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GEOCHEMICAL MODELING AT RAFT RIVER

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ABSTRACT

Chemical analysis of water from three depth regimes at the Raft River KGRA indicate the presence of at least two distinct hydrothermal fluids. One fluid predominates in the fracture system on the west side of the valley, known as the Bridge Fault. This fluid is characterized by low conductivity (2,000 to 3,000 μs) and 6 to 9 μg/ml F^-. The second fluid, encountered in the center of the valley, appears to be associated with the Narrows Structure and is characterized by a conductivity of 6,000 to 11,000 μs and F^- of 3 to 6 μg/ml.

Contour mapping of conductivity and Cl^-/F^- ratios indicates upwelling of both deep geothermal fluids into the shallow system. This recharge into the intermediate and shallow zones produces high-conductivity water which is used for irrigation. Application of a simple mixing model shows that all the water sampled in intermediate and deep zones can be described by mixtures of two nearly pure fluids. One mechanism, consistent with the known data, is deep upwelling of a highly mineralized fluid which is heated by the basement rock and then penetrates sediment layers through fractures. The second fluid is relatively recent meteoric water conductively heated by the basement rock.

INTRODUCTION

Geochemical modeling requires a large number of sampling points, preferably at a variety of depths. For this reason, it is most useful for field development when only a few wells have been drilled. Currently at Raft River, in southcentral Idaho, there are 7 deep wells, 7 intermediate wells and 14 shallow wells in a 12-square mile area.

This paper defines what is known about the chemical composition of fluids at Raft River and correlates it with known geology, geophysics, and geohydrology. What results is a model consistent with known information, although no claim is made that this description is a unique solution.

CHEMICAL COMPOSITION

Seven deep wells have been drilled at Raft River as shown in figure 1. Wells RRGE-1 and -2 and RRGP-4 and -5 were drilled to intersect the Bridge Fault. Wells RRGE-3 and RRGI-6 and -7 were drilled toward the center of the valley. Two major structures appear to be related to the geothermal resource. The Bridge Fault is a north-south fault paralleling the Jim Sage Mountains. The Narrows Structure trends northeast-southwest and intersects the Bridge Fault near RRGP-4 (Williams, et al., 1976).

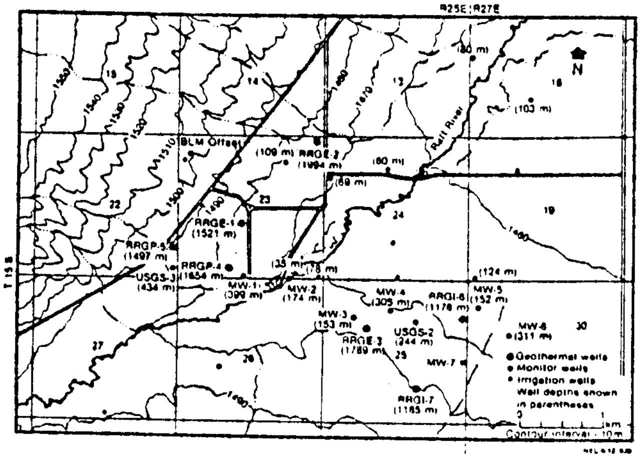

Fig. 1 Map of Raft River Geothermal Development Area showing the location of deep intermediate and shallow wells.

Wells penetrate three depth regimes in this portion of the Raft River valley. The shallow system is defined as 30 to 155 m deep. This is the water used for domestic and irrigation use. The intermediate system is defined as between 170 and 500 m and the deep system as below 1000 m. The major environmental problem associated with geothermal development at Raft River is to avoid increasing the quantity of geothermal fluid entering the shallow system. Chemical analysis is shown in table 1.

Table 1. Chemical analysis (μg/ml) of deep wells, >1000 m (3800 to 6200 ft).

