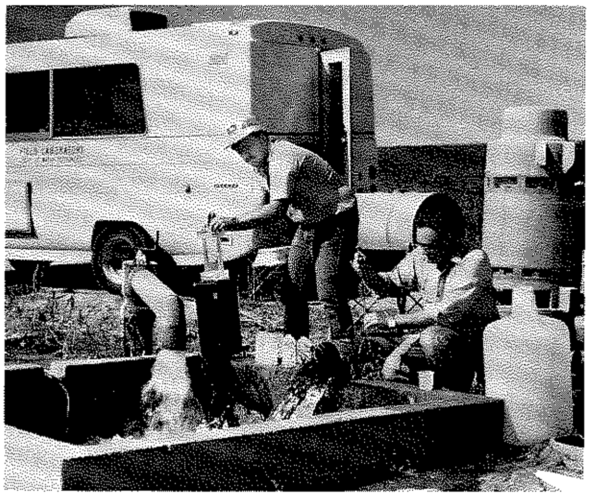
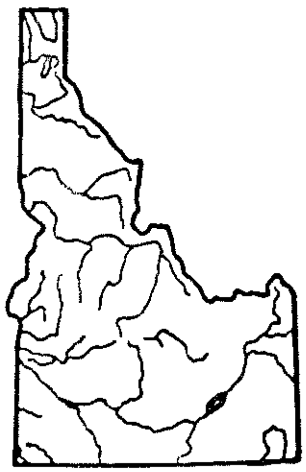
GEOTHERMAL INVESTIGATIONS IN IDAHO

Part 11

GEOLOGICAL, HYDROLOGICAL, GEOCHEMICAL AND GEOPHYSICAL INVESTIGATIONS OF THE NAMPA-CALDWELL AND ADJACENT AREAS, SOUTHWESTERN IDAHO



Well 2N-3W-27bab1, south of Lake Lowell, being sampled for chemical and isotopic constituents. Photo-Alan Mayo



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GEOTHERMAL INVESTIGATIONS IN IDAHO
PART 11

Geological, Hydrological, Geochemical and Geophysical
Investigations of the
Nampa-Caldwell and Adjacent Areas
Southwestern Idaho

John C. Mitchell
EDITOR

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ABSTRACT

The investigations of the Nampa-Caldwell area reported on herein are part of an integrated geological, hydrological, geochemical and geophysical survey being done by the Idaho Department of Water Resources Geothermal Section for the purpose of evaluating the geothermal potential of the area.

Idaho and Snake River Group rocks of Plio-Pleistocene age are exposed in scattered gravel pits and road cuts within the Nampa-Caldwell area. These rocks consist of terrace gravels of the Boise River drainage, basalts of the Snake River Group (Pleistocene) and basalts, sands, silts, and claystones of the Pliocene Glenns Ferry Formation.

The Glenns Ferry Formation is underlain by the lower Idaho Group in the subsurface beneath the western Snake River Plain in the Nampa-Caldwell area. Beneath the Idaho Group is a thick section of basalt and sediments. Silicic volcanic rocks of the Idavada Group are notably absent to a depth of 4.3 km (2.7 mi) in a deep well just east of Nampa. Latites, dacites and vitric and lithic tuffs are penetrated near the bottom of the well that resembles the Miocene and older volcanic rocks described in parts of the Owyhee Mountains to the south of the study area.

Within the graben-like basin known as the western Snake River Plain geophysical studies have revealed complex basin structures. A large basin exists in the Nampa-Caldwell area, and another in the Meridian-Northwest Boise area. These basins are separated by a structural high with an axis that runs from approximately Meridian to Middleton.

Hydrologic studies have identified three geologic units as important cold water aquifers within the middle to upper Glenns Ferry and overlying formations.

Within the middle Glenns Ferry Formation, a "blue clay" unit acts as an aquitard that separates the three upper cold water aquifers from lower aquifers containing warm water ($>$20°C).

From oil and gas well and water well drilling data, six permeable zones which may contain hot water are suspected to exist at depths of approximately 91-213 m (300 to 700 ft), 457 m (1,500 ft), 640 m (2,100 ft), 1037 m (3,400 ft), 1311 m (4,300 ft) and 1677 m (5,500 ft). These depths will vary in different locations because of variability of the subsurface due to basin related geologic complexities.

Temperature logs recorded by oil company logging crews immediately upon completion of many of the oil or gas wells indicate subsurface temperatures of the six suspected permeable zones to be 30°C, 43°C, 49°C, 58°C, 66°C and 75°C. Temperatures from the suspected fifth zone in the Deer Flat No. 1 well were recorded at 107°C and water stood in the well bore within 61 m (200 ft) of the surface. These temperatures are thought to be minimum due to cooling effects of drilling fluids circulated within boreholes during drilling operations.

Thicknesses of these units probably vary but estimates of thicknesses from electrical logs from the above mentioned wells appear to be respectively near 15 m (50 ft), 40 m (131

ft), 31 m (100 ft), 100 m (330 ft), 61 m (200 ft) and 75 m (245 ft). Aquifer characteristics may very so aquifer yield may be a limiting factor in development in certain areas.

Geochemical studies using stable isotopes of hydrogen and oxygen show that thermal water in the Nampa-Caldwell area is depleted by about 20 ‰ in D and by about 2.3 ‰ in ^{18}O relative to cold water and indicates the water may be either rain or snow water that fell more than 11,000 years ago or evaporated river water which has undergone isotopic exchange of oxygen with aquifer minerals.

The isotope data may show the effects of considerable mixing of a thermal parent water with an isotopic composition near a $\delta D = -150$ ‰ and a $\delta^{18}O = -18$ ‰ with colder waters from Lake Lowell and canal systems, Snake River water, Reynolds Creek basin or similar elevations, perhaps the Boise and Payette rivers and applied irrigation water.

The geothermal parent water in the Nampa-Caldwell area appears, from isotope data, to be identical to parent geothermal water in the Bruneau-Grand View and Boise areas of the western Snake River Plain, or to have a similar source(s) and/or age.

Chemical data and mixing models, which correlates well with isotope data, indicate geothermal waters may be migrating upward from deeper permeable zones of about 75°C and 87-95°C temperatures.

A detailed heat-flow contour map of the western Snake River Plain was produced from 65 temperature gradients measured in the region. Thermal conductivities of 247 samples, selected from well cuttings, drill cores and rock outcrops, were determined to calculate heat-flow values. In addition, 60 previously-measured temperature gradients and 85 previously-determined thermal conductivities from surrounding areas and from within the area were used to determine whether internal consistencies or regional correlations in the heat-flow data occur. Measurement locations were relatively evenly dispersed, averaging one per 43 km (17 mi).

The average thermal conductivity for the major rock units were: granite = 6.01 ± 0.50 TCU, sand and clay = 3.49 ± 0.90 TCU, clay = 2.79 ± 0.51 TCU, silicic volcanics = 4.54 ± 0.24 TCU, basalt = 3.62 ± 0.85 TCU. The average temperature gradient for the area was 78°C/km (4.29°F/100 ft) and the average heat-flow value was 2.55 HFU.

The Boise front zone shows a close correlation between high near-surface gradients and structure. The fault zones produce permeable conduits to the convecting groundwater. The isogeothermal distribution is similar to that of theoretical models of the Basin and Range type. The heat is refracted away from the sediments with low thermal conductivities in the graben structure towards the horst structure (Idaho batholith), which exhibits high thermal conductivities. Theoretical models of convecting water along fault zones reflect isogeothermal patterns shown in the Boise front zone.

The oil well survey in the Nampa-Caldwell area was selected to show that high temperatures can exist near the surface where there are no visible structures and in areas of low heat flow. This area's low heat flow is caused by infiltration of irrigation water which "washes out" shallow (60-90 m, 200-300 ft.) temperature gradient measurements. The well was artesian, but the position of a hot water aquifer was suggested to be at 540 m (1,771 ft.) in certain areas.

CHAPTER 1 - INTRODUCTION

By
John C. Mitchell[1]
and
John E. Anderson[1]

PURPOSE AND SCOPE

For several years residents of the Nampa-Caldwell area have reported encountering warm to hot waters in shallow wells drilled for domestic and/or irrigation purposes. Based on these reports and regional evaluations of the geothermal potential of southern Idaho, the Department of Water Resources recognized the need for further evaluation of the Nampa-Caldwell area as a possible geothermal resource, particularly its potential for space heating purposes, since the area lies in close proximity to moderate-sized urban communities.

The area under study included approximately 925 sq km (357 sq mi) of the Nampa-Caldwell portion of Canyon County, an area within the central portion of the western Snake River Plain immediately west of Boise, Idaho. See figure 1-1 for location. Geologic mapping, hydrologic, geochemical, geophysical, including detailed gravity and areomagnetic surveys, were run to acquire badly needed data. In addition, existing magnetotelluric and reflection seismic data were purchased and reinterpreted in light of newly acquired data.

The geologic, hydrologic, geochemical and geophysical studies reported here were initiated primarily to assist in properly locating areas most likely to contain hot water. It was anticipated that these surveys would supplement each other and other studies and provide needed subsurface geologic information essential to the determination of geologic conditions controlling the occurrence of reported hot waters. The type and location of major faulting in the area, the general structural and/or stratigraphic configuration of the area, and pertinent information concerning the nature and extent of the geothermal resources are thus topics of major concern to be addressed based on results of the surveys conducted.

Specifically, geologic mapping was undertaken to better address structural geology as existing maps were deemed inadequate to acquire information on possible faults observed on the Landsat imagery and in the subsurface geologic and hydrologic data.

Shallow subsurface geologic and hydrologic data were obtained from existing water well logs to determine the number and extent of shallow aquifers and shallow subsurface structural configuration. Enhanced Landsat false color infrared imagery was also studied to detect evidence of major structural features which could control thermal water in the area and provide possible migration paths for recharge to thermal and nonthermal water.

A reconnaissance geochemical survey was conducted in order to obtain more information on water quality, aquifer temperatures and possible recharge sources and age of thermal and nonthermal water.

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[1] Idaho Department of Water Resources.

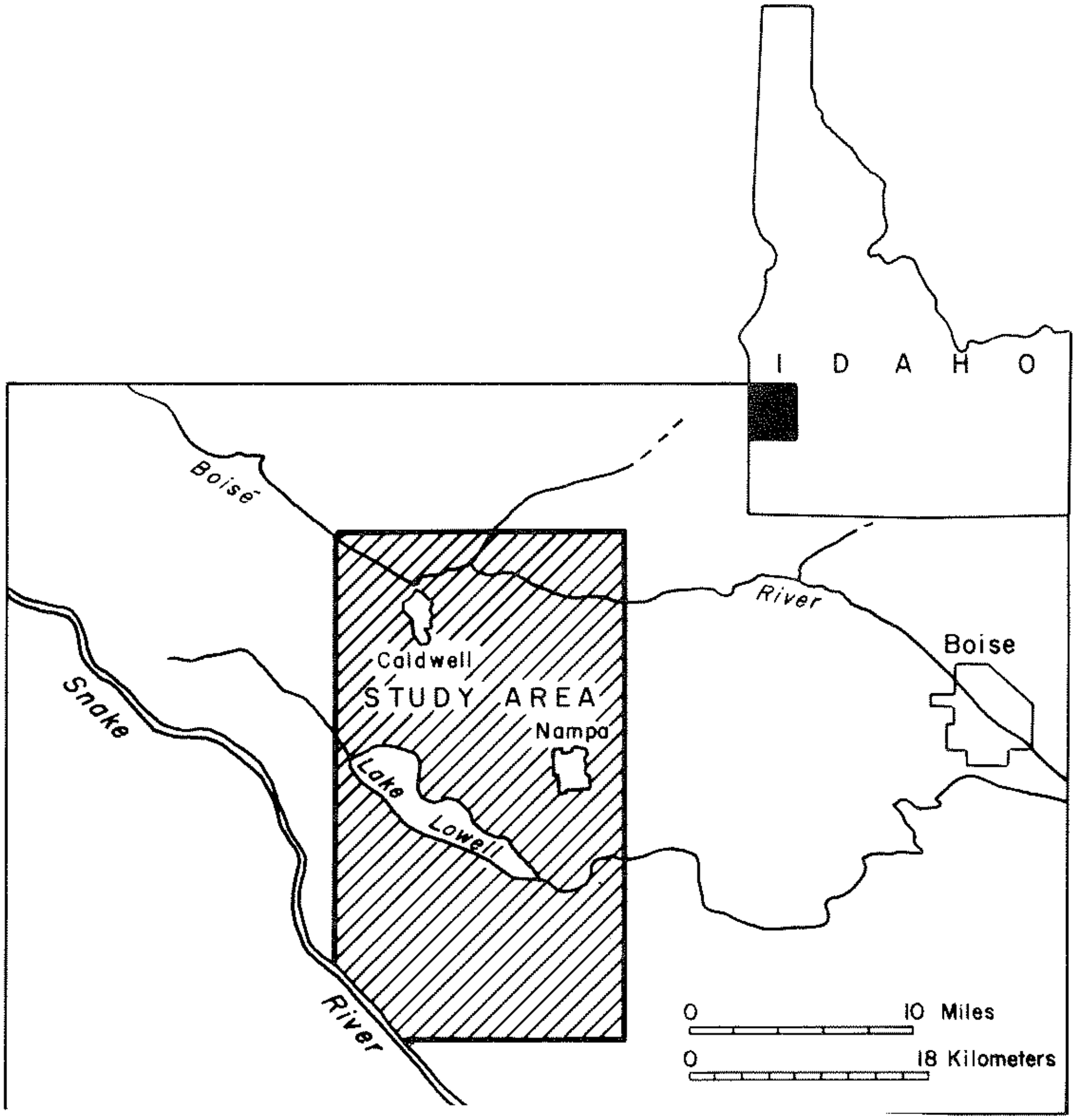


FIGURE 1-1. Index map showing principal area investigated for this report. Modified from Olsen (1980).

Temperature gradients and heat flow data were obtained from existing unused drill holes. These surveys were conducted to better understand the thermal regime of the area, to assist in determining drilling depths, and to establish constraints within which regional interpretations of geological, geochemical, hydrological and geophysical data must fit.

Seismic data previously obtained for oil and gas exploration were purchased to obtain information on structural and stratigraphic relations and configurations in the subsurface to best determine how drilling for geothermal resources might be conducted in the least costly manner. Particular emphasis in data interpretation was placed on subsurface faulting as to type, location and depth, on the theory that thermal water generally migrates upward along faults and spreads laterally into permeable zones. Intersecting a fault, or a permeable zone near a fault, by drilling, might produce hotter water at shallower depths than if the drill target were a deep permeable zone removed some distance from faults.

Magnetotelluric data was purchased to augment interpretation of the seismic data and to determine lateral continuity and depth of low-electrical conductive zones that could represent thermal water bearing zones.

Detailed gravity and areomagnetic surveys were run for the express purpose of obtaining information on shallow subsurface structure, subsurface distribution of volcanic features and to augment interpretations made by seismic and magnetotelluric geophysical methods in the immediate Nampa-Caldwell area.

During the course of these investigations certain aspects of geology were thought to occur in both the Nampa-Caldwell and Boise areas. Therefore, selected investigations were carried by Anderson (1981) and S. H. Wood into the Boise area. These led to the siting and successful drilling of the 656 m (2,152 ft.) deep Idaho Capitol Mall #1 geothermal exploration well which produced 3000 l/min (800 gpm) pumped 1135 l/min (300 gpm) flow of 67°C water. Some aspects of these studies in the Boise area are included in this report. Other aspects of the study are only definable by looking at their regional character and were investigated from that point of view. Therefore, the report contains information not only on the Nampa-Caldwell area but other areas of the Western Snake River Plain as well.

The basic data (except seismic and magnetotelluric) generated as a result of these studies are available upon request from Idaho Department of Water Resources, 450 W. State Street, upon payment of reproduction charges.

PREVIOUS WORK

A number of significant earlier studies of regional geology, structural geology, stratigraphy, paleontology, geochemistry, and regional gravity and magnetics have been done and are cited below.

Russell (1903) published a preliminary report on the artesian basins in southwestern Idaho and southeastern Oregon. The first significant geologic study of the Nampa-Caldwell area was done by Lindgren and Drake (1904). It includes a geologic map and descriptions of lithologic units. Kirkham (1931a) published a revision of the Payette and Idaho Formations in which he treated the geology of the Nampa-Caldwell area. That same year Kirkham also published a paper on the Snake River downwarp and a paper on the igneous rocks of southwestern Idaho (Kirkham, 1931b, 1931c). A groundwater hydrology study, which included a geologic and hydrologic description of the Nampa-Caldwell area, was published by Nace et al. (1957). In 1958, Savage published a comprehensive study of the geology and mineral resources of Ada and Canyon counties in which all of the significant geologic literature to that date is summarized. Malde and Powers (1962) published a study of upper Cenozoic stratigraphy which included the study area. Newton and Corcoran (1963) published a study of the petroleum geology of the western Snake River Plain which includes stratigraphic information from wells within or near the study area which aid in stratigraphic correlation and interpretation of subsurface geologic structures. The U.S. Geological Survey has an open file report on a regional aeromagnetic map of southwestern Idaho which includes the Nampa-Caldwell area (USGS, 1971). Mabey, et al. (1974) compiled a preliminary gravity map of southern Idaho and Mabey (1976) published an interpretation of this map, including two-dimensional interpretive models. The Idaho Department of Water Resources (1979) has published a report on the potential for direct heat application of geothermal resources of Idaho, which includes information on Canyon County. In addition to the published materials mentioned above, several deep oil and gas exploration wells have been drilled in or near the study area, logs of which are available from the Idaho Department of Lands. Several reflection seismic lines have been run in the Nampa-Caldwell area by private companies, the results of which have not been released to date. Other less directly related studies of interest are: Armstrong and others (1975), Birkeland and others (1971), Ekren and others (1978), Kittleman and others (1965), Evernden and others (1964), Hill and others (1961), Hill, (1963, 1972), Hill and Pakiser (1965), Malde (1965b), Malde and others (1963), Brott and others (1978), Priest and othèrs (1972), and Warner (1975, 1977).

WELL-AND-SPRING NUMBERING SYSTEM

The numbering system used by the Idaho Department of Water Resources and the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and Meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. Quarter sections are lettered a, b, c and d in counterclockwise order from the northeast quarter of each section (figure 1-2). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 2N-03W-27bab1 is in the NW1/4 NE1/4 NW1/4 of Section 27, T.2 N., R.3 W., and was the first well inventoried in that tract. In this report for surface water sample locations (from rivers, canals, streams, lakes, reservoirs, etc.) and wells logged for temperature gradients, the numeral in the designation is omitted. Where oil or gas wells are referred to, the customary designation of the industry is used.

USE OF METRIC UNITS

The metric or International System (SI) of units is used in this report to present water chemistry data. Concentrations of chemical substances dissolved in the water are given in milligrams per liter (mg/l) rather than in parts per million (ppm) as in some previous Water Information Bulletins. Numerical values for chemical concentrations are essentially equal whether reported in mg/l or ppm for the range of values reported in this report. Water temperatures are given in degrees Celsius (°C). Conversion of °C to °F (degrees Fahrenheit) is based on the equation, $°F = 1.8°C + 32$. Figure 1-3 shows the relation between degrees Celsius and degrees Fahrenheit.

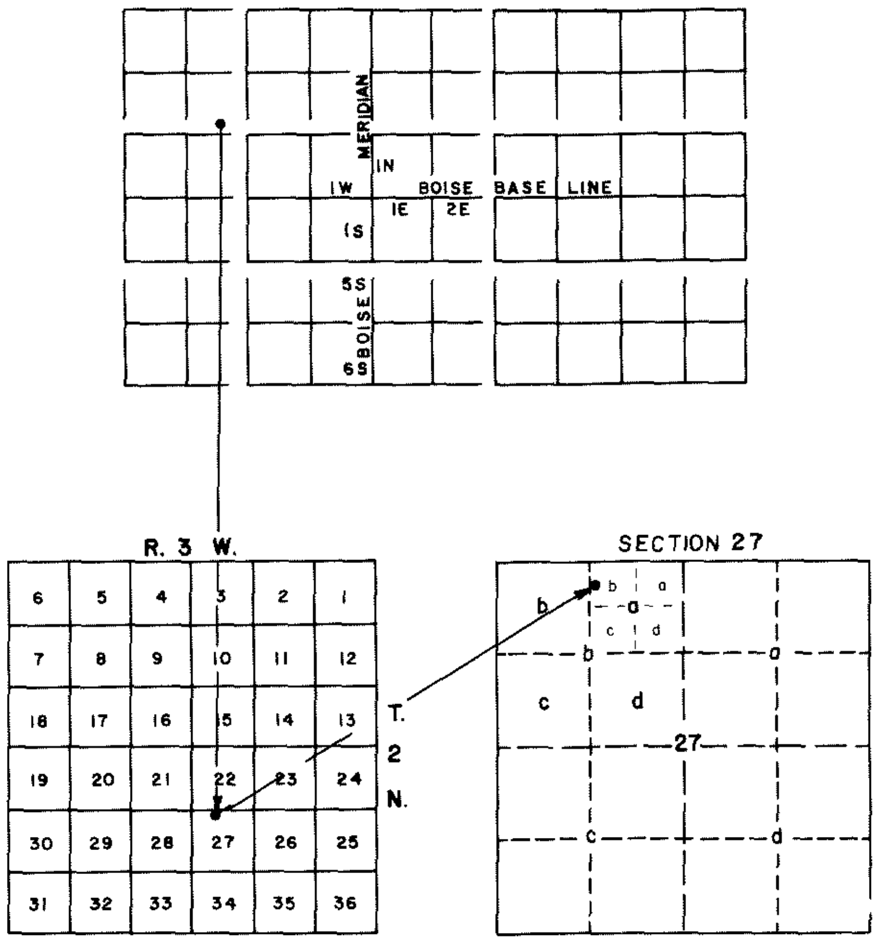


FIGURE 1-2. Diagram showing the well- and spring numbering system.

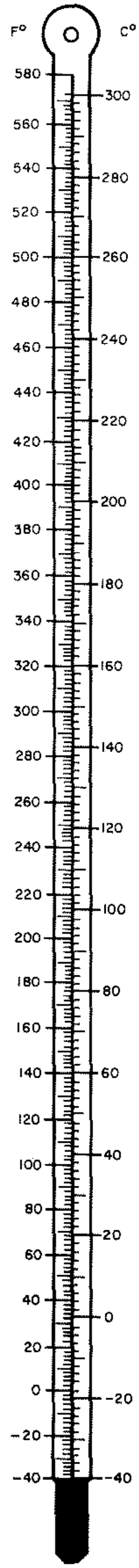


FIGURE 1-3. Temperature conversion graph.

Linear measurements (inches, feet, yards and miles) are given in their corresponding metric and English units (millimeters, meters and kilometers). Weight and volume measurements are also given in their corresponding metric and English units. Table 1-1 gives conversion factors for these units. Area measurements are listed in both SI and English units except when referring to areas described by official rectangular subdivision of public lands. Standard abbreviations of all units listed in Table 1-1 are also given immediately to the right (in parentheses) of the units.

TABLE 1-1
Conversion Factors

To Convert from	To	Multiply by
	DISTANCE	
inches (in)	centimeters (cm)	2.540
feet (ft)	meters (m)	0.305
yards (yd)	meters (m)	0.914
miles (mi)	kilometers (km)	1.609
centimeters (cm)	inches (in)	0.394
meters (m)	feet (ft)	3.281
meters (m)	yards (yd)	1.094
kilometers (km)	miles (mi)	0.621
	AREA	
square miles (sq mi)	square kilometers (sq km)	2.589
sq kilometers (sq km)	square miles (sq mi)	0.386
	VOLUME — MASS	
gallons (gal)	liters (l)	3.785
ounces (oz)	grams (gm)	28.349
liters (l)	gallons (gal)	0.264
grams (gm)	ounces (oz)	0.035
	ENERGY	
British thermal units (BTU)	calories (cal)	1.996
British thermal units (BTU)	joules (j)	1054.35
calories (cal)	British thermal units (BTU)	0.004
calories (cal)	joules (j)	4.186
joules (j)	British thermal units (BTU)	0.0009
joules (j)	calories (cal)	0.239
	GRADIENTS	
degrees Fahrenheit/100 ft (°F/100 ft)	degrees Celcius/kilometers (°C/km)	1.822
degrees Celcius/kilometer (°C/km)	degrees Fahrenheit/100 ft (°F/100 ft)	0.055
	THERMAL CONDUCTIVITY	
$\frac{\text{millicalories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(mcal)}}{\text{(cm/sec °C)}}$	$\frac{\text{calories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(cal)}}{\text{(cm/sec °C)}}$	0.001
$\frac{\text{calories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(ucal)}}{\text{(cm/sec °C)}}$	$\frac{\text{millicalories}}{\text{centimeter/second °Celcius}}$ $\frac{\text{(mcal)}}{\text{(cm/sec °C)}}$	1000
	HEAT FLOW	
$\frac{\text{microcalories}}{\text{centimeter}^2\text{ second}}$ $\frac{\text{(ucal)}}{(\text{cm}^2\text{ sec})}$	milliwatts/meter² (mwatt/m²)	41.871
milliwatts/meter² (mwatt/m²)	$\frac{\text{microcalories}}{\text{centimeter}^2\text{ second}}$ $\frac{\text{(m)}}{(\text{cm}^2\text{ sec})}$	.024

CHAPTER 2 - GEOLOGY

By
Spencer H. Wood[1]
and
John E. Anderson[2]

INTRODUCTION

The cities of Nampa and Caldwell lie within the western Snake River Plain. The plain is a northwest-trending physiographic lowland and contains the incised valleys of two major rivers flowing to the northwest. The Snake River rises at the far eastern end of the plain and flows nearly 700 km (435 mi) across the arcuate plain until it turns north and descends through Hells Canyon and into the Columbia. The Boise River heads in the granitic mountains north of the plain and then flows northwestward until it joins the Snake.

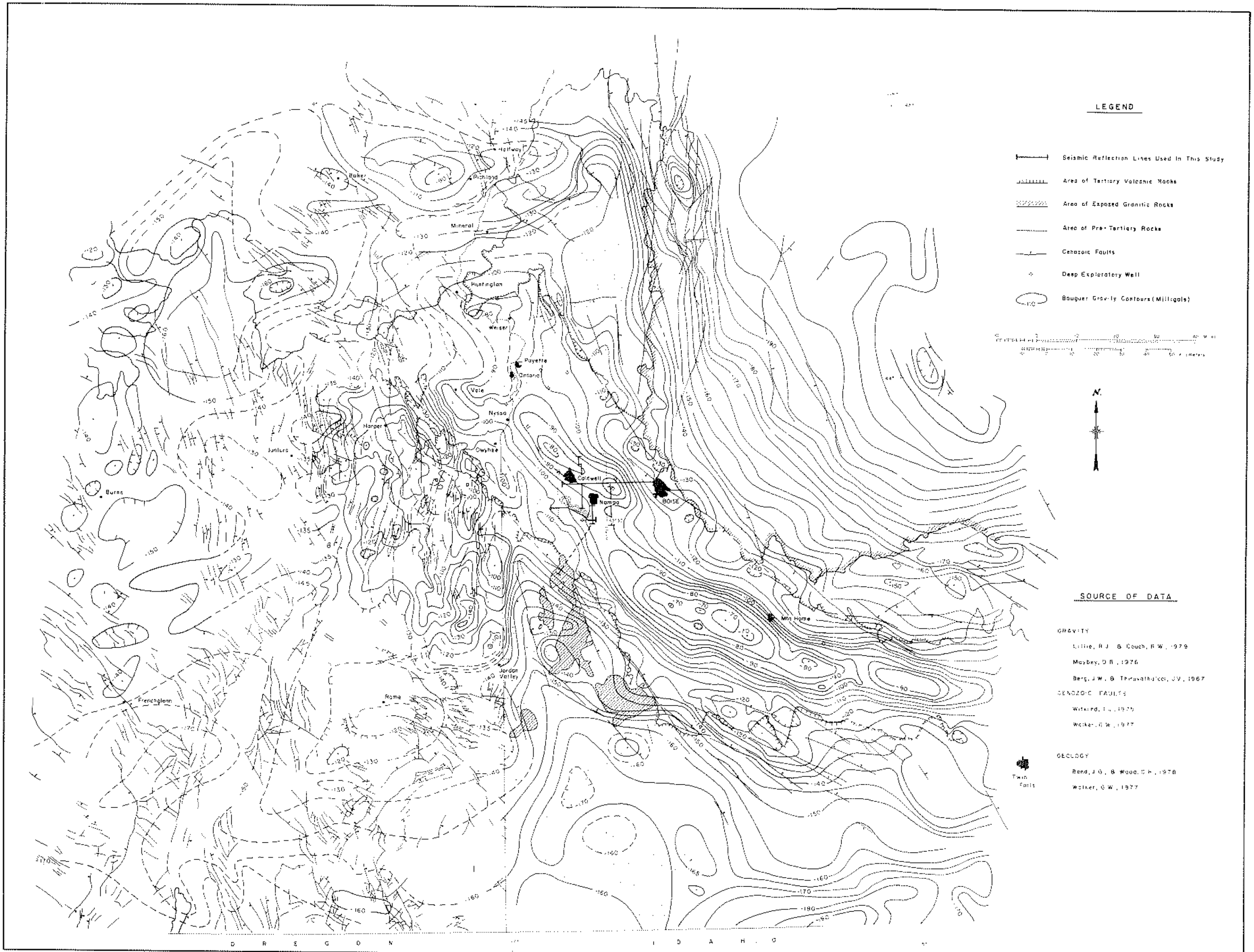
The plain is also a great structural basin formed by downwarping and faulting in late Cenozoic time (Figure 2-1). The amount of late Cenozoic vertical movement in the western plain is impressive. The basin-fill sediments and volcanic flows have been drilled to a depth of 4.3 km (2.7 mi), and Mabey (1976) has suggested the total basin fill may be 7 km (4.4 mi) or more.

A variety of ideas and models have recently been advanced since Armstrong and others (1975) published the K-Ar geochronology of silicic volcanics of the plain. Their study shows that the inception of silicic volcanism becomes progressively younger eastward across the plain; and that basalt volcanism persists for a long time after the inception of silicic volcanism. Brott and others (1978) show evidence for increasing values of heat flow eastward across the plain and emphasizes the significance of the increase in elevation eastward across the plain. These features of the plain are modelled by an eastward propagating thermal event which passed through the western plain 8 to 16 million years ago and is currently manifested as dormant volcanism and as the hydrothermal systems of the Yellowstone area.

The model of an eastward propagating thermal event coincident with the eastward development of the plain is reasonably consistent with available data. A similar, but diametrically opposite, pattern of silicic volcanism is recognized as having propagated westward across eastern Oregon also from the area of the western plain (MacLeod and others, 1975), but this system was not accompanied by the formation of a deep structural basin.

