NP--2901208

DE82 901208

ASSESSMENT OF GEOTHERMAL RESERVOIRS BY
ANALYSIS OF GASES IN THERMAL WATERS

Final Report
(1/1/80 - 8/15/81)

Principal Investigator:

David L. Norman

Co-Author:

Carl A. Bernhardt

Department of Geoscience
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

The work from which this material is drawn was conducted with the support of the New Mexico Energy Research and Development Institute. However, the authors remain solely responsible for the content of this material.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Mow

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO.	2. PUBLICATION DATE	3. PERFORMING ORGAN. REPORT NO.
4. TITLE AND SUBTITLE Assessment of Geothermal Reservoirs by Analysis of Gases in Thermal Waters		5. CONTRACT NO. EMD# 68R-2305
6. AUTHOR(S) David I. Norman and Carl A. Bernhardt		7. TYPE OF REPORT & PERIOD COVERED Final Report, 1/1/80-8/15/81
8. PERFORMING ORGANIZATION NAME AND ADDRESS New Mexico Institute of Mining and Technology Department of Geoscience Socorro, New Mexico 87801		
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS New Mexico Energy Institute Box 3EI Las Cruces, NM 88003		
10. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) Gases were measured in fifty-one thermal wells and springs in New Mexico including sixteen wells in the Lightning Dock geothermal area. Correlation of gases with alkali geothermometry indicates CO ₂ and He increase in abundance with reservoir temperature while N ₂ , Ar, NO, Kr and CH ₄ show slight decreases. H ₂ S generally occurs in waters with reservoir temperatures >100°C however, H ₂ S is not present in all high temperature waters. Gas ratios, principally CO ₂ /N ₂ , CO ₂ /Ar, CO ₂ /CH ₄ , He/N ₂ and He/Ar correlate better with geothermometry than abundances of individual gases. This study indicates the gas data which could be used to identify waters from reservoirs of T>100°C are CO ₂ , CO ₂ /N ₂ , CO ₂ /Ar, CO ₂ /CH ₄ , He/N ₂ and He/Ar in well waters as well as CO ₂ , CO ₂ /CH ₄ , CO ₂ /N ₂ , and CO ₂ /Ar in spring waters. A geothermometer based on CO ₂ -CH ₄ ratio is proposed. Indications are that the CO ₂ /CH ₄ geothermometer works in temperature ranges of 50-300° and nearly as well as the other chemical geothermometer. Gases and gas ratios which correlate positively with reservoir temperature show a regular zonation pattern around the hot wells in the Lightning Dock geothermal area. This agrees with other studies which indicated that the hot wells are the point of upwelling thermal waters. It is concluded that gases in waters can be a valuable exploration tool to locate favorable sites for drilling in geothermal fields.		
11. KEY WORDS (6 to 12 entries; alphabetical order capitalize only the first letter of the first key word unless a proper name; separated by semicolons) Carbon dioxide; exploration; gas; geothermal; geothermometer; helium; methane; reservoir; resource; spring; thermal; water		
12. AVAILABILITY NOT AVAILABLE FOR EXTENSIVE DISTRIBUTION		
13. NUMBER OF PAGES	14. PRICE	

TABLE OF CONTENTS

	Page
List of Tables.	iv
List of Figures	v
Abstract.	vii
Acknowledgment.	ix
Introduction.	1
Experimental Design	1
Locations.	1
Sampling and Analytic Procedures	4
Results	4
Discussion.	6
Gases as Indicators of Thermal Waters.	6
CO ₂ /CH ₄ Geothermometers.	13
Influence of CO ₂ on the Na-K-Ca Geothermometer	19
Study of the Lightning Dock Geothermal District.	21
Use of Gases in Geothermal Exploration.	35
Regional Exploration	35
District Exploration	42
Summary and Conclusions	43
References.	45
Appendix I: Methods of Water Sample Collection and Analysis.	48
Appendix II: Method of Sample Collection and Analysis of Gases in Water.	49
Appendix III: Correlation Coefficients	59
Appendix IV: Data.	63
Appendix V: Gas Data and Gas Equilibria Calculations on Jemez Geothermal Wells and Springs	129

LIST OF TABLES

	Page
1. The CO_2/CH_4 geothermometer.	14
2. Comparison of reservoir temperatures for thermal well waters calculated using the quartz, Na-K, Na-K-Ca and CO_2/CH_4 geothermometers	17
3. Comparison of reservoir temperatures for thermal spring waters calculated using the quartz, Na-K, Na-K-Ca and CO_2/CH_4 geothermometers	18
4. Comparison of helium concentration and alkali geothermometry in well and spring waters from various geographical areas in New Mexico. 37	
5. Gases and gas ratios in well and spring waters which this study suggests are useful indicators of geothermal reservoirs	41

LIST OF FIGURES

	Page
1. Location of hot wells and springs sampled.	3
2. Relationship of CO ₂ , He, Kr, and Ar content of well waters with alkali geothermometry	7
3. Relationship of CO ₂ , He, Kr, and Ar content of spring waters with alkali geothermometry	8
4. Relationship of gas ratios in well waters with alkali geothermometry	9
5. Relationship of gas ratios in spring waters with alkali geothermometry	10
6. Relationship of log(CO ₂ /CH ₄) with temperature.	15
7. Comparison of the silica and Na-K-Ca geothermometers	16
8. The difference between temperatures calculated by the chalcedony and Na-K-Ca geothermometers vs. concentration of CO ₂ in the water. .	20
9. Paces (1975) disequilibrium index (I) vs. CO ₂ concentration.	20
10. Isopleths for B/Ca molar ratio (x 10) in shallow well waters	22
11. Isotherms drawn for the best estimate shallow reservoir temperatures	23
12. Map of kriged, steady-state head values (after Fig. 10, Hawkins, 1981)	24
13. Location of shallow wells sampled in the Animas Valley	25
14. Isopleths drawn for molar % CO ₂ in shallow well waters	26
15. Isopleths drawn for CO ₂ /N ₂ molar ratios in shallow well waters . . .	27
16. Isopleths drawn for CO ₂ /Ar molar ratios in shallow well waters . . .	28
17. Isopleths drawn for CO ₂ /CH ₄ molar ratios in shallow well waters. . .	29
18. Isopleths drawn for He concentration in cc(SPT)/liter H ₂ O (x 10 ⁴) in shallow well waters	30
19. Isopleths drawn for He/N ₂ molar ratios in shallow well waters. . . .	31
20. Isopleths drawn for He/Ar molar ratios in shallow well waters. . . .	32
21. Isopleths drawn for He/Ne molar ratios in shallow well waters. . . .	33

22. Hydrological-geothermal model of the Animas Valley (after Logsdon, 1981).	34
23. Mole percent CO ₂ of total dissolved gases versus T _{Na-K-Ca} in well and spring waters	39

ABSTRACT

Gases were measured in fifty-one thermal wells and springs in New Mexico including sixteen wells in the Lightning Dock geothermal area. Correlation of gases with alkali geothermometry indicates CO_2 and He increase in abundance with reservoir temperature while N_2 , CH_4 , Ar, NO, and Kr show slight decreases. Hydrogen sulfide generally occurs in waters with reservoir temperatures $>100^\circ\text{C}$, however, H_2S is not present in all waters from high temperature reservoirs. Gas ratios, principally CO_2/N_2 , CO_2/Ar , CO_2/CH_4 , He/N_2 , and He/Ar , correlate better with geothermometry than abundances of individual gases.

High levels of CO_2 and He in thermal waters have been reported by others. They are attributed to dissolution of rock by thermal waters and/or magmatic gases. It is suggested that the reason better correlations of gas ratios to reservoir temperature are observed than for individual gases is that gases are lost from thermal waters as they near the surface. Gas loss will affect the gas ratios less than the concentration of individual gases.

The study indicates the gases in well waters which could be used to identify waters from reservoirs which have temperatures greater than 100°C are CO_2 concentration, $\text{CO}_2/\Sigma\text{gases}$, CO_2/N_2 , CO_2/Ar , CO_2/CH_4 , He/N_2 , and He/Ar with those underlined the most useful. In spring waters CO_2/CH_4 would be a useful indicator gas ratio and $\text{CO}_2/\Sigma\text{gases}$, CO_2/N_2 , and CO_2/Ar could possibly be useful. Helium, widely used in the exploration for thermal waters, alone is not a good indicator of thermal waters in regional exploration because abundances of helium in thermal waters is greatly affected by other factors other than reservoir temperature.

A geothermometer based on the $\text{CO}_2\text{-CH}_4$ ratio is proposed. Indications are that the CO_2/CH_4 geothermometer works in the temperature range of $50\text{-}300^\circ\text{C}$ and

works nearly as well as the chemical geothermometers.

No effect on the Na-K-Ca geothermometer by CO_2 in waters of $T < 75^\circ\text{C}$, as suggested by Paces (1975), was determined.

Gases and gas ratios which correlate positively with reservoir temperatures show a regular zonation pattern around hot wells in the Lightning Dock geothermal area. Isopleth plots suggest a dispersion halo of hot waters northward from the hot wells. This agrees well with the model proposed by Landis and Logsdon (1980) and Logsdon (1981) who suggested hot wells are the point of upwelling thermal waters and thermal fluids then flow northward down the hydrological gradient mixing with near-surface waters. It is concluded that gases in waters can be a valuable exploration tool to locate favorable sites for drilling in geothermal fields.

ACKNOWLEDGEMENT

The analytic equipment for this study was provided in part by a grant from the Research Corporation - Atlantic Richfield Foundation.

We would like to thank the many individuals who gave us access to their property and cooperated with us in sampling their thermal wells and springs.

INTRODUCTION

The principal object of this study was to evaluate the potential of gases in thermal waters in exploration for geothermal resources. Several ideas in particular were to be tested. It was to be determined if any gas, group of gases, or gas ratios are indicators of high temperature waters. A geothermometer based on gas equilibria was to be tested. The principal application of these methods would be in regional exploration.

The usefulness of gas data in exploration on a local scale was also to be investigated. In particular, it was proposed that gas data might yield information concerning a geothermal hydrologic regime such as lateral flow of thermal waters; mixing of thermal water and surface water; or location of the main reservoir. Ideally, it was proposed, gas data could be used to bullseye a plume of thermal water.

Other objectives of the project were to provide an inventory of gases in thermal waters in New Mexico and to evaluate Paces' (1975) suggestion that CO_2 has an effect on Na-K-Ca geothermometer.

EXPERIMENTAL DESIGN

Locations

Fifty-one samples were collected (Fig. 1). Thirty-five samples were from thermal springs and wells throughout the state. Site selection was based on published occurrences of thermal waters and in consultation with others who had worked on thermal waters in the State including Dr. Chandler A. Swanberg, New Mexico State University, Las Cruces, and Dr. George R. Jiracek, San Diego State University, California.

Sixteen samples were collected at the Lightning Dock geothermal area near Lordsburg, NM to test the use of gas data to locate principal geothermal

FIGURE 1. Location of hot wells and springs sampled:

1. Mamby Hot Spring
2. Ponce de Leon Hot Spring
3. Statue Spring
4. Ojo Caliente
5. San Antonio Hot Spring
6. Spence Hot Spring
7. Soda Dam Spring
8. Jemez Hot Spring
9. San Ysidro Spring
10. Kaseman Well #2 (Warm Springs)
11. Montezuma Hot Springs
12. Blue Canyon Well
13. Socorro Spring
- 14-16. Bosque del Apache - Wells #9, 13, 20
- 17-19. Truth or Consequences - Yucca Bath, Sierra Grande, Artesian Bath
- 20-21. Radium Springs - Bath House, Well #2
- 22-23. Las Alturas Estates - Geothermal Well #1 and Presidents Well
24. Hillsboro Warm Spring
25. Mimbres Hot Spring
26. Faywood Hot Spring
27. Kennecott Warm Spring Well #3
28. Riverside Well
29. Cliff Well
- 30-32. Gila Hot Springs
33. Middle Fork Gila Hot Spring
34. Lower Frisco Hot Spring
35. Upper Frisco Hot Spring
- 36-51. Lightning Dock

Figure 1.

reservoirs. The Lightning Dock geothermal area was chosen for a more intensive study area because there were many available sampling sites and most important, several studies (Landis and Logsdon, 1980; Logsdon, 1981) indicated an area of high temperature water and a wide spread zone of mixing of thermal and near surface waters.

Sampling and Analytic Procedures

Appendices I and II detail sampling and analytic procedures. At each sample site a 33 ml sample was collected for gas analysis; two samples were collected for chemical geothermometry; the pH was recorded; and the water temperature was measured. Samples for gas analysis were analysed within a few days after collection. In the interim they were kept chilled.

Gases were measured by mass spectrometry. The analytic procedures used could measure gases to 0.1 ppb (dissolved in water). The system was calibrated for the following gases: H_2 , CO_2 , CO , COS , N_2 , NH_3 , NO , N_2O , NO_2 , H_2S , SO_2 , Cl_2 , F_2 , He , Ne , Ar , Kr , CH_4 , C_2H_6 , C_3H_8 , and C_6H_{12} . Because of the problem in differentiating the various nitrogen oxides with the mass spectrometer, all nitrogen oxides are reported as NO . The mass spectrometer could have been calibrated for other gases if they had been observed.

Water samples were analysed for Na , K , Ca , Li , and SiO_2 .

RESULTS

Virtually all waters had measurable amounts of N_2 , O_2 , CO_2 , CH_4 , He , Ne , NO , Ar , and Kr . Less commonly occurring in thermal well and spring waters are NH_3 , H_2S , SO_2 , and H_2 . Xenon was detected in most waters but its concentration was too low to measure with the analytical procedures used. Small amounts of organic gases other than CH_4 were detected, principally in spring waters.

These organic gases generally were at the detection limit of ~ 0.1 ppb. Benzene in particular was looked for and not detected. Gas data are in Appendix IV.

Air contamination of the samples was a problem which could not be circumvented by sampling procedures. This contamination was of several types. In some wells air leaked in the discharge pipe and the waters were aerated by the turbine pump. Spring waters were, of course, in contact with the atmosphere. Even in springs which had a fairly rapid discharge, turbulence in the waters made collection of pristine spring water problematical. Air contamination was determined by estimating excess N_2 . This was assumed to be the N_2 greater than that soluble in water at $20^\circ C$. Excess N_2 and the other atmospheric gases in their atmospheric ratios to N_2 , were subtracted from the analysis.

In spring waters this is not easily done. It is not known if equilibrium between the various atmospheric gases and those in solution was attained. Also spring waters may contain variable amounts of shallow groundwater containing oxygen. The data in Appendix IV are given for all samples uncorrected for atmospheric contamination. For selected wells, atmospheric corrections were made to the analyses. The corrected analysis for a well is found on the page immediately following the uncorrected analysis in Appendix IV.

Contamination by atmospheric gases is not considered to be serious for analyses of reduced gas species. Samples were kept chilled and analyses were made within a day or two after collection, at most, in order to minimize oxidation of reduced gas species. In waters which H_2S could be smelled during sampling (the human nose is a very sensitive detector of H_2S), H_2S was always measured. Methane and ammonia are much slower to react with O_2 than H_2S , hence they should have been little affected by oxidation before analysis.

DISCUSSION

Gases as Indicators of Thermal Waters

One of the principal objectives of this study was to determine if any gas or groups of gases were indicators of geothermal reservoirs. To determine this gas data were compared to subsurface water temperatures determined by chemical geothermometry. Correctly the gas data should have been compared with actual deep water temperatures, however, actual reservoir temperatures were not known in virtually all sites sampled.

Correlation coefficients were calculated between gas data and the various chemical geothermometers (Appendix III). The supposition was that if any gas was to be of value in indicating hot waters it should show a positive correlation with geothermometry even though the chemical geothermometers might error in their prediction of subsurface temperature.

Correlation coefficients were calculated separately for well and spring data as well as for the data as a whole. This was done because gases in spring waters have been more effected by atmospheric contamination and near-surface efferescence. It is considered that gas analyses of well waters more accurately approximates the gas content of subsurface waters.

In well waters, CO_2 and He show the highest positive correlation with geothermometry (Fig. 2). Argon, Kr, N_2 , and CH_4 have significant negative correlations with Na-K-Ca geothermometry (Fig. 2). The same correlations are evident, for the most part, in gases in thermal spring waters (Fig. 4), although the correlations are not nearly as pronounced.

The strongest correlations with geothermometry occur with gas ratios CO_2/N_2 , CO_2/CH_4 , CO_2/Ar , He/Ar , and He/N_2 in well waters (Fig. 4). Similarly, the same gas ratios in spring waters show correlations with geothermometry, however;

Figure 2. Relationship of N_2 , Ar, He, Kr, CO_2 and CH_4 content of well water with alkali geothermometry. The correlation coefficients (r) indicated were calculated for a linear relation between gas concentration and TNa-K-Ca. However, some gases are plotted on a logarithmic scale because of the large range in the data.

Figure 3. Relationship of N₂, Ar, He, Kr, CO₂ and CH₄ content of spring water with alkali geothermometry. The correlation coefficients (r) indicated were calculated for a linear relation between gas concentration and T_{Na-K-Ca}. However, some gases are plotted on a logarithmic scale because of the large range in the data.

Figure 4. Relationship between gas ratios in well waters and $T_{\text{Na-K-Ca}}$. The correlation coefficients (r) indicated were calculated for a linear relationship between gases and $T_{\text{Na-K-Ca}}$. Because of the large variation in gas ratios, the data are plotted on a logarithmic scale.

Figure 5. Relationship between gas ratios in spring waters and $T_{\text{Na-K-Ca}}$. The correlation coefficients (r) indicated were calculated for a linear relationship between gases and $T_{\text{Na-K-Ca}}$. Because of the large variation in gas ratios, the data are plotted on a logarithmic scale.

the correlations are not nearly as good (Fig. 5).

