



INTEROFFICE CORRESPONDENCE

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to R. C. Stoker
from C. A. Allen *C.A.*
subject PRELIMINARY CHEMICAL EVALUATION OF THE RAFT RIVER AREA - CAA-G02-77

This letter follows up our conversations of the last two weeks on the chemical composition of geothermal water in the Raft River area. Included are graphs of the chemical composition of the three geothermal wells during their production lifetime to date. Both silica and Na-K-Ca geothermometers were calculated for both wells. A mixing model is proposed to explain the observed differences in chemical composition. Major conclusions from this evaluation are:

1. Differences in chemical composition point to two distinct geothermal reservoirs in the lower Raft River area.
2. The reservoir encountered by RRGE-3 contains 4100 $\mu\text{g}/\text{ml}$ of dissolved solids. The reservoir characterized by RRGE-2 contains 1250 $\mu\text{g}/\text{ml}$ dissolved solids.
3. RRGE-1, BLM and Crank wells can be described as mixtures of these two reservoirs. The Crank well contains 80% fluid from the RRGE-1 reservoir while the BLM and RRGE-1 wells are represented by 89% fluid from the RRGE-2 reservoir.
4. Geothermometry calculations using both silica and Na-K-Ca methods indicate that RRGE-1 and RRGE-2 predicted temperatures are converging. The predicted temperature from the SiO_2 geothermometer indicates fluid from both wells was at one time 320°F. The Na-K-Ca geothermometer predicts the reservoir temperature at 360°F. RRGE-3 geothermometers are rising and indicate higher reservoir temperatures than observed in RRGE-1 and RRGE-2.
5. If two reservoirs exist and RRGE-1 is a mixture of the two then the direction of flow of geothermal fluid in the RRGE-2 reservoir must be generally from the Northeast to the Southwest.

Chemical History of the Raft River Wells

All three wells have been periodically sampled since they were completed. Frequency of sampling and analysis has been low because of budgetary constraint and only intermediate flow. RRGE-1 has particularly suffered. A number of samples were taken during the first four months after drilling but since has only averaged annual sampling.

During the first few months of production the wells seem to vary considerably in composition. This is partially due to ejection of drilling fluids and the establishment of stable flow patterns at depth. RRGE-1 varied more than the other two, but during its early production sampling and analytical techniques were being developed. RRGE-1 and RRGE-2 both have leveled off over the last year. RRGE-3 is still too young to determine if its composition now remains relatively constant. Total dissolved solids content of the three wells is shown in Table 1. Figures 1, 2 and 3 show the chemical composition of each well during its lifetime to date.

Table 1

Total Dissolved Solids

	RRGE-1	RRGE-2	RRGE-3
TDS	1560	1267	4130
Conductivity	3373	2742	9530
TDS/cond.	.462	.462	.433

From Table 1 it is apparent that RRGE-3 is substantially different from RRGE-1 and RRGE-2.

Geothermometry

Silica and Na-K-Ca geothermometers were calculated for each sampling date. These are shown in Figures 4, 5 and 6. From Figure 4 it appears that both geothermometers in RRGE-1 are gradually increasing. This may be real or it may reflect the large amount of data scatter during early sampling and analysis. It must be remembered too that RRGE-1 flowed a lot less during the first year than the last year. RRGE-2 shows in Figure 5 relatively constant geothermometry predictions. This well was flowed more heavily during the first year following drilling than the second. RRGE-3, from Figure 6, appears to be increasing. This well has flowed relatively little compared to the other two and may not yet be chemically stable.

In all three cases the silica geothermometers predict lower temperatures in the range of 320°F to 345°F. The Na-K-Ca geothermometers predict temperatures from 360°F to 380°F. The reason for this difference is not