The present western Snake River Plain has the appearance of a northwest-trending graben 50 km (31 mi) wide. The western plain differs from the plain to the east in that the upper 700 to 1700 m (435 to 1056 ft) of basin fill is mostly sediment, whereas in the eastern plain the upper section is mostly Quaternary basalt. Although basalt volcanism has been active during the Quaternary of the western plain, it is not nearly so voluminous as in areas to the east.

[1] Department of Geology and Physics, Boise State University.
[2] Idaho Department of Water Resources.



S.H. Wood

FIGURE 2-1. Map showing generalized geology, major faults, and Bouguer gravity contours in southwestern and west-central Idaho and eastern Oregon.

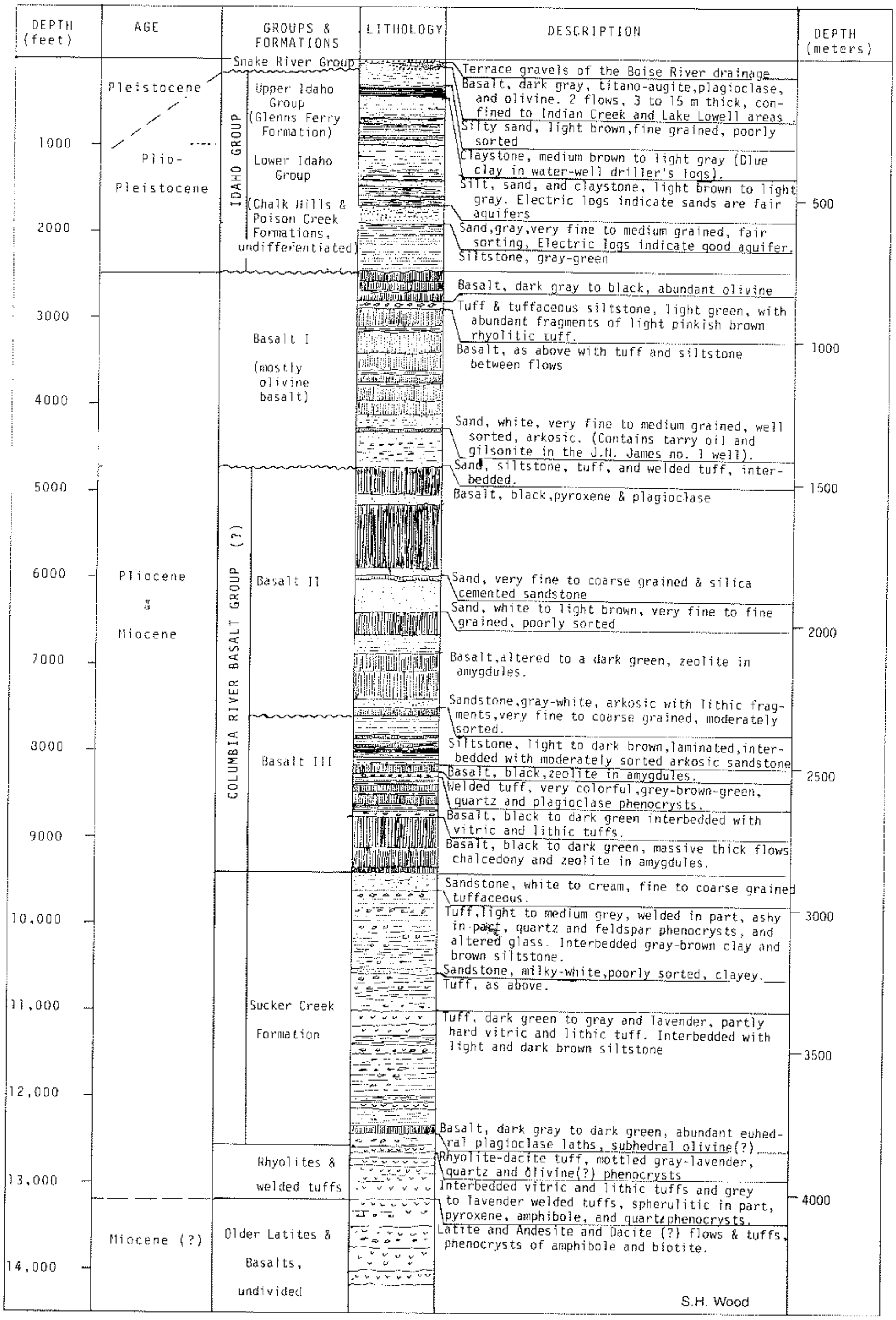
The main basis for this geological report of the Nampa-Caldwell area is a study of available well logs from deep wells in the area (fig. 2-2, and 2-3) and seismic reflection profiles (figure 2-4 and 2-5). Field mapping at a 1:24,000 scale was completed for all of the Nampa, Middleton, Caldwell and Lake Lowell quadrangles and a part of the Melba, Walters Butte and Given's Hot Springs quadrangles (figure 2-6, shown at 1:62,500 scale in pocket). Little geologic mapping had previously been done in the relatively featureless and flat part of the plain. Previous work by Lindgren and Drake (1904) and Savage (1958) did not recognize the extensive faulting of the Quaternary Gravels. Mapping utilized the limited exposures in sand and gravel pits, road cuts and river banks. Mapping of the Snake River Group basalts in the area relied heavily upon well logs filed by water-well drillers. The recent soil survey of Canyon County (Priest and others, 1972), and various terraces and topographic surfaces were also helpful in identifying the surficial deposits. In order to understand the subsurface stratigraphy a limited amount of detailed mapping was done of exposed strata on the margins of the plain.

The following section of this report discusses the stratigraphy of subsurface rocks and of the exposed surficial units. Exposures are quite limited, but localities are discussed in sufficient detail to allow examination of type sections of the mapping units. The structural geology of the Nampa-Caldwell area is discussed more fully in the geophysics chapter.

GENERAL STATEMENT

The thickness of Cenozoic volcanic and sedimentary fill in the western Snake River Plain is at least 4.3 km (2.7 mi) as demonstrated by the section penetrated by the exploratory well drilled near Meridian, Idaho (J.N. James No. 1). Basement rock was not penetrated. Because granitic rocks of the Idaho Batholith and associated metamorphic rocks occur in the mountains north and south of the plain (Taubeneck, 1971; Ekren and others, 1978a, and figure 2-1, it is commonly supposed that these rocks comprise basement beneath the plain. Although Challis volcanics have not been encountered in deep wells, it is possible that Challis volcanics and associated sediments lie deep in the subsurface, beneath the plain. Numerous, northeast-striking, porphyry dikes of intermediate to silicic composition invade the granitic rocks along the north margin of the plain. These porphyries have been dated at 40 to 42 $\pm$ 10 million years by the Lead-alpha method in the Lowman area (Jaffe and others, 1959 quoted in Armstrong, 1974) and may have been feeder dikes to Challis volcanism. The Challis volcanic sequence is at least 1,200 m (3900 ft) thick in the central Idaho Mountains and may be as thick as 3,200 m (10,500 ft) (Cater, et al., 1973). Challis-aged volcanics are also mapped in the eastern Owyhee Mountains by Ekren and others (1981) where they may be greater than 300 m (985 ft) thick.

In this report, the subsurface stratigraphy (figure 2-2) expected in the Nampa-Caldwell area is based upon the lithologic and geophysical logs of the 4.3 km deep Meridian well (J. N. James No. 1) and a limited amount of information from the Champlain Oil Company (Deer Flat No. 1) well recently drilled and abandoned south of Nampa. Interpretation of seismic reflection profiles discussed in Chapter 6 provides considerable stratigraphic information and shows that the section in the J. N. James No. 1 well may not be entirely representative of the western Snake River plain because it is drilled on a structural high with at least 700 m (2100 ft) of relief (figure 2-4). Some rock units similar to those encountered in the well are described from exposures at a number of localities on the margins of the plain by Malde and Powers (1962), Kittleman and others (1965), and Ekren and others (1981). Correlation of subsurface units to exposed sections can be made for some distinctive lithologic



The generalized stratigraphy of Cenozoic rocks beneath the Nampa-Caldwell-Meridian, Idaho, area is based upon the lithologic log of the M.T. Halbouty - Chevron, U.S.A. exploratory well near Meridian (Sec. 27, T4N, R1W), "J.N. James #1." Rock descriptions are from the cuttings log compiled by Hiner (1976): it is not known if any of the volcanic rock descriptions on the log were verified by petrographic examination. Surficial rock and sediment of the Snake River Group in the uppermost 50 m (166 ft) are shown for completeness, but the Snake River Basalts do not occur at the well. Basalts within the Idaho Group do not occur at this well and are not shown, but they are encountered in the Champlain Oil Co., Deer Flat #1, 22 km (6.7 mi) to the southwest. Stratigraphic units are defined by Malde and others (1963), and Ekren and others (1978a). Stratigraphic units reported in the operator's records of this well do not exactly agree with the interpretation here. Correlation of units in this well to exposed rocks on the margin of the plain are discussed in the text.

FIGURE 2-2. Generalized stratigraphy of Cenozoic rocks from J.N. James No. 1 well near Meridian, Idaho.

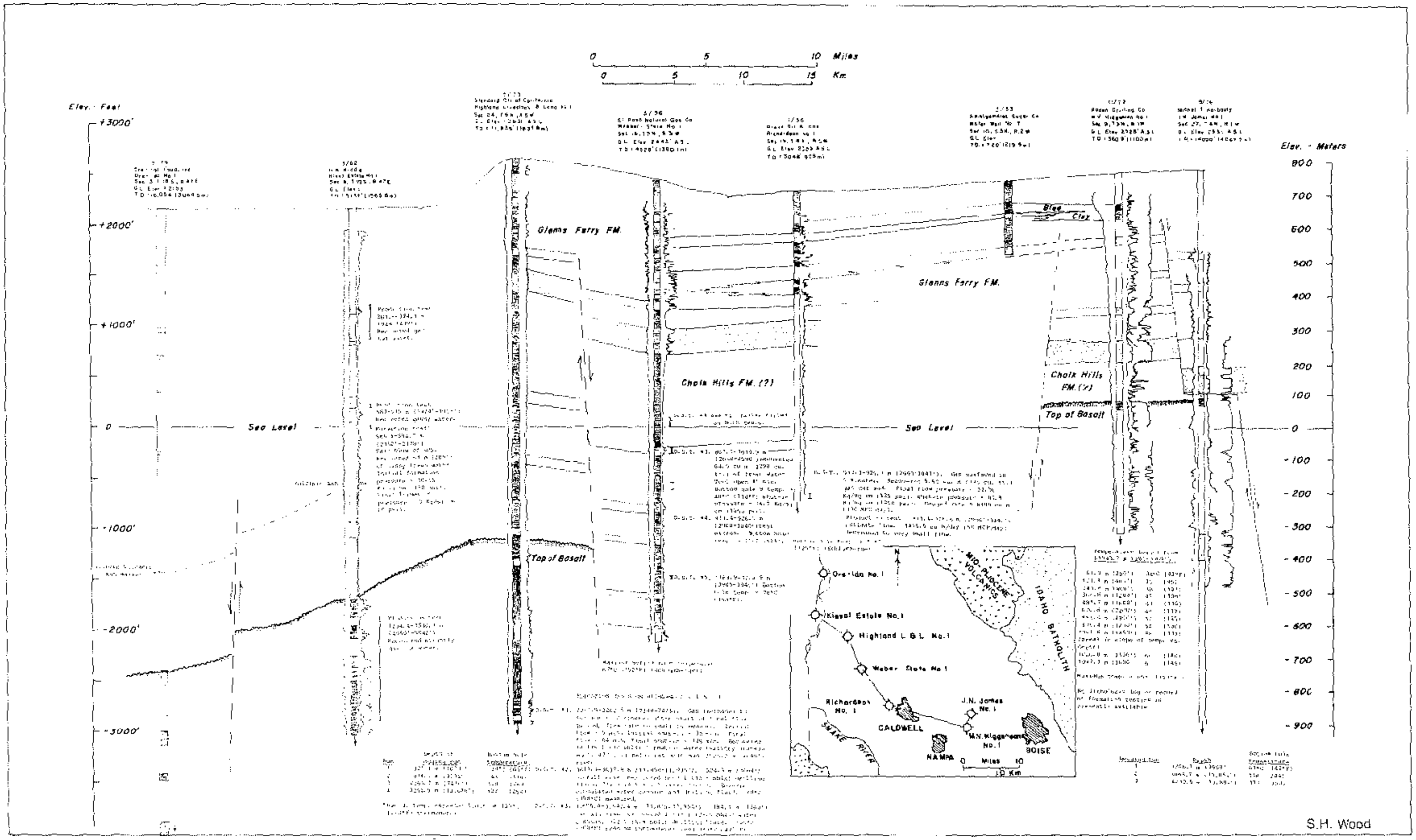
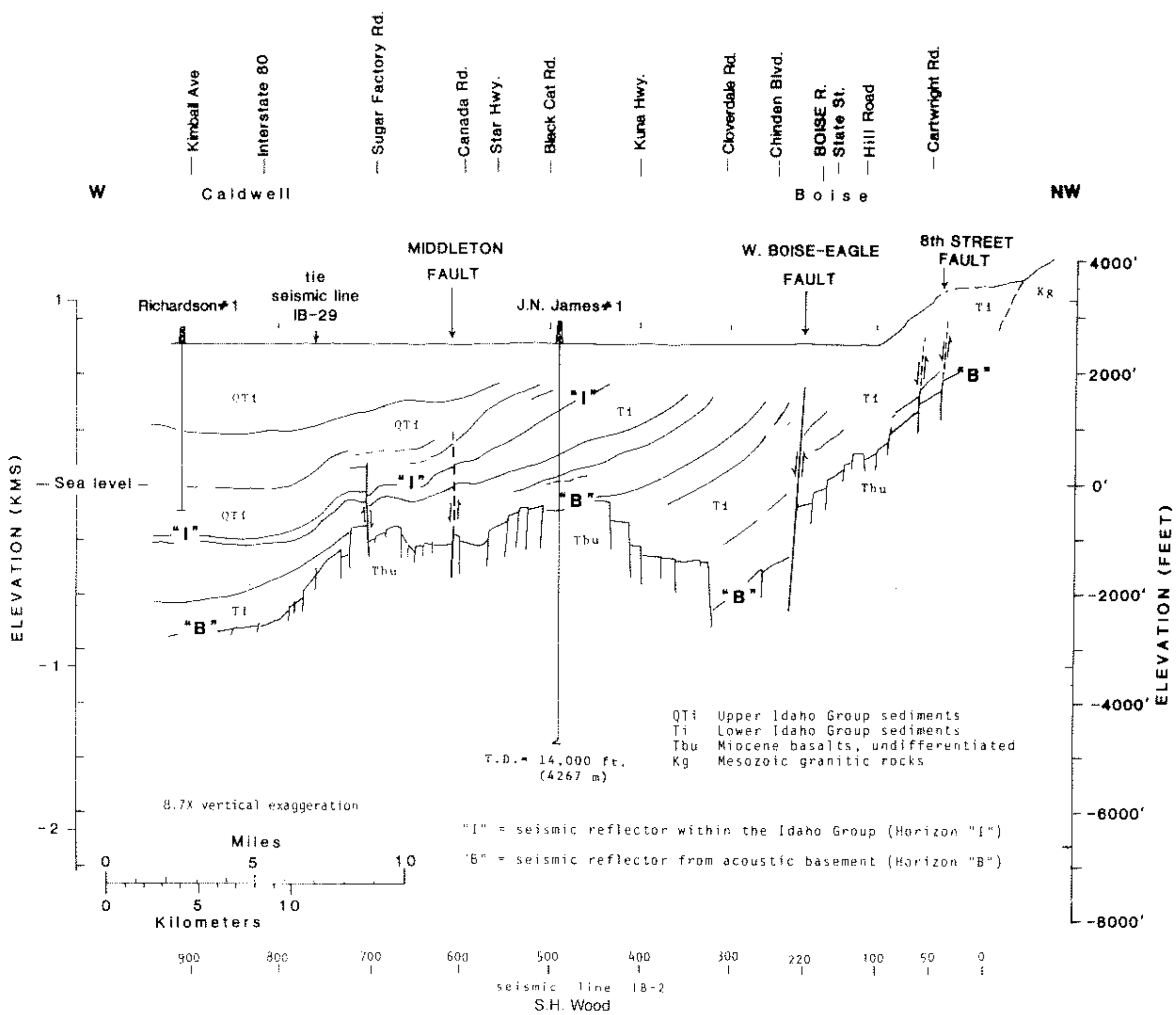
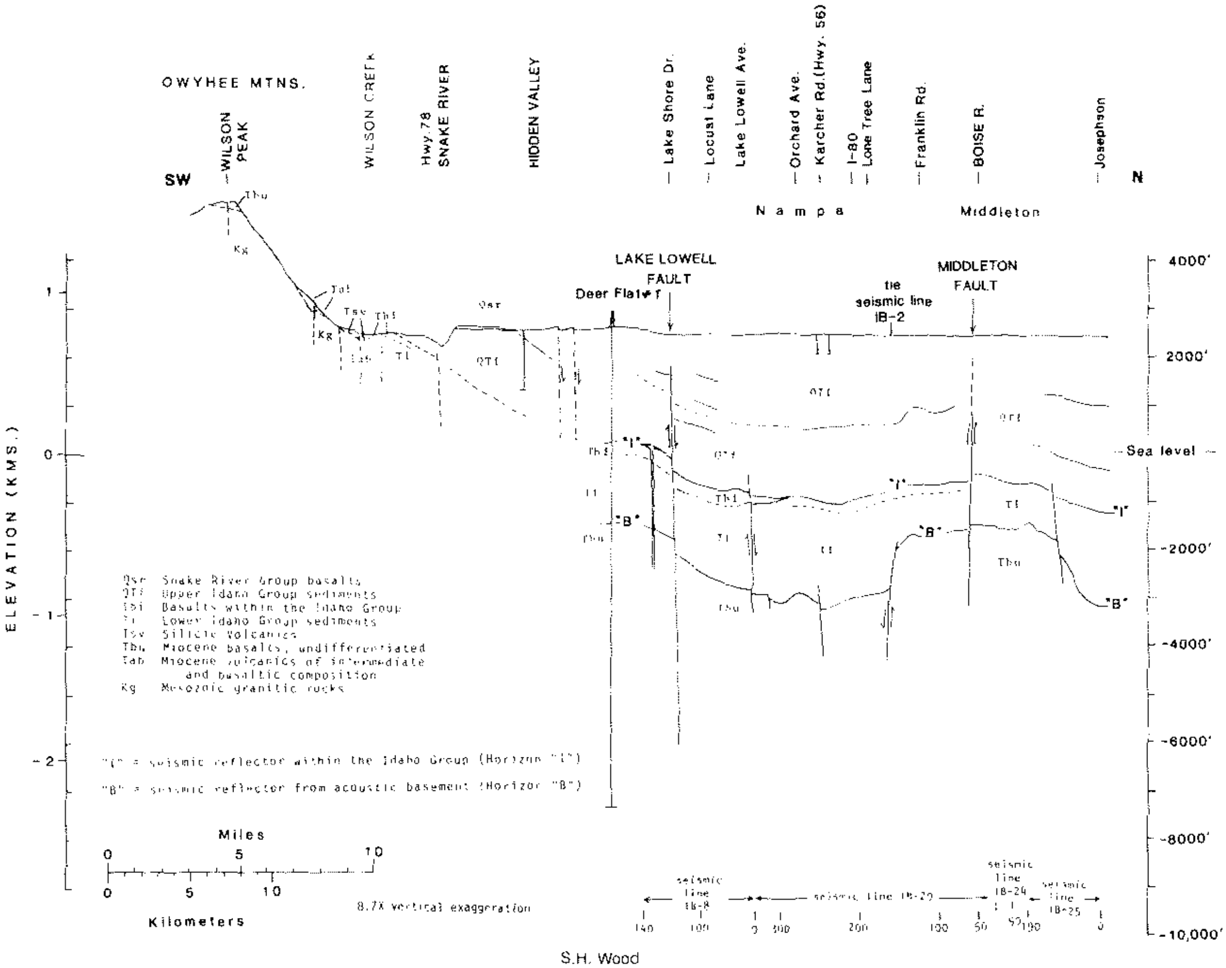


FIGURE 2-3. Stratigraphic cross section of late Cenozoic deposits, western Snake River Plain, Idaho, with electric log correlations, temperature and formation testing data



Structural cross-section prepared from seismic reflection profile IB-2. Line starts in the Boise foothills and runs down Stuart Gulch, v.p. 1-110, and then northwest along Hill Road, v.p. 110-135, along Castle Road, v.p. 135-180, across the Boise River at the Strawberry Glen Bridge, and then westward along Elm Lane to Caldwell, v.p. 260-1025. Location of section is shown on figure 2-1. The generalized stratigraphy of Cenozoic rocks beneath the Nampa-Caldwell-Meridian, Idaho, area is based upon the lithologic log of the M.T. Halbouty - Chevron, U.S.A. exploratory well near Meridian (Sec. 27, T4N, R1W), "J.N. James #1." Rock descriptions are from the cuttings log compiled by Hiner (1976): it is not known if any of the volcanic rock descriptions on the log were verified by petrographic examination. Surficial rock and sediment of the Snake River Group in the uppermost 50m (166 ft) are shown for completeness, but the Snake River Basalts do not occur at the well. Basalts within the Idaho Group do not occur at this well and are not shown, but they are encountered in the Champlain Oil Co., Deer Flat #1, 11 km (6.7 mi) to the southwest. Stratigraphic units are defined by Malde and others (1963), and Ekren and others (1978a). Stratigraphic units reported in the operator's records of this well do not exactly agree with the interpretation here. Correlation of units in this well to exposed rocks on the margin of the plain are discussed in the text.

FIGURE 2-4. East-west geologic cross-section along seismic reflection line IB-2.



Structural cross-section prepared from seismic reflection profiles IB-25, IB-24, IB-29, and IB-8. Seismic line begins 5.5 mi north of Middleton and continues south along Cemetery Road to Middleton, IB-25, v.p. 1-190, and then west 1.6 km (1 mi) along Highway 44, IB-24, v.p. 75-25, and then south on Middleton Road to the edge of Lake Lowell, line IB 29, v.p. 25-134, and from the south city limits of Nampa south along Highway 45, line IB8 - v.p. 1-140. Continuation of section south to the Owyhee Mountains is based upon preliminary results from the Champlain Oil Deer Flat No. 1 well, unpublished geologic mapping by S.H. Wood, and from Ekren, McIntrye, and Bennett (1978). Location of section is shown on Figure 2-1.

FIGURE 2-5. North-south geologic cross-section along seismic-reflection lines IB-25, IB-29, and IB-8.

units, but a number of units such as the Banbury Basalts, Columbia River Group(?), the Sucker Creek Formation and Owyhee Basalts do not have obvious correlative units exposed on the margin. No detailed stratigraphic work or geologic mapping has been published for the northeast margin of the plain. It is futile to attempt correlations to units that were only loosely defined in mapping by Lindgren (1898), Lindgren and Drake (1904), and Savage (1958 and 1961). Type sections and good stratigraphic descriptions have never been published for the Payette Formation, the Columbia River Basalts and the Idaho Group in this area. Many of the late Cenozoic fluvial, lacustrine and volcanic units are very similar in appearance and correlations have been made on the basis of similar lithology rather than detailed geologic mapping. Correlation is further complicated by numerous facies changes within sedimentary units such as described by Malde and Powers (1962), Malde (1972) and Kimmel (1979) in the Glenns Ferry Formation in the region east of this study area.

The lithologic log from the J.N. James No. 1 well (figure 2-2), the correlation cross section of wells in the western plain (figure 2-3) and cross sections prepared from seismic reflection profiles (figures 2-4 and 2-5) show the stratigraphy as it is presently understood in the Nampa-Caldwell area. Knowledge of rocks older than the massive basalt flows that constitute acoustic basement of seismic reflections is entirely from the J.N. James No. 1 well, and from discussions of exposed stratigraphy by Malde and Powers (1962), Newton and Corcoran (1963), Ekren and others (1978a), Armstrong and others (1976) and Armstrong and others (1980).

This discussion of subsurface stratigraphy should be prefaced by a statement that matching subsurface rock units in the center of the plain to published stratigraphic sequences of exposed rocks on the margins of the plain could not be made, in most cases, with available data. The greatest difficulty in matching the stratigraphy advanced by Armstrong and others (1980) is the lack of a clearly identifiable Idavada Group of silicic volcanics at intermediate depth in the well logs of the J. N. James No. 1 well drilled near Meridian, Idaho. Exposures and deep wells on both the north and south margins of the Snake River Plain strongly suggest that the Idavada Group of silicic volcanics should be at least 330 m (1,000 ft) thick beneath the Plain (Arney and others, 1980; Wood and Vincent, 1980; McIntyre, 1979; Ekren and others, 1978a; Malde and Powers, 1962). A section of basaltic volcanics is encountered from 720 m to 2,895 m (2,360 to 9,500 ft) in the J.N. James well; however, only one 20 m (70 ft) thick unit of rhyolitic tuff is reported in that section (Hiner, 1976). The well bottoms in a thick unit of silicic and intermediate volcanics extending from 3,840 m (12,600 ft) to total depth of 4,267 m (14,000 ft), but these seem too deep to be correlative with the Idavada Group. Acoustic basement is a thick massive basalt section overlain by a number of thinner basalt flows interbedded with sediment. No geochemical data or detailed petrographic studies upon which to subdivide the subsurface basalts are available. Lack of an obvious Idavada Group within the subsurface volcanic section makes it impossible at this time to correlate the section under the Plain with the stratigraphic section of Armstrong and others (1980). For instance, it is important to know if the uppermost basalts in the J.N.James No. 1 well are correlative with the Pliocene Banbury Group defined by Malde and Powers (1962) or if they are the Miocene basalts coequal with the Miocene-to-Pliocene aged Columbia River Group. These two groups of basalt should be separated by the Idavada Group. These questions will not be answered until the subsurface samples are given the same detailed geochemical and petrographic examination as the better studied surface exposures.

STRATIGRAPHY

Older Volcanics of Intermediate Composition

The J.N. James No. 1 well bottomed at 4,267 m (14,000 ft) in 240 m (800 ft) of volcanics variously described as latite, dacite(?), andesite, vitric and lithic tuffs, and minor basalt. Some of the felsic rock bears phenocrysts of amphibole and biotite. This section resembles the Miocene or older rocks described by Ekren and others (1981) in parts of the Owyhee Mountains. Volcanic rocks of intermediate composition are in the Reynolds and Salmon Creek drainages. Dikes bearing amphibole and biotite phenocrysts occur in the War Eagle Mountain area (Pansze, 1973). These rocks could also be Challis-aged volcanics mapped on the south side of the plain by Ekren and others (1981) and on the north side by Malde and others (1963).

Older Rhyolites and Welded Tuffs

The 195 m (640 ft) section from 3,828 m (12,560 ft) to 4,023 m (13,200 ft) contains a group of rhyolitic rocks described as gray-to-lavender welded tuffs that contain spherulites. Other rocks of the group are lithic and vitric tuffs. According to Hiner (1976) some of the rocks bear phenocrysts of pyroxene, amphibole and quartz. Because this unit is overlain by sediments that are considered the Sucker Creek Formation by Warner (1977), these rhyolites in the well are probably related to the Miocene "gold bearing rhyolites" of Malde and Powers (1962). A number of rhyolites underlying the Sucker Creek Formation are mapped in the Owyhee Mountains by Ekren and others (1981). In particular, the Silver City Rhyolites of Bennett and Galbraith, (1975) locally exceed 200 m in thicknesses. K-Ar dating on the Silver City Rhyolites yielded ages of 15.6 to 15.7 + 0.4 million years (Pansze, 1973).

Sucker Creek Formation

A unit of 815 m (2,760 ft) of monotonous brown claystone and siltstone with interbedded welded and non-welded ashy tuffs, and one basalt flow near the base of the unit is encountered from 2,865 m (9,400 ft) to 3,828 m (12,560 ft). Descriptions of the cuttings and the overall character of the unit, and the stratigraphic position are very similar to the type section of the Sucker Creek Formation of Kittleman and others (1965), and Ekren and others (1978a) along the Oregon-Idaho border.

Along the northern margin of the western Snake River Plain, much of the area mapped as Payette Formation by Lindgren (1898, p. 632), Kirkham (1931a or b), and Savage (1958 and 1961) may contain strata correlative with the Sucker Creek Formation; however, mapping and stratigraphic correlations necessary to establish continuity or contemporaniety of the formations has not been attempted to date. Kirkham (1931a or b) defined the Payette Formation as the silty and clayey sediments that interfinger with basalts of the Columbia River Group in the vicinity of Horseshoe Bend and Weiser. McIntyre (1976) found that much of the sediment in the Weiser area identified as Payette Formation by Kirkham (1931a, or b) was, in fact, overlying the main volcanic sequence in this region. A basaltic andesite dike cutting the Weiser area sediments yields a whole rock K-Ar age of 10 $\pm$ 0.6 million years indicating a late Miocene or older age for the sediments (McIntyre, 1976).

Age of the Sucker Creek Formation is late Miocene based upon Barstovian mammalian fossils collected near the type locality and middle Miocene based on flora of Mascall age (Kittleman, et al., 1965, p. 7). A basalt within the Sucker Creek Formation yielded a potassium-argon age of 16.7 million years (Evernden and James, 1964, p. 971). The above age assignments from the Owyhee Canyon area are consistent with four potassium-argon ages on the overlying Owyhee Basalts (Bryan, 1929) obtained by Watkins and Baksi (1974, p. 173) that ranged from 13.1 to 13.6 million years.

Basalt Section in the J.N. James No. 1 Well

Well logs indicate a 2,100 m (7,000 ft) thick section of basalt with lesser amounts of interbedded arkosic and tuffaceous sediments overlie the Sucker Creek Formation. This basalt section is entirely penetrated by J.N. James No. 1 well. Basalt is first encountered at a depth of 728 m (2,390 ft) and the basalt dominated section extends to a depth of 2,865 m (9,400 ft). Deep wells west of the study area, Highland Land and Livestock No. 1 (T.D. = 3,638 m [11,935 ft]) and Ore-Ida No. 1 (T.D. = 3,064 m [10,054 ft]) encounter a greater proportion of fine-grained sediment, much less basalt, and generally thinner basalt units (figure 2-2). Thick flows within the upper 100 to 150 m (300 to 500 ft) of this basaltic section act as the acoustic basement for seismic reflection profiling over most of the western plain.

The following breakdown of the 2,100 m (7,000 ft) section of basalt and sediments is based entirely upon the lithologic log description of Hiner (1976) and geophysical logs of the J.N. James No. 1 well where basalt is first encountered at 728 m (2,390 ft) depth.