The high amounts of CO_2 and He and low amounts of rare gases (other than He) in thermal waters is in agreement with the reports of others (Giggenbach, 1980; Roberts et al., 1975; Mazor, 1977). High amounts of He and CO_2 in thermal waters can be attributed to dissolution and alteration of rock by high temperature waters. However, the measurement of high $^3\text{He}/^4\text{He}$ in thermal well waters (Gutsalo, 1975; Welhan et al., 1979) suggests that a significant portion of the volatiles in geothermal waters can be from a magmatic source.

Mazor (1977) attributes decreasing abundance of the heavy rare gases in thermal waters with reservoir temperatures to boiling. His data indicate that rare gases occur at the levels of meteoric water in low temperature thermal waters. Since the rare gases cannot chemically react with rock, he postulates that the decreasing abundance of rare gases with temperatures he observed can most easily be explained by subsurface loss of volatiles by boiling. An alternative explanation is that decreased solubility of rare gases with temperature results in depletion of rare gases when meteoric water (originally saturated with rare gases) is heated.

The rare gas data are in general agreement with Mazor's observations. Low temperature waters have concentrations of Ar, Ne, and Kr at levels of surface waters. Rare gases from higher temperature sources show a general decrease in concentration with temperature.

Nitrogen acts in an analogous manner to the heavy rare gases. In waters from low temperature sources, nitrogen concentration is the same as the nitrogen concentration in surface waters. In higher temperature waters, the amount of nitrogen gas is a little less than found in surface waters and the concentration shows a decrease with increasing reservoir temperature. The CH_4 data follow the pattern of N_2 and the heavy rare gases. However, there is an important distinction. The baseline level of methane is many orders of magnitude greater

than in water in gaseous equilibrium with the atmosphere. Methane has to be acquired by ground waters from rocks and soils. The similarity of the methane data to that of N_2 and the heavy rare gases (Fig. 2) suggests that methane is acquired near the surface and that methane is from that time conserved in geothermal waters.

Several waters had much higher concentrations of CH_4 than the majority of samples. The source of this methane could be from deep hydrocarbon sources or perhaps from organic processes in soils. Because of the multiple and enigmatic sources of methane, it is to be expected that methane data should show considerable scatter.

The gas ratios CO_2/Ar , CO_2/N_2 , He/Ar , and He/N_2 correlate better with geothermometry than concentrations of CO_2 and He alone, may be explained by the normalizing effect of Ar and N_2 . Both Ar and N_2 gases are essentially conserved in thermal waters and the concentration of these gases should remain constant unless boiling has occurred. Boiling will greatly affect concentrations of individual gases, hence, it will diminish any relation between CO_2 - He and reservoir temperature. Since Ar - N_2 will also be lost from thermal waters during boiling, and because Ar - N_2 levels are relatively constant in thermal waters, dividing CO_2 - He concentrations by Ar - N_2 should minimize the effects of boiling on the CO_2 -temperature and He -temperature relationships.

The good correlation of CO_2/CH_4 with temperature cannot be so easily explained. Methane can be derived from inorganic oxidation-reduction reactions evolving CO_2 , from biologic processes, magmatic sources, and degradation of organic compounds (especially at high temperature). Isotopic studies have not given any definite answer to the source of CH_4 in thermal waters (Truesdell and Nehring, 1978, 1979; Panichi and Tongiorgi, 1976; Gunter and Musgrave, 1971). If CH_4 is acquired from organic material near the surface and henceforth acts as a conserved gas, then the CO_2 - CH_4 ratio is just an analog to CO_2/Ar

and CO_2/N_2 . However, CO_2/CH_4 may reflect equilibrium between $\text{CO}_2\text{-CH}_4\text{-H}_2\text{O}$ or $\text{CO}_2\text{-CH}_4\text{-H}_2\text{O-rock}$.

CO_2/CH_4 Geothermometer

The $\text{CO}_2\text{-CH}_4$ ratio varies exponentially with geothermometry. This exponential relationship may represent equilibria between CO_2 and CH_4 as in the expression

or may represent a more complicated chemical relation between CO_2 and rock. In either case, two simple expressions can be fit to the data to give an empirical relationship between CO_2/CH_4 and temperatures;

$$(1) \quad \log_{10} \left(\frac{\text{CO}_2}{\text{CH}_4} \right) = A + BT$$

$$(2) \quad \log_{10} \left(\frac{\text{CO}_2}{\text{CH}_4} \right) = A - \frac{B}{T}$$

This was done (Table 1) using $T_{\text{Na-K-Ca}}$ temperatures and $\text{CO}_2\text{-CH}_4$ data from well samples plus gas data released from Union Oil Company's geothermal wells in the Jemez Mountains (Appendix V). Expression (1) fits the data a bit better and therefore is preferred (Fig. 6).

Evaluating the accuracy of the CO_2/CH_4 relation to predict subsurface temperatures is difficult because source temperatures are not known for any of the sample sites. However, a number of lines of evidence suggest the CO_2/CH_4 relationship may be a useful geothermometer. Reservoir temperatures calculated using the CO_2/CH_4 empirical relationship compare favorably to temperatures calculated using the alkali and silica geothermometers (Tables 2 and 3). The silica geothermometer is considered to be a valuable tool in estimating source temperature, however; agreement between the silica and alkali

TABLE 1. The CO₂/CH₄ geothermometer.

Expression	(1) $\log_{10} \left(\frac{\text{CO}_2}{\text{CH}_4} \right) = A + BT$ T in °C, CO ₂ /CH ₄ molar ratio	(2) $\log_{10} \left(\frac{\text{CO}_2}{\text{CH}_4} \right) = A - \frac{B}{T}$ T in °K, CO ₂ /CH ₄ molar ratio
Constants	A = 0.237 B = 0.012	A = 7.36 B = 2110
Correlation coefficient between expression and data	r = 0.90	r = 0.87

Figure 6. Variation of CO_2/CH_4 with temperature;

- a) $\text{Log}_{10} (\text{CO}_2/\text{CH}_4)$ is plotted versus T . The line is the empirical geothermometer expression (1), $\log(\text{CO}_2/\text{CH}_4) = A + BT$.
- b) $\text{Log}_{10} (\text{CO}_2/\text{CH}_4)$ is plotted versus $1/T$. The line is the empirical geothermometer expression (2), $\log(\text{CO}_2/\text{CH}_4) = A - B/T$.

The data are from analysis of wells in this study plus data from the Jemez wells (Appendix V).

Figure 7. Comparison of the silica and Na-K-Ca geothermometers using data from this study. Circles are well data, triangles are spring data.

TABLE 2. Comparison of calculated reservoir temperatures for thermal well waters using the quartz, chalcedony, Na-K, Na-K-Ca, and CO_2/CH_4 (eqn. (1)) geothermometers. All temperatures are in $^{\circ}\text{C}$.

Sample No.	Location	T_Q	T_{ch}	T_{Na-k}	$T_{Na-K-Ca}$	$T_{\text{CO}_2/\text{CH}_4}$
12	Blue Canyon Well	73	42	159	49	39
14	Bosque Del Apache #9	92	61	176	58	112
15	Bosque Del Apache #20	94	63	158	68	-
16	Bosque Del Apache #13	116	87	146	144	110
18	Sierra Grande	95	64	193	176	111
19	Artesian Bath	93	63	194	176	120
20	Radium Springs	113	84	260	232	192
21	Radium Springs	114	85	257	226	220
22a	NMSU Well #1	120	92	247	202	238
22b	NMSU Well #1	-	-	-	-	226
23a	NMSU Pres. Well	119	90	234	194	207
23b	NMSU Golf Course	102	72	80	88	190
27	Warm Spring Well #3	102	72	208	48	138
28	Riverside	90	59	87	48	73
29	Telephone Co.-Gila	96	65	40	62	-5
30	Gila H.S.	119	90	126	48	67
32	Gila H.S.	119	90	121	85	47
36	Animas Valley	108	78	164	55	15
37	Animas Valley	133	106	164	149	161
38	Animas Valley	94	63	132	37	85
39	Animas Valley	89	58	138	44	49
40	Animas Valley	140	114	190	170	290
41	Animas Valley	95	63	131	67	70
42	Animas Valley	89	59	109	53	26
43	Animas Valley	89	59	128	45	48
44	Animas Valley	81	49	149	56	60
45	Animas Valley	88	58	128	40	78
46	Animas Valley	97	66	84	40	32
47	Animas Valley	89	58	161	74	4
48	Animas Valley	80	49	144	76	59
49	Animas Valley	96	66	123	42	13
50	Animas Valley	88	57	105	43	73
51	Animas Valley	83	52	114	42	-7
*	Baca #4	189	169	296	296	288
*	Baca #11	283	283	312	298	296
*	Baca #11	298	303	302	296	313
*	Baca #13	292	295	279	289	314
*	Baca #13	292	295	279	289	349

* Data in Appendix V.

TABLE 3. Comparison of calculated reservoir temperatures for thermal spring waters using the quartz, chalcedony, Na-K, Na-K-Ca, and CO_2/CH_4 (eqn. (1)) geothermometers. All temperatures are in $^{\circ}\text{C}$.

Sample No.	Location	T_Q	T_{ch}	T_{Na-K}	$T_{Na-K-Ca}$	$T_{\text{CO}_2/\text{CH}_4}$
1	Mamby Hot Spring	108	79	175	92	12
2	Ponce de Leon Spring	101	74	129	74	73
3	Statue Spring	66	34	205	80	58
4	Ojo Caliente	114	86	153	161	205
5	San Antonio Hot Spring	118	97	196	58	2
6	Spence Spring	119	89	118	39	7
7a	Soda Dam Spring	80	48	112	152	92
7b	Soda Dam Spring	-	-	-	-	113
8	Jemez Hot Spring	132	105	250	212	232
9	San Ysidro Spring	60	28	158	157	346
10	Kaseman Well #2	90	60	137	152	188
11	Montezuma Hot Spring	116	88	134	131	-116
13	Socorro Spring	88	57	152	55	-
17	Yucca Bath Spring	93	62	205	180	141
24	Hillsboro Warm Spring	155	130	193	173	85
25	Mimbres Spring	107	77	82	78	116
26	Faywood Spring	92	62	197	71	123
31	Gila H.S.	117	88	122	76	13
33	M. Fork Gila	120	92	118	77	97
34	L. Frisco Spring	125	97	174	154	35
35	U. Frisco Spring	101	71	34	46	35
*	Sulfur Spring	186	166	301	230	230

*Data in Appendix V.

geothermometers is much worse than agreement between the CO_2/CH_4 and alkali geothermometers (Figs. 6 and 7).

If the CO_2/CH_4 geothermometer is valid it must be based on some regular chemical-thermodynamic relationship or equilibria. Gas equilibria, including $\text{CO}_2\text{-CH}_4$, can be demonstrated for high temperature waters (Appendix V; Giggenbach, 1980; Truesdell and Nehring, 1978/79). In order to demonstrate gas equilibria it is necessary to have data for two reduced gas species as in the expression

Since H_2 and H_2S were measured in but a few samples, and CO was not measured in any samples, it is impossible from the results of this work to prove gas equilibria. However, the indications that gas equilibria do occur strengthens the contention that the $\text{CO}_2\text{-CH}_4$ empirical relation represents some regular chemical-thermodynamic relation with temperature.

Influence of CO_2 on the Na-K-Ca Geothermometer

Based on studies of thermal waters in granite terrains, Paces (1975) suggested that high pressures of CO_2 result in erroneously high temperature indication by the Na-K-Ca geothermometer for low temperature waters ($T < 75^\circ\text{C}$). Goff and Donnelly (1978), however, reported no influence on the Na-K-Ca geothermometer by CO_2 in the Clear Lake geothermal region, California, where samples came from several rock terrains.

No evidence to the effect of CO_2 on Na-K-Ca geothermometer could be found from data collected in this study (Fig. 8). However, if the gas data are plotted as Paces did, a relationship between the disequilibrium index (basically the difference between the discharge temperature of thermal waters and $T_{\text{Na-K-Ca}}$) and CO_2 concentration is apparent (Fig. 9). This simply reflects the correlation between CO_2 and $T_{\text{Na-K-Ca}}$ previously discussed. The correlation of He and the various

Figure 8. The difference between the temperatures calculated by the Na-K-Ca and chalcedony geothermometer. If the high concentration of CO_2 has an effect on the Na-K-Ca geothermometer as Paces (1975) proposed, there should be some apparent relation between $(T_{\text{Na-K-Ca}} - T_{\text{ch}})$ and CO_2 concentration.

Circles are well data and triangles are spring data.

Figure 9. Paces (1975) disequilibrium index (I) vs. CO_2 concentration. The negative trend of the data is similar to Paces (1975) Fig. 2.

$$I = \log(\text{Na}^+/\text{K}^+) + \beta \log(\text{Ca}^{+2}/\text{Na}^+) + 2.21 - \frac{1.64}{10^3 T_m(^{\circ}\text{K})}$$

Simply $I = \frac{1}{T_{\text{Na-K-Ca}}} - \frac{1}{T_m}$ where T_m is the measured discharge temperature.

Open circles are well data and triangles are spring data.

gas ratios, as well as CO_2 , with $T_{\text{Na-K-Ca}}$, strongly suggest that high concentration of CO_2 is indicative of high reservoir temperature, not as Paces suggests that $T_{\text{Na-K-Ca}}$ is an artifact of high CO_2 pressures.

Study of the Lightning Dock Geothermal System

The Lightning Dock geothermal area in the Animas Valley near Lordsburg is recognized as one of the potential geothermal resource areas in New Mexico (White and Williams, 1975). The Lightning Dock area has been studied by a variety of geophysical, geochemical and geological studies (Jiracek and Smith, 1976; Smith, 1978; Deal et al., 1978; Landis and Logsdon, 1979; Logsdon, 1981; Elston and Deal, 1981; and Hawkins, 1981). Discharge temperatures reach 96°C . Alkali and silica geothermometers indicate subsurface reservoir temperatures of approximately 165° . A 250°C reservoir temperature is predicted by Logsdon (1981).

Studies of trace elements, stable isotopes and geothermometry of well waters in the Lightning Dock area indicate that they show a regular zonation around the hottest wells with a large dispersion in values northward (see Figs. 10 and 11 as examples). This is remarkable because with the exception of the few hot wells ($T = 85^\circ$) the temperatures of the waters sampled were non-thermal with temperatures of 16 to 26°C . On the basis of geophysical and hydrological evidence as well as the chemical studies of Landis and Logsdon (1980), Logsdon (1981) suggested a hydrological model for the Lightning Dock geothermal system (Fig. 22). A subsequent study of the ground water hydrology (Fig. 12) lends further support to Logsdon's model.

Sixteen wells were sampled (Fig. 13). Isopleth diagrams were drawn for the gas ratios and gases which showed a strong correlation with geothermometry (Figs. 14-21). The gas isopleth diagrams all agree remarkably well with one

Figure 10. Isopleth diagram for B/Ca molar ratio ($\times 10^3$) in shallow well waters after Logsdon (1981). Isopleths drawn from data on 37 wells. The sixteen wells sampled for gas analysis are shown for reference.

Figure 11 Isotherms drawn for the best estimate shallow reservoir temperatures, after Logsdon (1981). The sixteen wells sampled for gas analysis are shown for reference. Isotherms based on data from 37 wells.

Figure 12. Map of kriged, steady-state head values (after Fig. 10, Hawkins, 1981).

Figure 13. Location of shallow wells sampled in the Animas Valley.

Figure 14. Isopleths drawn for molar % CO₂ in shallow well-waters.

Figure 15. Isopleths drawn for CO_2/N_2 molar ratios in shallow well-waters.

Figure 16.. Isopleths drawn for CO_2/Ar molar ratios in shallow well-waters.

Figure 17. Isopleths drawn for CO_2/CH_4 molar ratios in shallow well-waters.

Figure 18. Isopleths drawn for He concentration in cc(STP)/liter H_2O ($\times 10^4$) in shallow well-waters.

Figure 19 . Isopleths drawn for He/N_2 molar ratios in shallow well-waters.

Figure 20. Isopleths drawn for He/Ar molar ratios in shallow well-waters.

Figure 21. Isopleths drawn for He/Ne molar ratios in shallow well-waters.

Figure 22. Hydrological-geothermal model of the Animas Valley (after Logsdon, 1981). Logsdon's model is that the heat source for the system is recent basaltic volcanism off the map to the SW. Hot waters move northeasterly within igneous rock in the deep subsurface with small amounts leaking upward along a major northeast trending fracture. Major upward flow of hot waters occurs at a fault intersection. Near the surface the thermal waters flow down the hydrological gradient, north-northwesterly, in valley fill sediments at the same time mixing with non-thermal waters.

another and the trace element isopleth diagrams of Landis and Logsdon (1980) and Logsdon (1981) (Fig. 10). Gas isopleths show a regular zonation around the hottest wells and have an extension northward. The data agree well with Logsdon's model.

Both the ideas to be tested in the study of a geothermal area appear to work. Gases do show a regular zonation around apparent centers of uprising thermal waters. The fan shape in the gas isopleth diagrams suggest dispersion of thermal waters northward, i.e. gas data can be used to understand local hydrology.

USE OF GASES IN GEOTHERMAL EXPLORATION

Regional Exploration

The object in regional exploration is to locate districts which may have the potential for a geothermal resource. The question is are there good indicator gas or gas ratios for geothermal resource areas. In addition, it can be asked if gas data from springs as well as wells can be useful in geothermal resource exploration.