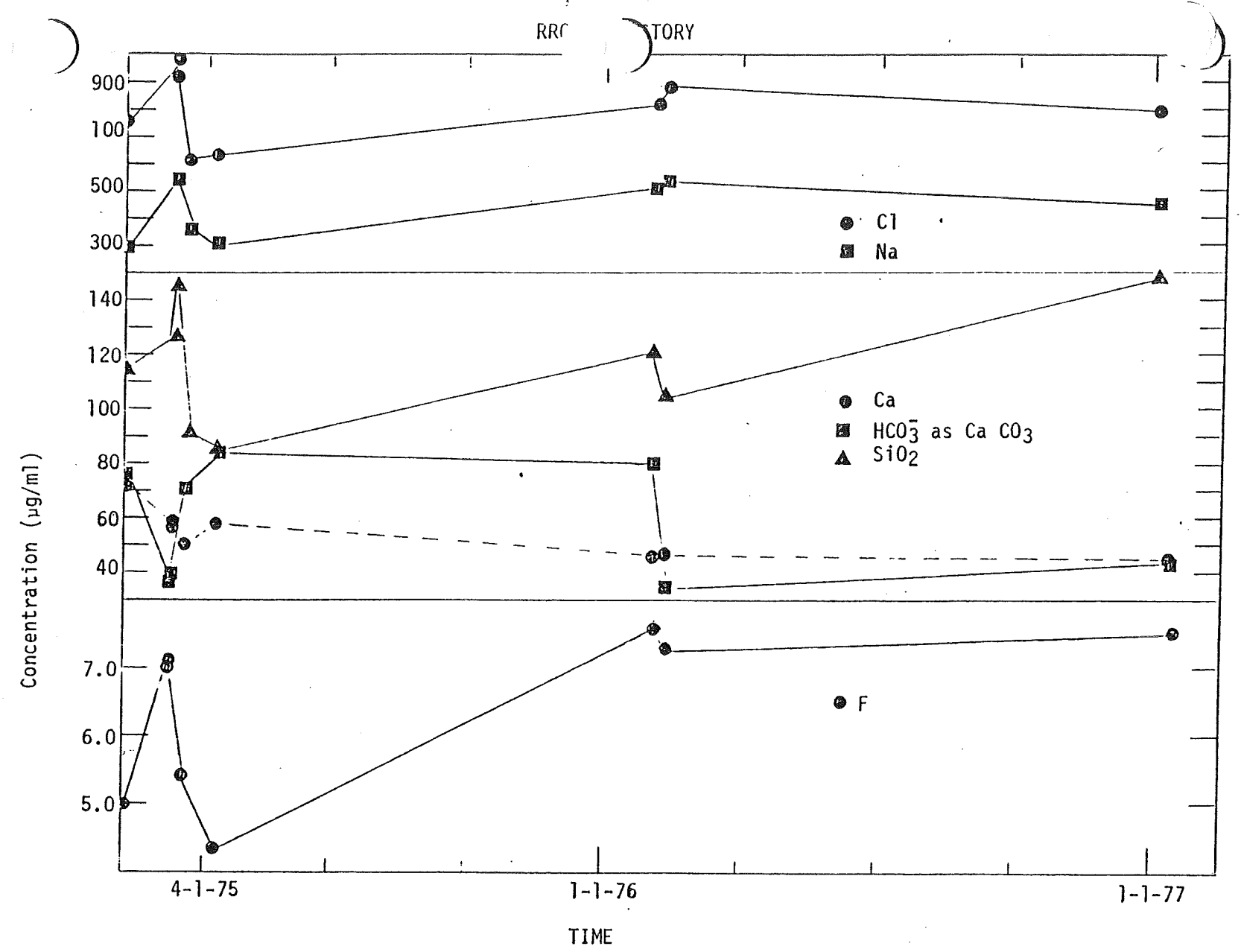


Figure 1

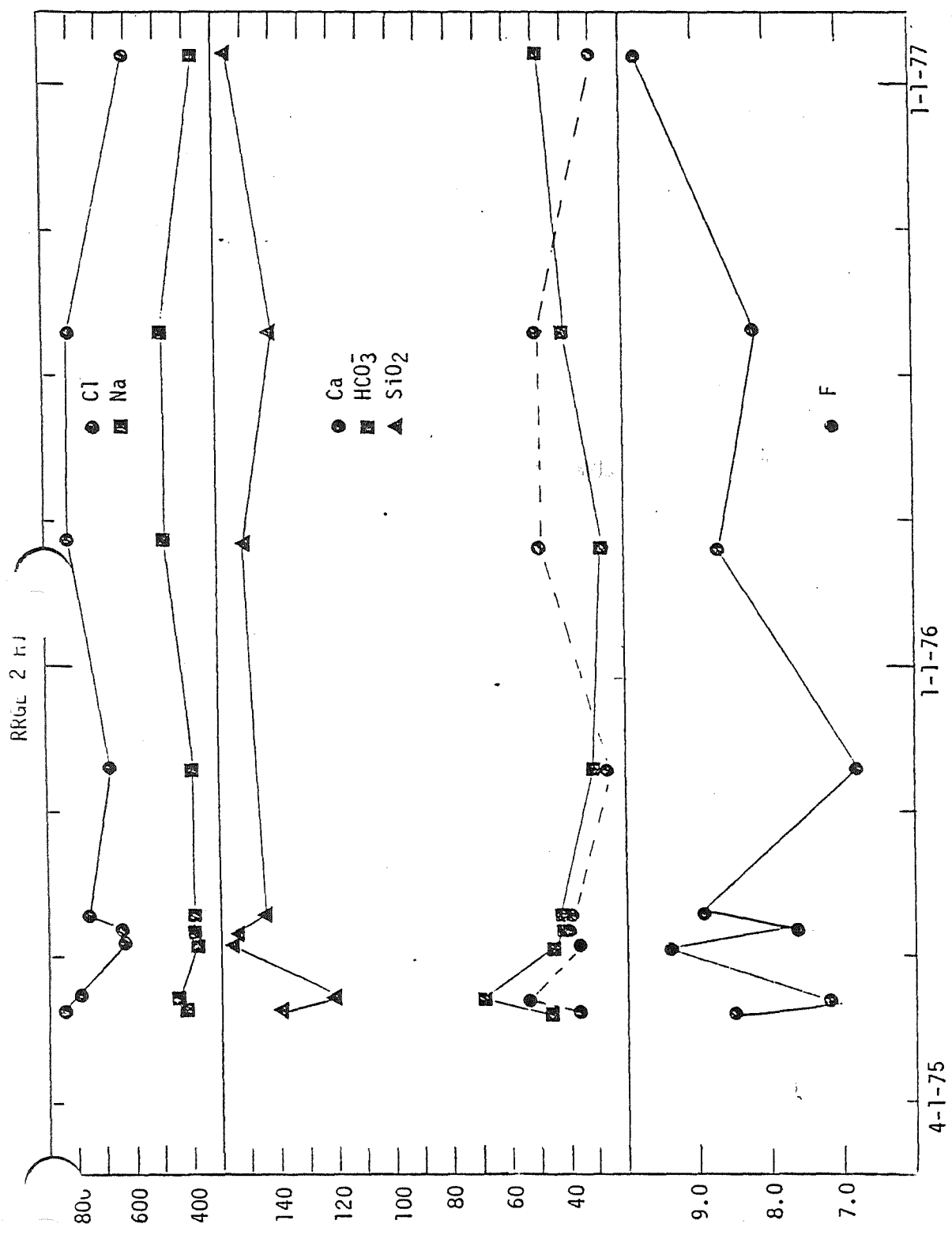


Figure 2

RRGE 3 HISTORY

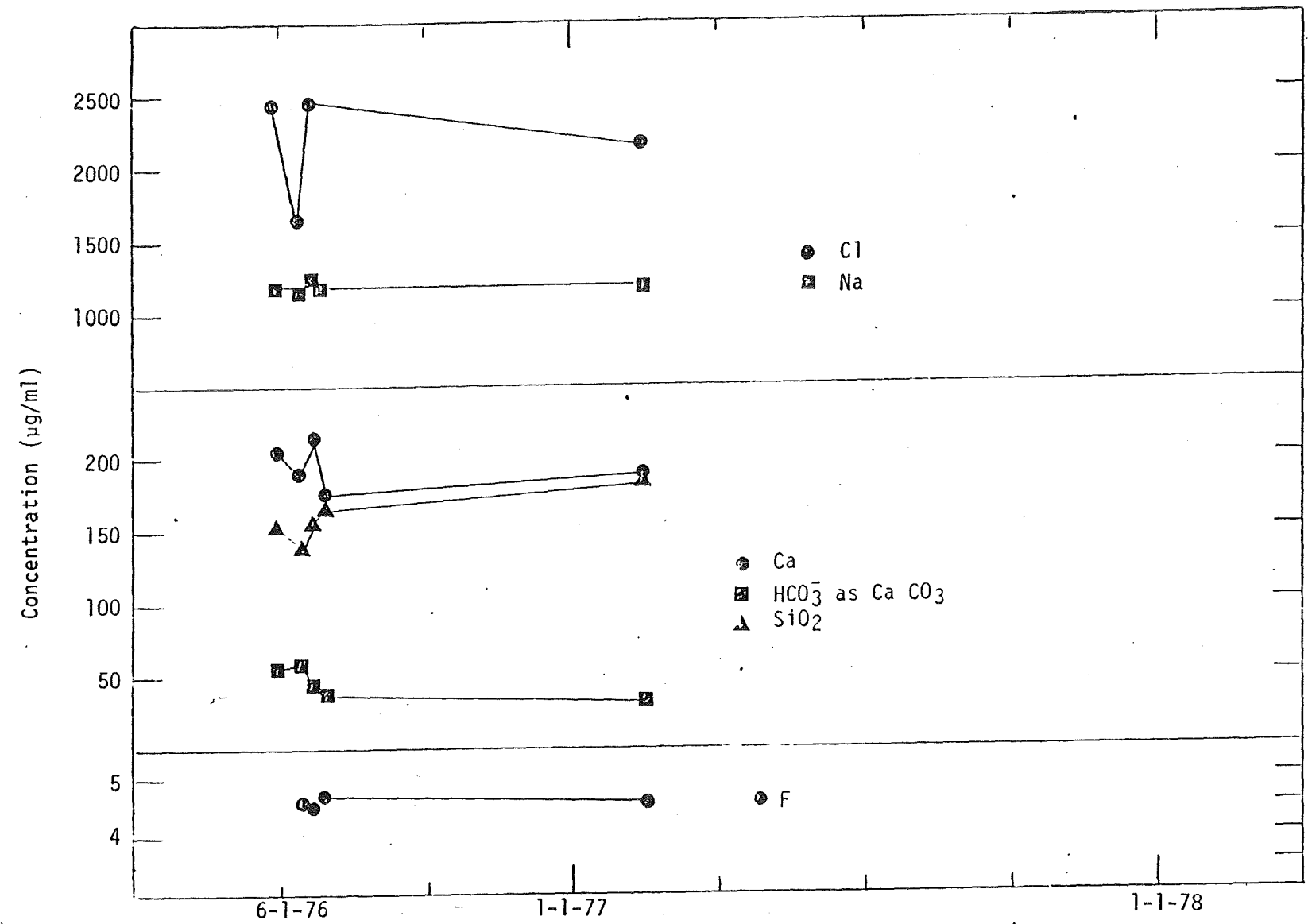


Figure 3

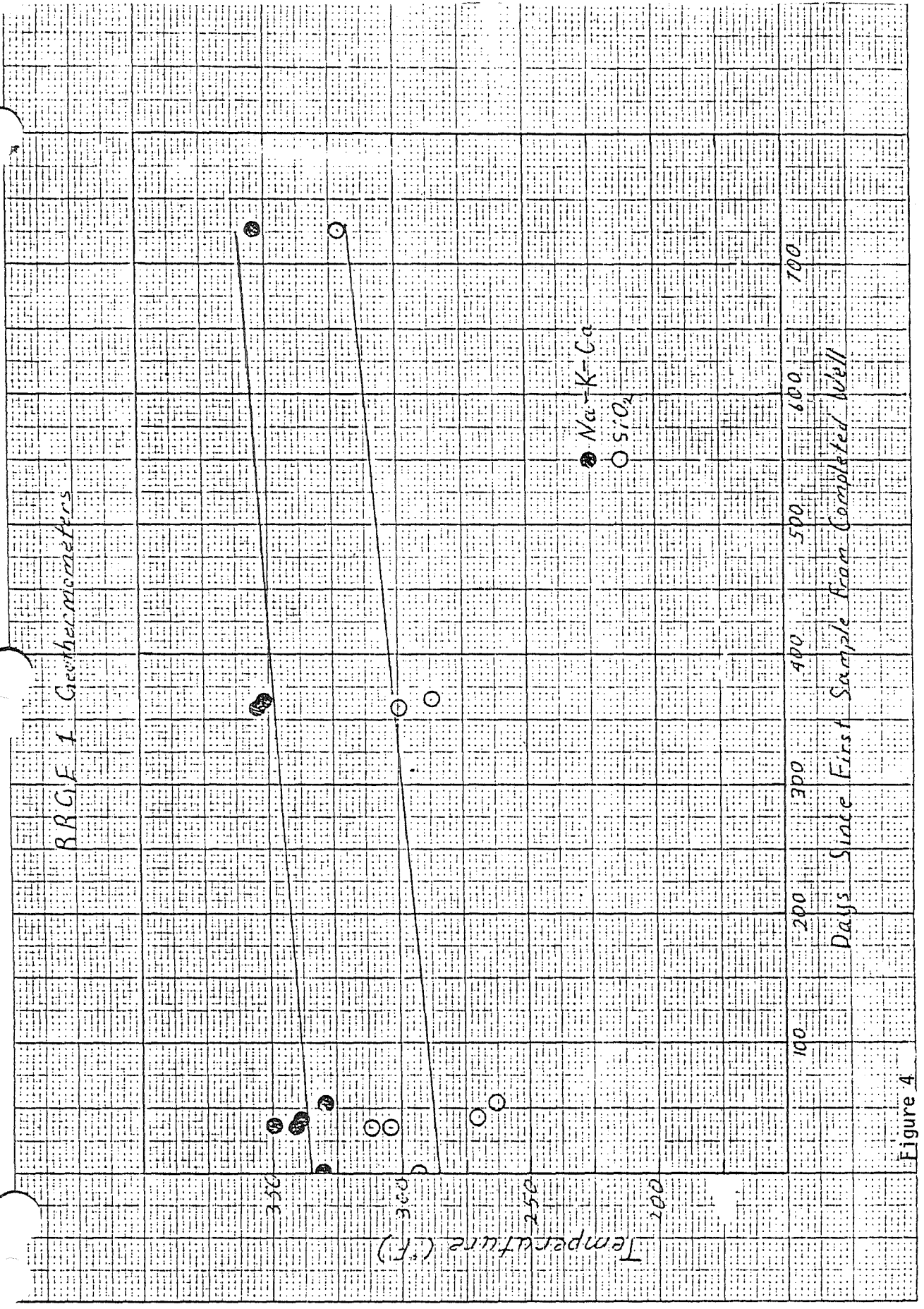


Figure 4

WELLS DATA SHEET

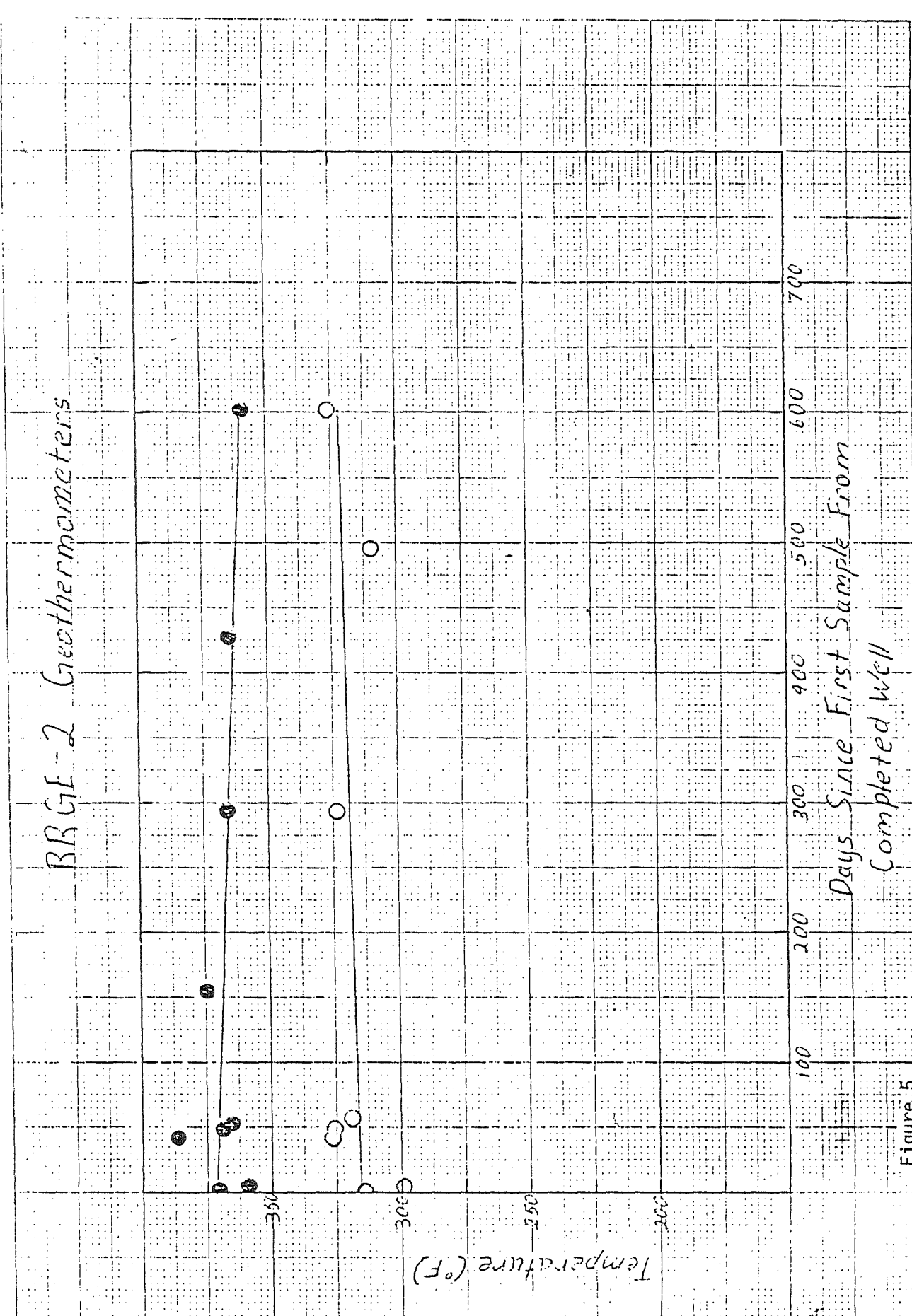


Figure 5

RRGE-3 Geothermometers

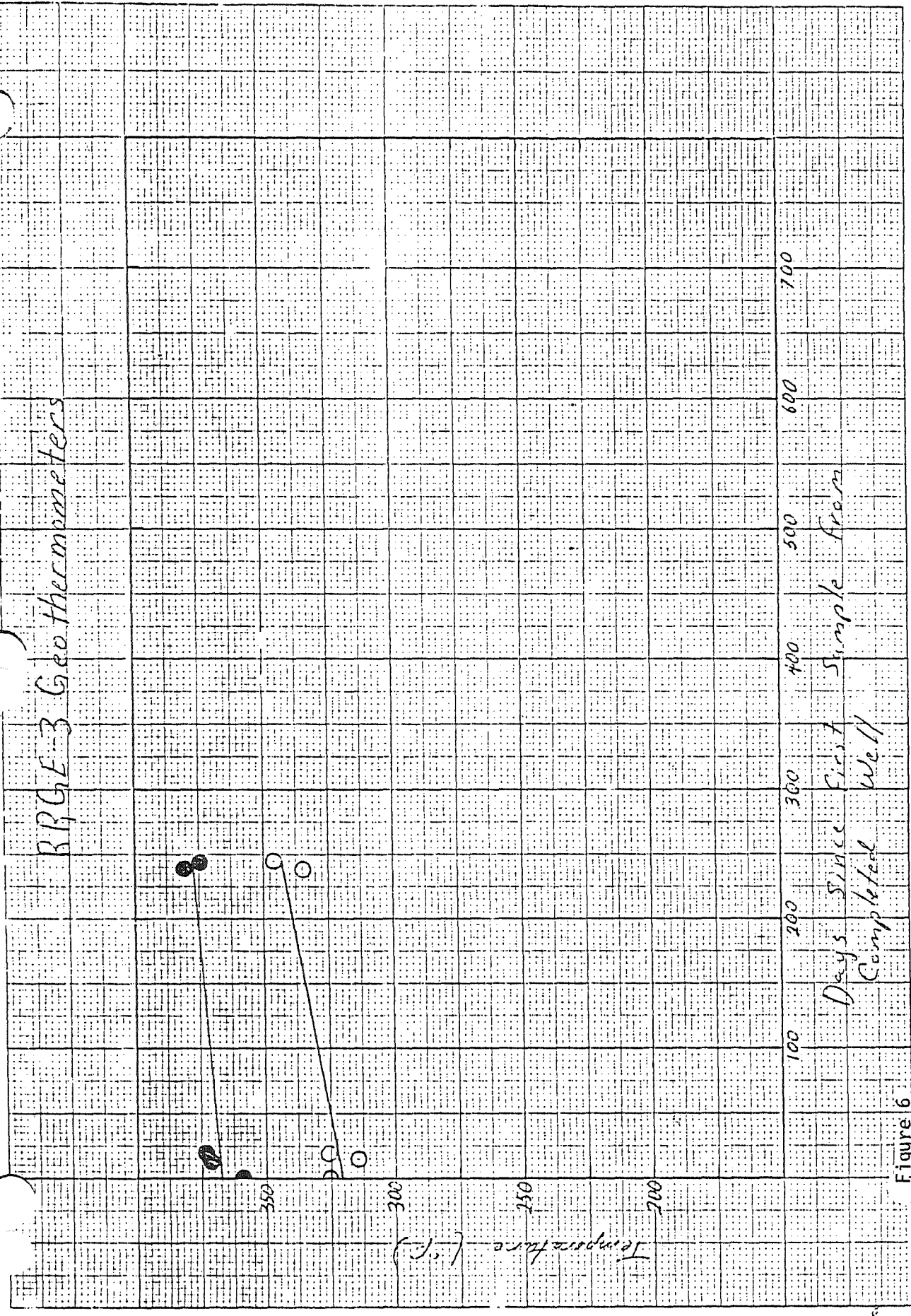


Figure 1

known, nor which represents the best temperature prediction. In any case temperatures substantially higher than observed in the wells are predicted.

Figure 7 displays the geothermometry results of the three wells. Both the silica and Na-K-Ca predicted