

CHEMICAL AND LIGHT-STABLE ISOTOPE CHARACTERISTICS OF WATERS FROM THE RAFT RIVER GEOTHERMAL AREA AND ENVIRONS, CASSIA COUNTY, IDAHO; BOX ELDER COUNTY, UTAH

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Abstract—Chemical and light-stable isotope data are presented for water samples from the Raft River geothermal area and environs. On the basis of chemical character, as defined by a trilinear plot of per cent milliequivalents, and light-stable isotope data, the waters in the geothermal area can be divided into waters that have and have not mixed with cold water. The non-mixed waters have essentially a constant value of light-stable isotopes but show a large variation in chloride content. The variation of chloride composition is not the usual pattern for deep geothermal waters, where it is normally assumed that the deep water has a single chloride composition. Different mixed waters also have hot-water sources of varying chloride composition. Plots of chloride values on cross-sections show that water circulation patterns are confused, with non-mixed waters having different chloride concentrations located in close proximity. Three models can explain the characteristics of the deep geothermal water: (1) in addition to near-surface mixing of cold and hot water, there is deep mixing of two hot waters with the same enthalpy and isotopic composition but differing chloride concentrations to produce the range of chloride concentrations found in the deep geothermal water; (2) there is a single deep hot water, and the range of chloride concentrations is produced by the water passing through a zone of highly soluble materials (most likely in the sedimentary section above the basement) in which waters have different residence times or slightly different circulation paths; (3) the varying chloride concentrations in space have been caused by varying chloride concentrations in the deep feed water through time. Some of this older water has not been flushed from the system by the natural discharge. Although one model may seem more plausible than the others, the available data do not rule out any of them. Data for water samples from the Raft River and Jim Sage Mountains show that water from these areas is probably the source for the cold mixing water determined from end-members on mixing lines. Data for water samples in the Upper Raft River Valley show that the thermal anomaly found at Almo 1 is probably not related to the Raft River geothermal area. The water is different in type as shown by its placement on a trilinear plot, and the isotopes are different enough to show that it is probably a different water. Isotopic compositions of samples from a wide area around the Raft River geothermal system indicate that the likely source of the recharge water is the southern Albion Mountains and western Raft River Mountains. The recharge area is at one end of the Narrows zone, and the geothermal area is along the Narrows zone; thus it is likely that the Narrows zone defines the circulation path.

INTRODUCTION

The Raft River geothermal area in southeastern Idaho is under investigation by the Idaho National Engineering Laboratory as a site for demonstrating the generation of electricity from an intermediate-temperature reservoir. The U.S. Geological Survey has had a cooperative programme to study geological, geophysical, geochemical and thermal properties of the geothermal system. Williams *et al.* (1976) summarized preliminary studies of the system. More recently, Mabey *et al.* (1978) summarized gravity, magnetics and electrical studies, Ackermann (1979) detailed the seismic refraction study, Keys and Sullivan (1979) used borehole geophysics to define physical characteristics of the system, and Nathenson *et al.* (1979, 1980) interpreted temperature information obtained from drill-hole logs.

A topographic map along with sample locations is shown on Fig. 1. A geologic map of the Idaho portion of Fig. 1 is given in Armstrong *et al.* (1978). The geothermal system is located in

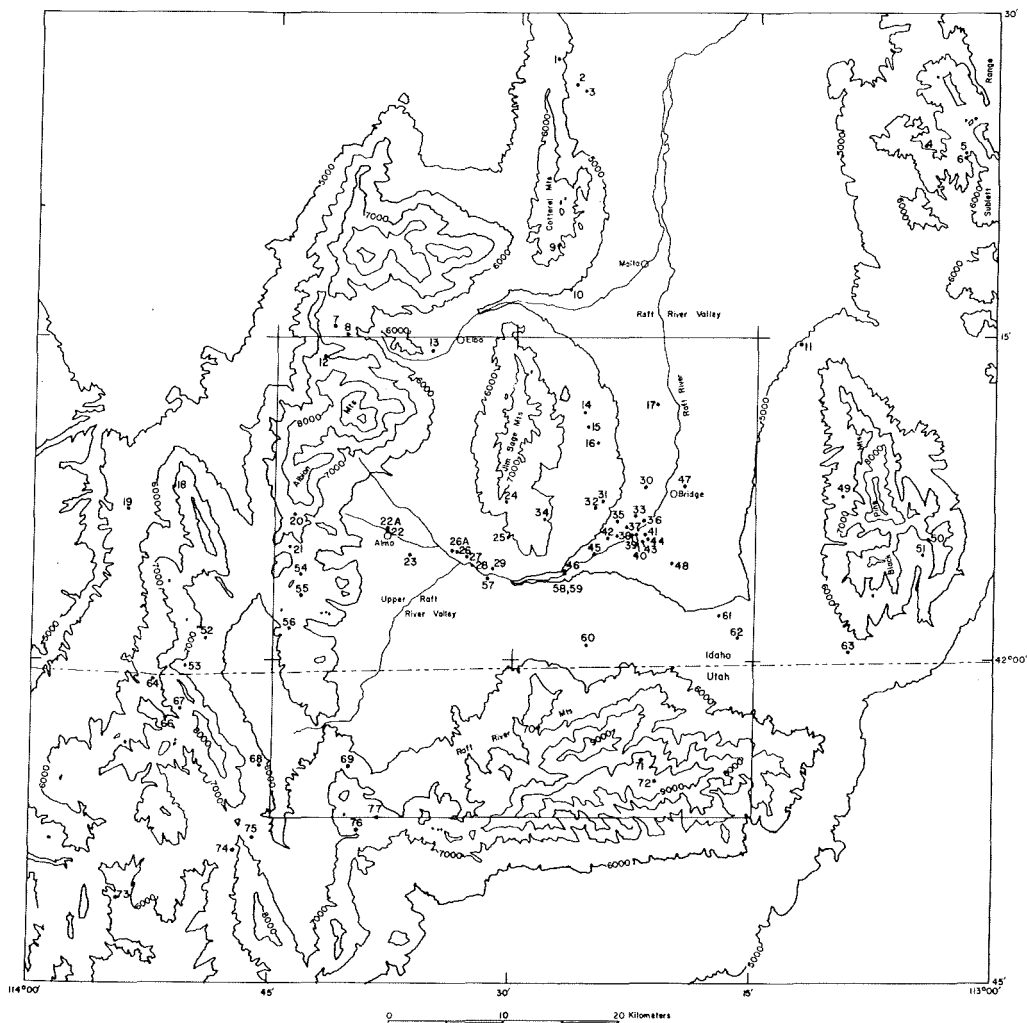


Fig. 1. Topographic map (1000-foot contours) of Raft River geothermal area and environs showing locations of water samples. The base map was traced from U.S. Geological Survey, Pocatello, 1954, Idaho, and Brigham City, 1954, Rev. 1970, Utah; Idaho. (Locations 22A and 26A were added after numbering was completed.)

the southern part of the Raft River Valley. Preliminary indications of the system were given by the Schmitt well drilled into the site of a former hot spring at location 35 (Stearns *et al.*, 1938) and the Crank hot well at location 39 (Nace *et al.*, 1961). Young and Mitchell (1973) calculated geothermometer temperatures from water samples for these two wells ranging from 135 to 145°C.

Previous geochemical studies have focused on the chemical signatures of waters in the system. Allen *et al.* (1979) presented contour maps of conductivity and the ratio of chloride to fluoride based on data obtained from shallow wells and deep geothermal wells. The conductivity indicates a complex circulation pattern; however, the chloride-to-fluoride ratio is not a very useful indicator, because the fluoride concentration is controlled by the solubility of fluorite (Nathenson *et al.*, 1980). Overton *et al.* (1979) used various chemical components and ratios to delineate fluid movement in the system. Spencer and Callan (1980) used trilinear plots

to infer water type (deep geothermal versus mixed water) and to show that the deep waters are similar in water type despite their large variations in total dissolved solids.

The purpose of this study is to analyse chemical and light-stable isotope data for the geothermal system and the surrounding area in order to help define the characteristics and limits of the geothermal system and to find the source of the recharge water. Presentation of the data, given in Table 1, is organized in this report by area. In the first section, data from area I in Fig. 2 will be discussed. This area includes the deep geothermal wells and shallow wells with waters that show evidence of the deep geothermal water. The next section gives data for areas II, III and IV. Areas II and IV are of interest as sources of mixing waters. Area III in the Upper Raft River Valley contains two thermal anomalies with waters that have both similarities to and differences from the anomaly in the Raft River Valley. The last section presents water isotope data from the rest of the area of Fig. 1 to determine the source of recharge water for the thermal system.