The gases He, Ar, N₂, Kr, CH₄, and CO₂ showed a meaningful correlation with chemical geothermometry as did the gas ratios CO₂/Ar, CO₂/N₂, CO₂/CH₄, He/Ar, He/N₂, and He/Ne. To be most useful for exploration, the indicators should show considerable variation in concentration with temperature. Also there should be a clear cut difference in concentration between gases in waters associated with waters of T > 100° and cooler water, irregardless of the type of reservoir rock type. Several gases and gas ratios meet these criteria based on the data from this study. Suggestions as to which gases would be most valuable for exploration, as well as concentrations of gases that indicate reservoir temperatures in excess of 100°C, are summarized in Table 5.

Discussion of individual gases and gas ratios follows.

(Helium)

Several studies suggest helium is a useful indicator gas for geothermal exploration (Hinkle, et al., 1978; Mazor, 1975; Roberts, et al., 1975). However, the results of this study suggest that helium concentration in water is not a good indicator of high temperature geothermal fluids. Helium concentration in geothermal waters show only a moderate increase with increasing reservoir temperature (Fig. 2), hence it is difficult to set a level at which He concentration would indicate high reservoir temperatures. Helium concentration in spring waters shows such a large variation in concentration (Fig. 3) to preclude its use as a regional exploration tool.

Another problem with the use of He as an exploration tool is that factors other than reservoir temperature affect the He content of ground water. Both well and spring waters from near the Jemez lineament (the focus of volcanism in New Mexico the last few million years) have better than an order of magnitude more He than waters from other areas (Table 4). Considering that there is only a 5 fold difference in He abundance between 50 and 150°C waters, variation in tectonic setting, rock type, and/or age of rocks has more of an effect on He abundance in geothermal waters than temperature.

The Lightning Dock area is considered to have potential as a geothermal resource. Well waters in the Lightning Dock area are low in He. In addition, the hottest wells, both in terms of discharge temperature and alkali geothermometry, have the lowest concentrations of He measured in the Lightning Dock area. (This may be due to boiling.) If helium concentration was used it would certainly fail to identify the Lightning Dock as a geothermal resource area.

It is concluded that helium gas is not a good regional indicator for geothermal waters.

TABLE 4. Comparison of helium concentration and alkali geothermometry in well and spring waters from various geographical areas in New Mexico.

Location	No. of Samples	Ave. He in cc/liter ($\times 10^4$) $\pm \sigma$	Ave. $T_{Na-K-Ca} \pm \sigma$ ($^{\circ}C$)
Jemez Lineament	10	450 $\pm$ 780	118 $\pm$ 56
So. Rio Grande Rift	12	24 $\pm$ 24	147 $\pm$ 70
Animas Valley (Lightning Dock)	16	3 $\pm$ 2	64 $\pm$ 39
Others	11	17 $\pm$ 17	81 $\pm$ 43

(Carbon Dioxide)

Carbon dioxide is the principal gas in geothermal waters as indicated in this study and by Mahon, McDowell, and Finlayson (1980). Both the concentration of CO_2 and the percentage of CO_2 in the total dissolved gases increase with reservoir temperature (Figs. 2 and 23). No influence on CO_2 concentration by rock type is evident.

The most useful indicator gas for geothermal resources is CO_2 . Carbon dioxide abundance is only a fair indicator gas in well waters and poor in spring waters, however; the best indicators determined in this study are all CO_2 -gas ratios.

One of the gas ratios, $\text{CO}_2/\Sigma\text{gases}$, can be measured with only simple equipment. It would be both an inexpensive and good tool for regional exploration of geothermal resources.

(Hydrogen Sulfide)

The smell of sour gas is common in many hot spring areas. The nose can detect 10^{-6}m H_2S (34 ppb or 0.02 cc/L), hence quite small concentrations are easily noticed. However, H_2S alone is not a necessary component of geothermal fluids. For example, H_2S occurs in only two of ten well and spring waters analyzed in the Clear Lake, California, geothermal district (Nehring, 1979). Only seven of the fifty-one water samples in this study had detectable amounts of H_2S ($\sim 10^{-6}\text{m}$), hence meaningful correlations of H_2S with temperature were not possible. However, the average $T_{\text{Na-K-Ca}}$ temperature of these seven waters is 154°C . This suggests a strong association of H_2S with high temperature waters as has been noted by Truesdell (1974).

Hydrogen sulfide gas therefore may be considered to be an indicator but not a necessary component of waters from a geothermal resource.

Figure 23. Mole percent CO₂ of total dissolved gases versus $T_{\text{Na-K-Ca}}$ in well and spring waters. Well data are circles, spring data are triangles.

(Gas Ratios)

The gas ratios involving CO_2 and He for the most part correlate better with geothermometry than abundance of CO_2 and He. Helium is not a good indicator gas and it follows that the He-gas ratio are only fair indicators of thermal waters in well waters and not reliable as indicators in spring waters. Virtually all CO_2 -gas ratios are good indicators of geothermal reservoirs. Some of the ratios such as CO_2/Ne , CO_2/Kr which could be used as indicators are not listed because they are more difficult to measure and because all the CO_2 -gas ratios measure the same thing. They measure the increase in CO_2 content relative to a conserved gas which acts as a baseline.

 $(\text{CO}_2/\text{CH}_4)$

The CO_2/CH_4 is the gas measurement which we consider to have the greatest potential as a geochemical tool for geothermal exploration. It is the only gas or gas ratio which is a good indicator of high temperature waters in both well and spring waters. In addition, the CO_2/CH_4 ratio can be used to estimate reservoir temperature.

The correlation between CO_2/CH_4 and geothermometry for spring waters is not as high as for well waters. Most of the data far off the regression line for CO_2/CH_4 (Fig. 5) are for waters very high in CH_4 . If these data are ignored, well and spring data fit a CO_2/CH_4 regression line equally well. The source of the high CH_4 in some spring waters could be from biological sources in the spring waters or from nearby swampy ground. It is recommended if CO_2/CH_4 in spring waters is to be used for geothermal exploration, that springs with $\text{CH}_4 > \text{CO}_2$ be considered to have excess CH_4 from an unknown source and the data be ignored.

The reason CO_2/CH_4 appears to work as a geothermal indicator in springs in contrast to other CO_2 and He gas ratios is that CO_2 and CH_4 concentrations

TABLE 5. Gases and gas ratios in well and spring waters which this study suggests are useful indicators of geothermal reservoirs. Minimum values for indicating reservoir temperatures in excess of 100° are listed. Gases and gas ratios not listed are not considered to be useful indicator gases for geothermal exploration. (Molar units used throughout.)

Gas Measurement	Well Waters		Spring Waters	
	Usefulness	Minimum value for 100°C reservoir temperature	Usefulness	Minimum value for 100°C reservoir temperature
CO ₂	F	10 cc/liter	n.r.	-
% CO ₂ of Σ gases	G	45%	F	45%
CO ₂ /N ₂	G	1	F	1
CO ₂ /Ar	G	50	F	50
CO ₂ /CH ₄	G	30	G	30
He/N ₂	F	2×10^{-4}	n.r.	-
He/Ar	F	1×10^{-2}	n.r.	-
He/Ne	F	10	n.r.	-

G = good indicator gas
 F = fair indicator gas
 n.r. = not reliable indicator gas

are little affected by atmospheric contamination. Almost all CH_4 and CO_2 in thermal waters was introduced in the subsurface. Concentration of these gases in thermal waters is much higher than water in equilibrium with the atmosphere, hence when spring waters contact the atmosphere no CO_2 or CH_4 is gained from air. In contrast N_2 , Ar, and Ne are generally undersaturated in regards equilibrium with the atmosphere. Hence, the CO_2/N_2 , CO_2/Ar , He/N_2 , He/Ar , and He/Ne ratios in spring waters can be considerably affected by atmospheric contamination.

District Exploration

Here the purpose of exploration is to understand the hydrology of the geothermal system so as to locate sites that will be the best target for drilling. The study on the Lightning Dock area indicate that all the gas and gas ratios that have a significant correlation with the alkali geothermometer show a regular zonation around the postulated site of upwelling geothermal waters and thermal water diffusion halo. These data strongly suggest that gas data can be used as a tool to locate plumes of thermal waters and to help interpret the hydrology of the geothermal system. The strong point of this tool may be that a number of gases and gas ratios show a zonation. Hence, gas measurement does not have to rely on single gas species (which in some geologic environments may prove to be unreliable) to outline a potential drilling location.

Helium abundance and several gases and gas ratios (e.g. He/Ne) which are not good indicators in regional exploration, work well in district exploration. This is easily explained if one considers that upwelling thermal water will have different gas chemistry than near surface waters. As thermal waters mix with cool waters there should be a systematic change in gas chemistry zoned around the center of upwelling.

SUMMARY AND CONCLUSIONS

Active and noble gases in geothermal waters were measured in sixteen wells in the Lightning Dock geothermal area and thirty-five other springs and wells throughout New Mexico. Discharge temperature, pH, alkalies, and dissolved silica were measured for each sample. Correlation coefficients and scatter diagrams between gases, gas ratios, and chemical geothermometers were calculated. Scatter diagrams for the gases and gas ratios which have the highest correlation with the alkali geothermometers were plotted. Isopleth plots were made of selected gases and gas ratios for the Lightning Dock samples. Based on these data the following conclusions were reached.

1. The gases measured in all waters are N_2 , CO_2 , CH_4 , O_2 , He, Ar, Ne, and Kr. NH_3 , NO, H_2S , and H_2 were measured in only some samples.

2. Of the principal gases, CO_2 and He increase with reservoir temperature as indicated by alkali geothermometry. With the exception of O_2 , the other principal gases show a gradual decrease in abundance with increasing reservoir temperature.

3. In waters from low temperature reservoirs N_2 is the principal gas; in waters from reservoirs above $100^\circ C$ CO_2 is the dominant gas species.

4. Ratios of CO_2 and He to Ar and N_2 have a better correlation to alkali geothermometry than the concentration of either CO_2 and He. Suggested to explain this observation is that volatile loss (boiling) of geothermal waters will result in changes in the abundance of gases, but have less of an effect on gas ratios.

5. The CO_2/CH_4 increases regularly with reservoir temperature. An empirical relation between CO_2/CH_4 and temperature was determined. It was proposed that this relation can be used as a geothermometer.

6. Gases and gas ratios which would be useful for regional exploration in well water are CO_2 , CO_2/Σ gases, CO_2/CH_4 , CO_2/Ar , CO_2/N_2 , He/Ar , and He/N_2 . In spring waters, CO_2/CH_4 is the only good indicator gas for high temperature waters; however, CO_2 , CO_2/Σ gases, CO_2/N_2 and CO_2/Ar could be used with fair results.

7. Helium gas itself is not a good indicator gas for geothermal fluids.

8. Hydrogen sulfide is not present in all waters from high temperature sources, but its occurrence is a good indication of reservoir temperatures $> 100^\circ\text{C}$.

9. In the Lightning Dock geothermal area CO_2 , He and the gas ratios CO_2/Σ gases, CO_2/CH_4 , CO_2/Ar , CO_2/N_2 , He/Ar , He/N_2 , and He/Ne were regularly zoned around what is considered to be the center of rising of a geothermal system. The above gases and gas ratios indicated a zone of mixing between thermal and cool waters down the hydrologic gradient from the center of the geothermal system.

10. Gases and gas ratios can be a valuable tool in district exploration to locate geothermal centers.

REFERENCES

- D'Amore, F. and Panichi, C., 1980, "Evolution of deep temperatures of hydrothermal systems by a new gas geothermometer", *Geochim. Cosmo. Acta*, 44, pp. 549-556.
- Deal, E. and Elston, W., 1981, "Geology of the Lightning Dock KGRA and Vicinity, Pyramid Mountains and Animas Valley, Hidalgo County, New Mexico", Circular in press, New Mexico Bureau of Mines, Socorro, New Mexico.
- Deal, E., Elston, W., Erb, W., Peterson, S., Reiter, D., Damon, P., and Shafiquallah, M., 1978, "Cenozoic volcanic geology of the basin and range province in Hidalgo County, Southwestern New Mexico", *New Mex. Geol. Soc. Guidebook to the 29th Field Conference*, pp. 219-229.
- Dyck, W., Pelchat, J., and Muller, G., 1976, "Equipment and procedures for the collection and determination of dissolved gases in natural waters", *Geol. Surv. Canada, Paper 75-34*, 11 p.
- Fouillac, C. and Michard, G., 1981, "Sodium/lithium ratio in water applied to geothermometry of geothermal reservoirs", *Geothermics*, 10, pp. 55-70.
- Fournier, R., 1979, "A revised equation for the Na/K geothermometer", *Geothermal Resources Council Transactions*, 3, pp. 221-224.
- Fournier, R. and Rowe, J., 1966, "Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells", *Am. J. Sci.* 264, pp. 685-697.
- Fournier, R. and Truesdell, A., 1973, "An empirical Na-K-Ca geothermometer for natural waters", *Geochim. Cosmo. Acta*, 37, pp. 1255-1275.
- Giggenbach, W., 1980, "Geothermal gas equilibria", *Geochemica et Cosmo. Acta*, 44, pp. 2021-2032.
- Giggenbach, W., 1981, "Geothermal mineral equilibria", *Geochim. Cosmochim. Acta*, 45, pp. 393-410.
- Goff, F. and Donnelly, J., 1978, "The influence of P_{CO_2} , salinity, and Ledrock type on the Na-K-Ca geothermometer as applied in ² the Clear Lake Geothermal region, California", *Geothermal Resource Council Transactions*, 2, pp. 211-213.
- Gunter, B. and Musgrave, B., 1971, "New evidence on the origin of methane in hydrothermal gases", *Geochim. Cosmochim. Acta*, 35, pp. 113-118.
- Gutsalo, L. K., 1975, "Helium isotopic chemistry in thermal waters of the Kuril Islands and Kamchatka", *Second United Nations Symposium on the Development and Use of Geothermal Resources*, San Francisco, May, 1975, 1, pp. 745-749.
- Hawkins, D., 1981, "Geohydrology of the lower Animas Valley, Hidalgo County, New Mexico: A computer simulation study, Independent Study Project for M.S. degree, Dept. of Geoscience, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

- Hinkle, M., 1978, "Helium, mercury, sulfur compounds and carbon dioxide in soil gases of the Puhimau Thermal area, Hawaii Volcanoes National Park, Hawaii", USGS open file report 78-246.
- Hinkle, M., Denton, E., Biglow, R., and Turner, R., 1978, "Helium in soil gases of the Roosevelt hot springs known geothermal resource area, Beaver County, Utah", U.S. Geol. Surv. J. of Res., 6, pp. 563-570.
- Jiracek, G. and Smith, C., 1976, "Deep resistivity investigations at two KGRA's in New Mexico: Radium Springs and Lightning Dock", in Woodward, L. and Northrop, S. (eds.), Tectonics and Mineral Resources of Southwestern North America, New Mexico Geol. Soc. Spec. Pub. 6, pp. 71-76.
- Landis, G. and Logsdon, M., 1980, "Computer-based chemical and stable isotope modeling of geothermal systems in New Mexico", New Mexico Energy Research and Development Program, Final Report EMD 78-2120.
- Logsdon, M., 1981, "The aqueous geochemistry of the Lightning Dock known geothermal resource area, Animas Valley, Hidalgo County, New Mexico", unpub. M.S. thesis, University of New Mexico.
- Mahon, W., McDowell, G., and Finlayson, J., 1980, "Carbon dioxide: Its role in geothermal systems", New Zealand Jour. Sci., 23, pp. 133-148.
- Mazor, E., 1975, "Atmospheric and radiogenic noble gases in thermal waters - their potential application to prospecting and steam studies", Proc. 2nd. Int. Symp. on Geothermal Energy, pp. 793-802.
- Mazor, E., 1977, "Geothermal tracing with atmospheric and radiogenic noble gases", Geothermics, 5, pp. 21-36.
- Nehring, N., 1979, "Gases from springs in the Geysers-Clear Lake area", USGS Prof. Paper 1141, pp. 205-209.
- Paces, T., 1975, "A systematic deviation from Na-K-Ca geothermometer below 75°C and above 10^{-4} atm P_{CO_2} ", Geochemica et Cosmo. Acta, 39, pp. 541-544.
- Panichi, C., and Tongiorgi, E., 1976, "Carbon isotopic composition of CO_2 from springs, fumaroles, mofetts and travertines of Central and Southern Italy, UN Symp. of Geothermal Energy, San Francisco, 1975, pp. 815-825.
- Roberts, A., Friedman, I., Donovan, T., and Denton, E., 1975, "Helium survey, a possible technique for locating geothermal reservoirs", Geophys. Res. Let., 2, pp. 209-210.
- Smith, C., 1978, "Geophysics, geology, and geothermal leasing status of the Lightning Dock KGRA, Animas Valley, New Mexico", New Mexico Geol. Soc. Guidebook to the 29th Field Conference, pp. 343-348.
- Truesdell, A., 1974, "Chemical evidence of subsurface structure and fluid flow in geothermal systems" in: Int. Symp. on Water Rock Interaction, Prague, Czechoslovakia, pp. 59-60.

- Truesdell, A. and Nehring, N., 1978/79, "Gases and water isotopes in a geochemical section across Lardarello, Italy, geothermal field", Pageoph, 117, pp. 276-289.
- Welham, J., Poreda, R., Lupton, J., and Craig, H., 1979, "Gas chemistry and helium isotopes at Cerro Prieto", Geothermics, 8, pp. 241-244.
- White, D. and Williams, D., 1975, "Assessment of geothermal resources of the US", U.S. Geol. Surv. Circ. 726, 155 p.

APPENDIX I

METHODS OF WATER SAMPLE COLLECTION AND ANALYSIS

Collection of water sample

A 500 ml sample of water was collected from each thermal spring and well sampled. The sample container was a 500 ml narrow mouth polyethylene bottle. Five milliliters of concentrated nitric acid was added to each sample.