	RRGE-1	RRGE-2	RRGE-3	RRGP-4	RRGP-5	RRGI-6	RRGI-7
Na	469	331	1245	718	179	2,020	2,100
K	33	31	103	---	34	32	---
Ca	53	32	127	81	50	199	315
Sr	1.4	0.8	5.2	---	1.2	8.0	---
Mg	0.6	0.7	1.0	---	0.5	1.4	1.6
Li	1.6	1.0	3.4	---	1.6	5.1	---
Cl^-	709	701	2116	1370	590	3,636	4,085
F^-	5.7	7.9	3.7	6.4	6.2	5.8	4.9
$SO_4^=$	40	29	44	---	40	60	64
HCO_3^-	34	42	26	35	40	62	26
SiO_2	134	155	158	---	136	91	83
TDS	1607	1161	4280	---	1481	6,330	---
Cond. (μs/ml)	2987	2157	7997	4000	2857	11,594	12,000
pH	7.3	7.6	7.2	7.0	7.5	7.3	

CONTOUR MAPPING

Horizontal distribution of fluids in the three regimes helps identify the sources of geothermal water and its areal extent. Wells which penetrate the Bridge Fault have conductivities between 2,000 and 3,000 µs. Hot wells to the east of the Bridge Fault have conductivities from 5,000 to 12,000 µs. RRGP-4, located on the intersection of the Bridge Fault and the Narrows Structure, has a conductivity of 4,000 µs. These are summarized in table 2.

Table 2. Conductivity of Raft River geothermal wells.

Bridge Fault	Cond. (µs)	Intersection	Cond. (µs)	Center Valley	Cond. (µs)
RRGE-1	2,987	RRGP-4	4,000	RRGE-3	7,997
RRGE-2	2,157			RRGI-6	11,594
RRGP-5	2,857			RRGI-7	12,000
BLM	2,996			Crook	5,430

Either lost circulation or porous zones were encountered during drilling RRGE-1 and -3, RRGP-5, and RRGI-6 between 500 and 700 m (Reynolds Electrical and Engineering Co., 1975; Miller et al., 1979). This may be a single large zone or several disconnected zones. Seven wells used for monitoring hydrologic response penetrate the intermediate zone. These are located in the injection field and along the southern edge of the geothermal development. Because they lie in an approximate straight line, contours developed from the intermediate zone are restrictive.

Figure 2 shows the conductivity of the seven deep wells. Dashed contour lines approximate the conductivity profile in the intermediate zone and solid lines the conductivity of the shallow zone. At depth, conductivity values in excess of 10,000 µs are found in the central part of the valley. In the intermediate zone, conductivities in excess of 10,000 µs are found near the intersection of the Bridge Fault and the Narrows Structure (in MW-1), a distance of approximately 2 km to the west. The high in the shallow zone indicates dilution and spreading down dip.

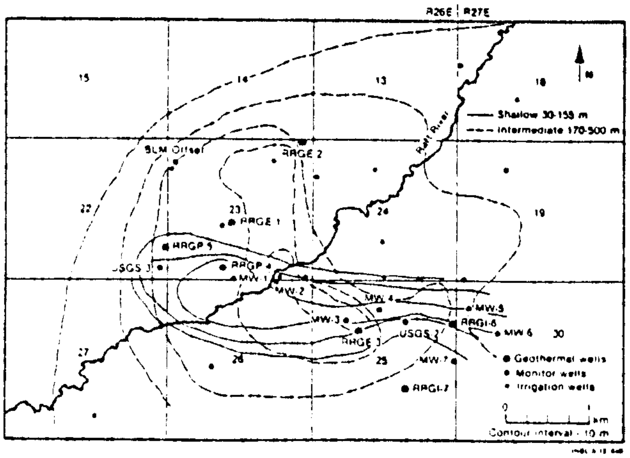

Fig. 2 Conductivity contours in the shallow and intermediate zones.

This indicates flow of the high TDS water from east to west through the deep to intermediate zones with upwelling into the intermediate zone near RRGP-4. The water continues to migrate upward into the shallow system and spread northeast.