BASALT UNIT I — The lowermost unit of interbedded sediment and basalt extends from 2,322 m (7,620 ft) to 2,865 m (9,400 ft), a thickness of 542 m (1,780 ft). The lower 189m (620 ft) is made up of at least two thick basalt flows, described as black to dark green with zeolite and calcite amygdules. These thick flows rest upon Sucker Creek Formation sediments. The upper part of this unit is mostly brown siltstone with minor arkosic sandstone interbedded with thin basalt flows. Chevron geologists considered this unit to be a part of the Sucker Creek Formation (unpublished records on file with the Idaho State Petroleum Engineer, see Hiner, 1976).

BASALT UNIT II — A 884 m (2,900 ft) thick unit of basalt, extends from 1,438 m (4,720 ft) to 2,322 m (7,620 ft). This unit consists of about 60 percent thick flows of pyroxene-plagioclase phyric basalt and about 40 percent moderately-to-poorly-sorted, fine to coarse grained, arkosic sandstone. Absence of visible olivine in the flows is inferred because it is not mentioned in the well log (Hiner, 1976). Identification of such phenocrysts in basalt on field lithologic logs must be regarded with caution for it is unlikely that the drill cuttings were viewed in thin section with a petrographic microscope.

BASALT UNIT III — The uppermost basalt unit from 728 m (2,390 ft) to 1,438 m (4,720 ft) is composed of 520 m (1,700 ft) of dark grey to black, olivine basalt with minor interbeds of arkosic white sand, welded and non-welded tuff, and siltstone and claystone. The lithologic log describes cuttings of a light-pinkish-brown rhyolite tuff from the upper part of this unit. Such a distinctive rock may serve as a marker in other wells. It is also possible that this tuff is the lone representative of the Idavada Group in this area. The lower part of the unit contains 61 m (200 ft) of well sorted sand indicating the possibility of sand aquifers within the basalt. This sand also contains a tarry-black hydrocarbon-like material (Hiner, 1976). Thick flows within this unit constitute the regional acoustic basement mapped as a reflection horizon in figure 2-7 and discussed in Chapter 6.

Basalts in Adjacent Areas

The basalt stratigraphy in this region of Idaho is complex. No correlative subsurface marker beds have thus far been established. Age of the basalts are not known, although it is likely that much of this basalt section is Miocene to early Pliocene in age, and is related to the basalts of the Columbia River Group. Recent studies of the Columbia River Group summarized in Swanson and others (1979) indicate that the Lower-to-Middle-Miocene Imnaha and the widespread Grande Rhonde Basalt Formations extend into the Weiser embayment of the Columbia River Basalt Plateau. These basalt units are down faulted to the west (Newcomb, 1970), and dip to the west and southwest beneath sediments of the lower Idaho Group. They presumably underlie a part of the western Snake River Plain. Feeder dikes of these two oldest formations of the Columbia River Group comprise the majority of dikes of the north-northwest striking Chief Joseph dike swarm of northeastern Oregon and western Idaho (Taubeneck, 1970 and Swanson and others, 1979). Most flows of the Imnaha basalt are coarse grained and plagioclase phyric. Zeolite amygdules and smectite alteration are common and widespread. Imnaha basalt flows are known only in the southeastern part of the Columbia Plateau, on both sides of the Blue Mountain-Seven Devils uplift. Maximum thickness of the Imnaha basalt is reported to be about 500 m (1600 ft) in Hells Canyon (Vallier and Hooper, 1976; and Hooper, 1981).

The Grande Ronde Basalt is now recognized as the most widespread formation of the Columbia River Group and exceeds 500 to 700 m (1640 to 2300 ft) thick on the north flank of the Blue Mountains (Swanson and Wright, 1981). Basalt flows of the Grande Ronde Formation are overwhelmingly aphyric to very sparsely phyric fine-grained tholeiitic basalts (Swanson and others, 1979). Most flows in the Grande Ronde contain rare plagioclase microphenocrysts and plagioclase-clinopyroxene clots visible in hand specimens. Olivine is generally absent as phenocrysts but is commonly present in the ground mass of all but the least magnesium flows.

K-Ar ages on the Grande Ronde Basalt range from 14 to 15.5 million years. The underlying Imnaha Basalt has not been extensively dated. Chemical and petrographic variations within these formations are discussed in Wright and others (1973 and 1979). Magneto-stratigraphy of the group is summarized in Swanson and others (1979).

Geochronology and magneto-stratigraphy of the Basalts of the Owyhee Ridge in eastern most Oregon (Bryan, 1929, and Kittleman and others, 1965) are discussed by Watkins and Baksi (1974). No detectable age difference was found across the 16 flows in this area. Four K-Ar age determinations ranged from 13.1 to 13.9 million years. These ages indicate the Owyhee Basalts are a younger group of flows than the recognized Columbia River Group in the area immediately north of the Snake River Plain. The Owyhee Basalts are described as fine grained with rare phenocrysts of plagioclase in a ground mass of olivine, pyroxene and feldspar, Watkins and Baksi (1974).

Previous workers have applied local formation names of basalts to distant localities without consideration of the basalt petrography, geochemistry, or careful geologic mapping. Formation names such as the Grassy Mountain Formation (Bryan 1929, Kittleman and others, 1965), the Banbury Basalt (Stearns and others, 1938, Malde and Powers, 1962, Armstrong and others, 1975 and 1980, and Ekren and others, 1978a) have led to considerable confusion when applied regionally in the western Snake River Plain. These two formations may have correlatives within the lower Idaho Group, but neither of them are expected in the

J.N. James well section. The seismic reflection profiles across the well site show a regional, complexly-faulted; acoustic basement overlain by Idaho Group sediments with a marked unconformity (figures 2-4 and 2-5). The basalts on the structural high can be considered to be older than other basalts that are interbedded and conformable with the sedimentary section of the Idaho Group that laps upon the structural high.

Idavada Volcanic Group

To be consistent with the stratigraphic system of Malde and Powers (1962), Ekren and others (1981), and Armstrong and others (1980), the Idavada Group of silicic volcanics is discussed here. However, no obvious silicic or intermediate volcanics of the Idavada Group are noted in the upper two subunits of the basalt section with the exception of the light pinkish brown fragments of a felsic tuff in the J.N. James No. 1 well encountered between 853 and 884m (2,800 and 2,900 ft). Likewise, the only silicic volcanics noted in the lithologic log of the Highland Land and Livestock No. 1 well are described as greenish gray and light brown hard felsites between 2,659 and 2,774 m (8,720 and 9,100 ft), and black obsidian(?) at 1,650 m (5,415 ft) depth. The remainder of the volcanic units in the Highland Land and Livestock No. 1 well are described as basalt. In the Ore-Idaho Foods No. 1 well, no hard felsic rocks are described, but hard tuffs are noted in the intervals 1,692-1,700 m (5,550-5,580 ft), 2,560-2,585 m (8,400-8,480 ft) and at 2,972 to 2,978 m (9,750-9,770 ft). None of the above rock units bear a resemblance to the Idavada Group described in the north side of the Plain by Malde and Powers (1962) and Malde and others (1963). Nor do any of the above seem thick enough to be correlatives with the various rhyolites and welded tuffs mapped in the Owyhee Mountains by Ekren and others (1981).

The Idavada silicic volcanics are described by Malde and Powers (1962) as being mostly silicic latite, bearing phenocrysts of andesine, clinopyroxene, hypersthene and magnetite. They are distinguished from the older "gold-bearing" silicic rocks by their lack of hornblende or biotite. The Idavada sequence is made up of both intermediate-to-silicic ash flow and lava-flow units, that commonly have prophyritic black vitric layers and thinly flow-banded lavender and gray felsite layers. Ekren and others (1978b) have suggested that some of the widespread silicic rocks were initially emplaced as very hot ash flow sheets that remelted and remobilized as lava flows. Ekren and others (1981) also indicate that some of the silicic volcanics in the Owyhee Mountains of this group may have originated from vents in the present area of the Snake River Plain.

Ages for the Idavada Volcanic Group are published by Armstrong and others (1980). Thirteen potassium-argon dates range from 14.2 and 13.5 million years for the member units of the formation near Poison Creek to 9.6 million years for the stratigraphically youngest units.

The Idaho Group

The sedimentary deposits and local basaltic vents and lava flows that unconformably overlie the rhyolite rocks (Idavada Group) on the margins of the plain are considered by Malde and Powers (1962) to be the Idaho Group. Seven overlapping formations are discussed in their redefinition of the group. The Idaho Group in the western Snake River Plain is locally overlain by a relatively thin group of fresh, unaltered basalt flows and associated fluviatile and to a lesser extent lacustrine deposits. This latter group, containing numerous unaltered, olivine basalt lavas, is called the Snake River Group.

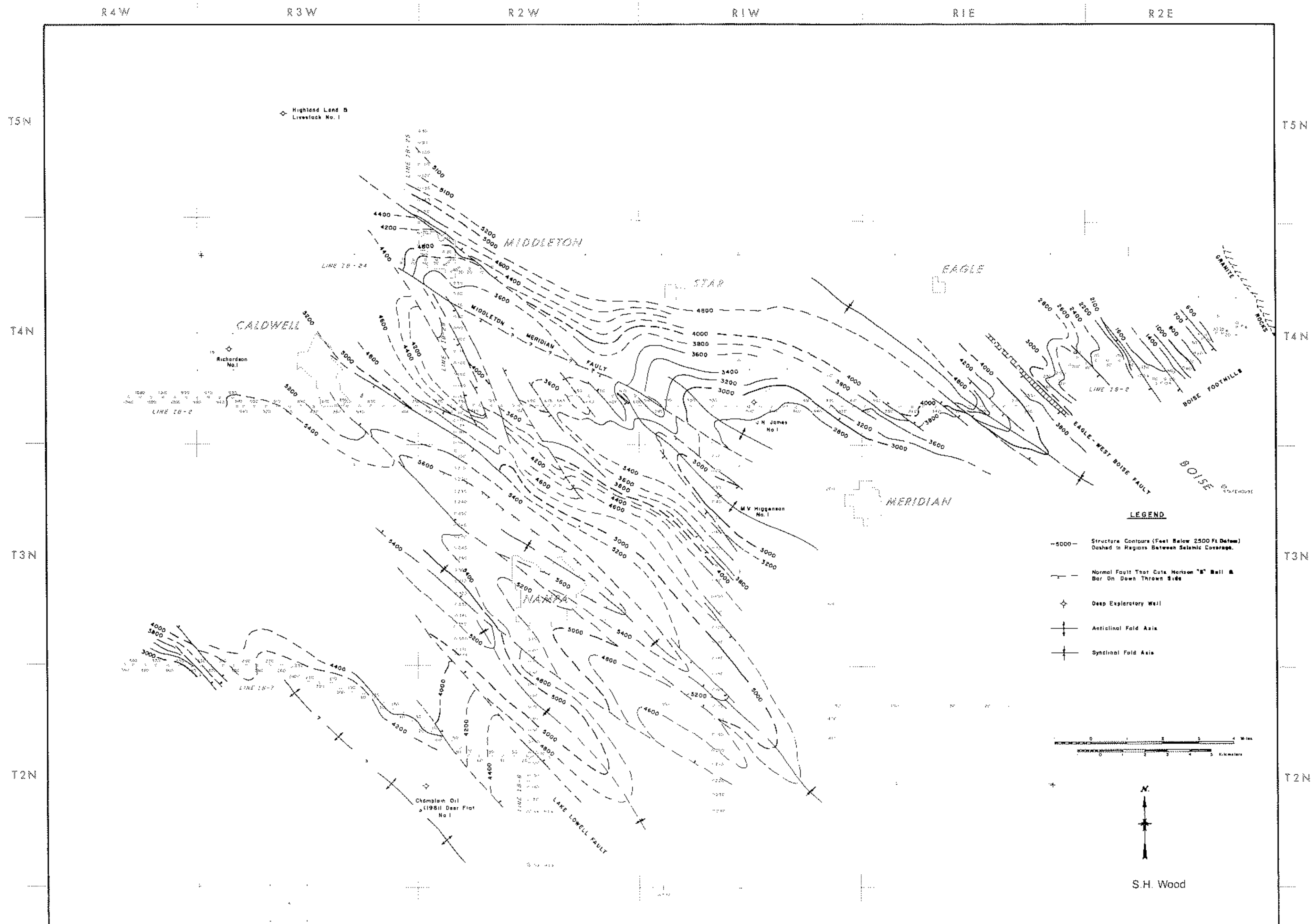


FIGURE 2-7. Structural contour map on acoustic basement (Horizon "B").

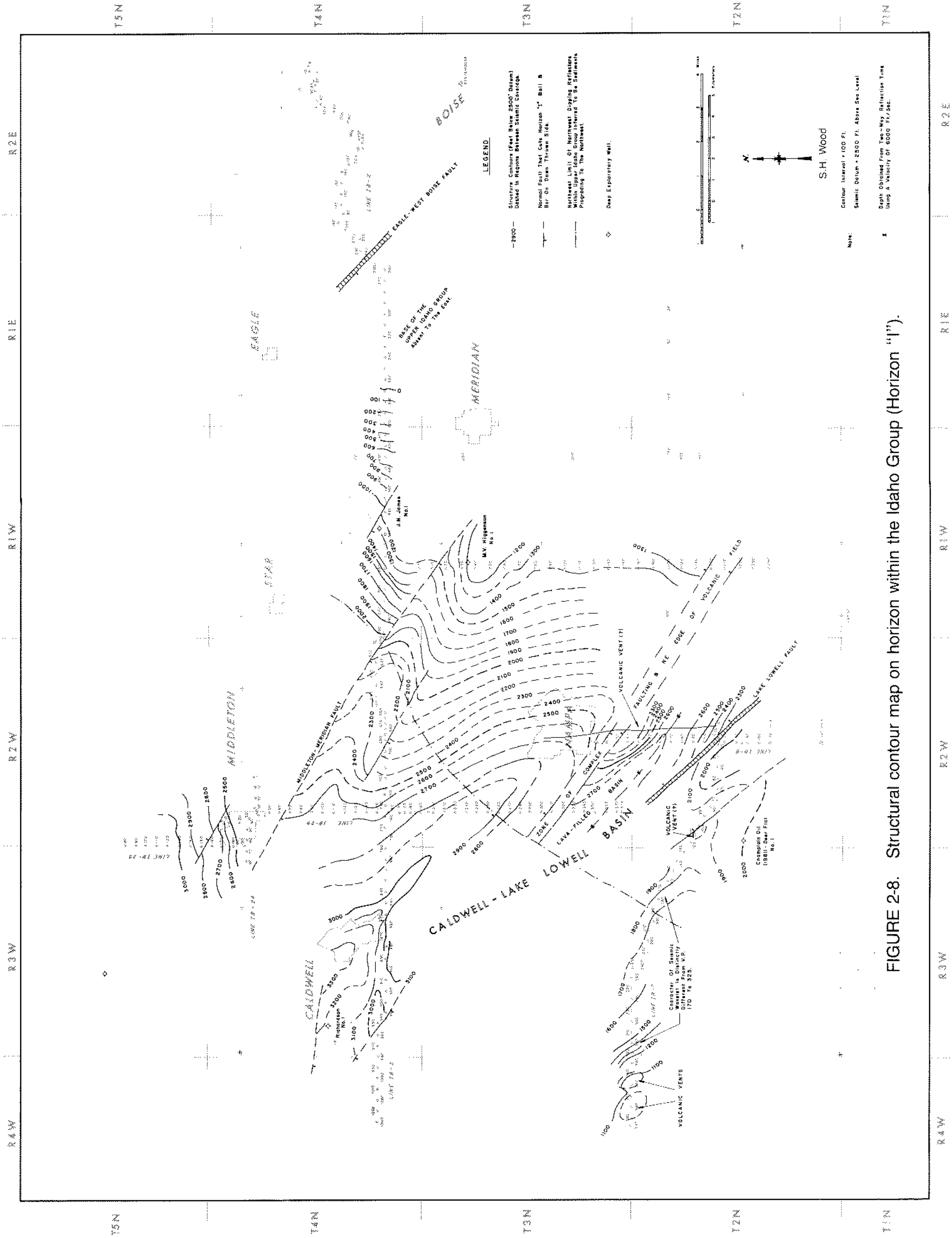


FIGURE 2-8. Structural contour map on horizon within the Idaho Group (Horizon "I").

The stratigraphic relationships within the Idaho Group beneath the western plain are complex; however, geophysical well logs (figure 2-3) and seismic reflection profiles, discussed in this study, produce a generally consistent group of subsurface units beneath the Nampa-Caldwell area. All those deposits lying between the seismically-defined "acoustic basement" and the Snake River Group are considered to be the Idaho Group in this report. Seismic reflection data shows that a maximum of 1710 m (5,600 ft) of Idaho Group sediment underlies the western part of the study area (figure 2-7). A similiar thickness is penetrated by the Ore-Ida Foods No. 1 well at Ontario (figure 2-3). The Idaho Group lies unconformably upon the faulted and eroded surface of basalts that acts as acoustic basement.

In the Nampa-Caldwell area the subsurface Idaho Group can be subdivided into a lower and an upper part. The division is made at the upper surface of a local subsurface basalt field within the group that is mapped from seismic reflection profiles south of Nampa. This surface can be traced as a seismic reflection (Horizon "I", figures 2-4 and 2-5) over most of the study area, but its lithologic character changes from a siltstone-basalt contact south of the zone of complex faulting (figure 2-8) to a sandstone-siltstone contact in the region north of Nampa. The surface rises to the east and northeast so that its depth is less than 330m (1,000 ft) beneath the Meridian area, and it may be eroded and absent from the area east and north of Meridian. The seismic horizon used to subdivide the upper and lower Idaho Group unconformably overlies the structural subsurface high of older basalts in the middle of the Plain (figure 2-5). The seismic reflection profiles also indicate that the lower Idaho Group thickens to the north and east, and that most of the exposed Idaho Group on the north margin of the Plain should be considered Lower Idaho Group. In contrast the upper Idaho Group thickens to the southwest and reaches a maximum of about 915 m (3,000 ft) beneath Caldwell.

LOWER IDAHO GROUP (including Poison Creek Formation, Banbury Basalt, and the Chalk Hills Formation) — Type localities for sediments and basaltic volcanics of the Lower Idaho Group are entirely on the south side of the Snake River Plain along the northern edge of the Owyhee Mountains. Malde and Powers (1962) defined the Poison Creek and Chalk Hills formations, but their age relationship to one another and to related basaltic volcanics is obscure (Ekren and others, 1978a). K-Ar age control within the Banbury Basalt and the Idaho Group is published by Armstrong and others (1980). The Banbury Basalt mapped by Malde and others (1963), on the north side of the Plain is dated at 9.4 $\pm$0.6 million years correcting earlier reported younger ages (Armstrong, 1980). The exposed sediments are generally described as lake and stream deposits of buff, white, brown, and grey sand, silt, clay diatomite, numerous thin beds of vitric ash and some basaltic tuffs. Well-cemented arkosic sandstones within the Poison Creek unit form dipping mesas and tilted buttresses along the north side of the Owyhee Mountains. Basalts intruding and within these beds are described as intergranular-to-ophitic textured olivine basalt, and some are mapped by Ekren and others (1978a) as the Banbury Basalt Formation.

Boise Area — Sediments similar to those of the lower Idaho Group exposed along the edges of the Owyhee Mountains on the south side of the Plain are exposed in the Boise foothills where the lower Idaho Group is a series of arkosic, deltaic and lake margin sand units and buff siltstones about 200 m (650 ft) thick (Wood and Vincent, 1980). On the north side of the Plain in the Boise foothills these sediments rest upon an irregular erosion surface of silicic volcanics of the Idavada Group, or upon weathered, eroded, plagioclase phyric basalt flows and basaltic tuffs that are similar to the Banbury Basalt Formation north of Mountain Home, described by Malde and others (1963). A flow of fine-grained olivine-bearing basalts also occurs within the lower part of the arkosic lake margin sand units, and at places these basalts rest upon an eroded surface of a sedimentary unit of tuffaceous silt and white vitric tuffs.

Most of the Idaho Group exposed in the Boise area might be the Lower Idaho Group. Previous workers have described these sediments as the Glenns Ferry Formation of the Idaho Group (Savage, 1958, Hollenbaugh, 1973, Thomas and Dion, 1974); however cross sections of the Plain prepared from seismic reflection profiles (figure 2-4) show that these foothills units emerge to the northeast from deep beneath the Plain at dips of 7° to 10°, and they may not be a part of the Glenns Ferry Formation. The Glenns Ferry Formation, if it exists as a subsurface unit beneath Boise, must lie unconformably on the Lower Idaho Group and be less than 300 m (1,000 ft) thick. Stratigraphic details of the upper 300 m (1,000 ft) are not known, for we have no seismic reflection data for the upper section. The widespread "blue clay" encountered in water wells within the upper 180 m (600 ft) of section may be a part of the Glenns Ferry Formation, and so might the sandy coarse facies that rests upon it. It is important for geohydrologic considerations to recognize that the emerging deep units are not conformable. A geohydrologic framework for the upper 300 m (1,000 ft) of section beneath Boise is proposed by Burnham (1979) and represents the first reasonable geologic explanation of the groundwater system; however, well data is sparse and inconclusive regarding the detailed stratigraphy of the upper section.

Nampa-Caldwell Area — West of Boise, in the Meridian area, the Lower Idaho Group fills a deep basin developed by faulting and downwarping before and during the deposition (figures 2-4, 2-5). The basin is bounded to the southwest by structurally high basalt. Lower Idaho Group sediments filled and overtopped the structure and sediments were transported to the west-southwest into the Lake Lowell-Caldwell Basin. Thick sand units at 600 to 700 m (2,000 to 2,300 ft) depth, encountered in wells drilled upon the structural high probably represent a deltaic facies prograding to the west across the submerged high to the subsiding basin to the south in the Lake Lowell-Caldwell area. These sands should exist as aquifers along the top of the high and to the northeast where they emerge or are truncated by younger sediments. The contrast between the deep and shallow investigation resistivity logs (figure 2-9 and Chapter 3, indicates these sands should be good aquifers with moderate permeability. These sands have never been formation tested, nevertheless, they have resistivities and thicknesses comparable to shallower units in the Upper Idaho Group that yield good flows to wells. It is not known if, in the Lower Idaho Group, these sands persist in the subsurface south of the structural high into the Lake Lowell-Caldwell Basin. Coarse arkosic sandstone of the Lower Idaho Group outcrops along the north margin of the Owyhee Mountains south of Nampa and Caldwell (Ekren, and others, 1981). Some of these sandstones have fair permeability; however, many are also tuffaceous and silty and of low permeability. However, the source of these sands may not be the same as the sand in the subsurface for they may have been derived from sources south of the subsiding plain.

The Lower Idaho Group locally contains subsurface basaltic lava fields and several thin flows. A subsurface basaltic lava field is mapped from seismic reflection profiles in the area immediately southwest of Nampa (figure 2-5). The basalt appears to be thickest in the Lake Lowell basin. The top of the basalt surface ranges in depth from 549 m (1,800 ft) to about 823 m (2,700 ft). Within areas that were topographically low at the time of eruption seismic profiles indicate the Idaho Group Basalts may be as much as 150 m (500 ft) thick.

In the Champlain Oil Company (Deer Flat No. 1) well only a few flows 10 to 20 m (30 to 65 ft) thick are encountered at 822 m (2,040 ft) depth. Much of the basaltic material occurs as interbedded sedimentary tuffaceous silt and sand. To the west in the vicinity of Knowlton Heights, the basalt shallows to a depth of 335 m (1,100 ft) and several volcanic vents appear on the reflection profiles (figure 2-5). Subsurface occurrence of these basalts is shown on figure 2-8, and the horizon (Horizon "I") at which the basalts occur is arbitarily used in this report to subdivide the Idaho Group into an upper and lower part.

UPPER IDAHO GROUP — The Upper Idaho Group, as defined in this report, includes the sedimentary sequence above seismic Horizon "I" (figures 2-2, 2-7, and figure 2-8). During deposition of the upper Idaho Group the axis of the sedimentary basin lay beneath Lake Lowell and Caldwell. The basin axis has a northwest trend and plunges down to the northwest. The deepest part of the basin lies northwest of Caldwell beyond the area for which seismic reflection coverage was obtained (figure 2-8). Sedimentation during Upper Idaho Group time was not affected by the large subsurface structural high in the middle of the basin for it was buried by sediments.

A number of continuous seismic reflections occur within the Upper Idaho Group. These reflections are at depths of 240 to 1000 m (800 to 3,200 ft), and are apparently higher velocity siltstone and claystone. These sand units are encountered in deep wells and are well defined by their high resistivity on electrical logs shown on figure 2-9 and higher acoustic velocity on some logs. These widespread sands may represent fluvial episodes that extended out into the basin during epoisodes of regression of a lacustrine environment.

The base of the upper Idaho Group, as defined by reflector "I" in the subsurface, is probably close to the base of the Glenns Ferry Formation as mapped by Malde and others (1963) and Ekren and others (1981). In the foothills along the base of the Owyhee Mountains between Marsing and Murphy, Idaho, gray siltstone of the Glenns Ferry Formation rests unconformably on sediments and basaltic volcanics of the Chalk Hills and Poison Creek Formations. To the east, in the Bruneau area, the base of the Glenns Ferry Formation is locally marked by algal and oolitic limestone resting on beveled beds of the Chalk Hills Formation with slight angular discordance (Malde and Powers, 1962, p. 1207). Oolitic limestone near the base of the Glenns Ferry Formation has been described at numerous localities in a recently completed study by Kimmel (1979).

On the north margin of the plain in the foothills between Boise and Emmett, oolitic sand and limestone occur in the uppermost strata of a sequence of deltaic sands and siltstone that rest upon older basalt (Wood, 1981, unpublished mapping). Oolitic and algal limestone is a common shoreline facies of large saline lakes (Eardley, 1938), and it is likely that the occurrence of oolitic deposits around margins of the Snake River Plain may mark a limited stratigraphic interval within the Idaho group and show the outline of a large lake that existed during Idaho Group time. Kimmel (1979) has suggested that oolitic limestone and sandstone may locally serve as a definition for the base of the Glenns Ferry Formation. It is not known if oolitic sand occurrences on the margins of the plain are stratigraphically equivalent to the seismically defined boundary between the upper and lower Idaho Group; however, there does appear to be a coincidence between the stratigraphic occurrence of oolites on the margins, locally identified unconformities and the uppermost occurrence of local basalt fields in the strata of the Idaho Group of the western plain.

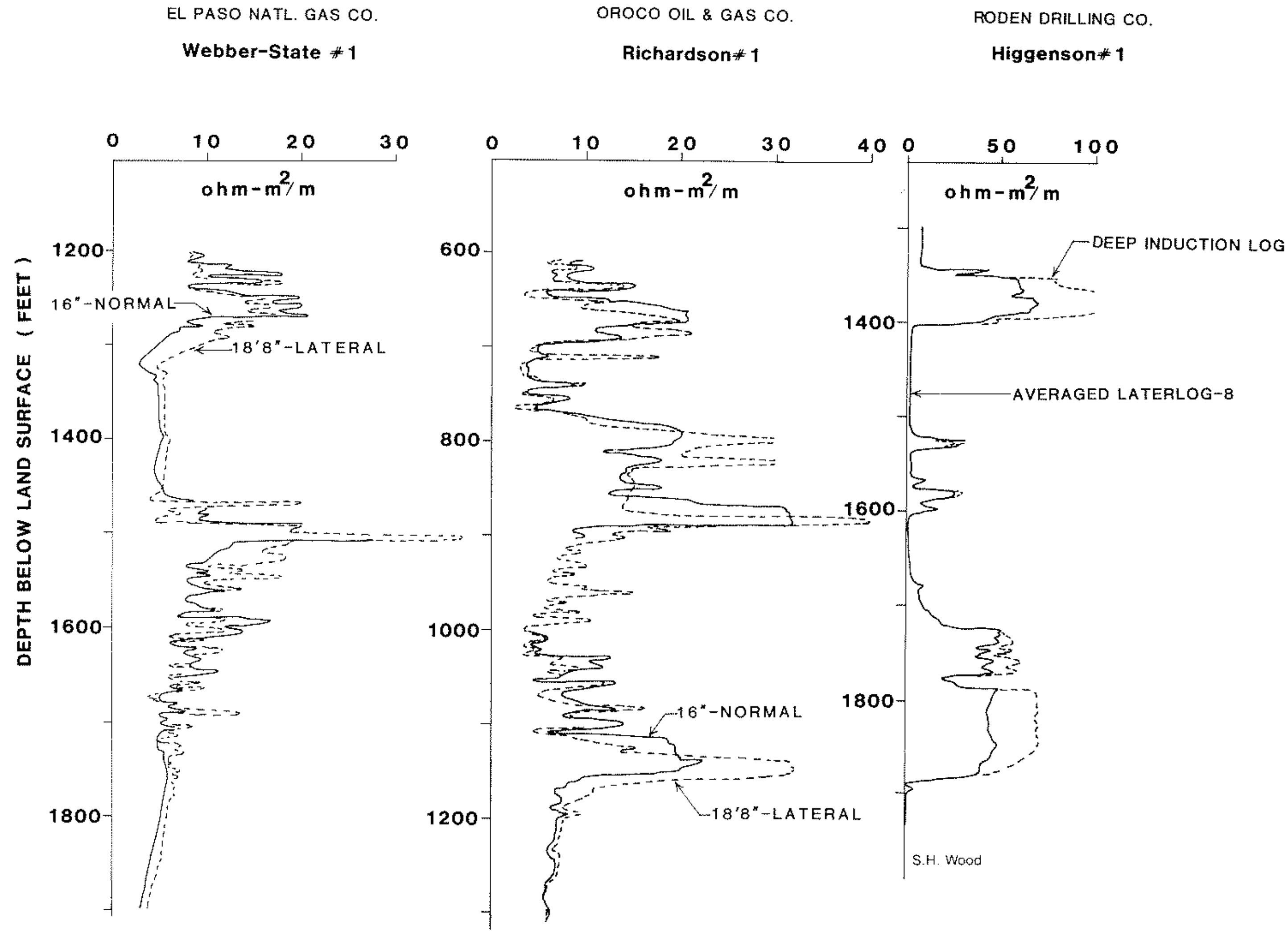


FIGURE 2-9. Resistivity log character of deep aquifer in the Nampa-Caldwell area.

Exposures of the Glenns Ferry Formation mapped along the Snake River Canyon south of Nampa and Caldwell are entirely within the upper Idaho Group (figure 2-6). Here the section consists of 100 m (300 ft) of monotonous, indistinctly-bedded, gray, lacustrine siltstone and fine sandstone. The only variation in this lithology is a 10 m ± (30 ft ±) thick layer of indurated buff-colored, tuffaceous, poorly sorted, fluvial sandstone that outcrops in Dead Horse Canyon (Sections 17, 18 and 20, T. 2N, R. 3W, figure 2-6). At this locality, and also locally along the basalt-capped white bluffs on the north side of the river, the Glenns Ferry siltstones are conformably overlain by a 20-m (65 ft) thick gravel deposit identified by clast content and stratigraphic setting as the Tuana Gravels of Malde and Powers (1962).