temperatures appear to be converging with time. Meanwhile, predicted temperatures from RRGE-3 seem to be diverging upward. This too shows RRGE-3 to be behaving chemically in a unique way.

Analysis of Results

Both the total dissolved solids and geothermometry indicate RRGE-3 is chemically unique. Two theories have been proposed to explain this.

- 1) By some mechanism RRGE-3 water was concentrated from RRGE-1 and RRGE-2 water or the other two diluted by ground water. The latter does not seem feasible since the large dilution would create a wide temperature disparity.
- 2) Two separate resources are involved.

If the first theory is correct the composition of RRGE-3 could be roughly calculated from the dissolved solids concentration factor.

$$\frac{(TDS)_3}{(TDS)_2} = F_c \quad \text{where: } F_c = 3.26 \quad (1)$$

where each component is calculated from

$$C_{3n} = F_c C_{2n} \quad (2)$$

Table 2 lists the calculated RRGE-3 composition and for comparison the average values from chemical analysis.

(See next page for Table 2)

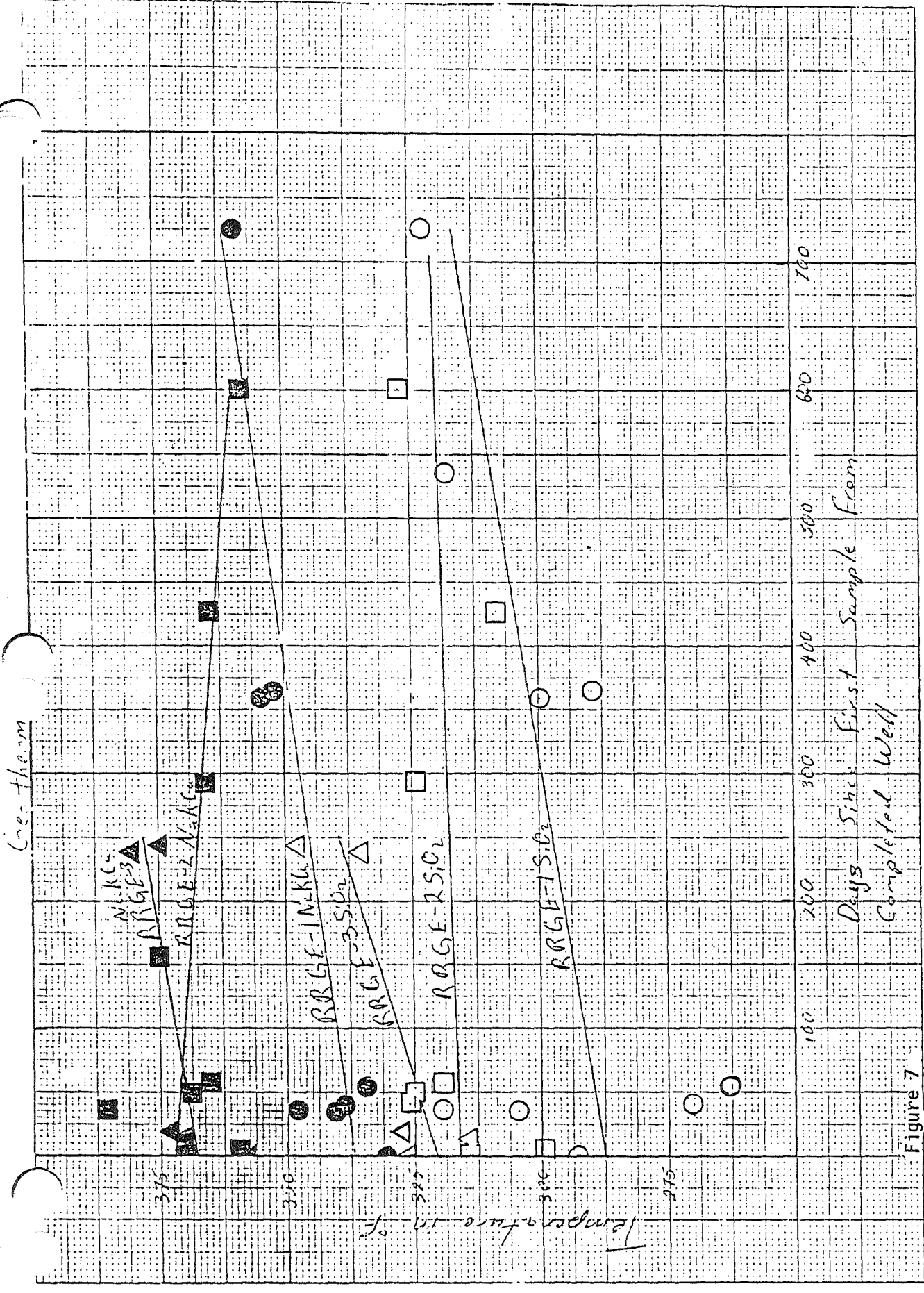


Figure 7

Table 2
COMPARISON OF CALCULATED AND ANALYSIS VALUES
OF RRGE-3 COMPOSITION. ($\mu\text{g/ml}$)

	Calculated	Chemical Analysis	Calculated Analysis
Cl	2380	2183	1.09
F	27.1	4.7	5.8
Na	1352	1190	1.14
K	108.9	97.2	1.12
Li	3.6	3.2	1.12
Ca	130	196	.66
Mg	.65	0.6	1.03
Sr	3.9	6.7	.58
SiO ₂	472	160	2.95
HCO ₃	140	46	3.04
SO ₄	173	63	2.74

Based on the Cl, Na, K, and Mg results this would seem a reasonable theory. However, by any kind of an evaporative mechanism it would appear impossible for SO₄, HCO₃ and F to be several times lower than predicted, yet Ca and Sr to be higher. The normal precipitates expected would be CaF₂, CaCO₃, CaSO₄ and similar Strontium salts. This would require the Ca and Sr levels to also be lower in the analysis results than predicted by the calculation.

