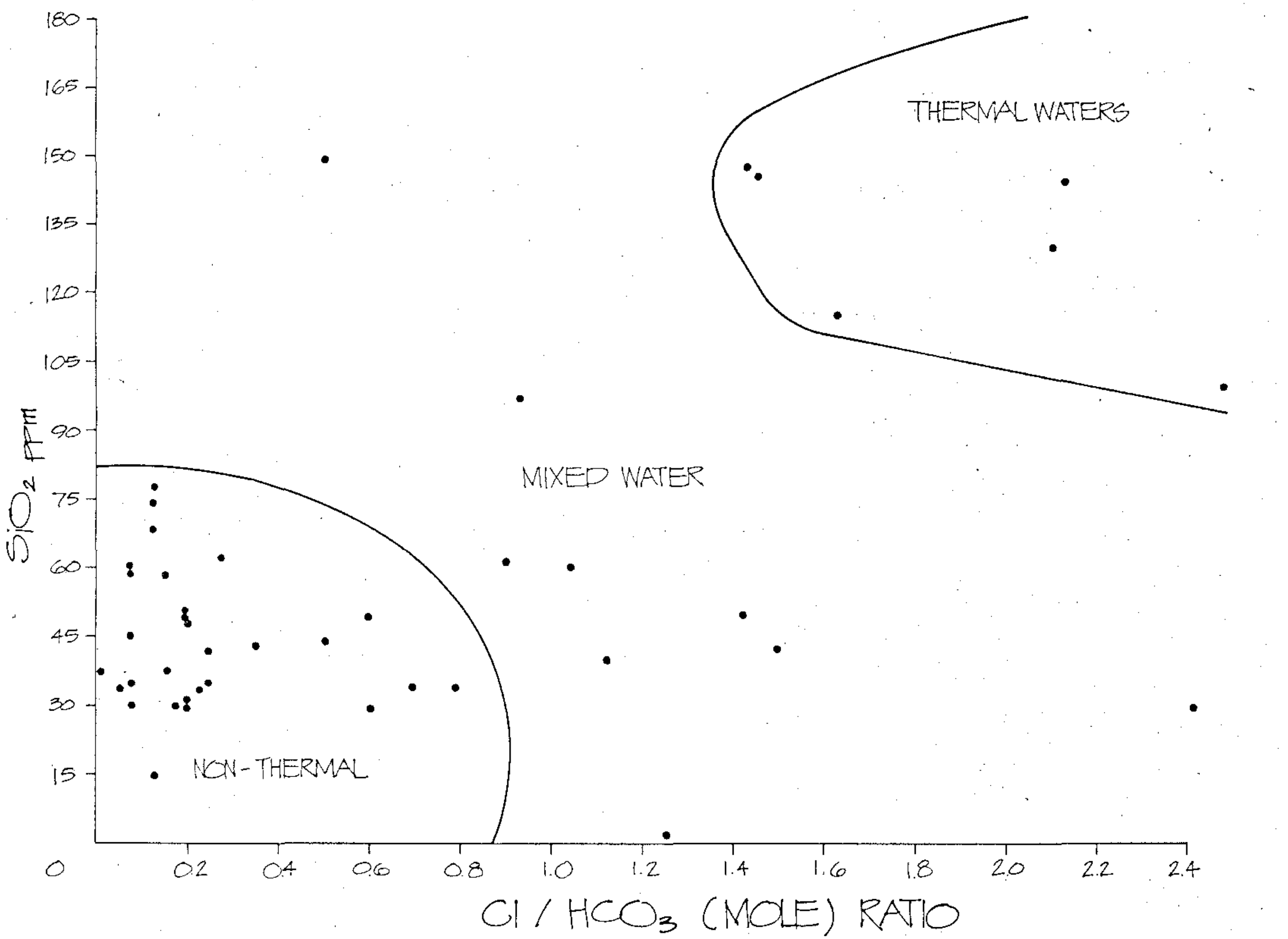

Figure 3. SiO_2 vs Cl/HCO_3 (Mole) ratio for Animas waters.