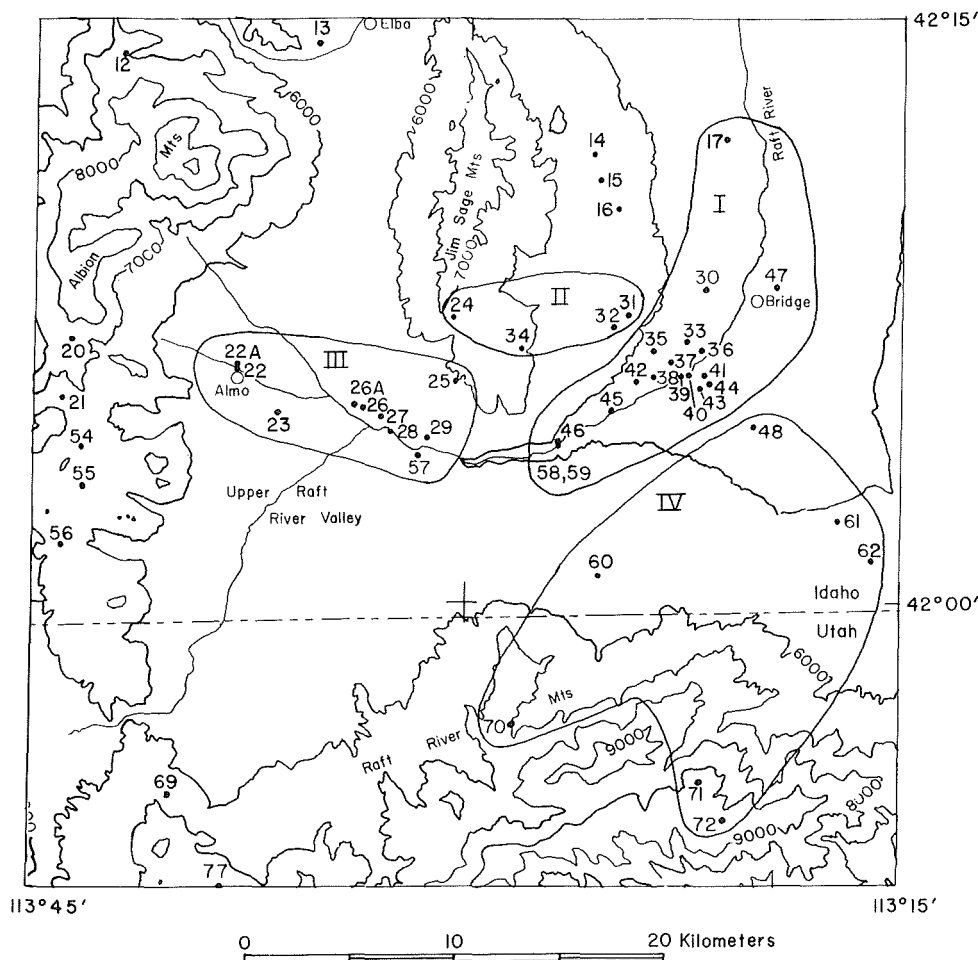


Fig. 2. Topographic map (1000-foot contours) of part of Fig. 1 outlined by box. Chemical and isotopic characteristics of water samples are discussed separately by areas I, II, III and IV shown on map.

Table 1. Water chemistry and isotopic compositions from wells and springs in the Raft River geothermal area and environs. Notes at end of table.

| No. | Name Location* | Sample† Date | T (°C) pH | Flow (LPM) | D‡ ¹⁸O | SiO₂ H (m)§ | Na H (m)¶ | K | Ca | Mg | Li | Cl | HCO₃ | SO₄ | F | ¶ | T** (°C) |
|-----|---------------------------------|--------------------|--------------|---------------|------------------|----------------|--------------|-----|-----|------|------|-----|------------|-----|-----|-----|-------------|
| 1 | Spring 11S26E18DBCS1 | RR27 7/25/75 | 11.5 7.2 | 76 | -135.0 -17.90 | - | - | - | - | - | - | 13 | - | - | - | - | - |
| 2 | Well 11S26E20DCC1 | RR40(M) 8/5/75 | 32 7.9 | 5100 | -124.3 -16.78 | 46 | 34 | 3.8 | 31 | 0.5 | - | 5.9 | 143 | 29 | 1.6 | -1 | 48 |
| 3 | Well 11S26E28BCB1 | RR35(M) 7/25/75 | 35 7.6 | 5100 | -124.5 -16.82 | 47 176 | 34 | 4.1 | 31 | 0.4 | - | 20 | 141 | 13 | 1.4 | -2 | 51 |
| 4 | Mud Spring 12S29E9BBBS1 | RR7610 11/11/76 | 2.5 6.9 | 6 | -128.0 -16.65 | - | - | - | - | - | - | - | - | - | - | - | - |
| 5 | Spring 12S29E11CBAS1 | RR7611 11/11/76 | 2 7.1 | 2 | -125.8 -16.60 | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 | Lake Fork Sprg 12S29E11CDAS1 | RR7612 11/11/76 | 3 8.4 | 38 | -125.6 -16.61 | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 | Spring 13S24E30DDBS1 | RR23(U) 8/6/75 | 10 7.6 | 76 | -125.2 -16.29 | 17 | 8.4 | 0.7 | 64 | 4.5 | - | 6.3 | 216 | 5.5 | 0.1 | 3 | -†† |
| 8 | Spring 13S24E32BDAS1 | RR26 8/6/75 | 8 6.4 | 38 | -126.6 -16.75 | - | - | - | - | - | - | 6 | - | - | - | - | - |
| 9 | Upper Nibbs Sp 13S26E6DBAS1 | RR33 8/8/75 | 9 6.5 | 38 | -128.5 -17.05 | - | - | - | - | - | - | 38 | - | - | - | - | - |
| 10 | Rice Spring 13S26E17CDCS1 | RR20(M) 8/8/75 | 21 8.2 | 380 | -132.7 -17.04 | 45 | 14 | 3 | 34 | 0.6 | - | 25 | 92 | 9.5 | 0.5 | 0 | 33 |
| 11 | Point Spring 13S28E32DCBS1 | RR25(U) 8/7/75 | 19 7.7 | - | -126.7 -16.67 | 14 | 31 | 2.4 | 50 | 28 | - | 88 | 180 | 27 | 0.2 | 3 | 28 |
| 12 | Spring 14S24E6BDCS1 | RR18(U) 8/6/75 | 6 6.8 | 190 | -133.6 -17.60 | - | - | - | - | - | - | 7 | - | - | - | - | - |
| 13 | Sears Spring 14S25E6BBBS1 | RR19(M) 8/5/75 | 28 8.2 | 760 | -132.0 -16.85 | 22 | 15 | 3.3 | 29 | 7.5 | - | 19 | 120 | 10 | 0.4 | 3 | 39 |
| 14 | Spring 14S26E21BCDS1 | RR45(U) 7/22/75 | 11 7.3 | 190 | -127.7 -16.24 | 41 | 17 | 3.7 | 24 | 5.3 | - | 30 | 82 | 10 | 0.2 | 3 | 46 |
| 15 | DH06 14S26E28BAC1 | (T) 9/10/79 | 15 9.1 | 61 | -144.1 -18.31 | 44 24 | 125 85 | 3.1 | 1.4 | 0.11 | 0.07 | 27 | 6 (113) | 26 | 3.2 | 5 | -†† |
| | | (T) 11/18/78 | 13 - | - | -144.5 -18.53 | 33 24 | 114 85 | 3.8 | 2.6 | 1.48 | 0.05 | 29 | - (115) | 22 | 3.2 | 1 | -†† |
| 16 | I.D.-5 14S26E33AAB1 | RR15(C) 3/28/75 | 12 7.2 | 95 | -134.8 -17.24 | 38 31 | 28 219 | 4.3 | 39 | 7.5 | 0.02 | 61 | 161 | 15 | 0.6 | -19 | 46 |
| 17 | Well 14S27E18CCC1 | RR30(M) 7/24/75 | 24 7.6 | 3100 | -131.0 -16.98 | 90 | 170 | 29 | 55 | 2.2 | - | 300 | 131 | 23 | 1.1 | -1 | 180 |