Fission-track ages have been determined on a number of volcanic ash members within the Idaho Group (Kimmel, 1979). Ages of ash layers within the Chalk Hills Formation range from 8.5 ± 1.2 to 7.0 ± 0.5 million years. Ash layers bracketing oolitic limestone in the basal Glenns Ferry Formation are 3.2 ± 0.4 to 2.5 ± 1.0 million years and 2.4±0.2 million years. This geochronology and field evidence of an unconformity between the Chalk Hills and Glenns Ferry Formation indicate a hiatus of deposits on the margin of the Plain between about 7.0 ± 0.5 and 3.2 ± 0.4 million years.

Tuana Gravels

Well sorted pebble and cobble gravels and coarse sand are exposed along the walls of the Snake River Canyon (Deadhorse Canyon in the SW corner of the Lake Lowell Quadrangle). Stratigraphic position and clast content indicates that these gravels correlate with the Tuana Gravels of Malde and Powers (1962). These gravels contain a few clasts of orange quartzite indicating a Snake River drainage provenance and distinguishing them from the Tenmile Gravels. At this locality Tuana Gravels dip 5 to 10° north and mark an angular unconformity with the overlying, horizontal, Bruneau lake beds. Thickness of gravel is 0 to 15 m (0-50 ft).

The Bruneau Formation

The lacustrine facies and basalt of the Bruneau Formation locally lie unconformably on the north dipping Tuana Gravels and Glenns Ferry Formation in localities along the north side of the Snake River (figure 2-10). The lacustrine deposits are horizontal and contain both gray siltstone and beds of brown tuffaceous sandstone bearing palagonized basalt and scoria. A number of scoria deposits, minor basalt flows and small basalt necks of the Bruneau Formation intrude and overlie the Glenns Ferry Formation. These basalt vents stand out as small hills where the Glenns Ferry Formation has been eroded away in the cutting of the modern Snake River Valley. The Bruneau Formation is mostly confined to the present Snake River Valley area and is probably less than 50 m (160 ft) thick or non-existent in the Nampa-Caldwell area. The formation thickens to the east and is up to 240 m (800 ft) thick in the Bruneau-Grandview area (Malde, 1965). The Bruneau Formation is thought to have originated from a complex series of lava dammed lakes along the canyon of the Pleistocene Snake River (figure 2-10), but many features of its origin have yet to be explained (Malde, 1965).

Age of the Bruneau Formation is middle Pleistocene based upon a single K-Ar determination on basalt of 1.4 million years (Evernden and others, 1964). All lavas have reversed magnetic polarity and are included in the Matuyama Polarity epoch (Malde and Williams, 1975).

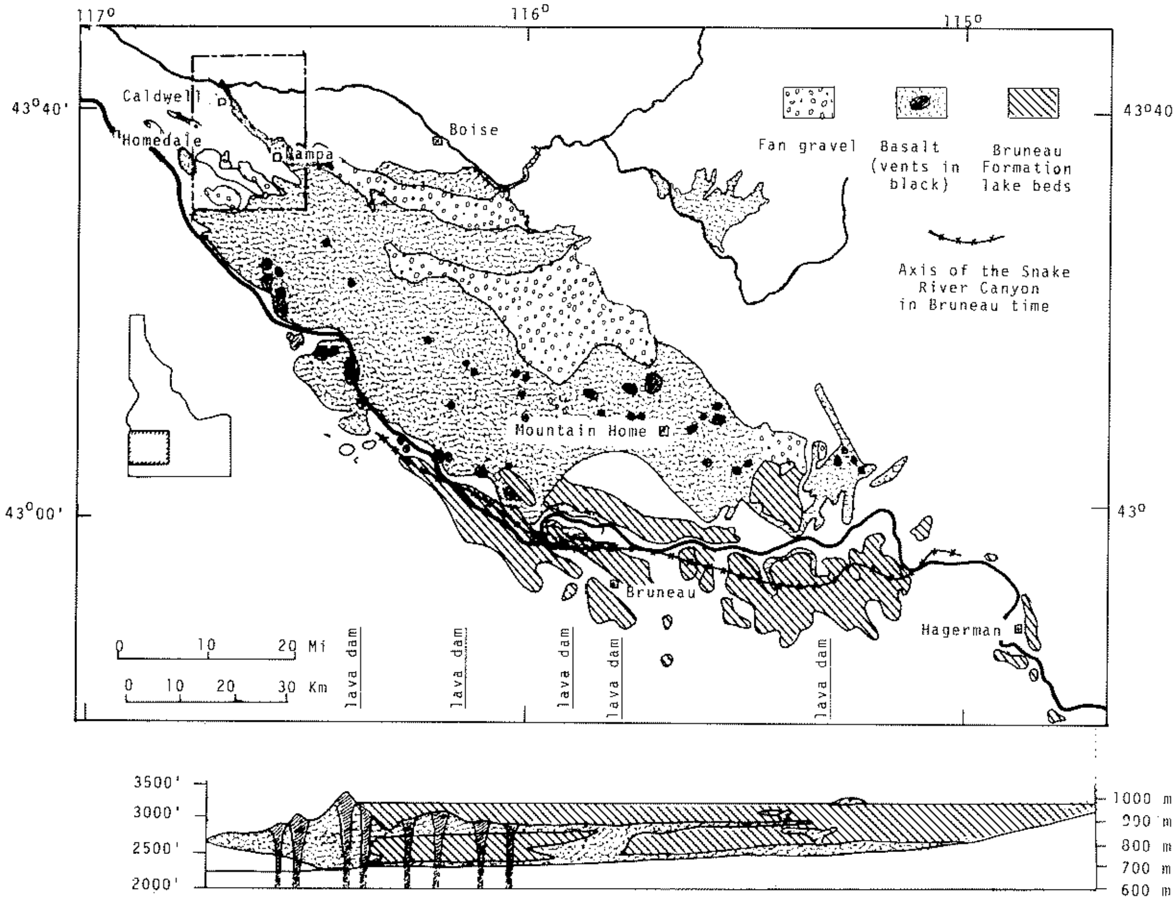


FIGURE 2-10. Occurrences of the Bruneau Formation in the western Snake River Plain. After Malde (1965a).

The Tenmile Gravels

In the Nampa-Caldwell area, the top of the upper Idaho Group is marked by a widespread fluvial gravel deposit that caps many of the hills in the area. The gravel extends eastward across the plain to the mountains east of Boise where it laps against the granitic bedrock. The gravel has a cobble assemblage of granitic rocks and felsic porphyries derived from the adjacent Idaho Batholith terrain. This gravel unit was named the Tenmile Gravels by Savage (1958) because it forms the entirety of Tenmile Ridge south of Boise where it is up to 150 m (500 ft) thick. In the Nampa-Caldwell area, the thickness rarely exceeds 15 m (50 ft). It is widely exploited as a source of gravel for construction and concrete pipe manufacturing. The geometry of the deposit and the cobble assemblage clearly mark the Boise River drainage as the source of the Tenmile Gravels. The Tenmile Gravels are distinct from the Tuana Gravels, because the Tuana Gravels bear a few orange quartzite cobbles and other metamorphics whereas the clasts of the Tenmile Gravels are almost entirely intrusive porphyries and granitic rocks. The stratigraphic relationship of the Tenmile Gravels to other Plio-Pleistocene units such as the Bruneau Formation is uncertain.

Snake River Group

SEDIMENTS OF THE DEER FLAT SURFACE — The higher upland surface both north and south of the Boise River is underlain by at least 30 m (100 ft) of unconsolidated fluvial sand and gravel. The sands are mostly coarse, arkosic and cross-bedded. The gravels are typically in beds 0.5 to 2 m (1.5 to 7 ft) thick and are composed of rounded clasts of intrusives derived from the Boise River drainage. The gravels are indistinguishable from the Tenmile Gravels. The unit is identified by its topographic position on a surface that is about 60 m (200 ft) above the present Boise River. The surface rises generally from 760 m (2,500 ft) on the west side of the map to 823 m (2,700 ft) elevation in the northeast corner of the Middleton 7 1/2 minute quadrangle (figure 2-6). A good exposure of this unit is located in a gravel pit in the SW1/4, Section 3, T. 4N, R. 4W, 3 km (1.9 mi) north of Caldwell. No extensive exposures of this unit are known south of the Boise River. The unit is best identified by the elevation of its surface and by soil development. Priest and others (1972) classify soils upon this surface in the Scism or the Power-Durham series characterized by a moderately well-cemented caliche horizon 0.5 to 1.2 m (1.5 to 4 ft) deep.

The Indian Creek Basalt flows erupted onto surfaces of the Deer Flat Sediments, and are reported in the driller's logs to be interbedded with this unit. The unit is probably middle Pleistocene in age.

INDIAN CREEK BASALT FLOWS — Basalt which outcrops in Section 13, T. 3N, R. 1W by the Nampa State School and also in the north Caldwell area along the Boise River is the same flow unit. The flow is about 0.7 km (0.5 mi) wide. This flow is named the Indian Creek Basalt, for it extends as a continuous flow from beyond the west edge of the map to Caldwell and parallels the course of Indian Creek. Subcrop of this flow has been mapped from the numerous driller's logs in the area. The flow is a gray, titano-augiteplagioclase-olivine basalt, and is typical of basalts of the Snake River Group. The gray color results from an abundance of small lath shaped plagioclase crystals.

One or more deeper flows are identified from the water-well driller's logs at depths of 15 to 30 m (50 to 100 ft). This deeper flow underlies much of the city of Nampa, but the previously discussed shallow flow lies mostly to the north of Nampa. Subcrops of both the flow units are shown with dotted lines on figure 2-6. Both flows probably erupted onto an aggrading surface of sediment and can be considered as interbedded with the fluvial sediments of the Deer Flat Surface. Paleomagnetism of samples from three localities was measured with a field fluxgate magnetometer. Declination was consistently east-northeast, and inclination was much too shallow to clearly identify the direction of paleomagnetism as reversed or normal. The cause of this anomalous magnetization is unknown. Because of the association of the flows with the sediment of Deer Flat Surface, and the presence of an indurated caliche, the age of these basalts is probably middle Pleistocene.

The Indian Creek Basalts constitute the important unconfined, shallow groundwater system of the Nampa-Lake Lowell-Caldwell area. The basalt flow aquifers are tapped by numerous, shallow, domestic and irrigation wells. The groundwater is presently recharged mostly by seepage of imported irrigation water and canal leakage. The water level is quite stable. Because of their shallow situation and high transmissivity, the Indian Creek basalt aquifers can be easily contaminated by surface spills or leakage from buried storage tanks. The extent of these aquifers, is shown in figure 2-6. Wells situated on the hills capped by the older Tenmile Gravels do not encounter shallow aquifers and wells must be drilled deeper to tap the confined aquifers of the upper Idaho Group in order to obtain flows adequate for irrigation.

WHITNEY TERRACE DEPOSIT — Alluvium of the Whitney Terrace of the Boise River (Nace and others, 1957) consists of rounded cobble and pebble gravels, arkosic sands and minor silts. The unit is identified by the relatively flat terrace surface 10 to 20 m (30 to 65 ft) above the present Boise River floodplain. Soils developed upon the terrace gravels have a well developed profile with a brown silty clay loam "B" horizon composed of up to 0.9 m (3 ft) of calcareous nodules extending to a depth of up to 1.3 m (4 ft). These soils are assigned to the Power and Greenleaf series by Priest and others (1972). Soil profiles developed on this surface suggest a pre-Wisconsin age for the Whitney Terrace Deposits, or an age of 100,000 years or more.

QUATERNARY ALLUVIUM AND FAN DEPOSITS — Recent fluvial deposits cover the modern flood plain of the Boise River and Indian Creek. The Boise River flood plain is about 5 km wide in the map area. In the Middleton Quadrangle, ephemeral tributaries have formed small alluvial fans that extend into the Boise River flood plain.

STRUCTURE

Early Pleistocene gravels and older stratigraphic units in the Nampa-Caldwell area have been deformed by normal faulting, gentle tilting of fault blocks and broad downwarping toward the axis of the plain. Normally faulted gravels and sand layers are observed in several quarries in the area (figure 2-6) with displacements of a few decimeters to 10 m (1 to 30 ft). All mapped faults strike in a Northwest-southeast direction with dips ranging from 55° to nearly vertical. The only exception is the North Caldwell Fault exposure with an east-west strike. Linear ridges capped by the Tenmile Gravels trend northwest through the area in the vicinity adjacent to, and southwest of, Lake Lowell. The steeper sides of these asymmetric ridges are interpreted as fault-line scarps of normal faults that have apparent displacements up to 30 m (100 ft). Cross sections constructed from driller's logs (figure 3-1) show offsets up to 50 m (150 ft) of distinctive lithologic units. These offsets are interpreted as normal faults (figure 2-6). Bedding attitudes on exposure of the late Pliocene or early Pleistocene Glenns

Ferry Formation and Tuana Gravels are generally down to the northwest 3° to 10°. These attitudes are taken along the north rim of the Snake River Canyon and are consistent with dips interpreted from seismic reflection profiles (figure 2-5).

Attitudes on the Tenmile Gravel bedding are generally horizontal, but variations in elevation of the base of the gravel indicate that the gravels are faulted and slightly tilted. The elevation of gravels and direction of throw on faults is not in any consistent direction and no broader structures larger than individual fault blocks one or two km (0.6 to 1.2 mi) wide are indicated by deformation of the gravels.

Lack of the Tenmile Gravels northeast of Nampa, in the area covered by Terrace deposits and Quaternary alluvium, is attributed to erosion of the gravels by the Boise River and not to downfaulting. Very few surface faults are shown in the area on the map (figure 2-6) because the younger Boise River alluvial deposits are not faulted. Seismic reflection profiles show that a number of subsurface faults do occur in this area, and these are shown with a different symbol on figure 2-6.

The upper surface of the middle Pleistocene Snake River Basalts varies somewhat, and along the north rim of the Snake River the basalts appear to be slightly tilted, a few degrees, downward toward the basin axis of the plain to the northeast. The basalt surface is probably slightly downwarped by continued subsidence of the plain, but the flows do not appear to be broken by faulting in the map area. The larger tilted and faulted basalt buttes in the map area are probably earlier basalts of the Bruneau Formation (Pickles Butte, and the buttes in Hidden Valley); although, some of these basalts may have been mapped as the Snake River Group on figure 2-6.

The middle Pleistocene Snake River Basalts are not obviously faulted except in the vent areas. Faulting and vent fissures trend northwest across the two major basalt-shield vents shown on the map (Kuna Butte and Powers Butte). Kuna Butte differs from Powers Butte in that its north flank is made up of tilted Tenmile Gravels that were either a pre-existing fault block, or were arched by a shallow intrusion of the basalt. It is not a simple shield volcano such as Powers Butte. The northwest trend of the vent fractures suggests that the basalt erupted from deep sources along fissures opened by the same northeast-southwest oriented extentional stresses that produced the faulting in the slightly older Tenmile Gravels.

CHAPTER 3 — GEOHYDROLOGY

By
John E. Anderson[1]
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INTRODUCTION

Hydrologic units contained in the upper 460 m (1,500 ft) of the study area differ greatly in their properties. These units are illustrated in cross sections prepared from lithologic logs of water wells (figure 3-1 in pocket). Unit materials range from highly permeable sand, gravel and fractured basalts to nearly impermeable clay layers. Because of the lenticular characteristics and faulting of the sediments of the Idaho Group, lateral continuity has been noted to change abruptly (figure 3-2). Under these conditions, groundwater in Canyon County at different places has been observed to occur under perched, unconfined and artesian (confined) conditions. Because the Idaho Group and Snake River Group (figure 2-2) are heterogeneous and lenticular, the porosity and the vertical and horizontal permeability vary greatly.

Permeable beds of sand in the Idaho Group are the principal aquifers in the study area. Water in some of the shallower aquifers is unconfined, but in some of the deeper aquifers it is confined under considerable artesian pressure (noted in wells up to 2.1 kgm/sq cm or 30 psig). Pumped wells yield water in quantities ranging from a few liters per minute to more than 9500 lpm (2,500 gpm). The great range in yield is due to the extreme variation in permeability of the interbedded lenses of clay, sand, silt and gravel.

Three geologic units have been identified as important shallow cold water aquifer systems within the study area. These are: (1) a lower sand, silt and gravel, (2) a fractured basalt, and (3) an upper sand and gravel. The lower sand, silt and gravel unit is found in the middle to upper Glenns Ferry Formation. The upper sand and gravel unit and basalts are part of the Snake River Group. The Snake River Group unconformably overlies the Glenns Ferry Formation (figure 2-2).

Some geologic units found at depths below 460 m (1,500 ft) have been identified as potential water bearing zones; however, drilling costs may limit the exploitation of these units.

SHALLOW HYDROLOGIC UNITS

Upper Sand and Gravel Unit

The upper sands and gravels found in the area are the exposed Tenmile Gravels, Tuana Gravels of the Idaho Group and more recently deposited Boise River gravels of the Snake River Group. Most of the rolling hills and northwest trending ridges in the study area

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TABLE 3-1.

Approximate Hydraulic Coefficients Of Some Aquifers In The Nampa-Caldwell Area Including Estimated Drawdown Of Water Table Or Artesian Pressure At Given Times And Distances (Data From Nace, West and Mower (1957).

Nampa District

Well No. and location	Owner	Date of Test	Pumping rates (gpm)	Average coefficient of transmissibility (gpd/ft)	Average coefficient of Storage	Average field permeability (gdp/ft)[2]
4N-3W-25da1	Pioneer Irrig. Dist.	Oct. 1953	1,550	208,000	0.004	5,000
3N-3W-3bb1	do	Nov. 1953	2,110	960,000	.23	23,000
11da1	do	Oct. 1953	2,175	1,200,000	.006	25,000
3N-2W-8cc1	do	do	1,480	136,000	.0006	——
9dd4	Amalgamated Sugar	Feb. 1953	1,830	276,000	.0001	5,900
3N-1W-7bb1	Pioneer Irrig. Dist.	Nov. 1953	1,060	165,000	.003	3,700
2N-1W-7bc4	U.S. Bur. Reclamation	Sep. 1953	2,900	1,700,000	.004	18,000

Aquifer characteristics and well data	Pioneer Irrigation District[1]	U.S. Bureau Reclamation[2]
Pumping rate — gpm	1,675	2,900
Duration of test — hrs.		28
Specific capacity of well — gpm/ft	80	150
Coefficient of transmissibility — gpd/ft	506,000	1,700,00
Coefficient of storage	.048	.0044
Coefficient of permeability — gpd/ft[2]	14,000	17,500
Drawdown: In pumped will at end of test — feet	23.8	20
In obervation well (computed)		
500 feet distant:		
After 30 days of pumping — feet	5.45	1.8
After 180 days of pumping — feet	6.62	2.2
2640 feet distant:		
After 30 days of pumping — feet	3.10	1.2
After 180 days of pumping — feet	4.30	1.5

[1] Average from five pumping tests.
[2] Formerly Ellis Farm Well.

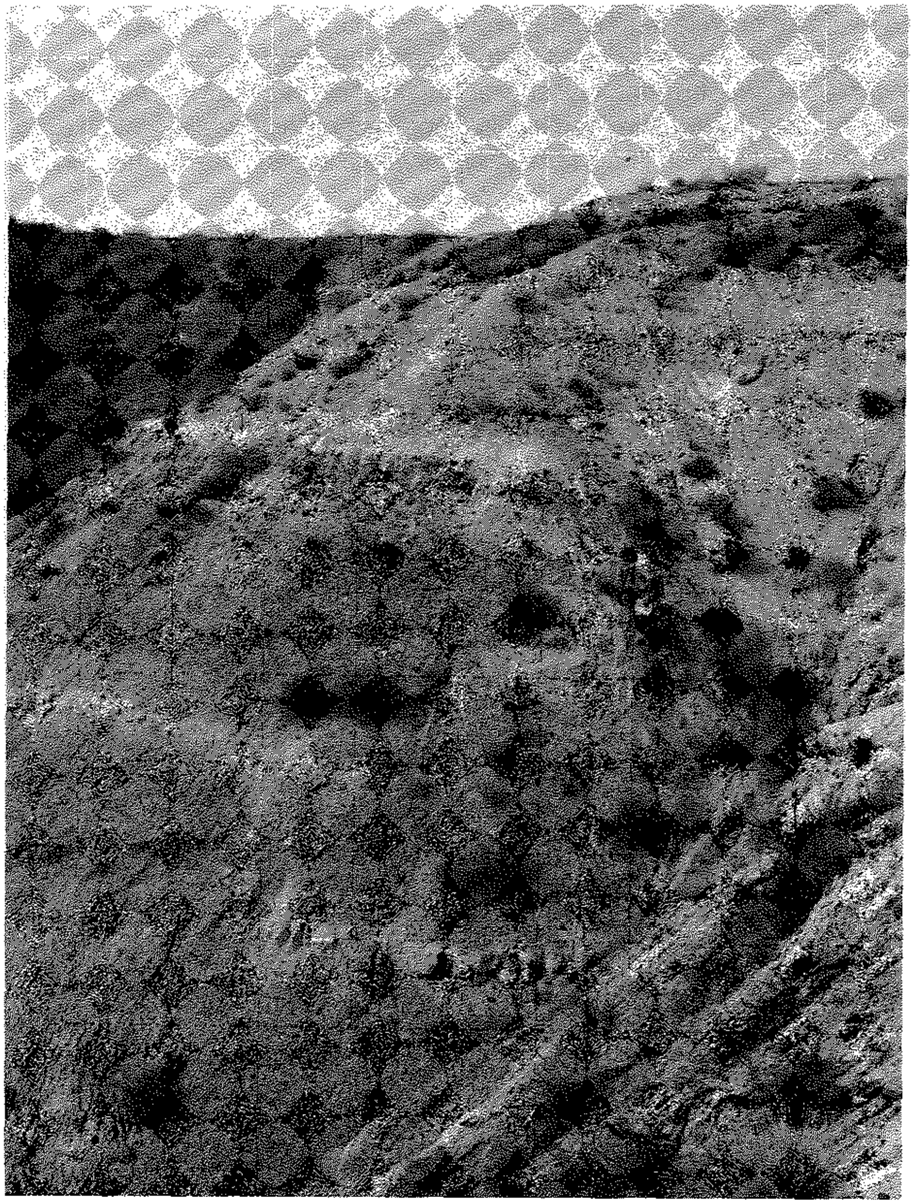

FIGURE 3-2. Photograph showing faulting of Idaho Group sediments in Nampa-Caldwell area.

are capped by these gravels (figure 2-6). The Tenmile Gravels are exposed over much of the study area where they are not capped by the basalts. For the most part this unit lies above the water table. High permeability characteristics of this unit facilitates groundwater recharge in the areas of exposure and locally supplies domestic wells for low yield purposes. This unit is not considered an important aquifer system except when found under the basalt cap and below the water table.

Basalt Unit

Russell (1902, pp. 38, 59) proposed the general term "Snake River Basalt" to "designate the basaltic rocks that underlie by far the larger part of the Snake River Plain and, to a great extent, forms the actual surface." Surface exposures of Indian Creek Basalt flows found in many parts of Canyon County are considered to be part of the Snake River group (figure 2-2). The tops of these flows are above the current water table except in the Indian Creek, Dry Lake, Nampa and Caldwell areas. The Indian Creek flows overlie the Glenns Ferry Formation and locally overlie and/or intertongue with the Tenmile and Tuana Gravels. Because of the valley-filling nature of the flows, the thickness of this unit, where present, varies from 12 m (40 ft) to approximately 152 m (500 ft) within the study area.

The contacts between flows are vesicular, porous and/or fractured. Well drillers' reports as well as surface exposures show the basalts to be highly jointed throughout. Intergranular permeability is low, but formational permeability is generally high due to the fracturing and jointing. The basalts, when encountered below the water table, yield initial large quantities of water to wells. Pump tests indicate yields up to 9,462 l/min (2,500 gpm) from this zone.

Lower Sand and Silt Unit

The lower sand and silt unit underlies a large part of Canyon County. This unit is defined for this report as being the sediments of the Deer Flat Surface or within the upper portion of the Glenns Ferry Formation (figure 2-2). This lower sand and silt unit consists of interbedded fluviatile and lacustrine deposits of clay, silt and sand, with lenses of gravel.

This unit is the major cold water bearing formation of the area, although the permeability of the unit varies greatly. The permeable sands of this unit yield artesian and unconfined waters to wells in quantities from a few to more than 7,570 lpm (2,000 gpm). Aquifers within the lower sand and silt unit are recharged from the infiltration of surface irrigation water, from minor amounts of precipitation and partially by the upward migrating thermal waters.

INTERMEDIATE HYDROLOGIC UNIT

Lying just below the shallow, lower cold water aquifer is a substantial layer of "blue clay." This unit, considered to be middle Glenns Ferry, is found at varying depths 91-213m (300-700 ft) below land surface within the study area and seems to be laterally extensive. "Blue Clay" has been noted in drillers logs as far west as Parma, as far east as Boise, and within the plain both north and south of the study area. The thickness of this unit in the Nampa-Caldwell area, as described in drillers logs, varies from a few meters to over 122 m (400 ft).

From visual examination of drill cuttings from the area, the "blue clay" appears to be particles of very fine silt and clay. The color of the clay in place ranges from pale blue (5B 6/2) to pale blue green (5BG 7/2). The color of the clay is due to sulfide enrichment and may indicate deposition under a reducing environment. However, secondary iron sulfide enrichment could be caused by post depositional water migration. Upon prolonged exposure to the air the "blue clay" turns light olive grey (5Y 6/1) to brownish grey (5YR 4/1) in color.

A sand aquifer of varying thickness, up to 15 m (50 ft), is found near the base or just below the base of the"blue clay". When this sand aquifer is found near the base, but within the blue clay, it is described by the drillers as being a blue sand. When it is found just below the base of the clay, it is described as a gray sand. Wells that have been drilled into or through this blue clay layer normally encounter waters that are 5°C to 33°C warmer than encountered in the aquifers found above this layer.

An example of this is found in two wells, 1N-2W-9acc1 and 1N-2W-9ccb1, which are about 0.4 km (1/4 mile) apart. One well was drilled to a depth of 67 m (220 ft) and did not encounter the blue clay layer. This well has a surface discharge temperature of 15°C (59°F). The other well, was drilled to a depth of 157 m (515 ft) and penetrated 37 m (120 ft) of blue clay from 98 to 134 m (320 to 440 ft) below land surface. A water bearing clayey sand was encountered from 134 to 157 m (440 to 515 ft). This well has a surface discharge temperature of 23°C (73°F).

The "blue clay" may be acting as an impermeable or semiimpermeable capping layer above anomalous warm water aquifers and/or structural zones. Such an impermeable layer would retard the upward migration of the anomalous waters except where sufficient faulting, slumping or fracturing has taken place. Man made interconnections between the overlying cold water aquifers and the anomalous warm water aquifers under the clay by well drilling indicate, in nearly all cases, the clay acting as a capping barrier. Temperature gradient profiles taken in selected wells within the study area show temperatures in the first aquifer below the "blue clay" to be 5°C to 15°C higher than those aquifers above the clay. Well construction in many of the selected wells measured is allowing mixing of the warm waters with the shallower, colder waters. In these cases colder water may be migrating to near the bottom of the well due to density difference. If this is happening, bottom hole temperatures could be actually higher than recorded. However, the isotope data (Chapter 4) suggests that temperatures from the aquifer within the "blue clay" are only about 30°C, and may be fairly uniform throughout the entire area. Hotter water is thought to be derived from permeable zones below the blue clay aquifer or from faults.

DEEP HYDROLOGIC UNITS

From deep oil and gas well log interpretations (figure 2-3), there are indications of additional permeable zones in the deeper rock units found under the study area. From these log interpretations, it appears some of these zones may have sufficient thickness and areal distribution to sustain long term withdrawals, with water temperatures exceeding 38C°(100°F), provided sufficient permeability exists. No data on permeability of these units is available at present.

Available temperature depth logs from these wells indicate increasing temperature gradients with depth, ranging from 15°C (59°F) near the surface to 350°C (660°F) at 4,270m (14,000 ft, see figure 3-3). Geophysical logs from the J.N. James No. 1 and Champlin Oil

Company Deer Flat No. 1 well, including the Chevron/Halbouty abandonment records from the J.N. James No. 1 well, indicate three and possibly five permeable water bearing zones above the 1,900 m (6,200 ft.) depth. These potential water bearing zones, as indicated from the J.N. James No. 1 well, are at depths of 457 m (1,500 ft), 640 m (2,100 ft), 1,037 m (3,400 ft.), 1,311 m (4,300 ft.) and 1,677 m (5,500 ft.). However, the depths to these suspected zones will vary throughout the study area due to subsurface, basin-related geologic complexities (figure 2-4 and 2-5). An example of this variability in depth is found in two wells (J.N. James No. 1 and Deer Flat No. 1 (2N-2W-19bl). A permeable zone indicated at about 1,311 m (4,300 ft) in the J.N. James No. 1 well may be the same zone intersected at 1,860 m (6,100 ft) in the Deer Flat No. 1 well.

Information made available to the authors from the Deer Flat No. 1 well indicates this zone is quite permeable, with water rising under artesian head within 61 m (200 ft) of the surface. Temperature logs suggest this zone to be 107°C (225 °F) at 1,860 m (6,100 ft). This zone appears to be about 61 m (200 ft) thick and consists primarily of sand with clay stringers.

Another highly permeable zone is noted in the Deer Flat No. 1 well at 884 m (2,900 ft). This zone is reported to yield water at 71°C (160°F), is approximately 31 m (100ft) thick and consists mostly of sand and clay. This zone may be the same permeable zone intersected at 610 m (2,000 ft) in the J.N. James No. 1 well.

Temperature logs recorded by the oil companies immediately upon completion of many of the oil wells drilled in the area indicate minimum subsurface temperatures of the five suspected permeable zones to be 43°C (110°F), 49°C (120°F), 58°C (137°F), 66°C (150°F) and 75°C (167°F), respective to depth (figure 3-3).

Thicknesses of these units probably vary, but estimates of thicknesses from electrical logs from the above mentioned wells appear to be respectively near 40 m (131 ft), 31 m (100 ft), 100 m (330 ft), 61 m (200 ft) and 75 m (245 ft).

The uppermost of these potential aquifers is located in the lower Glenns Ferry or uppermost Chalk Hills Formation. This zone, from well log data, consists of a grey arkosic sand and silt with lenses of clay and pebbles. It appears to vary in thickness but is estimated to average about 40 m (130 ft) This material has probably been derived from the erosion of the granitic rocks of the Idaho Batholith. Heat flow data suggests the water temperature of this zone could be as high as 60°C (140°F). Hydrologic characteristics of this zone is unknown at this time.