A 10 ml sample of water was collected for silica analysis from each sample site. The 10 ml samples were diluted to 100 milliliters by adding 90 milliliters of deionized-distilled water. The samples were stored in 125 milliliter polyethylene bottles.

Analysis of water sample

The sodium, potassium, calcium, and silica contents of the thermal waters were determined by standard methods of water analysis: sodium and potassium were analysed by atomic absorption, calcium by titration (EDTA direct titration), and silica by the molybdate-blue colorimetric method.

APPENDIX II

METHOD OF SAMPLE COLLECTION AND ANALYSIS OF GASES IN WATER

Sampling of wells and springs

Sampling Device

A 33 ml sample of water was collected at each sample site. Figure 1 is a schematic diagram of the sampling apparatus used to collect samples for gas analysis. The sample apparatus consists of a 200 ml pyrex sample bypass and a pyrex sample container connected together by an Ace(R) vacuum connector. The sample container is evacuated to 10^{-4} Torr before a sample site is visited.

Water from a thermal spring or well is circulated through the sample bypass for several minutes to minimize air contamination of the sample. The valve between the bypass and the sample container (V_2) is opened and a water sample is pulled into the evacuated sample container. Valve three is opened to allow water and gas to flow through the sample container. After several minutes valve 2 and valve 3 are closed and the sample container is disconnected from the bypass and is refrigerated until it is analyzed.

Sampling Wells

Two methods were used to sample wells (Fig. 2). As illustrated in Fig. 2a a section of 1/2" o.d. tygon tubing is connected between the sample bypass and a fitting or a sampling duct on the well discharge pipe. Water from the well flows through the tygon tubing into the sampling device. Where a direct coupling to the well was impossible, the sample was collected as illustrated in Fig. 2b.

Using this method, a representative sample is more difficult to obtain because air contamination, two phase flow, or degassing may occur.

Fig. 1.
Schematic illustration of
water sampling apparatus.
Glass-body, high vacuum glass
stopcocks used throughout

From a $\frac{1}{4}$ - $\frac{1}{2}$ Fitting

Fig. 2a.

Sampling Wells

From Discharge Pipe

Fig. 2b.

Sampling springs

The apparatus to sample springs is illustrated in Fig. 3. A section of tygon tubing connects the sample bypass with a 15 cm diameter funnel. The funnel is placed over the main zone of upwelling water and gas to obtain the most representative sample. A hand vacuum pump is used to maintain a vacuum on a 2-gal. carboy. The vacuum draws water from the spring and through the sample bypass. After a sample is drawn into the sample bypass, valve 1 is closed. Water is then drawn through the sample container via the vacuum line from the carboy which is attached to valve 3. After a few minutes valve 2 and 3 are closed trapping a sample of water and gas.

Procedure for Gas Analysis

System

The gas analysis system is illustrated in Fig. 4. The system is similar to the system developed by Dyck et al, (1975). The gas analysis system consists of three parts; a sample inlet, a gas separation line, and the mass spectrometer. The sample inlet and gas separation line are made of pyrex. Water separation trap 2 and gas separation trap 1 are filled with glass beads to provide a large surface area for condensed gases. High-vacuum, bellow-seal stop cocks are used throughout. Volumes of each section of the inlet and separation line are known. The mass spectrometer is an Inficon IQ200, manufactured by Leybold Heraeus, Inc.

The IQ200 mass spectrometer measures masses 1 to 200 over a concentration range of five orders of magnitude. The mass spectrometer analyser is evacuated to a pressure of 10^{-8} to 10^{-9} Torr using a diffusion pump. A small ion-vac pump is used to maintain a high vacuum on the analyser when the mass spectrometer is not in use.

Sampling a Spring

Fig. 3.

The cracking outline of the various gases measured were determined by inputting pure standard gases into the mass spectrometer. The sensitivities of the various gases were determined by measurement of known mixtures of each gas with nitrogen.

Gas ratios are determined with a computer by a least squares fit routine. The routine determines the gas ratios by fitting the cracking outlines of known gases to the cracking outline of the unknown.

A quantitative gas analysis is made by measuring the pressure of the sample using a capacitance manometer. The moles of gas in the sample are calculated using the ideal gas law. Normalizing the gas ratios determined by the mass spectrometer, and multiplying them by the moles of gas in the sample yields the number of moles of each gas.

Analytical Procedures

The gas separation line and sample inlet is evacuated to 10^{-5} Torr. The water separation traps are cooled down with a dry ice-alcohol mixture and the gas separation traps are cooled down with liquid nitrogen. The sample is injected into the sample inlet by opening the valve between the inlet and sample container. After several minutes of boiling with the sample being agitated by a magnetic stir bar, the sample becomes degassed and the water freezes. The dry ice cooled traps condense water and the liquid nitrogen traps condense CO_2 , NH_3 , NO , H_2S , SO_2 , and heavy hydrocarbons. The noncondensable gases consist of N_2 , O_2 , CH_4 , NO , and the rare gases.

Twenty minutes is allowed for the pressure to stabilize. Pressure of the gas sample is measured with the capacitance manometer and a sample of the noncondensed gas is inlet into the mass spectrometer by opening the leak valve. The amplitudes of the mass spectra are recorded. After the noncondensable

gases are analysed an activated charcoal trap cooled by liquid nitrogen is opened to the gases. It absorbs the more reactive gases thereby increasing the relative concentrations of the rare gases. Helium, neon, argon, and nitrogen are measured in the depleted noncondensable gases. The noncondensable gases are pumped away then the liquid nitrogen traps are replaced by dry ice-alcohol traps and the condensed gases are released and measured.

The remaining gases are pumped away. The charcoal trap is heated to 80°C releasing the absorbed gases. Infrared lamps heat the water traps evaporating the water which condenses in the sample inlet. The sample inlet is removed and dried. A new sample is attached to the system and when the line pressure drops below 10^{-5} Torr the system is ready to run a new sample.

Checks on Experimental Procedure

Samples of Socorro tap water were analysed to determine the accuracy and precision of the measurements being made (Table 1). The precision varies with the concentration of the gas in water. Precision is ± 2.4 to 13% for the most abundant gases N_2 , O_2 , and Ar and ± 11 to 40% for gases of low concentration. Although the indicated precision for CO_2 is $\pm 25\%$, in most geothermal waters CO_2 is the principal gas, hence it would be expected that in analyses of CO_2 in most thermal waters should near the precision of measuring N_2 concentration in tap water.

Indicated accuracy of the analyses for most of the gases is good. Measured concentrations agree within the experimental error to theoretical values. The two exceptions are NO and CO_2 .

These gases were measured in higher abundance than theoretical values. It is believed that the NO measured is an accurate value and most probably

TABLE 1

Gas concentrations in cc(STP)/liter measured in
five samples of Socorro tap water.

Gas (cc(STP)/liter)	Average $\pm \sigma$	Precision in %	Theoretical Value
N ₂	11 $\pm$ 0.3	2.4	11
O ₂	5.8 $\pm$ 0.8	13	5.9
NO	0.045 $\pm$ 0.018	40	1.8×10^{-4}
CO ₂	1.2 $\pm$ 0.3	25	0.27
He	$(3.5 \pm 1.3) \times 10^{-5}$	36	4.3×10^{-5}
Ne	$(1.7 \pm 0.2) \times 10^{-4}$	11	1.9×10^{-4}
Ar	0.35 $\pm$ 0.04	11	0.31
Kr	$(7.0 \pm 1.1) \times 10^{-5}$	15	6.8×10^{-5}

reflects nitrates in Socorro ground water. The same with CO_2 . Socorro waters are from wells and subsurface waters typically have more CO_2 in them than surface waters. In addition, solubility of CO_2 in water is more highly dependent on water chemistry than any of the other gases. Since Socorro tap water is far from pure, it is understandable that the measured concentration is not equal to solubility of CO_2 calculated for distilled water.

APPENDIX III

CORRELATION COEFFICIENTS

Correlation coefficients were calculated between gas data and chemical geothermometers T_{quartz} , $T_{\text{chalcedony}}$, $T_{\text{Na-K}}$, $T_{\text{Na-K-Ca}}$ and $T_{\text{Na/Li}}$ plus between gas data and T_m , the discharge temperature of the well or spring. The correlation coefficients were calculated for all the data and for the spring and well data taken individually.

TABLE 1. Correlation coefficients for all data.

	TOTAL					
	T_Q	T_{ch}	T_{Na-K}	$T_{Na-K-Ca}$	$T_{Na/Li}$	T_m
N ₂	-.17	-.16	-.25	-.19	-.04	-.07
He	-.03	-.02	-.02	.24	.11	.18
Ne	-.16	-.16	-.03	-.13	-.20	-.32
Ar	-.27	-.27	-.36	-.32	-.32	-.18
Kr	.03	.02	-.20	-.27	-.15	-.10
H ₂ S	-.21	-.21	.10	.28	.31	.02
CO ₂	-.29	-.29	.15	.29	.23	.01
CH ₄	-.25	-.25	-.18	.09	.59	.03
NH ₃	-.39	-.39	.12	.05	.10	-.12
NO	-.17	-.16	-.26	-.33	-.42	-.34
He/N ₂	-.12	-.11	.05	.18	.15	-.02
He/Ne	.04	.05	.02	.25	.16	.17
He/Ar	.06	.07	-.01	.24	.17	.09
He/Kr	.11	.11	.17	.31	.17	.17
CO ₂ /N ₂	-.30	-.29	.27	.32	.30	.05
CO ₂ /Ne	-.07	-.06	.37	.49	.27	.24
CO ₂ /Ar	-.26	-.25	.28	.44	.51	.17
CO ₂ /Kr	-.10	-.10	.35	.50	.58	.28
CO ₂ /CH ₄	-.27	-.27	.07	.18	.11	.08
log (CO ₂ /CH ₄)	.06	.06	.51	.61	.08	.38
CO ₂ /H ₂ S	.12	.12	.37	.43	.09	.35
N ₂ /NH ₃	.02	.04	-.01	-.07	.03	.002
CO ₂ •He	-.31	-.31	.02	.17	.13	-.08
CO ₂ /Ar•He/Ar	-.33	-.33	-.01	.3	.49	.14
T_Q	1		.29	.41	.02	.40
T_{ch}		1	.30	.42	.01	.40
T_{NK}			1	.68	.11	.32
T_{NCK}				1	.26	.49
T_{NL}					1	.24
T_S						1

TABLE 2. Correlation coefficients for samples from wells

	T_Q	T_{ch}	T_{Na-K}	$T_{Na-K-Ca}$	$T_{Na/Li}$	T_m
N ₂	-.22	-.23	-.36	-.45	.09	-.24
He	.62	.62	.61	.79	.07	.74
Ne	-.27	-.27	-.06	-.11	.06	-.42
Ar	-.38	-.38	-.37	-.44	.42	-.25
Kr	-.26	-.26	-.18	-.38	-.12	-.10
H ₂ S	.23	.23	.01	.21	-.49	.20
CO ₂	.53	.53	.63	.69	.06	.63
CH ₄	-.41	-.41	-.31	-.37	-.03	-.48
NH ₃	-.13	-.13	.03	-.05	.02	-.13
NO	-.45	-.44	-.16	-.33	-.19	-.45
He/N ₂	.60	.60	.68	.84	-.04	.72
He/Ne	.59	.59	.58	.68	.06	.72
He/Ar	.62	.63	.67	.83	-.02	.70
He/Kr	.28	.28	.32	.33	.29	.33
CO ₂ /N ₂	.54	.54	.65	.72	.05	.64
CO ₂ /Ne	.48	.49	.56	.60	.12	.58
CO ₂ /Ar	.54	.54	.65	.72	.05	.63
CO ₂ /Kr	.47	.48	.63	.66	.09	.57
CO ₂ /CH ₄	.52	.53	.67	.71	.02	.62
log (CO ₂ /CH ₄)	.64	.65	.70	.77	-.05	.71
CO ₂ /H ₂ S	.44	.44	.49	.50	.14	.49
N ₂ /NH ₃	-.01	.01	-.33	.16	.46	.13
CO ₂ ·He	.39	.40	.55	.55	.07	.48
CO ₂ /Ar·He/Ar	.52	.53	.65	.70	.07	.62
T_Q	1	1	.41	.62	.18	.61
T_{ch}		1	.42	.63	.18	.62
T_{NK}			1	.80	.27	.56
T_{NCK}				1	.19	.68
T_{NL}					1	.21
T_S						1

TABLE 3. Correlation coefficients for samples from springs

	T_Q	T_{ch}	T_{Na-K}	$T_{Na-K-Ca}$	$T_{Na/Li}$	T_m
N ₂	-.10	.09	-.2	.07	.03	.24
He	-.17	-.15	-.01	.24	-.06	.04
Ne	-.13	-.13	-.01	-.19	-.34	-.35
Ar	-.19	-.19	-.42	-.23	-.46	-.05
Kr	.25	.24	-.22	-.10	-.18	-.1
H ₂ S	-.36	-.35	.16	.39	.29	-.23
CO ₂	-.51	-.5	.06	.26	.18	-.36
CH ₄	-.31	-.31	-.24	.21	.65	.09
NH ₃	-.56	-.56	.21	.01	-.01	-.46
NO	.04	.053	-.39	-.31	-.45	-.13
He/N ₂	-.25	-.24	.06	.16	-.02	-.36
He/Ne	-.09	-.08	.07	.23	-.02	-.05
He/Ar	-.05	-.02	-.08	.27	.03	-.12
He/Kr	-.03	-.04	-.01	.24	.07	-.19
CO ₂ /N ₂	-.57	-.56	.24	.24	.24	-.28
CO ₂ /Ne	-.42	-.42	.19	.39	.31	-.26
CO ₂ /Ar	-.59	-.59	.15	.36	.53	-.28
CO ₂ /Kr	-.43	-.43	.19	.39	.66	-.1
CO ₂ /CH ₄	-.41	-.40	.05	.20	.64	-.36
log (CO ₂ /CH ₄)	-.4	-.40	.25	.43	.25	-.19
CO ₂ /H ₂ S	-.53	-.53	-.15	.41	.49	.001
N ₂ /NH ₃	-.03	-.01	-.02	-.21	-.11	-.19
CO ₂ •He	-.43	-.45	.01	.22	.05	-.34
CO ₂ /Ar•He/Ar	-.56	-.57	-.17	.32	.45	-.07
T_Q	1	1	.21	.19	-.15	.15
T_{ch}		1	.22	.20	-.16	.14
T_{NK}			1	.22	.06	-.21
T_{NCK}				1	.28	-.14
T_{NL}					1	.08
T_S						1

APPENDIX IV

DATA

In addition to the data, reservoir temperature was calculated using the following geothermometers:

T_Q	= quartz geothermometer (Fournier and Rowe, 1966)
T_{ch}	= chalcedony geothermometer (Fournier and Rowe, 1966)
T_{Na-K}	= Na-K geothermometer (Fournier, 1979)
$T_{Na-K-Ca}$	= Na-K-Ca geothermometer (Fournier and Truesdell, 1973)
$T_{Na/Li}$	= Na/Li geothermometer (Fouillac and Michard, 1981)
T_{CO_2/CH_4}	= CO_2/CH_4 geothermometer, this study

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Mamby Hot Spring

Sample location: Taos: 26N. 11E.1.120

Location number: 1

Surface temperature: 38°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	86	69	Na	153
O ₂	21	17	K	8.9
He	0.25	2000*	Li	0.31
Ne	5.1 x 10 ⁻⁴	4.1*	Ca	28
Ar	1.7	1.4	SiO ₂	57
Kr			pH	7.6
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	9.4	7.5		
CH ₄	3.9	3.1		
C _n H _n				
NH ₃	1.2 x 10 ⁻²	95*		
NO	0.18	1400*		
N ₂ O				
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 108	
* - in ppm (volume)			Chalcedony: 79	
			Na-K: 175	
			Na-K-Ca: 92	
			CO ₂ /CH ₄ : 12	
			Na/Li: 119	
			moles gas/ liter H ₂ O: 5.6 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 125	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample of bubbling spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Mamby Hot Spring

Sample location:

Location number: 1

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12		Na	
O ₂	2.5		K	
He	0.036		Li	
Ne	7.1×10^{-5}		Ca	
Ar	0.24		SiO ₂	
Kr	n.d.		pH	
Xe				
H ₂				
H ₂ S			Geothermometry	
SO ₂			Quartz:	
CO ₂	1.3		Chalcedony:	
CH ₄	0.56		Na-K:	
C _n H _n			Na-K-Ca:	
NH ₃	2.6×10^{-3}		CO ₂ /CH ₄ :	
NO	1.6×10^{-2}		Na/Li:	
N ₂ O			moles gas/ liter H ₂ O: 7.9×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 17	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Corrected for excess gas from bubbling spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Ponce del Leon Spring

Sample location: Taos: 24.N.13E.7.000

Location number: 2

Surface temperature: 34°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>12</u>	<u>92</u>	Na	<u>157</u>
O ₂	<u>.77</u>	<u>5.9</u>	K	<u>4.5</u>
He	<u>1.1 x 10⁻²</u>	<u>847*</u>	Li	<u>0.30</u>
Ne	<u>1.5 x 10⁻⁴</u>	<u>12*</u>	Ca	<u>2.3</u>
Ar	<u>0.17</u>	<u>1.3</u>	SiO ₂	<u>49</u>
Kr	<u>2.5 x 10⁻⁵</u>	<u>1.9*</u>	pH	<u>7.4</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>		
SO ₂	<u> </u>	<u> </u>		
CO ₂	<u>0.43</u>	<u>3.3</u>		
CH ₄	<u>3.3 x 10⁻²</u>	<u>.25</u>		
C _n H _n	<u> </u>	<u>Tr.</u>		
NH ₃	<u>1.1 x 10⁻³</u>	<u>81*</u>		
NO	<u>5.1 x 10⁻²</u>	<u>3900*</u>		
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 101	
* - in ppm (volume)			Chalcedony: 71	
			Na-K: 129	
			Na-K-Ca: 74	
			CO ₂ /CH ₄ : 73	
			Na/Li: 115	
			moles gas/ liter H ₂ O: 5.8 x 10 ⁻⁴	
			volume gas (cc STP)/ liter H ₂ O: 13	
			Gas Analysis by:	
			Water Analysis by:	

