GeothermEx, Inc. 901 MENDOCINO AVE.
BERKELEY, CA. 94707
(415) 527-9876

A REVIEW OF THE GEOCHEMISTY OF THERMAL WATERS IN THE BRUNEAU-GRAND VIEW AREA, IDAHO

for

AMAX EXPLORATION, INC.
DENVER, COLORADO

by

C. W. Klein

GeothermEx, Inc.
Berkeley, California

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GeothermEx, Inc. 901 MENDOCINO AVE.
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(415) 527-9876

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SUMMARY AND CONCLUSIONS

1. Previous studies of groundwater geochemistry of the Bruneau-Grand View area have been evaluated. Over 100 complete chemical analyses of well and spring waters exist, plus 15 analyses of associated gases, and 19 deuterium-oxygen isotope analyses.

2. Studies have documented the quartz and cation geothermometers and have correlated chemical parameters with aquifer rock type, showing that waters produced from sedimentary rocks of the Idaho Group have higher chemical temperatures than waters from underlying volcanic units (Banbury basalt, Idavada volcanics), due to effects of rock composition.

3. The regional hydrologic model predicts flow at depth from south to north. Recharge occurs in the Owyhee uplands to the south, into volcanic rocks and underlying granites. The volcanic rocks dip northwards toward the Snake River. Overlying sedimentary rocks act as a hydrologic barrier, creating artesian conditions. The sedimentary section thickens northwards, and the depth of wells drilled into the volcanic rocks generally increases in that direction.

4. Surface temperatures of artesian and pumped well waters are generally higher in the north. The hottest wells (83°-84°C), near Grand View, are generally the deepest. Their flow rates are high enough for minimal conductive cooling during ascent from depth. There is no evidence that the higher well temperatures in the north indicate regionally higher heat flow.

5. The area is divided into five parts: Castle Creek, Grand View, Little Valley, the south end of Bruneau Valley, and the Owyhee uplands. Little Valley is closest to the AMAX leaseholds, and has been given the most attention. Chemical analyses have been plotted on trilinear composition diagrams, and Na graphed versus K, by geographic area, aquifer type, sample temperature, and chemical geothermometry.

6. Water composition is different in aquifers of different rocks and from area to area. The most common volcanic water is Na-HCO_3, with minor Ca and SO_4. Sedimentary waters divide into a high salinity Na-HCO_3 type found in Grand View and Castle Creek, and a lower-salinity mixed-cation HCO_3-SO_4 type from scattered localities in all areas.

7. On trilinear composition diagrams, volcanic-aquifer waters of Little Valley and the south end of Bruneau Valley occupy separate elongated fields which in part overlap. Volcanic-aquifer waters from Castle Creek and Grand View are similar and almost always distinct from those of Little and Bruneau Valleys. Several deep wells at the N end of Little Valley are distinct from those to the south and very similar to the deepest, highest-temperature waters in the Grand View area.

8. A composition trend in some Little Valley waters may be due to mixing of waters from volcanic and sedimentary rocks, or may illustrate evolution of the volcanic to the sedimentary type as the deeper volcanic waters circulate upwards into and react with overlying sedimentary rocks.

9. Many waters intuitively seem likely to be mixtures of components of different temperature and composition. This is suggested by the high permeability of many volcanic rocks, the high flow rates of wells and springs, artesian conditions, shallow temperature anomalies, evidence for substantial recharge into fractured volcanic rocks in the Owyhee uplands, and production of many wells from more than one zone at depth. Despite this, however, graphical treatment of data does not illustrate mixing trends other than that of point 8.

10. The hottest waters of the region tend to have the lowest Ca and Mg relative to Na and K, and higher SO_4 relative to HCO_3. The hottest waters also have the highest Na/K ratio, which is opposite of what would be expected if temperature alone were controlling water composition. It seems more likely that the correlation of temperature and composition is due in part to a correlation with rock composition.

11. Ca and Mg probably are controlled by temperature, whereas Na/K may be mostly influenced by rock composition. Compositional data of thermal waters do not indicate mixing. In particular, there is no evidence for a deep, high-temperature component of anomalous chemical character.

12. U.S.G.S. Circular 790 lists an estimated mean reservoir temperature of 107 ± 6°C for the entire Bruneau-Grand View area, in light of the chemical and sulfate-water oxygen-isotope geothermometers and artesian well temperatures. Individual subareas may be significantly hotter at depth.

13. Silica geothermometry indicates 130°-140°C by conductive quartz and 100°-110°C by chalcedony for Little Valley. In Grand View, Castle Creek and northern Little Valley, silica yields 137°-157°C (conductive quartz) and 110°-133°C (chalcedony). Chalcedony temperatures generally are preferred herein, because of abundant glassy SiO_2 in Idavada volcanic rocks, and because of similarity with cation temperatures in volcanic-rock aquifers.

14. Cation temperatures of waters from volcanic-rock aquifers exceed 100°C only in Little Valley and Bruneau Valley. Little Valley shows a bimodal distribution of 78°-92°C and 174°-198°C. This split is spurious, due to the peculiar way in which the cation geothermometer is calculated. A more reasonable cation temperature estimate is 80°C-110°C, which corresponds well with chalcedony temperatures 100°-110°C for the same waters.

15. Estimated temperatures for most deep volcanic waters of the Grand View and Castle Creek areas correspond well with the maximum observed well temperature (84°C), whereas the estimated temperatures for Little Valley are notably higher than the maximum observed well temperature (43°C). This may indicate conductive cooling, mixing of deep and shallow waters, or anomalously high geothermometry. Evidence is moot.

16. Deep waters from volcanic rocks at the north end of the Little Valley area (points 7 and 13) have believable chemical temperatures higher than elsewhere regionally. Minimum temperature estimates are 120°-130°C; temperatures of 150°-170°C are indicated, but less certain. More work may be advised here.

17. All of these waters come from outside the AMAX leasehold. No wells or deep springs are known in the leasehold which might be sampled. Because the hydrologic model suggests that waters have moved northward horizontally beneath the AMAX leasehold, the conclusions herein probably provide a fairly reliable estimate of conditions beneath the leasehold as well. However, local, undetected anomalies may be present.

18. The Bruneau-Grand View data base probably is representative of water chemistries at depth. Little new information would likely arise from additional sampling elsewhere than in northern Little Valley, given the relatively low temperatures indicated by chemical geothermometers.

INTRODUCTION

In October 1980, Dr. Harry J. Olson of AMAX requested a review of existing geochemical work in the Bruneau-Grand View area of Idaho, to determine whether further geochemical exploration or data processing would be valuable in evaluating AMAX's leaseholds in the area. A preliminary review of existing data led me to recommend further processing and interpretative studies. Results of this work are presented in this report.

Thermal waters of the Bruneau-Grand View area are only at moderate temperatures. Generally, the highest temperatures are in the north. The hottest well issues 83°C to 84°C water at the surface from 2,970 feet depth, near Grand View. The hottest spring issues 45°C water in the southern end of Bruneau Valley. Despite this, the region as a whole is of interest because of the large area (about 11 townships) within which thermal waters are known to exist in abundance. For the purposes of this report, the Bruneau-Grand View area is considered to encompass the entire region from Bruneau Valley in the east and southeast, through Grand View, to and including Castle Creek KGRA in the northwest (plate 1).

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REVIEW OF EXISTING DATA AND INFORMATION

Data Base

A large number of chemical analyses of well and spring waters are available for the Bruneau-Grand View area. Data reviewed for this report are reproduced in Appendix 1. Sample locations appear on plate 1, which shows the locations of all waters for which there are analyses of Ca, Mg, Na, K, HCO_3, CO_3, SO_4, Cl, F and SiO_2, plus pH. Also shown are the locations of some additional wells from which no chemical data or only partial data are available; representation of these is not complete.

The U. S. Geological Survey collected and analyzed about 20 samples in the early 1950's (Littleton and Crosthwaite, 1957), a dozen samples in 1972 (Young and Mitchell, 1973) and 94 samples in 1973 (Young and Whitehead, 1975). Several partial analyses have been published by the Idaho Department of Reclamation (Ralston and Chapman, 1969).

The references above include hydrogeologic data such as water levels, well logs, stratigraphic correlations and discussions of the major aquifers, flow patterns and recharge.

Analyses of gases from wells are included in Young and Whitehead (1975), and 14 deuterium-oxygen isotope analyses are reported by Rightmire and others (1975). Several sulfate-water oxygen-isotope temperatures have been reported by Nehring and others (1979).

Groundwater in a missile silo well at T9S-R5E-4dad in the Owyhee uplift has been sampled repeatedly by the U. S. Geological Survey. Resulting analyses are available from survey files in Boise and the computer file WATSTOR, and representative examples are in Appendix I.

AMAX analyses of waters from the area comprise a set numbered W10220 through W10228, collected in 1976 in the vicinity of Castle Creek KGRA, west and north of Grand View. These exist as original and field report forms and analyses, and are not listed in the computer-based geothermal file. In contrast, the geothermal file does include 92 of the 94 chemical analyses reported by Young and Whitehead (1975), listed under file name Granview Idaho Recon 1977. The samples have been assigned numbers W11461 through W11553, which duplicates part of a sequence in the file named Nevada California Recon 1978.

Data include thermal waters from both deep (to over 3,000 feet) and shallow wells. Many of the wells are artesian. Thermal springs and cool, shallow well waters also are represented, plus a few examples of mountain spring waters in the Owyhee uplift, which are believed to represent part of the recharge into the area's artesian aquifer(s).

Nearly all data are from areas to the north of the AMAX leasholds along the base of the Owyhee uplift. There are no waters from within the leaseholds (as shown on lease maps dated 2/12/79). Topographic maps show no springs in the leaseholds, and judging from topography there may be few or no wells. H. L. Whitehead, U. S. Geological Survey, Boise, reports that the upland areas of T8S, R4 and 5E, are unpopulated, with no wells that he is aware of (telephone conversation, November 1980). He also indicated that the samples reported in Young and Whitehead (1975) represent a high percentage of the deep wells in the region.

Several wells are as close as 1-1/2 miles north of the eastern AMAX leaseholds in T7 and 8S, R4 and 5E, and 30 to 40 analyzed waters are from the area within about 6 miles to the north and northeast. The chemistry of groundwaters beneath the leaseholds can be inferred fairly reliably from these data, because regional groundwater flow is believed to be from south to north. The leaseholds are traversed by several of the major north-dipping northwest-striking normal faults along the edge of the Owyhee uplift, and they overlie several heat-flow anomalies. It is probable that the faults are conduits for upwelling thermal waters, which migrate northwards in volcanic rock units from beneath the leasehold areas and are then tapped by the sampled wells.

The westernmost leaseholds, in T6 and 7S, R2 and 3E, are more distant from water sample points, with virtually no samples within 3 miles, and very few within 6 miles. No closer springs are apparent on topographic maps.

