# A HYDROGEOCHEMICAL STUDY
# OF THE ANIMAS AREA,
# HIDALGO COUNTY, NEW MEXICO

by

Frank Dellechaie

December 22, 1975
Amax Exploration, Inc.

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## SUMMARY

1. The Animas area is located in Hidalgo County of south western New Mexico. The area contains six hot wells and at least 10 warm wells. No springs of even very low discharge were found. The hottest wells are located in Section 7 of T25S, R19W. Well W90015 is the most interesting thermal feature in the area. Well deposits consist entirely of chloride salts and carbonates.

2. Non-thermal waters generally contain less than 400 mg/l of dissolved solids, an average of 33 mg/l of $SiO_2$ and an average of 1.5 mg/l of fluoride. Cations and anions occur as follows:

$HCO_3 > SO_4 > Cl \qquad Na > Ca > Mg > K.$

3. The hottest waters of the Animas area contain sulfate as the principle anion and they are described as follows:

$SO_4 > Cl > HCO_3 \qquad Na > K \simeq Ca > Mg.$

Hot waters contain about 1200 mg/l of dissolved solids and do not exceed 145 mg/l of $SiO_2$. Hot waters have low concentrations of Li, B, $NH_3$ and $H_2S$. Chloride concentrations indicate hot water systems at depth. pH ranges from slightly basic to basic (9.1).

4. Sample W90015 was last in equilibrium with an igneous suite of minerals and carbonates. Samples X90441 and X90439 should be in equilibrium with similar minerals.

5. Maximum subsurface temperatures do not exceed 165°C. Quartz and alkali geothermometers are in excellent agreement for samples W90015, X90441 and X90439.

6. Chemical data at hand is inadequate to prove or disprove dilution of the hottest waters. Isotope analysis and deep drilling are necessary to resolve dilution modeling.

7. The chemical data included in this report begs the following speculation on the source of the hot waters. The most conservative model dictates that all hot waters originate through deep circulation along faults on the west flank of the Pyramid Mountains. A more radical model places a cooling pluton, deeply buried beneath the Pyramid Mountains. Silica saturated, sodium chloride water then rises with great difficulty (owing to silica deposition) to the near surface region where they mix with dilute groundwaters producing the thermal features located in Section 7. This second model would be quite believable if very young rocks existed in the area and if a large continuous heat flow anomaly was associated with the bounding fault on the west flank of the Pyramid Mountains.

8. The hydrogeochemistry of the Animas area is ambiguous with regard to the geographic distribuiton of the chemical anomalies and subsurface temperatures. I feel that the area may hold promise for electric production in spite of the inadequate 165°C subsurface temperatures. Further heat flow studies and a $^4$He survey are needed to further prove the existence of a 220°C reservoir.

## THERMAL FEATURES

Fifty-seven water samples were collected from the Animas area (Figure 1) during the winter and summer of 1975.

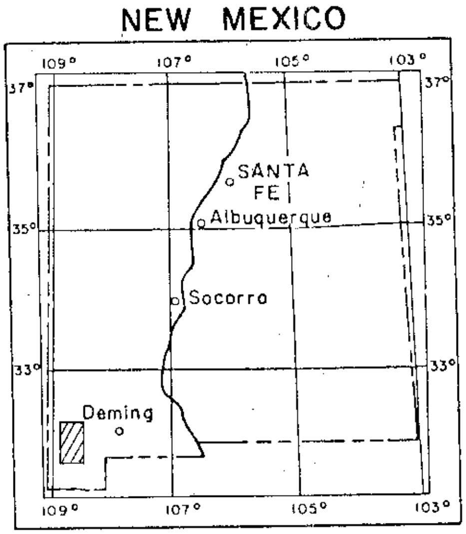

Figure 1. Location map of the Animas, NM, Geothermal Prospect

All data in this report relate to wells because no flowing springs exist in the prospect area. Well temperatures range from 18.5°C to 101°C. This survey indicates that the background water temperature is 19°C. The area includes six hot wells and at least 10 warm wells (Table 1). Well deposits consist of chloride salts and some calcite.

The hottest wells are located in Section 7 of T25S, R19W. Hot waters, probably in excess of 120°C, ascend along a concealed north-south trending fault but do not surface naturally. During the 1950's, drillers encountered super-heated water at 80 to 88 feet in a green-red altered rhyolite. One of these wells (W90015) can be pumped at 200-300 gallons per minute.

Table 1. Thermal features of the Animas Area.

| | | T°C | Flow lpm | Heat discharge cal/sec | Well depth km | Well gradient °C/km |
|---|---|---|---|---|---|---|
| W90015 | Superheated Hot Well | 101 | --- | --- | 0.020 | 4085(?) |
| X90441 | McCants Hot Well | 85 | 189 | $2.1x10^5$ | 0.091 | 722(?) |
| X90439 | Folk Hot Well | 65 | 132 | $1.0x10^5$ | 0.021 | 2176(?) |
| W90002 | 46°C Hot Well | 46.5 | 946 | $4.3x10^5$ | ? | ? |
| W90001 | Banner Mine Hot Well | 46 | 1325 | $5.9x10^5$ | 0.853 | 31 |
| W90003 | 38°C Hot Well | 38 | 1893 | $5.7x10^5$ | 0.366 | 51 |
| W90006 | Cooper Tank Warm Well | 33 | 946 | $2.2x10^5$ | ? | ? |
| W90027 | Wamel Warm Well | 32 | 189 | $4.0x10^4$ | ? | ? |
| W90039 | Elbrock Warm Well | 27 | 1893 | $2.4x10^5$ | 0.100 | |
| W90430 | Uler Ranch Warm Well | 27 | 19 | $1.7x10^3$ | 0.091 | 77 |
| X90442 | Weatherby Warm Well | 22 | 75 | $3.4x10^3$ | 0.091 | 84 |
| X90437 | Sec 34 Cold Well | 18.5 | 19 | $-2.5x10^2$ | | 30 |

$2.4x10^6$ cal/sec
$9.5x10^3$ BTU/sec

Descriptions of each thermal feature are listed in Appendix 1 at the end of this report. Plates 1 through 8 are pictorial representations of some of the thermal wells. Sample locations are posted on two maps in the pocket at the end of this report.

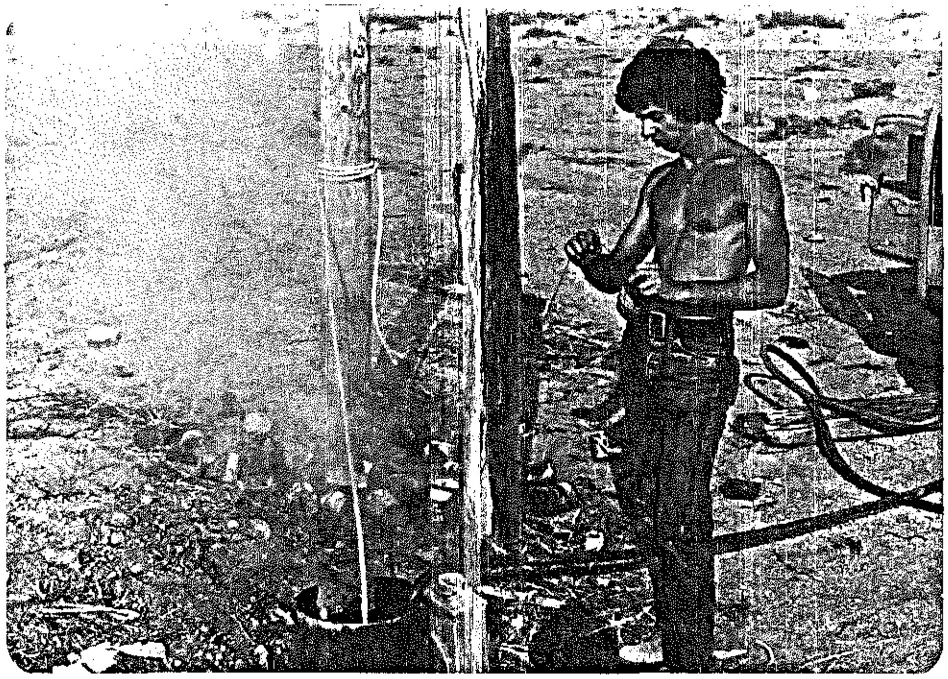

Plate 1. Superheated Hot Well, 101°C at 20 meters.

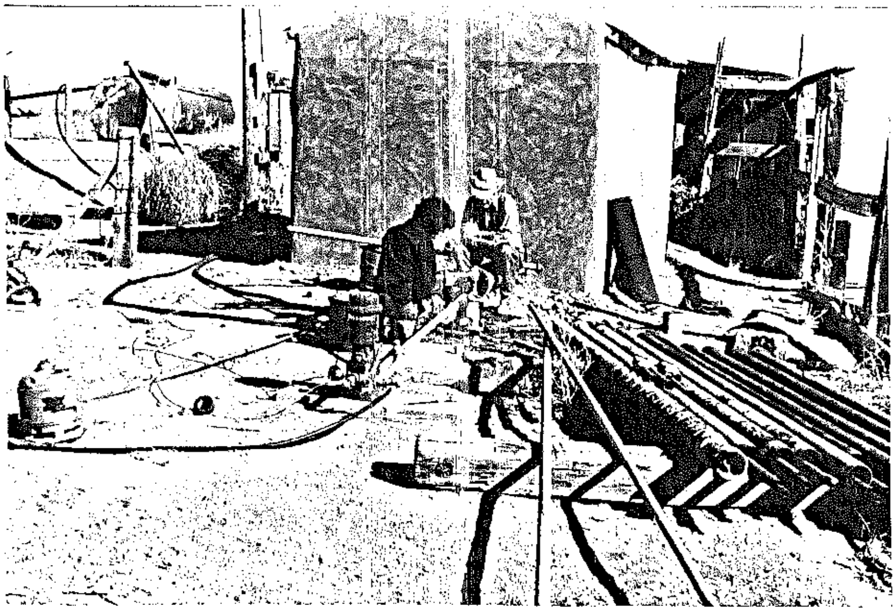

Plate 2. McCants Hot Well with Tom McCant, 85°C at 91 meters.

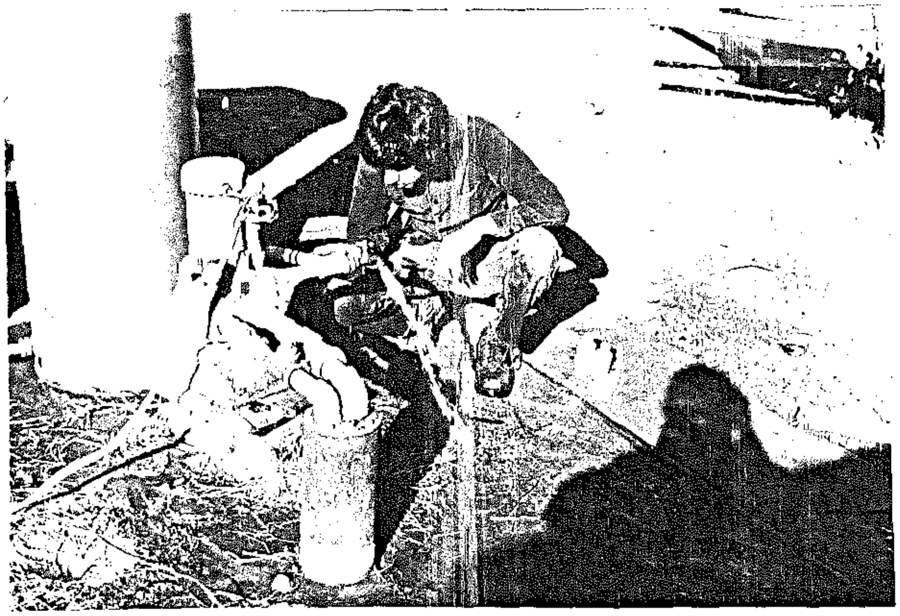

Plate 3. Folks Hot Well, 65°C at 21 meters.

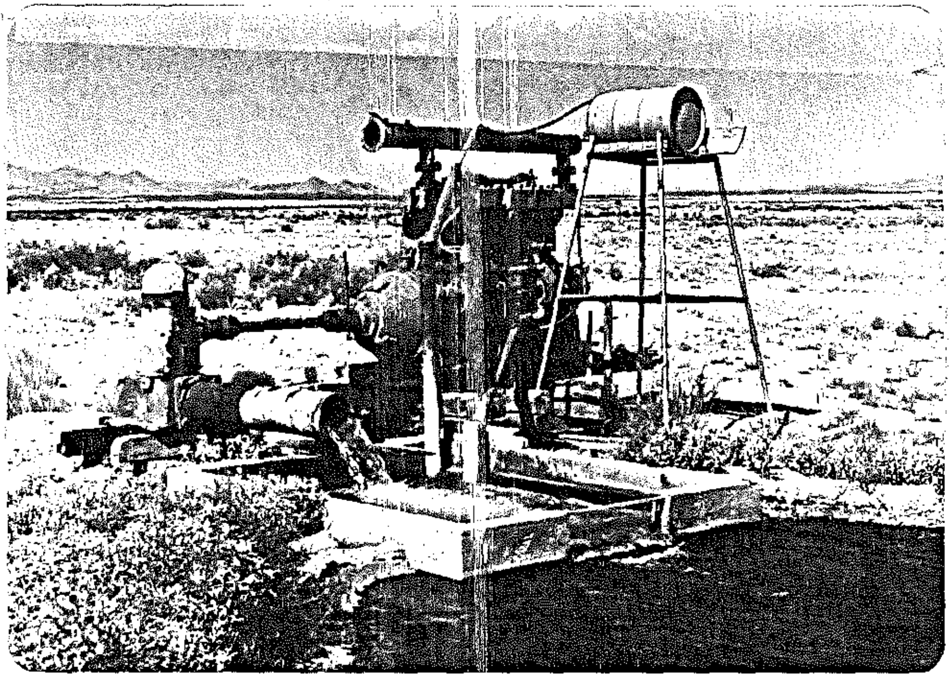

Plate 4. 46°C Hot Well, 46.5°C.

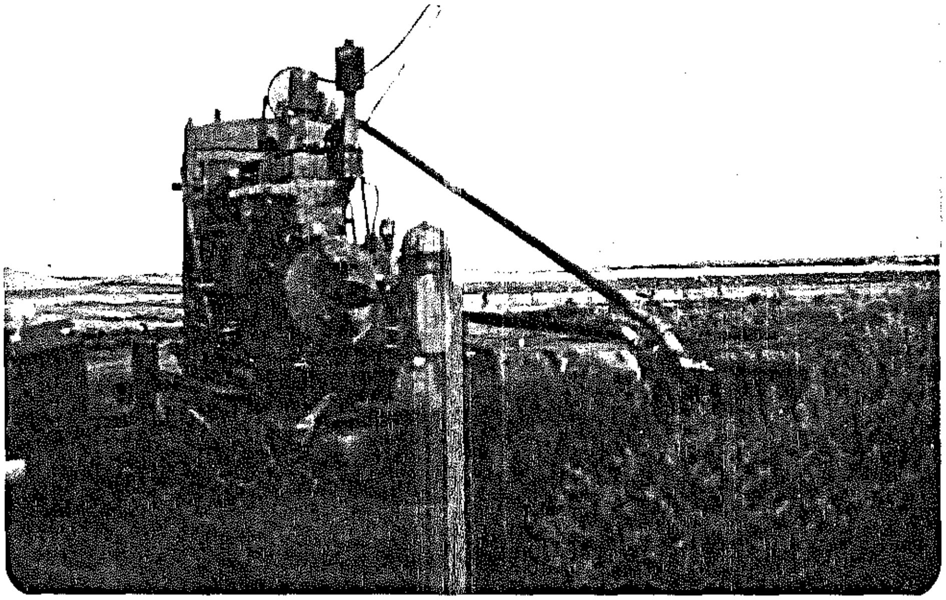

Plate 5. 38°C Hot Well, 38°C.

