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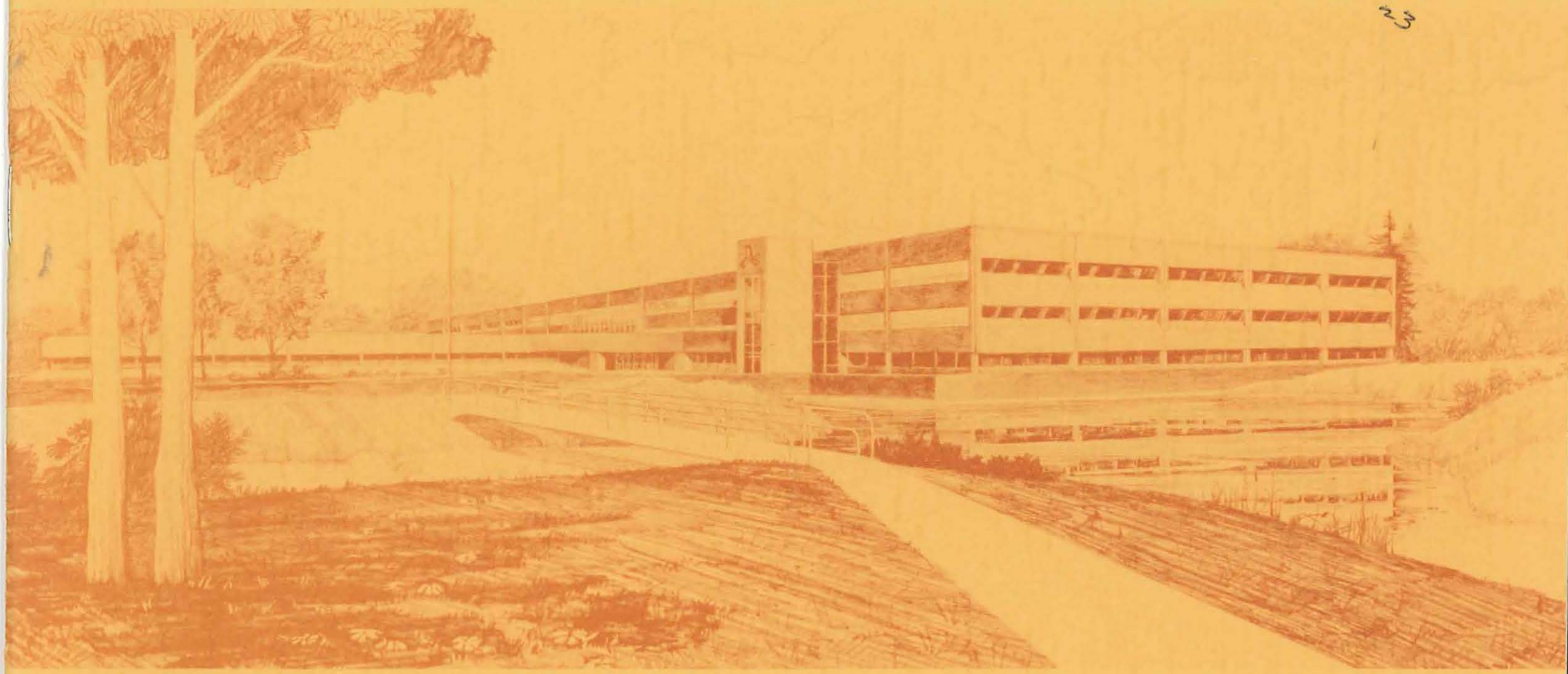

U.S. Department of Energy
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# Geochemical Modeling of the Raft River Geothermal Field

Harold L. Overton
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Published November 1979

Prepared for the
U. S. Department of Energy
Under DOE Contract No. DE-AC07-76ID01570

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# GEOCHEMICAL MODELING OF THE RAFT RIVER GEOTHERMAL FIELD

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**EG&G Idaho, Inc.**
**Idaho Falls, Idaho 83401**

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# ABSTRACT

This interim report presents the results to date of chemical modeling of the Raft River KGRA. Earlier work indicated a northwest-southeast anomaly in the contours. Modeling techniques applied to more complete data allowed further definition of the anomaly. Models described in this report show the source of various minerals in the geothermal water. There appears to be a regional heat source that gives rise to uniform conductive heat flow in the region, but convective flow is concentrated near the upwelling in the Crook well vicinity. Recommendations are made concerning field expansion and additional work needed to refine the overall reservoir model.

# CONTENTS

# GEOCHEMICAL MODELING OF THE RAFT RIVER GEOTHERMAL FIELD

## INTRODUCTION

This is an interim report of chemical modeling studies made of the Raft River known geothermal resource area (KGRA). It presents results obtained thus far and interpretations based on data available to date. Model revisions will be reported as additional data become available.

Chemical modeling is an analytical technique that can be used to gain information about the extent and properties of geothermal reservoirs. Basically, the chemical composition of water samples taken from wells throughout a geothermal system is used to characterize the reservoir and form conclusions concerning the heat source, minerals, and water and their flow within the system.

## GEOLOGIC BACKGROUND

The Raft River valley in south central Idaho is bounded by the Jim Sage and Cottrell Mountains to the west, the Raft River Range to the south, and the Black Pine and Sublett Ranges on the east. The floor of the valley is a graben which was downthrown during the late Tertiary age and filled with approximately 1800 m of Tertiary and Pleistocene sediments.[1] The geology of the surrounding mountain ranges varies. The Jim Sage and Cottrell mountains occur in Tertiary volcanic and sedimentary rocks. The Black Pine and Sublette ranges to the east contain Paleozoic sedimentary rocks. The Raft River mountains are made up of Precambrian adamellite (quartz monzonite) and Paleozoic sediments. The deepest wells in the valley terminate in the quartz monzonite, indicating that the floor of the basin is formed from the Precambrian rocks exposed in the Raft River range.

Paleozoic metamorphic layers (quartzites and schists) overlay the quartz monzonite and are overlain with sediments from the Salt Lake Formation (Mid-Pliocene Age). The Salt Lake Formation makes up the bulk of the sediments in the basin and consists of tuffaceous sandstone, siltstone, and conglomerates. The Raft River Formation, consisting of Pleistocene sand, gravel, silt, and clay, is thought to overlay the Salt Lake Formation. The upper layers are alluvial and fluvial sediments.

The Bridge Fault (Figure 1) is an important structural feature in the region of the geothermal field. The fault runs north to south and forms a trace at the base of the Jim Sage Mountains and dips steeply eastward. The structure is a normal fault with the east down-dropped relative to the west.

Based on geologic information, the Raft River reservoir model is a portion of a sediment-filled basin having a fault as one boundary, which allows vertical heat and fluid movement. The intersection of faults results in maximum vertical movement of fluid flow in that region.

## ANALYSES PERFORMED AND RESULTS

### Chemical Analyses

Figure 2 is a topographic map of the area, showing the shallow wells in the vicinity of the Raft River geothermal field with some data available in 1974. For each well location, the total dissolved solids (TDS) and lithium data are recorded.[2] Contours of these ion concentrations have been superimposed on the map. The central contours, which run north-south agree with the orientation of the Bridge Fault; however, the contours in the southeast section of the map indicate an east-southeast—west-northwest anomaly. These two features are the principal geochemical anomalies.