| | | | | | | | | | | | | | | | | | |
|-----|----------------|----------|-----|------|--------|------|-----|-----|-----|------|------|-----|-----|-----|-----|-----|-----|
| 18 | Spring | RR768 | - | - | -128.9 | - | - | - | - | - | - | - | - | - | - | - | - |
| | 15S22E10DADS1 | 11/76 | | | -17.41 | | | | | | | | | | | | |
| 19 | Wilson Sprg | RR769 | 16 | 4 | -132.0 | - | - | - | - | - | - | - | - | - | - | - | - |
| | 15S22E17CDBS1 | 11/10/76 | 7.2 | | -17.08 | | | | | | | | | | | | |
| 20 | Indian Grove S | RR37 | 5 | 19 | -135.1 | - | - | - | - | - | 5 | - | - | - | - | - | - |
| | 15S23E14DDCS1 | 7/31/75 | 5.9 | | -18.16 | | | | | | | | | | | | |
| 21 | Emery Canyon S | RR29 | 9 | 38 | -131.9 | - | - | - | - | - | 45 | - | - | - | - | - | - |
| | 15S23E26DBBS1 | 7/31/75 | - | | -17.36 | | | | | | | | | | | | |
| 22A | Durfee Spring | (R) | 34 | 19 | - | 42 | 70 | 3.0 | 34 | 8.5 | - | 80 | 152 | 29 | 3.6 | 0 | 47 |
| | 15S24E22DACCS1 | 8/65 | 7.7 | | - | | | | | | | | | | | | |
| 22 | Flowing well | RR43 | 37 | 3800 | -133.2 | - | - | - | - | - | 82 | - | - | - | - | - | - |
| | 15S24E22DDB1 | 8/5/76 | 7.8 | | -17.38 | 152 | | | | | | | | | | | |
| | | RR78(M) | 38 | 380 | - | 44 | 70 | 3.1 | 37 | 9.3 | - | 80 | 169 | 33 | 2.9 | -2 | 46 |
| | | 7/25/72 | 7.4 | | - | 152 | | | | | | | | | | | |
| 23 | Almo 2 | RR764(U) | 17 | 104 | -131.8 | - | - | - | - | - | - | - | - | - | - | - | - |
| | 15S24E35AAB1 | 2/4/76 | 8.7 | | -17.32 | 349 | | | | | | | | | | | |
| 24 | Jim Sage Sprg | RR39 | 18 | 38 | -132.7 | - | - | - | - | - | 55 | - | - | - | - | - | - |
| | 15S25E14BBCS1 | 8/5/75 | 7.8 | | -17.2 | | | | | | | | | | | | |
| 25 | Spring | RR42 | 20 | 380 | -132.0 | - | - | - | - | - | 54 | - | - | - | - | - | - |
| | 15S25E26BBDS1 | 8/5/75 | 8.1 | | -16.96 | | | | | | | | | | | | |
| | | (U) | 16 | 38 | - | 43 | 16 | 3.5 | 35 | 8.1 | - | 47 | 92 | 12 | 0.2 | 3 | 38 |
| | | 4/27/77 | 8.9 | | | | | | | | | | | | | | |
| 26A | Grape Creek S | (M) | 22 | 75 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | 15S25E29CCAS1 | | | | | | | | | | | | | | | | |
| 26 | Almo 1 | RR761(U) | 59 | 76 | -132.4 | 60 | 110 | 4 | 3.7 | 0.3 | - | 81 | 118 | 36 | 7.3 | -5 | 129 |
| | 15S25E29CDD1 | 11/19/75 | - | | -17.40 | | | | | | | | | | | | |
| | | RT765(T) | 60 | 19 | - | 104 | 115 | 5 | 5.5 | 0.04 | 0.2 | 76 | 160 | 57 | 7.3 | -15 | 143 |
| | | 10/7/76 | 8.9 | | -17.55 | 366 | | | | | | | | | | | |
| | | - | 57 | - | - | 81.4 | 113 | 4 | 4.7 | 0.03 | 0.17 | 78 | 150 | 43 | 7.9 | -12 | 135 |
| | | 8/7/76 | - | | - | | | | | | | | | | | | |
| 27 | A.H. 15 | RR64(U) | - | - | - | 34 | 240 | 8.8 | 44 | 8.7 | - | 260 | 341 | 91 | 1.9 | -9 | 82 |
| | 15S25E32AAD1 | 4/18/74 | 7.5 | | - | 15 | | | | | | | | | | | |
| 28 | Spring | RR48 | 12 | 95 | -128.3 | - | - | - | - | - | 283 | - | - | - | - | - | - |
| | 15S25E33CACCS1 | | 7.1 | | -16.75 | | | | | | | | | | | | |
| | | (U) | 9 | 76 | - | 41 | 250 | 21 | 140 | 29 | - | 350 | 370 | 200 | 0.4 | 3 | 78 |
| | | 4/26/77 | 9.4 | | - | | | | | | | | | | | | |
| 29 | A.H. 17 | RR68(U) | - | - | - | 26 | 64 | 9 | 68 | 13 | - | 110 | 215 | 43 | 1.3 | -1 | 64 |
| | 15S25E34DCS1 | 4/18/74 | 7.4 | | - | 15 | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | |
|----|----------------------------|---------------------|-----------|------|------------------|-------------|--------------|-----|-----|------|------|------|-----|----|-----|----|-----|
| 36 | Well 15S26E24BAD1 | RR31(M) 7/24/75 | 29 7.4 | 3400 | -129.7 -16.85 | 47 - | 380 | 16 | 100 | 6.3 | - | 650 | 177 | 65 | 1.9 | -1 | 94 |
| 37 | RRGE-1 15S26E23CAA1 | RR62(U) 2/6/76 | 90 - | 3400 | - | 130 1104 | 550 1521 | 40 | 56 | 0.2 | - | 920 | 52 | 66 | 7.3 | -3 | 175 |
| | | RT762(T) 10/6/76 | - - | - | -131.5 -17.62 | 137 1104 | 451 1521 | 40 | 45 | 0.1 | 1.6 | 748 | 69 | 66 | 7.3 | -4 | 184 |
| | | RT771(T) 10/7/77 | 95 8.9 | - | -133.4 -17.63 | 144 1104 | 505 1521 | 35 | 58 | 0.3 | 1.6 | 896 | 46 | 59 | 6.2 | -6 | 171 |
| 38 | I.D.-3 15S26E22DDD1 | RR72(C) 12/6/74 | 82 8.1 | 189 | - | 56 60 | 1300 434 | 14 | 56 | 0.5 | 1.8 | 2000 | 63 | 52 | 5 | 2 | 103 |
| | | RR17(C) 1/13/75 | 79 8.2 | 95 | -133.7 -17.40 | 51 291 | 1300 434 | 13 | 56 | 0.4 | 1.8 | 2100 | 73 | 51 | 5.1 | -3 | 100 |
| | | (C) 3/31/75 | 44 - | 38 | - | 39 60 | 1100 122 | 11 | 55 | 0.5 | 1.6 | 1700 | 69 | 49 | 5.2 | 2 | 98 |
| | | RR13(C) 4/1/75 | 56 6.3 | 38 | -133.3 -17.68 | 48 60 | 1200 122 | 13 | 59 | 0.6 | 1.7 | 1800 | 54 | 54 | 4.9 | 5 | 102 |
| 39 | Crank well 15S26E23DDC1 | RR74(M) 5/18/72 | 90 7.7 | 227 | - | 97 165 | 1110 | 35 | 130 | 0.4 | - | 1900 | 36 | 61 | 14 | -1 | 139 |
| | | RT744(T) 7/13/74 | 93 6.7 | - | -135.0 -17.30 | 87 165 | 1180 | 33 | 130 | 0.37 | 2.4 | 1850 | 122 | 60 | 5.7 | 6 | 135 |
| 40 | Well 15S26E23DDD1 | RR32(M) 7/30/75 | 33 7.0 | 1900 | -130.3 -16.68 | 53 79 | 450 | 19 | 140 | 8.3 | - | 820 | 174 | 69 | 2.3 | 1 | 94 |
| 41 | Well 15S26E24DCC1 | RR47(M) 7/29/75 | 31 7.5 | 3800 | -131.0 -17.24 | 55 78 | 340 | 16 | 88 | 7.1 | - | 560 | 161 | 52 | 2.5 | 3 | 96 |
| 42 | A. H. 1 15S26E27BAA1 | RR67(U) 4/17/74 | - 7.7 | - | - | 45 30 | 150 | 10 | 110 | 23 | - | 400 | 138 | 36 | 1.9 | -1 | 66 |
| 43 | RRGE-3 15S26E25BDA1 | RT763(T) 10/6/76 | - - | - | - | 123 1291 | 1260 1803 | 115 | 194 | 0.3 | 2.7 | 2200 | 95 | 61 | 4.7 | 4 | 191 |
| | | RR771 2/3/77 | - - | - | -135.5 -17.59 | - 1291 | - 1803 | - | - | - | - | - | - | - | - | - | - |
| | | RT772(T) 10/7/77 | - - | - | -134.8 -17.73 | 171 1291 | 1210 1803 | 69 | 238 | 0.32 | 2.9 | 2430 | 43 | 15 | 4.4 | -4 | 164 |
| 44 | I.D.-2 15S26E25ACA1 | RR71(C) 10/17/74 | 30 - | 57 | - | 41 197 | 330 198 | 14 | 51 | 9 | - | 470 | 179 | 78 | 2.3 | 0 | 83 |
| | | RR16(C) 1/14/75 | 30 7.7 | 83 | -131.5 -16.98 | 88 197 | 370 198 | 34 | 35 | 3.9 | 0.64 | 570 | 176 | 32 | 2.8 | -3 | 133 |
| 45 | A. H. 6 15S26E28DCD1 | RR66(U) 4/17/74 | - 7.1 | - | - | 17 30 | 100 | 11 | 67 | 12 | - | 210 | 136 | 53 | 1.5 | -4 | 75 |
| 46 | A. H. 12 15S26E32CCD1 | RR63(U) 4/18/74 | - 7.6 | - | - | 32 9 | 110 | 11 | 100 | 24 | - | 230 | 238 | 74 | 2 | 0 | 68 |

Table 1. *continued*

| No. | Name Location* | Sample† Date | T (°C) pH | Flow (LPM) | D‡ ¹⁸O | SiO₂ H (m)§ | Na H (m)¶ | K | Ca | Mg | Li | Cl | HCO₃ | SO₄ | F | ¶ | T** (°C) |
|-----|---------------------------------|--------------------|--------------|---------------|------------------|----------------|--------------|-----|-----|------|------|-----|------|-----|------|-----|-------------|
| 47 | Well 15S27E8ACCI | RR28(U) 7/31/75 | 10 7.6 | 2840 | -126.5 -16.91 | 40 | 240 | 11 | 120 | 20 | - | 460 | 246 | 63 | 1 | 0 | 72 |
| 48 | Well 15S27E31DAA1 | RR21 8/7/75 | 15 7.9 | - | -130.2 -17.15 | - | - | - | - | - | - | 62 | - | - | - | - | - |
| 49 | Six Mile Sprg 15S28E15AAAS1 | RR24(U) 8/7/75 | 8 8.3 | 5100 | -129.0 -16.98 | 8 | 12 | 0.7 | 52 | 9.8 | - | 18 | 194 | 13 | 0.1 | 0 | †† |
| 50 | Sp Mine Tunnel 15S29E28BDAS1 | RR22 8/7/75 | 8 7.7 | 3400 | -122.5 -16.55 | - | - | - | - | - | - | 49 | - | - | - | - | - |
| 51 | Spring 15S29E33BBAS1 | RR41(U) 8/7/75 | 8 7.7 | 57 | -129.3 -16.91 | 16 | 58 | 2 | 100 | 36 | - | 96 | 186 | 110 | 0.4 | 27 | - |
| 52 | Spring 16S22E25ABAS1 | RR767 5/27/76 | 12 6.9 | 4 | -128.4 -16.90 | - | - | - | - | - | - | - | - | - | - | - | - |
| 53 | Spring 16S22E35DBDS1 | RR766 - | - - | - | -127.6 -16.75 | - | - | - | - | - | - | - | - | - | - | - | - |
| 54 | Spring 16S23E1BBBS1 | RR763 12/21/75 | 9 - | 8 | -133.9 -17.59 | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 | Spring 16S23E12CCDS1 | RR762 12/21/75 | 5 - | 8 | -125.6 -16.14 | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 | Well 16S23E23DBB1 | RR765 3/10/76 | 10 9.0 | - | -126.7 -16.33 | - | - | - | - | - | - | - | - | - | - | - | - |
| 57 | A. H. 8 16S25E10BBC1 | RR65(U) 4/18/74 | - 7.7 | - | - - | 17 12 | 58 | 3.7 | 90 | 14 | - | 150 | 215 | 37 | 0.8 | -3 | 34 |
| 58 | I.D.-4 16S26E5BBA1 | RR14(C) 3/28/75 | 40 6.8 | 95 | -128.6 -17.42 | 37 19 | 240 77 | 13 | 58 | 9 | 0.68 | 380 | 138 | 44 | 4.4 | 3 | 91 |
| 59 | The Narrows HS 16S26E5BBAS1 | RT745 7/74 | 38 6.2 | - | -131.0 -17.40 | - | - | - | - | - | - | 426 | - | 44 | - | - | - |
| | | RR60(C) 9/4/74 | 27 8.1 | 170 | - - | 68 | 260 | 15 | 56 | 5.8 | - | 430 | 123 | 41 | 4.6 | -2 | 112 |
| 60 | Spring 16S26E21CDBS1 | RR38(U) 7/29/75 | 16 7.1 | 190 | -126.4 -16.59 | 19 | 150 | 4.7 | 80 | 34 | - | 200 | 347 | 75 | 0.3 | 4 | 51 |
| 61 | Spring 16S27E15BDAS1 | RR34 7/29/75 | 12 6.6 | 76 | -125.6 -17.02 | - | - | - | - | - | - | 30 | - | - | - | - | - |
| 62 | 16S27E23 | RT746 7/74 | 17 - | - | -124.0 -16.33 | - | - | - | - | - | - | 188 | - | - | - | - | - |
| 63 | Spring 16S28E26 | RT747(T) 7/74 | 14 7.0 | - | -125.1 -16.37 | 29 | 52 | 2.4 | 10 | 13.3 | 0.01 | 90 | 190 | 25 | 12.5 | -54 | - |