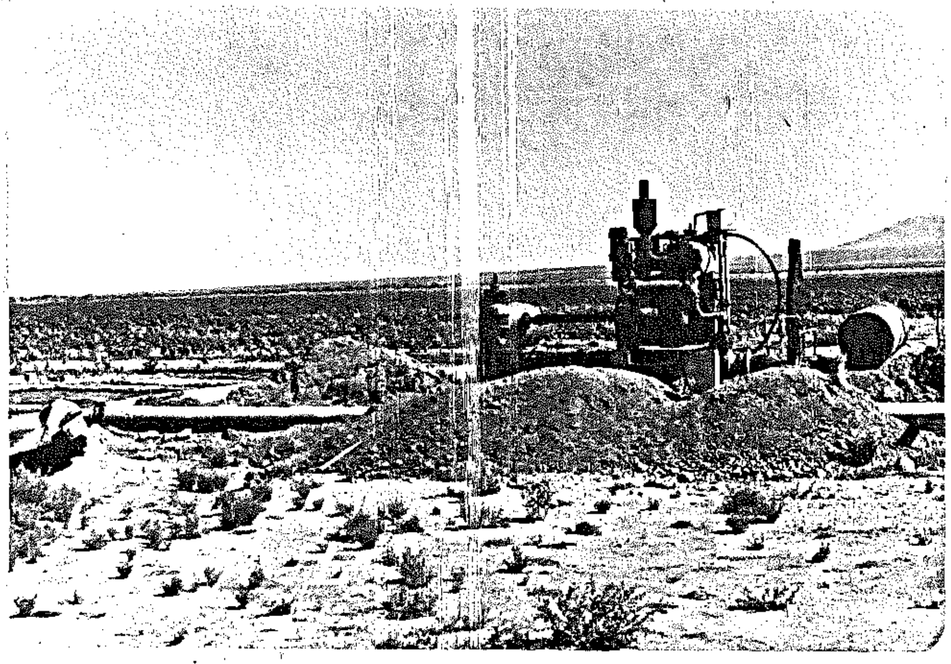

Plate 6. Cooper Tank Warm Well, 33°C.

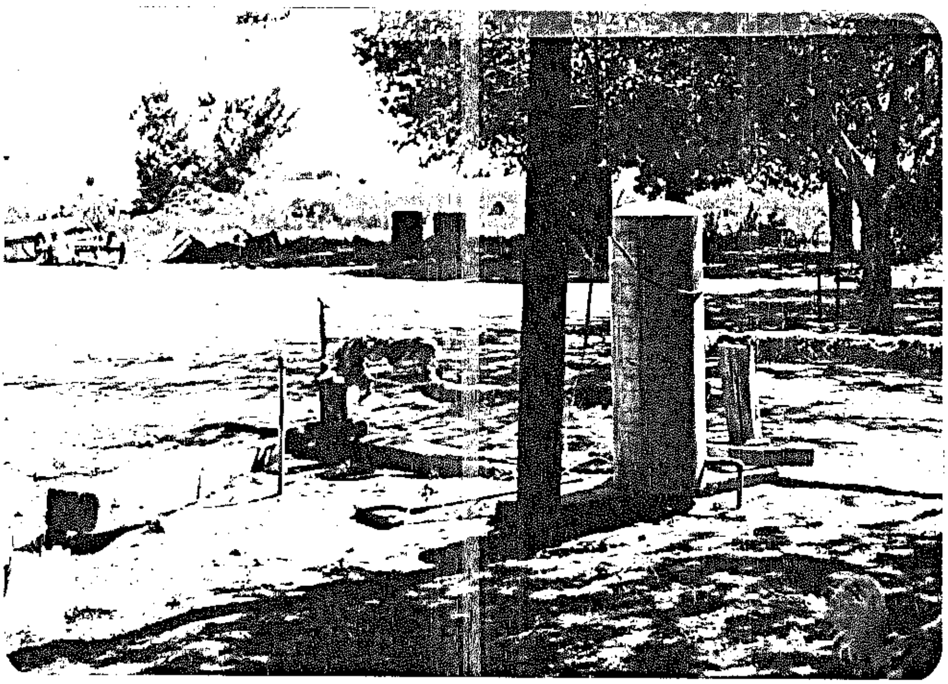

Plate 7. Wamel Warm Well, 32°C.

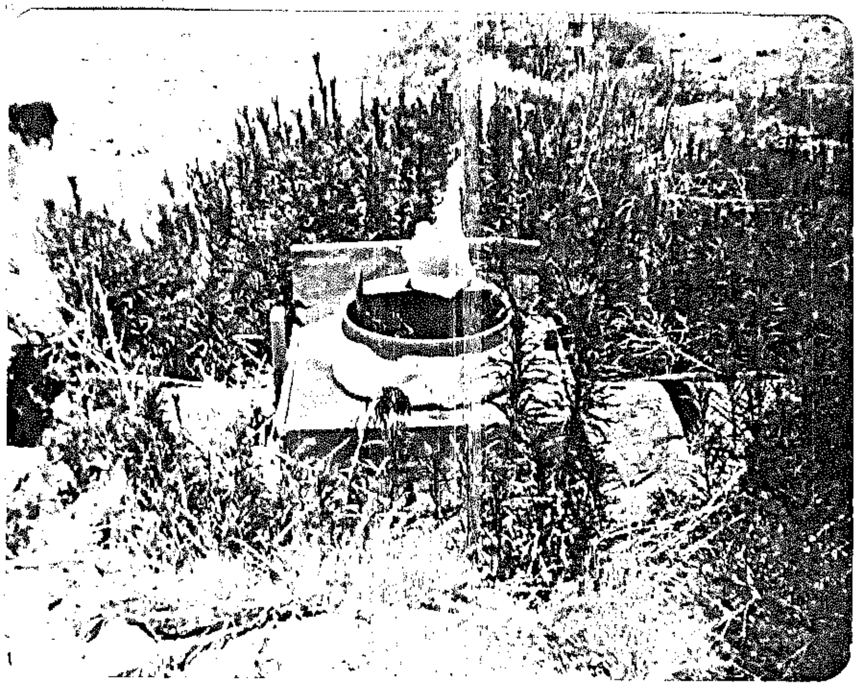

Plate 8. Elbrock Warm Well, 27°C.

## CHEMISTRY

The non-thermal waters of the Animas area generally contain less than 400 mg/l of dissolved solids and exhibit near neutral pH. Bicarbonate is the principle ion while sodium, silica, sulfate, calcium and chloride follow in that order. Cold waters contain an average of 33 mg/l of $SiO_2$. Fluoride concentrations average about 1.5 mg/l in cold water. Section 34 Cold Well (X90437) was selected for best representing the average background chemistry of the area (Table 2).

Thermal waters range from neutral to basic (9.1). The hottest waters contain sulfate as the principle anion while bicarbonate predominates in the warm waters (Tables 2 and 3). Sulfate waters generally originate from moderate depths and are not common to springs associated with very deep circulation along faults. Chloride values for the hottest waters indicate hot water systems at depths , however, these values seem low compared to the concentrations of the remaining ions. Fluoride concentrations are very high in the Animas area; the thermal waters are especially enriched with as much as 15 mg/l. Boron and lithium values are disappointingly low and do not exceed 1 and 0.8 mg/l respectively. Ammonia was only detected in the three hottest wells at very low levels (0.20 mg/l). Hydrogen sulfide was not detected. Silica concentrations do not exceed 145 mg/l. The Banner Mine sample (W90001) is somewhat perverse and should be considered mine water rather than pure geothermal effluent.

Table 2. Chemical analyses of the thermal features of the Animas area, New Mexico. Units are mg/l unless otherwise noted.

| | Superheated Hot Well W90015 | McCants Hot Well X90441 | Folks Hot Well X90439 | 46°C Hot Well W90002 | Banner Mine Hot Well W90001 | 38°C Hot Well W90003 | Cooper Tank Warm Well W90006 | Wamel Warm Well W90027 | ElBrock Warm Well W90039 | Uler Ranch Warm Well X90430 | Weatherby Warm Well X90442 | Sec. 34 Cold Well X90437 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 7.8 | 8.1 | 7.0 | 8.3 | 7.0 | 9.1 | 7.8 | 7.6 | 7.9 | 8.2 | 7.7 | 7.8 |
| Cl | 112 | 84 | 130 | 87 | 42 | 32 | 54 | 32 | <10 | 24 | <10 | 16 |
| F | 15 | 12 | 7.8 | 10.1 | 0.8 | 7.8 | 6.8 | 3.5 | 4.3 | 3.2 | 4.3 | 1.2 |
| $HCO_3$ | 90 | 80 | 93 | 400 | 119 | 128 | 248 | 200 | 147 | 172 | 177 | 138 |
| $CO_3$ | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| $SO_4$ | 400 | 460 | 700 | 265 | 1100 | 140 | 190 | 350 | 85 | 50 | 95 | 42 |
| $SiO_2$ | 145 | 130 | 99 | 63 | 33 | 44 | 41 | 35 | 39 | 32 | 41 | 48 |
| Na | 340 | 330 | 420 | 400 | 100 | 160 | 240 | 130 | 74 | 110 | 78 | 61 |
| K | 20 | 19 | 26 | 6.0 | 3.6 | 1.2 | 9.2 | 7.1 | 2.1 | 3.3 | 3.1 | 2.1 |
| Ca | 20 | 21 | 70 | 11 | 480 | 2 | 17 | 6.1 | 32 | 9 | 50 | 36 |
| Mg | 0.3 | 0.1 | 5 | 2 | 21 | <0.1 | 3 | 8 | 3 | 1 | 7 | 3 |
| Li | 0.5 | 0.5 | 0.8 | 0.4 | <0.1 | 0 1 | 0.3 | 0.2 | 0.1 | 0.1 | 0.2 | <0.1 |
| B | 0.4 | 0.3 | 0.2 | 1.0 | 0.2 | <0.2 | 0.6 | <0.2 | 0.2 | 0.2 | 0.2 | <0.2 |
| Mo µg/l | NA | 25 | 30 | NA | NA | NA | NA | NA | NA | 10 | 2 | <1 |
| $NH_3$ | 0.12 | 0.12 | 0.20 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| $H_2S$ | < 0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| TDS | 1143 | 1137 | 1552 | 1245 | 1900 | 529 | 810 | 772 | 396 | 405 | 464 | 347 |
| | | | | | | | | | | | | |
| T°C | 101 | 85 | 65 | 46.5 | 46 | 38 | 33 | 32 | 27 | 27 | 22 | 18.5 |
| Flow (gpm) | --- | 50 | 35 | 250 | 350 | 500 | 250 | 50 | 500 | 5 | 20 | 5 |
| | | | | | | | | | | | | |
| $TSiO_2$°C | 159 | 152 | 137 | 113 | 83* | 96 | 93 | 86 | 91 | 82 | 93 | 99 |
| TNa/K°C | 129 | 133 | 134 | 35* | 89* | 1.8* | 94 | 123* | 72 | 76 | 97 | 86 |
| TNa-K-Ca | 165 | 165 | 160 | 111 | 12* | 85 | 140 | 66 | 39 | 81 | 42 | 35 |
| | | | | | | | | | | | | |
| $Cl/SO_4$ | 0.8 | 0.5 | 0.5 | 0.9 | 0.1 | 0.6 | 0.8 | 0.2 | 0.3 | 0.4 | 0.3 | 1.0 |
| $Cl/HCO_3$ | 2.1 | 1.8 | 2.4 | 0.4 | 0.6 | 0.4 | 0.4 | 0.3 | 0.1 | 0.2 | 0.1 | 0.2 |
| Cl/F | 4.0 | 3.7 | 8.8 | 4.6 | 28 | 2.2 | 4.2 | 4.8 | 1.2 | 4.0 | 1.2 | 7.1 |

NA = not analysed

* Does not represent true subsurface conditions

Table 3. Principle anions and cations of the Animas thermal and non-thermal waters.

| Spring Number and Name | | Anions | Cations | Inferred Water Age |
|---|---|---|---|---|
| W90015 | Superheated Hot Well | $SO_4$>Cl>$HCO_3$ | Na>K=Ca>Mg | Moderate |
| X90441 | McCants Hot Well | $SO_4$>Cl≃$HCO_3$ | Na>Ca>K>Mg | Moderate |
| X90439 | Folks Hot Well | $SO_4$>Cl>$HCO_3$ | Na>Ca>K>Mg | Moderate |
| X90001 | Banner Mine Hot Well | $SO_4$>$HCO_3$>Cl | Na>Ca>Mg>K | Young |
| W90003 | 38°C Hot Well | $SO_4$>$HCO_3$>Cl | Na>Ca>K>Mg | Young |
| W90027 | Wamel Warm Well | $SO_4$>$HCO_3$>Cl | Na>Mg>K>Ca | Young |
| W90002 | 46°C Hot Well | $HCO_3$>$SO_4$>Cl | Na>Ca>K>Mg | Young |
| W90006 | Cooper Tank Warm Well | $HCO_3$>$SO_4$>Cl | Na>Ca>K>Mg | Young |
| W90039 | El Brock Warm Well | $HCO_3$>$SO_4$>Cl | Na>Ca>Mg>K | Young |
| X90430 | Uler Ranch Warm Well | $HCO_3$>$SO_4$>Cl | Na>Ca>K>Mg | Young |
| X90442 | Weatherby Warm Well | $HCO_3$>$SO_4$>Cl | Na>Ca>Mg>K | Young |
| X90437 | Sec. 34 Cold Well | $HCO_3$>$SO_4$>Cl | Na>Ca>Mg>K | Very young |

Figures 2 through 7 are geochemical plots of the hot and cold waters of the Animas area. Two and possibly three groups of water exist. Figures 2 and 3, B-Cl and B-Na plots, respectively, reveal three groups. One group contains the hot wells of section seven, the second contains two irrigation wells located southeast of Lordsburg and the third group contains mixed thermal waters and non-thermal waters. The dearth of boron in the group containing the super heated water may indicate that these waters are mixed. Figure 4 clearly distinguishes the Banner Mine water as being unique. Figure 5 shows two groups. The group containing the super heated water is clearly older than the group near the origin. Figure 6 is a graphic presentation of Table 3. The hottest waters are of the sulfate variety, whereas the remaining waters are immature and bicarbonated. Figure 7 depicts the relationship between the TDS/$SiO_2$ ratio and the $SiO_2$ concentration. The Banner Mine water is again distinguished as being unique.