Recent data, listed in the appendix, from analyses for the Ca/Cl ratio of the hot, deep wells and shallow injection wells further delineate the southeast-northwest anomaly, as shown in Figure 3. The solid lines are contours inferred from deep well data and the dashed 0.1 and 0.15 contours are for the shallow data. The apparent horizontal displacement of these closed contours with respect

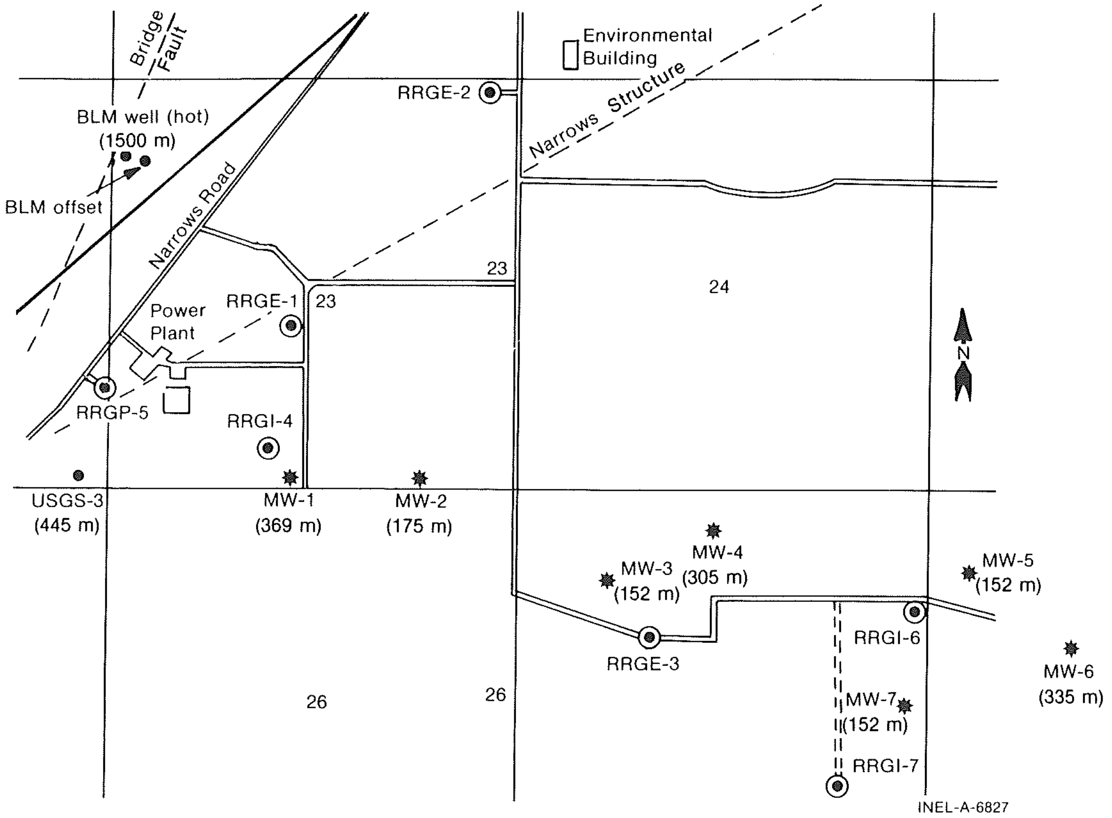

Figure 1. Raft River Geothermal Area well locations.

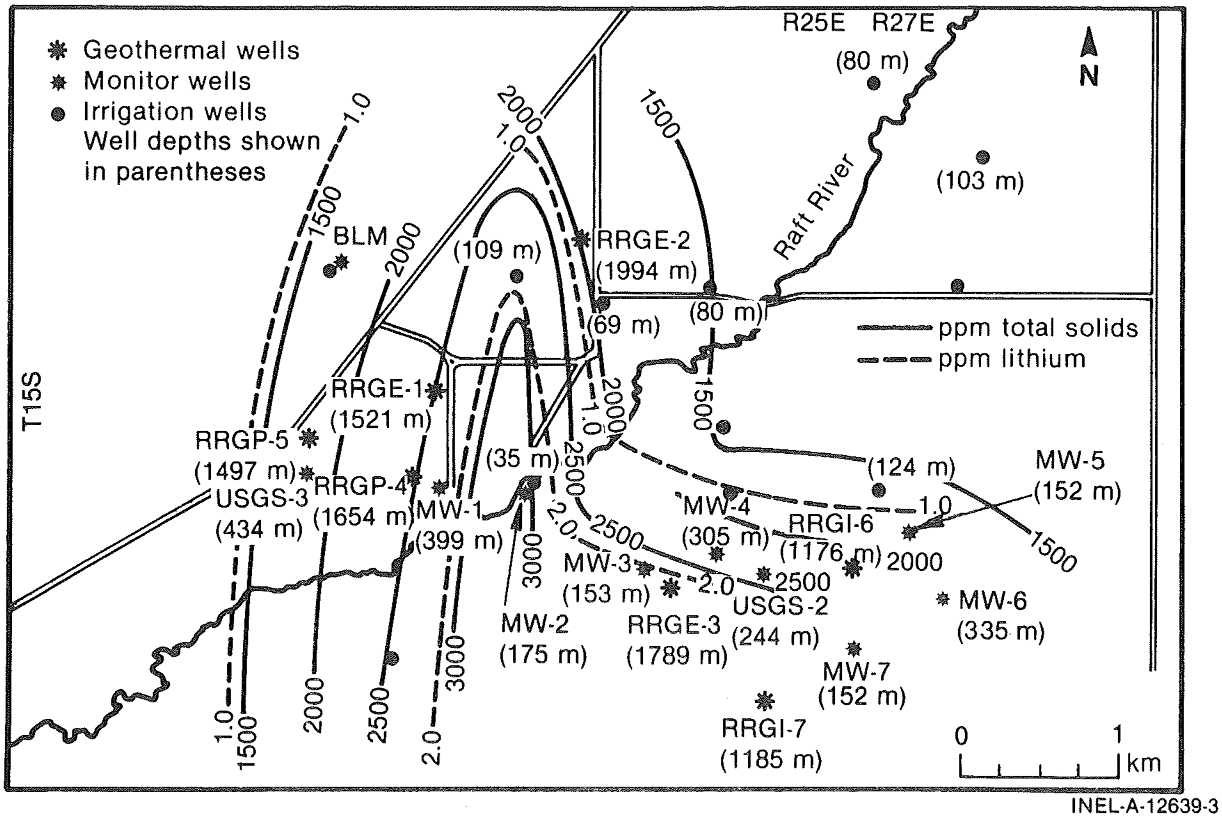

Figure 2. Raft River shallow groundwater geochemical map.