Structural interpretation, from aerial magnetic surveys, sesimic data, satellite imagery intperpretation and oil and water well data identifies a strucutrual zone trending north west just south of Lake Lowell. Offsetting has been estimated, from well log interpretation, to be as much as 60 m (200 ft) in the shallow section (see cross sections, figure 3-1). The flanking structure associated with this trough may influencing the upward migration of thermal waters as there is a higher density of anomalously warm wells paralleling this trend within the the study area. This seems to support the idea that thermal waters are migrating upward along structural zones with some of the water infiltrating into permeable zones along the way and the rest migrating further upward to mix with the surface derived cold water above the "blue clay."

Stevens (1962) postulates a groundwater divide to run near the south edge of Lake Lowell. It appears to trend in a general northwestward direction. On the south side of this divide, groundwater flows in a southwesterly direction. On the north side of the divide, groundwater appears to flow west-northwest. This divide may be due to the fault system associated with the structural trough mentioned above.

Recharge for the shallow, cold aquifer systems is principally from surface infiltration, much of which is deep percolating irrigation water. Recharge to the deeper permeable zones may be originating from the Owyhee Mountains to the south and/or from the Idaho Batholith to the north. However, water chemistry analysis indicate these might be semi-confined permeable zones. If these waters are ancient, the method and degree of confinement is unsolved at this time. A study to determine the age, rate of migration, source of recharge and recharge rate for these deeper waters should be undertaken.

CONSIDERATIONS FOR GEOTHERMAL EXPLORATION

Geothermal gradients in the Nampa-Caldwell area are consistently in excess of 30°C/km down to a depth of at least 3 km (10,000 ft) as shown in figure 3-3 and discussed in Chapter 5. At a depth of 1,000 m (3,300 ft), temperatures in excess of 45°C are expected over most of the area. The problem for development of commercial amounts of geothermal water will be to encounter rocks at depth with good intergranular or fracture permeability. Subsurface geological and geophysical data suggest two situations which might yield good flows to wells. Youthful major fault zones which cut the upper part of the stratigraphic section and have the largest displacements should retain good fracture permeability, particularly where they cut hard brittle formations at depth. Relative youth of faulting increases the possibility that the fractures have not been plugged by the deposition of minerals such as zeolites, quartz, and clays. These fault zones are shown on figures 2-7 and 2-8 and are labeled the "Eagle-West Boise Fault zone, the Middleton Fault zone, and the Lake Lowell Fault zone." Other faults appear to be older on the seismic sections, but geologic mapping (figure 2-6) and correlation of driller's logs (figure 3-1), indicates that a number of other faults are also younger but are not crossed by available seismic lines or are not detected because of poor resolution of the shallow section of the seismic sections.

Deep sand aquifers within the lower Idaho Group, and possibly within the older basalt section, may also be good producers of hot water. None of these confined sand aquifers have been tapped by wells for water, but it is likely they would yield hot artesian waters at temperatures of at least the geothermal gradient indicated in figure 3-3. Sand aquifers of the lower Idaho Group were encountered in the two deep wildcat wells in the Meridian area, but have not been encountered in the recently drilled geothermal wells in the Boise area, nor do they occur in the deep wells that lie off of the structural high that trends northwest between Meridian and Middleton (figure 2-4 and figure 2-5). These sand aquifers are probably best developed in the area northwest of Nampa, but their extent is not known.

Electrical log character suggest good permeability in these deep sands by the separation of the deep investigation induction log (DIL) trace and the shallow investigation laterlog 8 (LL8) resistivity trace (figure 2-9). Well test data on these deeper sands are sparse in this area, but an indication of possible geohydrologic characteristics of the deep confined sands might be inferred from previous well tests conducted on shallower confined and unconfined sand units. Data on the geohydrologic characteristics of the shallower 60 to 180 m (200 to 600 ft) sand units were acquired from tests that consisted of two production test

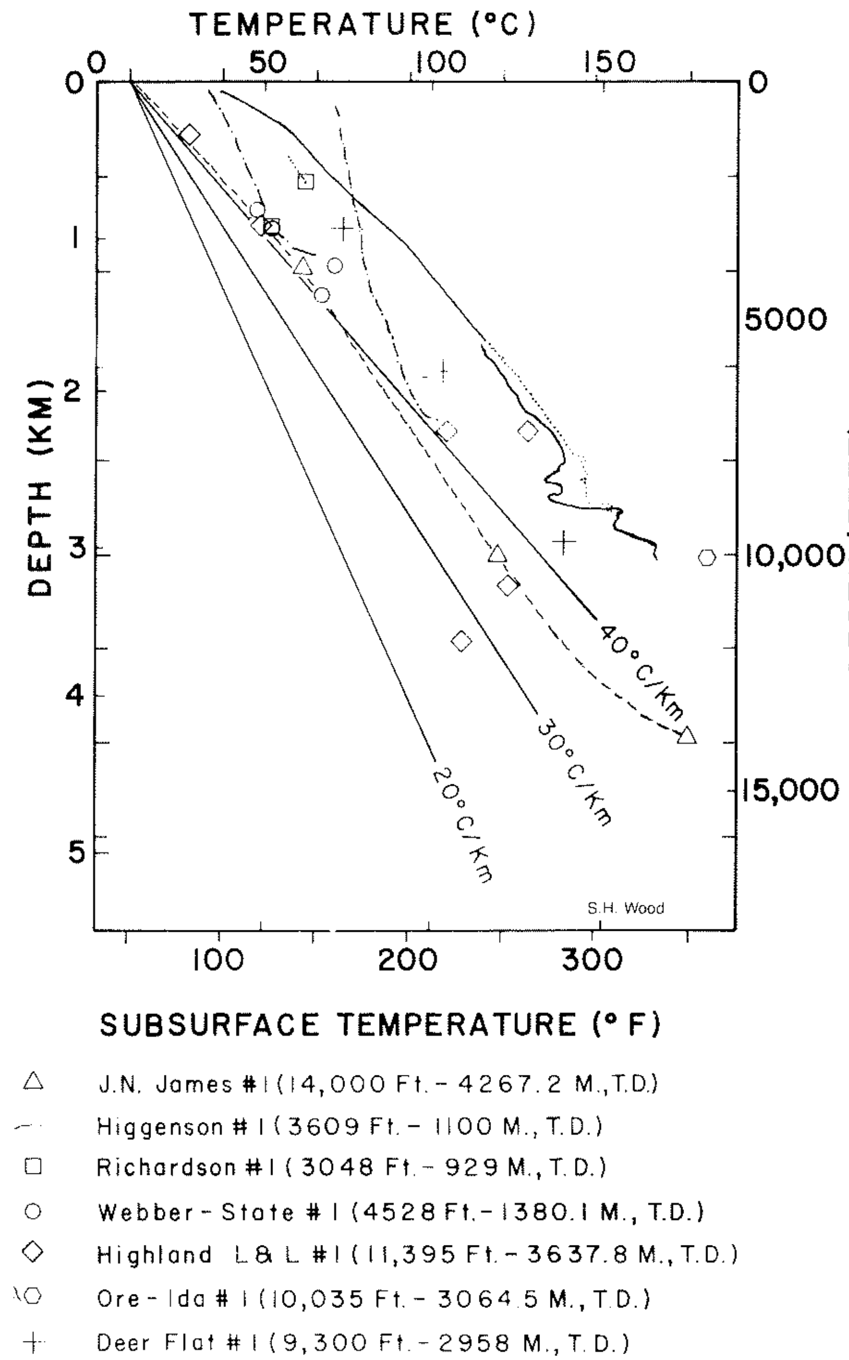

FIGURE 3-3. Geothermal gradients from selected deep wells in the western Snake River Plain.

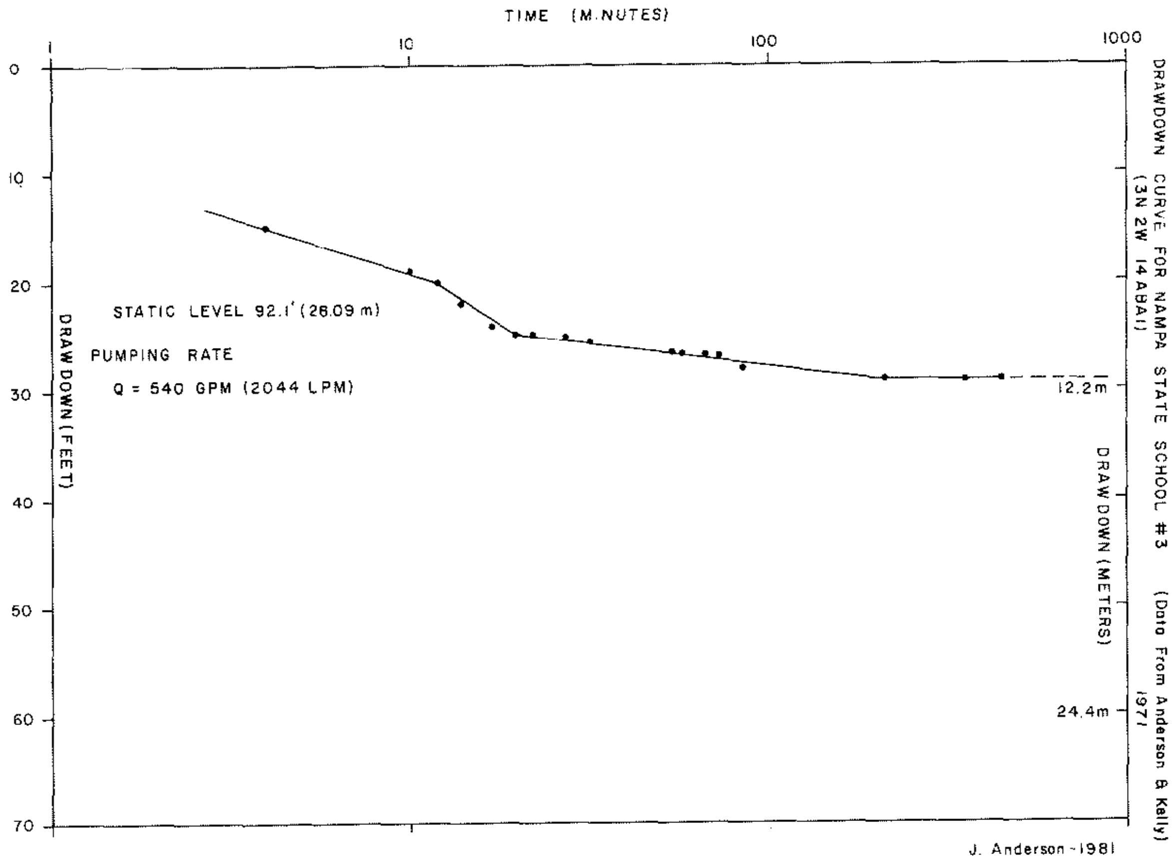

FIGURE 3-4. Drawdown curve for the Nampa State School and Hospital well.

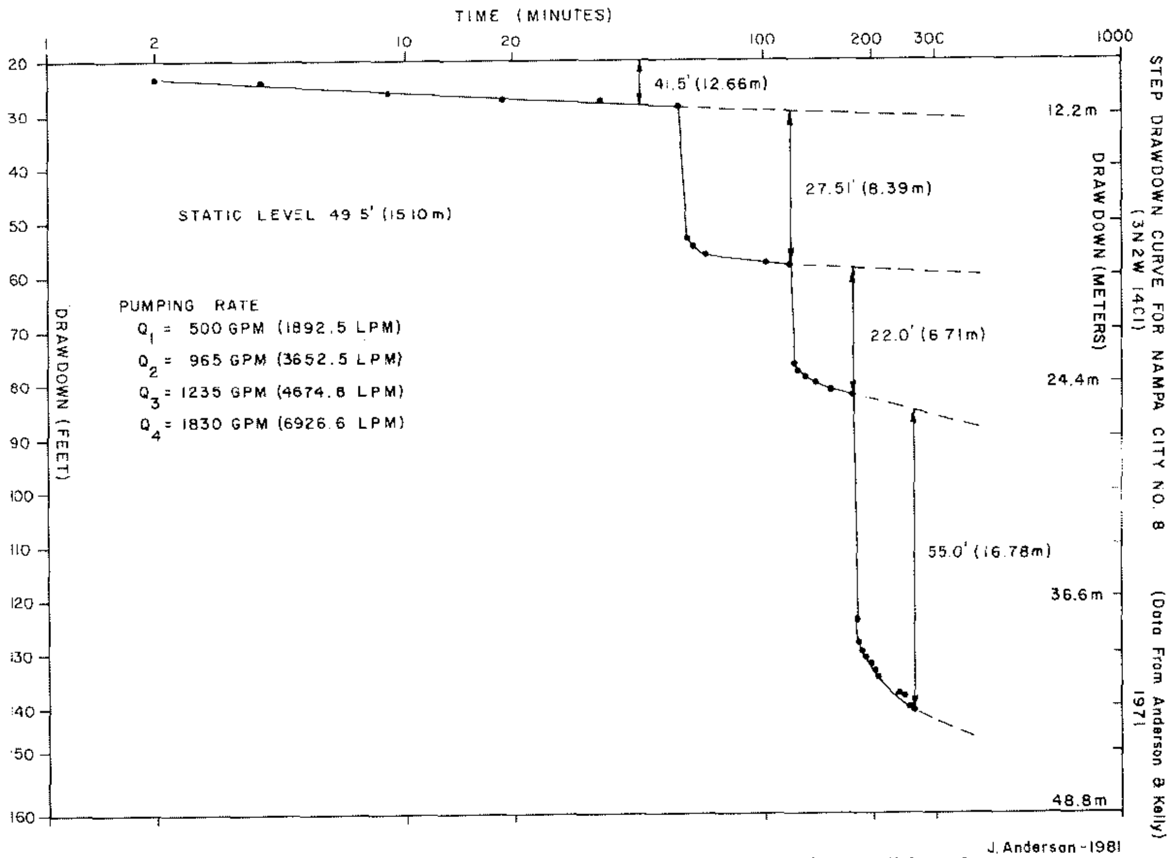

FIGURE 3-5. Drawdown curve for the Nampa City well No. 8.

wells and several observation wells (Nace, West and Mower, 1957). The resulting data on the hydrologic characteristics of the units tested are given in Table 3-1. Well-interference tests were made on the Idaho State School well (3N-2W-14ada1) and the City of Nampa well No. 8 (3N-2W-14c1) by Anderson and Kelly engineering consultants (Kelly, 1976, written communication). The City of Nampa No. 8 well is completed in three sand units, each about 6 m (20 ft) thick, between 122 and 184 m (400 and 605ft). The Idaho State School well is completed in two sand units each about 8 m (25 ft) thick between 116 and 165 m (380 and 542 ft) depth. Test pumping of the State School well for one day at 3936 l/min (1,040 gpm) lowered the water level in the Nampa No.8 well by 0.56m (1.8ft). Temperature of water was 20°C (68°F). Analysis of drawdown of the No. 8 well by Kelly (1976) suggests a transmissivity of about 2480 m^2/day (26,700ft^2/day) and a dimensionless storativity of $6x10^{-4}$. Drawdown in the State School well was 13 m (43 ft) indicating a well capacity of 289 l/min (24 gal/gal/ft) of head decline. Analysis of the recovery of the State School well indicates transmissivity of about 2,000m^2/day (21,400 ft^2/day). Drawdown curves for these two wells are shown in figures 3-4 and 3-5.

The resistivity logs of the Higgenson No. 1 well near Meridian (figures 2-3 and 2-9) can be used to compare these tested, shallower sand aquifers at 120 to 180 m (400 to 600ft) to the deep and warmer sand aquifers between 418 and 564 m (1,370 and 1,850 ft) depth. The (LL8) trace reads the resistivity of the annulus invaded by filtrate from the drilling mud, and the (DIL) trace should be a record of true formation resistivity. The resisitivity-log separation between the DIL trace and the LL8 trace is 100 to 300 ohm-m^2/m in the shallower sands, and between 30 and 50 ohm-m^2/m for the deep aquifers within the lower Idaho Group. Resistances of the annular zone invaded by the mud filtrate (LL8 reading) are about 100 and 50 ohm-m^2/m for the shallow and deep sands, respectively. Mud filtrate resistivity measured by Schlumberger is 3.2 ohm-m^2/m. Because the resistivity of the invaded zone in the deep and shallow sands is similar (within a factor of 2), both sands probably have similar permeability. The decrease in separation of the LL8 and DIL resistivities with depth may be caused by either increased temperature and/or increased ion content of the deeper formation water. The sands between 418 and 564 m (1,320 to 1850ft) have a logged temperature of 45°C. This temperature increase of 25°C would theoretically decrease the resistivity of 100 mg/l NaCl water from 55 to 35 ohm-m^2/m, or about a 20 ohm-m^2/m. A salinity increase from 100 mg/l to 600 mg/l and the same temperature increase would decrease the resistivity of the formation water about 50 ohm-m^2/m. Thus, the large decrease in resistivity separation can be partly accounted for by increasing temperature and total dissolved solids in deeper formation waters.

Deeper sandstone aquifers within the basalt section are discussed briefly in Chapter 6. Evaluation of sandstone aquifer characteristics in these zones might be possible when formation-test data and logs are released from the Deer Flat No. 1 well in the spring of 1982.

In summary, geothermal waters of moderate temperature suitable for space heating can be expected at depths of 450 to 1200 m (1,500 to 4,000 ft) over most of the Nampa-Caldwell area. Oil and gas wildcat wells have explored the subsurface, but the deep water-bearing units have not been tested to assess their water producing capacity. The most favorable drilling targets are along the major youthful faults detected by the seismic reflection survey (Chapter 6). Areas of proven warm water wells at shallower depths, 200 to 300m (600 to 1,000ft), generally lie in the area around Lake Lowell and south to the Snake River. North of this area few warm water wells have been drilled, and locations of warm water wells are spotty. These anomalously warm wells are probably located near fault zones with fracture permeability that serve as conduits for ascending warm waters.

CHAPTER 4 — GEOCHEMISTRY

By
John C. Mitchell[1]

STABLE ISOTOPE INVESTIGATION

Isotopes are two forms of the same element which differ only in the number of neutrons (uncharged atomic particles) in the nucleus of the atom. This means that different isotopes of the same element will differ only in their relative mass. It is this mass difference that governs their kinetic behavior and allows isotopes to fractionate during the course of certain chemical and physical processes occurring in nature.

The four stable isotopes that have proven most useful in water resource evaluation are hydrogen (^1H or H), deuterium (^2H or D), oxygen 16 (^{16}O) and oxygen 18 (^{18}O). These isotopes make up 99.9 percent of all water molecules.

Isotopic compositions are reported in " δ " notation in parts per thousand (per mil = ‰) relative to Standard Mean Ocean Water (SMOW) as defined by Craig (1961b), where $\delta\ i = [(R_i/R_{std} - 1 \times 1000]$. R_i equals either $^{18}O/^{16}O$ or D/H while i and std represent the sample and standard, respectively.

The result of isotopic fractionation during evaporation of ocean water and subsequent condensation of vapor in clouds is that fresh (meteoric) water is generally depleted in ^{18}O and D (enriched in ^{16}O and H) compared to seawater. The isotopic variations of water in rain, snow, glacier ice, streams, lakes, rivers and most nonthermal groundwaters are extremely systematic; the higher the latitude or elevation, the lower (more depleted in heavy isotopes) the δD and $\delta^{18}O$ values of the waters. On the basis of a large number of analyses of meteoric waters collected at different latitudes, Craig (1961b) showed that the $\delta^{18}O$ and δD values relative to SMOW are linearly related and can be represented by the equation:

$$\delta D = 8\delta^{18}O + 10$$

which is plotted in figure 4-1. Groundwater sampled in an area whose isotopic composition plots on the trend (meteoric water) line are generally considered to be meteoric waters. Gat (1971) reported that incongruous results in isotope hydrology studies have generally been interpreted to mean: (1) geographic displacement of groundwaters by flow, (2) recharge from partially evaporated surface waters, (3) recharge under different climatic conditions, (4) mixing with nonmeteoric water bodies—brines, sea-water, connate, metamorphic or juvenile waters, (5) differential water movements through soils or aquifers which result in fractionation processes (membrane effects), and (6) isotopic exchange or fractionation between water and aquifer materials. Several of these processes tend to be distinctive, either in enriching or depleting the waters in heavier isotopes, and can be recognized. Others tend to be similar in results; therefore, interpretations may be ambiguous.

[1] Idaho Department of Water Resources.

Sampling

Sites for isotope sampling in the Nampa-Caldwell and adjacent areas were chosen on the basis of well log data on file at Idaho Department of Water Resources. Casing records, well depths, lithologies penetrated, measured surface temperature and structural geology considerations, so far as known, were considered. Landsat images of the western Snake River Plain were studied to locate sample sites on or near lineaments passing through the Nampa-Caldwell area based on the hypotheses that the lineaments might be migration channels through which recharge waters moved into the Nampa-Caldwell area. However, sampling was restricted by lack of proper access ports at well heads from which reliable isotope samples could be obtained. Consequently, about half the sample sites were determined by accessibility. Rivers (except the Boise, inadvertently omitted), lakes and canals in, and adjacent areas outside the area of study, were also sampled. Boise River water should be similar isotopically with Lake Lowell inlet waters as Lake Lowell inlet waters are derived from the Boise River. A total of 40 samples were analyzed by mass spectrometry by Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, MA. On the basis of duplicate samples and analyses the data appear to be precise within 1 ‰ for δD and 0.2 ‰ for δ^{18}O. These data are given in Table 4-1, and sample locations are shown on figure 4-2 and figure 4-3 (in pocket). The data are shown plotted as δD and δ^{18}O in per mil units on figure 4-4.

Observations

From Table 4-1 the range of δD values for thermal waters (> 20°C) sampled in the Nampa-Caldwell area is from −136 to −151 ‰. The range of δ^{18}O values is from −15.5 to −18.0 ‰. For cold waters (<20°C) sampled in and around the Nampa-Caldwell area, the range of δD values is from -123 to -135 ‰, and the δ^{18}O of cold waters ranges from -15.0 to -16.7 ‰. The thermal waters are therefore depleted by about 20‰ in δD and by about 2.3‰ in δ^{18}O relative to cold water from in and around the Nampa-Caldwell area.

As shown by figure 4-1, the Nampa-Caldwell waters are somewhat similar to other geothermal waters in Idaho. They most closely resemble waters studied by Rightmire, Young, and Whitehead (1976) and Young and Lewis (1980) in the Bruneau-Grand View area but are displaced still further to the right of the meteoric water line and exhibit a somewhat greater spread between thermal and nonthermal water. This heavy isotope enrichment for cold waters (displacement to the right of meteoric water line) is typical of some arid and semiarid localities. The isotopically lighter thermal waters (displaced downslope from cold waters) are, however, distinctive. Figure 4-1 shows that all of the high temperature thermal waters are derived from meteoric waters on their trend line, while the thermal waters from Weiser, Bruneau-Grand View and Nampa-Caldwell areas cannot be derived directly from the plotted nonthermal waters.

Figure 4-4, which is an enlarged version of a portion of figure 4-1, shows that most of the data fall on, or near, one of a group of straight lines that converge to intersect well 2N-3W-27bab1 at a δD of -150 ‰ and a δ^{18}O of -18‰. Most cold waters sampled are observed to plot in the upper right portion of the graph near the upper right extremities of the lines. Exceptions are those samples of thermal waters taken outside the Nampa-Caldwell area, which also plot in this section of the diagram. Most thermal waters plot in the lower left portion of the plotting field.

TABLE 4-1

Isotope Sample Locations, Measured Surface Temperature, δD, δ¹⁸O, Cl and F Values from Sampled Water in the Nampa-Caldwell and Adjacent Areas of Southwest Idaho

Sample or Well No. (Location)		Measured Surface Temperature (°C)	$\delta^{18}O$ SMOW ‰	δD SMOW ‰	Cl mg/l	F mg/l
7N-4W-22aca	Payette R., Gem Co.	12+	-14.4	-125	-	-
7N-2E-15daa	Payette R., Boise Co.	-	-14.6	-124	-	-
6N-1W-25bbd1	Willow Cr., Gem Co.	23	-14.2	-124*	6.3	-
5N-1E-35aca1	Dry Cr., Ada Co.	40	-16.9*	-143	4.9	11
5N-1E-36bdb1	Dry Cr., Ada Co.	24	-15.4	-128	-	-
4N-4W-04dcc1		21	-17.7	-147	5.9	-
4N-4W-05dbd1		24	-17.3	-145	6.2	-
4N-3W-19adc1	Richardson #1	40	-17.2*	-142*	5.8	1.5
3N-2E-10acc1	Capitol Mall #1, Ada Co.	65	-17.0	-141	6.9	16.9
3N-3W-03bbc1		19	-15.6	-128	21.	.57
3N-3W-30ddd1		16	-16.5	-137	98.	.60
3N-2W-14ada1		22	-17.4	-138	14.	.50
3N-2W-17bcb1		24	-16.3	-136	6.1	1.00
3N-2W-23bcd1		31	-17.1	-151	4.1	1.9
3N-2W-26ddb1		18	-16.6	-135	38.	.68
3N-2W-31bbb1		15	-15.9*	-132	104.	.43
3N-2W-31dcb1		15	-16.7	-138	-	-
2N-3W-08cdd1		22	-16.8	-141	24.	.61
2N-3W-22acd1		26	-17.4	-143	26.	.69
2N-3W-22bdc1		28	-17.6	-147	16.	.50
2N-3W-25bda1		26	-16.5	-146	7.1	1.6
2N-3W-27bab1		30	-18.0	-150	11.	.85
2N-3W-35caa1		28	-17.6	-147	8.1	1.3
2N-2W-04dca1		23	-17.0	-144	20.	2.3
2N-2W-06aba1		15	-15.9	-131	-	6.3
2N-2W-16daa1		26	-17.1*	-139	16.	1.0
2N-2W-16dba	Lake Lowell Inlet	13+	-16.5	-132	21.	.4
2N-2W-18bab1		14	-16.1	-138	7.1	.55
2N-2W-34aac1		29	-16.3	-140*	28.	3.6
2N-2W-34bda1		51	-17.0	-142*	11	4.3
2N-2W-34daa1		31	-17.0	-142	11	2.4
1N-2W-03cab1		20	-16.5	-138	9.9	-
1N-2W-03cbb1		20	-16.3	-138*	-	-
1N-2W-08acb1		21	-16.7	-139	74.	.36
1N-2W-09bba1		22	-15.8	-141	24.	.34
1N-2W-09ccb1		24	-17.0	-142	38.	.75
1N-2W-17dcc1		21	-16.2	-139	165.	.38
1S-2W-17abb1		21	-17.3	-142	14.	4.7
1S-2W-17bad	Snake River near Walters Ferry Bridge	12+	-16.5	-133	21.	.4
2S-3W-36daa1	Reynolds, Owyhee Co.	8	-15.0	-123	25. x	-

* Average of two analyses or samples.
\+ Average water temperature over one year period from 12 monthly averages.
\- Data not available.
x Average chloride of 4 analyses each from six wells.

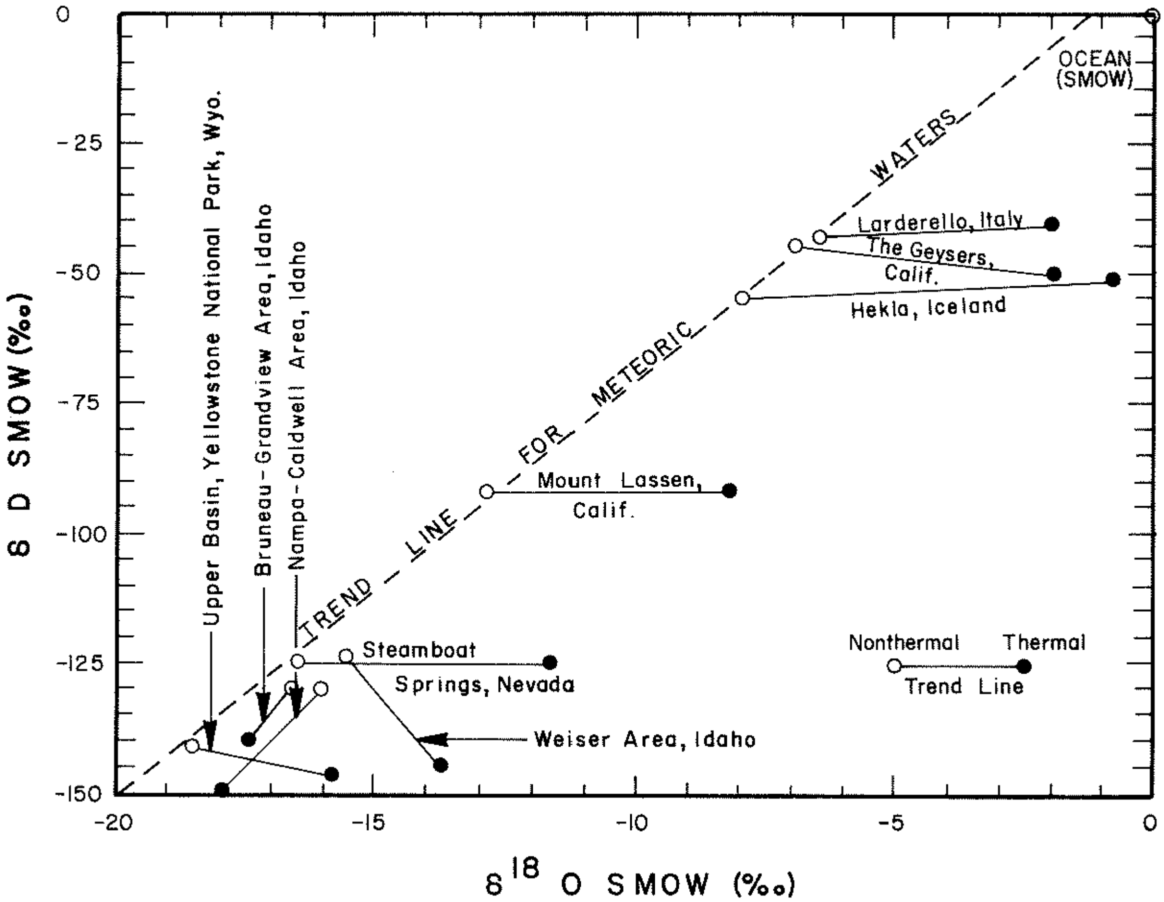

FIGURE 4-1. Isotopic composition of thermal and nonthermal waters of the Nampa-Caldwell area, Canyon County, Idaho compared with selected meteoric and thermal waters of Idaho and the world. Modified from Rightmire et. al. (1976) after White et. al. (1973).