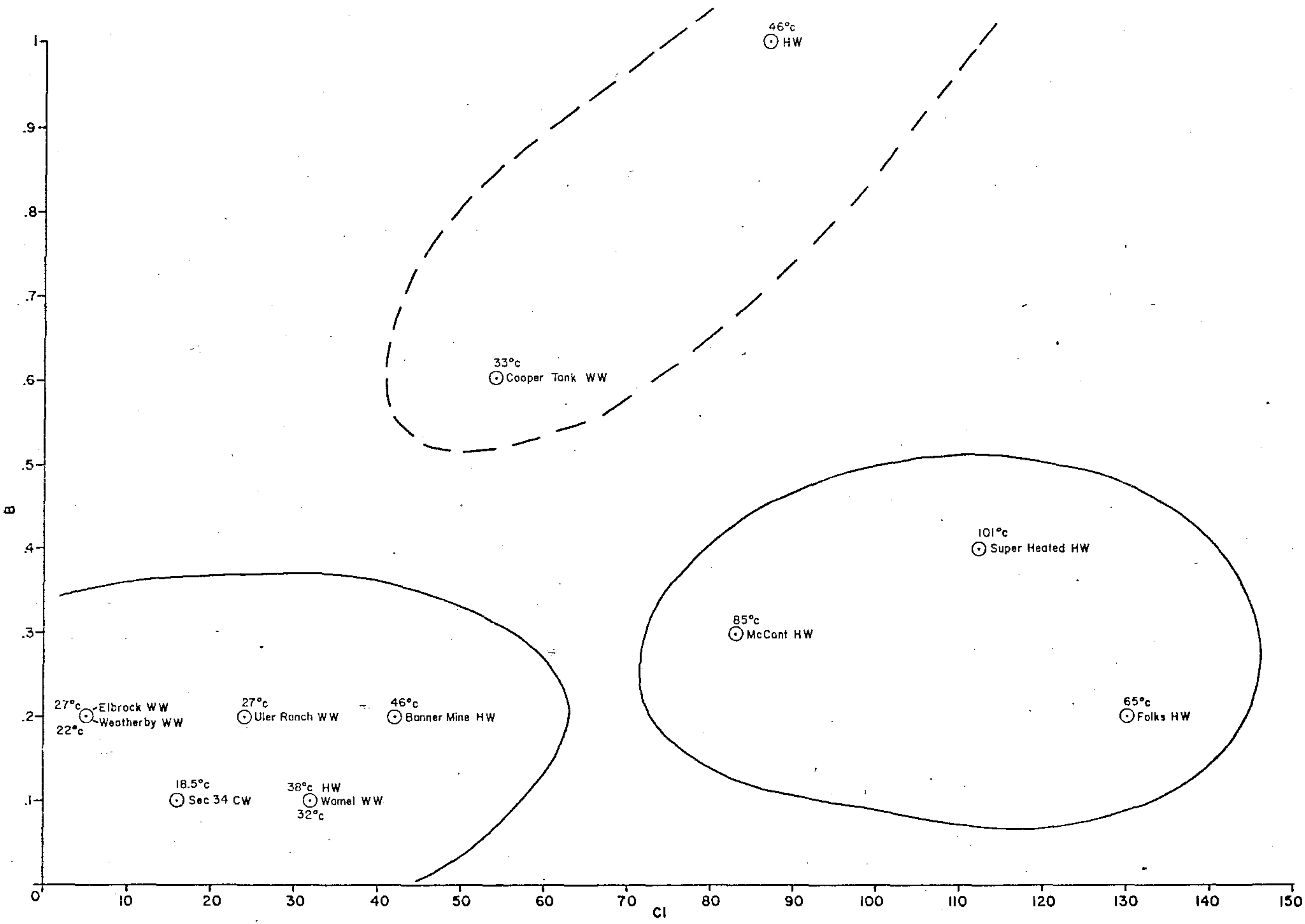

Figure-2. The relationship between B and Cl for the thermal and non-thermal waters of the Animas, New Mexico area.

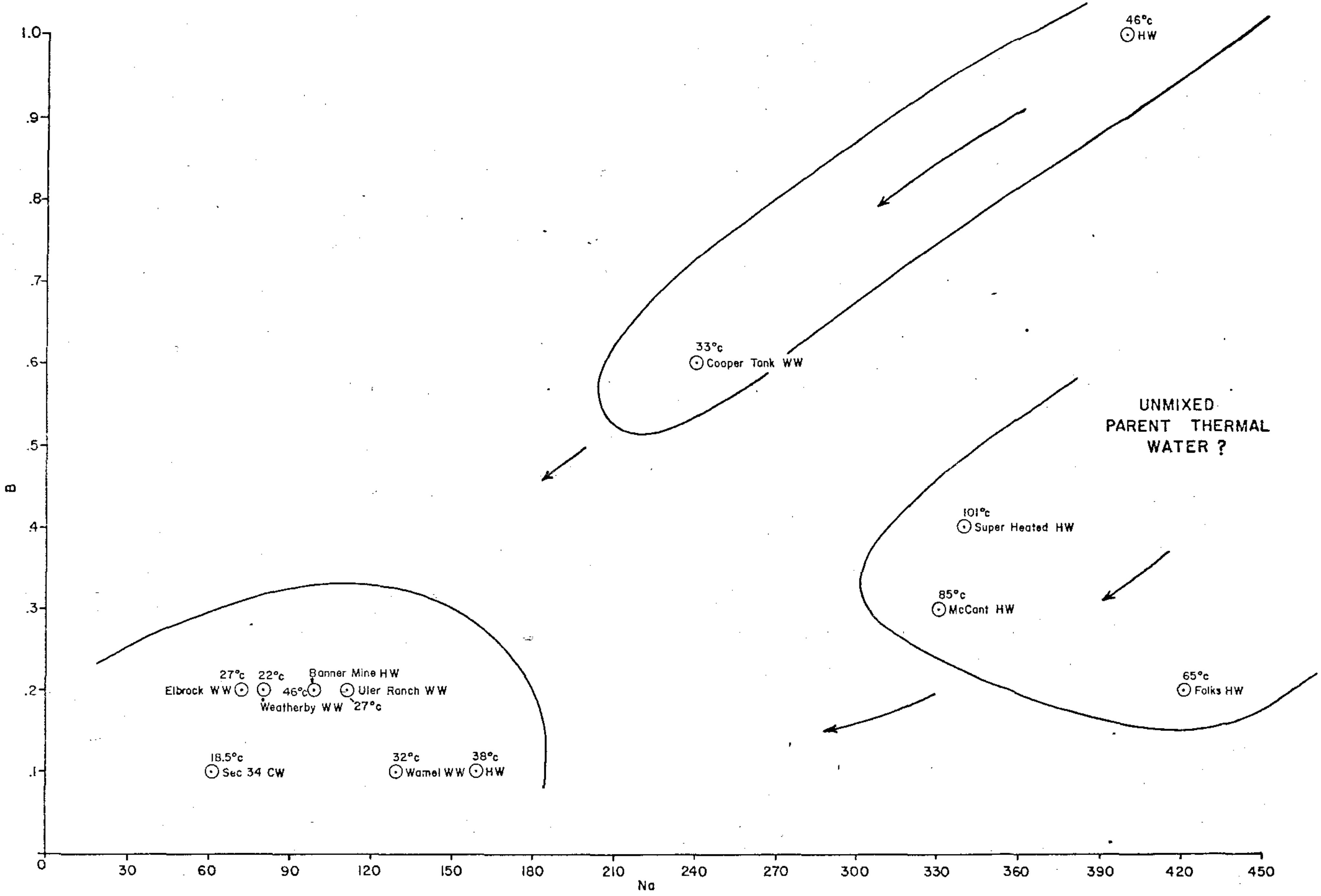

Figure 3. The relationship between B and Na for the thermal and non-thermal waters of the Animas, New Mexico area.

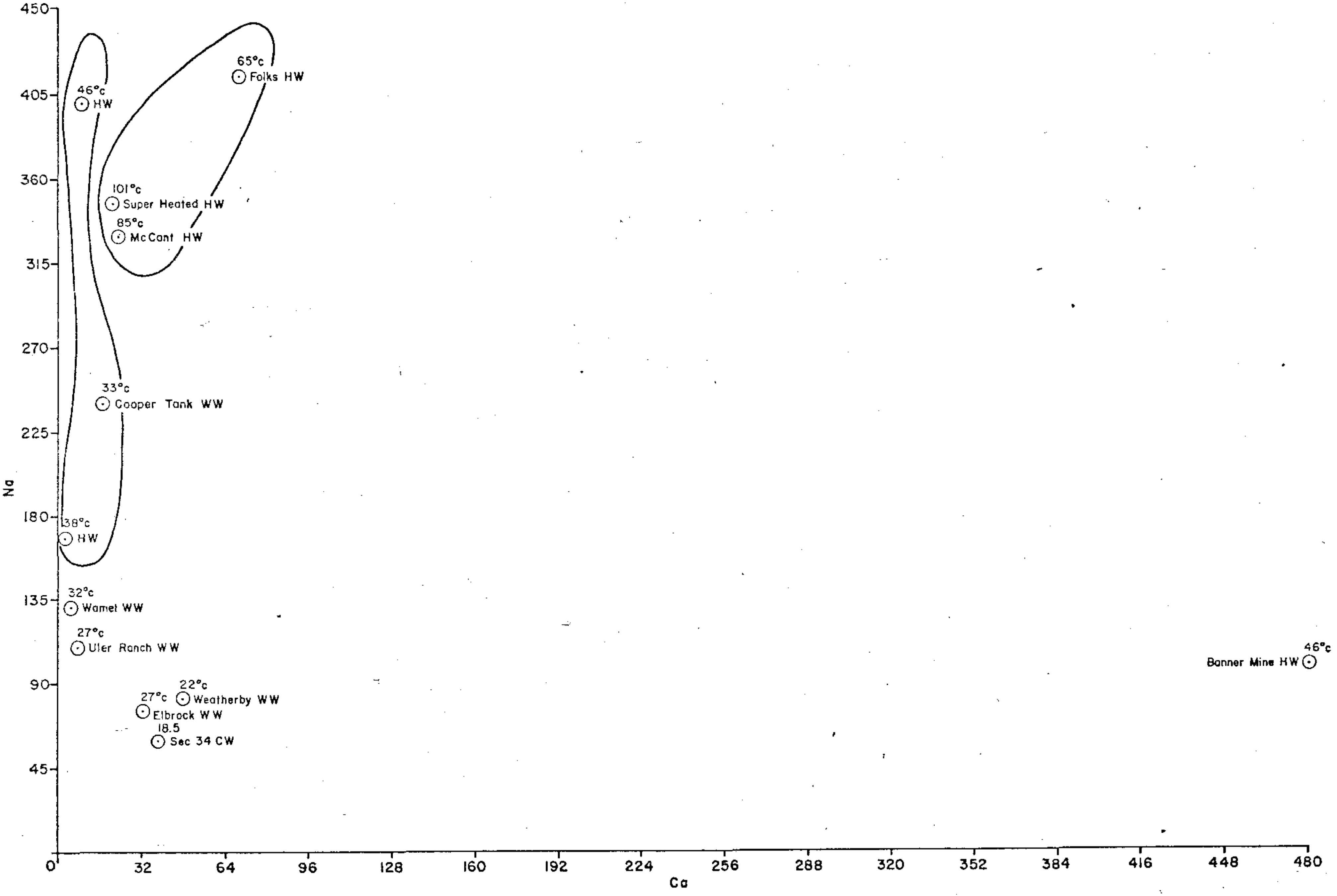

Figure 4. The relationship between Na and Ca for the thermal and non-thermal waters of the Animas, New Mexico area.

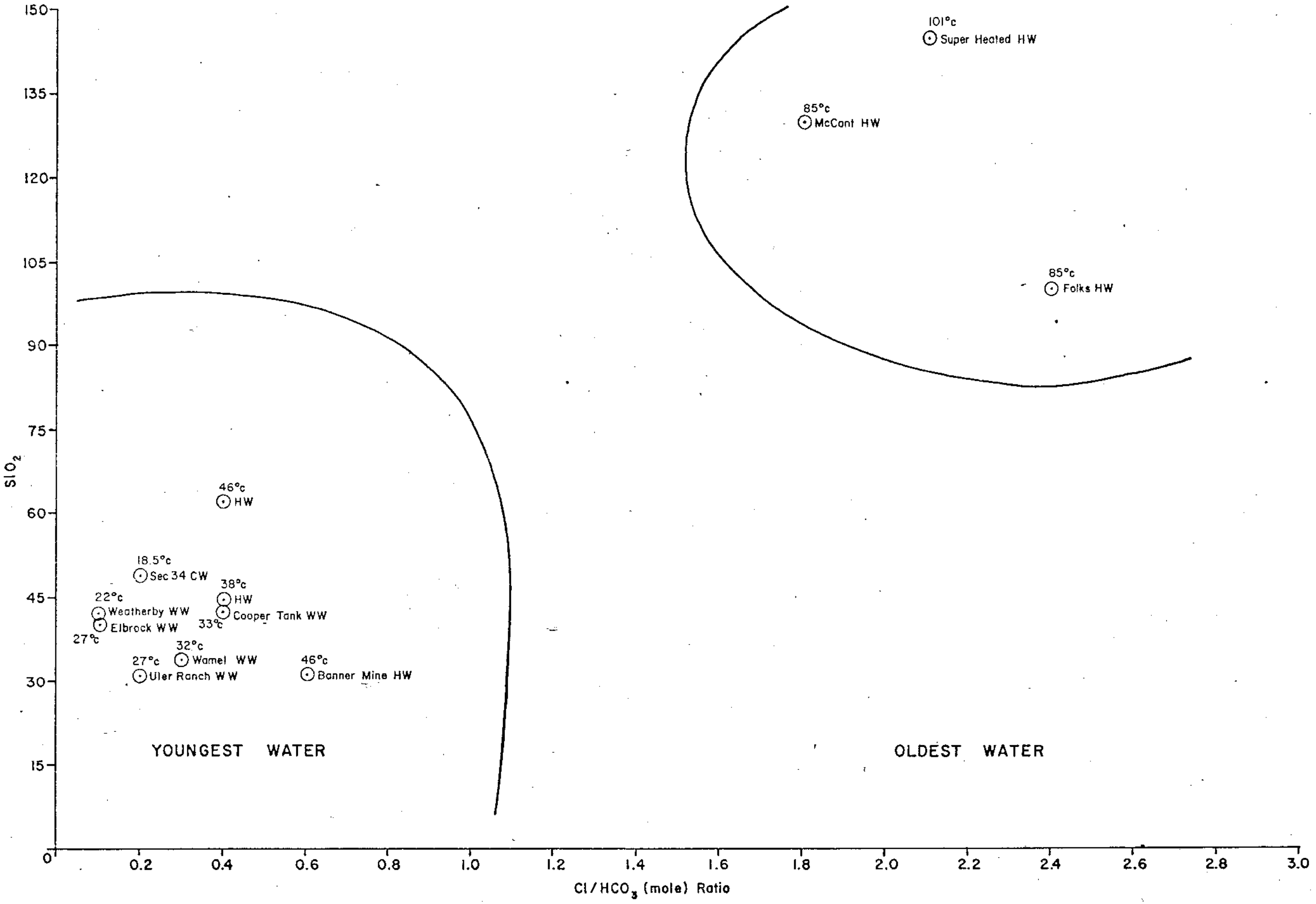

Figure 5. The relationship between $SiO_2$ and the $Cl/HCO_3+CO_3$ mole ratio for the thermal and non-thermal waters of the Animas, New Mexico area.