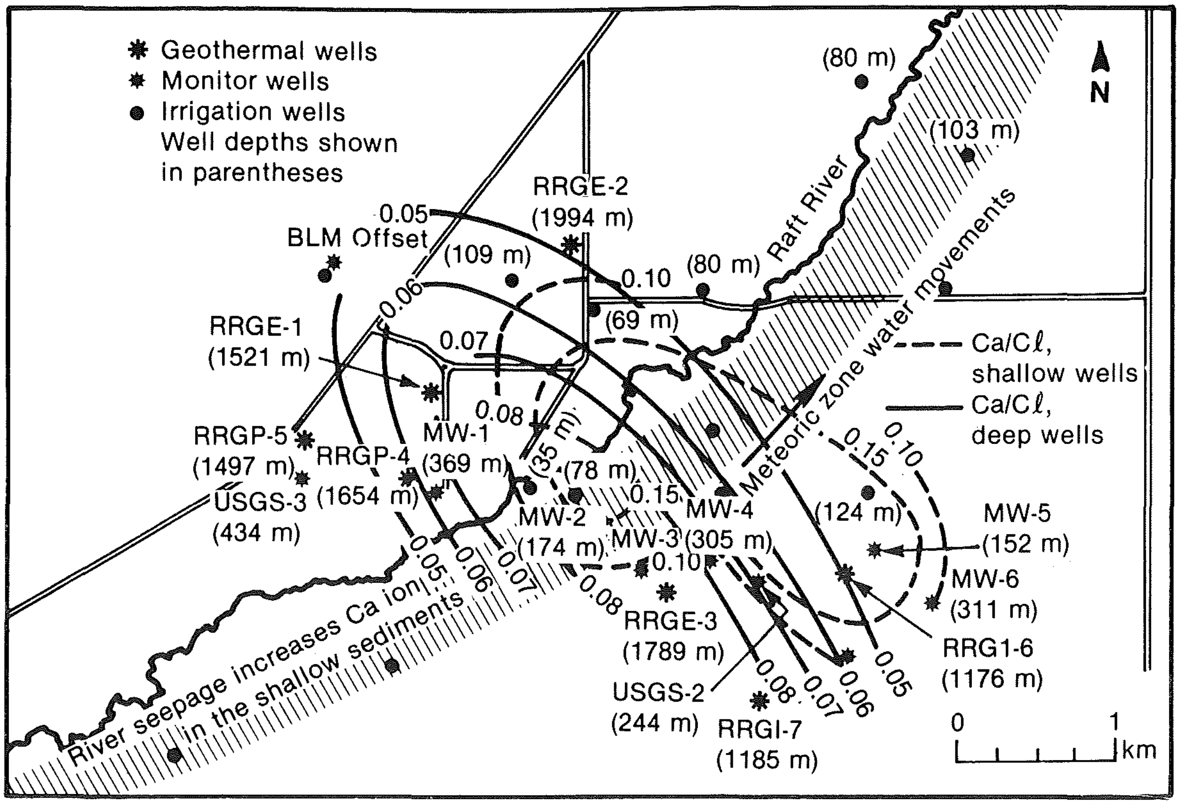

**Figure 3. Calcium variations in deep and shallow well water, Raft River geothermal field.**

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to those of the deep wells indicates that the ions are swept to the northeast as they move upward. This is evidently caused by shallow groundwater movement towards the northeast within the first 100 m of sediments. The reversed contrast in the Ca/Cl magnitudes beteen the deep and shallow levels masks the fact that the concentration of both ions increases with depth, while their ratio decreases. This observation is discussed below.

Also in Figure 3, note the irregularity in the shape of the contours on the southwest side of the 0.15 shallow well plot. This abnormality occurs along the southeast side of the river and is probably due to the higher groundwater flow underneath the river near the Narrows Structure. This infiltration of calcium-containing river water flushes the ions to the northeast.

Figure 4 shows the Sr/Cl ratio contours superimposed on a schematic cross sectional diagram of the field. This presentation is similar to a general trend for all mineral concentrations in a northwest-southeast cross-section. Up-welling geothermal mineralized fluid, mixed with meteoric water that originates near the western edge of the field, moves up from the basement and flows in the intermediate water system to the southeast, as indicated by the Sr/Cl contours. Two of the possible explanations for the high mineral content in the waters are:

1. The upwelling flow carries minerals into the shallow system where a concentration mechanism operates to build up the mineral content in a relatively stagnant body of water to the southeast. The mechanism could be a steaming ground phenomenon occurring early in the history of the Raft River Formation. Although no evidence of Travertine has been noted in the well cuttings or surface topology to support this hypothesis, there is calcite of significant amounts. In this case, the mineral source would be under the region of upwelling water.

2. As the basin filled up during the formation of the shallow sediments, subsurface water remained relatively stagnant with a high mineral content. Temperature increase due to conduction aided mineral dissolution. The upwelling may have begun flowing at a later geologic time. As

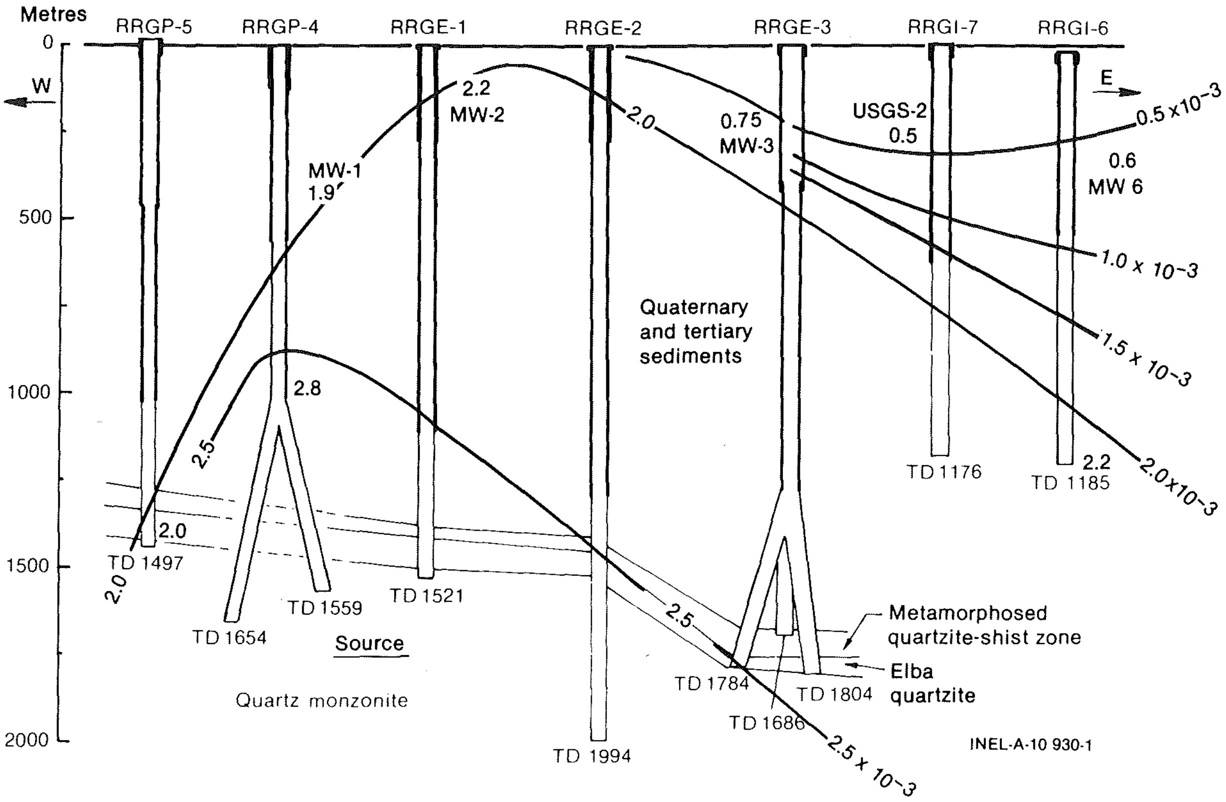

**Figure 4. Sr/Cl distribution in groundwater along on east-west cross-section, Raft River geothermal field.**

the less concentrated meteoric fluid moved into the shallow water system, it swept the mineralized water to the southeast, thus yielding the contours in Figure 4. In this case, the mineral sources would be the earlier stagnant waters.