Interpretive Studies

AMAX in-house reports have included IOM's by Frank Dellechaie dated April 2, 1976, March 3, 1978 and April 6, 1978, and a section on geochemistry in an IOM by John Deymonaz, February 7, 1978, which is basically a summary of Young and Whitehead (1975).

The April 2, 1976 memo considered 6 hot artesian well waters sampled by Young and Whitehead (1975) from T4S, R1E, T4S, R2E and T5S, R1E, in the vicinity of Castle Creek KGRA. It was concluded that 4 of these were at equilibration below 100°C, but that two waters indicated maximum temperatures of 150°-160°C or slightly higher. Thermal water compositions were similar to those elsewhere in the Bruneau-Grand View area, as well as to waters in the Idaho batholith. Circulation with granitic rocks at depth was inferred. In summary, the Castle Creek KGRA was not considered to be a prime prospect worthy of large capital expenditure.

The March 3, 1978 memo illustrated that waters from certain shallow wells in the Bruneau-Grand View area have chemical temperatures higher than those of deeper, hotter wells. This is due to effects of aquifer rock composition, and is discussed below. Dellechaie felt that chemical temperatures between 75° and 143°C provided by the deepest, hottest wells are realistic.

The April 6, 1978 memo included silica-enthalpy mixing calculations which are said to reflect equilibrium with chalcedony for 4 Grand View area waters. Minimum hot component temperatures are 203 to 238°C and the fraction cold water is about 90% in each case. It was correctly pointed out that the quantitative significance of the mixing calculations decreases rapidly as the cold water fraction increases, but no other interpretation of the calculations was presented.

Other reports have reached conclusions essentially equivalent to Dellechaie's. Young and Whitehead (1975), for example, stated that aquifer temperatures at depth, as estimated by silica and sodium-potassium-calcium geochemical thermometers, probably do not exceed 150°C, but that a mixed-water silica thermometer indicates that temperatures at depth may exceed 180°C.

Isotope studies by Rightmire and others (1975) have established that recharge to the thermal aquifers is not entirely from within the local surface-drainage area, but may come from higher elevations near the Bruneau River to the southeast; and/or that the recharge occurred at a time in the past when regional climate was cooler than at present.

U.S.G.S. Circular 790 tabulatedan estimated mean reservoir temperature of 107±6°C for the Bruneau-Grand View area, in light of the chemical and isotope geothermometers and artesian well temperatures. Data used include sulfate-water oxygen isotope temperatures of

95°C to 130°C for several samples (Nehring and others, 1979). The estimate is for the area as a whole, however, and for waters in the aquifers feeding the deeper (to 3,000 feet) artesian wells. It remains possible that these aquifers are fed by a deeper, hotter source, and that individual localities may have significantly greater upflow and therefore higher temperatures.

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NEW TREATMENT OF DATA

Objectives and Methods

In reviewing the existing data it became apparent that graphical treatment would be helpful in resolving uncertainties of water origin and circulation.

The basic hydrologic model of the Bruneau-Grand View area holds that water in the deep volcanic aquifers originates as recharge in the Oywhee uplift and flows down-gradient in north-dipping volcanic units towards the Snake River. If this is true, then it is of interest to know whether there are gradations in water composition from south to north, and whether there are distinct relationships between water temperature and composition. For example, do the moderate temperature thermal waters of the Grand View area resemble the lower temperature thermal waters of Little Valley?

The AMAX leaseholds overlie a set of parallel normal faults along the northern margin of the Owyhee uplift; heat-flow data indicate that thermal upwelling occurs in association with these zones (AMAX heat flow map, 2/7/78). Is there evidence to suggest that the low-temperature thermal waters near the uplift are actually mixtures of a high temperature component and cooler waters? Could the same thermal component be related to the hot water tapped by wells near Grand View? Finally, existing reviews of chemical geothermometry have been limited to tabulation of calculated temperatures, and to silica mixing models applied without consideration of other chemical parameters. Would insight into the geothermometry be aided by consideration of bulk composition, ionic ratios, and geographic and geologic patterns?

The Bruneau-Grand View area herein is divided into four principal subareas, although the boundaries between them are not well defined. These are Castle Creek, Grand View, Little Valley, and the south end of Bruneau Valley (plate 1). The principal area of interest is Little Valley, given its proximity to both the easternmost AMAX leaseholds and the northern edge of the Owyhee uplift.

The south end of Bruneau Valley also is close to the eastern leaseholds, but the northern half of Bruneau Valley is not included because of its greater distance and because of a desire to limit the size of the study. The Grand View and Castle Creek areas are the closest to the westernmost leaseholds. Waters in these areas have temperatures higher than in Little Valley or Bruneau Valley. A fifth, smaller group of samples comprises scattered localities in the Owyhee uplift.

All complete chemical analyses from each geographic area were processed to check for errors, using cation-anion balance, and to calculate equivalent ratios between principal ions. Ionic imbalances greater than $\pm$10% were found to be rare, and only one analyses was discarded because of a large apparent error, probably in reported Na (Young and Whitehead, 1975, sample 7S-4E-25adc1). The analyses were then plotted on trilinear composition diagrams by geographic group, aquifer type and water temperature. Selected waters have been shown on the dual basis of cation temperature in volcanic rock aquifers and sulfate-water oxygen isotope temperature (figure 1, parts A-H).

Geographic Sub-Areas

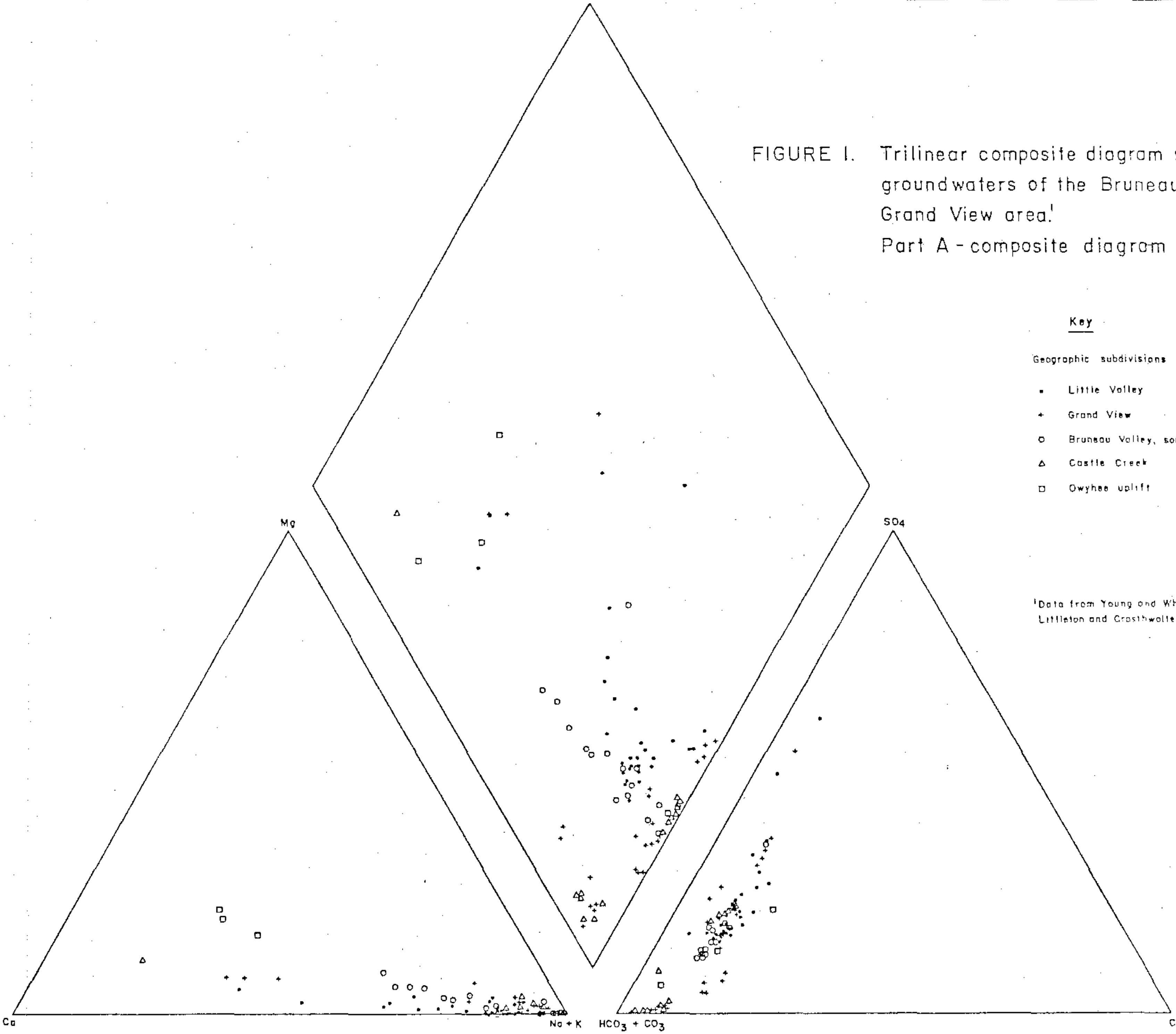
Figures 1 and 2 show that there are distinctions in groundwater composition from area to area on the basis of temperature and aquifer type. The waters of most areas cluster into well-defined groups and are generally of Na-HCO_3 type with minor but notable Ca and SO_4. Scattered examples with high and dominant Ca amongst the cations and sometimes also high SO_4 amongst the anions always prove to be waters from Idaho Group sedimentary rocks or from these and the underlying Banbury basalt.

Total salinity usually is 5 to 10 milliequivalents per liter, but there is a group of much more saline Na-HCO_3 waters from Castle Creek and Grand View areas in the Idaho Group sediments. These are notably lacking in SO_4. SO_4 probably comes from sulfides in the underlying volcanic rocks.

Waters in volcanic rocks of the Grand View and Castle Creek areas generally have Na + K higher relative to Ca than waters of Little Valley and Bruneau Valley south, and this correlates with the higher observed water temperatures in the two northern areas. Many of the Little Valley waters are distinguished from those of Bruneau Valley by higher relative SO_4 and frequently by lower relative Mg. These are probably effects of rock composition and are not caused by temperature differences, in spite of the fact that observed temperatures of the Bruneau Valley waters generally are higher than those of Little Valley.

Na/K ratios vary with aquifer type and geographic ara. Young and Mitchell (1975) and Dellechaie (1976) noted higher concentrations of Na in waters from Idaho Group sedimentary rocks than in those from the underlying volcanic rocks, and also stated that Na/K ratios are lower in the sedimentary aquifers. This is only partially true. The

FIGURE I. Trilinear composite diagram showing groundwaters of the Bruneau-Grand View area.[1]
Part A - composite diagram



Key

Geographic subdivisions

- • Little Valley
- + Grand View
- o Bruneau Valley, south end
- △ Castle Creek
- □ Owyhee uplift

[1] Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files.