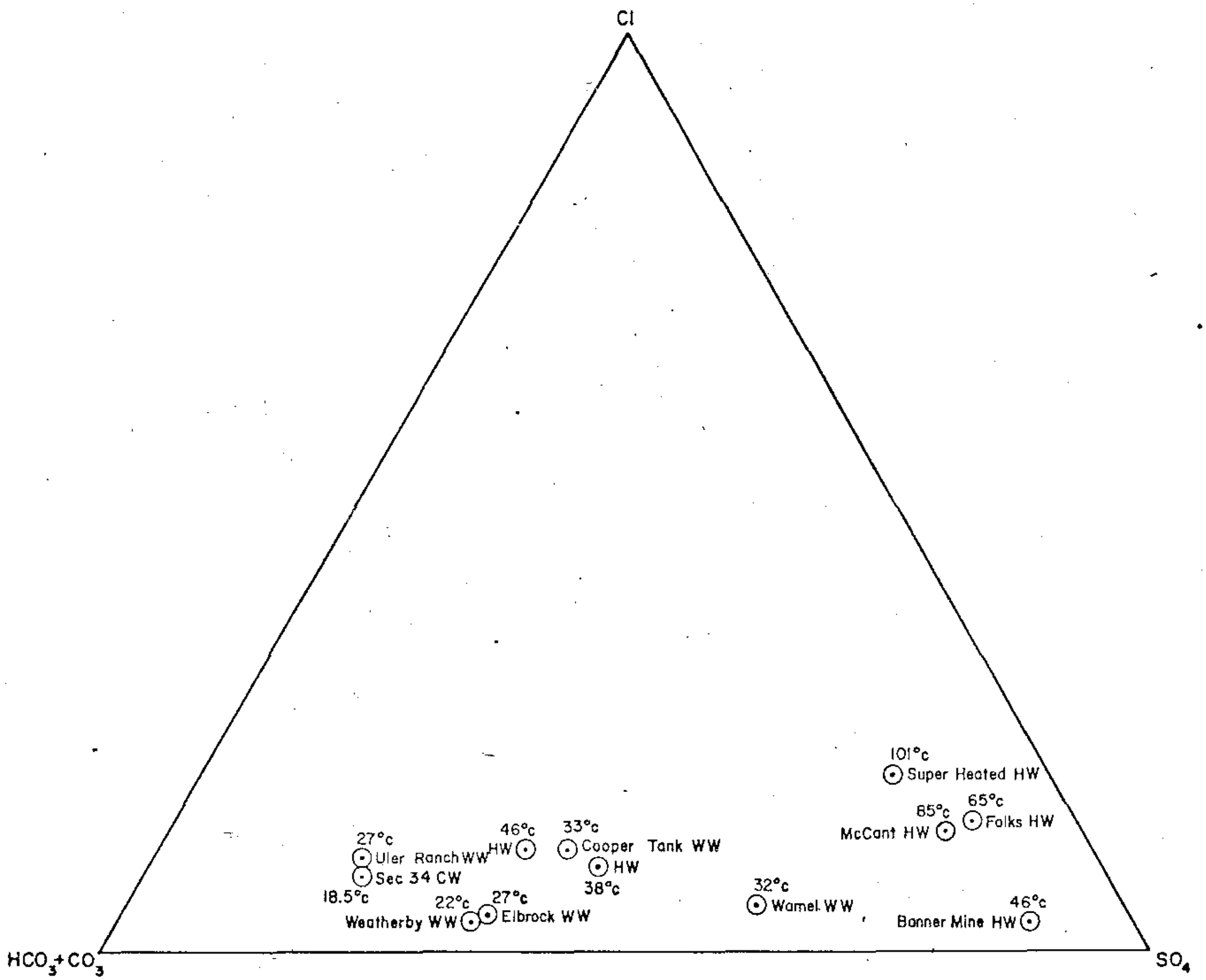

Figure 6. The relationship between $HCO_3$+$CO_3$, $SO_4$ and Cl for the thermal and non-thermal waters of the Animas, New Mexico area.

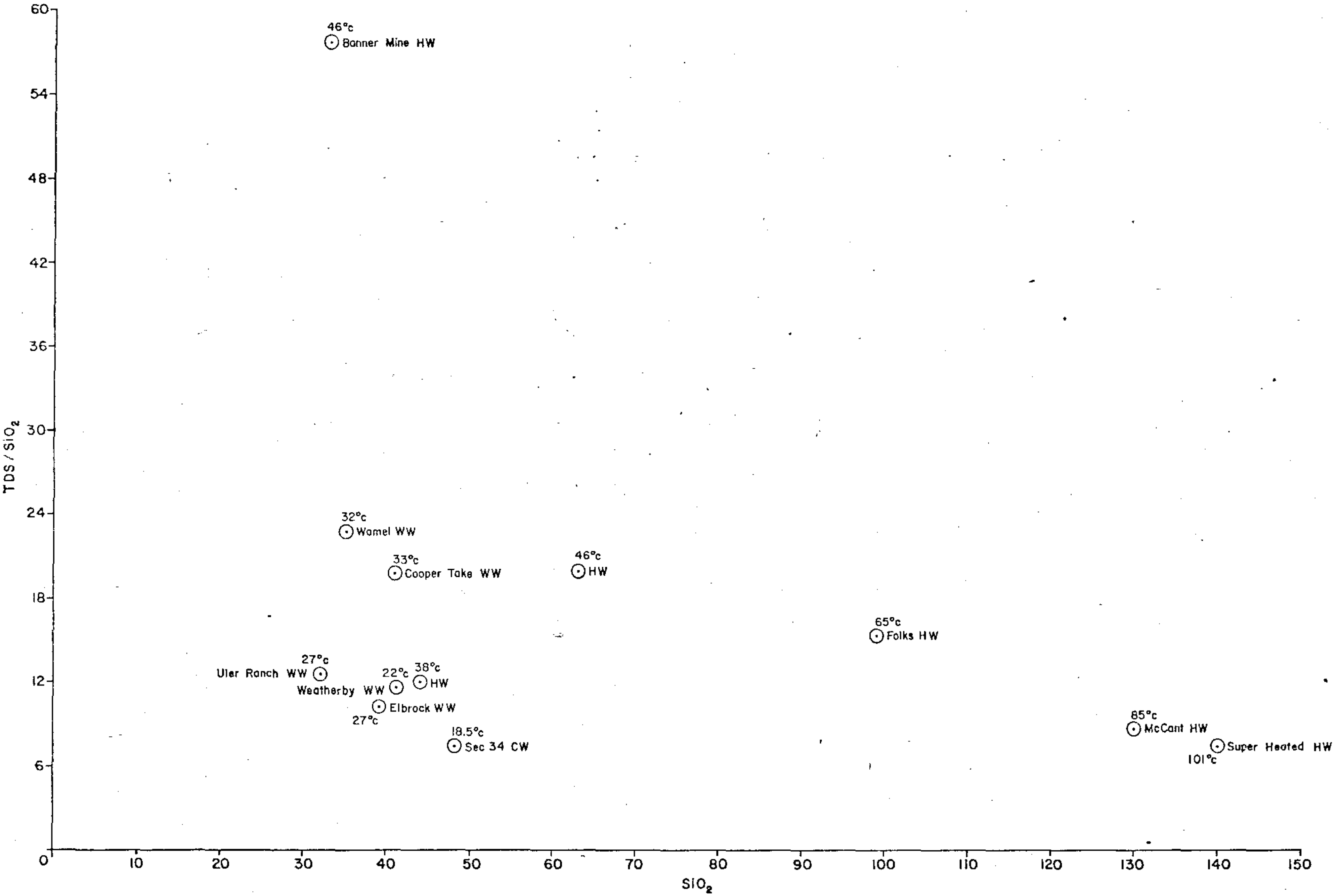

Figure 7. The relationship between the TDS/$SiO_2$ ratio and $SiO_2$ for the thermal and non-thermal waters of the Animas, New Mexico area.

## SUBSURFACE TEMPERATURES

Subsurface reservoir temperatures indicated by the water chemistry reveal maximum temperatures of 165°C. The alkali and quartz temperatures show very good correlation for samples W90015, X90441 and X90439 (Table 2).

## MIXING OF HOT WATERS

The hottest waters in the Animas area could possibly be mixed with some unknown volume of cold groundwater. Figures 2 and 3 show that the hottest waters in the area (Superheated Hot Well, McCants Hot Well and Folks Hot Well) are depleted in boron, compared to waters which are considerably colder. These hottest waters also seem somewhat depleted in chloride. Arguing against dilution are the very high concentration of fluoride (15 mg/l) in the hottest waters. The waters of Roosevelt Hot Spring, proven at 230°C contain only 7.5 mg/l of fluoride. The excellent correlation between subsurface temperatures for the hottest waters provides a second argument against dilution. Good subsurface temperature correlation indicates that hot waters must have mixed at considerable depth so that sufficient time was provided for good reequilibration.

The chemical data at hand is insufficient to prove dilution or no dilution. Water isotope analysis may answer dilution questions. I feel that 165°C is a credible subsurface temperature. Deep drilling will obviously prove the existence of higher temperatures.

## HYDROGEOCHEMICAL COMPARISON

The chemistry of the Super Heated Hot Well (W90015) was compared to 18 well and spring analyses from known producing reservoirs of the world. The only reasonable comparison is shown in Figure 8. The correlation is good with the exception of $SiO_2$, Ca, and $SO_4$. The Icelandic hot water issues out of a mainly basaltic terrain, in one of the high temperature regions.

## MINERAL EQUILIBRIUM

The degree of saturation of 285 possible hypothetical minerals has been calculated (Table 4) for McCants hot well (X90441). This water was last in equilibrium with a predominately igneous suite of minerals and carbonates.

Table 4. Gibbs Free Energies in kcal/mole for McCants Hot Well (X90441).

| | | |
|---|---|---|
| T°C | 85°C | |
| TDS | 1137 mg/l | |
| Carbonates | Calcite | 0.4 |
| | Aragonite | 0.3 |
| Silicates | Fayalite | 3.3 |
| | Kenyaite | 3.2 |
| | Magadite | 3.2 |
| | Quartz | 0.9 |
| | Chalcedony | 0.5 |
| | Cristobalite | 0.2 |
| Meq/l | cations | 13.4 |
| | anions | 12.2 |

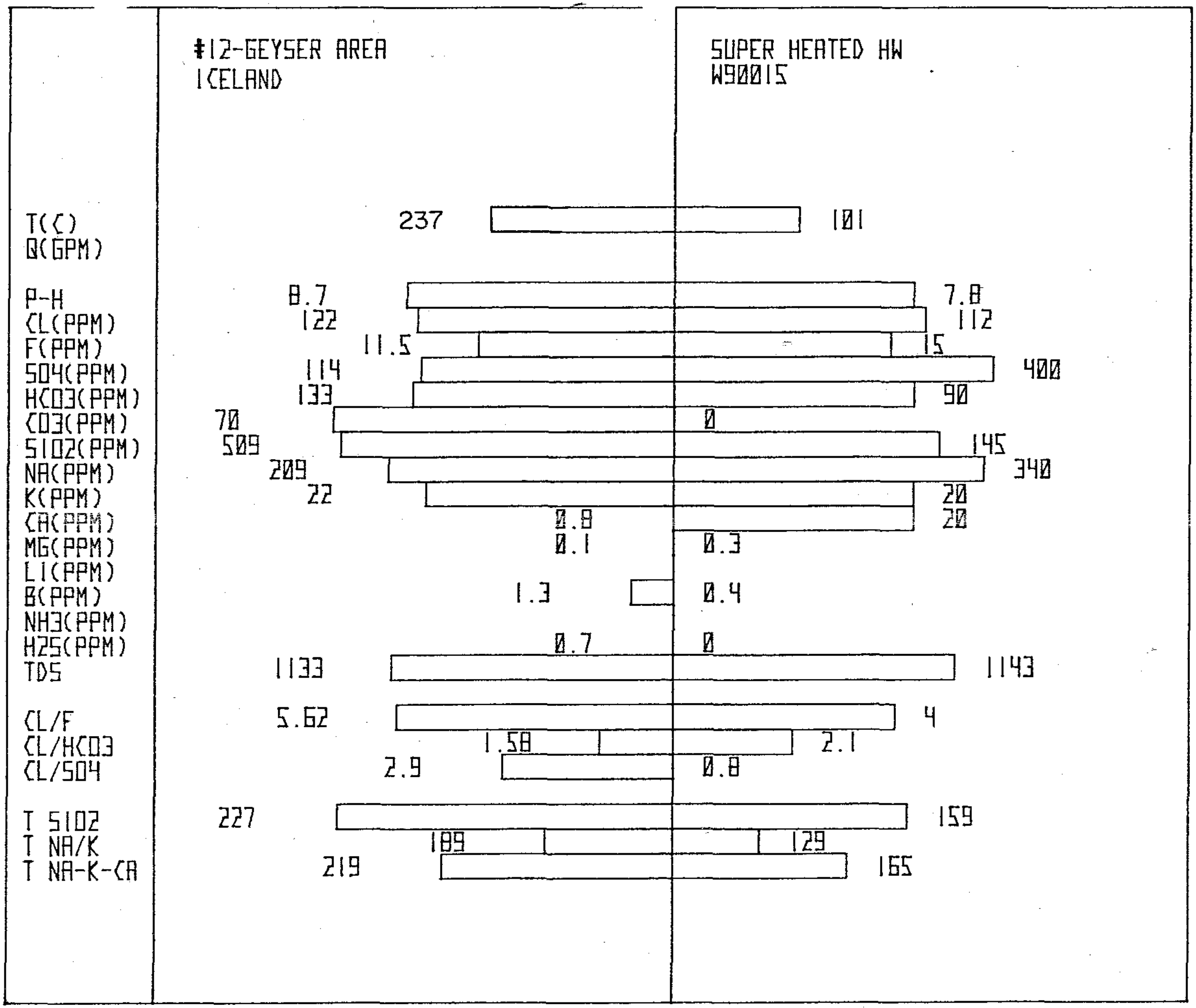

Figure 8. A chemical comparison of Animas sample W90015 (Super Heated Hot Well) and a producing well from the high temperature area (Geyser area) Iceland.