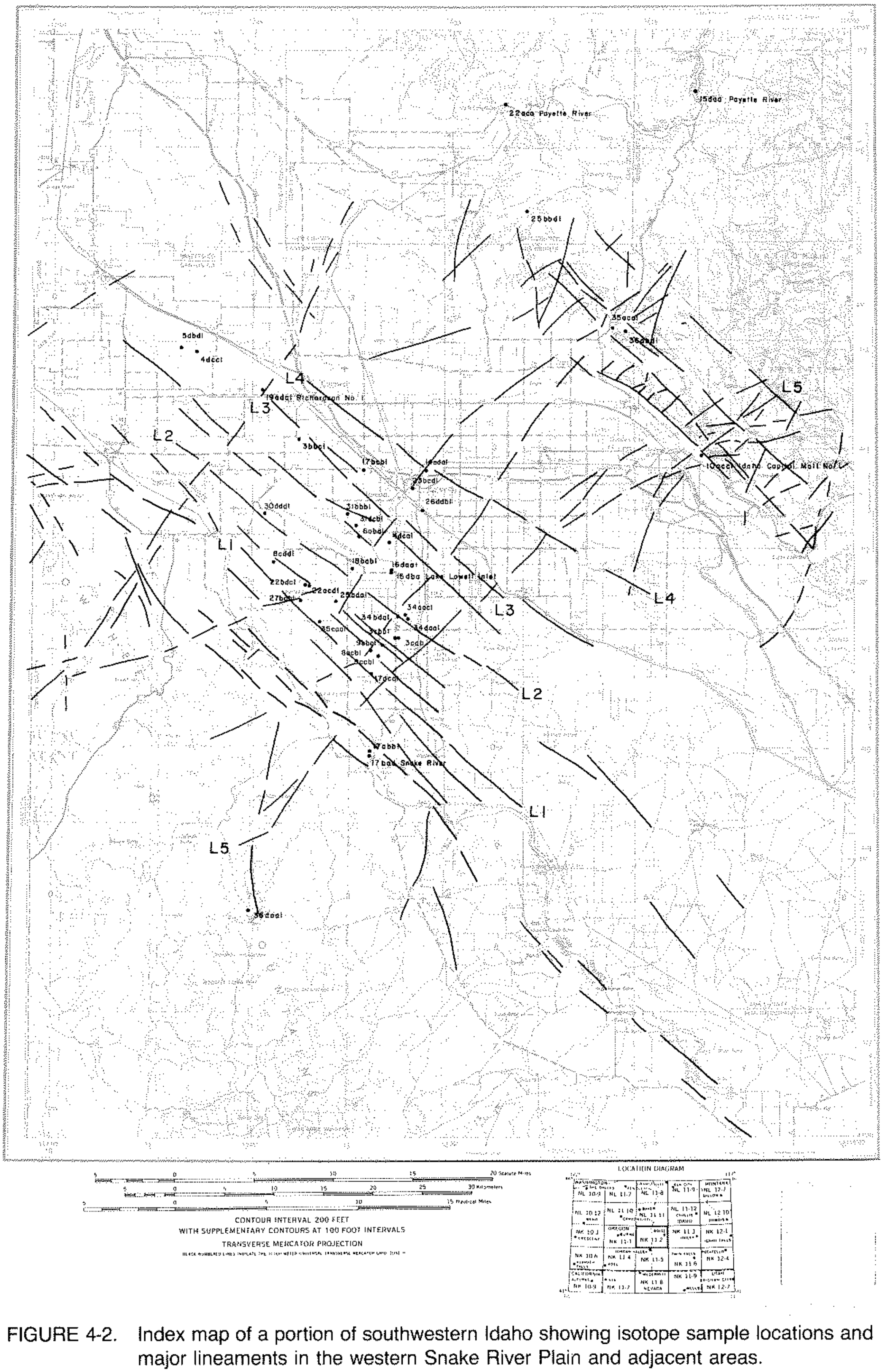

FIGURE 4-2. Index map of a portion of southwestern Idaho showing isotope sample locations and major lineaments in the western Snake River Plain and adjacent areas.

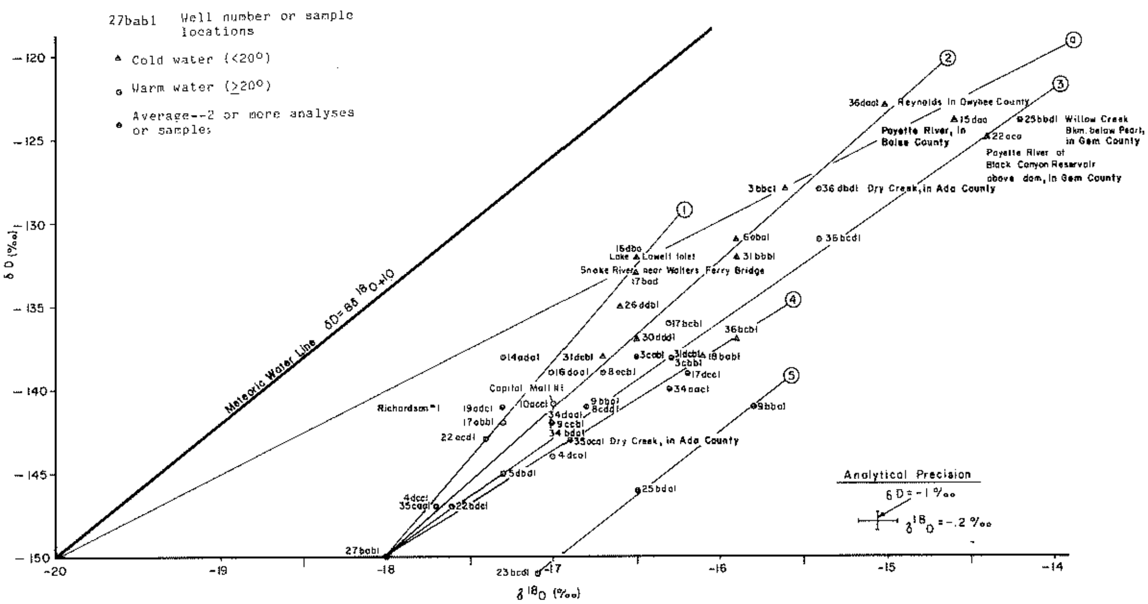

FIGURE 4-4. Isotopic composition of thermal and nonthermal waters from selected wells and surface waters in the Nampa-Caldwell area.

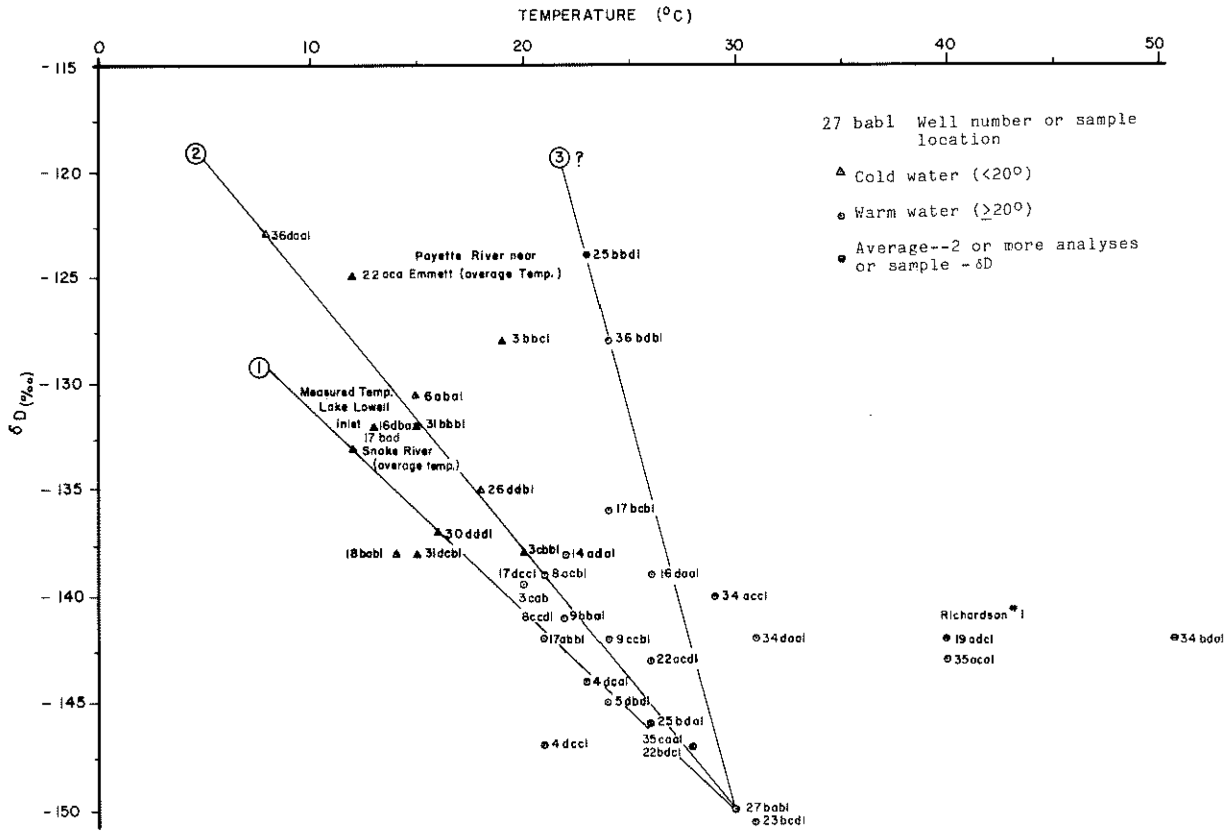

FIGURE 4-5. Measured surface temperatures of selected wells and surface waters versus δ D in the Nampa-Caldwell and adjacent areas of southwestern Idaho.

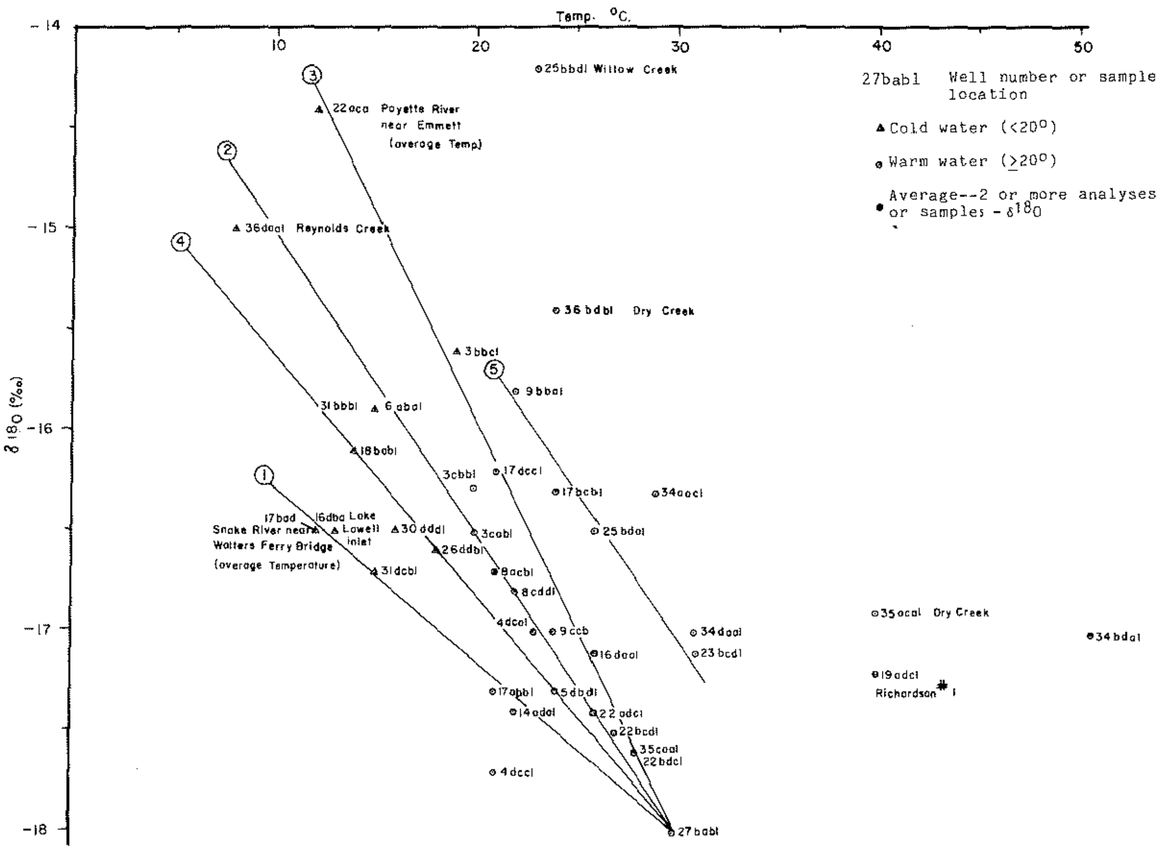

FIGURE 4-6. Measured surface temperatures of selected wells and surface waters versus $\delta^{18}O$ in the Nampa-Caldwell and adjacent areas of southwestern Idaho.

It should be noted that other straight lines can be drawn through other data points (i.e., line a, and a line from 6N-1W-25bbd1 to 4N-3W-19adc1). Other straight line data do not include all data points, do not correlate with temperature data (see below), nor do they have cold waters as one end member and thermal water as the other.

Figures 4-5 and 4-6 are plots of measured surface temperatures of water from wells versus δ D and δ ^{18}O, respectively. Straight line plots are obtained for certain data points which again converge toward the sample from well 2N-3W-27bab1. Several points which do not fall on any of the established converging lines generally are higher temperature water from deeper wells or water from thermal wells sampled outside the Nampa-Caldwell area. A comparison of figure 4-4 with figures 4-5 and 4-6 reveals a 63% correlation of data points for line 1. If deep water data are not included, the correlation is 71%. A comparison of figure 4-4 with figures 4-5 and 4-6 for line 2 reveals a 67% correlation between figures 4-4 and 4-6. If deep water data is ignored, the percent correlation is 75%. Table 4-2 summarizes the common data points of lines 1 and 2 for figures 4-4, 4-5 and 4-6. There is little or no correlation for line(s) 3-4(?) data on figures 4-4, 4-5, and 4-6 as there is considerable scatter in the data related to line(s) 3-4(?) of figure 4-4 when compared to line 3 of figures 4-5 and 4-6. The argument can be made that line(s) 3-4(?) of figure 4-4 are really one line which would fall between lines 3 and 4. Due to the window of analytical precision, the lines cannot be separated. Line 5 data appears on figures 4-4 and 4-6 only. On figures 4-5, line 5 data plots on line 2.

Plots of fluoride and chloride versus δ D and $\delta^{18}O$ were studied in an effort to determine if changes in their concentration were related to the isotopic composition of the water. The figures merely showed that dissolved concentrations of these elements are low in the sampled waters and are not related to the isotopic composition; therefore, the diagrams are not included as part of this report.

Discussion

There are several interpretations or theories which might be applied to explain the above mentioned observations of the data plotted in figures 4-1, 4-4, 4-5 and 4-6. White, Barnes and O'Neil (1973), and Truesdell and Hulston (1980), interpreted data of a similar nature to that of figure 4-4 from the California coast ranges and Long Valley, California to represent fluid mixtures, in various proportions, of end member waters. Water from well 2N-3W-27bab1 may represent unmixed geothermal water from the Glenns Ferry Formation derived from an aquifer within or below the "blue clay" (see Chapter 3 of this report for a discussion of the "blue clay"). Records for this well show unperforated casing extending from within the "blue clay" layers to the surface. Most other wells in the Nampa-Caldwell area are perforated, either continuously, or in various zones or have large sections of hole uncased. The drillers logs show that many wells take water from several zones. Well 2N-3W-27bab1 water may therefore, represent one parent water from which most other well waters of the Nampa-Caldwell area are derived. The other parent water(s) may be represented by either Lake Lowell or Snake River water, (line 1) Reynolds, or similar elevations (line 2), or Payette River and/or Willow Creek water (line 3). Data points falling on or near the lines could represent mixtures of the parent waters in various proportions. Well 1S-2W-17abb1, which plots on the Snake River mixing line (line 1), was drilled within a few hundred meters of the Snake River. Well 4N-3W-19adc1 (Richardson No. 1, line 1) may be a mixture of water represented by water from well 2N-3W-27bab1, Lake Lowell and/or Snake River, or perhaps Boise River water. The temperature depth profile (from Smith, figure 5-13) indicates water

TABLE 4-2

Correlation Of Data Points for Line 1 And 2
Between Figures 4-4, 4-5, and 4-6

Line 1 Data			Line 2 Data		
δD vs. $\delta^{18}O$ figure 4-4	δD vs. t figure 4-5	$\delta^{18}O$ vs. t figure 4-6	δD vs. $\delta^{18}O$ figure 4-4	δD vs. t figure 4-5	$\delta^{18}O$ vs. t figure 4-6
16dba	16dba	16dba	36daa1	36daa1	36daa1
17bad	17bad	17bad	3bbc1		
16daa1			6aba1	6aba1	6aba1
19adc1**			31bbb1	31bbb1	31bbb1
17abb1	17abb1	17abb1	26ddb1*	26ddb1	26ddb1
22acd1			30ddd1		
4dcc1***	4dcc1	4dcc1	31dcb1		
27bab1*****	27bab1	27bab1	8acb1	8acb1	8acb1
			34daa1		
			9ccb1	9ccb1	9ccb1
			34bda1**		
			35cca1	35caa1	35caa1
			22bdc1****	22bdc1	22bdc1
			27bab1*****	27bab1	27bab1
			10acc1**		

* Probably analytical or sampling error, see text.

** Thermal water from sources deeper and hotter than the aquifer from within the "blue clay."

*** Conductively cooled (?) water, see text.

**** In this region of the graphs, lines are so close together as to lie within each others "window" of analytical precision. It is difficult to assign a given value to a given line. Sample 22bdc1 has been assigned to line 2, as temperature verses δD and $\delta^{18}O$ graphs of figures 4-5 and 4-6 indicate that this is a more reasonable location.

***** In making the percent calculation, the sample from well 2N-3W-27bab1 was included in the calculation for both lines 1 and 2 of Table 4-2. The argument can be made that the data is therefore biased in favor of the mixing hypothesis. If the data point from well 2N-3W-27bab1 is not included, the agrument can be made that this has biased the data in favor of some other hypothesis. If the data point is not included in the percent correlation of lines 1 and 2 data of Table 4-2, the correlation is still greater than 50 percent with the other reasonable assumptions included. The correlation is considered significant and can only be adequately explained by mixing of thermal and nonthermal waters in various proportions with no conductive cooling. Note line 5 date not included.

from well 4N-3W-19adc1 is a mixture from at least three zones. A thermal water temperature of 63°C was recorded at a depth of 650 m (2,130 ft.) in well 4N-3W-19adc1. The temperature was still rising with depth when the end of the cable for the downhole temperature probe was reached at 650 m. Deeper penetration into the well bore could not be achieved with available equipment. The fact that isotopic data from wells 4N-3W-19adc1 and 2N-2W-34bda1 (surface temperature 48°C) plots on lines 1 and 2, respectively, of figure 4-4, indicates that the deep water is isotopically identical to water from the aquifer within the "blue clay" represented by water from well 2N-3W-27bab1. On line 2, well 2N-2W-34bda1 may represent water which is a mixture of 2N-3W-27bab1 type water with a water represented by well 2S-3W-36daa1 near Reynolds in Owyhee County 50 air kilometers due south of Caldwell in the Owyhee Mountains, or water from similar elevations. The ratio of the length of the line segment connecting data points 2N-3W-27bab1 and 2N-2W-34bda1, to the length of the segment connecting 2N-2W-34bda1 and 2S-3W-36daa1 (line 2, figure 4-4), represents the fraction of the hot water end member. These data indicate that a significant proportion of the recharge for the shallow groundwater (above the "blue clay") may come from the aquifer within or below the "blue clay," and also from several other sources, including perhaps Reynolds Creek Basin, or similar elevations, Lake Lowell, the Snake River through applied irrigation and possibly leakage from Lake Lowell and its canal systems. The direct temperature-isotope dependence for the data points on lines 1 and 2 of figures 4-5 and 4-6 is a result that would be expected if the waters are mixtures of warm and cold water from two sources. In mixing of warm and cold water (no other processes taking place) the resultant temperature of the mixture would depend only on the initial temperatures of the warm and cold waters and their volumes involved in mixing. Isotopic composition of the mixed water would also be proportional to the volumes of end member waters.

The temperature-isotope dependence, therefore, is not interpreted as being caused by depletion or enrichment due to kinetic responses of the isotopes, but rather to mixing of parent waters of different isotopic compositions; one warm, the other cold, in various proportions, primarily within well bores as the result of well construction with little conductive cooling after mixing. Some mixing within aquifers may also occur.

Water isotope data from several wells which plot on line(s) 3-4(?) of figure 4-4 are known from chemical analysis (see section on Chemical Data, this chapter) to be high in nitrate and/or sulfate. These include wells 4N-4W-5ddd1, 2N-3W-8cdd1, 2N-2W-18bab1, 34bda1, 34aac1, 1N-2W-3cbb1 and 17dcc1. Water isotope data from wells 3N-2W-26ddb1 and 31bbb1 (also high in nitrate) plot on line 2 of figure 4-4. Stevens (1962) reported high nitrate-sulfate waters in southern Canyon County to be mixtures of native Glenns Ferry Formation water (present terminology) with applied irrigation water or recycled water. The water isotope data along line(s) 3-4? have lower δD values (are more depleted in D) or have higher $\delta^{18}O$ values) relative to data on other lines. Intuitively, these waters, if evaporated sprinkler or corrigate applied irrigation waters as suggested by the chemical data, should show higher δD and $\delta^{18}O$ values (show enrichment in both D and ^{18}O). Therefore, for these waters factors other than simple mixing, evaporation, or added nitrate and/or sulfate may be involved. Insufficient data are available on line 1 to suggest that these data fit Stevens (1962) criteria for mixed canal seepage Glenns Ferry Formation water. Water from Reynolds Creek Basin or similar elevations (line 2 data) or Payette River water (line 3 data) would probably be modified by aquifer influences during migration into the Nampa-Caldwell area and chemical criteria may not be of help in identifying these as sources.

Various points of figures 4-4, 4-5 and 4-6 do not fall on any lines and this could be due to several processes including isotope exchange reactions with aquifer or permeable zone constituents, seasonal changes in isotopic composition of the recharge water, multiple mixing, conductive and/or convective cooling of mixed waters, or waters from deeper and hotter aquifers with the same or different isotope ratios, or analytical or sampling errors. The high measured surface temperature of water from well 4N-3W-19adc1 (Richardson #1) and 2N-2W-34bda1 arises because the water from these wells ascends rapidly from hotter sources deeper than the "blue clay" aquifer.

An example of conductive or convective cooling might be represented by water from well 4N-4W-4dcc1 which plots on line 2 of figure 4-4, but plots 6.5°C to the left of line 2 on both figures 4-5 and 4-6. If 6.5°C is added to the temperature of this well, it will also plot on line 2 of both figures 4-5 and 4-6. Perhaps, after mixing, the water cools by 6.5°C by conductive or convective heat transfer as the water flows through the aquifer and up the well bore.

An example of sample or analytical error might be shown by water from well 3N-2W-26ddb1 which plots on line 2 of figure 4-5 only. If a $\delta^{18}O$ value of -.3 ‰ is subtracted from the $\delta^{18}O$ value of -16.6 ‰ reported in the analyses for well 3N-2W-26ddbl, this data will plot on line 2 of figures 4-4, 4-5, and 4-6. The parallelism of line 5 to line 2 of figures 4-4 and 4-6 suggests that a systematic error, either in the sampling or analyses of line 5 data, is possible. If -.9‰ to -1.0 ‰ is added to the $\delta^{18}O$ values found in Table 4-1 this data will plot on line 2 of figures 4-4 and 4-6, as it does in figure 4-5. The sample from well 3N-2W-23bcd1 (line 5) was taken from a 100 meter long, 15 cm diameter discharge pipe only partially full of water. This may have allowed atmospheric gasses to mix with the water, or more importantly, allowed some evaporation of thermal water to take place before sample 3N-2W-23bcd1 was collected. Steam was seen emerging from the discharge pipe along with the thermal water when this well was sampled. The slight depletion in δD (1 ‰) over sample 2N-3W-17bda1 could be due to Rayleigh type (non-equilibrium) evaporation from sample 3N-2W-23bcd1. This might indicate two wells in the area with parent geothermal water compositions near a δD = -150 and $\delta^{18}O$ = -18. The fact that errors in data or changes in temperatures are easily located is strong evidence for validity of the data interpretation.

Statistical analyses performed on the data for lines 1, 2 and 3 of figure 4-4 indicates a wave type function best fits the data of each of the individual lines. Sinisoidal type functions can be drawn through the data points with wave length about δD = 1 ‰ and amplitude of about $\delta^{18}0$ = 0.2 ‰. The wave length and amplitude decrease downslope becoming much less pronounced in the thermal region of the plot. The cause of this slight deviation from straight line fit is not known, but it may be due to slight seasonal variations in isotope values in cold recharge waters. Upon mixing with thermal waters the effects of these seasonal variations may become diluted, thereby producing the observed smaller amplitude and wave lengths toward the thermal region of the plot.

Line a of figure 4-4 represents a line of slope 5 which runs through Lake Lowell (16bda) and Snake River (17bad) data points (R.H. Mariner, 1981, personal communication). The fact that several lines of slope 5 can be drawn through the data of figure 4-4 may be indicative of the effects of evaporation to dry air of meteoric water before recharge to the ground water system. This could indicate a pre-evaporation isotopic composition δD = -150 ‰ and $\delta^{18}0$ = -20 ‰ (Ellis and Mahan, 1977 p. 75). Thermal water of isotopic composition δD = -150 ‰ and $\delta^{18}0$ = -18 ‰ could be derived from the pre-evaporated water composition by an enrichment in $^{18}0$ of 2 ‰ in the parent thermal water brought about by oxygen isotope exchange of water with aquifer or reservoir minerals. Exchange of oxygen isotopes could take place at fairly low temperatures in volcanic ash formations, such as the Sucker Creek Formation, provided sufficient glassey material and permeability is available (H.W. Krueger, A.B. Muller, 1981, personal communication). Isotopic exchange is the generally accepted method of explaining the trend line (oxygen shifts) observed in isotopic compositions of water from many of the higher temperature geothermal systems (Larderello, Geysers, Heckla, Mount Lassen and Steamboat Springs) of the world (figure 4-1). Pre-evaporation isotopic compositions of Payette River, Boise River and Snake River water are unknown at present but might be similar to integrated isotopic values of spring water within upper reaches of their drainage basins. River waters, particularly Snake River water, would be modified by many influences during downstream flow and pre-evaporation isotope values might be difficult to obtain. δD isotope values of meteoric waters in recharge areas of the Payette River drainage basin seem to be near -128 to -131 ‰ (Lewis and Young, 1980) and in the Boise River drainage basin may be near -135 to -139 ‰ . This would seem to rule out the Payette and Boise river upper drainage reaches as sources of recharge of the goethermal parent water with subsequent ^{18}O enrichment by isotopic exchange, provided the isotopic composition of spring waters in upper reaches of these drainages is indicative of pre-evaporative isotopic composition of the river water. These conclusions are speculative and more data investigating the possibility of recharge to the thermal systems from river waters, including the Bruneau River in Owyhee County, are needed before the conclusions can be substantiated.

Several other lines parallel to line a (slope 5) might be drawn through the data on figures 4-4. These lines do not include all data points, do not correlate with temperature data, do not have cold waters as one end member and thermal water as the other, lead to even lower δD values than exist in the thermal waters if interpreted as evaporation lines and would mean that all water from nearly every sampled well has undergone differing amounts of evaporation from five or six unidentifable sources, a conclusion which seems highy unlikely. These lines are not considered further in this report.

Regarding the origin of the geothermal water, Rightmire, Young and Whitehead (1976) interpret light thermal waters, or displacement downslope for thermal water in the Bruneau-Grandview and Weiser areas, to mean precipitation at higher elevations where climatic conditions are cooler or precipitation during a period of time when the climate was cooler than that prevailing today. Cooler temperatures at higher elevations will result in depleted isotope values, but these should be reflected in cold water in the sampled thermal area also, unless the cold water is recharged at lower elevations. A time period which was generally cooler than the Holocene (present) geologic Epoch was the Pleistocene Epoch or ice age that ended approximately 7,800 to 11,000 years ago. Young and Lewis (1980) proposed that Bruneau-Grand View area thermal waters might be at least 2,400 to 3,300 years old and could be be as much as 8,000 years old, or older, or could have come from elevations of 460 to 825 m (1,500 to 2,700 ft) higher in elevation than cold springs they sampled. Mayo (1981, personal communication) reported that thermal waters in the Blackfoot Reservoir area of southeastern Idaho have been age dated at 14,000 to 36,000 years old. If Pleistocene precipitation is the source water, then circulation times for recharge of the thermal aquifers may be relatively long (7,800 to 11,000 years or greater if old water is being displaced by new recharge), or there may be relatively little present day recharge for the system. Relatively little present day recharge could mean the waters are being depleted.

Water levels in wells in the Bruneau-Grand View area were reported by Young and Whitehead (1973) to have declined, which suggests depletion of water or recharge insufficient for present withdrawal (recharge over long periods). Stevens (1962) noted rising water levels in wells in the Dry Lake area south of Lake Lowell, which he attributed to increased irrigation from surface water. Recently, however, water levels were noted to drop sharply, as much as 15 m (50 ft) in one year (NormanSvaty, personal communication, 1979). This could reflect additional groundwater pumpage or the drought conditions of 1976, which would indicate a recharge lag time of about 3 years (if drought related), but perhaps only for the aquifers above the "blue clay."

Alternate hypotheses which might explain the isotopically light (depleted) thermal waters in the Nampa-Caldwell area are: (1) exchange of hydrogen and oxygen isotopes between water and other hydrogen and oxygen containing sources within aquifers or permeable zones. Methane gas and some hydrogen sulfide is suspected in some wells in the area and organic debris was accumulated within the sediments as they were deposited. Methane gas, hydrogen sulfide, and organic accumulations could be a source of hydrogen. However, estimated aquifer temperatures do not seem high enough for appreciable exchange to have occurred and exchange of deuterium would result in enrichment rather than depletion (A.B. Muller, 1981, personal communication). (2) Fractionation of isotopes by semipermeable membrane processes in clays may also occur. Sufficient data is not available at present to evaluate this effect. (3) The thermal water may be isotopically lighter because of subsurface boiling and steam separation in deep aquifers with the separated steam phase recondensing and reequilibrating chemically in aquifers above those where steam separation occurs. Again, aquifer temperatures do not appear high enough at shallow depth where boiling could occur, and the isotope data do not show the characteristic oxygen shift of high temperature systems (figure 4-1) unless the evaporated river water hypothesis as a source of the geothermal water is accepted. (4)The trend line (line 2) could represent a meteoric water line for the Nampa-Caldwell and adjacent areas but this does not explain the separation of thermal and nonthermal waters, nor does it explain lines 1 and 3-4(?). (5) the data of figure 4-4 might be interpreted as two fold scatter with lines 1 and 3-4(?) representing data clusters due to (a) sampling or analytical inaccuracy or imprecision ($\delta D = \pm 1$ ‰, $\delta^{18}O = \pm 0.2$ ‰). Or, line(s) 3-4(?) might represent water that has been at higher temperatures and which might be oxygen shifted slightly. Hotter, older waters would be those that plot in the lower left portion of the plotting field, while cooler, younger waters from higher elevations would be those found in the upper right portion of figure 4-4. This would imply spatial relationships of the isotope data along directions of flow. No such relations have been found in the data. Many separate individual sources of cold and hot water would be required to explain each oxygen shift, and the divergent nature of the plots of figure 4-4 through 4-6 is not explained by these hypotheses.