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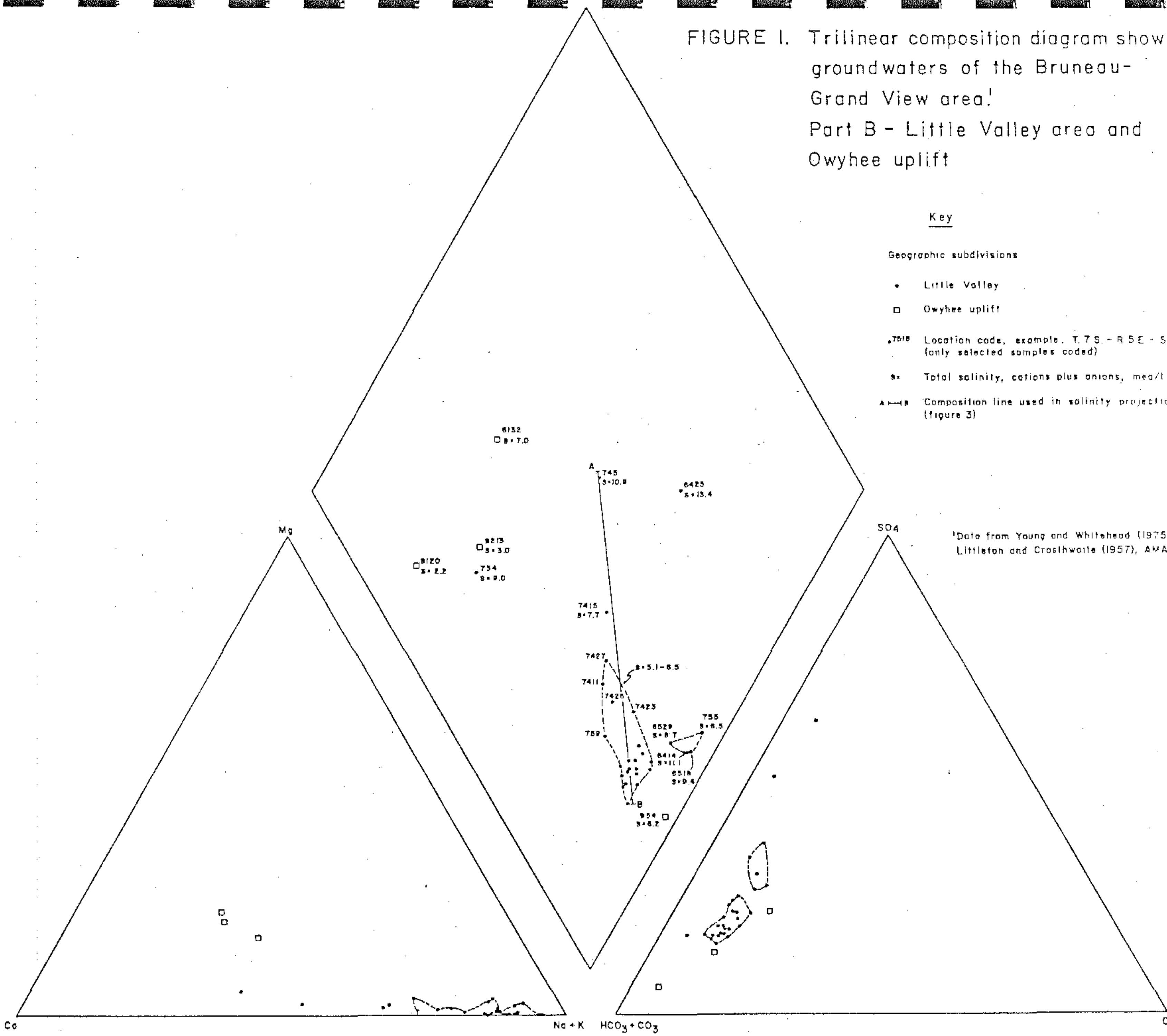
FIGURE 1. Trilinear composition diagram showing groundwaters of the Bruneau-Grand View area[1]
Part B - Little Valley area and Owyhee uplift



Key

Geographic subdivisions

- • Little Valley
- □ Owyhee uplift
- •7518 Location code, example, T. 7 S. - R 5 E - Sec. 18 (only selected samples coded)
- S = Total salinity, cations plus anions, meq/l
- A ⊢⊣ B Composition line used in salinity projection (figure 3)

[1]Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files

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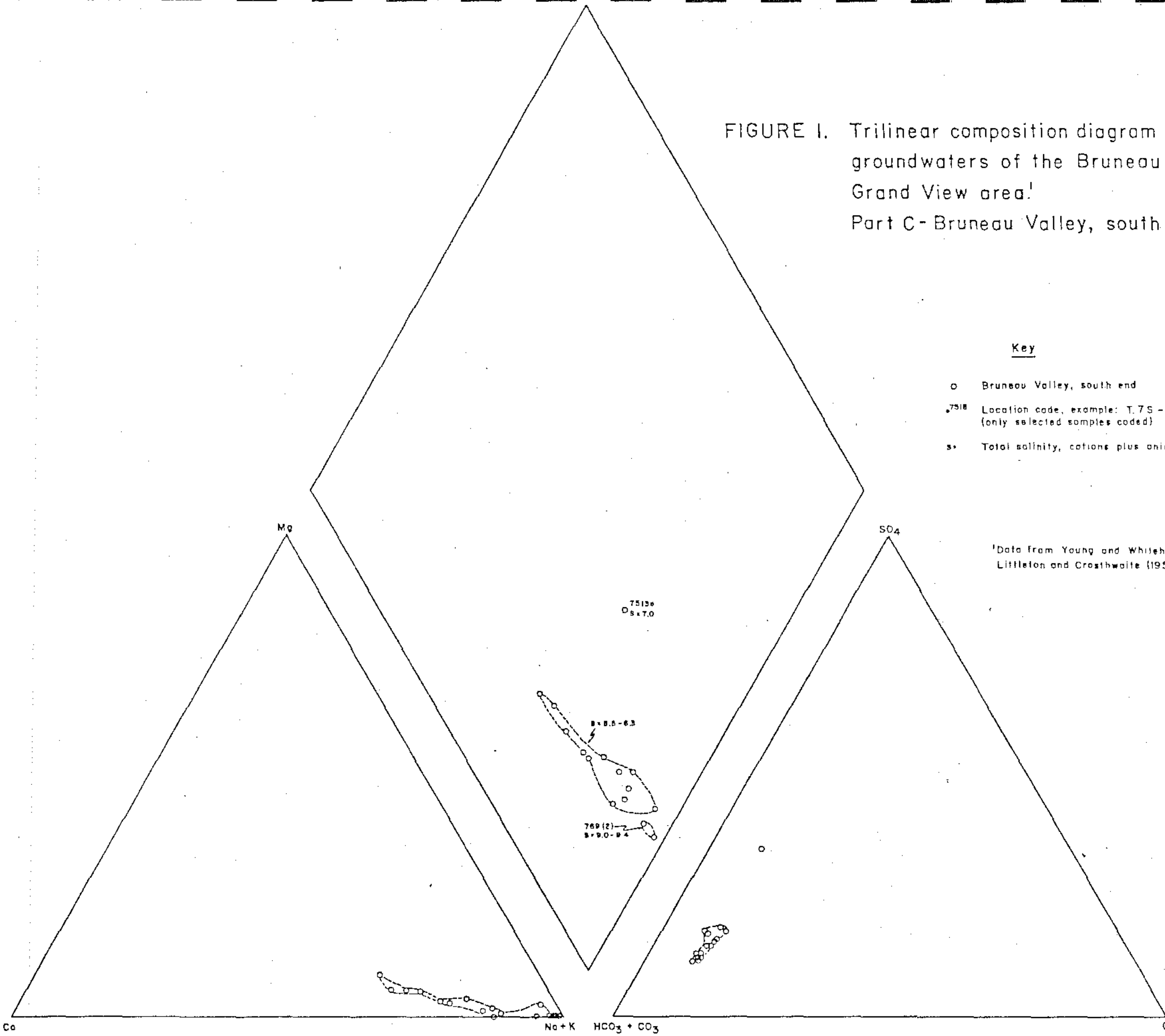
FIGURE 1. Trilinear composition diagram showing groundwaters of the Bruneau - Grand View area.[1]
Part C - Bruneau Valley, south end



[1]Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files.

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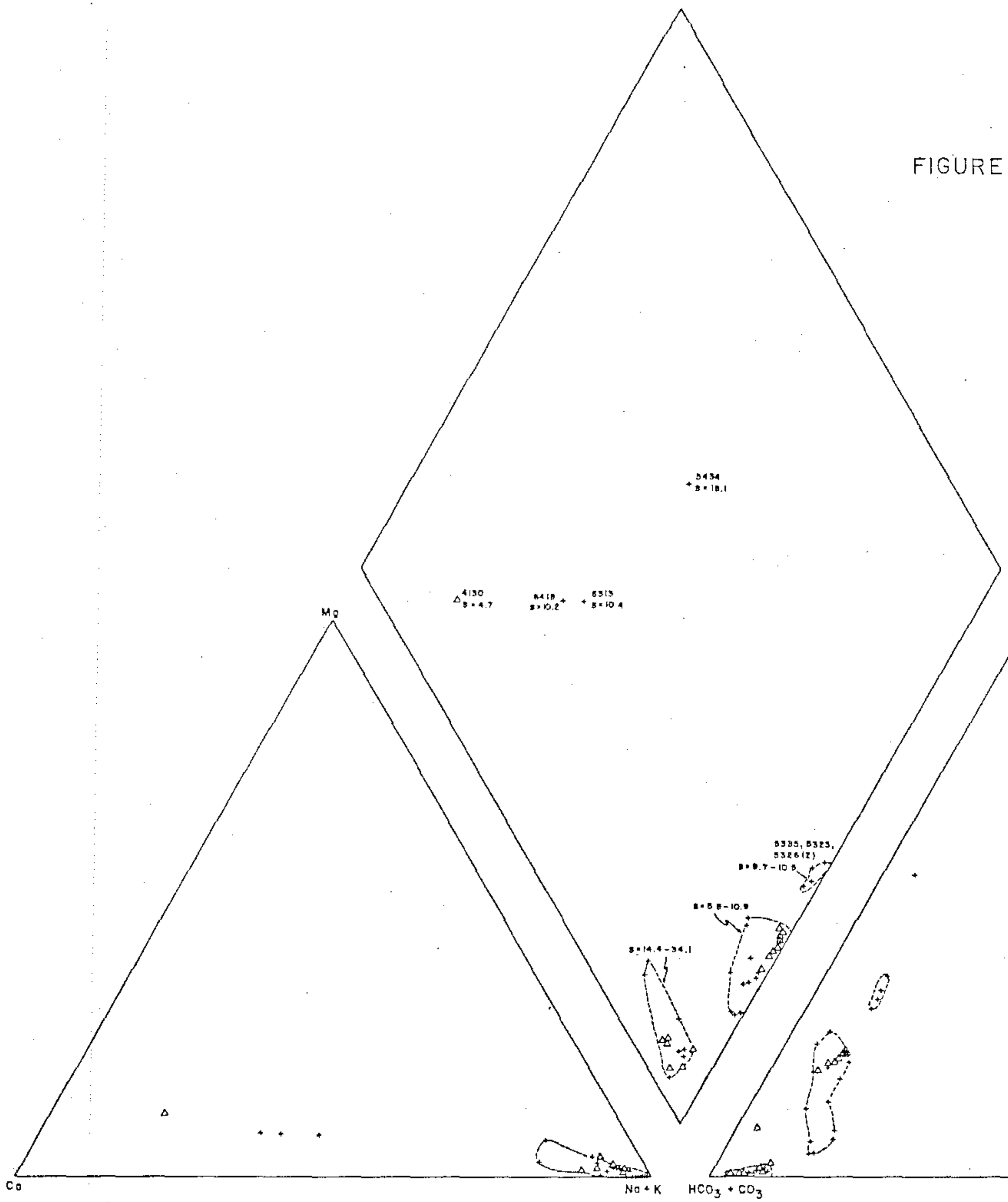
FIGURE 1. Trilinear composition diagram showing groundwaters of the Bruneau-Grand View area[1]
Part D - Grand View and Castle Creek areas



Key

Geographic subdivisions

- + Grand View
- Δ Castle Creek

•7S18 Location code, example: T.7 S - R 5 E. - Sec. 18 (only selected samples coded)

s = Total salinity, cations plus anions, meq./l

[1] Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files.