Bridge-Fault water is unique because of the low Cl/F ratio. Contours of Cl/F in figure 3 in the shallow zone indicate an upwelling of water from the Bridge Fault in a northeast-southwest ellipse centered about 1 km to the west of RRGP-4.

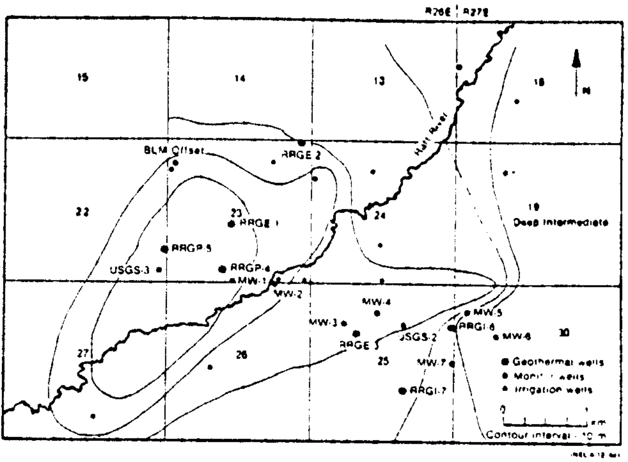

Fig. 3 Chloride-fluoride ratio contours in the shallow zone.

Contour mapping indicates both geothermal waters are upwelling into the shallow system, central-valley water near RRGP-4 and Bridge Fault water near the surface expression of the Bridge Fault. Irrigation water consists of meteoric water mixed with geothermal water in this part of the valley.

MIXING

Table 1 identifies two different deep waters. Significant differences in composition within the two groups raises the possibility of mixing of the two types of water. This section describes a test of the thesis that geothermal waters are mixed at depth.

Mixing fractions are based on conductivity and calculated using equations

$$X_i C_1 + (1 - X_i) C_2 = C_i \qquad (1)$$

or

$$X_i = \frac{C_2 - C_i}{C_2 - C_1} \qquad (2)$$

where X_i is the mixing fraction, C_i is the conductivity of mixed water, C_1 is the conductivity of Bridge-Fault water (type 1), and C_2 is the conductivity of central-valley water (type 2). For the purpose of this calculation, it is assumed that the lowest conductivity water (from RRGE-2) represents nearly pure Bridge-Fault water (C_1) and the highest conductivity water from RRGI-7 represents nearly pure central-valley water (C_2). It is recognized that this assumption is idealistic, but for the purpose of mixing identification, it is reasonable.

Table 3 shows the mixing fractions calculated by equation (2). Mixing fractions for both deep and intermediate wells are included. In the intermediate zone, the BLM well is the highest fraction of type 1 water and monitor well MW-1 the smallest fraction of type 1 water.

Table 3. Mixing fractions calculated from conductivity.

	Well	Conductivity (μs)	X_i
DEEP			
	RRGE-2	2,157	1.000
	RRGP-5	2,857	0.929
	RRGE-1	2,987	0.916
	RRGP-4	4,000	0.813
	RRGE-3	7,997	0.407
	RRGI-6	10,500	0.152
	RRGI-7	12,000	0.000
INTERMEDIATE			
	BLM	3,000	0.914
	RRGP-5_i	3,700	0.843
	Crook	5,800	0.630
	MW-2	6,400	0.570
	USGS-3	6,600	0.549
	MW-4	7,400	0.467
	MW-6	7,600	0.447
	RRGI-4	7,620	0.445
	MW-1	10,400	0.163

To test the mixing hypothesis, the predicted composition of several components which presumably are not involved in thermally dependent reactions were calculated and compared to measured values. Results are shown in table 4.

Predicted values for lithium and fluoride correlate with actual values with an average deviation of less than 20%. Predicted strontium values correlate well for the deep wells except for RRGP-4 where the sample was likely affected by drilling water. In the intermediate system, a large deviation between predicted and actual values of strontium were observed in the Crook well, USGS-3, MW-4, and MW-6. This may be due to a third component or water-rock reactions in the intermediate zones which involve strontium. Because of its ionic size, strontium can replace calcium in plagioclase and potassium feldspar (Mason, 1962). It is also possible that with the limited number of samples for these wells that the actual value is incorrect.