Comments	
Sample from small uncovered spring	

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Statue Spring

Sample location: Taos: 25N.8E.26.400

Location number: 3

Surface temperature: 29°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	2.5	1.2	Na	187
O ₂	1.6	0.78	K	16
He	1.6 x 10 ⁻³	7.6	Li	0.45
Ne	3.0 x 10 ⁻⁴	1.5*	Ca	135
Ar	0.10	320*	SiO ₂	21
Kr	9.5 x 10 ⁻⁶	.045	pH	7.0
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	66
CO ₂	204	97	Chalcedony:	34
CH ₄	0.25	0.12	Na-K:	205
C _n H _n			Na-K-Ca:	80
NH ₃	1.9	0.91	CO ₂ /CH ₄ :	58
NO	6.5 x 10 ⁻³	31*	Na/Li:	130
N ₂ O				
			moles gas/ liter H ₂ O: 9.2 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 210	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from spring

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Ojo Caliente
Sample location: Taos: 24N.8E.24.110
Location number: 4
Surface temperature: 43°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>2.4</u>	<u>8.6</u>	Na	<u>938</u>
O ₂	<u>0.22</u>	<u>0.78</u>	K	<u>40</u>
He	<u>4.2 x 10⁻²</u>	<u>1500*</u>	Li	<u>3.5</u>
Ne	<u>7.3 x 10⁻⁵</u>	<u>2.6*</u>	Ca	<u>32</u>
Ar	<u>5.3 x 10⁻²</u>	<u>.19</u>	SiO ₂	<u>65</u>
Kr	<u>4.2 x 10⁻⁶</u>	<u>.15*</u>	pH	<u>7.8</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>		
SO ₂	<u> </u>	<u> </u>		
CO ₂	<u>25</u>	<u>89</u>		
CH ₄	<u>5.0 x 10⁻²</u>	<u>0.18</u>		
C _n H _n	<u> </u>	<u>tr.</u>		
NH ₃	<u>2.3 x 10⁻²</u>	<u>827*</u>		
NO	<u>1.5 x 10⁻²</u>	<u>530*</u>		
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz:	114
* - in ppm (volume)			Chalcedony:	86
			Na-K:	153
			Na-K-Ca:	161
			CO ₂ /CH ₄ :	205
			Na/Li:	164
			moles gas/ liter H ₂ O: 1.2 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 28	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from sodium sulfate spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: San Antonio Hot Springs

Sample location: Sandoval: 20N.3E.29.120

Location number: 5

Surface temperature: 42°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>5.5</u>	<u>57</u>	Na	<u>23</u>
O ₂	<u>3.1</u>	<u>32</u>	K	<u>1.8</u>
He	<u>1.3 x 10⁻⁴</u>	<u>13*</u>	Li	<u>0.05</u>
Ne	<u>1.9 x 10⁻⁴</u>	<u>19*</u>	Ca	<u>5.0</u>
Ar	<u>0.18</u>	<u>1.8</u>	SiO ₂	<u>80</u>
Kr	<u>2.0 x 10⁻⁵</u>	<u>2.1*</u>	pH	<u>7.4</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>		
SO ₂	<u> </u>	<u> </u>		
CO ₂	<u>0.62</u>	<u>6.4</u>		
CH ₄	<u>0.34</u>	<u>3.5</u>		
C _n H _n	<u> </u>	<u> </u>		
NH ₃	<u> </u>	<u> </u>		
NO	<u>1.1 x 10⁻²</u>	<u>1100*</u>		
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz:	125
* - in ppm (volume)			Chalcedony:	97
			Na-K:	196
			Na-K-Ca:	58
			CO ₂ /CH ₄ :	20
			Na/Li:	123
			moles gas/ liter H ₂ O: 4.3 x 10 ⁻⁴	
			volume gas (cc STP)/ liter H ₂ O: 9.7	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from discharge pipe from capped spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Spence Spring

Sample location: Sandoval: 19N.3E.28.310

Location number: 6

Surface temperature: 42°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	5.6	56	Na	61
O ₂	3.8	38	K	1.5
He	1.7×10^{-4}	17*	Li	0.76
Ne	1.2×10^{-4}	12*	Ca	17
Ar	0.21	2.1	SiO ₂	69
Kr	1.7×10^{-4}	17*	pH	7.6
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	118
CO ₂	0.37	3.7	Chalcedony:	89
CH ₄	0.18	1.8	Na-K:	118
C _n H _n			Na-K-Ca:	39
NH ₃			CO ₂ /CH ₄ :	7
NO	7.7×10^{-3}	770*	Na/Li:	294
N ₂ O				
			moles gas/ liter H ₂ O: 4.6×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 10	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from spring pool				

Sample name: Soda Dam Spring
Sample location: Sandoval; 18N.2E.14.000
Location number: 7a
Surface temperature: 45°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	6.3	2.6	Na	995
O ₂	0.77	0.32	K	211
He	9.6 x 10 ⁻³	40*	Li	15
Ne		n.d.	Ca	187
Ar	0.10	400*	SiO ₂	30
Kr		n.d.	pH	7.7
Xe				
H ₂				
H ₂ S	0.34	0.14	Geothermometry (°C)	
SO ₂			Quartz:	80
CO ₂	220	93	Chalcedony:	48
CH ₄	9.8	4.1	Na-K:	112
C _n H _n		Tr.	Na-K-Ca:	152
NH ₃			CO ₂ /CH ₄ :	92
NO			Na/Li:	319
N ₂ O				
			moles gas/ liter H ₂ O: 1.1 x 10 ⁻²	
			volume gas (cc STP)/ liter H ₂ O: 240	
			Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				
Comments				
Spring sampled twice				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Soda Dam Spring

Sample location:

Location number: 7b

Surface temperature: 45°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	21	10	Na	
O ₂	6.7	3.2	K	
He	9.0 x 10 ⁻³	43*	Li	
Ne		n.d.	Ca	
Ar	0.16	750*	SiO ₂	
Kr		n.d.	pH	
Xe				
H ₂				
H ₂ S	0.21	0.10	Geothermometry (°C)	
SO ₂			Quartz:	
CO ₂	180	84	Chalcedony:	
CH ₄	4.6	2.2	Na-K:	
C H n n			Na-K-Ca:	
NH ₃			CO ₂ /CH ₄ : 113	
NO			Na/Li:	
N ₂ O				
			moles gas/ liter H ₂ O: 9.5 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 210	
			Gas Analysis by:	
			Water Analysis by:	
<p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p>				
<p>Comments</p> <p>Duplicate sample</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Jemez Spring

Sample location: Sandoval: 18N.2E.23.000

Location number: 8

Surface temperature: 53°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	4.8	2.5	Na	638
O ₂	1.6	0.82	K	78
He	2.3 x 10 ⁻³	1.2*	Li	9.1
Ne	6.8 x 10 ⁻⁵	0.36*	Ca	92
Ar	0.13	670*	SiO ₂	91
Kr	8.6 x 10 ⁻⁶	.045	pH	7.2
Xe				
H ₂				
H ₂ S	0.84	0.44	Geothermometry (°C)	
SO ₂			Quartz:	132
CO ₂	180	97	Chalcedony:	105
CH ₄	0.17	880*	Na-K:	250
C H n n			Na-K-Ca:	212
NH ₃			CO ₂ /CH ₄ :	232
NO	7.4 x 10 ⁻³	39*	Na/Li:	250
N ₂ O				
n.d. - not detected			moles gas/ liter H ₂ O: 8.4 x 10 ⁻³	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 190	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from main spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: San Ysidro Spring

Sample location: Sandoval: 15N.1E.10.200

Location number: 9

Surface temperature: 24°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	14	0.96	Na	1780
O ₂	5.4 x 10 ⁻²	36	K	81
He	3.6 x 10 ⁻²	24	Li	5.8
Ne	2.6 x 10 ⁻⁴	0.13*	Ca	323
Ar	0.61	410*	SiO ₂	18
Kr	1.8 x 10 ⁻⁴	0.12*	pH	7.6
Xe				
H ₂				
H ₂ S	1.8	.12	Geothermometry (°C)	
SO ₂			Quartz:	60
CO ₂	1500	99	Chalcedony:	28
CH ₄	6.2 x 10 ⁻²	41*	Na-K:	158
C _n H _n			Na-K-Ca:	157
NH ₃	1.7	0.11	CO ₂ /CH ₄ :	346
NO	3.3 x 10 ⁻³	2.2*	Na/Li:	153
N ₂ O				
n.d. - not detected			moles gas/ liter H ₂ O: 6.9 x 10 ⁻²	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 1500	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from bubbling spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Kaseman well #2 (warm springs)

Sample location: Sandoval: 16N.1W.1.410

Location number: 10

Surface temperature: 54°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	77	14	Na	3700
O ₂	0.30	550*	K	121
He	0.66	1200*	Li	5.7
Ne	1.0×10^{-3}	30*	Ca	341
Ar	1.5	2.7	SiO ₂	39
Kr	1.3×10^{-4}	0.24	pH	6.8
Xe				
H ₂				
H ₂ S	0.55	0.10	Geothermometry (°C)	
SO ₂			Quartz:	90
CO ₂	462	84	Chalcedony:	60
CH ₄	1.5	0.28	Na-K:	137
C H n n		Tr.	Na-K-Ca:	152
NH ₃	7.2×10^{-2}	920*	CO ₂ /CH ₄ :	188
NO		130*	Na/Li:	101
N ₂ O				
n.d. - not detected			moles gas/ liter H ₂ O: 2.5×10^{-2}	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 550	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from bubbling spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Kaseman Well #2

Sample location:

Location number: 10

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12	_____	Na	_____
O ₂	0.05	_____	K	_____
He	0.10	_____	Li	_____
Ne	1.6×10^{-4}	_____	Ca	_____
Ar	0.23	_____	SiO ₂	_____
Kr	2.0×10^{-5}	_____	pH	_____
Xe	_____	_____		
H ₂	_____	_____		
H ₂ S	0.086	_____	Geothermometry	
SO ₂	_____	_____	Quartz:	
CO ₂	72	_____	Chalcedony:	
CH ₄	0.23	_____	Na-K:	
C _n H _n	_____	_____	Na-K-Ca:	
NH ₃	7.9×10^{-2}	_____	CO ₂ /CH ₄ :	
NO	1.1×10^{-2}	_____	Na/Li:	
N ₂ O	_____	_____	moles gas/ liter H ₂ O: 3.9×10^{-3}	
_____	_____	_____	volume gas (cc STP)/ liter H ₂ O: 85	
_____	_____	_____	Gas Analysis by:	
_____	_____	_____	Water Analysis by:	
<div style="display: flex; justify-content: space-between;"> <div> <p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p> </div> </div>				
<p>Comments</p> <p style="text-align: center;">Corrected for excess gas from bubbling spring</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Montezuma Hot Spring

Sample location: San Miguel: 17N.15E.36.440

Location number: 11

Surface temperature: 49°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	_____	87	Na	203
O ₂	_____	.084	K	6.3
He	_____	0.70	Li	.41
Ne	_____	n.d.	Ca	11
Ar	_____	1.5	SiO ₂	68
Kr	_____	3.0*	pH	7.7
Xe	_____	_____		
H ₂	_____	_____		
H ₂ S	_____	_____	Geothermometry (°C)	
SO ₂	_____	_____	Quartz:	116
CO ₂	_____	.20	Chalcedony:	88
CH ₄	_____	2.8	Na-K:	134
C _n H _n	_____	_____	Na-K-Ca:	131
NH ₃	_____	104*	CO ₂ /CH ₄ :	-116
NO	_____	210*	Na/Li:	118
N ₂ O	_____	_____	moles gas/ liter H ₂ O:	
_____	_____	_____	volume gas (cc STP)/ liter H ₂ O:	
_____	_____	_____	Gas Analysis by:	
_____	_____	_____	Water Analysis by:	
<div style="display: flex; justify-content: space-between;"> <div> <p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p> </div> </div>				
<p>Comments</p> <p style="margin-left: 40px;">Sample of gas bubbling from spring</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Blue Canyon Well
Sample location: Socorro; 3S.1W.16.323
Location number: 12
Surface temperature: 33°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	8.5	53	Na	55
O ₂	5.4	34	K	3.3
He	2.9 x 10 ⁻⁴	18*	Li	.06
Ne	1.1 x 10 ⁻⁴	6.6*	Ca	27
Ar	.34	2.1	SiO ₂	28
Kr	1.4 x 10 ⁻⁴	8.7*	pH	7.2
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	73
CO ₂	1.8	11	Chalcedony:	42
CH ₄	.35	2.2	Na-K:	159
C _n H _n			Na-K-Ca:	49
NH ₃			CO ₂ /CH ₄ :	39
NO	1.6 x 10 ⁻²	1000*	Na/Li:	81
N ₂ O				
			moles gas/ liter H ₂ O: 7.1 x 10 ⁻⁴	
			volume gas (cc STP)/ liter H ₂ O: 16	
			Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from faucet from well

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Socorro Spring

Sample location: Socorro: 3S.1W.21.111

Location number: 13

Surface temperature: 32°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	11	80	Na	53
O ₂	.53	3.8	K	3.0
He	4.2 x 10 ⁻⁴	30*	Li	.05
Ne	4.5 x 10 ⁻⁴	30*	Ca	18
Ar	.22	1.6	SiO ₂	26
Kr	1.7 x 10 ⁻⁵	1.2*	pH	7.2
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.1	15		
CH ₄				
C _n H _n		Tr.		
NH ₃				
NO	1.2 x 10 ⁻²	830*		
N ₂ O				
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 88	
* - in ppm (volume)			Chalcedony: 57	
			Na-K: 152	
			Na-K-Ca: 55	
			CO ₂ /CH ₄ : -	
			Na/Li: 83	

Surface temperature: 17°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	13	60	Na	140
O ₂	Tr.	Tr.	K	8.3
He	4.0 x 10 ⁻⁴	19*	Li	
Ne	2.3 x 10 ⁻⁴	11*	Ca	120
Ar	.23	1.1*	SiO ₂	40
Kr	8.2 x 10 ⁻⁵	3.9*	pH	7.7
Xe				
H ₂				
H ₂ S	2.1 x 10 ⁻²	1000*	Geothermometry (°C)	
SO ₂			Quartz:	92
CO ₂	8.2	39	Chalcedony:	61
CH ₄	.22	1.03	Na-K:	176
C _n H _n		Tr.	Na-K-Ca:	58
NH ₃			CO ₂ /CH ₄ :	112
NO	1.3 x 10 ⁻²	640	Na/Li:	
N ₂ O				
n.d. - not detected			moles gas/ liter H ₂ O: 9.4 x 10 ⁻⁴	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 21	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from discharge pipe from well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Bosque del Apache Well #20

Sample location: Socorro: 6S.1E.12.231

Location number: 15

Surface temperature: 24°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	15	87	Na	96
O ₂	.29	1.7	K	4.4
He	9.0×10^{-4}	53*	Li	
Ne	2.1×10^{-4}	13*	Ca	24
Ar	.30	1.8	SiO ₂	42
Kr	2.9×10^{-4}	17*	pH	7.9
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	1.6	9.5		
CH ₄				
C _n H _n				
NH ₃				
NO	1.7×10^{-2}	980*		
N ₂ O				
n.d. - not detected N.M. - not measured * - in ppm (volume)			Geothermometry (°C) Quartz: 94 Chalcedony: 63 Na-K: 158 Na-K-Ca: 68 CO ₂ /CH ₄ : Na/Li:	
			moles gas/ liter H ₂ O: 7.7×10^{-4} volume gas (cc STP)/ liter H ₂ O: 17 Gas Analysis by:	
			Water Analysis by:	
Comments Sample from faucet from well				

Surface temperature: 33°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	14.3	51	Na	810
O ₂	Tr.	Tr.	K	8.4
He	5.0 x 10 ⁻³	180*	Li	1.1
Ne	1.8 x 10 ⁻⁴	6.4*	Ca	120
Ar	.28	.35	SiO ₂	67
Kr	8.4 x 10 ⁻⁵	3.0*	pH	7.4
Xe				
H ₂				
H ₂ S	1.6 x 10 ⁻²	580*		
SO ₂				
CO ₂	13	47		
CH ₄	.36	1.3		
C _n H _n		Tr.		
NH ₃				
NO	1.0 x 10 ⁻²	370*		
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments Sample from discharge pipe of well			Geothermometry (°C) Quartz: 116 Chalcedony: 87 Na-K: 146 Na-K-Ca: 144 CO ₂ /CH ₄ : 110 Na/Li: 94	
			moles gas/ liter H ₂ O: 1.3 x 10 ⁻³ volume gas (cc STP)/ liter H ₂ O: 28 Gas Analysis by: Water Analysis by:	