This contradiction eliminates evaporative concentration as a method for relating RRGE-2 and RRGE-3. Dilution was already eliminated. Based on the chemical composition it would seem the two wells could not be drilled into the same resource. Even taking into account the standard deviation on chemical analysis it is not possible to relate RRGE-2 and RRGE-3 by evaporation or dilution. A composite analysis and standard deviation is shown in appendix 1.

Now let's turn our attention to the second theory which assumes two resources. Based on the total dissolved solids in appendix 1, the five wells in the area line up as follows:

$$\text{RRGE-2} < \text{RRGE-1} \leq \text{BLM} < \text{Crank} < \text{RRGE-3}$$

On this basis RRGE-2 would best seem to characterize one resource and RRGE-3 another. The intermediate wells then could be described as a mixture. It must be kept in mind that RRGE-2 and RRGE-3 also could be mixtures but to make this analysis we will adopt the convention:

RRGE-2 represents resource A, and RRGE-3 represents resource B

To test this theory we will try to predict the composition of RRGE-1, BLM and Crank wells from mixtures of RRGE-2 and RRGE-3. The basis for calculating mixing fractions will be the total dissolved solids. Let X_m be the fraction of resource A water in well m. The prediction can then be made by calculating X_m from the total dissolved solids content.

$$X_m(\text{TDS})_2 + (1-X_m)(\text{TDS})_3 = (\text{TDS})_m$$

Table 3 gives the mixing ratios.

Table 3 (3)

TOTAL DISSOLVED SOLIDS AND MIXING FRACTIONS
 IN THE RAFT RIVER WELLS

	RRGE-2	RRGE-1	BLM	Crank	RRGE-3
TDS	1267	1560	1640	3720	4130
X_m	1	.898	.870	.143	0

To calculate the concentration of each component C_{mn} equation (3) is modified.

$$X_m C_{2n} + (1-X_m) C_{3n} = C_{mn} \quad (4)$$

Using equation (4) concentrations of the intermediate wells were calculated and compared with the chemical analysis. Results are shown in Table 4.

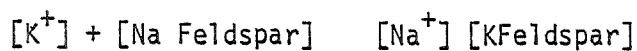
(See next page for Table 4)

Table 4
 COMPARISON OF CALCULATED COMPOSITION OF RRGE-1, BLM AND CRANK
 WELLS USING THE MIXING MODEL OF EQUATIONS (3) AND (4)

Component	RRGE-2	RRGE-1		BLM			Crank			RRGE-3	
	Analysis	Calc.	Analysis	Calc. Analysis	Calc.	Analysis	Calc. Analysis	Calc.	Analysis	Calc. Analysis	Analysis
Cl	708±70	857	776±184	1.10	898	1009	.89	1960	1900	1.03	2170±302
F	8.25±1.0	7.8	6.32±1.47	1.23	7.8	6.25	1.25	5.1	4.9	1.04	4.55±.25
Li	1.21±.57	1.40	1.48±.40	.95	1.46	1.4	1.04	2.8	2.5	1.12	3.1±.2
Na	416±44	494	455±99	1.08	516	530	.97	1075	1074	1.00	1185±52
K	33.4±5.3	39.9	31.3±7.0 (36.4±3.1)	1.28	41.7*	20	2.08	88.1*	34	2.54	97.2±7.3
Ca	35.3±8.7	51.4	53.5±9.5	.96	55.8	55	1.01	170	130	1.30	193±15
Sr	1.03±.32	1.61	1.56±.35	1.03	1.77	1.4	1.26	5.9*	2.8	2.10	6.7±.7
HCO ₃	41.3±11.2	41.6	6.4±20	.65	41.7	.51	.82	44	34	1.29	44.4±11.1
SO ₄	54.1±5.1	54.0	60.2±6.7	.90	54.0	61	.88	53.4	54	.99	53.3±14.6
SiO ₂	131±31.0	134	121±36	1.11	134.5*	99	1.35	154*	104	1.48	158±17

* Not within the standard deviation of chemical analysis results.

Generally speaking, the mixing model predicts the composition of RRGE-1 within the standard deviation of the chemical analysis. Unfortunately there have not been enough samples over a sufficient length of time to generate a statistical analysis for the BLM and Crank Wells. It is apparent though that all of the species fit well except for K and SiO₂ in both wells and Sr in the Crank well. The BLM and Crank wells are shallow of the order of 500 feet compared to 5,000 feet for the three production wells. Using the silica and Na-K-Ca geothermometers they predict temperatures from 40 to 100 degrees less than the deeper wells. It appears that some thermal re-equilibration occurs during water migration from 5,000 to 500 feet. SiO₂ is deposited in the fracture zone and ion exchange occurs in feldspar according to the reaction:



resulting in lower than predicted potassium and slightly increased sodium. This is consistent with the mixing model. The only unexplained deviation then is the low strontium concentration found in the Crank well. This well has not been sampled for two years and RRGE-3 is less than one year old.

The mixing model works very well. With only the one Sr exception. This strongly indicates the two resource theory is correct. Resource A is characterized by RRGE-2 and Resource B by RRGE-3. RRGE-1 and the BLM are nearly 90% Resource A water. During reservoir evaluation tests, good communication was established between RRGE-1 and RRGE-2. The Crank well is 85% resource B. A good test of the two resource theory would be to duplicate the reservoir evaluation tests above. By flowing RRGE-3 and pressure monitoring RRGE-2 the lack of communication would be supportive of two resources.

Implications

If there are two resources involved, as the preceding evaluation indicates, several deductions can be made on the nature of the reservoirs.