| | | | | | | | | | | | | | | | | | |
|----|---------------------------------|----------------------|-----------|----|------------------|----|----|-----|----|-----|------|-----|-----|----|-----|----|----|
| 64 | 15N18W36 | RR51 9/3/75 | 11 7.5 | 19 | -127.7 -16.74 | - | - | - | - | - | - | 22 | - | - | - | - | - |
| 65 | Gambles Hole W 46N69E10DCD1 | R7613(U) 11/10/76 | 34 7.2 | - | -134.1 -17.40 | 23 | 10 | 4.6 | 29 | 8.1 | 0.02 | 3.3 | 144 | 13 | 0.4 | -3 | 43 |
| 66 | 14N18W12 | RR52 9/3/75 | 7 6.9 | 4 | -131.1 -17.30 | - | - | - | - | - | - | 13 | - | - | - | - | - |
| 67 | Mine Tunnel 14N17W6 | RR59 9/3/75 | 8 6.9 | 11 | -129.5 -16.84 | - | - | - | - | - | - | 12 | - | - | - | - | - |
| 68 | Spring 14N17W23DCS1 | RR54 9/3/75 | 10 6.2 | 19 | -134.1 -17.61 | - | - | - | - | - | - | 47 | - | - | - | - | - |
| 69 | Spring 14N16W22CDS1 | RR56 9/26/75 | 7 6.3 | 19 | -121.2 -16.74 | - | - | - | - | - | - | 13 | - | - | - | - | - |
| 70 | Dipping Vat S 14N14W8DCDS1 | RR58(U) 10/9/75 | 8 6.4 | 11 | -121.5 -15.72 | 12 | 74 | 2.8 | 71 | 16 | - | 110 | 159 | 32 | 0.2 | 24 | 33 |
| 71 | Spring 14N13W20CBS1 | RR55 9/26/75 | 6 6.3 | 4 | -127.1 -16.98 | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 | Spring 14N13W29DS1 | RR50 9/26/75 | 7 6.1 | 19 | -130.2 -17.66 | - | - | - | - | - | - | 11 | - | - | - | - | - |
| 73 | Spring 13N18W28DDAS1 | R7614 11/10/76 | 9 6.9 | 38 | -130.5 -16.89 | - | - | - | - | - | - | - | - | - | - | - | - |
| 74 | Spring 13N17W15BDAS1 | R7615 11/10/76 | 10 7.3 | 6 | -130.1 -17.23 | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 | Spring 13N17W11CADS1 | R7616 11/10/76 | 8 6.9 | 38 | -133.2 -17.55 | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 | Clarkes Basin S 13N16W10ADS1 | RR53 10/9/75 | 8 7.8 | 19 | -123.9 -16.35 | - | - | - | - | - | - | 46 | - | - | - | - | - |
| 77 | Pine Spring 13N16W2DAS1 | RR57 10/9/75 | 8 8.1 | 19 | -132.9 -17.63 | - | - | - | - | - | - | 27 | - | - | - | - | - |

*Locations are given in township, range and section. Letters designate the quarter section, the 40-acre tract, and the 10-acre tract. Letter A is north-east corner, letter B is north-west corner, etc. Letter S designates a spring and final number is the number of the site in the smallest division.

†Chemical analyses of water samples were performed by J. M. Thompson (T), or U.S. Geological Survey Laboratory, Salt Lake City, Utah (U), or are taken from Ross (1971) (R), Crosthwaite (1976) (C), or Mitchell *et al.* (1980) (M). Chemical constituents are in mg/l.

‡Deuterium analyses were done at the Scottish Research and Reactor Centre by J. Borthwick. Oxygen-18 analyses were done at the U.S. Geological Survey by N. L. Nehring and Cathy Janik. Isotope analyses reported as parts per thousand difference from standard mean ocean water (SMOW). Isotope values for samples RT771 (location 37) and RT772 (location 43) have been corrected for single-stage steam loss from 145 to 95 and 93°C, respectively, using the fractionation factors from Truesdell *et al.* (1977).

§Depth of well (m) or top of depth range of where sample obtained if known.

||Bottom of depth range (m) where sample obtained. May be less than total depth.

¶Cations (Na, K, Ca, Mg and Li) minus anions (Cl, HCO₃, SO₄, and F) over one-half of total ions in mequ (%).

**Best estimate of Na - K - Ca geothermometer temperature of Fournier and Truesdell (1973). Magnesium correction of Fournier and Potter (1979) applied where significant.

††Low potassium makes accuracy of geothermometer questionable.

‡‡Numbers in parentheses are CO₂ concentrations. Low concentrations of Ca and Mg cause analytical problems. Geothermometer temperature not meaningful.

AREA I: DEEP THERMAL AND MIXED WATERS

In the study of the chemical composition of geothermal waters, it is usually found that the deep geothermal water has a single chloride composition. This characteristic permits chloride concentration to be used as an indication of mixing of deep hot water and cold water. Unfortunately, the chloride concentration of the deep water at Raft River is not constant, so the interpretation of water composition is more complex. Figure 3 shows a plot of silica vs chloride for the water samples from area I. The three deep wells RRGE-1, -2 and -3 are locations 37, 33 and 43, respectively. Several analyses are shown for each well. Some of the variability is analytical, but some also reflects varying amounts of concentration by boiling when the sample was taken. All three wells have measured temperatures of around 145°C, so the chloride composition in the deep water is essentially independent of temperature. For samples from the shallow wells, it is important to have some indication of mixing other than the chloride concentration. Figure 4 shows a trilinear plot of percentage equivalents (see e.g. Hem, 1970, pp. 264 – 270) for these waters. Note that an expanded scale has been used, and this diagram represents only one-fourth of the area of a full diagram. The three deep well samples (locations 33, 37 and 43) form a group defined by a very small percentage of magnesium and a large percentage of chloride. On this basis, the near-surface samples can be grouped as non-mixed and mixed. Samples at locations (L-) 30D, 35, 38, 39 are non-mixed while the remainder have mixed with cold water. (Deep and shallow samples were obtained from the well at location 30,

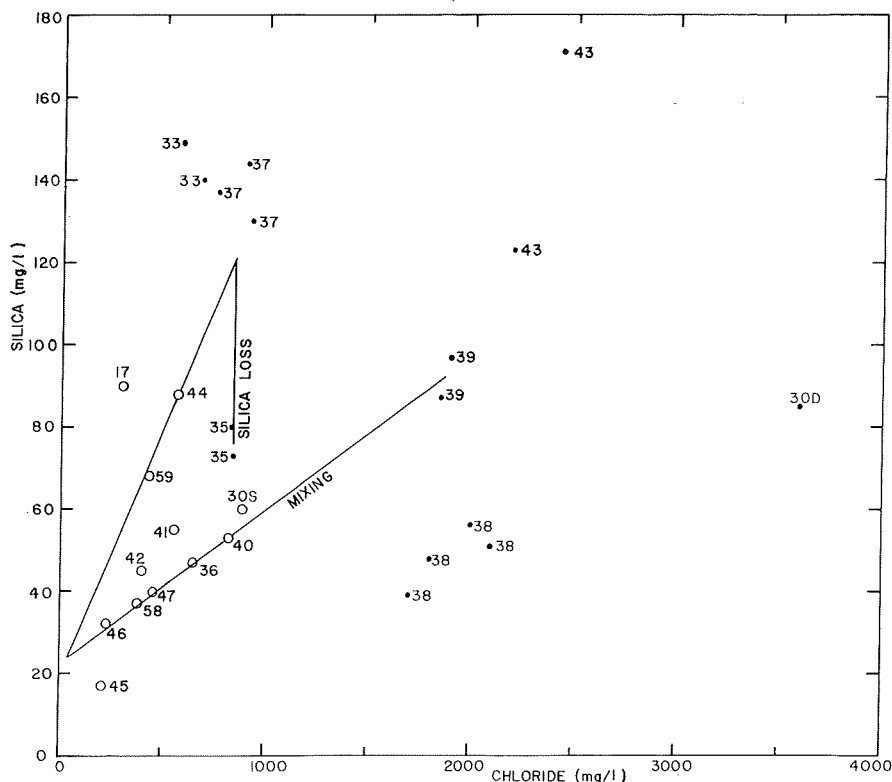


Fig. 3. Silica vs chloride concentrations for water samples from area I of Fig. 2. Open circles are mixtures of deep thermal water and cool near-surface water; dots are samples of deep thermal water. Division into two groups based on Fig. 4. Examples of lines of mixing and silica loss due to conductive cooling are shown. Locations 30S and 30D are shallow and deep samples taken from the same well. Repeated numbers are data from different collections of the same location.