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Yucca Bath Spring
Sample location: Sierra: 13S.4W.33.000
Location number: 17
Surface temperature: 43°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	7.6	42	Na	746
O ₂	2.0	11	K	65
He	4.1 x 10 ⁻⁴	23*	Li	1.2
Ne	6.4 x 10 ⁻⁵	3.5*	Ca	165
Ar	.20	1.1	SiO ₂	41
Kr	2.4 x 10 ⁻⁵	1.4*	pH	7.2
Xe			Geothermometry (°C)	
H ₂				
H ₂ S				
SO ₂				
CO ₂	8.1	45		
CH ₄	.23	1.3	Quartz:	93
C H n n		Tr.	Chalcedony:	62
NH ₃			Na-K:	205
NO	1.2 x 10 ⁻²	680*	Na-K-Ca:	180
N ₂ O			CO ₂ /CH ₄ :	141
			Na/Li:	106
			moles gas/ liter H ₂ O: 7.9 x 10 ⁻⁴ volume gas (cc STP)/ liter H ₂ O: 18	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from spring in bath house				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Sierra Grande

Sample location: Sierra: 13S.4W.33.000

Location number: 18

Surface temperature: 44°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	11	38	Na	853
O ₂	2.4	8.6	K	64
He	1.8×10^{-3}	65*	Li	1.3
Ne	2.1×10^{-4}	7.3*	Ca	152
Ar	.31	1.1	SiO ₂	43
Kr	4.8×10^{-5}	1.7*	pH	7.6
Xe	_____	_____		
H ₂	_____	_____		
H ₂ S	_____	_____	Geothermometry (°C)	
SO ₂	_____	_____	Quartz:	95
CO ₂	14	51	Chalcedony:	64
CH ₄	38	1.2	Na-K:	193
C _n H _n	_____	Tr.	Na-K-Ca:	176
NH ₃	_____	_____	CO ₂ /CH ₄ :	111
NO	1.6×10^{-2}	580*	Na/Li:	100
N ₂ O	_____	_____	moles gas/ liter H ₂ O: 1.3×10^{-3}	
_____	_____	_____	volume gas (cc STP)/ liter H ₂ O: 28	
_____	_____	_____	Gas Analysis by:	
_____	_____	_____	Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from faucet in bath house from well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Artesian Bath Well

Sample location: Sierra: 13S.4W.33.000

Location number: 19

Surface temperature: 45°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	11	39	Na	864
O ₂	2.2	8.0	K	65
He	1.9 x 10 ⁻³	69*	Li	1.3
Ne	2.8 x 10 ⁻⁴	10*	Ca	148
Ar	.32	1.2	SiO ₂	42
Kr	2.7 x 10 ⁻⁵	1.0*	pH	7.6
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	14	51		
CH ₄	.30	1.1		
C _n H _n		Tr.		
NH ₃				
NO	1.5 x 10 ⁻²	570*		
N ₂ O				
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 93	
* - in ppm (volume)			Chalcedony: 63	
			Na-K: 194	
			Na-K-Ca: 176	
			CO ₂ /CH ₄ : 120	
			Na/Li: 100	

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Radium Springs Bath House

Sample location: Dona Ana: 21S.1W.10.213

Location number: 20

Surface temperature: 53°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	6.5	9.4	Na	1167
O ₂	.58	.8	K	185
He	4.3 x 10 ⁻³	60*	Li	1.2
Ne		n.d.	Ca	92
Ar	.20	.28	SiO ₂	63
Kr		n.d.	pH	6.8
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	65	90		
CH ₄	.19	.26		
C _n H _n				
NH ₃				
NO	2.4 x 10 ⁻²	330*		
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry (°C)	
Quartz:	113
Chalcedony:	84
Na-K:	260
Na-K-Ca:	232
CO ₂ /CH ₄ :	192
Na/Li:	78

moles gas/ liter H ₂ O:	3.2 x 10 ⁻³
volume gas (cc STP)/ liter H ₂ O:	72
Gas Analysis by:	
Water Analysis by:	

Comments
Sample from faucet in bath house

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Radium Springs Well #2

Sample location: Dona Ana: 21S.1W.10.213

Location number: 21

Surface temperature: 53°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	6.0	8.0	Na	1120
O ₂	.32	.42	K	173
He	3.4 x 10 ⁻³	45*	Li	1.2
Ne	1.1 x 10 ⁻⁴	1.4*	Ca	.20
Ar	.12	.16	SiO ₂	64
Kr	5.6 x 10 ⁻⁶	.075*	pH	6.8
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	68	91		
CH ₄	.09	.12		
C _n H _n				
NH ₃				
NO	7.1 x 10 ⁻³	95*		
N ₂ O				
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 114	
* - in ppm (volume)			Chalcedony: 85	
			Na-K: 257	
			Na-K-Ca: 226	
			CO ₂ /CH ₄ : 220	
			Na/Li: 80	
			moles gas/ liter H ₂ O: 3.4 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 75	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from faucet of well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: NMSU Geothermal Well #1

Sample location: Dona Ana: 23S.2E.34.000

Location number: 22a

Surface temperature: 61°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	8.6	4.1	Na	386
O ₂	2.6 x 10 ⁻²	120*	K	54
He	6.7 x 10 ⁻³	32*	Li	.51
Ne	1.0 x 10 ⁻⁴	.55*	Ca	82
Ar	.21	1000*	SiO ₂	73
Kr	5.7 x 10 ⁻⁵	.27	pH	6.8
Xe				
H ₂				
H ₂ S	3.8 x 10 ⁻²	180*	Geothermometry (°C)	
SO ₂			Quartz:	120
CO ₂	200	96	Chalcedony:	92
CH ₄	.16	750*	Na-K:	247
C _n H _n			Na-K-Ca:	202
NH ₃			CO ₂ /CH ₄ :	238
NO	6.1 x 10 ³	29*	Na/Li:	92
N ₂ O				
			moles gas/ liter H ₂ O: 9.5 x 10 ⁻³	
			· volume gas (cc STP)/ liter H ₂ O: 210	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: NMSU Geothermal Well #1

Sample location:

Location number: 22b

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	13	5.5	Na	_____
O ₂	2.6×10^{-2}	170*	K	_____
He	6.2×10^{-3}	27*	Li	_____
Ne	5.8×10^{-5}	.26	Ca	_____
Ar	0.30	1300*	SiO ₂	_____
Kr	1.2×10^{-5}	0.045	pH	_____
Xe	_____	_____		
H ₂	_____	_____		
H ₂ S	9.2×10^{-2}	400*	Geothermometry (°C)	
SO ₂	_____	_____	Quartz:	
CO ₂	220	94	Chalcedony:	
CH ₄	0.25	0.11	Na-K:	
C H n n	_____	_____	Na-K-Ca:	
NH ₃	_____	_____	CO ₂ /CH ₄ : 226	
NO	1.4×10^{-2}	63*	Na/Li:	
N ₂ O	_____	_____		
_____	_____	_____	moles gas/ liter H ₂ O: 1.0×10^{-2}	
_____	_____	_____	volume gas (cc STP)/ liter H ₂ O: 230	
_____	_____	_____	Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				
<p>Comments</p> <p style="margin-left: 40px;">Duplicate sample</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: NMSU Presidents Well

Sample location: Dona Ana: 23S.2E.34.000

Location number: 23

Surface temperature: 59°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>7.6</u>	<u>4.0</u>	Na	<u>450</u>
O ₂	<u>1.3 x 10⁻²</u>	<u>67*</u>	K	<u>55</u>
He	<u>3.6 x 10⁻³</u>	<u>19*</u>	Li	<u>.48</u>
Ne	<u>6.8 x 10⁻⁵</u>	<u>.36*</u>	Ca	<u>105</u>
Ar	<u>0.18</u>	<u>940*</u>	SiO ₂	<u>71</u>
Kr	<u>1.9 x 10⁻⁵</u>	<u>0.10*</u>	pH	<u>7.1</u>
Xe	<u> </u>	<u> </u>	Geothermometry (°C)	
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u>0.10</u>	<u>530*</u>	Quartz:	119
SO ₂	<u> </u>	<u> </u>	Chalcedony:	90
CO ₂	<u>180</u>	<u>96</u>	Na-K:	234
CH ₄	<u>0.34</u>	<u>0.18</u>	Na-K-Ca:	194
C _n H _n	<u> </u>	<u> </u>	CO ₂ /CH ₄ :	207
NH ₃	<u> </u>	<u> </u>	Na/Li:	130
NO	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 8.6 x 10 ⁻³ volume gas (cc STP)/ liter H ₂ O: 190 Gas Analysis by:	
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>	Water Analysis by:	
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>	Comments	
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample location: NMSU, Las Cruces

Surface temperature: 30°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	80	9.3	Na	2400
O ₂	8.1 x 10 ⁻³	94*	K	26
He	3.3 x 10 ⁻³	38*	Li	.26
Ne	1.1 x 10 ⁻⁴	1.3*	Ca	680
Ar	0.19	2200*	SiO ₂	50
Kr	3.9 x 10 ⁻⁵	.45*	pH	
Xe				
H ₂				
H ₂ S	0.28	0.33	Geothermometry (°C)	
SO ₂			Quartz:	102
CO ₂	78	91	Chalcedony:	72
CH ₄			Na-K:	80
C _n H _n			Na-K-Ca:	88
NH ₃			CO ₂ /CH ₄ :	190
NO	1.7 x 10 ⁻²	200*	Na/Li:	-.14
N ₂ O				
			moles gas/ liter H ₂ O: 3.5 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 86	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Hillsboro Warm Spring

Sample location: Sierra: 31°57.2' 107°34.9'

Location number: 24a

Surface temperature: 34°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	9.2	54	Na	186
O ₂	3.1	18	K	14
He	8.0 x 10 ⁻⁴	47*	Li	.28
Ne	3.8 x 10 ⁻⁴	23*	Ca	10
Ar	.29	1.7	SiO ₂	135
Kr	2.4 x 10 ⁻⁴	1.4*	pH	6.8
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	4.6	27		
CH ₄	.26	1.5		
C _n H _n	Tr.	Tr.		
NH ₃	4.6 x 10 ⁻²	.27		
NO	1.0 x 10 ⁻²	580*		
N ₂ O				
n.d. - not detected			Geothermometry (°C) Quartz: 155 Chalcedony: 130 Na-K: 193 Na-K-Ca: 173 CO ₂ /CH ₄ : 85 Na/Li: 100	
N.M. - not measured				
* - in ppm (volume)				
Comments Sample of spring water			moles gas/ liter H ₂ O: 7.4 x 10 ⁻⁴ volume gas (cc STP)/ liter H ₂ O: 17 Gas Analysis by:	
			Water Analysis by:	

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Hillsboro Warm Spring

Sample location: Sierra:

Location number: 24b

Surface temperature: 34°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	_____	95	Na	_____
O ₂	_____	.76	K	_____
He	_____	52*	Li	_____
Ne	_____	.49*	Ca	_____
Ar	_____	1.1	SiO ₂	_____
Kr	_____	2.9*	pH	_____
Xe	_____	_____	Geothermometry (°C)	
H ₂	_____	_____	Quartz:	
H ₂ S	_____	_____	Chalcedony:	
SO ₂	_____	_____	Na-K:	
CO ₂	_____	.80	Na-K-Ca:	
CH ₄	_____	2.0	CO ₂ /CH ₄ : -53	
C _n H _n	_____	Tr.	Na/Li:	
NH ₃	_____	_____	moles gas/ liter H ₂ O:	
NO	_____	1100*	volume gas (cc STP)/ liter H ₂ O:	
N ₂ O	_____	_____	Gas Analysis by:	
_____	_____	_____	Water Analysis by:	
_____	_____	_____		
_____	_____	_____		
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
<p>Comments</p> <p style="text-align: center;">Sample of gas bubbling from spring</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Mimbres Spring

Sample location: Grant: 18S.10W.13.110

Location number: 25

Surface temperature: 58°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>48</u>	<u>71</u>	Na	<u>111</u>
O ₂	<u>16</u>	<u>23</u>	K	<u>1.3</u>
He	<u>6.3 x 10⁻³</u>	<u>92*</u>	Li	<u>.13</u>
Ne	<u>1.0 x 10⁻³</u>	<u>15*</u>	Ca	<u>2.4</u>
Ar	<u>1.3</u>	<u>1.9</u>	SiO ₂	<u>55</u>
Kr	<u>3.3 x 10⁻⁴</u>	<u>4.8*</u>	pH	<u>7.9</u>
Xe	<u> </u>	<u> </u>	Geothermometry (°C)	
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>		
SO ₂	<u> </u>	<u> </u>		
CO ₂	<u>.34</u>	<u>.5</u>	Quartz:	107
CH ₄	<u>3.2</u>	<u>4.7</u>	Chalcedony:	77
C _n H _n	<u>Tr.</u>	<u>Tr.</u>	Na-K:	82
NH ₃	<u> </u>	<u> </u>	Na-K-Ca:	78
NO	<u>.10</u>	<u>1500*</u>	CO ₂ /CH ₄ :	-50
N ₂ O	<u> </u>	<u> </u>	Na/Li:	85
<u> </u>	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 3.0 x 10 ⁻³ volume gas (cc STP)/ liter H ₂ O: 68 Gas Analysis by:	
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from bubbling spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Mimbres Spring

Sample location:

Location number: 25

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12		Na	
O ₂	4		K	
He	1.6×10^{-3}		Li	
Ne	2.5×10^{-4}		Ca	
Ar	0.33		SiO ₂	
Kr	8.3×10^{-5}		pH	
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	0.34			
CH ₄	0.80			
C _n H _n				
NH ₃				
NO	2.5×10^{-2}			
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry	
Quartz:	
Chalcedony:	
Na-K:	
Na-K-Ca:	
CO ₂ /CH ₄ :	
Na/Li:	

moles gas/ liter H ₂ O:	8.0×10^{-4}
volume gas (cc STP)/ liter H ₂ O:	18
Gas Analysis by:	
Water Analysis by:	

Comments
Corrected for excess gas from bubbling spring

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Faywood Spring

Sample location: Grant: 20S.11W.20.243

Location number: 26

Surface temperature: 55°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>12</u>	<u>41</u>	Na	<u>98</u>
O ₂	<u>2.2</u>	<u>7.6</u>	K	<u>7.7</u>
He	<u>1.1 x 10⁻³</u>	<u>39*</u>	Li	<u>.15</u>
Ne	<u>1.2 x 10⁻⁴</u>	<u>4.1*</u>	Ca	<u>47</u>
Ar	<u>.29</u>	<u>.99</u>	SiO ₂	<u>40</u>
Kr	<u>6.7 x 10⁻⁵</u>	<u>2.3*</u>	pH	<u>8.0</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>	Geothermometry (°C)	
SO ₂	<u> </u>	<u> </u>	Quartz:	92
CO ₂	<u>15</u>	<u>50</u>	Chalcedony:	62
CH ₄	<u>.29</u>	<u>.99</u>	Na-K:	197
C H n n	<u> </u>	<u>Tr.</u>	Na-K-Ca:	71
NH ₃	<u>1.6 x 10⁻²</u>	<u>540*</u>	CO ₂ /CH ₄ :	123
NO	<u>5.2 x 10⁻³</u>	<u>180*</u>	Na/Li:	101
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 1.3 x 10 ⁻³	
<u> </u>	<u> </u>	<u> </u>	volume gas (cc STP)/ liter H ₂ O: 29	
<u> </u>	<u> </u>	<u> </u>	Gas Analysis by:	
<u> </u>	<u> </u>	<u> </u>	Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from concrete lined spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Warm Spring Well #3

Sample location: Grant; 20S.11W.18.324

Location number: 27

Surface temperature: 34°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	25	52	Na	51
O ₂	5.2	12	K	4.6
He	1.3×10^{-3}	31*	Li	.07
Ne		n.d.	Ca	53
Ar	.37	.87	SiO ₂	50
Kr	6.0×10^{-5}	1.4*	pH	6.7
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	102
CO ₂	15	36	Chalcedony:	72
CH ₄	.19	.44	Na-K:	208
C _n H _n			Na-K-Ca:	48
NH ₃			CO ₂ /CH ₄ :	138
NO	1.4×10^{-2}	330*	Na/Li:	94
N ₂ O				
			moles gas/ liter H ₂ O: 1.9×10^{-3}	
			volume gas (cc STP)/ liter H ₂ O: 43	
			Gas Analysis by:	
			Water Analysis by:	
<p>Comments</p> <p style="margin-left: 40px;">Sample from faucet of well</p>				

n.d. - not detected

N.M. - not measured

* - in ppm (volume)

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Warm Spring Well #3

Sample location:

Location number: 27

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12		Na	
O ₂			K	
He	1.3×10^{-3}		Li	
Ne	n.d.		Ca	
Ar	.22		SiO ₂	
Kr	6.0×10^{-5}		pH	
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	15			
CH ₄	.19			
C _n H _n				
NH ₃				
NO	1.4×10^{-2}			
N ₂ O				
n.d. - not detected N.M. - not measured * - in ppm (volume)			Geothermometry Quartz: Chalcedony: Na-K: Na-K-Ca: CO ₂ /CH ₄ : Na/Li:	
			moles gas/ liter H ₂ O: 1.2×10^{-3} volume gas (cc STP)/ liter H ₂ O: 27 Gas Analysis by:	
			Water Analysis by:	
Comments Corrected for atmospheric contamination				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Riverside Well

Sample location: Grant; 6S.17.W.4224

Location number: 28

Surface temperature: 38°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	17	73	Na	138
O ₂	.21	.92	K	1.8
He	2.8×10^{-3}	120*	Li	.14
Ne	1.4×10^{-4}	6.6*	Ca	21
Ar	.39	1.7	SiO ₂	39
Kr	6.7×10^{-4}	2.9*	pH	6.8
Xe	_____	_____	Geothermometry (°C) Quartz: 90 Chalcedony: 59 Na-K: 87 Na-K-Ca: 48 CO ₂ /CH ₄ : 73 Na/Li: 77	
H ₂	_____	_____	moles gas/ liter H ₂ O: 1.0×10^{-3} volume gas (cc STP)/ liter H ₂ O: 23 Gas Analysis by:	
H ₂ S	_____	_____	Water Analysis by:	
SO ₂	_____	_____		
CO ₂	5.3	23		
CH ₄	.41	1.8		
C _n H _n	_____	_____		
NH ₃	_____	_____		
NO	2.3×10^{-2}	1000*		
N ₂ O	_____	_____		
_____	_____	_____		
_____	_____	_____		
_____	_____	_____		
n.d. - not detected N.M. - not measured * - in ppm (volume)				
Comments Sample from faucet of well				