These calculations support the hypothesis that two fluids exist in the deep Raft River development area. These fluids are associated with the Bridge Fault and the central valley, and perhaps with the Narrows Structure as well. Mixing occurs at depth with wells which intercept the Bridge Fault containing nearly all type 1 water. Wells in the central part of the valley contain mostly type 2 water. Wells located between RRGE-2 and RRGI-7 produce mixtures.

Table 4. Predicted vs measured concentration based on mixing model.

Well	X_i	Li Pred.	Li Act.	Sr Pred.	Sr Act.	F Pred.	F Act.
DEEP							
RRGE-2	1.000	1.0	1.0	0.8	0.8	7.9	7.9
RRGP-5	0.929	1.3	1.6	1.4	1.2	7.5	6.2
RRGE-1	0.916	1.4	1.6	1.5	1.4	7.4	5.7
RRGP-4	0.813	1.9	2.8**	2.4	6.3**	6.9	5.1**
RRGE-3	0.407	3.8	3.4	5.9	5.2	4.6	3.7
RRGI-6	0.152	5.1	5.1		8.0	3.2	5.8
RRGI-7	0.000	5.8	5.8*		9.4	2.3	5.0**
INTERMEDIATE							
BLM	0.014	1.4	1.4	1.5	1.5	7.4	6.2
RRGP-5	0.843	1.8	1.7				
Crook	0.630	2.8	2.5	4.0	2.1	5.8	5.9
MW-2	0.570	3.1	2.6	4.5	3.8	5.5	5.7
USGS-3	0.549	3.2	2.1	4.7	2.1	5.4	5.1
MW-4	0.467	3.6	3.7	4.9	3.3	4.9	5.6
MW-6	0.447	3.7	3.2	5.0	1.4	4.8	4.1
RRGP-4	0.445	3.7	3.1	5.0	6.3	4.8	4.5
MW-1	0.163	5.0	4.8	7.2	7.0		2.8

*Value calculated from RRGI-6.

**Well flowed for insufficient time following drilling and samples were contaminated with drilling fluid.

Figure 4 shows the correlation between deep well location and mixing fraction. The vertical axis represents a straight line between RRGE-2 and RRGI-7 on an arbitrary scale with RRGE-2 being 1.0 and RRGI-7 as 0.0. The points on figure 4 represent perpendicular projections of the deep wells onto the line. There is definite correlation between well location and the extent of mixing in the deep zones.

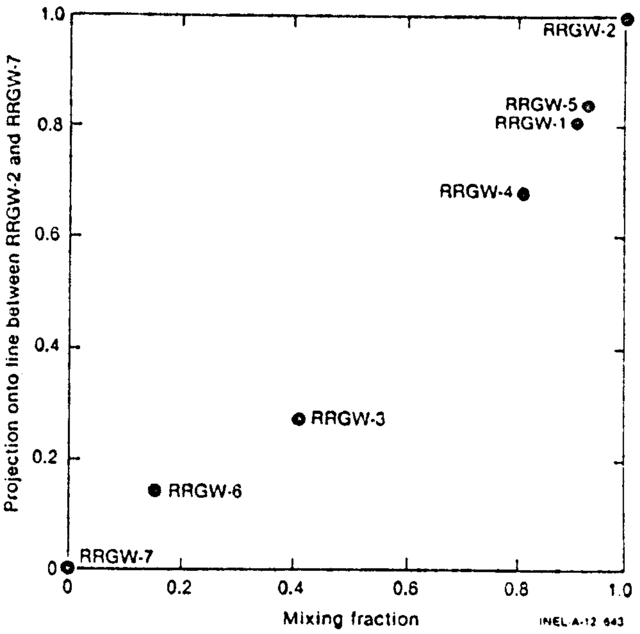

Fig. 4 Correlation between well location and mixing.