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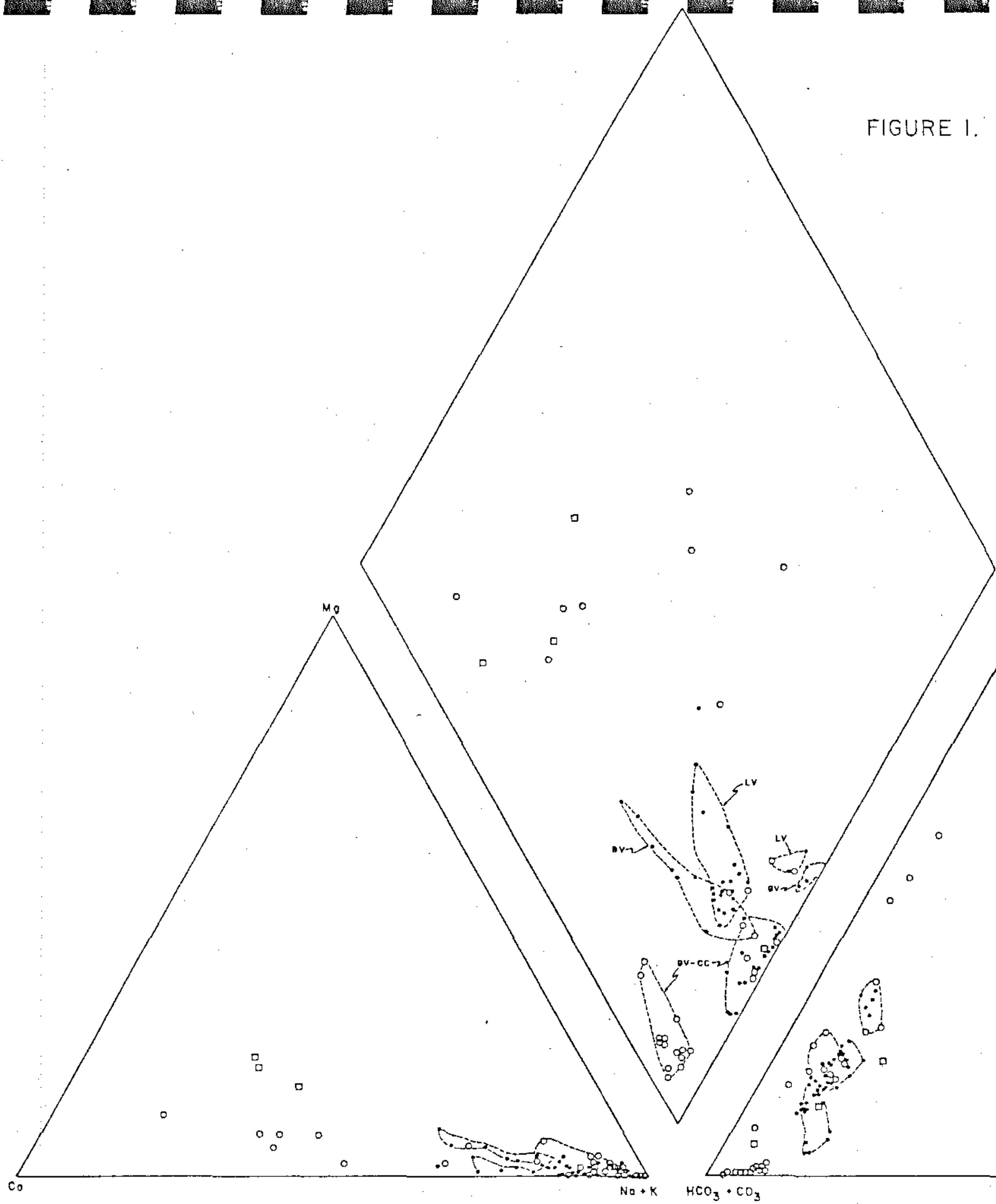

FIGURE I. Trilinear composition diagram showing groundwaters of the Bruneau-Grand View area.[1]
Part E - aquifer type[2]

Key

- ○ Idaho group sedimentary rocks ± Banbury Basalt
- • Volcanic rocks
- □ Granitic rocks
- ⸝⸝ Geographic subdivision outline (from parts B - D)
  - LV = Little Valley
  - GV = Grand View
  - CC = Castle Creek
  - BV = Bruneau Valley, south end

[1]Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files.

[2]From Young and Whitehead (1975) and Littleton and Crosthwaite (1957) based on well logs, casing records and geology

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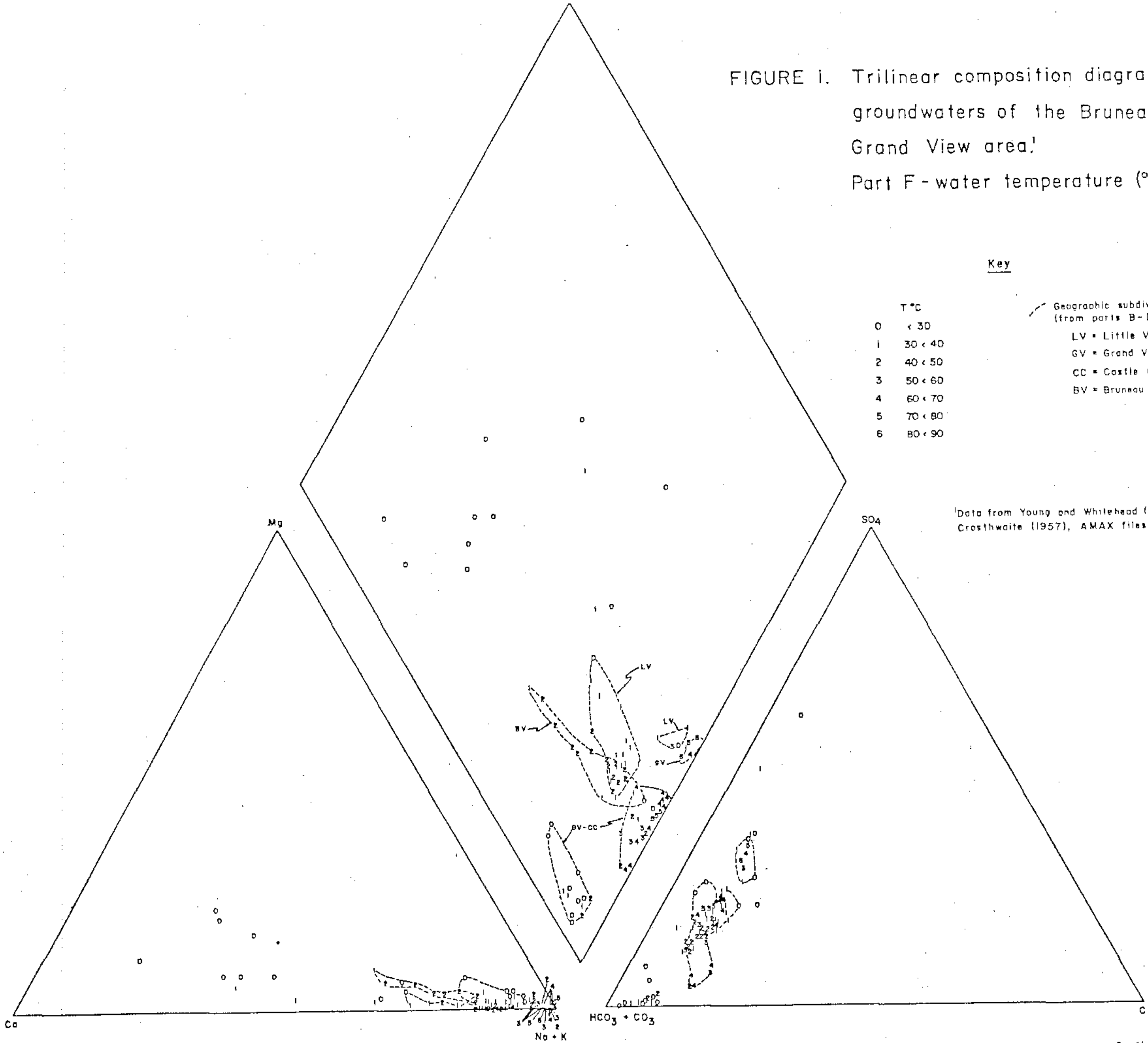

FIGURE 1. Trilinear composition diagram showing groundwaters of the Bruneau - Grand View area.[1]
Part F - water temperature (°C, at surface)

Key

	T °C
0	< 30
1	30 < 40
2	40 < 50
3	50 < 60
4	60 < 70
5	70 < 80
6	80 < 90

Geographic subdivision outline (from parts B - D)
LV = Little Valley
GV = Grand View
CC = Castle Creek
BV = Bruneau Valley, south end