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Surface temperature: 25°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	11	92	Na	216
O ₂	0.29	2.4	K	0.85
He	3.6 x 10 ⁻⁴	30*	Li	0.27
Ne	1.0 x 10 ⁻⁴	8.6*	Ca	4.0
Ar	0.29	2.4	SiO ₂	44
Kr	2.9 x 10 ⁻⁵	2.4*	pH	8.2
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	0.42	3.5		
CH ₄	0.25	2.1*		
C _n H _n				
NH ₃				
NO				
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry (°C)	
Quartz:	96
Chalcedony:	65
Na-K:	40
Na-K-Ca:	62
CO ₂ /CH ₄ :	0
Na/Li:	89

moles gas/ liter H ₂ O:	5.4 x 10 ⁻⁴
volume gas (cc STP)/ liter H ₂ O:	12
Gas Analysis by:	
Water Analysis by:	

Comments
Sample from faucet of well

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Middle Artesian Well, Gila Hot Springs

Sample location: Grant: 3S.13W.5.120

Location number: 30

Surface temperature: 62°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	11	85	Na	142
O ₂	0.99	7.6	K	3.5
He	6.4×10^{-4}	49*	Li	0.26
Ne	1.2×10^{-4}	9.6*	Ca	57
Ar	0.31	2.4	SiO ₂	71
Kr	1.9×10^{-4}	15*	pH	7.6
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	119
CO ₂	0.68	5.2	Chalcedony:	90
CH ₄	6.2×10^{-2}	0.48	Na-K:	120
C H n n			Na-K-Ca:	48
NH ₃			CO ₂ /CH ₄ :	67
NO	4.9×10^{-3}	380*	Na/Li:	112
N ₂ O				
			moles gas/ liter H ₂ O: 5.6×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 13	
			Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from Artesian Well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Gila Hot Spring

Sample location: Grant: 3S.13W.5.120

Location number: 31

Surface temperature: 59°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	13	91	Na	135
O ₂	0.77	5.5	K	3.4
He	1.8×10^{-3}	130*	Li	.26
Ne	8.5×10^{-5}	23*	Ca	13
Ar	0.27	1.9	SiO ₂	68
Kr	3.4×10^{-5}	2.4*	pH	7.4
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	0.27	1.9	Geothermometry (°C)	
CH ₄	0.11	0.79	Quartz:	117
C H n n		Tr.	Chalcedony:	88
NH ₃			Na-K:	122
NO	6.6×10^{-3}	470*	Na-K-Ca:	76
N ₂ O			CO ₂ /CH ₄ :	13
			Na/Li:	115
n.d. - not detected			moles gas/ liter H ₂ O: 6.4×10^{-4}	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 14	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	
Comments:				
Sample from discharge pipe of capped spring				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Northern Artesian Well, Gila Hot Springs

Sample location: Grant: 3S.13W.5.120

Location number: 32

Surface temperature: 65°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	15	82	Na	148
O ₂	1.0	5.6	K	3.7
He	2.5×10^{-3}	140*	Li	0.24
Ne	7.5×10^{-5}	4.1*	Ca	10
Ar	0.35	2.0	SiO ₂	71
Kr	6.1×10^{-5}	3.4*	pH	7.6
Xe	_____	_____	Geothermometry (°C) Quartz: 119 Chalcedony: 90 Na-K: 121 Na-K-Ca: 85 CO ₂ /CH ₄ : 47 Na/Li: 104	
H ₂	_____	_____	moles gas/ liter H ₂ O: 7.9×10^{-4} volume gas (cc STP)/ liter H ₂ O: 18 Gas Analysis by: _____ Water Analysis by: _____	
H ₂ S	_____	_____		
SO ₂	_____	_____		
CO ₂	1.7	9.2		
CH ₄	0.27	1.5		
C _n H _n	_____	Tr.		
NH ₃	_____	_____		
NO	1.5×10^{-2}	860*		
N ₂ O	_____	_____		
_____	_____	_____		
_____	_____	_____		
_____	_____	_____		
n.d. - not detected N.M. - not measured * - in ppm (volume)				
Comments Sample from artesian well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Middle Fork Gila River Hot Spring

Sample location: Catron: 2S.14W.24.442

Location number: 33

Surface temperature: 65°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	41	95	Na	164
O ₂	0.52	1.2	K	3.9
He	2.3 x 10 ⁻³	53*	Li	.45
Ne	1.3 x 10 ⁻⁴	3.0*	Ca	17
Ar	0.20	0.46	SiO ₂	73
Kr	1.3 x 10 ⁻⁴	3.5*	pH	7.6
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	120
CO ₂	1.3	3.1	Chalcedony:	92
CH ₄	5.2 x 10 ⁻²	0.12	Na-K:	118
C _n H _n		Tr.	Na-K-Ca:	77
NH ₃			CO ₂ /CH ₄ :	97
NO	4.7 x 10 ⁻³	110*	Na/Li:	140
N ₂ O				
			moles gas/ liter H ₂ O: 1.9 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 43	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from bubbling spring

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Middle Fork Gila River Hot Spring

Sample location:

Location number: 33

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12		Na	
O ₂			K	
He	6.7×10^{-4}		Li	
Ne	1.3×10^{-4}		Ca	
Ar	0.26		SiO ₂	
Kr	4.4×10^{-5}		pH	
Xe				
H ₂				
H ₂ S			Geothermometry	
SO ₂			Quartz:	
CO ₂	1.3		Chalcedony:	
CH ₄	0.05		Na-K:	
C _n H _n			Na-K-Ca:	
NH ₃			CO ₂ /CH ₄ :	
NO	4.7×10^{-3}		Na/Li:	
N ₂ O			moles gas/ liter H ₂ O: 6.3×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 14	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Corrected for excess gas.				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Lower Frisco Spring

Sample location: Catron: 12S.20W.23.120

Location number: 34

Surface temperature: 49°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	16	67	Na	296
O ₂	4.3	18	K	17
He	1.4 x 10 ⁻³	59*	Li	.46
Ne	4.9 x 10 ⁻⁴	21*	Ca	51
Ar	.36	1.5	SiO ₂	80
Kr	1.2 x 10 ⁻⁴	5.1*	pH	7.6
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.9	12	Geothermometry (°C)	
CH ₄	0.65	2.7	Quartz:	125
C _n H _n		Tr.	Chalcedony:	97
NH ₃			Na-K:	174
NO	2.6 x 10 ⁻²	1100*	Na-K-Ca:	154
N ₂ O			CO ₂ /CH ₄ :	35
			Na/Li:	101
n.d. - not detected			moles gas/ liter H ₂ O: 1.1 x 10 ⁻³	
N.M. - not measured			volume gas (cc STP)/ liter H ₂ O: 24	
* - in ppm (volume)			Gas Analysis by:	
			Water Analysis by:	

Comments
Sample from bubbling spring near river

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Upper Frisco Spring

Sample location: Catron; 5S.19W.35.100

Location number: 35

Surface temperature: 39°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>4.8</u>	<u>44</u>	Na	<u>71</u>
O ₂	<u>4.4</u>	<u>40</u>	K	<u>.24</u>
He	<u>3.2 x 10⁻⁴</u>	<u>29*</u>	Li	<u>.01</u>
Ne	<u>1.8 x 10⁻⁴</u>	<u>17*</u>	Ca	<u>.8</u>
Ar	<u>.61</u>	<u>5.5</u>	SiO ₂	<u>49</u>
Kr	<u>1.4 x 10⁻⁴</u>	<u>13*</u>	pH	<u>8.1</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>	Geothermometry (°C)	
SO ₂	<u> </u>	<u> </u>	Quartz:	101
CO ₂	<u>6.3 x 10⁻²</u>	<u>0.57</u>	Chalcedony:	71
CH ₄	<u>1.4 x 10⁻²</u>	<u>0.13</u>	Na-K:	34
C _n H _n	<u> </u>	<u> </u>	Na-K-Ca:	46
NH ₃	<u> </u>	<u> </u>	CO ₂ /CH ₄ :	35
NO	<u>4.4 x 10⁻²</u>	<u>4000*</u>	Na/Li:	-4
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 5.1 x 10 ⁻⁴	
<u> </u>	<u> </u>	<u> </u>	volume gas (cc STP)/ liter H ₂ O: 11	
<u> </u>	<u> </u>	<u> </u>	Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from spring in concrete lined pool

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-30-12

Sample location: Hidalgo; 24S.20W.1.440

Location number: 36

Surface temperature: 19°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	14	62	Na	375
O ₂	5.8	25	K	6.8
He	1.6×10^{-4}	7*	Li	.19
Ne	1.8×10^{-4}	7.7*	Ca	171
Ar	0.29	1.3	SiO ₂	56
Kr	4.1×10^{-5}	1.8*	pH	7.1
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	108
CO ₂	2.2	9.5	Chalcedony:	78
CH ₄	0.85	3.7	Na-K:	104
C _n H _n			Na-K-Ca:	55
NH ₃			CO ₂ /CH ₄ :	15
NO	2.5×10^{-2}	1100	Na/Li:	44
N ₂ O				
			moles gas/ liter H ₂ O: 1×10^{-3}	
			volume gas (cc STP)/ liter H ₂ O: 23	
			Gas Analysis by:	
			Water Analysis by:	
<p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p>				
<p>Comments:</p> <p>Sample from well discharge pipe</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-30-12

Sample location:

Location number: 36

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12	_____	Na	_____
O ₂	_____	_____	K	_____
He	1.6×10^{-4}	_____	Li	_____
Ne	1.8×10^{-4}	_____	Ca	_____
Ar	.27	_____	SiO ₂	_____
Kr	4.1×10^{-5}	_____	pH	_____
Xe	_____	_____	Geothermometry Quartz: _____ Chalcedony: _____ Na-K: _____ Na-K-Ca: _____ CO ₂ /CH ₄ : _____ Na/Li: _____	
H ₂	_____	_____	moles gas/ liter H ₂ O: 6.8×10^{-4} volume gas (cc STP)/ liter H ₂ O: 15 Gas Analysis by: _____ Water Analysis by: _____	
H ₂ S	_____	_____		
SO ₂	_____	_____		
CO ₂	2.2	_____		
CH ₄	.85	_____		
C H n n	_____	_____		
NH ₃	_____	_____		
NO	2.5×10^{-2}	_____		
N ₂ O	_____	_____		
_____	_____	_____		
_____	_____	_____		
_____	_____	_____		
n.d. - not detected N.M. - not measured * - in ppm (volume)				
Comments Corrected for atmospheric contamination				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 3-28-4

Sample location: Hidalgo: 24S.20W.25.421

Location number: 37

Surface temperature: 20°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	8.6	47	Na	491
O ₂	2.5	14	K	25
He	5.8×10^{-4}	32*	Li	0.95
Ne	2.3×10^{-4}	13*	Ca	104
Ar	.20	1.1	SiO ₂	94
Kr	2.7×10^{-5}	1.5*	pH	7.0
Xe	_____	_____	Geothermometry (°C)	
H ₂	_____	_____	Quartz:	133
H ₂ S	_____	_____	Chalcedony:	106
SO ₂	_____	_____	Na-K:	164
CO ₂	6.5	36	Na-K-Ca:	149
CH ₄	0.23	1.3	CO ₂ /CH ₄ :	101
C _n H _n	_____	Tr.	Na/Li:	115
NH ₃	_____	_____	moles gas/ liter H ₂ O: 7.9×10^{-4}	
NO	1.4×10^{-2}	760*	volume gas (cc STP)/ liter H ₂ O: 18	
N ₂ O	_____	_____	Gas Analysis by:	
_____	_____	_____	Water Analysis by:	
_____	_____	_____		
_____	_____	_____		
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
<p>Comments</p> <p style="margin-left: 40px;">Sample from discharge pipe of well</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 3-28-3

Sample location: Hidalgo: 24S.20W.35.124

Location number: 38

Surface temperature: 20°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	7.7	43	Na	66
O ₂	3.6	20	K	2.0
He	5.2×10^{-4}	29*	Li	0.05
Ne	1.7×10^{-4}	9.6*	Ca	30
Ar	0.25	1.4	SiO ₂	42
Kr	4.3×10^{-5}	24*	pH	7.0
Xe	_____	_____	Geothermometry (°C) Quartz: 94 Chalcedony: 63 Na-K: 132 Na-K-Ca: 37 CO ₂ /CH ₄ : 85 Na/Li: 63	
H ₂	_____	_____	moles gas/ liter H ₂ O: 7.9×10^{-4} volume gas (cc STP)/ liter H ₂ O: 18 Gas Analysis by:	
H ₂ S	_____	_____	Water Analysis by:	
SO ₂	_____	_____		
CO ₂	6.5	36		
CH ₄	0.36	2.0		
C _n H _n	_____	_____		
NH ₃	_____	_____		
NO	1.3×10^{-2}	710*		
N ₂ O	_____	_____		
_____	_____	_____		
_____	_____	_____		
_____	_____	_____		
n.d. - not detected N.M. - not measured * - in ppm (volume)				
Comments Sample from discharge pipe of well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 3-28-2

Sample location: Hidalgo: 25S.20W.12.213

Location number: 39

Surface temperature: 8°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12	59	Na	105
O ₂	5.4	27	K	3.5
He	1.8 x 10 ⁻⁴	9.2*	Li	.35
Ne	1.7 x 10 ⁻⁴	8.3*	Ca	61
Ar	.54	2.7	SiO ₂	37
Kr	1.7 x 10 ⁻⁵	.87*	pH	7.0
Xe			<div>Geothermometry (°C)</div> <div>Quartz: 89</div> <div>Chalcedony: 58</div> <div>Na-K: 138</div> <div>Na-K-Ca: 44</div> <div>CO₂/CH₄: 49</div> <div>Na/Li: 155</div> <div>moles gas/ liter H₂O: 8.9 x 10⁻⁴</div> <div>volume gas (cc STP)/ liter H₂O: 20.0</div> <div>Gas Analysis by:</div> <div>Water Analysis by:</div>	
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.4	12		
CH ₄	.36	1.8		
C _n H _n				
NH ₃				
NO	2.0 x 10 ⁻²	1000*		
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from discharge pipe of well

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-19-7 (Hot Well)

Sample location: Hidalgo; 25S.19W.7.134

Location number: 40

Surface temperature: 96°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	1.8×10^{-2}	6.6	Na	299
O ₂	5.0×10^{-4}	.18	K	22
He	3.6×10^{-6}	13*	Li	0.74
Ne	4.9×10^{-6}	17*	Ca	29
Ar	3.1×10^{-4}	1100*	SiO ₂	106
Kr	2.2×10^{-7}	.77*	pH	6.8
Xe				
H ₂	5.6×10^{-4}	0.2		
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	140
CO ₂	0.26	91	Chalcedony:	114
CH ₄	5.0×10^{-5}	180*	Na-K:	190
C H n n			Na-K-Ca:	170
NH ₃			CO ₂ /CH ₄ :	290
NO	1.7×10^{-5}	61*	Na/Li:	132
N ₂ O				
			moles gas/ liter H ₂ O: 1.2×10^{-5}	
			volume gas (cc STP)/ liter H ₂ O: 0.28	
			Gas Analysis by:	
			Water Analysis by:	
<p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p>				
<p>Comments</p> <p>Sample from pressure gage fitting on well discharge pipe. Gas sample has been depleted by subsurface boiling.</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 3-28-1

Sample location: Hidalgo: 25S.20W.13.120

Location number: 41

Surface temperature: 19°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	15	54	Na	408
O ₂	3.0	11	K	12
He	4.9 x 10 ⁻⁴	18*	Li	0.45
Ne	1.6 x 10 ⁻⁴	23*	Ca	233
Ar	0.29	1.1	SiO ₂	41
Kr	1.2 x 10 ⁻⁴	4.4*	pH	6.9
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	93
CO ₂	8.4	31	Chalcedony:	63
CH ₄	0.68	2.5	Na-K:	131
C _n H _n			Na-K-Ca:	67
NH ₃			CO ₂ /CH ₄ :	70
NO	3.0 x 10 ⁻²	1100*	Na/Li:	81
N ₂ O				
			moles gas/ liter H ₂ O: 1.2 x 10 ⁻³	
			volume gas (cc STP)/ liter H ₂ O: 27	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Comments
Sample from discharge pipe of well

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 3-28-1

Sample location:

Location number: 41

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12		Na	
O ₂			K	
He	4.9×10^{-4}		Li	
Ne	1.6×10^{-4}		Ca	
Ar	0.25		SiO ₂	
Kr	1.2×10^{-4}		pH	
Xe				
H ₂				
H ₂ S			Geothermometry	
SO ₂			Quartz:	
CO ₂	8.4		Chalcedony:	
CH ₄	0.68		Na-K:	
C _n H _n			Na-K-Ca:	
NH ₃			CO ₂ /CH ₄ :	
NO	3.0×10^{-2}		Na/Li:	
N ₂ O			moles gas/ liter H ₂ O: 9.6×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 21	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample corrected for air contamination				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 7-6-13