Data for Ca concentrations from produced waters are superimposed on the northwest-southeast cross section in Figure 5. The calcium contours show a subsurface dome of high ion content similar to that in Figure 4 for Sr/Cl. Well 3 has the highest hydrogen ion measurement (indicating relative stagnancy) with associated pH, which can account for the increased Ca solubility.

The distribution of fluoride in the water samples (Figure 6) appears more complicated than for the Sr or Ca data. Depending on which of the models is applied, the contours can be explained as follow:

1. In the concentration mechanism model (steaming ground hypothesis), the F source is postulated to be near the upwelling at well 4. Near the bottom of wells 2 and 3, as concentration occurs the high Ca concentration causes precipitation of F as $CaF_2$ in a proposed calcite anomaly to the southeast.

2. In the flushing model, the geothermal/meteoric fluid with its high F content has flushed over the more stagnant layers of deep water leaving an F ion gradient with depth, which goes through a maximum and then decreases near the basement.

There does appear to be a strong dependence between the concentrations of Ca and F as shown in Figure 7 for subsurface water analyses. The data fit an equation of the form:

$$[F] = 23\,[Ca]^{-0.28} \qquad (1)$$

This indicates that precipitation of $CaF_2$ may affect the F concentration by combination with previously deposited soluble calcium. More calcium is dissolved in the low pH waters.

The Sr versus Li data for several wells, including all deep and monitor wells, are plotted

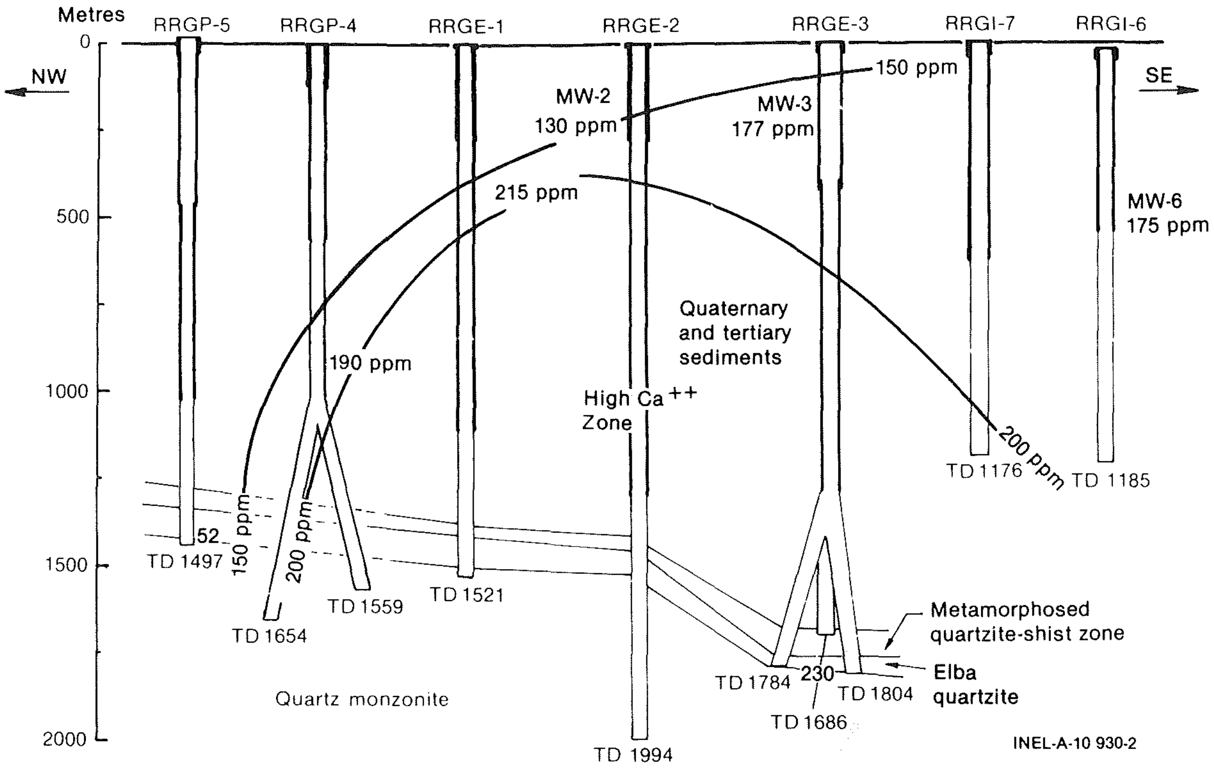

Figure 5. Distribution of calcium ions in groundwater along a northwest-southeast cross section, Raft River geothermal field.

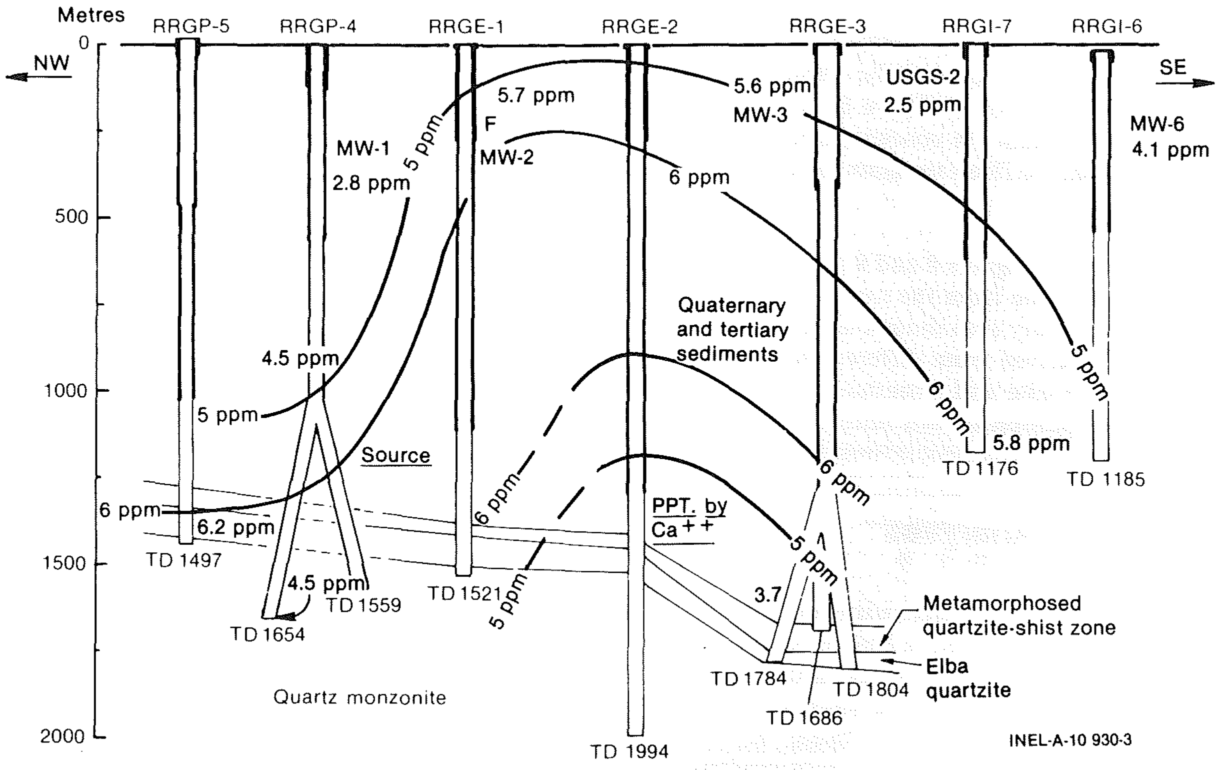

Figure 6. Fluoride distribution in the subsurface water along a northwest-southeast cross section, Raft River geothermal field.