- 1) If RRGE-1 and the BLM wells are mixtures of resources A and B, then resource A must flow from the North. The fault associated with RRGE-2 runs NE-SW. Since RRGE-1 is SW of RRGE-2, the only way to explain less mixing in RRGE-2 than RRGE-1 is for the water to be moving south along the fault. Figure 8 is a map which

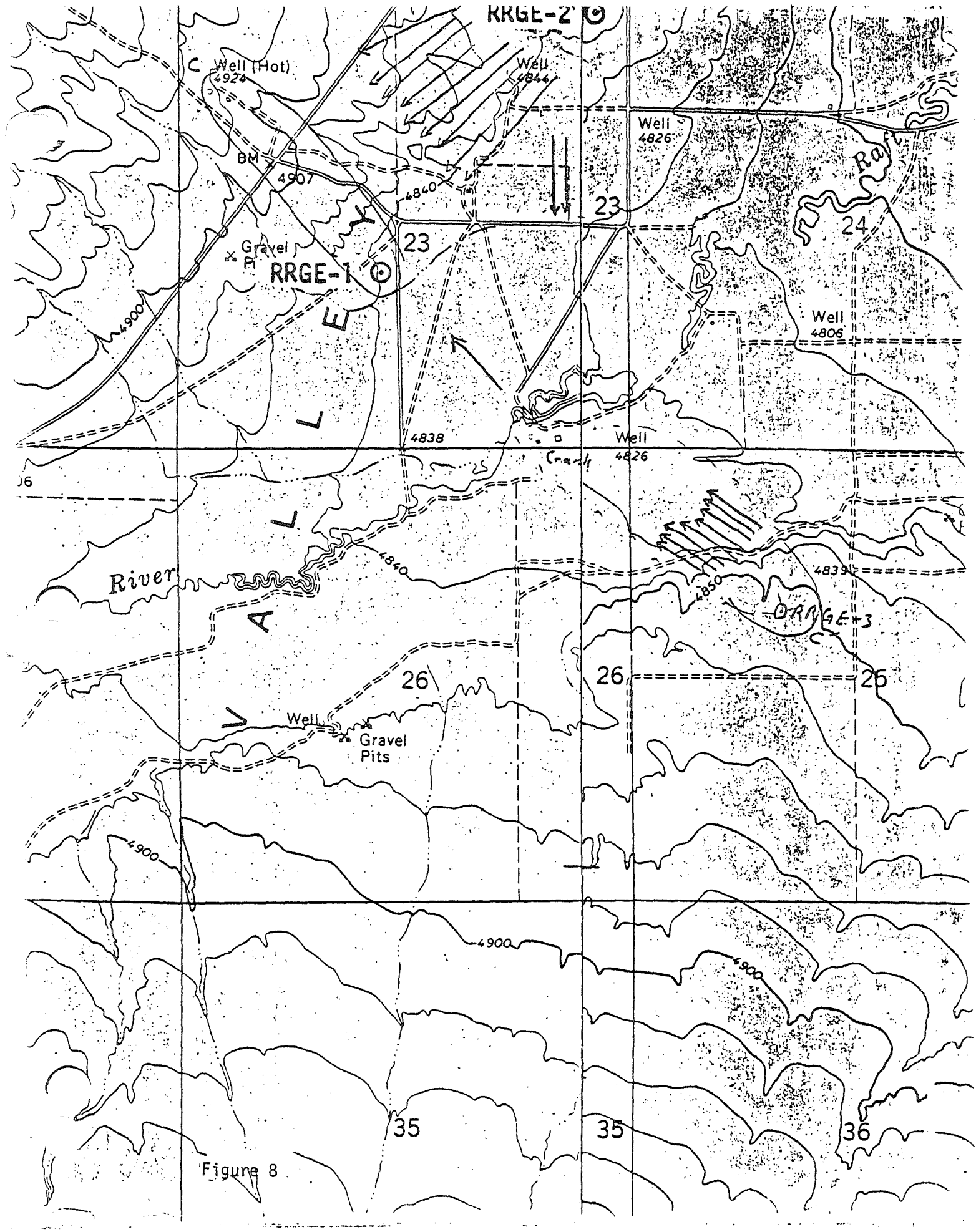


Figure 8

shows the flow as deduced from chemical evaluation. The arrows generally represent the volume and direction of flow. This removes the Narrows as a possible heat source for resource A.

- 2) The presence of resource B implies a fault which is not obvious at the surface. As seen in Figure 8 the four wells BLM, RRGE-1, Crank and RRGE-3 are nearly in a straight line. Figure 9 shows the cross section C-C' from Figure 8. The relationship between RRGE-3 and the Crank well is similar to the relationship between RRGE-1 and the BLM well. This implies a fracture zone connecting the two. Fractured zones are normally associated with faults. The fault associated with resource B could be identified and followed with a surface helium survey.
- 3) A significant question arises concerning these two resources. Do resources A and B represent two conduits from the same heat source, or are two heat sources involved? If a single heat source is involved, then it must be located to the North. This is because flow between RRGE-2 and RRGE-1 is generally from north to south. If two heat sources are involved, then the heat source for resource B could be to the NE, E, S, or SW. It could not be to the West or North.