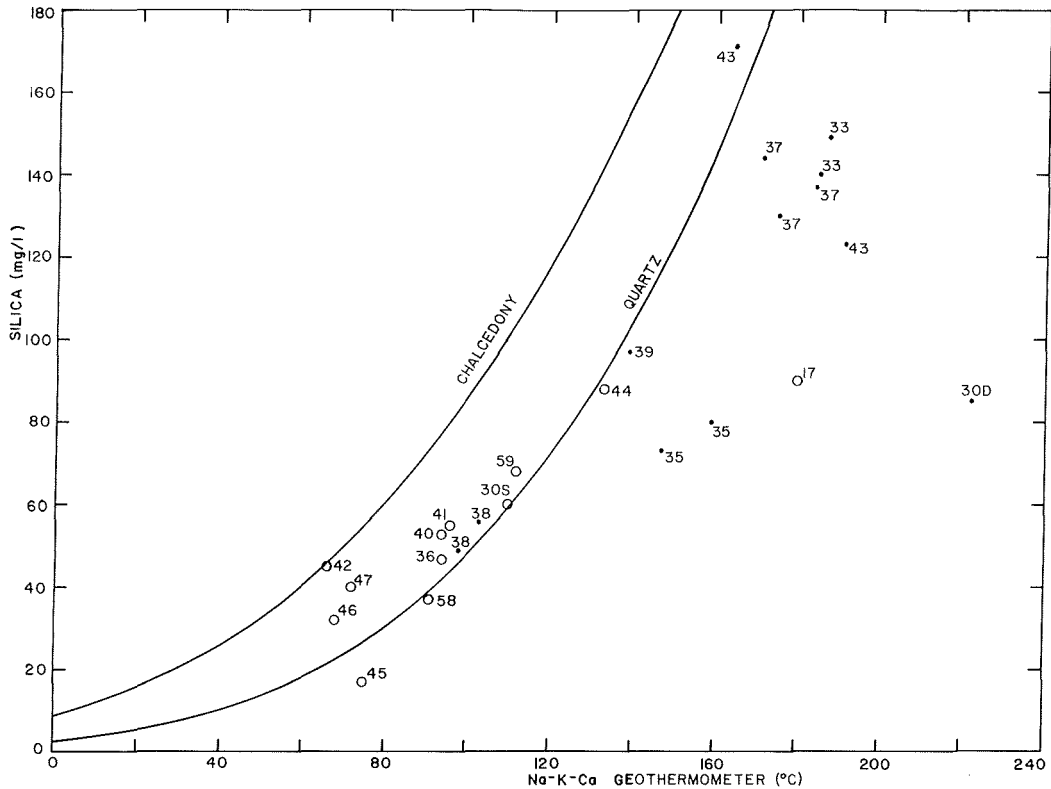


Fig. 5. Silica concentration vs Na – K – Ca geothermometer temperatures for water samples from area I of Fig. 2. Dots are deep thermal water and open circles are mixed waters based on Fig. 4. The Na – K – Ca geothermometer is from Fournier and Truesdell (1973) with Mg-correction of Fournier and Potter (1979) where significant. Curves for silica concentration vs temperature are based on chalcedony and quartz solubility data of Fournier and Rowe (1966) as quoted in Truesdell (1976). Repeated numbers are data from different collections of the same location.

temperature measured in the system (149°C). Silica concentrations are also somewhat high for the measured temperatures. The Na – K – Ca temperatures for the Schmitt well (L-35) and the Crank well (L-39) are between 135 and 159°C; these temperatures are in better agreement with measured subsurface temperatures than geothermometer temperatures determined from deep well samples. This better agreement may be caused by the shallow wells tapping active flowing water while the deep wells tap nearly stagnant water.

The deep sample from I.D.-1 (L-30D) gives the highest Na – K – Ca temperature (222°C) along with the highest chloride concentration (3600 mg/l), yet the maximum temperature in the well is 42°C at a depth of 320 m. The well seems to be on the edge of the geothermal system (Nathenson *et al.*, 1980). One might interpret the sample from I.D.-1 as showing that there is a high-temperature parent water and that the sample of this parent water found in I.D.-1 has lost silica (Fig. 3). A parent water at 3600 mg/l chloride, 222°C and 350 mg/l silica could be mixed with cold water to produce a water at 145°C, 2300 mg/l chloride and 226 mg/l silica. This mixed water would correspond to that found in RRGE-3 (L-43) if precipitation lowered the silica content to around 130 mg/l. However, the data from this well are the only indication of temperatures over 200°C in the system.

The sample from I.D.-3 (L-38) is more simply interpreted; it seems to be non-mixed and has re-equilibrated to a geothermometer temperature of around 100°C. The maximum measured temperature in this well is 89°C, in excellent agreement with the geothermometer temperatures.

The data for the mixed waters shown in Fig. 5 indicate that the geothermometers for these samples have re-equilibrated to lower temperatures. This is in conflict with the pattern in Fig. 3 that seems to indicate that the silica concentration is determined by mixing. This point will be addressed further with the isotope data. Comparing the data for location 45 with that for other mixed waters shows that it is anomalously low in silica concentration for its Na-K-Ca temperature (Fig. 5) and for its chloride content (Fig. 3). It seems likely that the silica value should be higher.

Figure 6 shows the deuterium and oxygen isotope data for area I. It is important to note that the scales are greatly expanded. The standard deviation for deuterium analyses is about $\pm 1\text{‰}$ and for oxygen-18 analyses is about $\pm 0.2\text{‰}$. Thus the differences between many of the samples are not significant. To the accuracy of the data, the deep thermal waters all have essentially the same isotopic composition ($\delta D = -134.4\text{‰}$; $\delta^{18}O = -17.5\text{‰}$). The mixed waters are all enriched in both deuterium and oxygen-18 relative to the thermal waters, so it is generally possible to distinguish between the two groups on the basis of their isotopic as well as chemical composition.

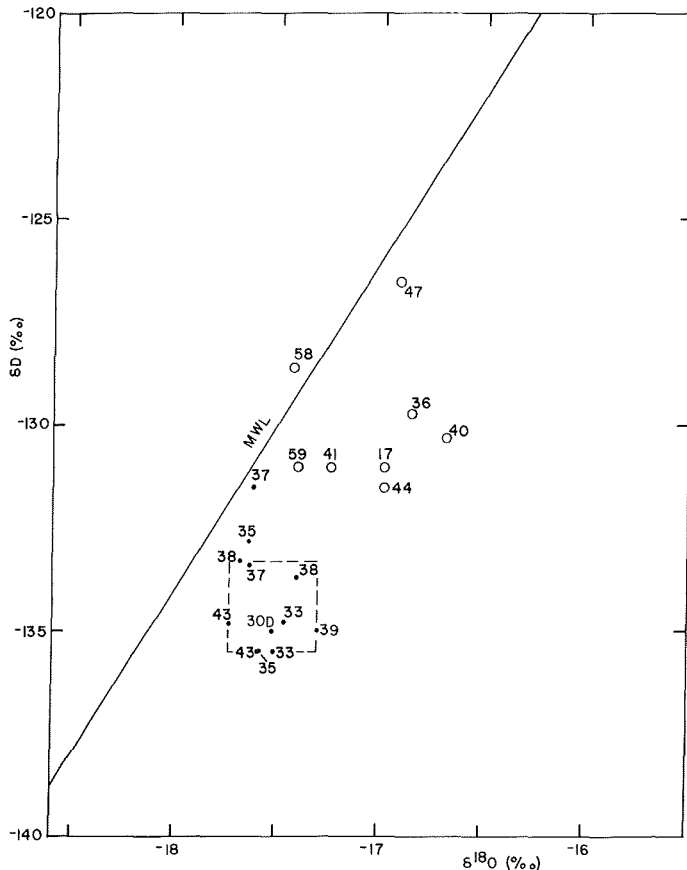


Fig. 6. Deuterium vs oxygen-18 isotopes (parts per thousand difference from SMOW) for water samples from area I of Fig. 2. Dots are deep thermal waters and open circles are mixed waters based on Fig. 4. Note expanded scales. Standard deviations are $\pm 1\text{‰}$ for deuterium and $\pm 0.2\text{‰}$ for oxygen-18. Meteoric water line (MWL) is that of Craig (1961). Repeated numbers are data from different collections of the same location. The box is drawn to include data for most of the samples of deep thermal water.

Figure 7 shows deuterium values as a function of chloride concentration. Based on the isotopic data in Fig. 6, the three deep wells (L-33, -37 and -43) tap the same water. However, the data shown in Fig. 7 do not rule out the possibility that these deep waters are formed by mixing two waters of the same enthalpy and isotopic composition, one having a high chloride concentration and one having a lower concentration. However, the recharge area of the two waters would likely be the same, as discussed in a following section. The interpretation (based on Fig. 4) that samples for locations 30D, 38 and 39 are not mixed with cold water is confirmed by the isotope data.