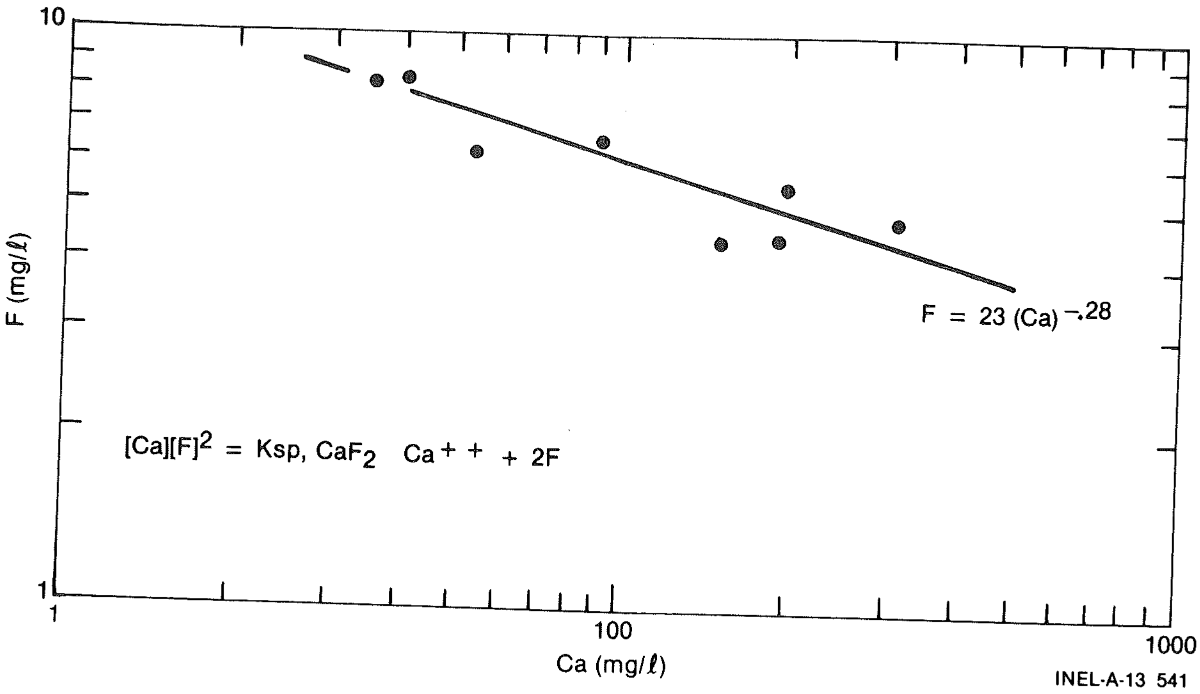

**Figure 7.** Influence of calcium ions on fluoride ion solubility in the Raft River wells.

in Figure 8. These ions appear to increase together, indicating that their sources are in the same general locality and that these ions move similarly in the groundwater flow.

The F versus Li concentrations are shown in Figure 9. There is not the same dependence apparent as shown in Figure 8 for Sr versus Li. Lines of constant Ca concentration are sketched onto the data to illustrate again the effect of Ca on F content.

The data in Figures 8 and 9 indicate that F, Sr, and Li originate from the same general source in the local vicinity even though ultimately they were probably derived from different sources (lithium from monzonite and strontium from limestone), but no indication of this ultimate source can be derived from the present information.

## Thermal Analyses

The procedure for estimating relative convective heat flow is illustrated in Figure 10. The gradient data were taken from well logs, and while the thermal equilibrium state of the wells is in some question, trends can be used to locate the local heat source.[3] In the figure, the average gradient $G_t$ is