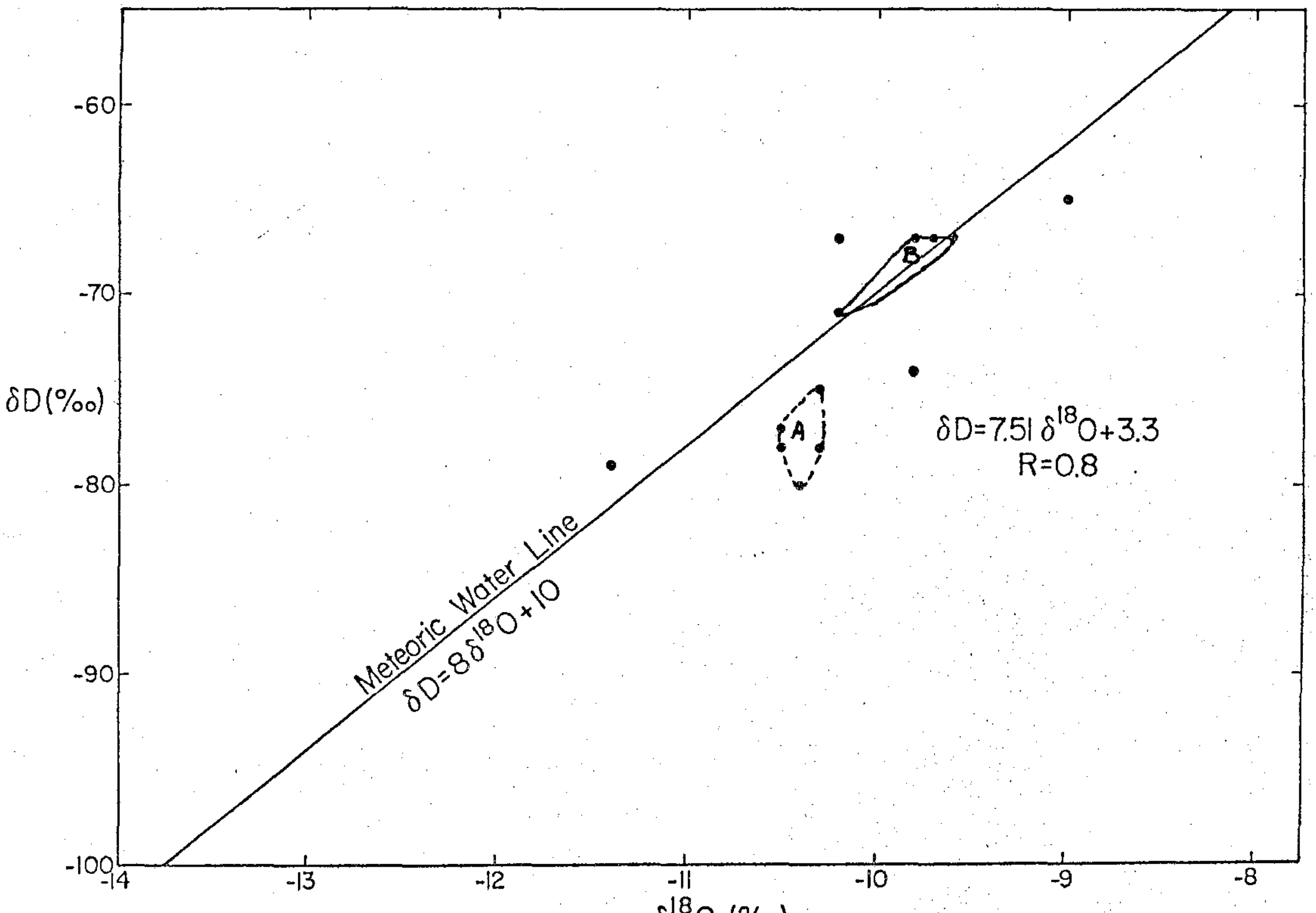

Figure 4. δD and $\delta^{18}O$ values for the P-series waters. The meteoric line after Craig (1961). The isotope data after Logsdon 1981.