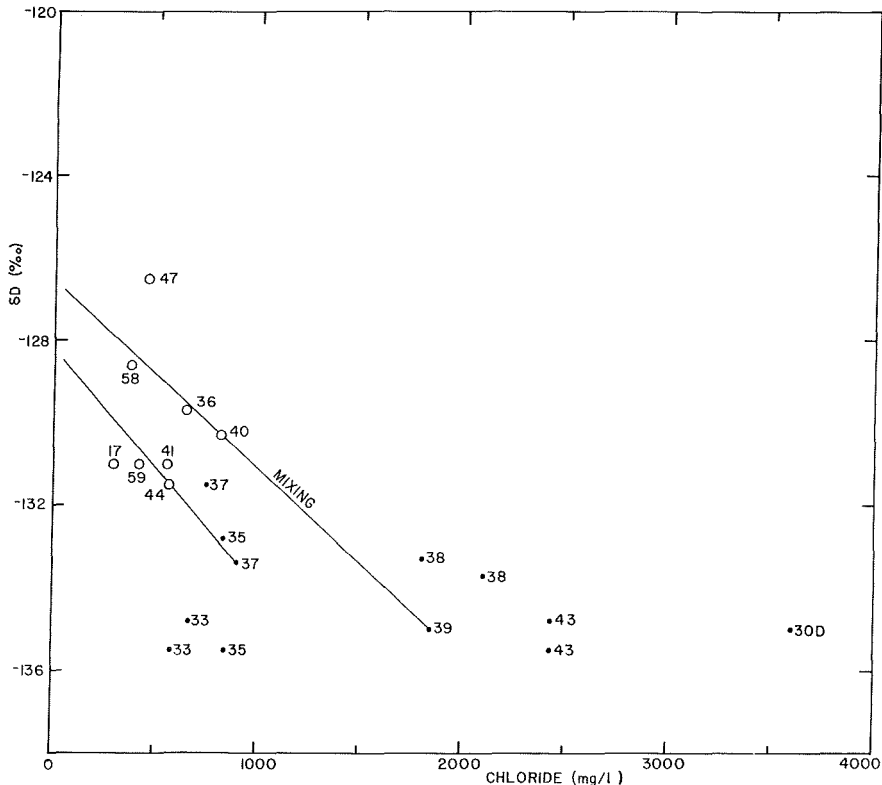


Fig. 7. Deuterium vs chloride concentration for water samples from area I of Fig. 2. Dots are deep thermal water and open circles are mixed water based on Fig. 4. Lines shown are mixing lines. Repeated numbers are data from different collections of the same location.

The mixed waters show similar trends based on the deuterium vs chloride plot (Fig. 7) and the silica vs chloride plot (Fig. 3). For example, in both Figs. 3 and 7 the data for locations 58, 36 and 40 define a mixing line with the sample from location 39 as the non-mixed parent. Likewise, the data for locations 44 and 59 also define a mixing line on both plots but with a different hot end member (L-37). It is thus instructive to do a mixing calculation in order to ascertain the meaning of the calculated geothermometer temperatures. Location 39 is the Crank well (93°C) and location 40 is a nearby irrigation well (33°C). It seems reasonable to assume that water from the Crank well is one end member for forming the mixed water in the irrigation well. Any conservative quantity A measured in the irrigation well A_{40} can be related to the same quantity measured in the Crank well A_{39} , and the composition of cold water A_{cw} by the equation

$$A_{40} = xA_{39} + (1 - x)A_{cw} \quad (1)$$

where x is mass fraction of hot water in the mixed water. Taking the chloride composition of cold water to be 50 mg/l, the quantity x is 0.428. The calculated value for deuterium in the cold water is -126.8‰ which is equivalent to the measured value of -126.4‰ for sample 60 located in the general direction from which the mixing water would be derived. The calculated cold-water silica concentration is 28 mg/l, which is quite a reasonable value. Based on a cold-water temperature of 10°C and hot-water temperature of 93°C , the mixed-water temperature should be 46°C . This is in reasonable agreement with the measured temperature of 33°C but is wildly different from either the 73°C chalcedony temperature or the 94°C Na-K-Ca geothermometer temperature for L-40. Since the mixing temperature is 25 to 50°C less than the calculated geothermometer temperatures, this would seem to indicate that the geothermometers give fictive temperatures. The discrepancy may be explained by the silica concentration being determined by mixing while the Na-K-Ca geothermometer temperature is determined by a partial re-equilibration to the mixing temperature. Alternatively, the hot water can be assumed to be at 145°C , with the mixed water then at 68°C . This interpretation is in reasonable agreement with the geothermometer temperatures, but much higher than the measured temperature and would require large amounts of conductive cooling. If the mixed water were coming from a hot spring, this ambiguity could probably be resolved, but with well data it is not possible to do so.

Being able to distinguish mixed and non-mixed waters, it is instructive to consider the vertical distribution of chemical variations. Figure 8 shows a cross-section from Schmitt (L-35) to I.D.-2 (L-44) with chloride values placed at the open section of each drill hole. Deep water from near RRGE-1 (L-37) can supply the water found in Schmitt (L-35). Deep water of 1800–1900 mg/l chloride could be found between RRGE-1 and RRGE-3 (L-37 and L-43) and supply I.D.-3 (L-38) and Crank (L-39). As discussed above, the water from Crank can supply the irrigation well at L-40. The situation for I.D.-2 (L-44) is more complex. From Fig. 3, the parent for I.D.-2 is unequivocally a water with less than 1000 mg/l chloride (such as L-37); however, there does not seem to be any easy way to get such water to L-44 (Fig. 8).

A similar situation is found in the data in Fig. 9 for a cross-section from I.D.-4 (L-58) to the irrigation well at L-47. The source water for the spring at The Narrows (L-59) and the water

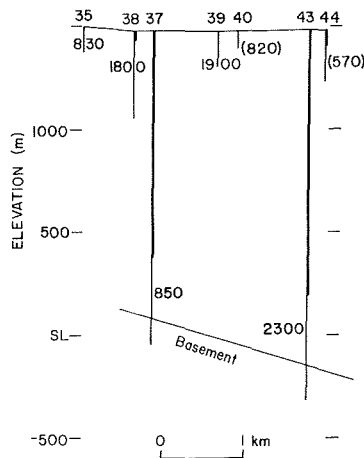


Fig. 8. North-west to south-east section passing through locations 35, 37 and 43. Other wells are projected onto the section. Well depth is shown by a thin line while cased depth is shown by a thick line where known. Basement depths are from Covington (1977a,c). Representative chloride concentrations are shown for each well. Data in parentheses are for mixed waters.

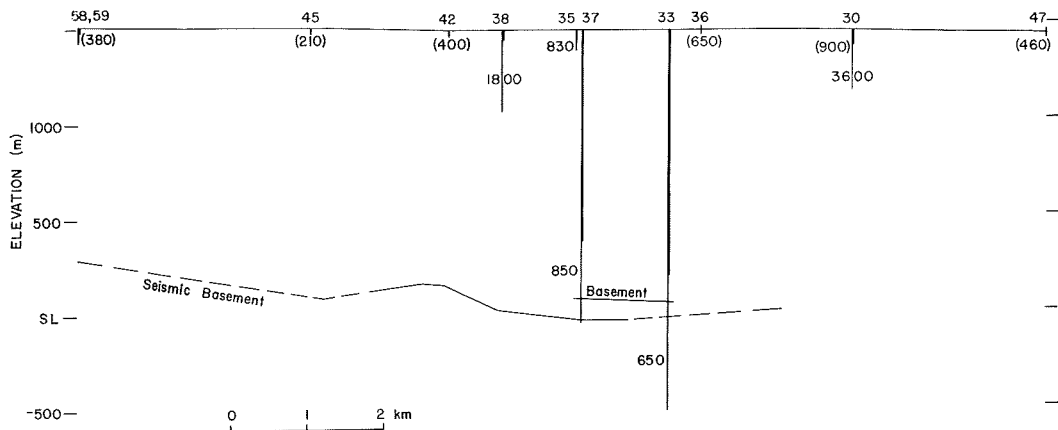


Fig. 9. South-west to north-east section passing through locations 58 and 42. Other wells are projected onto the section. Well depths are shown by a thin line and cased depths by a thick line. Depths of wells at locations 36 and 47 are unknown. Basement depths are from Covington (1977a,b). Seismic basement is from Ackermann (1979) sections A - A' and C - C'. Representative chloride concentrations are shown for each well. Data in parentheses are for mixed waters. Data at location 30 are for a shallow sample and a deep sample taken with a packer in place.

found nearby in I.D.-4 (L-58) is somewhat ambiguous. The data in Figs. 3 and 7 show that the source for the hot spring (L-59) is a water with less than 1000 mg/l. The data for I.D.-4 imply a high-chloride source with more dilution. Except for deuterium and silica concentrations, the chemical analyses of the water from the well and the hot spring are nearly identical (Table 1). They could be made consistent with the hot spring data if it is assumed that the water from I.D.-4 lost silica while in the formation and that the difference in isotopic composition is the maximum expected uncertainty. In the data for the non-mixed waters in Fig. 9 the pattern is yet more confusing. I.D.-3 (L-38) shows high chloride at intermediate depth. Schmitt (L-35) and RRGE-1 (L-37) show intermediate chloride values at shallow and great depth. I.D.-1 shows highest chloride at an intermediate depth (L-30D). The mixed waters found at locations 36, 30S and 47 seem most compatible with a high-chloride parent.

OTHER WATERS NEAR THE MAIN THERMAL AREA

In Fig. 2, areas II, III and IV are outlined. The waters in areas II and IV are of interest to look for evidence of extensions of the geothermal system, or sources for the mixing water found in the shallow wells in the thermal area. Area III, in the Upper Raft River Valley, contains two thermal anomalies that may be related to the thermal system in the Raft River Valley. The data for these three areas are presented in Figs. 10, 11 and 12 with coded symbols for each area. Note that some samples were only analysed for isotopes and chloride and no other chemical data were obtained. The trilinear plot of Fig. 10 is at full scales. All of the waters from the three areas form a group on the anion triangle. On the cation triangle, the waters from the Upper Raft River Valley (small dots) define a linear trend while the other waters are grouped.

Area IV, south of the thermal anomaly, is the northeastern part of the Raft River Mountains and the alluvial fan below them. The data are coded in Figs. 10, 11 and 12 as open triangles. In Fig. 10, samples from locations 60 and 70 plot toward the centre of the trilinear diagram with Mg and SO₄ having the smallest percentages in milliequivalents. The spring at location 60 has a measured temperature of 16°C. This is sufficiently above the mean annual ground temperature of 9–11°C (M. Nathenson and T. C. Urban, unpublished data) to indicate some deep circulation.