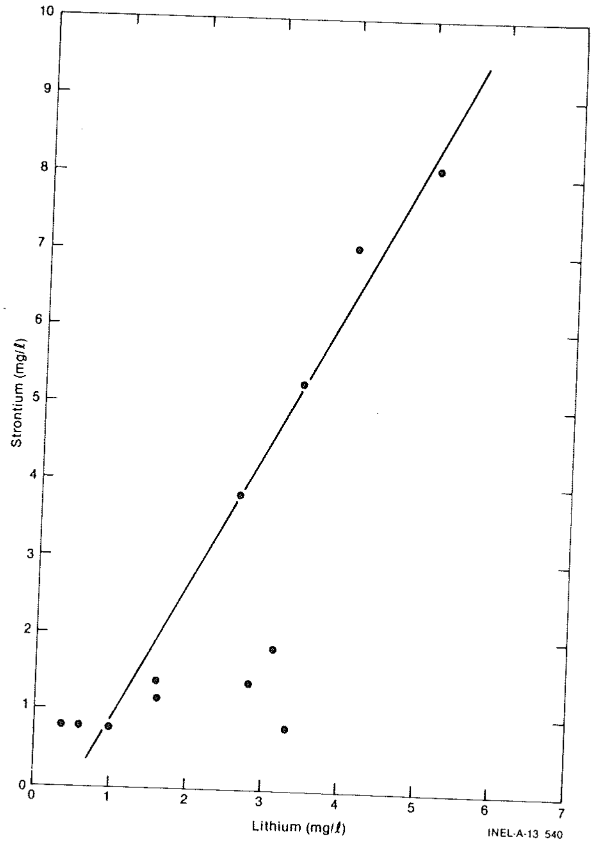

**Figure 8.** Strontium lithium relationships in monitor and deep well water samples, Raft River geothermal field.

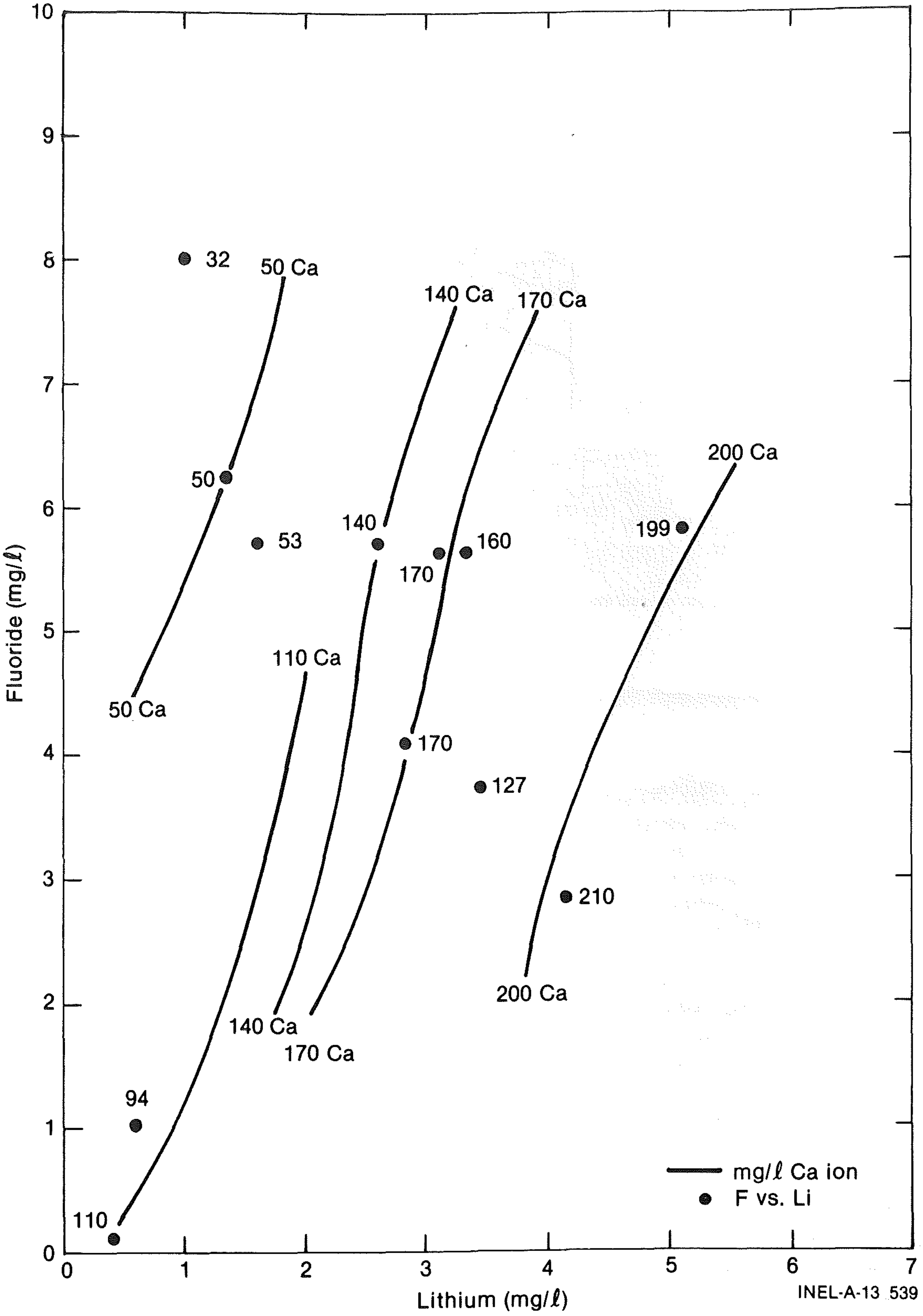

**Figure 9. Fluoride-lithium relationships and effect of calcium content on fluoride concentration in monitor and deep well water samples, Raft River geothermal field.**

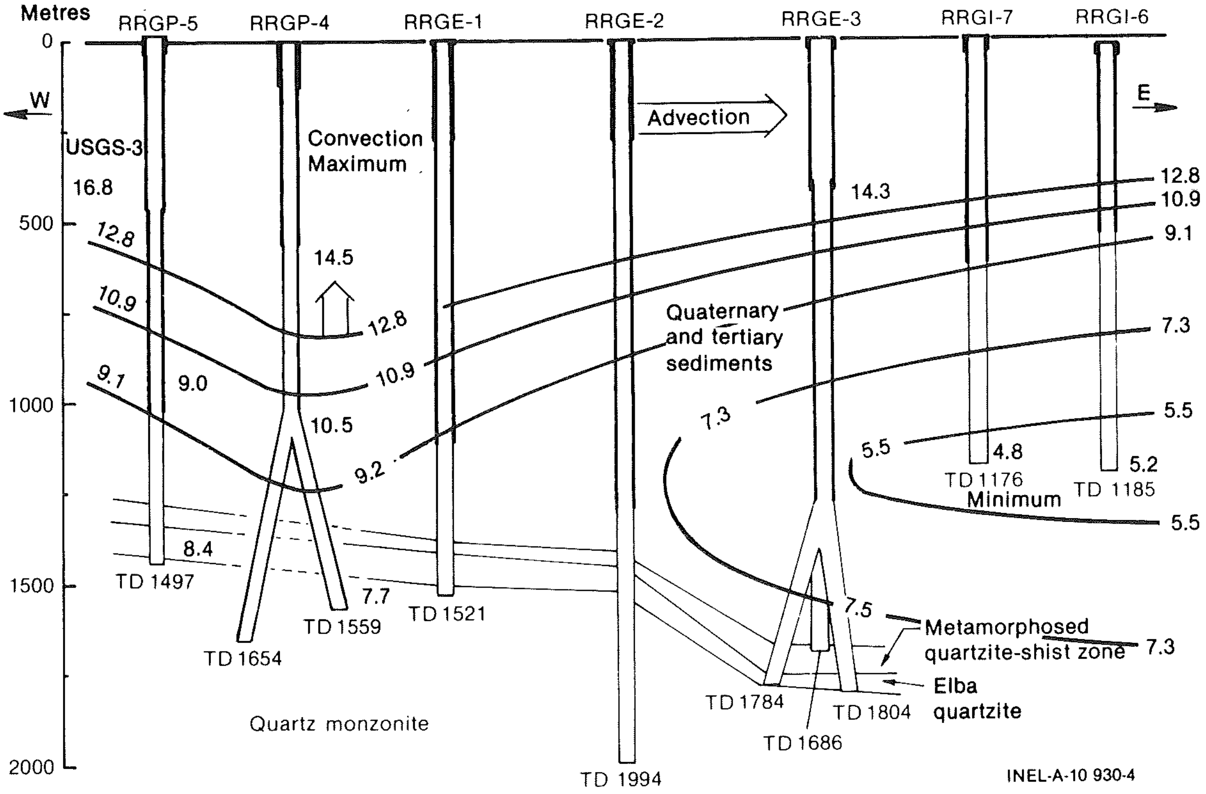

**Figure 10. Average temperature gradients, in $^{o}C/100$ m, from well legs along on east-west cross section, Raft River geothermal field.**

plotted along the east-southeast—west-northwest cross section where:

$$G_t = \frac{dT}{dz} \simeq \frac{T_{max} - 8.67^{o}C}{depth} \quad . \qquad (2)$$

If the regional heat flow (due to conduction) results in $G_t = 7.3^{o}C/100$ m, as observed by inspection of the lower limit data in Figure 10, the convective component of heat flow velocity is:

$$velocity \simeq \frac{dT}{dz} - 7.3\ ^{o}C/100\ m \quad . \qquad (3)$$

The higher the apparent geothermal gradient (dT/dz), the higher the convective flow. No deep hot water upward flow is observed near wells 6 and 7 where the gradients are near normal. This indicates conductive heat flow only. Consequently, it is expected that lower permeabilities and less upward ionic movement occurs to the southeast in the direction of these wells. The high gradient ($12.8^{o}C/100$ m) at intermediate depths indicate that convective heat flow is located mainly near the Crook well, RRGE-1, RRGP-4, and that the vertical rise of minerals is a maximum there. It also implies that the upwelling is a maximum in this region.

Advection occurs almost everywhere in the shallow sediments due to the rapid movement of meteoric water in those highly permeable sandstones. Figure 11 shows the convective and conductive heat flow components from four wells in a southwest-northeast cross section. Note that this orientation is different from that of Figure 10.