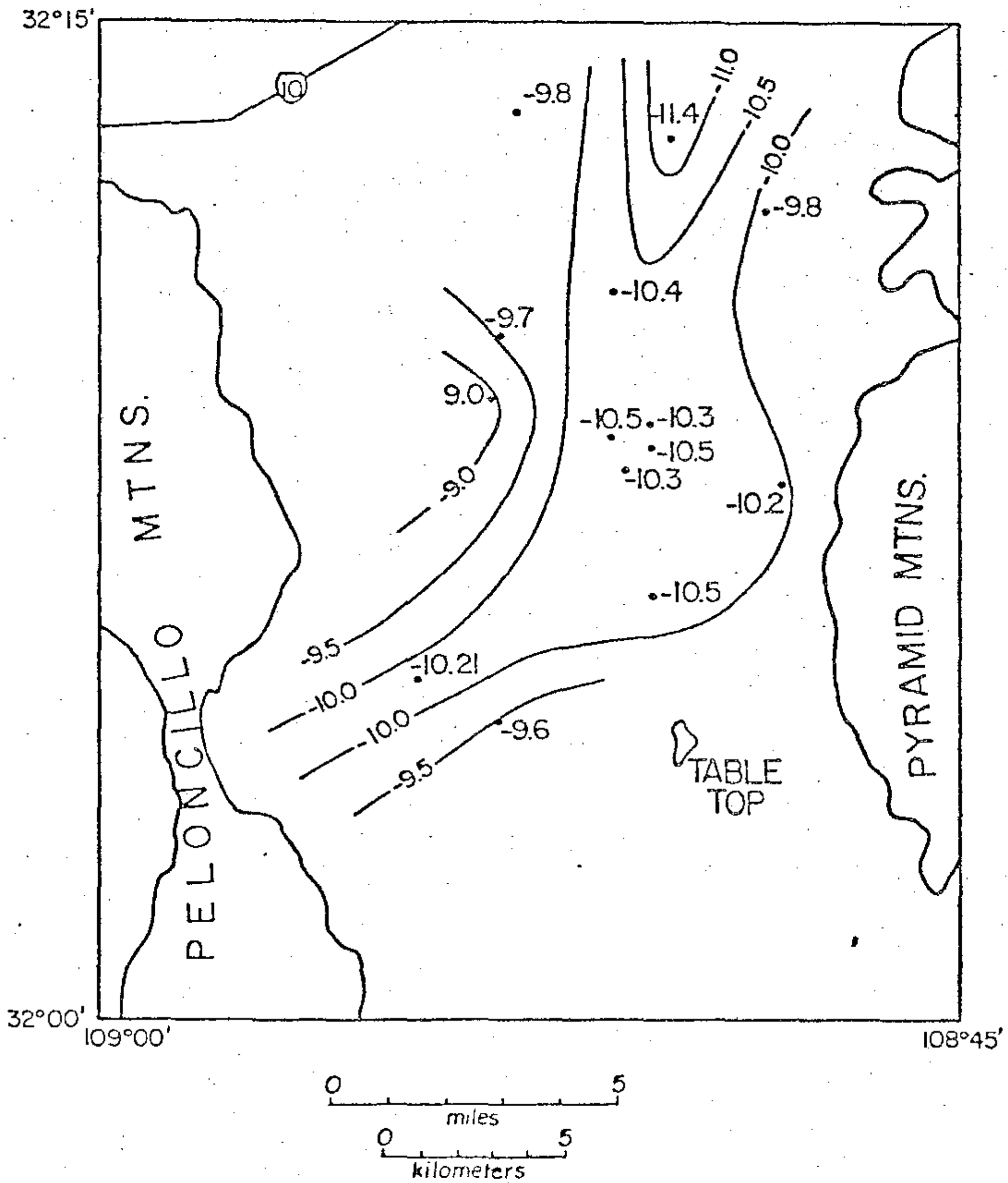

Figure 5. Contour map of $\delta^{18}O$ values for the P-series of water samples after Logsdon (1981).