# GEOCHEMICAL

# SAMPLE FORMS

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ______ Sample No. X W90015 Date 7-2-75 Time 1730

Name: Super Heated Hot Well West Location: Co. Hidalgo State N. Mexico

SW¼ NE¼ Sec. 7 T 25S R 19W ; ______ Km/mi. ______ of ______

Lat.: ______ Long.: ______ Sampler: John C. Deymonez

Elevation: 4205 Quad. Swallow Fork

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 101

Ground Temp. °C ______

Air Temp. 28

Odor 0

Fluid Color 0

Fluid Taste 0

Bubbling mod

Boiling mod

Vegetation 0

Fluid issues from no discharge- used sampling device

Salt: Type ______

Quantity ______

Color ______

Form ______

Sinter: Type ______

Quantity ______

Color ______

Form ______

Discharge: 0 gpm/Lpm

Well Data: Depth 86'

Bore 12"

Pump Type none

Level of water in bore ~ 70'

Type of piping steel

Artesian Head ______

Rock Data:

Type (surface) Qal

Color ______

Grain size ______

Megascopic Minerals ______

Alteration: ______

Rx Type (at depth) altered Rhyolite

Water used for nothing

Immediate area used for: junk pile

Quality of sample: [✓ Exc], Good, Poor

Probable cause of manifestation well

Property owned by MacDonald, Lordsburg, N. Mexico

Previous and/or Current Leases no

Comments: ______

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ____ Sample No. X 90441 Date 1-26-75 Time 12:45

Name: McCants Hot Well Location: Co. Hidalgo State N. Mexico

NW¼ Sec. 7 T25S R: 19W ; ____ Km/mi. ____ of ____

Lat.: ____ Long.: ____ Sampler: Frank Dellechaie

Elevation: 4215 Quad. Swallow Fork Peak

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

| | |
|---|---|
| Water Temp. °C 85 | Discharge: 50 gpm/Lpm |
| Ground Temp. °C | Well Data: Depth 90' |
| Air Temp. | Bore 6" |
| Odor 0 | Pump Type electric sub |
| Fluid Color clear | Level of water in bore ? |
| Fluid Taste hard | Type of piping steel |
| Bubbling yes | Artesian Head no |
| Boiling yes | Rock Data: |
| Vegetation none | Type (surface) Qal |
| Fluid issues from steel pipe | Color |
| | Grain size |
| | Megascopic Minerals |
| Salt: Type NaCl | |
| Quantity minor | |
| Color white | Alteration: |
| Form amorp | Rx Type (at depth) |
| Sinter: Type | Water used for drinking, cattle |
| Quantity | Immediate area used for: ranching |
| Color | |
| Form | Quality of sample: [✓ Exc.], Good, Poor |

Probable cause of manifestation well

Property owned by Tom McCants

Previous and/or Current Leases none

Comments:

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. Sample No. X 90439 Date 1-27-75 Time 10:15

Name: Folks Well Location: Co Hidalgo State N. Mexico

Sec. 7 T 25S R: 19W ; Km/mi. of

Lat.: Long.: Sampler:

Elevation: 4200 Quad. Swallow Fork Peak

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 65

Ground Temp. °C

Air Temp.

Odor 0

Fluid Color 0

Fluid Taste 0

Bubbling 0

Boiling 0

Vegetation 0

Fluid issues from steel pipe

Salt: Type

Quantity

Color

Form

Sinter: Type

Quantity

Color

Form

Discharge: 50 [✓ gpm]/Lpm

Well Data: Depth 70

Bore 4"

Pump Type electric

Level of water in bore?

Type of piping steel

Artesian Head no

Rock Data:

Type (surface) Qal

Color

Grain size

Megascopic Minerals

Alteration:

Rx Type (at depth)

Water used for drinking

Immediate area used for: ranching

Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by Folk

Previous and/or Current Leases ?

Comments:

SKETCHES

# AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ______ Sample No. X W90002 Date 6-27-75 Time 10:30

Name: 46⁰ Hot Well Location: Co Hidalgo State N. Mexico

______ Sec. ______ T 23N R: 17W ; ______ Km/mi. ______ of ______

Lat.: ______ Long.: ______ Sampler: John C. Deymonez

Elevation: 4250 Quad Lordsburg, N. Mexico

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 46.5 Discharge: 250 gpm/Lpm

Ground Temp. °C ______ Well Data: Depth ______

Air Temp. 30 Bore 16"

Odor 0 Pump Type gas engine driven sub

Fluid Color 0 Level of water in bore ______

Fluid Taste chloride sulfate Type of piping steel

Bubbling 0 Artesian Head --

Boiling 0 Rock Data:

Vegetation lt. & dk. green algae Type (surface) Qal

Fluid issues from 12" steel pipe Color ______

8' from well head Grain size ______

Megascopic Minerals ______

Salt: Type 0

Quantity ______

Color ______ Alteration: ______

Form ______ Rx Type (at depth) ______

Sinter: Type $CaCO_3$ Water used for irrigation

Quantity mod Immediate area used for: farming

Color white

Form amor Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by ?

Previous and/or Current Leases ?

Comments: water sample

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. _____ Sample No. X W90001 Date 6-20-75 Time 12:00

Name: Banner Mine Location: Co. Hidalgo State N. Mexico

NE¼ NE¼ Sec. 23 T 23S R: 19W ; _____ Km/mi. _____ of _____

Lat.: _____ Long.: _____ Sampler: John Deymonez

Elevation: 4700 (surface) Quad. Gary

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 46 Discharge: 350 [✓ gpm]/Lpm

Ground Temp. °C _____ Well Data: Depth 2800'

Air Temp. 44 @2000' Bore _____

Odor S= Pump Type _____

Fluid Color red Level of water in bore water issues from fracture at about 1500' level

Fluid Taste Fe Type of piping _____

Bubbling 0 Artesian Head _____

Boiling 0 Rock Data:

Vegetation 0 Type (sub surface) chalcopyrite (bornite, pyrite)

Fluid issues from poolwell Color _____

drilled at 2000' level Grain size _____

Megascopic Minerals _____

Salt: Type _____

Quantity _____

Color _____ Alteration: _____

Form _____ Rx Type (at depth) chalcopyrite (bornite, pyrite)

Sinter: Type _____ Water used for cooling

Quantity _____ Immediate area used for: mining copper (minor gold & silver

Color _____

Form _____ Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by Banner Mining Co.

Previous and/or Current Leases no

Comments: mine 2000' - temp. $100^0$F.
water $130^0$F
FeO & Lime. Heavy Fe stains in mine.

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ______ Sample No. X W90003 Date 6-29-75 Time 2015

Name: 38$^0$C Hot Well Location: Co Hidalgo State N. Mexico

SE¼ SW¼ Sec. 8 T 23S R: 17W ; ______ Km/mi. ______ of ______

Lat.: ______ Long.: ______ Sampler: John Deymonez

Elevation: 4203 Quad. Lisbon

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 38

Ground Temp. °C ______

Air Temp. 24

Odor 0

Fluid Color clear

Fluid Taste sweet sulfate

Bubbling 0

Boiling 0

Vegetation olive green algae

Fluid issues from 12" steel pipe 2' from well head

Salt: Type NaCl

Quantity V minor

Color white-rust red

Form amor

Sinter: Type $CaCO_3$

Quantity minor

Color white-rust red

Form amor

Discharge: 500 gpm/Lpm

Well Data: Depth ~1200

Bore 14"

Pump Type diesel engine driven sub

Level of water in bore ?

Type of piping steel

Artesian Head ______

Rock Data:

Type (surface) Qal

Color ______

Grain size ______

Megascopic Minerals ______

Alteration: ______

Rx Type (at depth) rhyolite

Water used for irrigation

Immediate area used for: farming

Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by ?

Previous and/or Current Leases ______

Comments: sample taken

SKETCHES

JED 4-11

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ______ Sample No. X W90006 Date 6-30-75 Time 10:15

Name: Cooper Tank WW Location: Co. Grant State N. Mexico

NW¼ SE¼ Sec. 8 T 24S R: 16W ; ______ Km/mi. ______ of ______

Lat.: ______ Long.: ______ Sampler: John Deymonez

Elevation: 4345 Quad. Muir Ranch

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 33

Ground Temp. °C ______

Air Temp. 30

Odor 0

Fluid Color 0

Fluid Taste mild sulfate

Bubbling 0

Boiling 0

Vegetation 0

Fluid issues from 8' steel pipe 15' from well head

Salt: Type ______

Quantity ______

Color ______

Form ______

Sinter: Type ______

Quantity ______

Color ______

Form ______

Discharge: 250 gpm/Lpm

Well Data: Depth ______

Bore 12"

Pump Type gas engine driven sub

Level of water in bore ______

Type of piping steel

Artesian Head ______

Rock Data:

Type (surface) Qal

Color ______

Grain size ______

Megascopic Minerals ______

Alteration: ______

Rx Type (at depth) ______

Water used for irrigation

Immediate area used for: farming

Quality of sample: [✓ Exc], Good, Poor

Probable cause of manifestation well

Property owned by ?

Previous and/or Current Leases ______

Comments: sample taken

SKETCHES

TED 4-14

# AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ______ Sample No. X W90027 Date 6-21-75 Time 1545

Name: Wamel #2 Location: Co Hidalgo State N. Mexico

SE¼ NE¼ Sec. 14 T 26S R: 20W ; ______ Km/mi. ______ of ______

Lat.: ______ Long.: ______ Sampler: John Deymonez

Elevation: 4290 Quad. Table Top Mtn.

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 32

Ground Temp. °C ______

Air Temp. 31

Odor 0

Fluid Color 0

Fluid Taste v. mild NaCl mild sulfate

Bubbling 0

Boiling 0

Vegetation 0

Fluid issues from 1½" galvanized steel pipe at well head

Salt: Type ______

Quantity ______

Color ______

Form ______

Sinter: Type $CaCO_3$

Quantity minor

Color brown

Form amor

Discharge: 50 gpm/Lpm

Well Data: Depth ______

Bore 6"

Pump Type sub. elect.

Level of water in bore ______

Type of piping steel

Artesian Head ______

Rock Data:

Type (surface) Qal

Color ______

Grain size ______

Megascopic Minerals ______

Alteration: ______

Rx Type (at depth) ______

Water used for home

Immediate area used for: farming

Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by Rufus Wamel

Previous and/or Current Leases yes. "Some company in Denver" (LVO)?

Comments: sample collected

SKETCHES

JED 2-5

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. ____ Sample No. X W90039 Date 6-23-75 Time 1320

Name: Antelope WW
Elbrock Warm Well Location: Co. Hidalgo State N. Mexico

NW¼ SW¼ Sec. 26 T 27S R: 20W ; ____ Km/mi. ____ of ____

Lat.: ____ Long.: ____ Sampler: Frank Dellechaie

Elevation: 4424 Quad. Pratt

Sample Type: Spring (p), well (p), creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 27 Discharge: 500 [✓ gpm]/Lpm

Ground Temp. °C ____ Well Data: Depth 330

Air Temp. ____ Bore 12"

Odor 0 Pump Type electric

Fluid Color 0 Level of water in bore 150

Fluid Taste 0 Type of piping steel

Bubbling 0 Artesian Head no

Boiling 0 Rock Data:

Vegetation 0 Type (surface) Qal-Basalt

Fluid issues from steel pipe Color ____

Grain size ____

Megascopic Minerals ____

Salt: Type ____

Quantity ____

Color ____ Alteration: ____

Form ____ Rx Type (at depth) ____

Sinter: Type ____ Water used for irrigation

Quantity ____ Immediate area used for: ranching

Color ____

Form ____ Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by same. Edward Elbrock, P.O. Box 25, Animas, N. Mexico

Previous and/or Current Leases no

Comments: R2 F14

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. Sample No. X 90430 Date 1-26-75 Time 4:30

Name: Uiler Ranch Well Location: Co. Hidalgo State N. Mexico

NW¼ SW¼ Sec. 15 T 21S R: 19W ; Km/mi. of

Lat.: Long.: Sampler: Frank Dellechaie

Elevation: 4347 Quad. Candor Peak

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 27

Ground Temp. °C

Air Temp.

Odor 0

Fluid Color 0

Fluid Taste 0

Bubbling 0

Boiling 0

Vegetation 0

Fluid issues from steel pipe

Salt: Type

Quantity

Color

Form

Sinter: Type

Quantity

Color

Form

Discharge: 5 [✓ gpm]/Lpm

Well Data: Depth 300'?

Bore

Pump Type

Level of water in bore

Type of piping

Artesian Head

Rock Data:

Type (surface) valley fill

Color

Grain size

Megascopic Minerals

Alteration:

Rx Type (at depth)

Water used for domestic

Immediate area used for: ranching

Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by Uiler

Previous and/or Current Leases ?

Comments:

SKETCHES

AMAX GEOTHERMAL GEOCHEMICAL SAMPLE FORM

Spring No. Sample No. X 90442 Date 1-27-75 Time 1410

Name: Weatherby Warm Well Location: Co Hidalgo State N. Mexico

SW½ Sec. 7 T 26S R: 20W ; Km/mi. of

Lat.: Long.: Sampler: Frank Dellechaie

Elevation: 4240 Quad.

Sample Type: Spring (p), [✓ well (p)], creek, river, soil, salt, sinter, travertine, gas, rock, snow.

Description:

Water Temp. °C 22

Ground Temp. °C

Air Temp.

Odor 0

Fluid Color 0

Fluid Taste 0

Bubbling 0

Boiling 0

Vegetation 0

Fluid issues from steel pipe

Salt: Type

Quantity

Color

Form

Sinter: Type

Quantity

Color

Form

Discharge: 20 [✓ gpm]/Lpm

Well Data: Depth 300'

Bore 6"

Pump Type windmill @90'

Level of water in bore 90

Type of piping steel

Artesian Head no

Rock Data:

Type (surface) valley fill

Color

Grain size

Megascopic Minerals

Alteration:

Rx Type (at depth)

Water used for drinking-cattle

Immediate area used for: ranching

Quality of sample: [✓ Exc.], Good, Poor

Probable cause of manifestation well

Property owned by Weatherby

Previous and/or Current Leases LVO

Comments:

SKETCHES

measurements were made to 60m depths at four locations and 40m depth at a fifth location. Water samples were obtained from two locations. Water pH was 2.5-3.0 at all locations down to 60m depth. The temperature structure at depth in four of the locations was very similar, with 5.5°C average temperature at 60m and 5.9°C average temperature at 10m. The fif [illegible] ocation was approximately centered ov [illegible] one of yellowish discoloration, about 10 [illegible] diameter and easily observable from the caldera rim. A temperature of 5.65°C was measured at both 60m and 10m depth indicating mixing and upwelling of water. This zone was marked by the odor of $H_2S$ and by concentrations of sulfur at the water surface. Constant bubbling and frothing activity caused by escaping gases was observed in various other regions of the lake. Three glaciers which formed on the inside of the caldera walls after the 1912 eruption now extend down to the lake level in several locations. At least 42 annual layers were counted in an exposed headwall of the South Glacier.