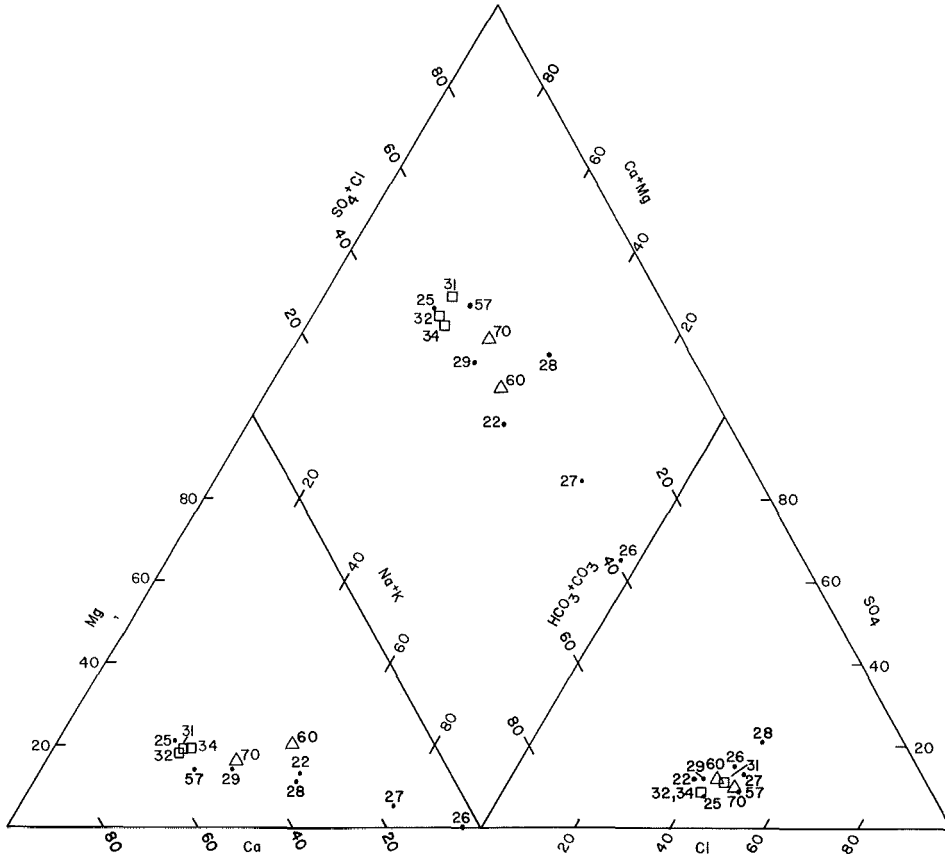


Fig. 10. Trilinear plot of percentage of milliequivalents for water samples from area II (squares), area III (dots) and area IV (triangles) of Fig. 2.

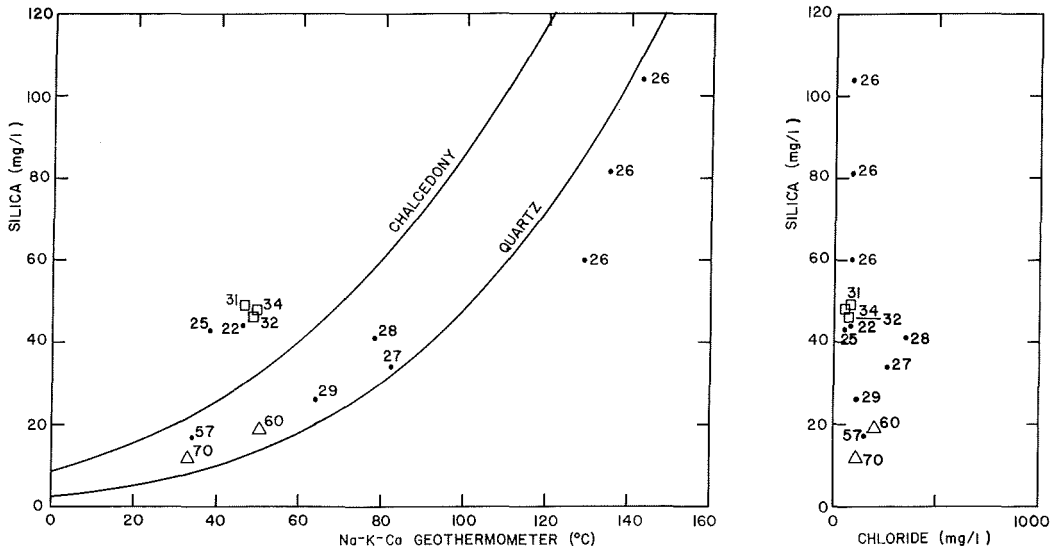


Fig. 11. Silica vs Na-K-Ca geothermometer temperature and silica vs chloride for water samples from area II (squares), area III (dots) and area IV (triangles) of Fig. 2.

A 150 m deep drill hole about 2 km to the north-east has a high thermal gradient for the area of $74^{\circ}\text{C}/\text{km}$ (M. Nathenson and T. C. Urban, unpublished data). The chloride concentration of the water at location 60 is 200 mg/l, which is above normal. One might interpret the data at location 60 to say that this water is a highly diluted version of the thermal water from the Raft River Valley. However, it is more likely that it developed its character while flowing through the Paleozoic sedimentary rocks of the Raft River Mountains. The sample at location 62 also has a high chloride concentration (188 mg/l); however, no other chemical data are available for this sample.

The isotopic data in Fig. 12, with the Area IV data represented by the open triangles, show a wide range. Isotopic data for location 60 are compatible with it being a highly diluted version of the thermal water. Location 48 is quite close to the area of thermal water, and its isotopes are similar to those of the mixed waters in Area I. However, the chloride concentration of the water from location 48 is only 62 mg/l, so it can have only a small amount of thermal water. Samples 60, 61 and 71 are in the right range to be the cold-water component found in the mixed thermal waters, and it seems likely that the Raft River Mountains are the source of some of the mixing water. None of the samples plot close to the box showing the range of isotopes of the deep thermal water in Fig. 12, so this cannot be the recharge area.

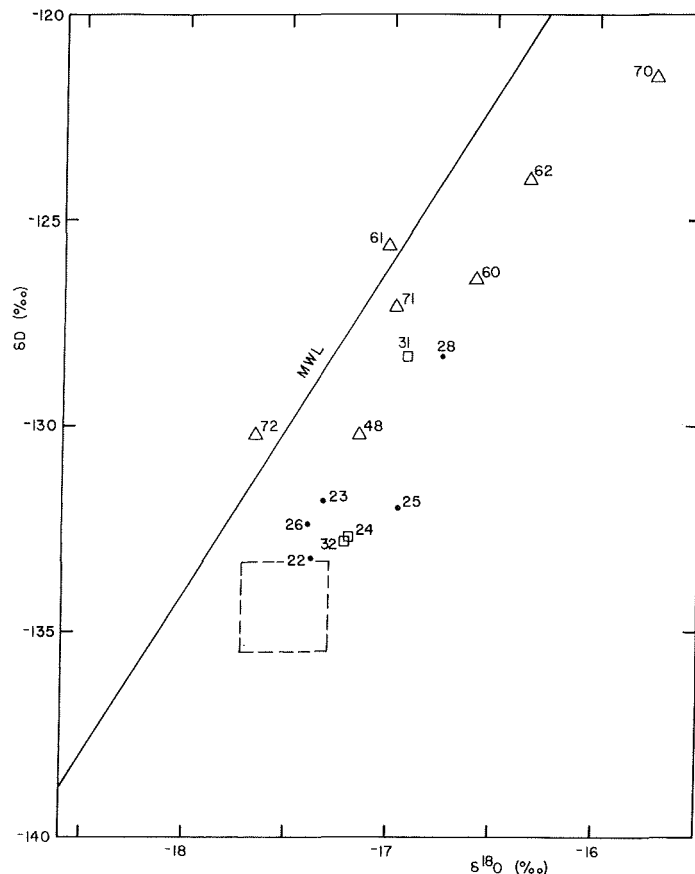


Fig. 12. Deuterium vs oxygen-18 for water samples from area II (squares), area III (dots) and area IV (triangles) of Fig. 2. Box shows range of data for deep thermal waters from Fig. 6.

Area II is the southeastern Jim Sage Mountains and the fans below them. Samples for this area are represented as open squares. The three locations with chemical analyses group very closely on the trilinear plot of Fig. 10. The samples are noticeably high in silica (Fig. 11) but have low chloride concentrations. The high silica is probably caused by circulation through the lavas of the Jim Sage Mountains. (Location 25 from Group III also has a high silica concentration and exits from the other side of the Jim Sage Mountains. Samples from locations 10, 14, 15 and 16 also have high silica and are also associated with the Tertiary volcanic rocks.) Isotopic data for area II in Fig. 12 span a fairly broad range. The waters at locations 24 and 32 are sufficiently enriched in deuterium and oxygen-18 not to be the recharge for the geothermal system, but are not enriched enough to be the source of the mixing water. Sample 31 is a spring that has the right isotopic composition to suggest that the Jim Sage Mountains could also provide mixing water for the mixed waters found in the thermal area.

Area III is the Upper Raft River Valley, and samples from this area are represented as small dots in Figs. 10, 11 and 12. In the western part of the valley, location 23 is a well with a normal thermal gradient of 52°C/km. Farther to the west, sample 22 is from a 150 m deep well, but it has a measured temperature of 37°C. Location 22A is a nearby hot spring with a temperature of 34°C and the same chemistry as the sample from location 22. (Data for location 22A plot at the same point as that for location 22 in Figs. 10 and 11.) The silica concentration for the sample from location 22 is high, but the Na – K – Ca temperature is 40°C, which is in good agreement with the measured temperature. The chloride concentration is low. It seems likely that this thermal anomaly is separate from that in the Raft River Valley, and it simply involves upward movement from depths of a few hundred meters.