[1] Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files

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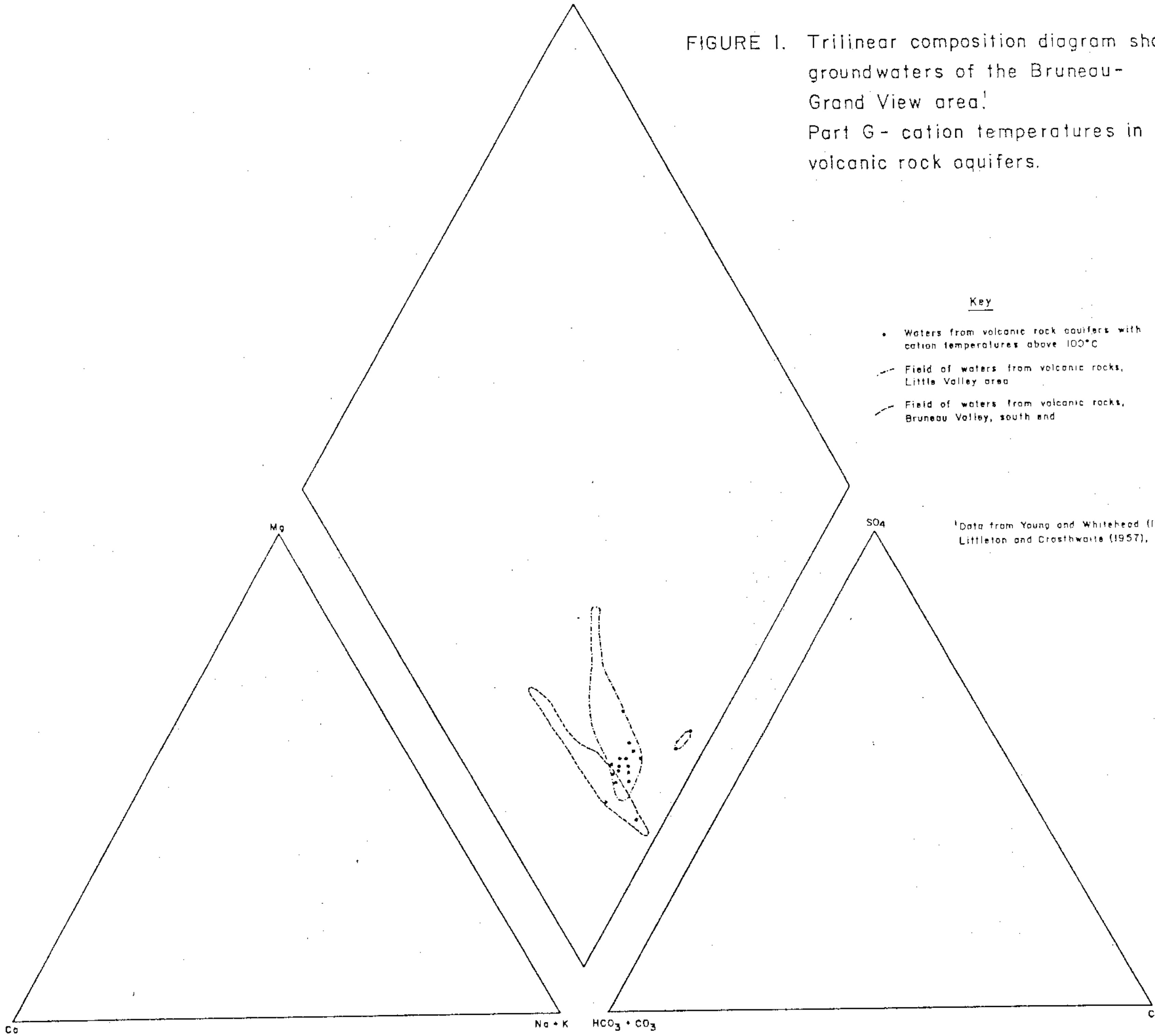
FIGURE 1. Trilinear composition diagram showing groundwaters of the Bruneau-Grand View area.[1] Part G - cation temperatures in volcanic rock aquifers.



Key

- • Waters from volcanic rock aquifers with cation temperatures above 100°C
- Field of waters from volcanic rocks, Little Valley area
- Field of waters from volcanic rocks, Bruneau Valley, south end

[1] Data from Young and Whitehead (1975), Littleton and Crosthwaite (1957), AMAX files

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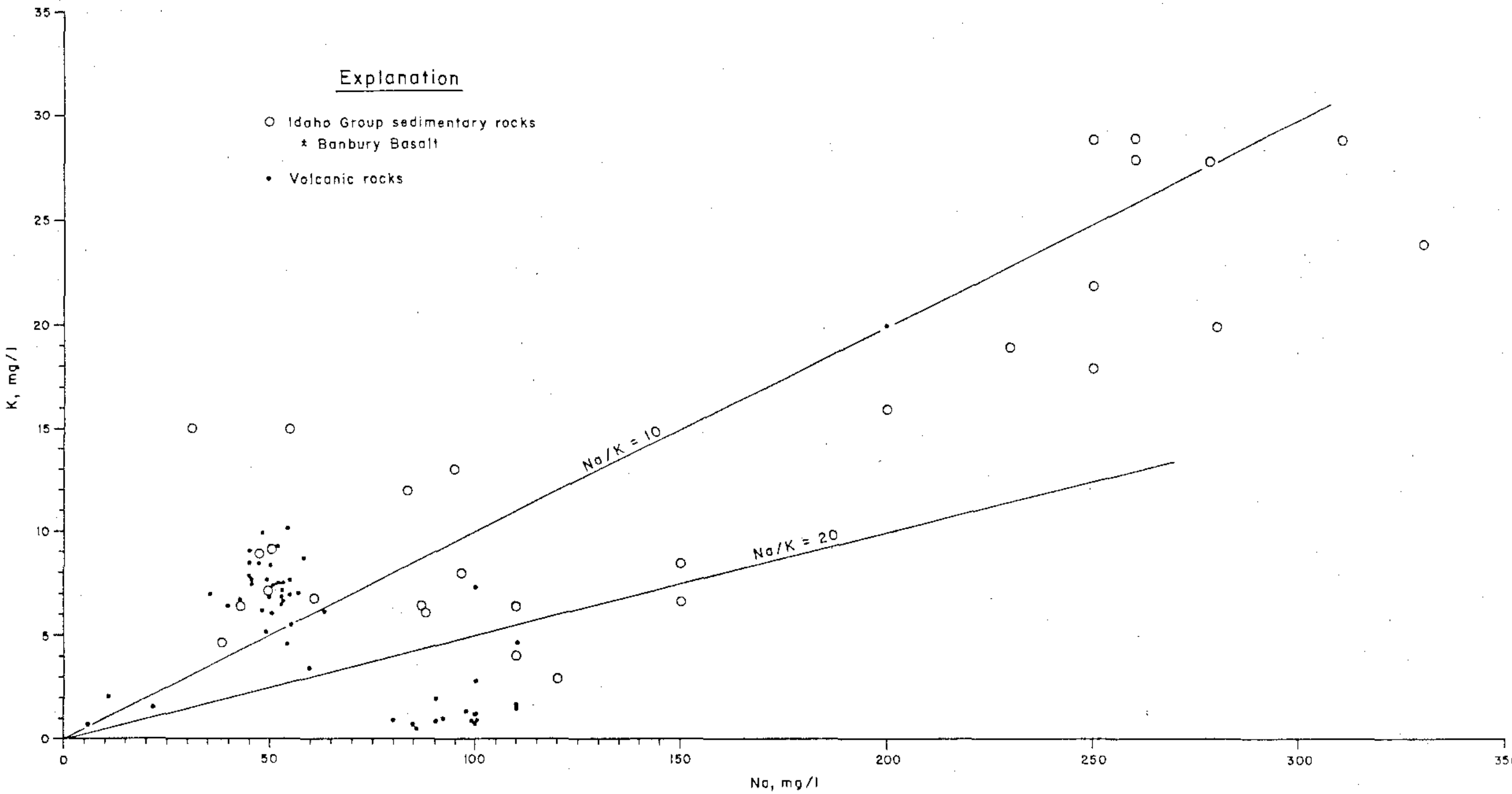

FIGURE 2. Na versus K in groundwaters of the Bruneau-Grand View area.
PART B - Aquifer type
(from Young and Whitehead (1975) and Littleton and Crosthwaite (1957) based on well logs, casing records and geology)

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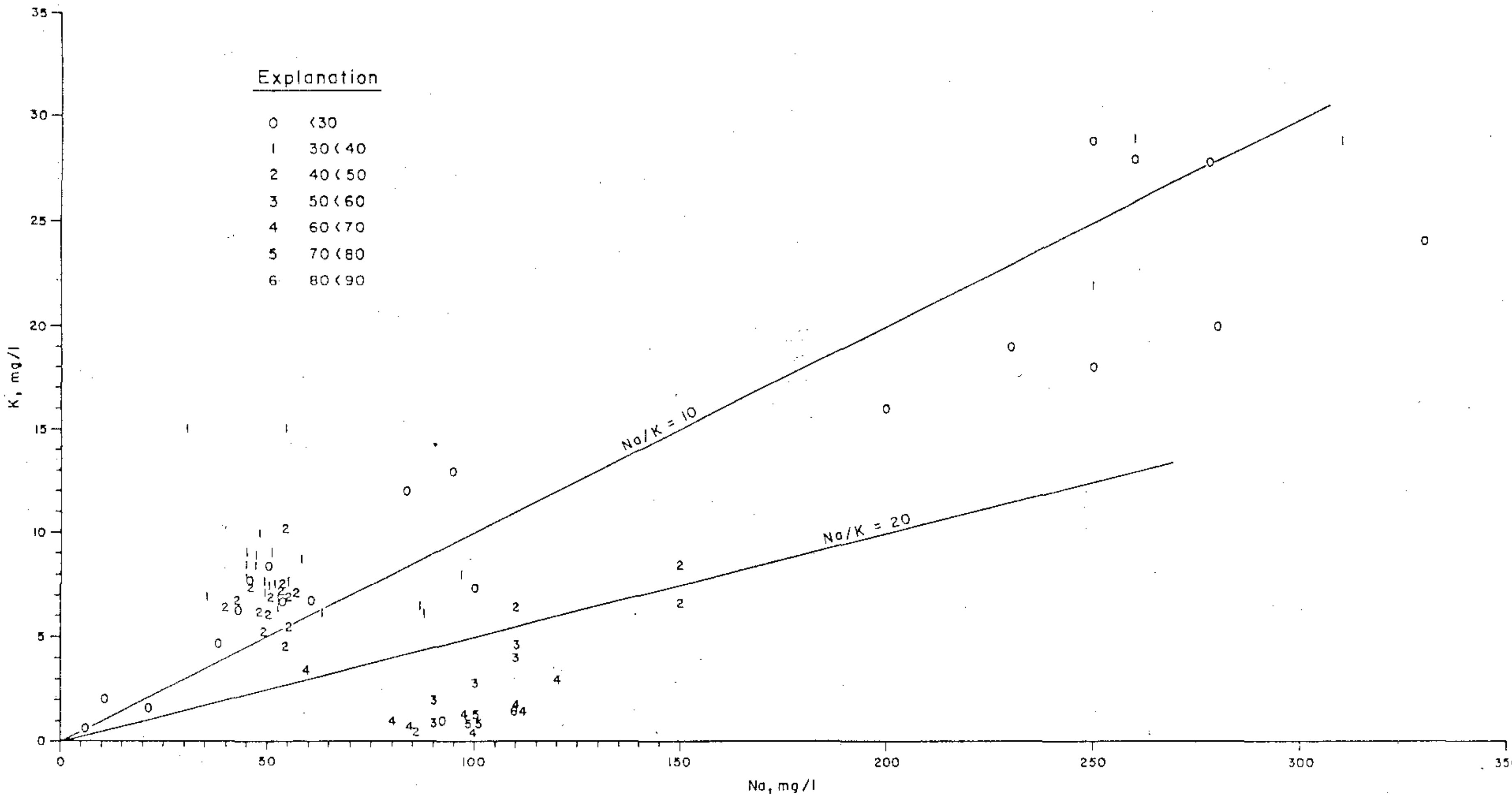

FIGURE 2. Na versus K in groundwaters of the Bruneau-Grand View area.
PART C - Water temperatures ($T^{O}C$, at surface).

lowest Na/K are indeed in sedimentary aquifers, but volcanic aquifer ratios fall into two groups, with lower ratios in Little Valley and Bruneau Valley than in Grand View and Castle Creek. Na/K in Little and Bruneau Valleys are equivalent to Na/K in sedimentary aquifers, whereas Na/K the Grand View-Castle Creek waters are consistently higher.