V 24

### RECENT GLACIOLOGICAL AND VOLCANOLOGICAL STUDIES OF THE SUMMIT OF MT. WRANGELL, ALASKA

C. S. Benson
R. J. Motyka (both at: Geophysical Institute, University of Alaska, Fairbanks, Alaska 99701)

The geothermal heat flux has increased significantly at the 4000m summit of Mt. Wrangell (62°N; 144°W) since 1964. This has resulted in melting over $22 \times 10^6 m^3$ of ice from the North Crater of the summit caldera, an order of magnitude increase in the area of exposed rock, and a settling of the glacier surface of up to 160m. The average heat flux over the past decade has exceeded 1000 µcal $cm^{-2} sec^{-1}$ over the $5 \times 10^5 m^2$ area of the North Crater. Field work at the summit in August, 1975, included establishment of five ground control points for aerial photogrammetry, measurement of glacier flow and resurvey of the snow surface in the caldera and North Crater, measurement of temperatures and temperature gradients in exposed ash and sand, and two 4m glaciological pit studies with cores extending below 10m. Nearly continuous air temperature, wind, atmospheric pressure, and seismic data were obtained over a three-week period. Aerial photographs were taken on 2 [illegible] ust. Pronounced local variations in hea [illegible] were observed and temperatures of acti [illegible] maroles are at the water boiling point (86°C). A subsidence of 6-8m since 1965 of the caldera snow surface located .5km to the SW of the North Crater indicates that some thermal activity extends into the main caldera. Preliminary analysis of glacier flow data indicate an apparent increase in glacier velocity since 1965. Glaciological-volcanological studies at the summit began in 1961.

V 25

### THE RECOVERY OF CHEMICAL ENERGY FROM A DRY-ROCK GEOTHERMAL RESERVOIR

J. R. Morris
C. G. Sammis (both at: Dept. of Geosciences, The Pennsylvania State University, University Park, Pa. 16802)

This paper assesses the conditions under which the heat associated with hydrothermal reactions may be recovered from a dry rock geothermal reservoir. A finite element computer model of a two-dimensional fracture in a hot, dry rock geothermal reservoir was developed and tested. Simulated water circulation through the fracture at constant velocity extracted heat from the wall rock via conduction as well as from chemical processes.

Hydrothermal reactions occurring between water and a granitic source rock may be subdivided into two categories; dissolving reactions and alteration reactions. While we find that the quartz dissolving reaction has little or no direct effect on reservoir temperatures for any combination of flow and fracture parameters, hydrothermal alteration reactions can contribute significant chemical energy to a fractured system under conditions of small flow rate and large alteration velocities. Detailed studies of the time dependence of rock and water temperatures with and without alteration will be presented. Although permeability studies are beyond the scope of this paper, it appears that both types of hydrothermal reactions will have an important secondary effect on re [illegible] voir development through changing the perm [illegible] ty with time.

V 26

### DEEP RESISTIVITY MEASUREMENTS AT TWO KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs) IN NEW MEXICO

George R. Jiracek
Christian Smith
Geoffrey A. Dorn
Michael T. Gerety (all at: Dept. of Geology, University of New Mexico, Albuquerque, New Mexico 87131)

Resistivity surveys have been conducted at two KGRAs in the Basin and Range Province of southern New Mexico: Radium Springs in the Rio Grande Rift near Las Cruces and Lightning Dock in the Animas Valley near Lordsburg. In both areas the bipole-dipole reconnaissance technique identified regions of low apparent resistivity ($\lesssim 10$ ohm-m) bordered by narrow zones of distinctly higher resistivity (20-100 ohm-m). Some lows coincide with the locations of hot springs and wells while the high resistivity trends may indicate subsurface structural control of the thermal waters. In the Animas Valley a dipole-dipole survey through the hot wells revealed a conductive layer ($\lesssim 10$ ohm-m) at depth (dipole separation $\gtrsim 5$ km). Three apparent connections extend to the surface, one in the vicinity of hot wells where boiling temperatures are encountered at less than 30 m depth. Shallow resistivity soundings at both areas have been obtained from asymmetric Schlumberger and bipole-dipole equatorial electrode arrays. Resistivity data near the hot wells at the Lightning Dock KGRA suggest conduit-like ascension of thermal waters along buried faults or fractures. Interpretations are supported by additional geologic and other geophysical investigations including gravity and magnetics.

V 27

### GEOCHEMICAL STUDIES OF TWO GEOTHERMAL AREAS IN NEW MEXICO

Chandler A. Swanberg (Dept. Physics/Earth Sciences, New Mexico State University, Box 3D, Las Cruces, New Mexico 88003)

Nearly 200 chemical analyses have been completed on waters collected from a broad region including the Radium Springs KGRA in south central New Mexico and another 33 analyses have been completed on waters collected in the vicinity of the Lightning Dock KGRA in southwest New Mexico. The samples represent both thermal and non-thermal waters.

The Radium Springs KGRA lies near the north end of a prominent NNW geochemical trend which extends for 80 km from just west of the Franklin Mountains in the south to San Diego Mountain in the north. This geochemical trend is congruent with the Valley fault for the southern 2/3 of its extent and the trend also intersects Radium Springs, the hot wells at Las Alturas, and the Quaternary Travertine deposits near San Diego Mountain, the three most prominent occurrences of geothermal activity in the area. Both thermal and non-thermal waters within this geochemical trend are characterized by high Na-K-Ca and silica estimated temperatures and by unusually high concentrations of fluoride and boron relative to samples collected in other parts of the area. These data indicate that the Valley fault acts as a conduit for ascending geothermal fluids.

Chemical data for the Lightning Dock KGRA indicate a possible reservoir base temperature near 170°C, based on Na-K-Ca and silica data from 4 hot shallow wells, located near a small ($\sim$4 mgals) residual gravity closure. A random sampling of non-thermal wells throughout the Animas Valley generally yield low geochemical temperatures.

## SEAWATER AND BASALT INTERACTIONS

*Crystal Room (HI), Wednesday 0830h*

JIM BISCHOFF (U.S. Geological Survey, Menlo Park, California), Chairman

V 28 INVITED PAPER

### HYDROTHERMAL REACTION AT MID-OCEAN RIDGES: SOME IMPLICATIONS AND CONSTRAINTS

T. J. Wolery
N. H. Sleep (both at: Dept. of Geol. Sci., Northwestern University, Evanston, Ill. 60201)

The global rate of hydrothermal heat advection at mid-ocean ridges has been estimated at $\sim 40 \times 10^{18}$ cal/yr by a thermal balance model. If the mean exit temperature of fluid is 75-225°C, then its mass flow rate is $2-6 \times 10^{17}$ g/yr. Such rates would cycle the mass of the oceans in only 2-7 m.y. Thus, MOR hydrothermal circulation may be a significant mechanism (along with subduction and volcanism at convergent plate boundaries) for chemical transfer between exogenic (shallow) and endogenic (deep) portions of the earth. The flux of $SiO_2$ from ocean crust to oceans by this mechanism is estimated at $0.02-1.4 \times 10^{14}$ g/yr, assuming that quartz solubility is an approximate control on composition of the exiting fluid. Leaching of calcium from oceanic crust may explain the origin of $\sim 1200 \times 10^{20}$ g of excess sedimentary calcium, which would require an average flux of $34 \times 10^{12}$ g/yr over 3.5 b.y. Similarly, a magnesium transfer of $\sim 65 \times 10^{12}$ g/yr from oceans to oceanic crust appears necessary for an approximate oceanic balance for this element. Experimental data on basalt-sea water reaction and the global flow rate estimate combine to yield Ca and Mg fluxes which are about an order of magnitude larger than those required. It seems likely that much of this discrepancy is due to the low water:rock ratios used in the experiments (3:1 to 30:1, v/v), which, from the rate of sea-floor spreading and the global flow rate estimate, correspond to reaction of nearly the entire oceanic crust. If the average thickness of hydrothermally altered basalt is only 200 m, for example, then water:rock ratios of 300:1 to 1300:1 would be more realistic. Examination of possible fluxes of oxidants and reductants associated with MOR hydrothermal circulation plus information on the permeability of the oceanic crust gained during recent drilling also support the conclusion that only a small fraction of the oceanic crust can be hydrothermally altered.

V 29 INVITED PAPER

### BASALT-SEAWATER INTERACTIONS FROM 25°C-300°C AND FROM 1-500 BARS: AN EXPERIMENTAL STUDY

W. E. Seyfried, Jr. (Department of Geology, Stanford University, Stanford, California 94305)

J. L. Bischoff (United States Geological Survey, Menlo Park, California 94025)
F. W. Dickson (Department of Geology, Stanford University, Stanford, California 94305)
(Sponsor: J. G. Liou)

The interaction between seawater and basalt in a ratio of 10:1 has been carried out for time periods up to several months in large volume gold and teflon cells. The experimental system employed provides continuous and thorough agitation of the basalt in the seawater; and furthermore allows aqueous samples to be withdrawn from the reaction cells throughout the duration of the runs, while maintaining the system at the desired pressure and temperature. Results to date indicate that the direction and magnitude of chemical exchange between the seawater and the basalt is strongly temperature dependent. The basalt gives up Ca and Si at all temperatures studied; however, the direction of Mg exchange is masked due to the rapid precipitation of seawater Mg as Mg-smectite to a degree dependent upon the Si activity in solution. This removal of seawater Mg as $Mg(OH)_2$ initially creates acid conditions solubilizing Fe and Mn. With the eventual depletion of Mg in the seawater, hydrolysis continues and the pH rises, significantly limiting both Fe and Mn concentrations. Potassium is leached from the basalt at temperatures >200°C, while at lower temperatures the altered seawater either shows no change or a slight depletion in potassium with respect to its initial content. Sulfide is solubilized from the rock only significantly at the highest temperature studied (300°C) reaching a concentration of 17 ppm after five weeks of reaction; while sulfate, precipitating as anhydrite, was continuously removed from the system in all runs greater than 150°C. Increases in $\Sigma CO_2$ are observed at both 200-300°C due to the solubilization of interstitial $CO_2$ trapped in the rock.

*Geothermal Resources Council, TRANSACTIONS, Vol. 1 May 1977*

# A GEOLOGICAL AND HYDRO-GEOCHEMICAL STUDY OF THE ANIMAS GEOTHERMAL AREA, HIDALGO COUNTY, NEW MEXICO

Frank Dellechaie

AMAX EXPLORATION, INC., 4704 Harlan Street, Denver, CO 80212

## Abstract

The Animas Valley thermal area lies on the west pediment of the Pyramid Mountains. The Pyramids are composed of Cretaceous to Tertiary igneous rocks.

Two hot wells produce 101°C water at a depth of 20 meters. The wells seem to relate to a northerly trending fault having at least 500 meters displacement with the west block downthrown.

An elliptical heatflow anomaly extending about 3 km in length occurs in this area.

Thermal waters contain about 1200 mg/l of dissolved solids and low concentrations of Li, B, $NH_3$ and $H_2S$. Silica concentrations do not exceed 145 mg/l. Cations and anions occur as:

$SO_4 > Cl > HCO_3$ Na>Ca>K>Mg.

Last equilibrium with a volcanic suite of minerals and carbonates is evidenced. Geothermometers indicate subsurface temperatures of approximately 160°C.

Apparently the thermal waters are escaping rapidly from a deep (>4 km) reservoir along a conduit formed by fault intersections. Evidence of igneous heat is lacking.

## Geology

A geothermal anomaly occurs in the Animas Valley, Hidalgo County, southwestern New Mexico (Figure 1). The region is arid, sparsely settled and only locally supports irrigated agriculture.

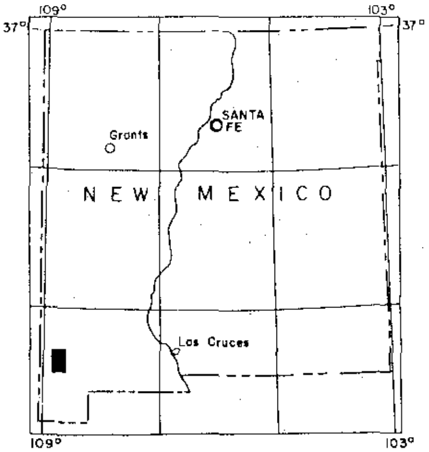

Figure 1. Location of the Animas geothermal area.

Six hot wells in T25S, R19W are the main indicators of geothermal potential. Two of the wells produce 101°C water from a zone of altered rhyolite at 20 meters depth. The thermal wells are on the pediment west of the Pyramid Mountains - a north trending range composed exclusively of Cretaceous to late Tertiary igneous rocks. The wells were drilled in the vicinity of a concealed range front fault with at least 500 meters displacement. This fault is evident on regional gravity maps (Figure 2) with sustaining evidence witnessed on imagery.

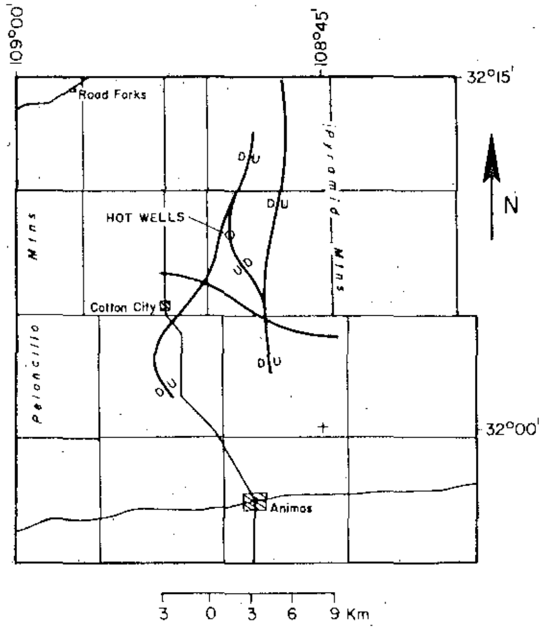

Figure 2. Concealed valley faults deduced from the regional gravity.

Additional evidence for the fault is supplied by a 2.25 km deep oil test some distance to the north (Summers, 1976). On the west side of the fault trace 500 meters of valley fill is encountered, while on the upthrown side, wells penetrate bedrock at less than 50 meters.

The Animas area is located in a region of crustal extension and thinning common to the Basin and Range province. The geologic history of the area consists of four main periods of volcanic activity and two main periods of intrusive activity. A thickness of about 600 meters of basalt was extruded during the lower Cretaceous.

A granodiorite stock was intruded into Cretaceous basalts during the early Tertiary when the mineral veins at the northern limit of the Pyramids were formed. A thickness of approximately 800 meters of andesite flows were erupted during early Tertiary times. These andesites were then intruded by a small monzonite stock. After a period of erosion, a thickness of 700 meters of rhyolite flows, tuffs, welded tuffs and basalt were erupted during the middle or late Tertiary. A second period of rhyolite eruption measuring about 200 meters in thickness occurred during middle-late Tertiary along with folding and high angle block faulting.

Lastly, quarternary basalts were erupted onto valley fill southwest of Cotton City. These obviously evidence sustained tectonism in the region but do not bear any visible relationship to the geothermal activity.

Heatflow

Heatflow determinations from 31 observation holes reveal a 3 km elliptical anomaly in the area of the hot wells. Well depths averaged less than 70 meters.

The resulting anomaly encloses values as high as 20 HFU. The shape and size of the anomaly seems consistent with a point source of hot water localized by a fault intersection. Dispersion is compatible with the northerly groundwater flow. The northern-most observation holes exhibit very high gradients at shallow depths but become isothermal at depth.