silica vs temperature plot (Figure 6). Water A is derived by boiling of the parent fluid R. Water B represents conductive cooling of the parent fluid or alternatively there could have been boiling then mixing to arrive at B. Water C could be derived from the parent by either conductive cooling to C' then mixing or by boiling following by mixing.

Logsdon (1981) made a numerical mass balance calculation on the mixing trend of the isotopic data. For the calculation he assumed recharge water of $\delta^{18}O$=-9.6 per mil, a deep reservoir component of $\delta^{18}O$=-13.4 per mil and a mixed water value of $\delta^{18}O$=-10.5 per mil. Therefore, the mass balance is:

$$-10.5\ 0/00 = x\ (-13.4\ 0/00) + 1-x\ (-96\ 0/00)$$

which yields a deep reservoir contribution of 24% which agrees well with the graphical mixing solution.

In conclusion, the hydrogeochemical study of the Animas area suggests the waters from the "Hot Wells" are mixed waters made up of a deep reservoir component, 21-39 %, and a shallow meteoric water component. The chemical signature seen in the mixed waters suggests a deep reservoir temperature of 220°C but does not tell us when that signature was acquired. In a report by Chris Klein of Geothermex received after the preparation of this memo, he concludes that the most conservative interpretation of the geothermometers is that subsurface temperatures reach at least 160-165°C based upon the solubility of chalcedony. Furthermore, he concludes a one-stage mixing model gives an upper limit of 210°C for the hot component.

The isotopic signature of the waters suggest that the deep reservoir component with a value of $\delta^{18}O$=13.4 per mil suggests the water originated as meteoric water, perhaps in Pleistocene time, circulated to depth, was heated and then rises convectively. The downward continuation of thermal data at Animas by Art Lange (1981) suggests the 220°C isotherm lies about 1.1 km below the "Hot Wells" for a homogeneous case and at about 2.1 km for the conductive mode. For a steady state model recharge in the Animas area could be in the 30,000 to 50,000 years range. Hence, the isotopic data could be compatible with a Pleistocene age. Thus, if the correct geothermal model for Animas is one of deep circulation then the system appears to indicate a potential reservoir at a depth of 2 km with a temperature of 220°C.