## CONCLUSIONS

A model for the water and heat movement in the vicinity of the Raft River reservoir is shown in Figure 12. This is based on the information previously discussed. The basement fracture running northwest-southeast is shown as questionable since calcium ions and the anomaly in Figure 2 are the only indications. The basic conclusions that led to this model are:

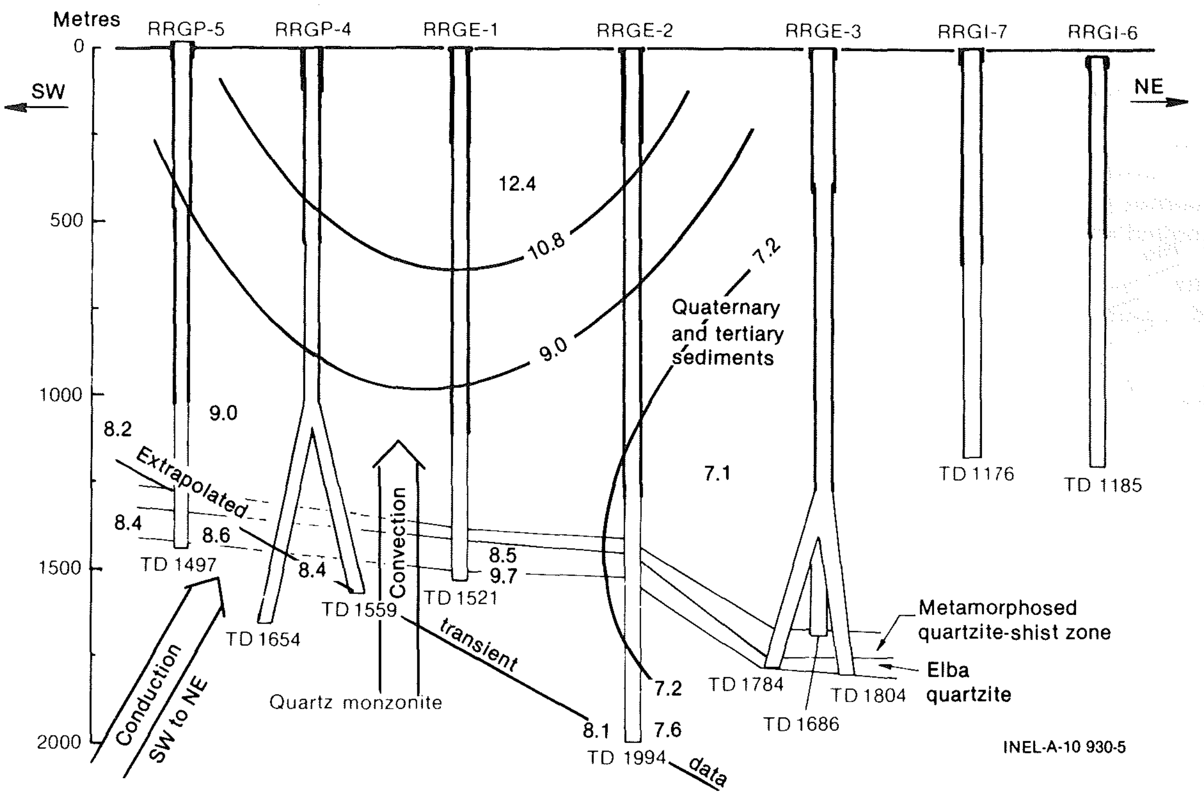

**Figure 11. Average temperature gradients, in $^{o}C/100$ m, from well legs along a southwest-northeast cross section, Raft River geothermal field.**

1. The main source of convective heat is an upwelling near the Crank well, which defines the useful reservoir heat source as opposed to the generalized conductive heat source. The mineral source and the conductive heat source are distributed throughout the basin.

2. Groundwater flows most rapidly to the northeast due to topography, and it is shallow and warmer than normal.

3. Heat conduction is high everywhere due to a regional source, but convection contributes significantly near the upwelling zone.

4. Temperature is highest on the southeast of the Raft River field. This is due to less mixing with eteoric water because of lower permeability resulting from conjectured calcite deposition in the past (concentration).

5. The best injection well location is to the northeast of the field, near the river, to avoid low permeability and to avoid flushing the high mineral water located to the southeast. However, warm (66°C) water injected to the south of the Crank well would move to the northeast into the upwelling region, preventing additional encroachment of cold, meteoric water into the production zone.

6. New production wells should be drilled along the north-south feature, either south of the Crank well to further define the field or north of the Crank well as an infield well. General consideration suggests that the field will support five production wells at 65 hectares per well.

## SUGGESTIONS FOR FURTHER WORK

The model shown in Figure 12 for the Raft River reservoir can be improved and clarified when definite conclusions can be made about the following features:

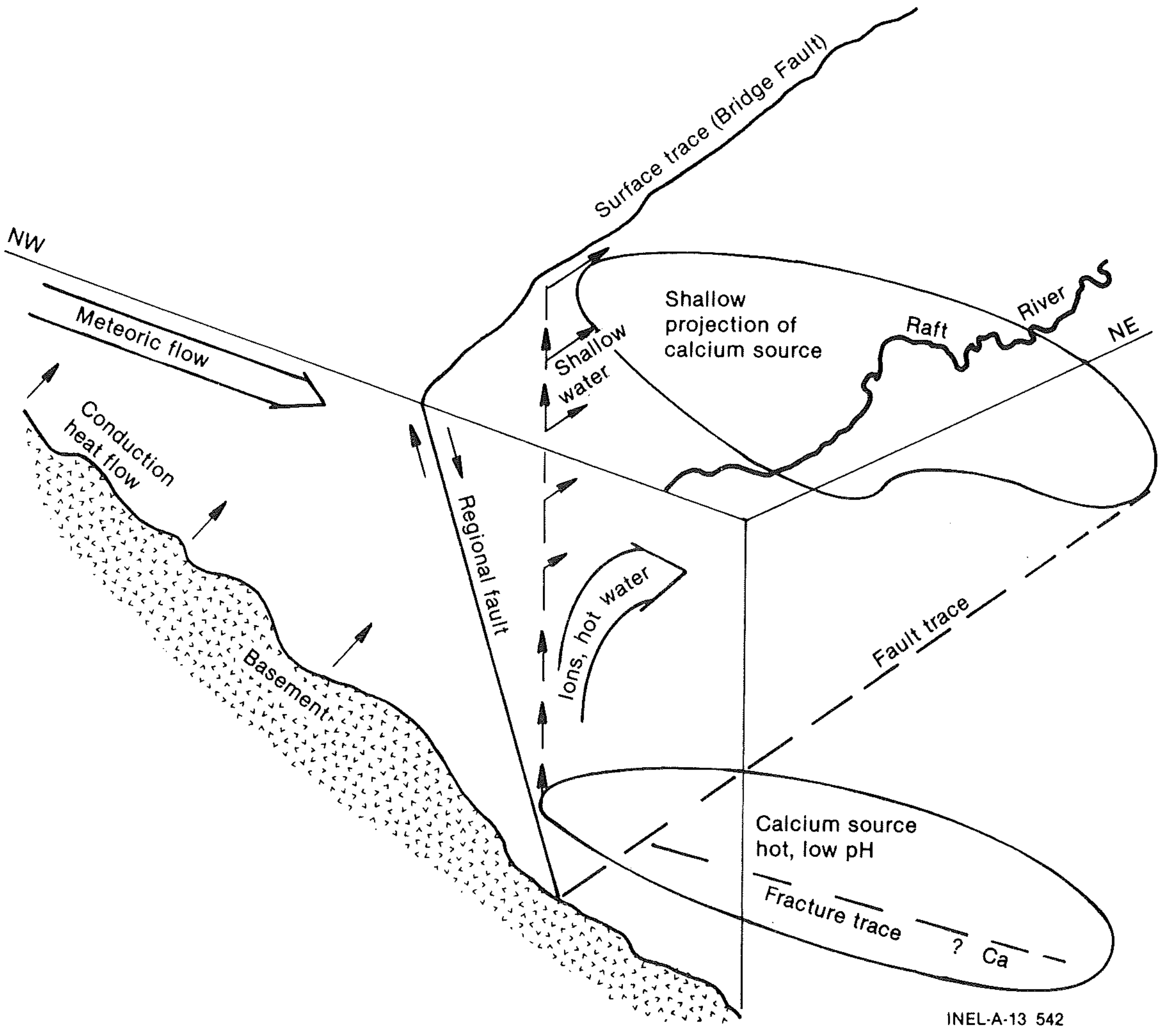

Figure 12. Heat and water flow model, Raft River geothermal field.

1. The Ca anomaly in Figure 3 suggests a basement fracture to the northwest-southeast, but its existence depends mainly upon low pH which is probably $H_2$ derived. The $H_2$ can come from the basement, but might be due entirely to relatively hot and stagnant water (with reducing organisms). The northwest-southeast orientation could be the direction of water movement prior to stagnation.

2. The major north-south chemical anomaly is clearly shown in the TDS map (Figure 2). Since this feature corresponds with the geologic interpretation as being related to a graben fault (Bridge Fault), it is considered to be the dominant feature both geologically and geochemically. However, this feature is not found in the calcium map (Figure 3). If this north-south anomaly is a region of upwelling water, it does not appear to disturb the relative stagnancy required to produce the low pH and high Ca waters shown in the northwest-southeast feature found to the southeast of the upwelling waters.

3. Equilibrium of Ca and F shown in Figure 7 suggests that theoretical equations can be derived from these chemical analyses using water data from a wide area (on the kilometer scale) to characterize the chemical interrelationships.

4. Geochemical analyses do not show any evidence of the Narrows Structure except for the irregularity in the shallow data

(Figure 3) near the Raft River. However, this irregularity can be explained by ground water movement. This negative indication suggests that the Narrows Structure may be a dormant feature, i.e., it may be sealed with a deposit such as gypsum if a fracture previously existed.

5. The correspondence of Sr and Li concentrations in ground water is generally good as shown in Figure 8, but is poor at low Sr concentrations.

6. A line of constant geothermal gradient, from extrapolated transient temperature data, suggests a region of constant thermal conductivity in the subsurface sediments (Figure 11).

Further work, to clarify the previously listed features, is suggested as follows:

1. Pressure transient analysis or seismic work sould be incorporated to confirm or deny the northwest-southeast anomaly.
2. In situ measurements of pH or Eh should be made in all deep waters or from cuttings from equivalent depths to substantiate the pH effect on the Ca distribution.
3. Known reaction equations and equilibrium constants should be incorporated into future analyses.
4. Subsurface mapping from logs and seismic data should be completed.
5. An investigation of measurement errors should be made to increase the reliability of contour placement.
6. The temperature field for the entire geothermal area should be mapped in three dimensions from original equilibrium well data.

## REFERENCES

1. Republic Geothermal, Inc., *Proposal for Producing Well Hydraulic Fracture Stimulation, Raft River Field Geothermal Reservoir Well Stimulation Program*, June 1977.
2. H. L. Overton, ''Hot Water Flow in Raft River Reservoir,'' unpublished report.
3. H. L. Overton, ''Appraisal of Water Movement From Subsurface Data,'' *The Log Analyst*, September—October 1978, pp. 3-20.

# APPENDIX A

# APPENDIX A

Table A-1 shows the average values from analyses of geothermal water samples taken from wells in the Raft River Geothermal Area. Except for the two USGS wells, water samples were analyzed at one or more laboratories: the INEL Site Laboratory, the Raft River Laboratory, and the laboratory at Energy Inc., a subcontracted firm in Idaho Falls. In some instances, individual values, which were considered to be more representative of the sample, were used in contour mapping. These instances are indicated in the table.

## TABLE A-1. AVERAGE VALUES FROM WELL WATER ANALYSES USED IN COUNTOUR MAPPING[a]

| Well | Ca | F | C1 | Sr | Li | TDS | Ca/Cl | Sr/Cl |
|---|---|---|---|---|---|---|---|---|
| RRGE-1 | 53 | 5.7 | 709 | 1.4 | 1.60 | 1607 | 0.07 | $1.97 \times 10^{-3}$ |
| RRGE-2 | 32 | 7.9 | 701 | 0.8 | 1.0 | 1161 | 0.05 | 1.14 |
| RRGE-3 | 127 | 3.7 | 2116 | 5.2 | 3.4 | 4130 | 0.06<br>0.09[b] | 2.46 |
| RRGP-4 | 150 | 4.53 | 2575 | 6.4 | 3.1 |  | 0.06 | 2.49 |
| RRGE-4 | 190 | 4.5 | 2250 | 6.3 | 3.1 |  |  | 5.29 |
| RRGP-5B | 50 | 6.2 | 590 | 1.2 | 1.6 | 1482 | 0.08 | 2.03 |
| RRGI-6 | 199 | 5.8 | 3632 | 8.0 | 5.1 | 6330 | 0.05 | 2.2 |
| RRGI-7 | 315 | 5.0 | 4085 |  |  |  | 0.08 |  |
| MW-1 | 210<br>215[b] | 3.4<br>2.8[b] | 3700 | 7.0 | 4.1 | 6590 | 0.06 | 1.89 |
| MW-2 | 140<br>130[b] | 5.7 | 1700 | 3.8 | 2.6 | 3130 | 0.08 | 2.24 |
| MW-3 | 170<br>177[b] | 5.6 | 2400 | 1.8 | 3.1 | 4920 | 0.07 | 0.75 |
| MW-4 | 160 | 5.6 | 2610 | 0.8 | 3.3 | 4510 | 0.06 | 0.31 |
| MW-5 | 110 | <0.1 | 560 | 0.8 | 0.4 | 1180 | 0.20 | 1.43 |
| MW-6 | 170<br>175[b] | 4.1 | 2340 | 1.4 | 2.8 | 4270 | 0.07 | 0.60 |
| MW-7 | 94 | 1.0 | 650 | 0.8 | 1.0 | 1300 | 0.14 | 1.23 |
| USGS-2[c] | 40 | 2.5 | 520 | 0.26 | 0.64 |  | 0.077 | 0.50 |
| USGS-3[c] | 56 | 5.1 | 2000 | 2.0 | 1.8 |  | 0.028 | 1.0 |
| Crook | 127 | 4.11 |  | 0.36 |  |  |  |  |
| BLM | 55 | 5.6 | 1139 | 1.35 | 1.4 |  | 0.048 | 1.19 |

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a. All concentrations in mg/l.

b. Most representative values.

c. Data source: E.G. Crosthwaite (Comp.), *Basic Data from Five Core Holes in the Raft River Geothermal Area, Cassia County, Idaho*, United States Department of the Interior Geological Survey, Boise, Idaho, open-file report 76-665, July 1976, p. 11.

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