Sample location: Hidalgo: 25S.20W.16.333

Location number: 42

Surface temperature: 26°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>10</u>	<u>64</u>	Na	<u>131</u>
O ₂	<u>3.7</u>	<u>23</u>	K	<u>2.6</u>
He	<u>1.6 x 10⁻⁴</u>	<u>9.7*</u>	Li	<u>0.14</u>
Ne	<u>8.1 x 10⁻⁵</u>	<u>5.1*</u>	Ca	<u>27</u>
Ar	<u>0.26</u>	<u>1.6</u>	SiO ₂	<u>38</u>
Kr	<u>9.6 x 10⁻⁵</u>	<u>6.0</u>	pH	<u>7.0</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>		
SO ₂	<u> </u>	<u> </u>		
CO ₂	<u>1.6</u>	<u>9.7</u>		
CH ₄	<u>0.46</u>	<u>2.9</u>		
C _n H _n	<u> </u>	<u>Tr.</u>		
NH ₃	<u> </u>	<u> </u>		
NO	<u>2.2 x 10⁻²</u>	<u>1400*</u>		
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>		
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
			Geothermometry (°C)	
			Quartz:	89
			Chalcedony:	59
			Na-K:	109
			Na-K-Ca:	53
			CO ₂ /CH ₄ :	26
			Na/Li:	80
			moles gas/ liter H ₂ O: 7.4 x 10 ⁻⁴	
			volume gas (cc STP)/ liter H ₂ O: 16	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from discharge pipe of well				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 7-6-15

Sample location: Hidalgo: 25S.20W.25.323

Location number: 43

Surface temperature: 19°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	<u>14</u>	<u>54</u>	Na	<u>160</u>
O ₂	<u>7.0</u>	<u>27</u>	K	<u>4.5</u>
He	<u>1.1 x 10⁻⁴</u>	<u>4.4*</u>	Li	<u>0.16</u>
Ne	<u>9.2 x 10⁻⁵</u>	<u>3.6*</u>	Ca	<u>105</u>
Ar	<u>0.39</u>	<u>1.5</u>	SiO ₂	<u>38</u>
Kr	<u>3.4 x 10⁻⁵</u>	<u>1.3*</u>	pH	<u>7.2</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>	Geothermometry (°C)	
SO ₂	<u> </u>	<u> </u>	Quartz:	89
CO ₂	<u>4.2</u>	<u>16</u>	Chalcedony:	59
CH ₄	<u>.65</u>	<u>2.5</u>	Na-K:	128
C _n H _n	<u> </u>	<u> </u>	Na-K-Ca:	45
NH ₃	<u> </u>	<u> </u>	CO ₂ /CH ₄ :	48
NO	<u>3.4 x 10⁻²</u>	<u>1300*</u>	Na/Li:	77
N ₂ O	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 1.5 x 10 ⁻³	
<u> </u>	<u> </u>	<u> </u>	volume gas (cc STP)/ liter H ₂ O: 26	
<u> </u>	<u> </u>	<u> </u>	Gas Analysis by:	
<u> </u>	<u> </u>	<u> </u>	Water Analysis by:	
<div style="display: flex; justify-content: space-between;"> <div> n.d. - not detected N.M. - not measured * - in ppm (volume) </div> </div>				
Comments Sample from well discharge pipe				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 7-6-15

Sample location:

Location number: 43

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12		Na	
O ₂			K	
He	1.1×10^{-4}		Li	
Ne	9.2×10^{-5}		Ca	
Ar	.31		SiO ₂	
Kr	3.4×10^{-5}		pH	
Xe				
H ₂				
H ₂ S			Geothermometry	
SO ₂			Quartz:	
CO ₂	4.2		Chalcedony:	
CH ₄	.65		Na-K:	
C H n n			Na-K-Ca:	
NH ₃			CO ₂ /CH ₄ :	
NO	3.4×10^{-2}		Na/Li:	
N ₂ O				
			moles gas/ liter H ₂ O: 7.8×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 17	
			Gas Analysis by:	
n.d. - not detected				
N.M. - not measured			Water Analysis by:	
* - in ppm (volume)				
Comments				
Corrected for air contamination				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-23-10

Sample location: Hidalgo: 25S.20W.25.411

Location number: 44

Surface temperature: 23°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	13	55	Na	138
O ₂	4.1	17	K	5.5
He	4.8×10^{-4}	20*	Li	0.17
Ne	1.7×10^{-4}	7.1*	Ca	72
Ar	0.29	1.2	SiO ₂	31
Kr	1.3×10^{-4}	5.4*	pH	7.0
Xe				
H ₂				
H ₂ S			Geothermometry (°C)	
SO ₂			Quartz:	81
CO ₂	6.0	25	Chalcedony:	49
CH ₄	.67	2.8	Na-K:	149
C _n H _n			Na-K-Ca:	56
NH ₃			CO ₂ /CH ₄ :	60
NO	2.1×10^{-2}	890	Na/Li:	88
N ₂ O				
			moles gas/ liter H ₂ O: 1.1×10^{-3}	
			volume gas (cc STP)/ liter H ₂ O: 24	
			Gas Analysis by:	
			Water Analysis by:	
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				
Comments				
Sample from well discharge pipe				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-23-11

Sample location: Hidalgo: 25S.20W.27.411

Location number: 45

Surface temperature: 20°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12	46	Na	105
O ₂	4.9	19	K	2.9
He	2.4×10^{-4}	9.2*	Li	.12
Ne	1.7×10^{-4}	6.6*	Ca	60
Ar	0.25	0.33	SiO ₂	37
Kr	4.7×10^{-5}	1.8*	pH	7.0
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	8.3	32		
CH ₄	0.55	2.1		
C _n H _n				
NH ₃				
NO	2.9×10^{-2}	1100*		
N ₂ O				
n.d.	- not detected			
N.M.	- not measured			
*	- in ppm (volume)			
			<p>Geothermometry (°C)</p> <p>Quartz: 88</p> <p>Chalcedony: 58</p> <p>Na-K: 128</p> <p>Na-K-Ca: 40</p> <p>CO₂/CH₄: 78</p> <p>Na/Li: 83</p>	
			<p>moles gas/ liter H₂O: 1.2×10^{-3}</p> <p>volume gas (cc STP)/ liter H₂O: 26</p> <p>Gas Analysis by:</p>	
			<p>Water Analysis by:</p>	
<p>Comments</p> <p>Sample from well discharge pipe</p>				

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample location: Hidalgo: T26S.R20W.5.411

Location number: 46

Surface temperature: 19°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	11	54	Na	113
O ₂	5.0	25	K	3.3
He	1.8 x 10 ⁻⁴	9.2*	Li	0.12
Ne	1.6 x 10 ⁻⁴	8.1*	Ca	74
Ar	.27	1.3	SiO ₂	45
Kr	6.0 x 10 ⁻⁵	3.0*	pH	6.8
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	3.4	17		
CH ₄	0.8	4.0		
C _n H _n		Tr.		
NH ₃				
NO	5.8 x 10 ⁻³	290*		
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry (°C)	
Quartz:	97
Chalcedony:	66
Na-K:	84
Na-K-Ca:	40
CO ₂ /CH ₄ :	32
Na/Li:	80

moles gas/ liter H ₂ O:	9.1 x 10 ⁻⁴
volume gas (cc STP)/ liter H ₂ O:	20
Gas Analysis by:	
Water Analysis by:	

Comments
Sample from well discharge pipe

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-23-5

Sample location: Hidalgo; 25S.20W.34.444

Location number: 47

Surface temperature: 21°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	<u>37</u>	<u>69</u>	Na	<u>98</u>
O ₂	<u>12</u>	<u>23</u>	K	<u>4.7</u>
He	<u>5.8 x 10⁻⁴</u>	<u>11*</u>	Li	<u>.11</u>
Ne	<u>1.4 x 10⁻⁴</u>	<u>2.6*</u>	Ca	<u>20</u>
Ar	<u>0.58</u>	<u>1.1</u>	SiO ₂	<u>37</u>
Kr	<u>9.5 x 10⁻⁵</u>	<u>1.8*</u>	pH	<u>7.0</u>
Xe	<u> </u>	<u> </u>		
H ₂	<u> </u>	<u> </u>		
H ₂ S	<u> </u>	<u> </u>	Geothermometry (°C)	
SO ₂	<u> </u>	<u> </u>	Quartz:	89
CO ₂	<u>2.7</u>	<u>5.1</u>	Chalcedony:	58
CH ₄	<u>1.4</u>	<u>2.6</u>	Na-K:	161
C _n H _n	<u> </u>	<u>Tr.</u>	Na-K-Ca:	74
NH ₃	<u>1.5 x 10⁻²</u>	<u>280*</u>	CO ₂ /CH ₄ :	4
NO	<u>2.7 x 10⁻²</u>	<u>500*</u>	Na/Li:	83
N ₂ O	<u> </u>	<u> </u>		
<u> </u>	<u> </u>	<u> </u>	moles gas/ liter H ₂ O: 2.4 x 10 ⁻³	
<u> </u>	<u> </u>	<u> </u>	volume gas (cc STP)/ liter H ₂ O: 53	
<u> </u>	<u> </u>	<u> </u>	Gas Analysis by:	
n.d. - not detected			Water Analysis by:	
N.M. - not measured				
* - in ppm (volume)				
Comments				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-23-5

Sample location:

Location number: 47

Surface temperature:

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12		Na	
O ₂			K	
He	5.8×10^{-4}		Li	
Ne	1.4×10^{-4}		Ca	
Ar	.28		SiO ₂	
Kr	9.5×10^{-5}		pH	
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.7			
CH ₄	1.4			
C _n H _n				
NH ₃	1.5×10^{-2}			
NO	2.7×10^{-2}			
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry Quartz: Chalcedony: Na-K: Na-K-Ca: CO ₂ /CH ₄ : Na/Li:	moles gas/ liter H ₂ O: 7.3×10^{-4} volume gas (cc STP)/ liter H ₂ O: 16 Gas Analysis by: Water Analysis by:
--	--

Comments Corrected for air contamination
--

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-19-6

Sample location: Hidalgo; 25S.20W.35.443

Location number: 48

Surface temperature: 24°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12	63	Na	170
O ₂	1.7	9.0	K	6.3
He	4.2×10^{-4}	22*	Li	.24
Ne	2.8×10^{-4}	15*	Ca	37
Ar	.27	1.4	SiO ₂	31
Kr	5.7×10^{-5}	3.0*	pH	7.6
Xe	_____	_____	<p>Geothermometry (°C)</p> <p>Quartz: 80</p> <p>Chalcedony: 49</p> <p>Na-K: 144</p> <p>Na-K-Ca: 76</p> <p>CO₂/CH₄: 59</p> <p>Na/Li: 96</p>	
H ₂	_____	_____		
H ₂ S	_____	_____		
SO ₂	_____	_____		
CO ₂	4.6	24		
CH ₄	.52	2.8		
C _n H _n	_____	_____		
NH ₃	_____	_____		
NO	1.7×10^{-2}	910*		
N ₂ O	_____	_____		
_____	_____	_____	<p>moles gas/ liter H₂O: 8.4×10^{-4}</p> <p>volume gas (cc STP)/ liter H₂O: 19</p> <p>Gas Analysis by:</p> <p>Water Analysis by:</p>	
_____	_____	_____		
_____	_____	_____		
_____	_____	_____		
<p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p>				
<p>Comments</p> <p style="text-align: center;">Sample from discharge pipe of well</p>				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY

DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 6-23-9

Sample location: Hidalgo: 26S.20W.4.344

Location number: 49

Surface temperature: 21°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12	62	Na	93
O ₂	4.6	23	K	2.4
He	3.8 x 10 ⁻⁴	19*	Li	.13
Ne	3.0 x 10 ⁻⁴	15*	Ca	37
Ar	0.34	1.7	SiO ₂	44
Kr	5.2 x 10 ⁻⁶	2.6*	pH	7.0
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.0	10		
CH ₄	0.80	4.0		
C _n H _n				
NH ₃				
NO	2.4 x 10 ⁻²	1200		
N ₂ O				
n.d. - not detected				
N.M. - not measured				
* - in ppm (volume)				

Geothermometry (°C)	
Quartz:	96
Chalcedony:	66
Na-K:	123
Na-K-Ca:	42
CO ₂ /CH ₄ :	13
Na/Li:	95

moles gas/ liter H ₂ O:	9 x 10 ⁻⁴
volume gas (cc STP)/ liter H ₂ O:	20
Gas Analysis by:	
Water Analysis by:	

Comments
Sample from well discharge pipe

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters
Grant No. EMD 2-68-2305 New Mexico Energy Institute
Sample name: Animas Valley 7-6-16

Sample location: Hidalgo: 26S.20W.9.344

Location number: 50

Surface temperature: 20°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.	parts per million	
N ₂	12	57	Na	131
O ₂	5.7	27	K	2.4
He	3.6 x 10 ⁻⁴	17*	Li	0.12
Ne	1.4 x 10 ⁻⁴	6.6*	Ca	41
Ar	.29	1.4	SiO ₂	37
Kr	5.5 x 10 ⁻⁵	2.6*	pH	7.2
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	2.9	14		
CH ₄	0.23	1.1		
C _n H _n				
NH ₃				
NO	9.2 x 10 ⁻³	440*		
N ₂ O				
n.d. - not detected			Geothermometry (°C)	
N.M. - not measured			Quartz: 88	
* - in ppm (volume)			Chalcedony: 57	
			Na-K: 105	
			Na-K-Ca: 43	
			CO ₂ /CH ₄ : 73	
			Na/Li: 72	
			moles gas/ liter H ₂ O: 9.4 x 10 ⁻⁴	
			volume gas (cc STP)/ liter H ₂ O: 21	
			Gas Analysis by:	
			Water Analysis by:	
Comments				
Sample from well discharge pipe				

NEW MEXICO INSTITUTE OF
MINING AND TECHNOLOGY
DEPARTMENT OF GEOSCIENCE

Gas Analysis of Geothermal Waters

Grant No. EMD 2-68-2305 New Mexico Energy Institute

Sample name: Animas Valley Well 7-6-14

Sample location: Hidalgo; 26S.20W.14.334

Location number: 51

Surface temperature: 22°C

Gas Analysis			Water Analysis	
	vol(cc)/liter	volume pct.		parts per million
N ₂	12	61	Na	96
O ₂	5.5	29	K	2.1
He	2.3×10^{-4}	12*	Li	.11
Ne	1.6×10^{-4}	8.1*	Ca	30
Ar	0.29	1.5	SiO ₂	33
Kr	1.1×10^{-4}	6.0*	pH	7.6
Xe				
H ₂				
H ₂ S				
SO ₂				
CO ₂	1.1	5.9	Geothermometry (°C)	
CH ₄	.76	4.0	Quartz:	83
C _n H _n		Tr.	Chalcedony:	52
NH ₃			Na-K:	114
NO	2.3×10^{-2}	.12	Na-K-Ca:	42
N ₂ O			CO ₂ /CH ₄ :	-7
			Na/Li:	84
			moles gas/ liter H ₂ O: 8.4×10^{-4}	
			volume gas (cc STP)/ liter H ₂ O: 19	
			Gas Analysis by:	
			Water Analysis by:	
<div style="display: flex; justify-content: space-between;"> <div> <p>n.d. - not detected</p> <p>N.M. - not measured</p> <p>* - in ppm (volume)</p> </div> <div> <p>Comments</p> <p style="margin-top: 10px;">Sample from discharge pipe of well</p> </div> </div>				

APPENDIX V

GAS DATA AND EQUILIBRIA CALCULATION ON THE
JEMEZ, NEW MEXICO WELLS AND SPRINGS

Gas geothermometry is compared to the chemical geothermometry released by DOE (Table 2). Gas geothermometers used are those proposed by Giggenbach (1980a, 1980b), and D'Amore and Panichi (1979). Giggenbach's gas geothermometers are based on gas-mineral equilibria. D'Amore and Panichi's gas geothermometer is an empirical relationship.

TABLE 1. Gas data in wells and springs in the Jemez, N. M. KGRC from data publicly released by Union Oil Company

	Baca Well #4 (ppm mol)	Baca Well #11 (ppm mol)		Baca Well #13 (ppm mol)		Sulfur Spring (mole %)
		<u>Two analyses</u>		<u>Two analyses</u>		
CH ₄	2.5	2.9	1.7	1.4	1.3	.1
H ₂ S	79.	257	229	49	92	.4
CO ₂	12,430	17,780	16,750	14,140	34,570	97.9
H ₂	12.5	23.3	37.6	5.7	0.6	0.03
N ₂	n.r	245	70	79	122	1.0
NH ₃	3.3	3.1	n.r	n.r	n.r	n.r
He	n.r	n.r	0.63	0.77	0.17	n.r

n.r = none reported

TABLE 2. Comparison of chemical and gas geothermometers for the Jemez, N.M. wells and springs.

	Baca #4	Baca #11		Baca #13		Sulfur Spring
		<u>a</u>	<u>b</u>	<u>a</u>	<u>b</u>	
T_{quartz}	189	283	298	292	292	186
$T_{\text{Na-K}}$	297	312	309	279	279	300
$T_{\text{Na-K-Ca}}$	296	298	296	289	289	227
$T_{\text{CO}_2\text{-CH}_4\text{-H}_2}^1$	318	335	350	304	255	498
$T_{\text{CO}_2\text{-CH}_4\text{-H}_2\text{S-H}_2}^1$	310	295	339	305	250	271
$T_{\text{CO}_2\text{-H}_2\text{S}}^2$	178	280	197	170	190	514
$T_{\text{CO}_2}^2$	225	228	228	227	246	-
$T_{\text{CO}_2\text{-CH}_4\text{-H}_2\text{S-H}_2}^3$	191	230	240	210	168	-
$T_{\text{CO}_2/\text{CH}_4}^4$	288	295	313	313	348	230

1. Giggenbach (1980)
2. Giggenbach (1981)
3. D'Amore and Panichi (1980)
4. This study