Further Work Needed

- 1) The low Sr level in the Crank well needs to be resolved. This well needs to be sampled and analyzed for Sr. A new complete well analysis would be in order. If Sr persists at a low level and if this low level cannot be explained by valid chemical arguments, then a new theory explaining the differences in chemical composition is required.
 - 2) Experiments attempting to establish communication between RRGE-2 and RRGE-3 should be performed. Lack of, or very weak, communication would support the two resource, mixing model theory.
 - 3) The fault associated with RRGE-3 should be identified and followed. This can be done by helium detection at the surface. Allied Chemical has a portable helium leak detector which could be used. The technology for its use was developed by Dick McAtee.
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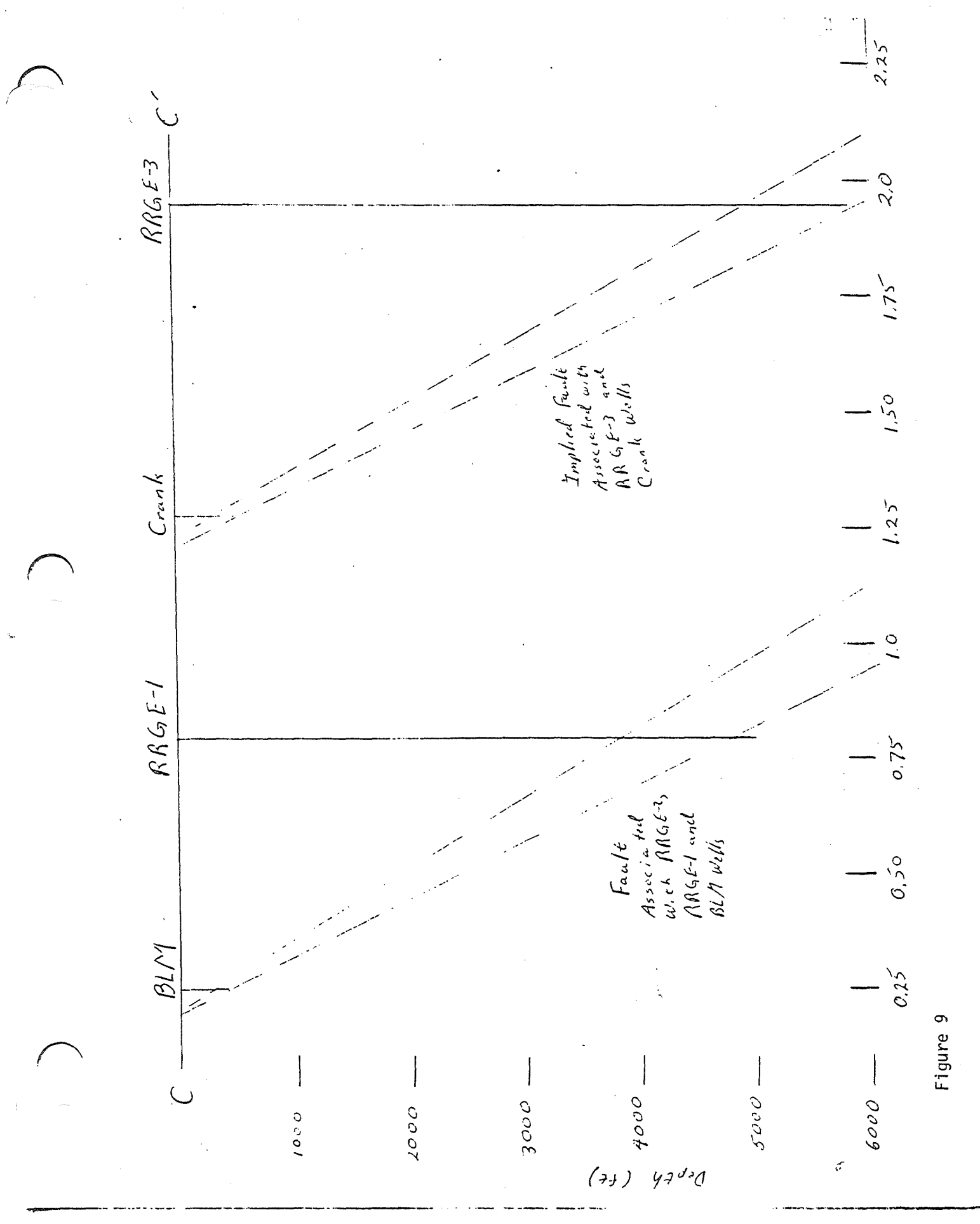


Figure 9

- 4) Further exploratory drilling in the area would be useful to find the hotter resources predicted by geothermometry.
- 5) Temperature logging of RRGE-3 while it is flowing at a low rate would be useful to determine if one leg is hotter than the other two. This would show up as a discontinuity in the temperature log.

Appendix

CHEMICAL CONCENTRATIONS AND
 STANDARD DEVIATIONS IN $\mu\text{g}/\text{ml}$

Chemical Species	RRGE-1		RRGE-2		RRGE-3		Raft River		BLM Well		Crank Well	
	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx
CL ⁻	776	184	708	70	2170	302	153	70	1139		1900	
F ⁻	6.32	1.47	8.25	1.06	4.55	0.25	0.65	0.21	5.6		4.11	
Br ⁻	<1.5		<1.5		<1.5		<1.5		<0.15		<0.15	
I ⁻	0.036	0.003	0.028	0.019			0.066	0.016	<0.040		<0.040	
*HCO ₃ ⁻	63.9	20.8	11.3	11.2	44.4	11.1	172.5	45.0	83		34	
SO ₄ ⁼	60.2	6.7	54.1	5.1	53.3	14.6	55.2	28.0	54		54	
NO ₃ ⁻	0.2		0.2		0.2		3.8		0.2			
Total NH ₃	1.56	1.19	0.60	0.41			1.0		0.59			
Total P	0.023	0.014	0.020	0.011			0.038	0.028	0.27			
S ⁼			0.256									
Si[OH] ₄	182	33	201	40	242	21	40.4	21.0	132		142	
Si	56.6	16.7	61.2	14.5	74.0	8.0	18.7	1.5	46		49	

Appendix cont.....

Chemical Species	RRGE-1		RRGE-2		RRGE-3		Raft River		BLM Well		Crank Well	
	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx	\bar{X}	Sx
Na	455	99	416	44	1185	52	77	26	550		1074	
K	31.3	7.0	33.4	5.3	97.2	7.3	7.7	0.7	2.0		34	
Sr	1.56	0.35	1.03	0.32	6.7	0.7	0.52	0.16	1.35		0.36	
Li	1.48	0.40	1.21	0.57	3.1	0.2	0.04	0.01	1.4		2.5	
Ca	53.5	9.5	35.3	8.7	193	15	85.3	29.6	55		130	
Mg	2.35	2.09	0.58	0.80	0.60	0.16	23.9	9.8	0.2		0.5	
pH							7.94	0.15				
Total Dissolved Solids	1560		1267		4130	36			1640		3720	
Conductivity	3373		2742		9530	1546			3030		6080	
*Total Gas	33.4	21.9	35.4	22.1					12.9			
H ₂	0.10	0.14	0.67	0.69					0.11			
K	31.3	7.0	33.4	5.3	97.2	73	7.7	0.7	20		34	
Sr	1.56	0.35	0.03	0.32	6.7	0.7	0.52	0.16	1.35		0.36	
Li	1.48	0.40	1.21	0.57	3.1	0.2	0.04	0.01	1.4			
Ca	53.5	9.5	35.3	8.7	193	15	85.3	29.6	55		130	
Mg	2.35	2.09	0.58	0.80	0.60	0.16	23.9	9.8	0.2		0.5	
pH							7.94	0.15				

* HCO₃⁻ Concentrations are recorded in µg/ml as CaCO₃

* Conductivity is recorded in µmho/cm

* Gas Volumes are in standard cc/liter

\bar{X} Average Value

Sx Standard deviation of a single value

ajw