Waters of Little Valley fall into three principal groups: (1) scattered waters from Idaho Group sediments which have highly variable compositions and salinities, (2) a trend of compositions from volcanic aquifers in the southern end of the Valley (figure 1, line A-B), and (3) a group in the northern end of the Valley area which resembles several waters from Grand View.

Figure 3 shows a graphical treatment of the waters from volcanic aquifers in the southern part of the Valley. Waters adjacent to line A-B have been projected first onto the line, then into a plane in which salinity is plotted against composition. Triangle A-B-C defines a plane which includes composition line A-B of the trilinear composition diagram and point C, which is defined as zero salinity above the plane of the trilinear diagram. In a projection such as this, any set of waters of varying salinity and composition which are mixtures of two end members will define a straight line in the plane A-B-C.

Relationships between points in this projection are only approximate, given that most of the waters do not lie exactly in plane A-B-C, but instead have been projected onto it from either side (above and below the page). Samples projected onto A-B-C from particularly far off are shown with the sample number in parentheses. These are included to illustrate relative salinity, but cannot reliably indicate mixing trends in this section.

Samples 745, 7415, 7427 and 7426* roughly define a line which connects 745 near side A-C of the triangle with the main group of Little Valley volcanic aquifer waters near side B-C. Water 745 is reportedly from a sedimentary aquifer, and it appears that 7425, 7427, 7411 and 7426 may be mixtures of such a water with deeper water from volcanic rocks. Surface temperatures of the well waters are roughly consistent with this. The main group of Little Valley volcanic waters is 32°-43°C, whereas the "mixed" waters are slightly cooler (27°-38°C). This may also be explained as an evolution of the volcanic waters towards a sedimentary type, as the deeper, hotter water circulates

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*All sample number are abbreviations of the T-R-S location: 745 is a water from T7S-R4E-Sec. 5.

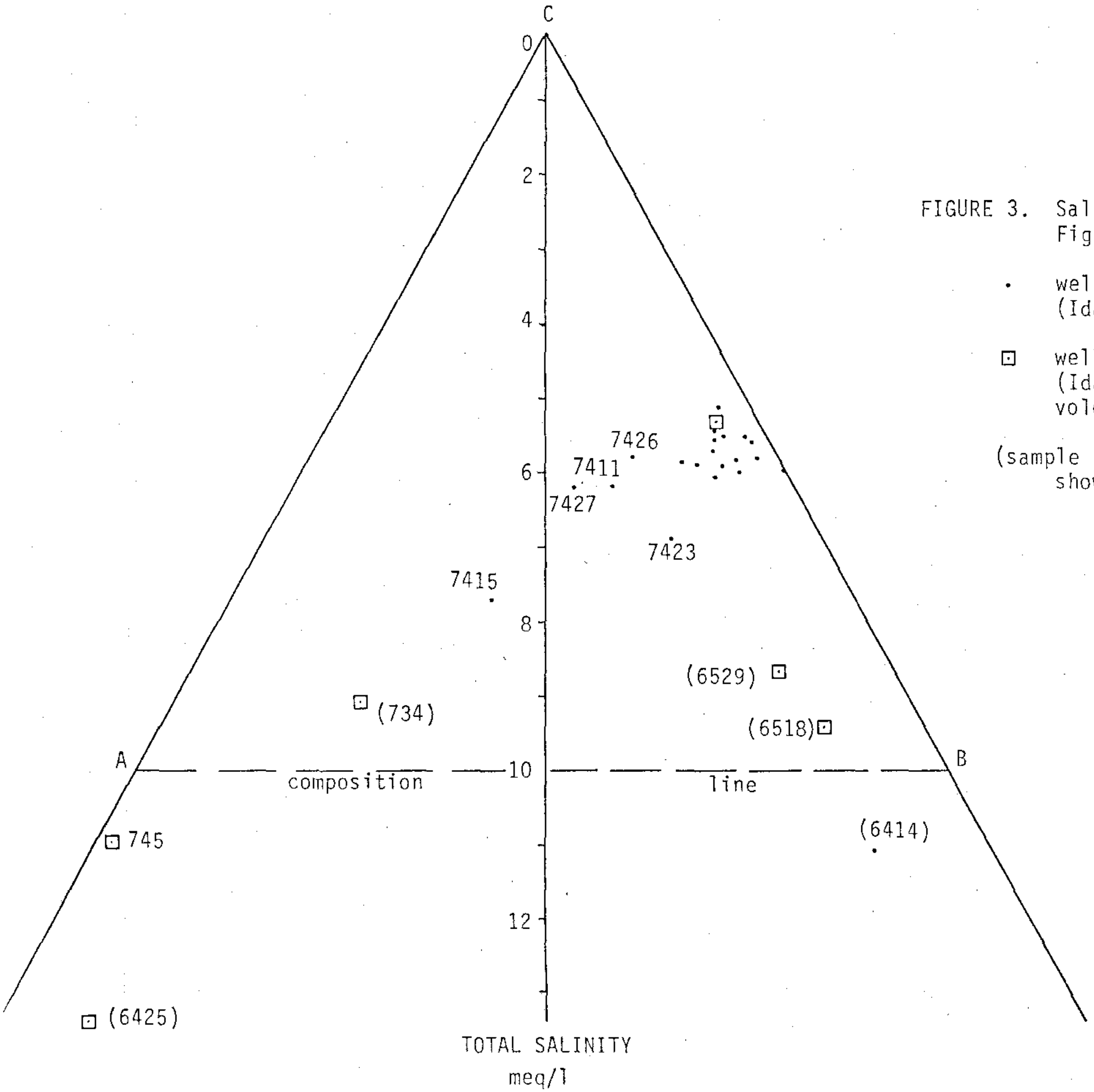

FIGURE 3. Salinity-composition projection from Figure 1, Part B.

· wells producing from volcanic rocks (Idavada volcanics, Banbury basalt)

⊡ wells producing from sediemntary rocks (Idaho Group) or sedimentary rocks and volcanic rocks.

(sample no.) - not on composition line, shown to illustrate salinity only.

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upwards into and reacts with sedimentary rocks under artesian conditions.

The mild temperatures of the Little Valley volcanic waters may reflect either (a) mixing of a deep, high-temperature component with a cool component of recharge, or (b) heating of recharge during rapid circulation to only moderate depths. If mixing were occurring, this would probably show up on figure 3, assuming that the high-temperature component were anomalous in either composition or salinity with respect to the recharge. There is no evidence for such mixing or for the presence of such a component, although there is one anomalous group of waters (6414, 6518, 6529) which will be discussed below.

The absence of evidence for mixing, coupled with the overall dilute Na-HCO_3 character of the Little Valley thermal waters, suggests that their temperatures at depth are not greatly above those observed at the surface. This applies to the main group of waters, from the south end of the valley in T7S, R4E.

Some thermal waters from the south end of Bruneau Valley have compositions identical to those of Little Valley, whereas others fall on a trend towards slightly higher levels of Mg and lower SO_4. There is no trend in salinity or temperature which can be taken to indicate mixing, and the observed range of compositions appears more likely controlled by rock composition and reactions at low temperature than thermal effects. As in Little Valley, evidence for a high-temperature thermal component is lacking.

In the north of the Little Valley area there are four waters which are anomalous with respect to those in the rest of the Valley, and which are very similar to several waters from the Grand View area. These are 6414, 6518, 6529 and 755 (compare figure 1, parts B and D). Water 6414 has the highest observed temperature (54°C) in the Little Valley area. Table 1 lists these waters along with the similar set from Grand View, which is notable as including the highest temperature wells of the entire Bruneau-Grand View region.

The aquifers are those indicated by Young and Whitehead (1975), tabulated from well logs, casing history and geology. However, the compositions of waters 6518 and 6529 strongly suggest that they are actually from volcanic rocks. Data suggesting this include concentrations of Ca, F and Cl and the ratio Cl/F as well as relationships shown on figure 1.

Whereas the ionic ratios expressed by figure 1 are quite similar for all of these waters, figure 2 shows that their Na/K ratios are

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Table 1. Comparison of selected Grand View and Little Valley thermal well waters.

Sample	Surface Temperature, °C	Total Salinity meq/l	Well Depth, feet	Producing aquifer(s) major/minor
Grand View				
5326bcb1	83	9.9	2,970	Idavada volcanics/Banbury basalt
5326bcb2	67	9.8	2,970	Idavada volcanics(?)/ Banbury basalt(?)
5335ccc1	71.5	9.7	2,570	Idavada volcanics(?)/ Banbury basalt(?)
5323cc	84	10.5	?	unknown
Little Valley				
6414abc	54	11.1	1,905	Idavada volcanics/Banbury basalt
6518ccb	27	9.4	2,960	Banbury basalt/Idaho Group
6529dcc	32.5	8.7	1,560	Idaho Group(?)
755dbc	32	6.5	2,405	Banbury basalt

somewhat variable, primarily due to variations in K. The waters probably all come from the same or similar rock units, and they constitute a coherent chemical anomaly; but it is uncertain if they represent a significant thermal anomaly, given the fact that they are produced from some of the deepest wells in the area.

Using surface temperature based on an estimated mean annual air temperature of 10°C, and well depth in the hottest wells, apparent gradients are calculated to be about 4.3°-4.5°F/100 feet in the hotter, deeper wells (5326, 5335, 6414). Discharge and production rates are high enough to suggest minimal conductive cooling during ascent of the well waters to the surface (c. 100 to over 1,000 gpm). However, there is no certainty that waters enter only at well bottom. These apparent gradients project to temperatures of over 450°F by 10,000 feet. There is no assurance that conductive conditions continue to such depth.

Geothermometers

Chemical geothermometry herein is limited mostly to data from the volcanic rock aquifers of the area. Young and Mitchell (1975) and Dellechaie (1976) previously pointed out that waters in the sedimentary aquifers tend to have higher silica and cation temperatures than the deeper volcanic waters and that this is an effect of rock composition and low-temperature reactions rather than equilibration at high temperatures.

Figure 1, part G illustrates that cation temperatures of waters from the volcanic rock aquifers exceed 100°C only in the Little Valley and Bruneau Valley areas.