Figure 4-7 is a modified plot of isotope data obtained by Young and Lewis (1980) from the Bruneau-Grand View area in southwest Idaho. Convergence of these data points to a water of the same composition as that of the parent geothermal water in the Nampa-Caldwell area ($\delta D = -150$ ‰, $\delta^{18}O = -18$ ‰) is indicated by the diagram. If the parent water is real in the Bruneau-Grand View area it would indicate (1) considerable mixing of thermal waters in the Bruneau-Grand View area, more so than previously realized, and (2) parent geothermal waters in both areas are from the same elevations or source and/or time, or the systems are interconnected. Also, isotope ratios from geothermal waters found in Ada County near Boise plot on lines 2 and 4. This could indicate that in the Boise area geothermal waters might be mixtures of geothermal water of near identical isotopic composition with

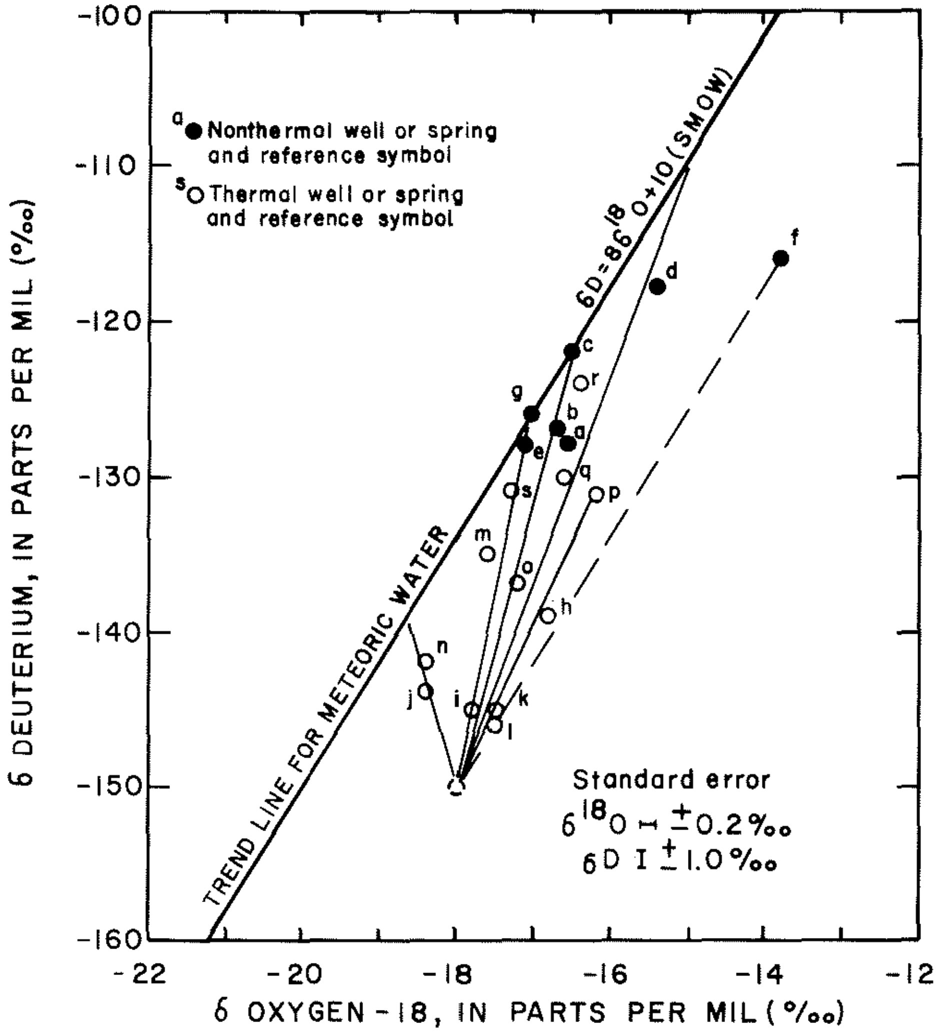

FIGURE 4-7. Isotopic compositions of thermal and and nonthermal waters from selected wells and springs in the Bruneau-Grand View and adjacent areas, Owyhee County, Idaho. Modified from Young and Lewis (1980, p. 19).

water from well 2N-3W-27bab1 and waters of isotopic composition similar to Payette River and/or Reynolds Creek water. However, more data from the Boise area are badly needed to confirm this assumption.

It appears, from the above arguments, that the hypothesis that most easily explains the isotopic data on lines 1 and 2 of figures 4-4 through 4-6 and agrees best with the known facts on the hydrology and geology, is mixing of thermal water of constant temperature and isotopic composition near a $\delta D = -150$ ‰ and $\delta^{18}O = -18$ ‰ with cooler waters of several distinctive isotopic compositions. This will be accepted as a working hypothesis until more data is available to substantiate or refute it. The origin of line(s) 3-4(?) data on figure 4-4, apparently involves thermal water represented by water from well 2N-3W-27bab1 with mixed irrigation or recycled water or water that has undergone systematic isotopic changes not presently recognized or completely understood. As no temperature-isotopic ratio correlation is observed for line(s) 3-4(?), factors other than simple mixing must be involved. Sampling of precipitation during various times of the year to obtain seasonal variations in the meteoric water may be the easiest way to substantiate or refute the mixing hypothesis.

The hypothesis that appears to best explain the origin of the thermal waters with available data in both the Nampa-Caldwell and Bruneau-Grand View areas is that of old water originating as precipitation during an extended time interval when climatic conditions were cooler than at present. Alternatively, the thermal water might have originated as evaporated river or lake water with subsequent ^{18}O enrichment through oxygen isotopic exchange with aquifer or permeable zone constituents at temperatures in excess of 100°C very deep ($>$ 1.5-2 km) within the geothermal system(s). [Such temperatures are known to exist in the area (Chapter 3)]. The easiest way to distinguish between the two hypotheses may be through age dating of the geothermal waters using unstable isotope techniques.

Isotope Data and its Relations to Lineaments

Figure 4-2 shows locations of major lineaments in the western Snake River Plain and isotope sample locations. The linear features were drawn from Landsat false color infrared images obtained from satellite data at 1:1,000,000, 1:500,000 and 1:250,000 scale, enhanced by the EROS Data Center.

Lineament features are noted that cross the Snake River Plain as well as those that nearly parallel the Plain axis as the majority of them do. The lineaments appear as faint cultural features and patterns, and, in the case of the lineaments parallel to the Plain's axis (northwest trending), they are associated with some parts of minor drainages which are parallel to the axis. Outside the culturally disturbed area, several of the lineaments parallel to the Plain's axis coincide with volcanic cones, buttes and domal structures. Some of the northeast trending lineaments (perpendicular to the Plain's axis) can be traced generally up draws or canyons into the mountain ranges flanking both sides of the Plain. In the culturally disturbed portion of the Plain, the lineaments represent edge of topographic features (hills, valleys and drainages) which force cultivation patterns that become apparent as linear features. These hills, valleys and drainages are thought, in some cases, to be fault bounded. Because of the huge scale of the features, these patterns are not apparent on the ground or on air photos. The correlation of lineaments parallel to the Plain's axis with volcanic features (L_1 and L_2, figure 4-2) indicates that some of these lineaments may represent some type of fault, fissure or perhaps a large scale deep seated joint system. Several correlate well with faults found on reflective seismic data (L_3 and L_4) and in the shallow well log data (L_1 and

L_4). The fact that several lineaments are seen to cross the Plain and extend into the mountain ranges on either flank may indicate that minor recurrent crustal instability could have occurred along the lineament after formation of the major features of the western Snake River Plain. The lineament (L_2) corresponds approximately with Stevens (1962 p. 20) groundwater divide. This lineament passes through Powers Butte, Initial Point and Little Joe Butte in southern Ada County. Other volcanic domes, cones and buttes are found in similar alignment along both sides of this lineament. The lineament could explain the groundwater divide (see Chapters 3 and 5, this report). Isotope data (figure 4-4) seem to ignore this divide as data from wells plotting on mixing lines 1, 2 and 3 are found on both sides of the divide. The divide apparently influences the shallow groundwater system and not the deep regional groundwater system (R.L. Whitehead, 1981, personal communication).

The warm water isotope data (line 2, figure 4-4) generally are found in wells near the Reynolds Creek-Freestone Creek lineament (L_5, figure 4-2), as might be expected if the lineament represents a migration path for recharge water into the Nampa-Caldwell area. The Idaho Capitol Mall No. 1 geothermal exploratory well was drilled near this lineament and did encounter a suspected fault (Anderson, 1981, p.9). Most cold water samples, except near Reynolds Creek, were taken from wells north of Lake Lowell. The position of the sampled cold water wells form a linear relation parallel to the Plain axis. However, well construction, zones perforated and aquifers penetrated may have more bearing on which line of figure 4-4 the isotope data from a particular well plots than does its location with respect to other geologic features.

The isotope data is considered remarkably consistent for an area as large as encompassed by this study and as complex as the water regime in the area appears to be. The isotope data furnish constraints within which interpretations of other geochemical data must lie in order to be considered valid.

CHEMICAL DATA

Water Classification

Water quality samples from 58 locations (figure 4-8 in pocket) in the Nampa-Caldwell area were collected for chemical analyses during the summer of 1979. Samples were run by the Idaho Department of Health and Welfare using standard methods of water analyses. Water quality data from various sources (mostly Stevens, 1962) are also shown in Table 4-3. Data from Table 4-3 show that groundwater in the Nampa-Caldwell area is not consistent in chemical composition. The pH values range from 7.7 to 8.8. Total dissolved solids ranges from 157 to 1571 mg/l, an order of magnitude difference. Calcium ranges from 1.6 to 175 mg/l and sodium from 16 to 726 mg/l. Fluoride ranges from .29 to 4.3mg/l, while chloride ranges from 5.8 to 240 mg/l. These are not extremely large fluctuations but are sufficiently inconsistent areally to make interpretations based on water chemistry alone uncertain.

Figure 4-9 is a trilinear plot of the Nampa-Caldwell water chemistry data. It shows the variability in chemical constituents of groundwaters in the area. The linear relations among certain wells on the plot might be interpreted as mixing, and, on the cation field, the plot seems to merge toward well 2N-3W-27bab1, as does the isotope data. The scatter of data, on the diagram makes simple mixing, except for a few wells in scattered locations, uncertain based on the trilinear diagram alone.

TABLE 4-3

Chemical Analyses Of Thermal and Nonthermal Waters From The Nampa-Caldwell Area Canyon County, Idaho (Chemical Constituents In Mg/1)

Spring or Well Identification Number and Name	Sample Collection Date	Measured Surface Temperature (°C)	Reported Well Depth below Land Surface (meters)	Discharge (est.) (l/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Phosphate (PO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Boron (B)	Ammonia (NH_3)	Specific Conductance (µmhos) (field)	pH (field)	Total Dissolved Solids (TDS)	Hardness: Carbonate	Hardness: Non-Carbonate	Alkalinity as $CaCO_3$	Percent Sodium (%Na)	Sodium Absorption Ratio (SAR)	Cation-Anion Balance (millequivalence)	Data Reference*
4N 4W 4DCC1	9/14/78	21	128.	295.	82	19.0	1.70	56	7.30	268.	0.0	1.70	0.06	6.2	1.80	0.06	-	-	350	7.6	307	54.	0.	220.	65.6	3.3	-11.765	2
4N 4W 5DBD1	9/19/78	24	-	227.	95	17.0	1.20	70	7.30	256.	0.0	2.50	0.04	5.9	1.60	4.40	-	-	355	7.7	330	47.	0.	210.	72.9	4.4	-4.479	2
RICHARDSON WELL NO. 1 4N 3W 19ADC1	9/11/78	40	-	189.	94	6.0	0.90	160	8.30	468.	0.0	3.20	0.02	5.8	1.50	0.07	-	-	680	7.8	509	19.	0.	384.	92.2	16.1	-2.804	2
3N 3W 3BBC1	6/29/79	13	34.	1514.	48	53.0	20.00	97	3.10	368.	0.0	78.00	0.11	21.0	0.57	7.10	-	-	826	7.3	508	214.	0.	302.	49.1	2.9	1.129	2
3N 3W 6DCD1	6/29/79	17	78.	757.	38	63.0	16.00	59	6.20	233.	0.0	124.00	0.01	41.0	0.49	2.60	-	-	733	7.2	464	223.	32.	191.	35.7	1.7	-2.984	2
3N 3W 16BDD1	6/29/79	11	30.	378.	41	41.0	11.00	83	4.20	234.	0.0	114.00	0.06	21.0	0.75	2.30	-	-	648	7.4	433	148.	0.	192.	54.1	3.0	-1.568	2
3N 3W 19DCB	6/29/79	23	-	-	2	21.0	4.30	16	2.10	111.	12.00	17.00	0.01	5.1	0.45	0.34	-	-	205	8.2	134	70.	0.	111.	32.4	0.8	-12.154	2
3N 3W 23CCC1	6/29/79	12	-	757.	45	36.0	11.00	39	3.30	190.	0.0	50.00	0.04	21.0	0.52	0.98	-	-	452	7.2	300	135.	0.	156.	37.9	1.5	-3.347	2
3N 3W 26BCA1	6/29/79	17	93.	757.	36	35.0	9.00	57	5.10	183.	0.0	74.00	0.03	25.0	0.58	0.72	-	-	486	7.2	332	124.	0.	150.	48.6	2.2	-1.854	2
3N 3W 30DDD1	6/14/79	16	-	757.	61	120.0	37.00	87	7.70	287.	0.0	265.00	0.04	98.0	0.60	0.27	-	-	1239	7.4	817	452.	216.	235.	29.1	1.8	-0.053	2
3N 3W 36ADC1	6/14/79	12	-	378.	38	53.0	13.00	75	2.30	238.	0.0	123.00	0.06	22.0	0.72	2.00	-	-	663	7.5	446	186.	0.	195.	46.4	2.4	-0.850	2
3N 2W 10ABA1	7/16/79	38	16.	114.	33	1.6	0.0	68	0.50	109.	17.00	19.00	0.08	9.0	14.00	0.07	-	-	314	8.6	215	4.	0.	118.	97.0	14.8	-10.194	2
3N 2W 14ADA1	9/12/78	22	213.	3406.	35	24.0	3.40	26	1.40	104.	0.0	36.00	0.02	14.0	0.50	0.74	-	-	225	7.7	192	74.	0.	85.	42.8	1.3	-4.415	2
3N 2W 17BCB1	9/12/78	24	23.	2271.	42	15.0	3.20	35	2.50	195.	0.0	6.40	0.02	6.1	1.00	0.53	-	-	230	7.6	207	51.	0.	160.	58.6	2.1	-15.662	2
3N 2W 23BCD1	9/12/78	31	57.	1703.	36	7.6	0.60	66	0.90	199.	0.0	1.90	0.03	4.1	1.90	0.17	-	-	300	7.7	217	22.	0.	163.	86.1	6.1	-2.740	2
3N 2W 26DDB1	6/ 4/79	18	34.	378.	37	83.0	20.00	87	5.40	298.	0.0	174.00	0.01	38.0	0.68	4.30	-	-	878	7.5	595	289.	45.	244.	39.0	2.2	0.117	2
3N 2W 31BBB1	6/14/79	15	49.	378.	42	140.0	34.00	121	7.10	257.	0.0	360.00	0.06	104.0	0.43	4.50	-	-	1339	7.4	939	489.	278.	211.	34.6	2.4	1.616	2
2N 3W 5BB 1	8/27/65	17	-	-	0	72.0	26.00	65	6.00	261.	0.0	126.00	0.0	51.0	0.0	22.00	-	0.52	845	7.3	496	287.	73.	214.	32.5	1.7	0.091	3
2N 3W 7AA 1	8/27/65	18	58.	-	-	67.0	19.00	52	4.00	413.	0.0	21.00	-	3.0	-	4.00	-	0.33	665	7.4	373	245.	0.	338.	31.1	1.4	-0.581	3
2N 3W 8CDD1	6/14/79	22	149.	3406.	60	65.0	15.00	48	8.00	226.	0.0	120.00	0.04	24.0	0.61	0.36	-	-	667	7.4	452	224.	39.	185.	30.8	1.4	-1.098	2

DATA REFERENCE: 1= SWANSON, 1977
2= MITCHELL,UNPUBLISHED, 1979 ANALYSIS BY IDAHO DEPT. OF HEALTH AND WELFARE.
3= USGS WRD FILE
4= STEVENS, 1962
-= DATA NOT AVAILABLE OR CONSTITUENTS NOT LOOKED FOR.

TABLE 4-3
(Continued)

Spring or Well Identification Number and Name	Sample Collection Date	Measured Surface Temperature (°C)	Reported Well Depth below Land Surface (meters)	Discharge (est.) (l/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Phosphate (PO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Boron (B)	Ammonia (NH_3)	Specific Conductance (µmhos) (field)	pH (field)	Total Dissolved Solids (TDS)	Hardness		Alkalinity as $CaCO_3$	Percent Sodium (%Na)	Sodium Absorption Ratio (SAR)	Cation-Anion Balance (milliequivalence)	Data Reference*
																						Carbonate	Non-Carbonate					
2N 3W 8DA 1	8/28/56	18	85.	-	-	37.0	13.00	36	6.00	147.	0.0	61.00	-	24.0	-	6.00	-	0.32	471	7.7	255	146.	25.	120.	33.8	1.3	1.992	4
2N 3W 9BC 1	8/27/56	16	68.	-	-	35.0	10.00	33	3.00	125.	0.0	56.00	-	20.0	-	3.00	-	0.14	419	8.2	221	128.	26.	102.	35.2	1.3	3.202	4
2N 3W 11CBA1	6/29/79	21	-	1135.	47	23.0	4.50	36	3.60	117.	0.0	29.00	0.02	10.0	0.87	0.65	-	-	326	6.7	212	76.	0.	96.	49.3	1.8	5.221	2
2N 3W 15CDCl	6/15/79	26	221.	30.	61	53.0	9.20	74	6.30	238.	0.0	120.00	0.04	21.0	0.93	457.00	-	-	675	7.9	919	170.	0.	195.	47.5	2.5	-36.022	2
2N 3W 22ACD1	6/15/79	27	186.	3406.	54	45.0	10.00	62	5.80	206.	0.0	112.00	0.03	26.0	0.69	0.38	-	-	587	7.8	417	153.	0.	169.	45.6	2.2	-4.622	2
2N 3W 22CB 1	5/ 6/54	27	-	-	-	40.0	11.00	55	6.50	242.	0.0	62.00	-	8.0	0.60	-	-	0.28	509	8.0	302	145.	0.	198.	43.8	2.0	-0.507	4
2N 3W 22DDC1	8/27/75	27	56.	-	50	39.0	11.00	55	4.90	183.	0.0	88.00	-	16.0	0.50	-	-	-	513	7.9	354	143.	0.	150.	44.6	2.0	0.547	1
2N 3W 22BDC1	6/15/79	28	-	757.	51	43.0	9.50	53	6.00	177.	0.0	109.00	0.04	20.0	0.51	0.83	-	-	549	7.9	379	146.	1.	145.	42.8	1.9	-3.507	2
2N 3W 23ACD1	6/28/79	28	-	757.	54	18.0	1.70	83	4.80	242.	0.0	29.00	0.04	10.0	2.20	0.05	-	-	484	7.5	321	52.	0.	198.	75.7	5.0	-2.043	2
2N 3W 23CC 1	8/28/56	23	-	-	-	24.0	10.00	61	6.00	194.	0.0	44.00	-	22.0	-	1.00	-	0.33	476	7.8	263	101.	0.	159.	55.0	2.6	0.984	4
2N 3W 25BDA1	6/28/79	26	178.	1135.	44	13.0	2.00	67	2.70	206.	5.00	8.00	0.01	7.1	1.60	0.03	-	-	386	7.2	251	41.	0.	177.	76.8	4.6	-2.541	2
2N 3W 26AAC1	6/28/79	25	229.	1135.	35	19.0	6.20	53	4.70	157.	0.0	47.00	0.05	15.0	0.70	0.33	-	-	388	6.7	258	73.	0.	129.	59.4	2.7	-1.714	2
2N 3W 27BAB1	6/15/79	30	-	757.	77	50.0	13.00	72	15.00	201.	0.0	200.00	0.06	11.0	0.85	0.15	-	-	763	7.8	537	178.	13.	165.	44.2	2.3	-4.970	2
2N 3W 34DB 1	8/27/56	27	111.	-	-	29.0	16.00	126	13.00	164.	0.0	268.00	-	8.0	-	1.00	-	0.26	859	8.4	541	138.	4.	134.	63.9	4.7	0.370	4
2N 3W 35CAA1	6/28/79	28	155.	1135.	44	9.0	1.40	77	5.10	178.	7.00	61.00	0.02	8.1	1.30	0.06	-	-	449	7.5	301	28.	0.	158.	82.8	6.3	-7.711	2
2N 3W 35CA 1	8/27/56	27	155.	-	-	6.0	1.00	77	4.00	198.	5.00	17.00	-	6.0	-	-	-	0.27	388	8.6	213	19.	0.	171.	87.4	7.7	-1.308	4
2N 2W 2ACC1	6/13/79	15	24.	30.	40	73.0	16.00	82	6.70	265.	0.0	155.00	0.04	36.0	0.34	3.70	-	-	801	7.5	543	248.	31.	217.	41.0	2.3	0.174	2
2N 2W 4DCA1	6/ 4/79	23	96.	1514.	23	12.0	1.70	75	1.30	206.	2.00	17.00	0.01	20.0	2.30	0.24	-	-	409	8.4	255	37.	0.	172.	80.9	5.4	-5.305	2
2N 2W 16DAA1	6/14/79	26	-	2649.	62	30.0	4.40	66	5.90	222.	0.0	69.00	0.05	16.0	1.00	0.14	-	-	506	0.0	363	93.	0.	182.	58.8	3.0	-6.717	2
2N 2W 18BAB1	6/28/79	14	15.	378.	39	34.0	13.00	44	2.80	251.	0.0	64.00	0.08	7.1	0.55	4.40	-	-	451	7.2	332	138.	0.	206.	40.3	1.6	-9.507	2
2N 2W 21CBC1	8/26/75	20	-	3028.	6	37.0	5.10	43	11.00	212.	0.0	42.00	-	22.0	0.70	0.01	-	-	485	8.0	271	113.	0.	174.	42.3	1.8	-6.254	3
2N 2W 27AAA1	6/ 7/79	22	87.	30.	28	40.0	4.40	79	2.10	166.	0.0	138.00	-	38.0	0.92	2.40	-	-	639	7.6	414	118.	0.	136.	58.8	3.2	-7.194	2
2N 2W 27ABB1	6/ 7/79	23	-	1798.	22	27.0	4.30	112	1.80	237.	0.0	112.00	-	28.0	2.50	1.10	-	-	645	8.1	427	85.	0.	194.	73.6	5.3	-3.904	2
2N 2W 27DAB1	6/ 7/79	22	147.	3028.	20	16.0	2.30	138	1.40	233.	0.0	145.00	-	32.0	2.50	0.25	-	-	721	8.1	472	49.	0.	191.	85.4	8.5	-5.714	2
2N 2W 31CDD1	6/13/79	24	244.	1514.	31	53.0	6.80	47	3.20	156.	0.0	107.00	0.07	21.0	0.55	0.03	-	-	513	7.5	346	160.	32.	128.	38.4	1.6	-0.741	2
2N 2W 31DAD1	6/11/79	22	160.	757.	27	29.0	4.00	34	3.00	127.	0.0	48.00	0.03	16.0	0.46	0.28	-	-	233	8.0	224	89.	0.	104.	44.4	1.6	-3.345	2
2N 2W 33CCC1	10/ 7/75	15	-	11.	64	33.0	6.60	68	18.00	268.	0.0	52.00	-	29.0	0.80	0.05	-	-	554	7.8	403	109.	0.	220.	52.7	2.8	-6.101	3
2N 2W 34AAC1	6/ 4/79	29	103.	568.	32	2.4	0.50	130	0.90	268.	22.00	80.00	0.02	38.0	3.60	0.05	-	-	673	8.8	441	8.	0.	256.	96.9	19.9	-15.951	2

2N	2W	34BDA1	9/13/78	48	196.	1892.	38	9.0	0.20	140	1.00	278.	8.40	61.00	0.02	20.0	4.30	10.00	-	-	600	8.4	428	23.	0.	242.	92.5	12.6	-3.507	2
2N	2W	34CDA1	6/ 7/79	30	85.	378.	24	19.0	3.60	90	2.80	249.	0.0	43.00	-	30.0	2.80	0.10	-	-	576	8.1	337	62.	0.	204.	74.8	5.0	-6.616	2
2N	2W	34DAA1	9/13/78	31	98.	378.	31	100.0	0.30	190	1.10	238.	0.0	180.00	-	68.0	2.40	0.04	-	-	930	8.6	689	251.	56.	195.	62.1	5.2	15.701	2
1N	3W	1BBC1	6/15/79	21	-	30.	67	130.0	45.00	94	19.00	332.	0.0	350.00	0.02	62.0	0.51	3.30	-	-	1349	7.3	934	509.	237.	272.	27.7	1.8	0.683	2
1N	3W	12BAB1	6/28/79	29	392.	757.	79	22.0	7.00	83	20.00	256.	0.0	107.00	0.08	8.1	1.40	0.09	-	-	640	7.3	453	84.	0.	210.	62.3	3.9	-7.468	2
1N	3W	12BA 1	8/27/56	32	458.	-	-	13.0	4.00	100	14.00	308.	13.00	6.00	-	8.0	0.0	1.00	-	0.38	554	7.8	310	49.	0.	274.	76.5	6.2	-1.405	4
1N	3W	13AAA1	6/28/79	20	185.	1892.	53	75.0	17.00	67	8.60	143.	0.0	145.00	0.05	74.0	0.36	12.00	-	-	877	7.2	522	257.	140.	117.	35.2	1.8	3.820	2
1N	2W	3CBB1	5/10/54	20	29.	1885.	40	18.0	6.20	24	3.70	114.	0.0	21.00	-	9.9	0.30	-	-	-	258	8.2	179	70.	0.	93.	41.0	1.2	-1.052	3
1N	2W	3CBB1	6/ 7/79	20	90.	1135.	39	36.0	12.00	35	4.40	127.	0.0	78.00	0.02	28.0	0.29	2.90	-	-	463	7.8	298	139.	35.	104.	34.5	1.3	-1.567	2
1N	2W	3CB 1	8/27/56	21	120.	-	-	72.0	8.00	24	2.00	112.	0.0	25.00	-	12.0	-	4.00	-	0.02	288	8.2	202	213.	121.	92.	19.5	0.7	31.911	4
1N	2W	3CB 1	8/27/56	21	120.	-	-	18.0	6.30	24	3.80	114.	0.0	21.00	-	10.0	0.40	3.20	-	0.08	258	7.9	142	71.	0.	93.	40.8	1.2	-1.976	4
1N	2W	3DBB1	6/ 7/79	20	-	568.	38	60.0	17.00	51	5.20	118.	0.0	158.00	-	72.0	0.31	4.50	-	-	709	7.7	464	220.	123.	97.	32.9	1.5	-4.273	2
1N	2W	4ADA1	10/27/53	17	146.	38.	73	15.0	4.80	62	0.0	218.	0.0	3.30	-	7.0	-	-	-	-	356	7.5	272	57.	0.	179.	70.2	3.6	0.016	3
1N	2W	4DA 1	5/10/56	22	244.	2631.	-	18.0	5.00	27	2.00	118.	0.0	15.00	-	6.0	-	2.00	-	0.54	243	8.1	133	65.	0.	97.	46.3	1.5	1.749	4
1N	2W	5BBC1	6/11/79	23	152.	946.	28	31.0	4.00	33	2.80	131.	0.0	43.00	0.06	15.0	0.37	0.01	-	-	306	8.1	221	94.	0.	107.	42.4	1.5	-1.520	2
1N	2W	5CAB1	6/11/79	23	133.	378.	40	73.0	16.00	82	6.70	133.	0.0	155.00	0.04	36.0	0.34	3.70	-	-	401	8.3	478	248.	139.	109.	41.0	2.3	14.431	2
1N	2W	5CB 1	8/27/56	22	133.	-	-	25.0	9.00	31	2.00	129.	1.00	23.00	-	9.0	-	1.00	-	0.58	295	8.4	164	99.	0.	107.	39.8	1.4	7.808	4
1N	2W	6ADD1	6/12/79	25	159.	378.	42	23.0	3.50	51	4.00	162.	0.0	37.00	0.06	16.0	0.87	0.01	-	-	373	7.7	257	72.	0.	133.	59.1	2.6	-2.196	2
1N	2W	6AD 1	8/27/56	24	159.	4542.	-	12.0	2.00	59	4.00	173.	6.00	10.00	-	6.0	-	1.00	-	0.49	338	8.2	185	38.	0.	152.	74.8	4.2	0.045	4
1N	2W	6CAA1	6/12/79	24	244.	1135.	35	29.0	4.30	36	3.80	129.	0.0	51.00	0.06	17.0	0.50	0.03	-	-	361	7.6	240	90.	0.	106.	45.2	1.7	-3.091	2
1N	2W	7ADC1	6/12/79	26	188.	1892.	74	16.0	1.80	70	8.10	187.	0.0	40.00	0.06	24.0	1.20	0.02	-	-	457	7.7	327	47.	0.	153.	72.5	4.4	-5.000	2
1N	2W	8AB 1	8/27/56	23	-	-	-	21.0	3.00	34	2.00	121.	1.00	22.00	-	1.0	-	1.00	-	0.09	283	7.7	144	65.	0.	101.	52.4	1.8	5.721	4
1N	2W	8ACB1	6/11/79	21	-	1892.	34	88.0	12.00	52	5.40	122.	0.0	155.00	0.03	74.0	0.36	2.30	-	-	715	7.8	483	269.	169.	100.	29.1	1.4	2.673	2
1N	2W	8DDD1	6/ 8/79	18	73.	1514.	46	175.0	80.00	155	9.20	250.	0.0	532.00	-	206.0	0.31	16.00	-	-	212	7.5	1342	766.	561.	205.	30.2	2.4	2.349	2
1N	2W	9AAA1	6/ 7/79	22	174.	30.	25	13.0	1.20	39	2.00	120.	0.0	11.00	-	16.0	0.38	0.0	-	-	250	8.1	166	37.	0.	98.	68.0	2.8	-3.335	2
1N	2W	9BBA1	6/ 8/79	22	200.	1514.	28	26.0	4.30	36	2.80	113.	0.0	56.00	-	24.0	0.34	0.02	-	-	320	7.9	233	83.	0.	93.	47.6	1.7	-6.072	2
1N	2W	9CCB1	6/ 8/79	24	157.	757.	35	37.0	6.00	67	5.10	161.	0.0	85.00	-	38.0	0.75	0.59	-	-	554	7.6	353	117.	0.	132.	54.1	2.7	-1.335	2
1N	2W	9DDD1	9/12/75	16	-	38.	57	69.0	28.00	59	30.00	451.	0.0	33.00	0.70	6.6	0.60	5.00	-	-	766	7.5	510	287.	0.	370.	28.3	1.5	3.892	3
1N	2W	10BA 1	8/27/56	21	135.	-	-	19.0	8.00	20	2.00	112.	0.0	15.00	-	7.0	0.0	3.00	-	0.10	248	7.7	129	80.	0.	92.	34.4	1.0	2.708	4
1N	2W	11AAA1	6/13/79	18	213.	568.	47	18.0	7.70	28	4.30	123.	0.0	25.00	0.06	11.0	0.33	0.95	-	-	283	7.6	202	77.	0.	101.	42.6	1.4	-0.386	2
1N	2W	16CBA1	6/ 8/79	18	-	2649.	34	73.0	20.00	68	6.10	209.	0.0	170.00	-	42.0	1.30	7.10	-	-	810	7.6	524	264.	93.	171.	35.2	1.8	0.399	2
1N	2W	16CB 1	8/28/56	26	-	-	-	92.0	34.00	69	7.00	134.	0.0	225.00	-	96.0	0.0	26.00	-	0.34	1069	8.1	614	369.	260.	110.	28.4	1.6	2.702	4
1N	2W	16CB 1	5/ 6/54	20	-	-	-	83.0	29.00	72	6.30	136.	0.0	217.00	-	89.0	0.60	23.00	-	0.20	950	7.8	586	326.	215.	111.	31.9	1.7	0.804	4
1N	2W	17DA 1	8/28/56	22	136.	-	-	39.0	15.00	69	6.00	181.	0.0	93.00	-	59.0	0.0	11.00	-	0.19	669	7.7	380	159.	11.	148.	47.4	2.4	-3.143	4
1N	2W	17DCC1	6/ 8/79	21	206.	946.	39	145.0	72.00	86	12.00	185.	0.0	448.00	-	165.0	0.38	13.00	-	-	1659	7.4	1071	658.	506.	152.	21.7	1.5	-0.131	2
1N	2W	17DC 1	8/28/56	23	207.	-	-	50.0	29.00	60	9.00	193.	0.0	138.00	-	50.0	0.0	12.00	-	0.08	787	7.7	442	244.	86.	158.	33.8	1.7	0.507	4