TEMPERATURE

Five wells penetrate the quartz monzonite basement at about 1500 m depth. Four of these, RRGE-1, RRGE-2, RRGP-4, and RRGP-5, are Bridge-Fault wells. RRGE-3, which also penetrates basement, is in the central valley. Bottomhole temperature is highest in RRGE-3 [150°C (302°F)] and lowest in RRGP-5 [133°C (272°F)]. The other three wells cluster between 141°C (285°F) and 145°C (296°F).

RRGE-3 is in the center of the valley, which indicates that this area has the highest temperature basement rock. This is not due to vertical temperature gradient since the temperature in RRGE-3 is 2.8°C (5°F) higher at the same depth than RRGE-2. This is inconsistent with a temperature source in the basement near the center of the valley with conductive heat transfer through the quartz monzonite.

MODEL

Based on the facts discussed above and the known geology and geophysics measurements, the model in figure 5 was constructed. This model is consistent with all the known facts, but may not be a unique description of the Raft River system. This model is in conceptual form and requires more accurate geological cross-section descriptions.

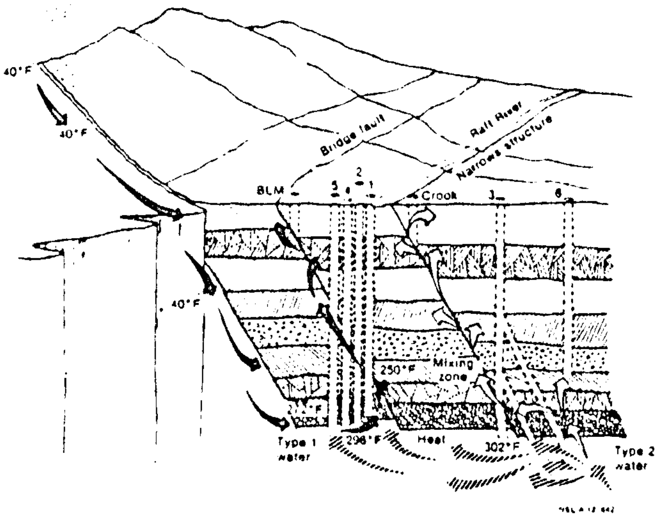

Fig. 5 Conceptual model of flow in the Raft River geothermal system.

The source of heat for this model is deep, recirculated water of unknown origin. It could come from the Snake River Plain, the Narrows, the Jim Sage Mountains, or other locations. What appears to occur is that mineralized water flows upward through the basement rock into the sedimentary burden above it. Flow of hot water through the basement heats the basement rock and provides a conductive heat source for heating recent meteoric water draining the east slope of the Jim Sage Mountains. This recent meteoric water is heated by the hot basement rock and moves up the Bridge Fault. This mechanism explains why wells which penetrate the Bridge Fault encounter relatively clean water.

The mineralized water which flows into the sedimentary material flows upward through fractures. As it encounters zones of water from the Bridge Fault or freshwater, it is diluted. Deep wells closest to the source contain the purest central-valley water. Intermediate zones of mixing and dilution explain mixing observed in the wells as a function of location.

CONCLUSIONS

- Two water types were identified, one produced from the Bridge Fault, which is low in total dissolved solids and one from the center of the valley, which contains at least four to five times the dissolved solids of Bridge-Fault water.
- Both types of water upwell into the intermediate and the near-surface aquifers. Bridge-Fault water appears along the line of the Bridge-Fault surface exposure and central-valley water upwells near RRGP-4 where the Narrows Structure and the Bridge Fault intersect at depth.
- RRGE-2 produces the purest Bridge-Fault water and RRGI-7 the purest central-valley water. Other deep wells produce mixtures of these two waters.
- Temperature of the basement rock (quartz monzonite) is highest in the central valley.
- One model, consistent with known facts, depicts deep water from an unknown source upwelling through the basement rock and flowing up through the sediment burden via fractures. The heated basement rock in turn heats meteoric water which flows up the Bridge Fault.
- Work is underway which will refine this model.

ACKNOWLEDGMENTS

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