The set of samples from the eastern part of the Upper Raft River Valley present more of a problem. Almo 1 (L-26) has a measured temperature over 70°C at 100 m (Nathenson *et al.*, 1980). The hot water found in Almo 1 probably makes its way to the surface at the Grape Greek warm spring (L-26A). Unfortunately, no chemical data are available for this spring. The water from Almo 1 has very low magnesium (Fig. 10) similar to the deep water found in the Raft River Valley. However, it has high bicarbonate and carbonate, which is very different from the deep water in the Raft River Valley. Water samples from nearby locations (27, 28, 29 and 57) have a similar character in anions but define a linear trend in the cations (Fig. 10). The silica-vs-chloride data (Fig. 11) show that locations 27 and 28 have much higher chloride concentrations than Almo 1 (L-26), and may be only vaguely related. Various levels of silica have been measured in samples from Almo 1, but they are all high. These silica concentrations may be caused by the high pH of the water. The Na – K – Ca temperatures are also high (129 – 143°C). Note that the chloride concentration is only about 80 mg/l, which is very low.

The isotopic data (Fig. 12) show that samples from locations 22, 23, 25 and 26 all have essentially the same isotopic composition. Thus, the water found in location 23 could be the cold version of the hot water found at L-22, and they could have the same source of local recharge. Locations 24, 25 and 32 span the two sides of the Jim Sage Mountains and have essentially the same isotopic composition as Almo 1. The sample from location 28 has significantly different isotopic character from Almo 1. This difference may indicate that the high-chloride water found at location 28, and maybe the high-chloride sample from location 29, for which there is no isotopic data, are not related to Almo 1. The similarity between isotope values in the Jim Sage Mountains and those found in Almo 1 suggests that the high temperatures in Almo 1 result from flow of conductively heated ground waters from beneath the Jim Sage Mountains. There is considerable local relief which would easily provide the drive for such a circulation system. There are insufficient data concerning the size of the thermal anomaly around Almo 1 to establish whether this is a valid interpretation or not; that is, if the anomaly is big enough, such local recharge does not provide enough area to collect the thermal

energy necessary for a large anomaly. The small amount of overlap of isotopic values from the Upper Raft River Valley (Fig. 12; dots) and the box showing the range of deep geothermal water in the Raft River Valley would seem to indicate that they are different waters.

DATA FOR SURROUNDING AREA

Isotopic and some chemical data were collected for many samples in a broad swath surrounding the thermal area (Fig. 1). Figure 13 shows the isotopic data. The box shows the range of data for samples of deep thermal water from Fig. 6. Of the samples that plot in or near the box on Fig. 13, locations 1 and 12 are far to the north with no likely hydrologic path to be the recharge water, and location 16 would seem to be too close to allow for a sufficient heat-gathering area. Locations 54, 68, 75 and 77 define a broad area starting in the southern Albion Mountains and ending in the western Raft River Mountains. The data confirm the hypothesized recharge area of Williams *et al.* (1976). The other sample with a similar isotopic composition is location 65 in northeastern Nevada (30 km west of location 75 in Fig. 1). This sample is from a thermal well, and the similarity of the isotopes may indicate that it has the same recharge as the Raft River geothermal area.

The sample obtained from location 15 is worth a special mention. The sample was obtained from an 85 m deep well with 0.7 bar pressure above atmospheric at the wellhead. The sample is

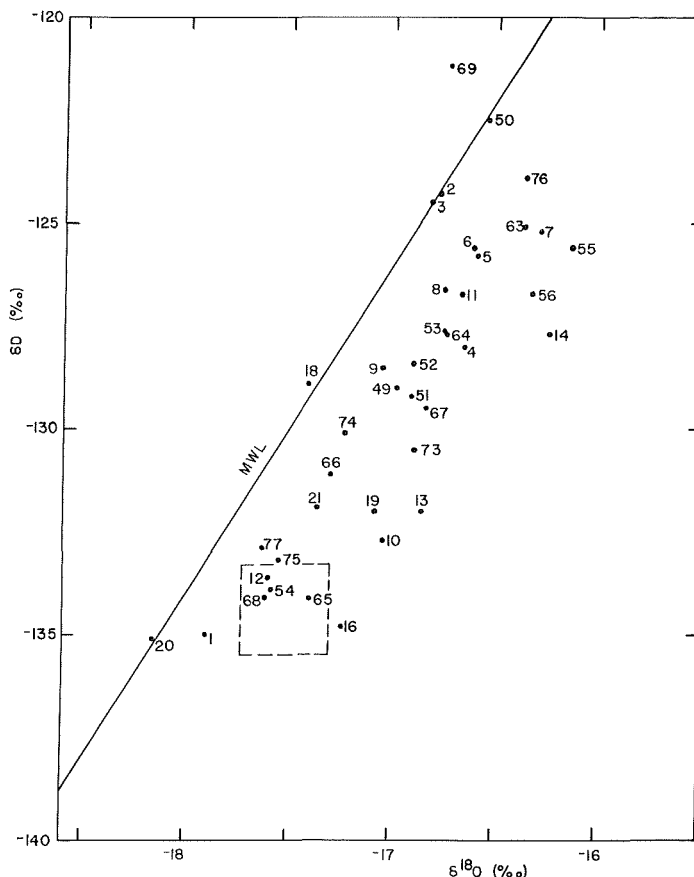


Fig. 13. Deuterium vs oxygen-18 for water samples outside of areas I, II, III and IV. See Fig. 1 for locations. Box shows range of deep thermal waters from Fig. 6.

sodium bicarbonate and carbonate water, and no other sample has a similar character. The deuterium value of -144‰ is below the bottom of Fig. 13. Samples at locations 14 and 16, to the north and south of location 15, are very different in chemical character from location 15 and have much heavier isotopes. There is some implication that this sample may be an ancient water held in place by being on a saddle between the Jim Sage Mountains and Sheep Mountain to the east.

DISCUSSION

The major points that have been obtained from the chemical and isotopic data may be summarized as follows: from the isotopic data shown on Figs. 6 and 13, the most likely sources for recharge of the geothermal water are the southern Albion Mountains and the western part of the Raft River Mountains. The isotope data for the geothermal water (Fig. 6) indicate that all of the water has the same isotopic composition, and the chemical signature of the geothermal water on the trilinear plot (Fig. 4) shows that the deep geothermal water is of one type. However, the deuterium-vs-chloride plot (Fig. 7) shows that the water of similar isotopic composition has a large range of chloride concentrations. Chloride data plotted on cross-sections (Figs. 8 and 9) show that the pattern of chloride concentrations is not very systematic. Low and high chloride concentrations occur in close proximity in water that can be identified as non-mixed. Calculated geothermometer temperatures for the deep water are generally much higher than measured temperatures; however, samples from shallow flowing wells Schmitt (L-35) and Crank (L-39) give closer agreement with measured deep temperatures.

Three models are possible to explain the characteristics of the deep geothermal water: (1) Kunze *et al.* (1977) and Allen *et al.* (1979) proposed a model involving the mixing of two waters to explain the varying concentrations in the deep geothermal water. Allen *et al.* (1979) proposed, in addition, that the source of the dilute water found in the deep wells is from the Jim Sage Mountains. Although we do not have many samples from the Jim Sage Mountains, the available data do not confirm this area as a possible source. The data presented here are compatible with the hypothesis that there are two deep waters: one with a high chloride concentration and one with a low chloride concentration, and that deep waters of intermediate composition are produced by mixing. The isotopic data indicate that the two waters would have to come from the same general recharge area; (2) a second possible interpretation is that the source of the varying dissolved-solids contents is a zone of highly soluble materials where waters having different chemical composition could be produced by varying residence times or somewhat different circulation paths. It is likely that any such zone of easily dissolved minerals would be in the sedimentary section above the basement. This explanation is somewhat simpler than the two waters hypothesis, because the two waters would require fairly different large-scale circulation paths from the same recharge area; (3) a third hypothesis is that the varying chloride concentrations in space reflect the evolution of the hydrothermal system through time. At an earlier time, the system was hotter, and under such conditions could have dissolved more rock during its large-scale circulation than it presently does. This would explain the higher geothermometer temperatures in the deep wells as relics of the past that have not had sufficient time or circulation to re-equilibrate. As the system evolved through time, various pockets of water have become isolated, and these pockets are what some of the wells have tapped. There does not seem to be any easy way to choose among these three hypotheses for the difference in constituents in the deep water at Raft River. Allen *et al.* (1979) used fluoride data to argue that it must be two waters mixing, since the fluoride concentration decreases with increasing conductivity. However, Nathenson *et al.* (1980) showed that the fluoride concentration is determined by the solubility of fluorite, so this fact cannot be used to distinguish among the three models. Tritium data for RRGE-1, -2 and -3, Schmitt, and Almo 1 (L-37, -33, -43, -35 and

-26) all give values of 0.2 T.U. or less with ± 0.2 error (F. J. Pearson, Jr. and A. H. Truesdell, written communication, 1977). This would indicate that the water is at least tens of years old, and that the length of any circulation path is substantial or that the waters are not moving very rapidly. Nathenson *et al.* (1980) made an order-of-magnitude estimate of the total natural discharge of deep geothermal water of 20 l/s, a not very substantial amount. Two factors that may be relevant are that the Raft River Valley recently had a more humid climate than now, which lasted until about 1922 (Nace *et al.*, 1961, p. 17), and that Lake Bonneville at its highest stage had a shoreline along the southeastern corner of Fig. 1 (Snyder *et al.*, 1964). The first factor shows that in the very recent past, the input to the hydrologic system was different than it is today, while the second shows that during the Pleistocene glacial periods a different configuration of the hydrologic system may have existed.

An interesting side issue is the presence of thermal anomalies in the Upper Raft River Valley. The source area for the water found in the deep wells in the Raft River Valley is at one end of the Narrows Zone of Mabey *et al.* (1978), and the implication is that the flow path is along this feature. The two thermal anomalies in the Upper Raft River Valley are to the north of this zone, so it is conceivable that separate circulation systems could be maintained.

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