Seismic

The area is seismically inactive. Only one -1.0 magnitude earthquake was recorded during a 13 day microearthquake survey. Analysis of 130 mine blasts recorded during the survey failed to indicate any anomalous velocity structures.

Chemistry

Nonthermal waters of the area generally contain less than 400 mg/l of dissolved solids. Cations and anions occur as:

$HCO_3 > SO_4 > Cl \quad Na > Ca > Mg > K.$

Cold waters contain an average of 24 mg/l of silica, 1.5 mg/l of fluoride and exhibit neutral pH.

Thermal waters exhibit neutral to slightly basic pH. Cations and anions occur as:

$SO_4 > Cl > HCO_3 \quad Na > Ca > K > Mg.$

The low concentrations of chloride, boron, ammonia and lithium would indicate last equilibrium with a crystalline rock (Table 1). The high fluoride concentrations also point to equilibration with high fluoride igneous rocks. Mineral equilibrium computations (Kharaka 1973) indicate saturation with carbonates and several igneous minerals (Table 2).

Table 1. Chemical analyses of the thermal features from T25S, R19W. Units are mg/l unless otherwise noted.

| | Superheated Hot Well | McCants Hot Well | Folks Hot Well |
|---|---|---|---|
| pH | 7.8 | 8.1 | 7.0 |
| Cl | 112 | 84 | 130 |
| F | 15 | 12 | 7.8 |
| $HCO_3$ | 90 | 80 | 93 |
| $CO_3$ | 0 | 0 | 0 |
| $SO_4$ | 400 | 460 | 700 |
| $SiO_2$ | 145 | 130 | 99 |
| Na | 340 | 330 | 420 |
| K | 20 | 19 | 26 |
| Ca | 20 | 21 | 70 |
| Mg | 0.3 | 0.1 | 5.0 |
| Li | 0.5 | 0.5 | 0.8 |
| B | 0.4 | 0.3 | 0.2 |
| $NH_3$ | 0.12 | 0.12 | 0.20 |
| $H_2S$ | <0.2 | <0.2 | <0.2 |
| TDS | 1143 | 1137 | 1152 |
| T°C | 101 | 85 | 65 |
| Flow (gpm) | --- | 50 | 35 |
| $TSiO_2$°C | 159 | 152 | 137 |
| TNa/K°C | 129 | 133 | 134 |
| TNa-K-Ca°C | 165 | 165 | 160 |
| $Cl/SO_4$ | 0.8 | 0.5 | 0.5 |
| $Cl/HCO_3$ | 2.1 | 1.8 | 2.4 |
| Cl/F | 4.0 | 3.7 | 8.8 |

Table 2. Gibbs Free Energies in kcal/mole for McCants Hot Well

| | | |
|---|---|---|
| Carbonates | Calcite | 0.4 |
| | Aragonite | 0.3 |
| Silicates | Fayalite | 3.3 |
| | Kenyaite | 3.2 |
| | Magadite | 3.2 |
| | Quartz | 0.9 |
| | Chalcedony | 0.5 |
| | Cristobalite | 0.2 |

The hot wells are enriched in silica and chloride and depleted in bicarbonate relative to other thermal and nonthermal waters of the Animas area (Figure 3). The hot wells are, however, generally similar to the regional waters regarding other major elements. The silica and alkali geothermometers correlate well (Table 1) indicating subsurface temperatures of approximately 160°C. (Fournier and Trusdell, 1973; Fournier and Rowe, 1966).

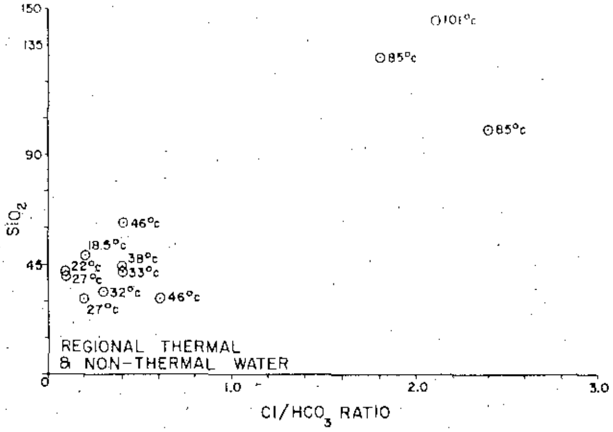

Figure 3. $SiO_2$ in mg/l versus the $Cl/HCO_3$ ratio for the waters of the Animas area.

## Discussion

Detailed mapping of the Pyramid and Central Peloncillo Mountains has not revealed any Pleistocene siliceous rocks. The probability of a recent intrusive event is thereby diminished. The area's aseismicity further demonstrates the lack of an active intrusive. The lack of seismicity may also be symptomatic of a lack of extensive fracture permeability. The heatflow observations suggest a focused point of hot water leakage, likely a fault intersection, which is being dispersed by a northerly underflow.

Geochemistry indicates that waters are heated in igneous and carbonate rocks. That is inferred by the low concentration of chloride, boron, lithium and ammonia and the very high concentrations of fluoride. Mineral equilibria studies also indicate that the waters are slightly saturated with carbonates.

Geothermometers show last equilibration at about 160°C. Waters would have to circulate to a depth of more than 4.0 kilometers in order to reach 160°C, assuming a regional gradient of 35°C per kilometer constant with depth.

Figure 4, a stratigraphic section compiled from Gillerman (1958) and the extensive work of the late R. A. Feller, is bisected by a high angle fault. The depth to which water may need to circulate in order to equilibrate with the lower Paleozoic and Precambriam rocks is approximately 4.0 kilometers. Although many explanations are possible, the conclusions to be drawn from existing geology, geophysics, and geochemistry implies that deep circulation of cold groundwater is the source of the thermal waters in the Animas area.

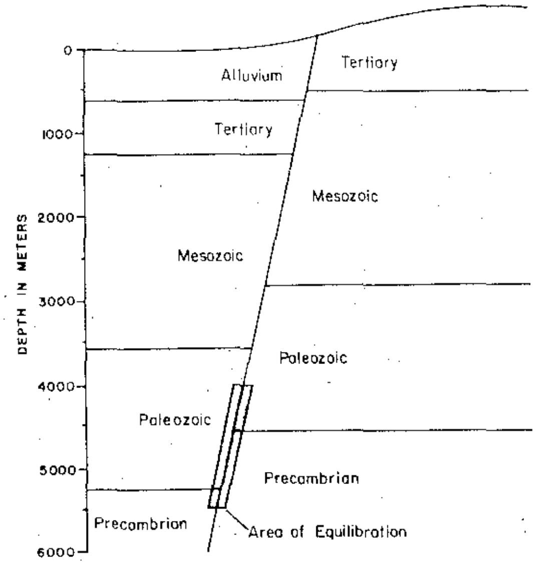

Figure 4. Stratigraphic section looking north in the vicinity of T25S, R19W.

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measurements were made to 60m depths at four locations and 40m depth at a fifth location. Water samples were obtained from two locations. Water pH was 2.5-3.0 at all locations down to 60m depth. The temperature structure at depth in four of the locations was very similar, with 5.5°C average temperature at 60m and 5.9°C average temperature at 10m. The [illegible] location was approximately centered [illegible] zone of yellowish discoloration, about 100m in diameter and easily observable from the caldera rim. A temperature of 5.65°C was measured at both 60m and 10m depth indicating mixing and upwelling of water. This zone was marked by the odor of $H_2S$ and by concentrations of sulfur at the water surface. Constant bubbling and frothing activity caused by escaping gases was observed in various other regions of the lake. Three glaciers which formed on the inside of the caldera walls after the 1912 eruption now extend down to the lake level in several locations. At least 42 annual layers were counted in an exposed headwall of the South Glacier.

V 24

### RECENT GLACIOLOGICAL AND VOLCANOLOGICAL STUDIES OF THE SUMMIT OF MT. WRANGELL, ALASKA

C. S. Benson
R. J. Motyka (both at: Geophysical Institute, University of Alaska, Fairbanks, Alaska 99701)

The geothermal heat flux has increased significantly at the 4000m summit of Mt. Wrangell (62°N; 144°W) since 1964. This has resulted in melting over $22 \times 10^6 m^3$ of ice from the North Crater of the summit caldera, an order of magnitude increase in the area of exposed rock, and a settling of the glacier surface of up to 160m. The average heat flux over the past decade has exceeded 1000 μcal $cm^{-2} sec^{-1}$ over the $5 \times 10^5 m^2$ area of the North Crater. Field work at the summit in August, 1975, included establishment of five ground control points for aerial photogrammetry, measurement of glacier flow and resurvey of the snow surface in the caldera and North Crater, measurement of temperatures and temperature gradients in exposed ash and sand, and two 4m glaciological pit studies with cores extending below 10m. Nearly continuous air temperature, wind, atmospheric pressure, and seismic data were obtained over a three-w[illegible]eriod. Aerial photographs were taken [illegible]ugust. Pronounced local variations in he[illegible]ux were observed and temperatures of active fumaroles are at the water boiling point (86°C). A subsidence of 6-8m since 1965 of the caldera snow surface located .5km to the SW of the North Crater indicates that some thermal activity extends into the main caldera. Preliminary analysis of glacier flow data indicate an apparent increase in glacier velocity since 1965. Glaciological-volcanological studies at the summit began in 1961.

V 25

### THE RECOVERY OF CHEMICAL ENERGY FROM A DRY-ROCK GEOTHERMAL RESERVOIR

J. R. Morris
C. G. Sammis (both at: Dept. of Geosciences, The Pennsylvania State University, University Park, Pa. 16802)

This paper assesses the conditions under which the heat associated with hydrothermal reactions may be recovered from a dry rock geothermal reservoir. A finite element computer model of a two-dimensional fracture in a hot, dry rock geothermal reservoir was developed and tested. Simulated water circulation through the fracture at constant velocity extracted heat from the wall rock via conduction as well as from chemical processes.

Hydrothermal reactions occurring between water and a granitic source rock may be subdivided into two categories; dissolving reactions and alteration reactions. While we find that the quartz dissolving reaction has little or no direct effect on reservoir temperatures for any combination of flow and fracture parameters, hydrothermal alteration reactions can contribute significant chemical energy to a fractured system under conditions of small flow rate and large alteration velocities. Detailed studies of the time dependence of rock and water temperatures with and without alteration will be presented. Although permeability studies are beyond the scope of this paper, it appears that both types of hydrothermal reactions will have an important secondary effect o[illegible]rvoir development through changing the p[illegible]lity with time.

V 26

### DEEP RESISTIVITY MEASUREMENTS AT TWO KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs) IN NEW MEXICO

George R. Jiracek
Christian Smith
Geoffrey A. Dorn
Michael T. Gerety (all at: Dept. of Geology, University of New Mexico, Albuquerque, New Mexico 87131)

Resistivity surveys have been conducted at two KGRAs in the Basin and Range Province of southern New Mexico: Radium Springs in the Rio Grande Rift near Las Cruces and Lightning Dock in the Animas Valley near Lordsburg. In both areas the bipole-dipole reconnaissance technique identified regions of low apparent resistivity (≲10 ohm-m) bordered by narrow zones of distinctly higher resistivity (20-100 ohm-m). Some lows coincide with the locations of hot springs and wells while the high resistivity trends may indicate subsurface structural control of the thermal waters. In the Animas Valley a dipole-dipole survey through the hot wells revealed a conductive layer (≲10 ohm-m) at depth (dipole separation ≳5 km). Three apparent connections extend to the surface, one in the vicinity of hot wells where boiling temperatures are encountered at less than 30 m depth. Shallow resistivity soundings at both areas have been obtained from asymmetric Schlumberger and bipole-dipole equatorial electrode arrays. Resistivity data near the hot wells at the Lightning Dock KGRA suggest conduit-like ascension of thermal waters along buried faults or fractures. Interpretations are supported by additional geologic and other geophysical investigations including gravity and magnetics.

V 27

### GEOCHEMICAL STUDIES OF TWO GEOTHERMAL AREAS IN NEW MEXICO

Chandler A. Swanberg (Dept. Physics/Earth Sciences, New Mexico State University, Box 3D, Las Cruces, New Mexico 88003)

Nearly 200 chemical analyses have been completed on waters collected from a broad region including the Radium Springs KGRA in south central New Mexico and another 33 analyses have been completed on waters collected in the vicinity of the Lightning Dock KGRA in southwest New Mexico. The samples represent both thermal and non-thermal waters.

The Radium Springs KGRA lies near the north end of a prominent NNW geochemical trend which extends for 80 km from just west of the Franklin Mountains in the south to San Diego Mountain in the north. This geochemical trend is congruent with the Valley fault for the southern 2/3 of its extent and the trend also intersects Radium Springs, the hot wells at Las Alturas, and the Quaternary Travertine deposits near San Diego Mountain, the three most prominent occurrences of geothermal activity in the area. Both thermal and non-thermal waters within this geochemical trend are characterized by high Na-K-Ca and silica estimated temperatures and by unusually high concentrations of fluoride and boron relative to samples collected in other parts of the area. These data indicate that the Valley fault acts as a conduit for ascending geothermal fluids.

Chemical data for the Lightning Dock KGRA indicate a possible reservoir base temperature near 170°C, based on Na-K-Ca and silica data from 4 hot shallow wells, located near a small (~4 mgals) residual gravity closure. A random sampling of non-thermal wells throughout the Animas Valley generally yield low geochemical temperatures.

## SEAWATER AND BASALT INTERACTIONS

*Crystal Room (HI), Wednesday 0830h*

JIM BISCHOFF (U.S. Geological Survey, Menlo Park, California), Chairman

V 28 INVITED PAPER

### HYDROTHERMAL REACTION AT MID-OCEAN RIDGES: SOME IMPLICATIONS AND CONSTRAINTS

T. J. Wolery
N. H. Sleep (both at: Dept. of Geol. Sci., Northwestern University, Evanston, Ill. 60201)

The global rate of hydrothermal heat advection at mid-ocean ridges has been estimated at $\sim 40 \times 10^{18}$ cal/yr by a thermal balance model. If the mean exit temperature of fluid is 75-225°C, then its mass flow rate is $2\text{-}6 \times 10^{17}$ g/yr. Such rates would cycle the mass of the oceans in only 2-7 m.y. Thus, MOR hydrothermal circulation may be a significant mechanism (along with subduction and volcanism at convergent plate boundaries) for chemical transfer between exogenic (shallow) and endogenic (deep) portions of the earth. The flux of $SiO_2$ from ocean crust to oceans by this mechanism is estimated at $0.02\text{-}1.4 \times 10^{14}$ g/yr, assuming that quartz solubility is an approximate control on composition of the exiting fluid. Leaching of calcium from oceanic crust may explain the origin of $\sim 1200 \times 10^{20}$ g of excess sedimentary calcium, which would require an average flux of $34 \times 10^{12}$ g/yr over 3.5 b.y. Similarly, a magnesium transfer of $\sim 65 \times 10^{12}$ g/yr from oceans to oceanic crust appears necessary for an approximate oceanic balance for this element. Experimental data on basalt-sea water reaction and the global flow rate estimate combine to yield Ca and Mg fluxes which are about an order of magnitude larger than those required. It seems likely that much of this discrepancy is due to the low water:rock ratios used in the experiments (3:1 to 30:1, v/v), which, from the rate of sea-floor spreading and the global flow rate estimate, correspond to reaction of nearly the entire oceanic crust. If the average thickness of hydrothermally altered basalt is only 200 m, for example, then water:rock ratios of 300:1 to 1300:1 would be more realistic. Examination of possible fluxes of oxidants and reductants associated with MOR hydrothermal circulation plus information on the permeability of the oceanic crust gained during recent drilling also support the conclusion that only a small fraction of the oceanic crust can be hydrothermally altered.