Cation temperatures of the Little Valley volcanic waters have a bimodal distribution, with one group at about 78°-92°C and another at about 174°-198°C, and with very few exceptions in between. However, there is no corresponding bimodal distribution of water compositions. The split in cation temperatures is spurious, created by a shift to 1/3 for the value of factor beta, made when temperatures calculated with beta = 4/3 exceed 100°C. The 100°C limit for use of beta = 4/3 is conventionally stated as a fixed rule, but it is actually an approximation. Table 2 shows that temperatures of the higher temperature group could as well be only 100°C to 110°C.

Given that most Little Valley volcanic waters have cation temperatures of about 80°-110°C, is this a reliable estimate of temperatures at depth?

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Table 2. Groundwaters from aquifers in volcanic rocks[1] having cation temperatures above 100°C.

Area[2]	Sample No.	Surface Temperature, °C	T°C NaKCa[4] $\sqrt{Ca}/Na$	Beta= 1/3	Beta= 4/3	Flow, gpm[3]
GV	5328	65	1.06	105	103	F
LV	6414	54	2.34	142	107	1350(P)
LV	741	40	5.69	182	103	409-688
LV	743	42	6.01	194	110	NF
LV	7410	37.5	6.56	198	109	NF
LV	7412	43	5.96	185	104	1400
LV	7413b	39	6.33	193	107	1300
LV	7413d	40	6.39	186	102	812-1000
LV	7414	39	6.85	196	106	1470(P)
LV	7423	38.5	6.86	188	100	3360-342(P)
LV	755	32	3.82	175	113	F
LV	757	39	6.57	199	110	2990-4000
LV	758	40	5.07	183	109	400
LV	7516	39.5	5.61	180	103	200
LV	7519	36.5	5.80	186	106	1170(P)
LV	7528	34	6.36	199	110	1300-1540(P)
BS	769	50	1.45	131	115	120
BS	863	39	5.53	182	105	130-160 (spring)
LV	6518	27	2.27	169	130	NF
LV	6529	32.5	3.52	161	106	F

(1) All samples represent wells, except for 863. Aquifers are in Idavada volcanic rocks and/or Banbury basalt. Data from Young and Whitehead (1975) and Young and others (1979).

(2) GV = Grand View; LV = Little Valley; BS = Bruneau Valley, south end

(3) NF = not flowing, pump rate not available; F = flowing, rate not available; P = pumped.

(4) Conductive quartz temperature = 122°-157°C, with all but 4 values in range 132°-137°C.

The answer to this is uncertain. Figure 4 shows that dissolved silica in Little Valley waters corresponds to chalcedony temperatures of about 100°-110°C and to quartz temperatures of about 130°-140°C. In this temperature range the chalcedony temperature is as likely as quartz to be meaningful. Both the silica and cation temperatures may be biased by rock composition or by a lack of chemical equilibration due to very rapid circulation or low-temperature conditions. Silicic volcanics in the section may be sources of anomalously high K and SiO_2 which can produce anomalously high temperature estimates.

Silica-temperature relationships among Little Valley waters do not indicate mixing. As discussed above, there is limited evidence in bulk composition data for mixing of volcanic and sedimentary aquifer waters, but none for mixing of thermal and non-thermal volcanic waters. These facts effectively discount application of silica mixing models to the Little Valley waters.

The absence of evidence for mixing in the volcanic aquifers is a bit surprising, given their high permeabilities and the abundant evidence for recharge into volcanic rocks of the Owyhee uplift close to the south end of Little Valley. It has been stated that the entire normal flow of Big Jacks Creek is absorbed by volcanic rocks in the faulted zone along the north edge of the uplift (Littleton and Crosthwaite, 1957). The effect of this recharge on heat flow in the area has been well-defined by gradient drilling (AMAX heat flow map, 2/7/78). If this recharge is mixing with warmer waters deeper in the volcanics, homogenization must be complete before the waters are tapped by valley wells.

Even if the highest temperatures are accepted (130°-140°C), there is no clear evidence of significantly higher temperatures.

In the case of deep waters at the north end of Little Valley, and at Grand View and Castle Creek, it is probable that the chemical geothermometers are meaningful. Surface temperaturs are higher and residence time at depths probably is longer.

Figure 4 shows that silica levels in the northern Little Valley waters (6414, 6518, 6529, 755) tend to be higher than in the south. Table 3 shows silica, cation and isotope geothermometers as applied to the set of northern Little Valley and similar Grand View waters. In northern Little Valley, minimum temperatures of at least 120°C and possibly 130°C appear reasonable. The higher quartz and cation temperatures of 150°-170°C are possible but less certain, particularly in light of the sulfate-water oxygen-isotope temperature. Note that the cation temperatures are subject to interpretation as being either about 140°-175°C <u>or</u> about 110°C, according to the choice of beta (see above).

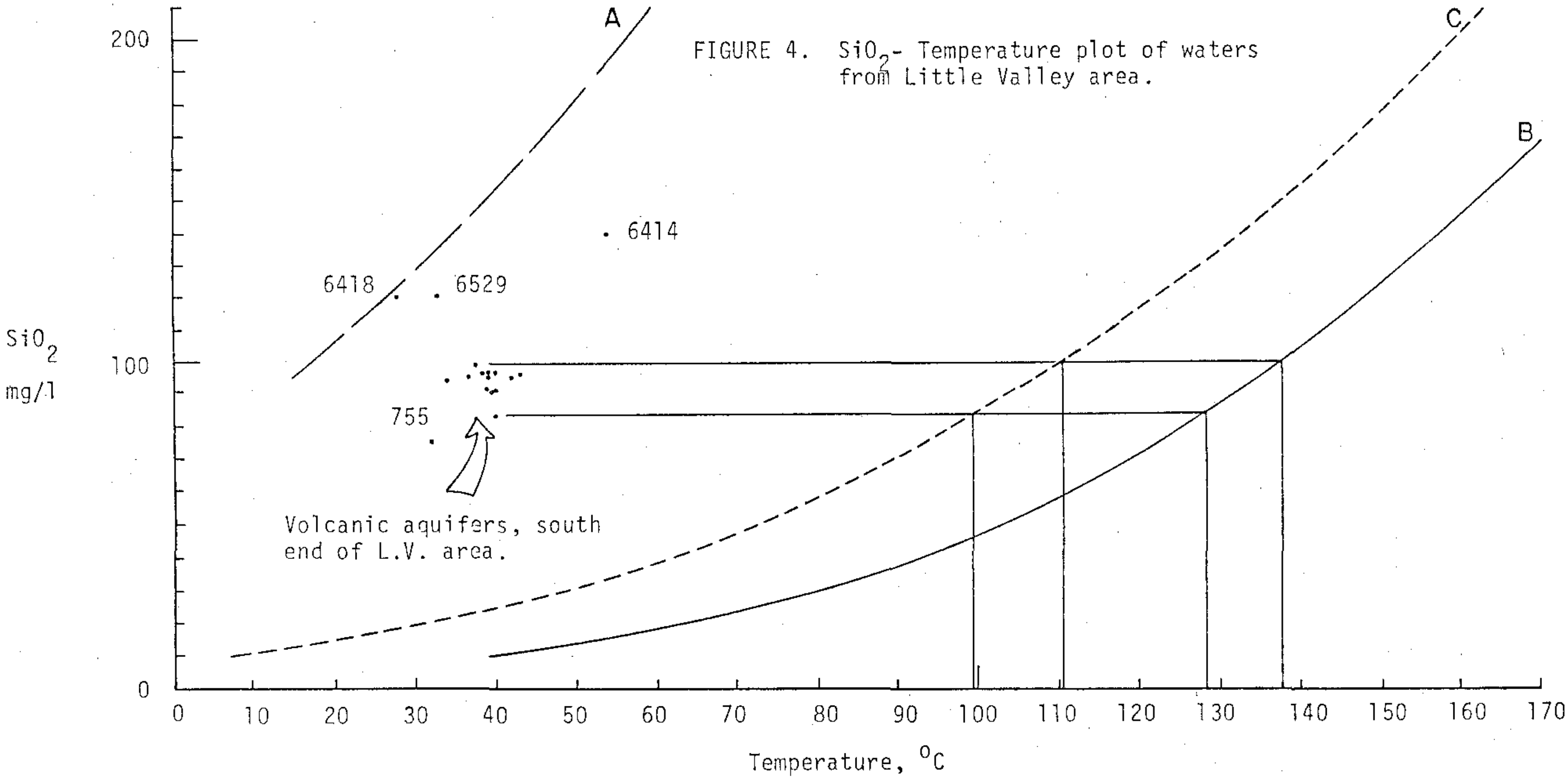

FIGURE 4. SiO_2- Temperature plot of waters from Little Valley area.

A = Amorphous Silica

B = Quartz

C = Chalcedony

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Table 3. Chemical geothermometers of waters from the north end of the Little Valley area and related Grand View waters.

Sample No.	T°C	T°C SiO_2			T°C NaKCa			Sulfate-water oxygen isotope T°C
		QTZ	CHAL	AMOR	√Ca/Na	β=1/3	β=4/3	
Grand View								
5326bcb1	83	143	116	22	1.51	106	91	95
5326bcb2	67	137	110	17	1.28	104	95	--
5335ccc1	71.5	137	110	17	1.70	74	92	--
5323cc	84	143	116	22	1.09	105	101	--
Little Valley								
6414abc	54	157	133	35	2.34	142	107	103
6518ccb	27	148	122	26	2.27	169	130	--
6529dcc	32.5	148	122	26	3.52	161	106	--
755dbc	32	122	93	3	3.82	175	113	--

QTZ = quartz, conductive
CHAL = chalcedony
AMOR = amorphous silica

For the purposes of this discussion, a maximum of 150°-175°C is selected as possibly realistic.