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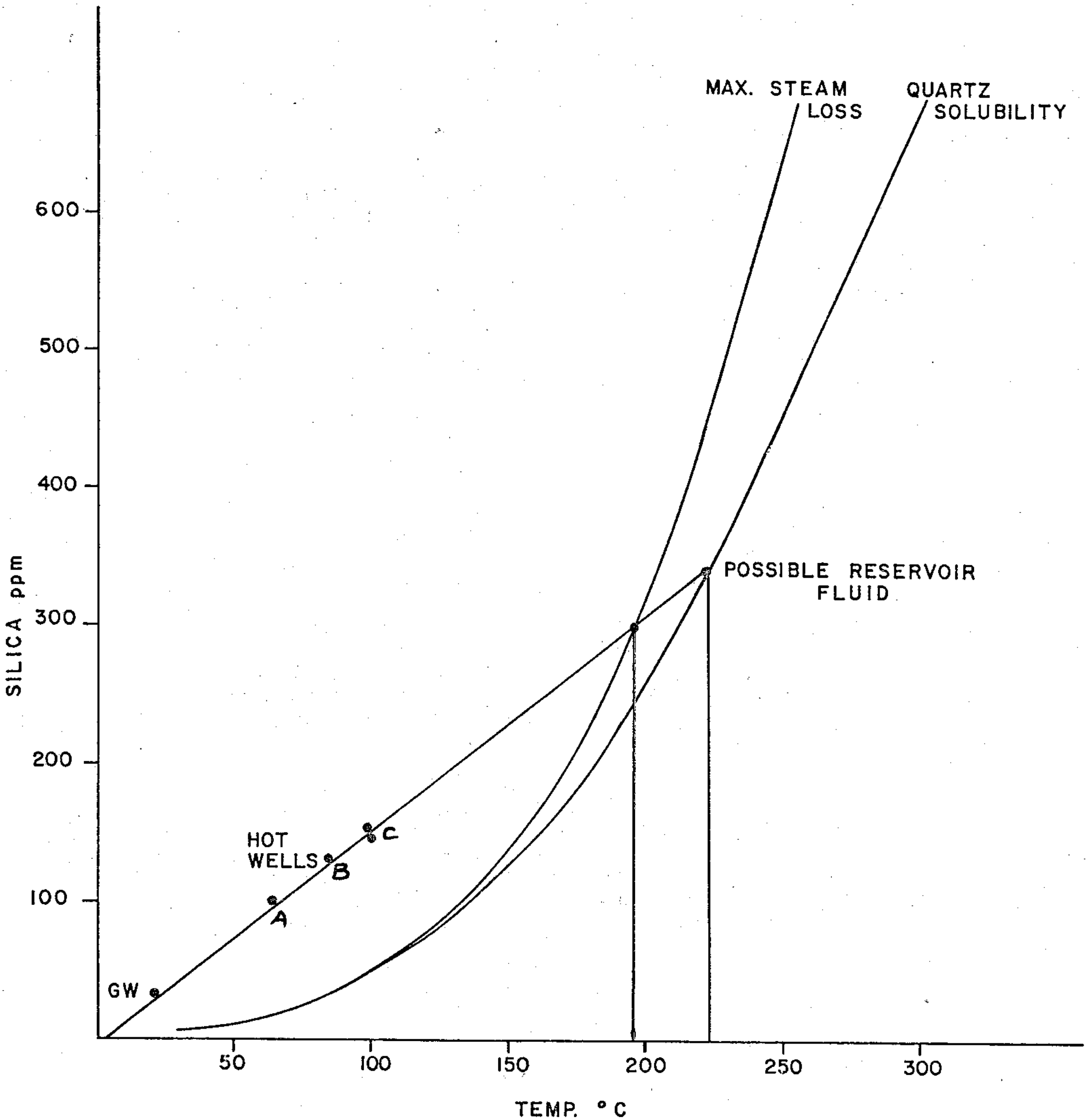

Figure 6. Silica concentration vs temperature.