V 29 INVITED PAPER

### BASALT-SEAWATER INTERACTIONS FROM 25°C-300°C AND FROM 1-500 BARS: AN EXPERIMENTAL STUDY

W. E. Seyfried, Jr. (Department of Geology, Stanford University, Stanford, California 94305)

J. L. Bischoff (United States Geological Survey, Menlo Park, California 94025)
F. W. Dickson (Department of Geology, Stanford University, Stanford, California 94305)
(Sponsor: J. G. Liou)

The interaction between seawater and basalt in a ratio of 10:1 has been carried out for time periods up to several months in large volume gold and teflon cells. The experimental system employed provides continuous and thorough agitation of the basalt in the seawater; and furthermore allows aqueous samples to be withdrawn from the reaction cells throughout the duration of the runs, while maintaining the system at the desired pressure and temperature. Results to date indicate that the direction and magnitude of chemical exchange between the seawater and the basalt is strongly temperature dependent. The basalt gives up Ca and Si at all temperatures studied; however, the direction of Mg exchange is masked due to the rapid precipitation of seawater Mg as Mg-smectite to a degree dependent upon the Si activity in solution. This removal of seawater Mg as $Mg(OH)_2$ initially creates acid conditions solubilizing Fe and Mn. With the eventual depletion of Mg in the seawater, hydrolysis continues and the pH rises, significantly limiting both Fe and Mn concentrations. Potassium is leached from the basalt at temperatures > 200°C, while at lower temperatures the altered seawater either shows no change or a slight depletion in potassium with respect to its initial content. Sulfide is solubilized from the rock only significantly at the highest temperature studied (300°C) reaching a concentration of 17 ppm after five weeks of reaction; while sulfate, precipitating as anhydrite, was continuously removed from the system in all runs greater than 150°C. Increases in $\Sigma CO_2$ are observed at both 200-300°C due to the solubilization of interstitial $CO_2$ trapped in the rock.

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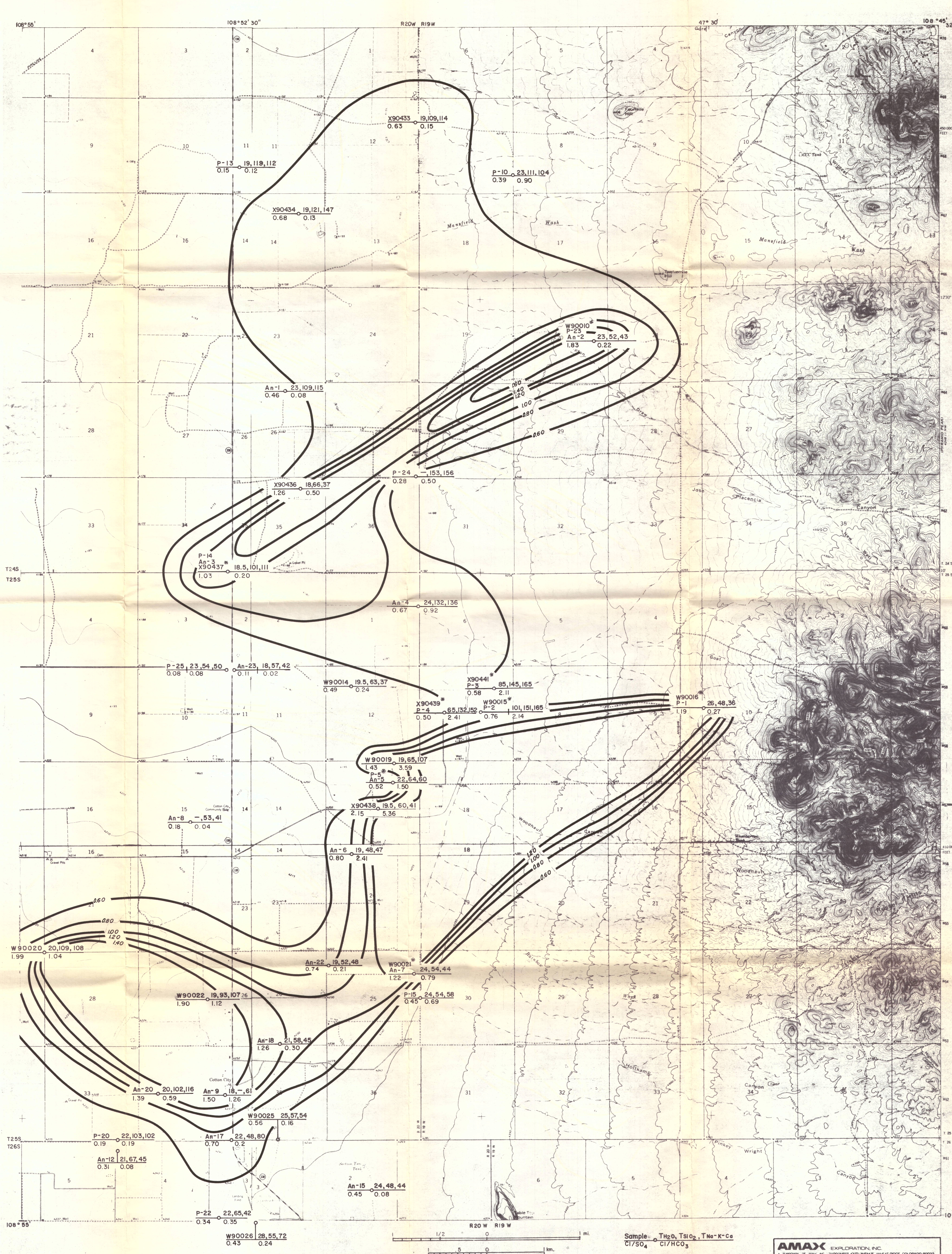

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$\frac{\text{Sample}}{\text{Cl/SO}_4} \circ \frac{T_{H_2O}, T_{SiO_2}, T_{Na-K-Ca}}{\text{Cl/HCO}_3}$

* Where multiple analyses exist for same well: indicates one used for map data.

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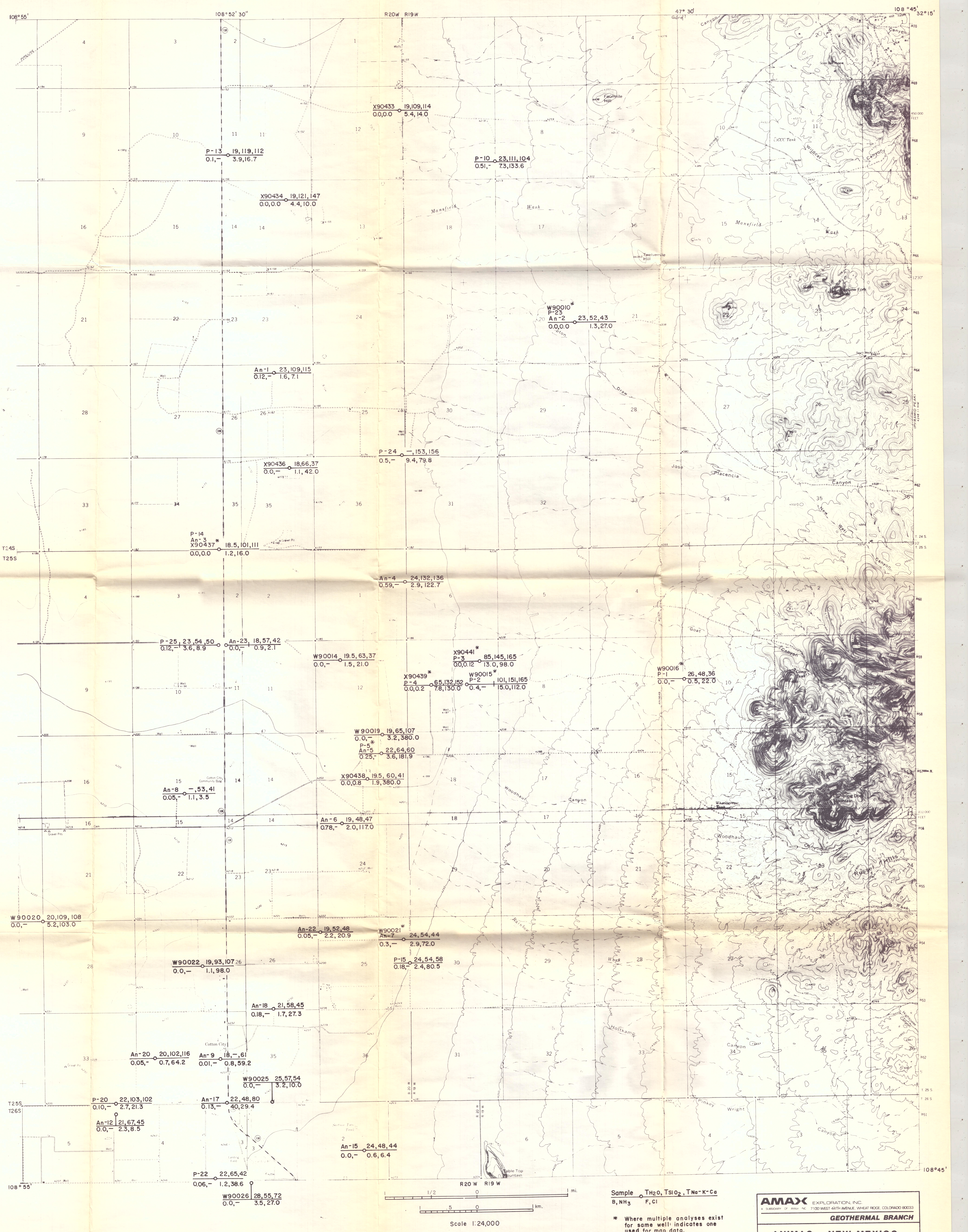
## ANIMAS - NEW MEXICO

Hydrogeochemical Map
$Cl/SO_4$ (MOLE) RATIO MAP

SOURCE: AMAX 1975, 1979, 1980 Logsdon 1981 M.S. Thesis



Sample $\frac{}{}$ $T_{H_2O}$, $T_{SiO_2}$, $T_{Na-K-Ca}$

B, $NH_3$ F, Cl

* Where multiple analyses exist for same well: indicates one used for map data.

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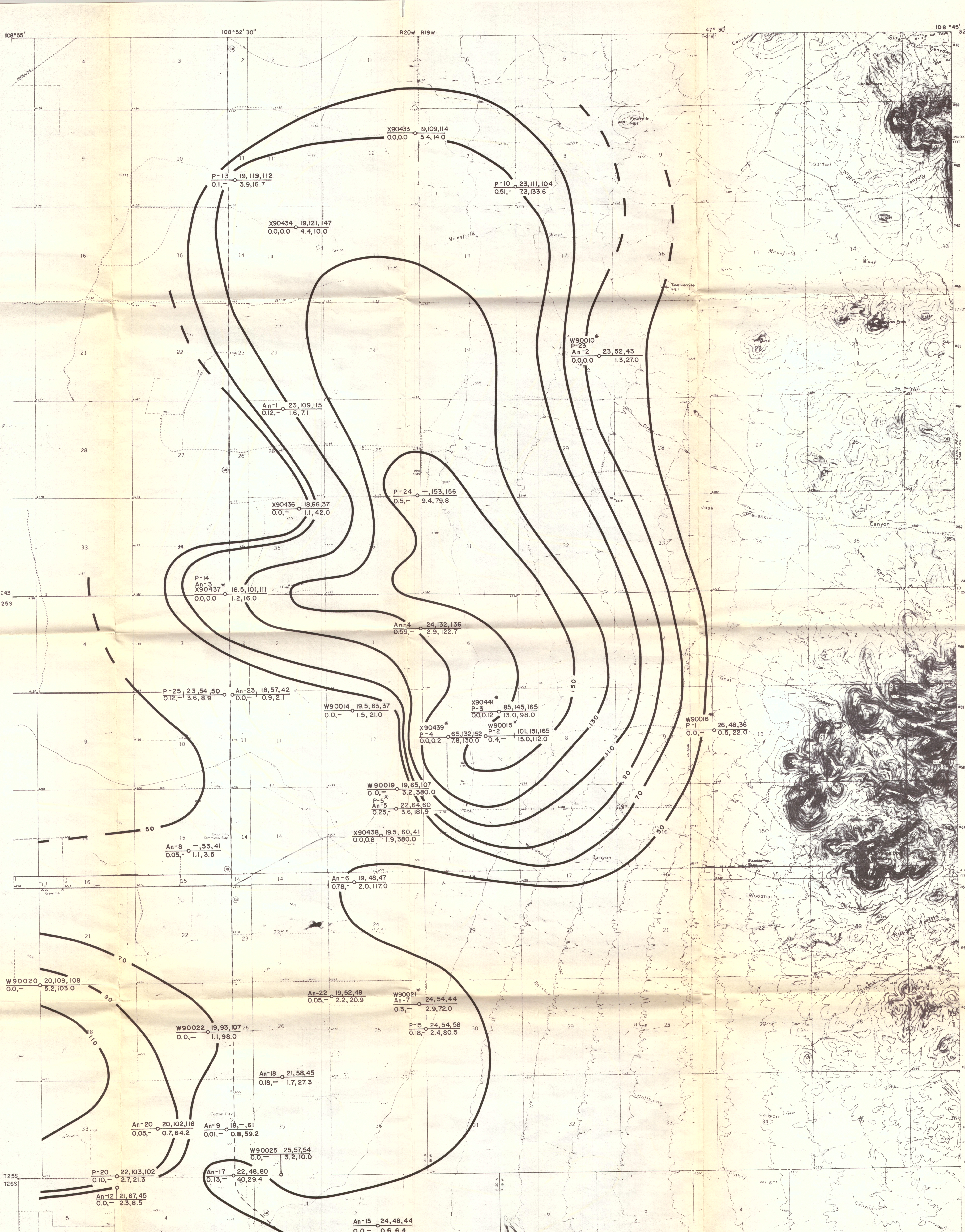
## ANIMAS - NEW MEXICO
Hydrogeochemical Map

SOURCE: AMAX 1975, 1979, 1980 Logsdon 1981 M.S. Thesis



1/2 0 1 mi.

5 0 1 km.

Scale 1:24,000

Sample $\underline{T_{H_2O}, T_{SiO_2}, T_{Na-K-Ca}}$

B, $NH_3$ F, Cl

* Where multiple analyses exist for same well: indicates one used for map data.

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## ANIMAS - NEW MEXICO

Hydrogeochemical Map

Map of Subsurface $SiO_2$ Temp.

SOURCE: AMAX 1977, 1979, 1980 LOGSDON 1981 M.S. Thesis