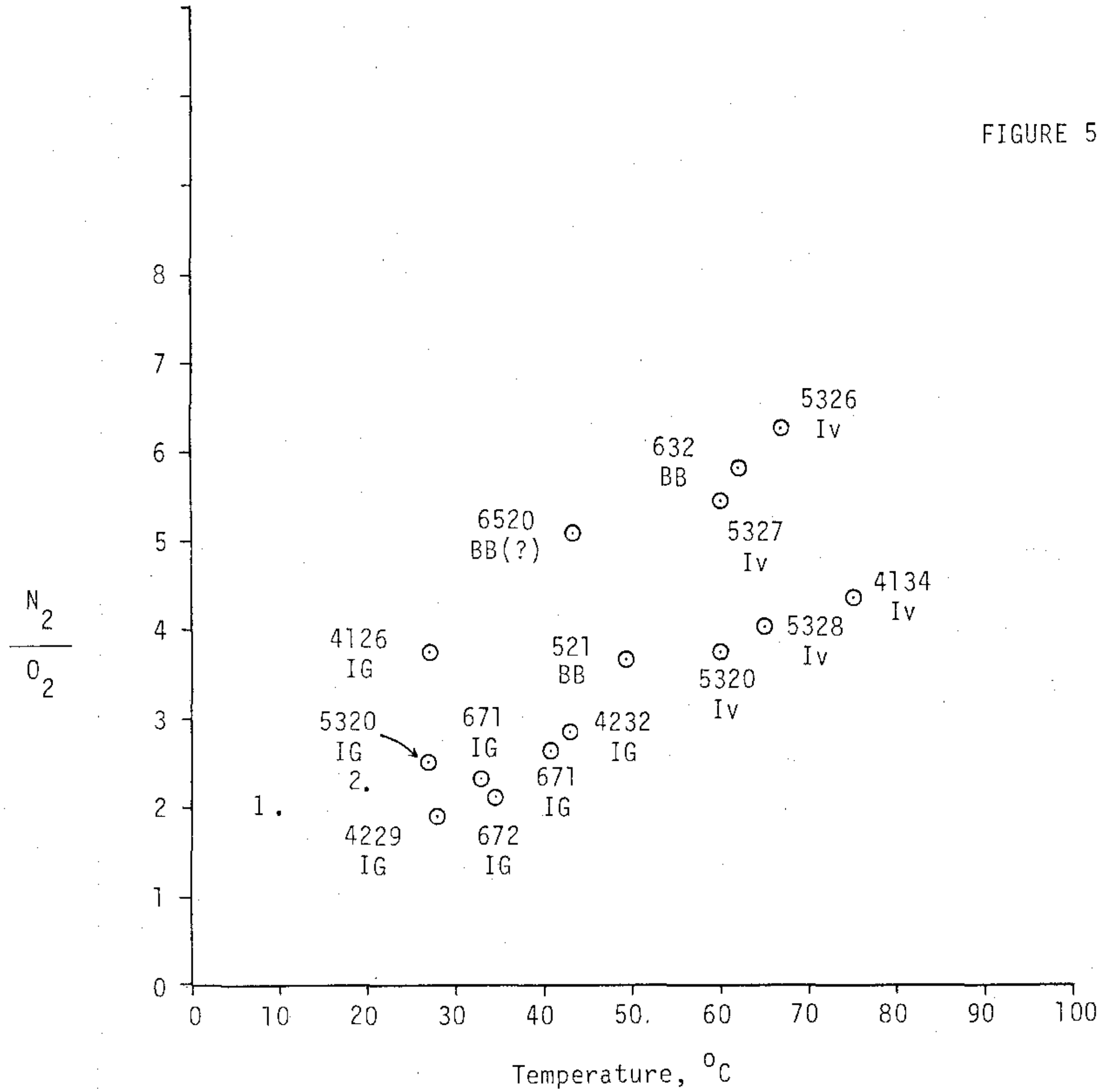
Gases

In their study of the Bruneau-Grand View area, Young and Whitehead (1975) encountered 15 wells which issue gases in addition to water. Samples of these were collected; analyses are reproduced in Appendix 1. The gases are uniformly N_2 and O_2, with 0% to 50% methane (CH_4). No CO_2 or H_2 which would be of thermal origin have been detected. Those wells that produce principally from Idaho Group sediments have 16% to 50% methane, whereas at most 5% issues from wells which produce principally from the underlying volcanic units. The N_2 and O_2 are doubtlessly atmospheric and, based on their solubilities in water at 10°-20°C, probably were present in meteoric recharge at a ratio of about $N_2/O_2 = 2$.

Figure 5 shows N_2/O_2 in the Bruneau-Grand View gases plotted against the surface temperature of each well. There is a strong positive correlation, which can fully be evaluated only using data for the change in solubility of each gas with temperature. These data are not immediately available. To the extent that the correlation is not due to solubility, it may be due to a loss of O_2 in rock-water reactions during increased residence time, or with rising temperature.

These gases were compared with analyses of similar gases from hot springs in Nevada and Oregon sampled by Mariner and others (1975) (figure 6). In Bruneau-Grand View, $N_2 + O_2$ is at least 50% by volume of the total gases present, the rest being methane. In 16 Nevada-Oregon gases $N_2 + O_2$ is also at least 50%, the rest being methane and CO_2. N_2/O_2 in the Nevada-Oregon gases is generally higher than at Bruneau-Grand View, ranging from 3.3 to 98. Only 2 samples fall within the lower range of the Bruneau-Grand View gases. This suggests that the Bruneau-Grand View waters on the average either are less hot at depth or have shorter residence times than the typical Nevada-Oregon thermal waters. However, to qualify this statement it should be noted that the lowest N_2/O_2 of column A, figure 6 is Mickey Spring, Oregon, which is boiling and has chemical temperatures of 170°-200°C.

FIGURE 5. N_2/O_2 versus temperature in gases from the Bruneau-Guard View area wells.**



Sample numbering:

5328 = T. 5 S. - R. 3 E. - Sec. 28

Major aquifer:

IG = Idaho Group sedimentary rocks

BB = Banbury Basalt

Iv = Idavada volcanics

*Volume percent ratio.

[1] N_2/O_2 in pure water at 10°C = 1.96
[2] N_2/O_2 in pure water at 20°C ≃ 2.22

**Data from Young and Whitehead (1975)

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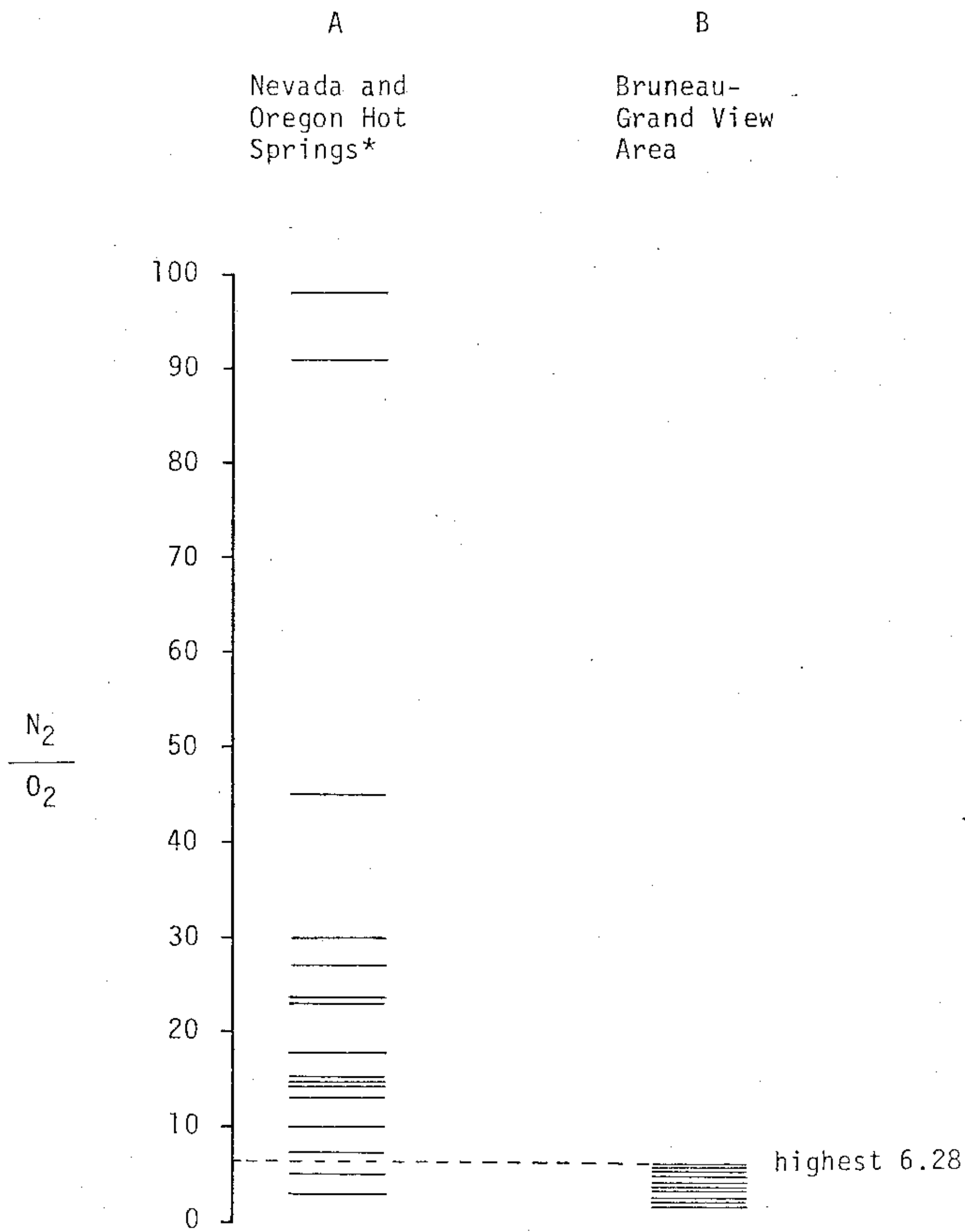
FIGURE 6. Frequency distribution of N_2/O_2 in gases associated with thermal waters of Nevada, Oregon and the Bruneau-Grand View area.



*Data from Mariner and others, 1975, gases with $N_2 + O_2 \geq$ 50% only.

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DISCUSSION

Only in northern Little Valley can temperatures of 150°-170°C be supported by critical analysis of geothermometry, aquifer composition and other factors.

Elsehwere, maximum temperatures of 110°-120°C are suggested by geothermometry, rock-water interactions and mixing considerations. In some parts of the region, temperature at depth may not exceed the maximum found to date in deep wells (84°C at Grand View; 43°C in southern Little Valley). No significant mixing trend is observed in any of these areas.

Despite the lack of samples from the AMAX leasehold, there is no reason to suspect significantly higher temperature at depth than elsewhere. This is based on the regional hydrologic model, which predicts northward flow of recharge water across the leasehold at depth. The sample localities of Bruneau and Little Valley apparently intercept water that in the past has traversed the AMAX leasehold at depth. No evidence of conductive cooling during transit is seen.

Therefore, if additional geochemical surveys are to be considered, only the northern Little Valley area is recommended. Work might include systemmatic resampling of known wells for major cation-anion analysis; sampling for gases; sulfate-water oxygen-isotope analyses; and possibly trace element or other isotope surveys. At such time it would be useful to perform a rapid reconnaissance of the AMAX property in search of sample-collection points.

Although very little evidence was seen of deeper, hotter systems, it remains possible that such systems exist either locally or regionally, isolated and insulated by impermeable overburden. Such systems, if they exist, might be at several thousand feet in depth, not only beneath the Idavada volcanics (which are quite permeable) but beneath the underlying rock unit. As such, temperature gradient data would be of little value in evaluating it, unless gradients were obtained in units beneath the Idavada volcanics. Similarly, the layered sequence of electrically conductive and non-conductive rocks might prove impenetrable to all geoelectrical techniques.

Thus, geochemistry casts a generally negative shadow over the Bruneau-Grand View province, with the possible exception of northern Little Valley. The permissive interpretation of a hotter, deeper system at depth does not lend itself easily to definitive exploration.

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