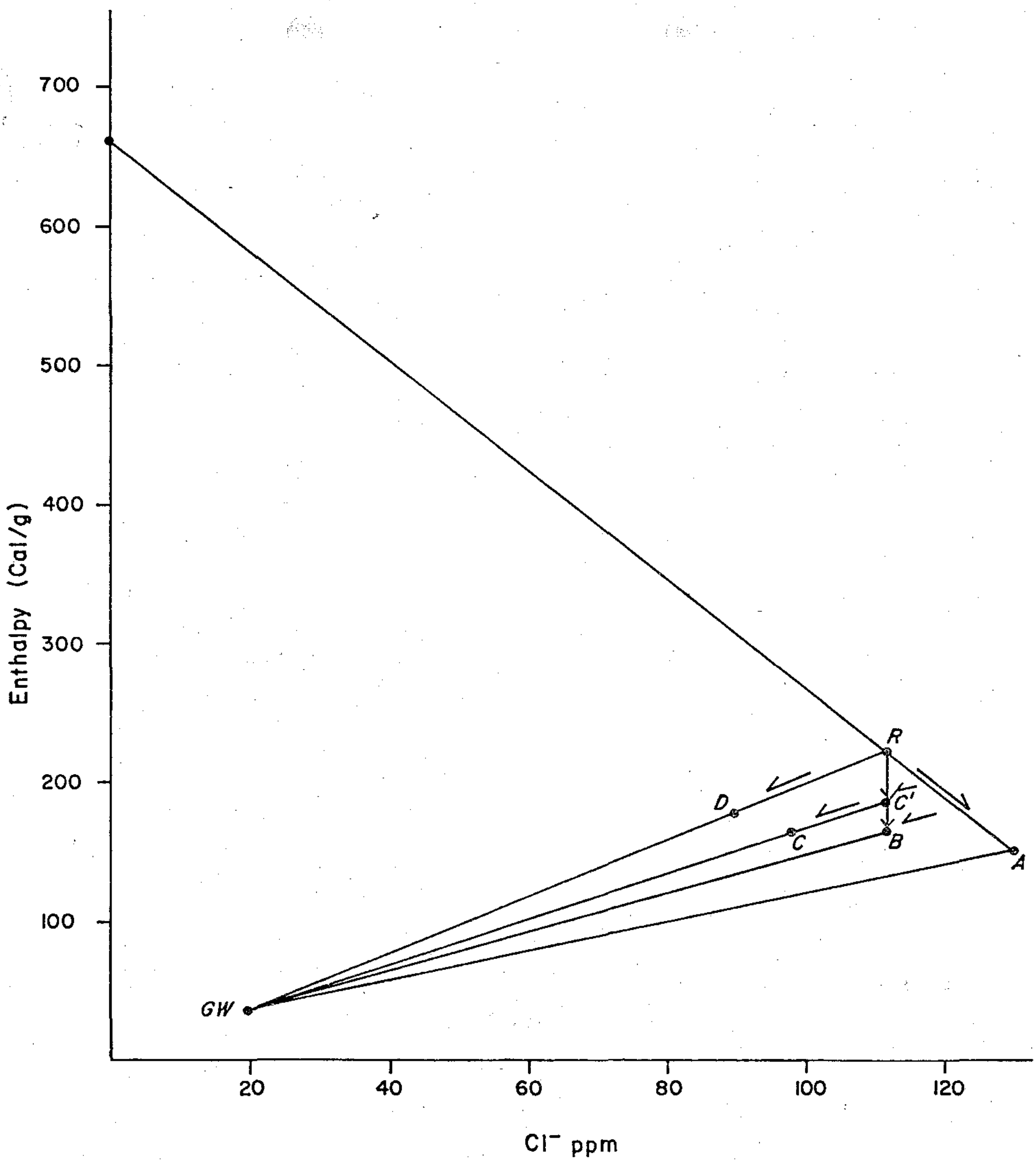

Figure 7. Enthalpy vs chloride concentration for selected Animas waters.

REFERENCES

Craig, H., 1961, Isotopic variation in meteoric waters; Sci. Vol. 133 p. 1702.

Dellechaie, F., 1975, a hydrogeochemical study of the Animas area, Hidalgo County, New Mexico; AMAX Exploration, Inc.

Fournier, R. D. and Truesdell, A. H., 1974, Geochemical indicators of subsurface temperature - Part II, estimation of temperature and fraction of hot water mixed with cold wter; Journ. of Res. U.S. Geological Survey, Vol. 2, p. 263.

Klein, C. W., 1981, Review of hydrogeochemistry of the Animas, New Mexico thermal anomaly; AMAX Exploration, Inc. report from Geothermex.

Lange, A. L., 1981, Downward continuation of temperaure data at Animas, New Mexico; AMAX Exploration, Inc. report.

Logsdon, M. J., 1981, The aqueous geochemistry of the Lightning Dock KGRA, Animas Valley, Hidalgo County, New Mexico; M.S. Thesis University of New Mexico.