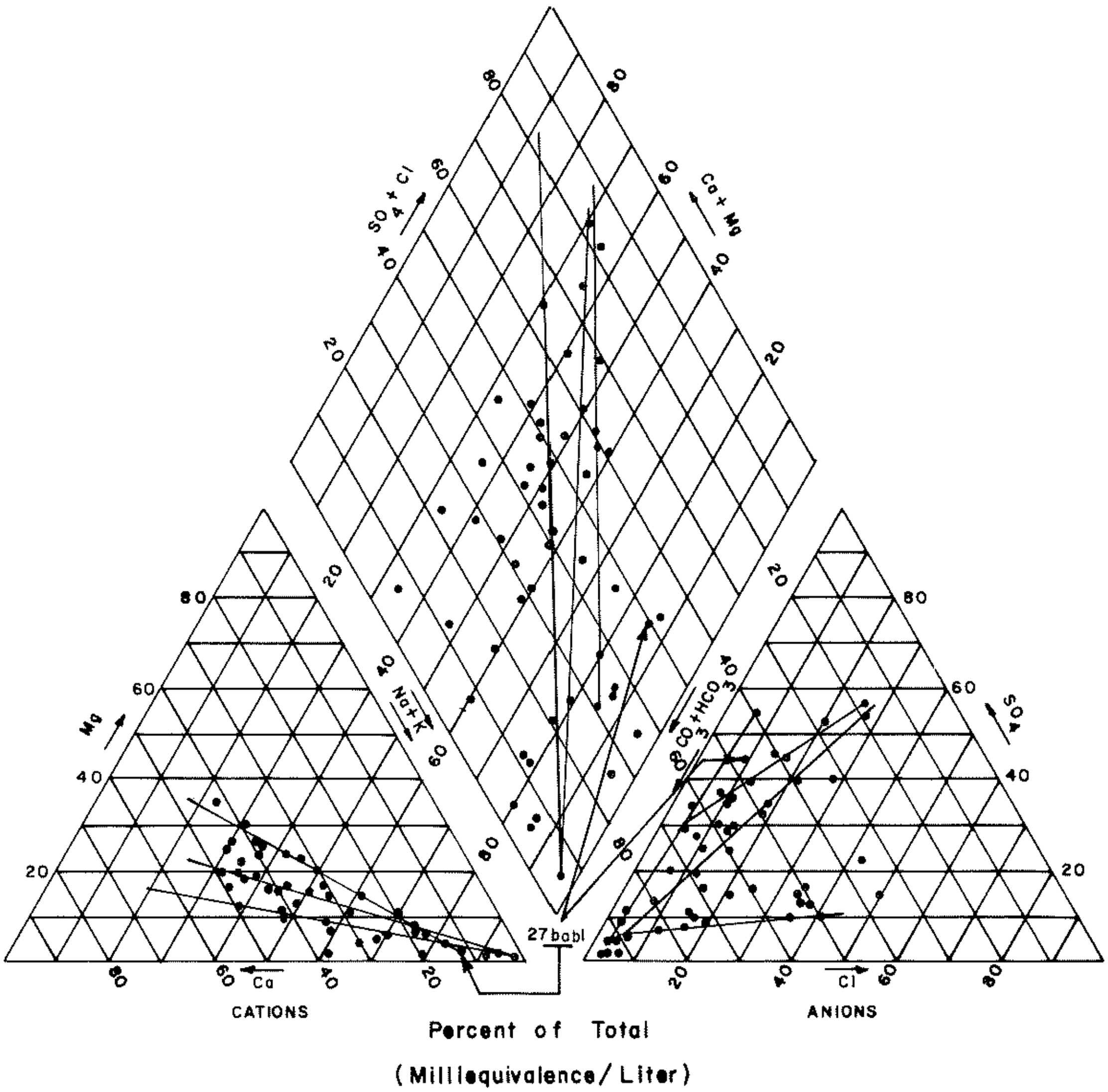

FIGURE 4-9. Trilinear diagram showing variations of chemical constituents in water sampled in the Nampa-Caldwell area.

Stevens (1962) reviewed the water chemistry available to him in southern Canyon County and was able to separate water from wells in the area into five groups according to source or aquifer from which the water was obtained. According to Stevens, water from the Idaho Formation, or Glenns Ferry Formation using present terminology, was distinguished as being high in sodium and bicarbonate, with appreciable amounts of carbonate. This type of water is represented by samples from wells 2N-3W-35ca1, 1N-3W-12ba1, 1N-2W-6ad1 and 1S-2W-17ab1. Mixtures of Glenns Ferry and canal seepage is distinguished by relatively low dissolved solids from wells 1N-2W-3cb1, 4da1, 5cb1, 8ab1 and 10ba1. Mixed Glenns Ferry and applied irrigation water is characterized by high dissolved solids and higher proportions of calcium, sulfate, chloride and nitrate than Glenns Ferry Formation water, Stevens (1962). This water is represented by samples from wells 2N-3W-5bb1, 7aa1, 8da1, 9bc1, 22bc1 and 23cc1; 1N-2W-16cb1, 17ad1 and 17dc1. Stevens recycled water was represented by well 2N-3W-34db1, and distinguished by high dissolved solids and a chemical composition classed as a sodium sulfate type water.

Water from the Snake River Basalt, identified by Stevens south of the present study area, is a calcium magnesium bicarbonate water contaminated with irrigation water. In addition to the above possibilities, Snake River water is now pumped to the farmland above the river in the southern part of Canyon County and is thought to contribute to the groundwater supply in some parts of the area. Its effects on the water chemistry of the area are not known, but may be similar to water from canal seepage by contributing to the dilution of native Glenns Ferry Formation water.

Environmental Aspects

With the exception of high sulphate values in several wells, available water chemistry suggest that significant environmental problems would probably not result from direct use of the thermal water for space heating purposes, provided sufficient recharge for the aquifers exists. However, more data, particularly on contaminants such as hydrogen, sulfide, boron, arsenic and mercury, should be collected as a precaution against water born chemical pollutants.

Forty water samples were collected and submitted to Idaho Department of Health and Welfare for analyses of gross alpha (α) and gross beta (β) radiological contaminants. Alpha particles are helium nuclei and β particles are electrons ejected from the nucleus of certain elements during radioactive decay. The result of these analyses are shown in Table 4-4. Sample locations are shown in figure 4-10 (in pocket). Six samples were found to exceed the U.S. Environmental Protection Agencies (EPA's) drinking water standards of 15 pCi/l (pico curies per liter) maximum for α emissions. The maximum radiation level for β emissions allowable by law is 50 pCi/l, where 1 Ci is equal to 3.7 x 10^{10} disintegrations per second. Water from wells 3N-3W3bbc1, 26bca1, 3N-2W-26ddb1, 31bbb1, 2N-2W-27aaa1 and 1N-2W-8ddd1 all exceeded the standard of 15 pCi/l for α emissions. The highest value found was from well 3N-3W-26bca1 at 59.8 pCi/l. Well 3N-3W-30ddd1 had 14.5 pCi/l, only slightly under the standard. All β radiation counts were well within the limits, the highest being 25.1 pCi/l from water from well 3N-3W-26bca1, which also gave the highest α counts. Water from well 2N-3W-27bab1 showed low radiation levels; the high radiation levels, therefore might be coming from sources above the "blue clay" in the cold water aquifers or permeable zones.

TABLE 4-4

Radiological Contaminants from Ground and Surface Waters in the Nampa Caldwell Area, Canyon County, Idaho

Well or Sample No.	Sample Collection Date	pCi/l Gross α	pCi/l Gross β
3N-3W-03bcc1	6-29-79	20.6*	1.1
06dca1	6-29-79	9.9	7.1
16bdd1	6-29-79	11.3	5.8
19dcb1	6-29-79	2.8	1.8
23ccc1	6-29-79	4.9	2.8
26bca1	6-29-79	59.8*	25.1
30ccc1	6-14-79	14.5	6.8
3N-2W-26ddb1	6-04-79	23.1*	11.0
31bbb1	6-14-79	24.7*	9.3
2N-3W-08cdd1	6-14-79	7.7	6.2
11cba1	6-29-79	.81	1.8
23acd1	6-28-79	3.6	3.7
25bda1	6-28-79	3.0	3.5
26aac1	6-28-79	3.8	3.6
27bab1	6-15-79	.44	19.1
35caa1	6-15-79	3.3	9.3
2N-2W-04dca1	6-04-79	2.7	1.1
16daa1	6-14-79	1.2	2.1
18bab1	6-28-79	2.8	2.0
27aaa1	6-07-79	16.7*	11.6
27dab1	6-07-79	6.7	3.9
31cdd1	6-13-79	4.5	3.3
31dad1	6-11-79	1.5	2.2
34dba1	6-04-79	1.5	1.8
34cda1	6-07-79	4.3	1.3
34aac1	6-04-79	2.1	1
1N-3W-12bab1	6-28-79	.42	17.9
01bbc1	6-15-79	6.4	21.1
1N-2W-03cbb1	6-07-79	5.9	3.8
05cab1	6-11-79	1.2	2.7
06caa1	6-12-79	1.9	4.3
07adc1	6-12-79	.1	4.8
08acb1	6-11-79	4.4	6.8
08ddd1	6-08-79	21.4*	11.4
09bba1	6-08-79	1.9	1.4
09ccb1	6-08-79	2.0	5.4
11aaa1	6-13-79	2.1	2.2
16cba1	6-08-79	9.9	10.1
17dcc1	6-08-79	7.4	15.1
22dad1	6-11-79	2.9	10.2
1N-1W-07cba1	6-13-79	5.6	5.7
13aaa1	6-28-79	3.1	4.9

* Exceeds EPA maximum permissible level for radiation in drinking water.

The source of the higher radioactivity in waters discharged from the six wells mentioned above is not known. A speculation is that the source may be dissolved chemical constituents from radioactive oxidate or reduzate minerals deposited within arkosic sands derived from weathering of the granitic rocks of the Idaho batholith which are found along both the northern and southern margins of the western Snake River Plain. A radioactive contaminant common in some geothermal systems in other areas is radon dissolved in thermal water and thought to be derived from natural radioactive disintegration of uranium or radium containing minerals.

Isotope and Chemical Data

The isotope data tend to support Stevens contention that waters from various sources are mixing in the Nampa-Caldwell area. Well 2N-3W-35ca1 is dominated by Glenns Ferry Formation water with only minor amounts of water from other sources. Certain waters, notably well 2N-2W-4dc1, (Stevens mixed canal seepage-Glenns Ferry water) does not fit the isotope data. It should plot on line 1 of figure 4-4 but plots instead on line 4(?). Isotopic data from wells 1N-2W-3cb1 and 17ad1, Stevens mixed Glenns Ferry-applied irrigation waters, fall on line(s) 3-4(?) of figure 4-4. The scatter in data and slight enrichment in ^{18}O on these lines compared to other lines may be due to evaporation process during application of the irrigation water via either sprinkler or corrugate irrigation practices as suggested by high nitrate and sulfate values for waters whose isotope data plots on line(s) 3-4(?) of figure 4-4. The correlations of isotope and chemical data are considered good but the discrepancies show the groundwater system in the Nampa-Caldwell area and chemical and physical changes involved are more complex than previously realized, and are still not completely understood.

CHEMICAL GEOTHERMOMETERS

Preliminary evaluations of geothermal systems have been successfully conducted using chemical geothermometers. In the Raft River Valley of southeastern Idaho, the reliability of these thermometers has been tested by deep drilling. The silica, sodium-potassium-calcium (Na-K-Ca) predicted aquifer temperatures, (Young and Mitchell, 1973) and mixing model calculations (Young and Mitchell, 1973, unpublished data) agreed very closely (within 10°C) with temperatures found at depth (Kunze, 1975). This proven reliability in the Raft River Valley gives some measure of confidence in applying the same methods to other areas of the state.

The degree of reliability to be placed on a chemical geothermometer depends on many factors. A detailed description of the basic assumptions, cautions and limitations for these chemical geothermometers is included in the references in the bibliography. The basic assumption is that the chemical character of the water obtained by temperature dependent equilibrium reactions in the thermal aquifer is conserved from the time the water leaves the aquifer until it reaches the surface. The concentration of certain chemical constituents dissolved in the thermal waters therefore, can be used to estimate aquifer temperatures.

Aquifer temperatures calculated from the chemical geothermometers and mixing models, along with the calculated atomic and molecular ratios of selected elements found in groundwater of the Nampa-Caldwell area are given in Table 4-5. These were calculated from values of concentration found in Table 4-3. pH corrections for the silica chemical geothermometers were made for many of the sampled waters but are not included in Table 4-5. In most instances, corrections amounted to only 1° or 2°C due to low pH's and temperatures. None of the pH corrections make appreciable difference in data interpretations.

TABLE 4-5

Estimated Aquifer Temperatures, Atomic And Molar Ratios Of Selected Chemical Constituents, Free Energies Of Formation Of Selected Minerals, Partial Pressures Of CO_2 Gas And R Values From Selected Thermal Springs And Wells In The Nampa-Caldwell Area, Canyon County, Idaho

Spring/Well Identification Number & Name	Discharge (est.) (l/min)	Measured Surface Temperature (°C)	Aquifer Temperatures and Percentage of Cold Water Estimated from Chemical Geothermometers (see footnotes)													Atomic Ratios							Molar Ratios						Free Energies of Formation of			Partial Pressure of CO_2 Gas (atmospheres)	R= Magnesium / Magnesium + Calcium + Potassium
																Sodium / Potassium	Sodium / Calcium	Magnesium / Calcium	Calcium / Fluoride	Chloride / Boron	Chloride / Fluoride	Calcium / Sodium	Calcium / Bicarbonate	Chloride / Carbonate & Bicarbonate	Ammonia / Chloride	Ammonia / Fluoride	Chloride / Sulfate	$\sqrt{Calcium}$ / Sodium	Quartz	Chalcedony	Amorphous Silica		
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	%9	%11	$\frac{Na}{K}$	$\frac{Na}{Ca}$	$\frac{Mg}{Ca}$	$\frac{Ca}{F}$	$\frac{Cl}{B}$	$\frac{Cl}{F}$	$\frac{Ca}{Na}$	$\frac{Ca}{HCO_3}$	$\frac{Cl}{CO_3+HCO_3}$	$\frac{NH_4}{Cl}$	$\frac{NH_4}{F}$	$\frac{Cl}{SO_4}$	$\frac{\sqrt{Ca}}{Na}$	ΔG Quartz	ΔG Chalcedony	ΔG Amorphous	PCO_2	$\frac{Mg}{Mg+Ca+K}$ *
4N 4W 4DCC1	295.	21	126	123	75	98	83	83	195	135	999	251	999	0	0	13.0	5.14	0.15	1.85	0.0	5.00	0.19	0.11	0.04	0.0	0.0	9.88	8.94	1.58	0.98	0.27	0.00651	11.0
4N 4W 5DBD1	227.	24	134	130	83	107	88	88	178	132	999	239	999	0	0	16.3	7.18	0.12	1.98	0.0	5.04	0.14	0.10	0.04	0.0	0.0	6.39	6.76	1.62	1.03	0.31	0.00517	8.7
RICHARDSON WELL NO. 1 4N 3W 19ADC1	189.	40	133	129	83	106	156	114	132	115	999	177	291	0	91	32.8	46.49	0.25	2.07	0.0	1.90	0.02	0.02	0.02	0.0	0.0	4.91	1.76	1.37	0.82	0.06	0.00955	12.6
3N 3W 3BBC1	1514.	13	99	100	49	69	43	43	106	75	999	999	999	0	0	53.2	3.19	0.62	19.75	0.0	44.08	0.31	0.22	0.10	0.0	0.0	0.73	8.62	1.40	0.78	0.08	0.01509	0.0
3N 3W 6DCD1	757.	17	89	91	39	58	54	54	179	111	999	178	999	0	0	16.2	1.63	0.42	44.85	0.0	60.95	0.61	0.41	0.30	0.0	0.0	0.90	15.45	1.20	0.59	-0.12	0.01286	0.0
3N 3W 16BDD1	378.	11	92	94	42	62	54	54	131	96	999	999	999	0	0	33.6	3.53	0.44	15.01	0.0	25.91	0.28	0.27	0.15	0.0	0.0	0.50	8.86	1.34	0.72	0.02	0.00743	0.0
3N 3W 19DCB	0.	23	-4	7	-48	-36	33	33	195	33	999	999	999	0	0	13.0	1.33	0.34	6.07	0.0	22.12	0.75	0.29	0.07	0.0	0.0	0.81	32.89	-0.63	-1.22	-1.94	0.00069	0.0
3N 3W 23CCC1	757.	12	96	98	46	66	43	43	163	104	999	999	999	0	0	20.1	1.89	0.50	21.64	0.0	32.82	0.53	0.29	0.19	0.0	0.0	1.14	17.67	1.38	0.76	0.06	0.00987	0.0
3N 3W 26BCA1	757.	17	87	89	37	56	59	59	167	111	222	155	218	99	99	19.0	2.84	0.42	23.10	0.0	28.61	0.35	0.29	0.23	0.0	0.0	0.91	11.92	1.17	0.56	-0.15	0.00995	0.0
3N 3W 30DDD1	757.	16	111	110	60	82	51	51	166	109	999	366	999	0	0	19.2	1.26	0.51	87.54	0.0	94.81	0.79	0.64	0.58	0.0	0.0	1.00	14.46	1.49	0.88	0.17	0.00948	0.0
3N 3W 36ADC1	378.	12	89	91	39	58	33	33	104	78	999	999	999	0	0	55.5	2.47	0.40	16.38	0.0	34.90	0.41	0.34	0.16	0.0	0.0	0.48	11.15	1.28	0.66	-0.04	0.00608	0.0
3N 2W 10ABA1	114.	38	83	86	33	52	53	53	43	53	999	86	999	0	0	231.3	74.09	0.0	0.34	0.0	0.05	0.01	0.02	0.12	0.0	0.0	1.28	2.14	0.68	0.12	-0.63	0.00032	0.0
3N 2W 14ADA1	3406.	22	85	88	35	54	25	25	135	99	117	107	999	93	0	31.6	1.89	0.23	15.01	0.0	22.75	0.53	0.35	0.23	0.0	0.0	1.05	21.64	1.06	0.47	-0.25	0.00204	0.0
3N 2W 17BCB1	2271.	24	93	95	43	63	50	50	152	108	182	139	132	94	92	23.8	4.07	0.35	3.27	0.0	7.11	0.25	0.12	0.05	0.0	0.0	2.58	12.71	1.14	0.55	-0.17	0.00502	0.0
3N 2W 23BCD1	1703.	31	87	89	37	56	40	40	67	64	103	101	999	81	0	124.7	14.75	0.13	1.16	0.0	1.95	0.07	0.06	0.03	0.0	0.0	5.84	4.86	0.93	0.35	-0.38	0.00457	0.0
3N 2W 26DDB1	378.	18	88	90	38	57	48	48	143	99	210	150	197	98	98	27.4	1.83	0.40	29.95	0.0	57.86	0.55	0.42	0.22	0.0	0.0	0.59	12.03	1.16	0.56	-0.15	0.00823	0.0
3N 2W 31BBB1	378.	15	93	95	43	63	49	49	140	98	999	999	999	0	0	29.0	1.51	0.40	129.63	0.0	154.34	0.66	0.83	0.69	0.0	0.0	0.78	11.23	1.29	0.68	-0.03	0.00827	0.0
2N 3W 5BB 1	0.	17	0	0	0	0	51	51	169	51	999	999	999	0	0	18.4	1.57	0.60	0.0	29.88	0.0	0.64	0.42	0.33	0.0	0.0	1.10	14.99	0.0	0.0	0.0	0.0	0.0
2N 3W 7AA 1	0.	18	0	0	0	0	40	40	157	40	999	999	999	0	0	22.1	1.35	0.47	0.0	2.77	0.0	0.74	0.25	0.01	0.0	0.0	0.39	18.08	0.0	0.0	0.0	0.0	0.0
2N 3W 8CDD1	3406.	22	110	110	59	81	59	59	215	132	999	202	999	0	0	10.2	1.29	0.38	21.09	0.0	50.51	0.78	0.44	0.18	0.0	0.0	0.54	19.29	1.38	0.79	0.07	0.00853	0.0
2N 3W 8DA 1	0.	18	0	0	0	0	58	58	215	58	999	999	999	0	0	10.2	1.70	0.58	0.0	22.85	0.0	0.59	0.38	0.28	0.0	0.0	1.07	19.40	0.0	0.0	0.0	0.0	0.0
2N 3W 9BC 1	0.	16	0	0	0	0	40	40	168	40	999	999	999	0	0	18.7	1.64	0.47	0.0	43.52	0.0	0.61	0.43	0.27	0.0	0.0	0.97	20.59	0.0	0.0	0.0	0.0	0.0
2N 3W 11CBA1	1135.	21	98	100	48	68	53	53	175	104	999	175	284	0	97	17.0	2.73	0.32	6.16	0.0	12.53	0.37	0.30	0.14	0.0	0.0	0.93	15.30	1.26	0.66	-0.06	0.02285	0.0
2N 3W 15CDC1	30.	26	111	110	60	82	60	60	164	122	999	179	999	0	0	20.0	2.43	0.29	12.10	0.0	27.02	0.41	0.34	0.15	0.0	0.0	0.47	11.30	1.32	0.74	0.01	0.00299	0.0
2N 3W 22ACD1	3406.	27	105	105	54	75	59	59	170	123	244	161	224	94	94	18.2	2.40	0.37	20.20	0.0	30.92	0.42	0.33	0.21	0.0	0.0	0.63	12.42	1.23	0.65	-0.08	0.00335	0.0
2N 3W 22CB 1	0.	27	0	0	0	0	63	63	187	63	999	999	999	0	0	14.4	2.40	0.45	7.15	8.70	31.60	0.42	0.25	0.06	0.0	0.0	0.35	13.21	0.0	0.0	0.0	0.0	0.0

2N	3W	22DDC1	0.	27	101	102	51	71	56	56	167	124	217	152	215	94	94	19.1	2.46	0.46	17.15	0.0	36.98	0.41	0.32	0.15	0.0	0.0	0.49	13.04	1.18	0.60	-0.12	0.00236	0.0
2N	3W	22BDC1	757.	28	102	103	52	72	59	59	184	133	214	151	202	93	93	15.0	2.15	0.36	21.02	0.0	39.97	0.47	0.37	0.19	0.0	0.0	0.50	14.21	1.18	0.60	-0.13	0.00232	0.0
2N	3W	23ACD1	757.	28	105	105	54	75	75	75	139	105	233	158	221	94	93	29.4	8.04	0.16	2.44	0.0	3.88	0.12	0.11	0.07	0.0	0.0	0.93	5.87	1.22	0.64	-0.09	0.00827	12.1
2N	3W	23CC 1	0.	23	0	0	0	0	72	55	174	72	999	999	999	0	0	17.3	4.43	0.69	0.0	20.31	0.0	0.23	0.19	0.19	0.0	0.0	1.35	9.22	0.0	0.0	0.0	0.0	37.9
2N	3W	25BDA1	1135.	26	95	97	45	65	61	61	118	87	182	139	132	93	90	42.2	8.99	0.25	2.38	0.0	3.85	0.11	0.10	0.06	0.0	0.0	2.40	6.18	1.13	0.55	-0.17	0.01380	0.0
2N	3W	26AAC1	1135.	25	85	88	35	54	68	68	167	102	105	102	999	88	0	19.2	4.86	0.54	11.48	0.0	12.87	0.21	0.18	0.16	0.0	0.0	0.86	9.44	1.02	0.43	-0.29	0.03257	0.0
2N	3W	27BAB1	757.	30	123	120	72	94	88	70	235	161	999	186	999	0	0	8.2	2.51	0.43	6.94	0.0	27.89	0.40	0.38	0.09	0.0	0.0	0.15	11.28	1.40	0.83	0.09	0.00337	27.1
2N	3W	34DB 1	0.	27	0	0	0	0	173	27	177	173	999	999	999	0	0	16.5	7.57	0.91	0.0	9.37	0.0	0.13	0.27	0.08	0.0	0.0	0.08	4.91	0.0	0.0	0.0	0.0	42.5
2N	3W	35CAA1	1135.	28	95	97	45	65	91	91	147	117	168	134	125	91	88	25.7	14.92	0.26	3.34	0.0	3.28	0.07	0.08	0.07	0.0	0.0	0.36	4.47	1.10	0.52	-0.21	0.00613	16.6
2N	3W	35CA 1	0.	27	0	0	0	0	92	92	132	92	999	999	999	0	0	32.7	22.37	0.27	0.0	6.77	0.0	0.04	0.05	0.05	0.0	0.0	0.96	3.65	0.0	0.0	0.0	0.0	17.0
2N	2W	2ACC1	30.	15	91	93	41	61	56	56	161	111	999	999	999	0	0	20.8	1.96	0.36	56.75	0.0	101.78	0.51	0.42	0.23	0.0	0.0	0.63	11.97	1.26	0.65	-0.06	0.00702	0.0
2N	2W	4DCA1	1514.	23	68	73	19	36	43	43	77	43	999	999	999	0	0	98.1	10.90	0.23	4.66	0.0	2.47	0.09	0.09	0.16	0.0	0.0	3.19	5.30	0.77	0.18	-0.54	0.00065	0.0
2N	2W	16DAA1	2649.	26	112	111	61	83	68	68	167	68	999	181	999	0	0	19.0	3.84	0.24	8.58	0.0	14.22	0.26	0.21	0.12	0.0	0.0	0.63	9.53	0.0	0.0	0.0	0.0	0.0
2N	2W	18BAB1	378.	14	90	92	40	59	41	41	145	92	999	999	999	0	0	26.7	2.26	0.63	6.92	0.0	29.31	0.44	0.21	0.05	0.0	0.0	0.30	15.22	1.26	0.65	-0.06	0.01345	0.0
2N	2W	21CBC1	3028.	20	27	36	-19	-5	79	79	254	172	999	999	999	0	0	6.6	2.03	0.23	16.84	0.0	25.06	0.49	0.27	0.18	0.0	0.0	1.42	16.24	0.13	-0.46	-1.18	0.00197	16.5
2N	2W	27AAA1	30.	22	76	80	26	45	36	36	96	79	999	999	999	0	0	64.0	3.44	0.18	22.14	0.0	20.61	0.29	0.37	0.39	0.0	0.0	0.75	9.19	0.93	0.34	-0.38	0.00400	0.0
2N	2W	27ABB1	1798.	23	67	72	17	35	41	41	73	75	999	999	999	0	0	105.8	7.23	0.26	6.00	0.0	5.12	0.14	0.17	0.20	0.0	0.0	0.68	5.33	0.76	0.17	-0.55	0.00181	0.0
2N	2W	27DAB1	3028.	22	63	68	14	31	46	46	55	66	999	999	999	0	0	167.6	15.04	0.24	6.86	0.0	3.03	0.07	0.10	0.23	0.0	0.0	0.60	3.33	0.72	0.13	-0.59	0.00176	0.0
2N	2W	31CDD1	1514.	24	80	84	30	49	37	37	149	102	999	58	999	0	0	25.0	1.55	0.21	20.46	0.0	45.68	0.65	0.52	0.23	0.0	0.0	0.53	17.79	0.96	0.37	-0.35	0.00489	0.0
2N	2W	31DAD1	757.	22	75	79	25	43	43	43	166	126	999	999	999	0	0	19.3	2.04	0.23	18.64	0.0	29.89	0.49	0.35	0.21	0.0	0.0	0.90	18.19	0.90	0.31	-0.41	0.00123	0.0
2N	2W	33CCC1	11.	15	113	112	63	84	215	94	258	175	999	999	999	0	0	6.4	3.59	0.33	19.43	0.0	19.55	0.28	0.19	0.18	0.0	0.0	1.51	9.70	1.52	0.91	0.21	0.00363	20.5
2N	2W	34AAC1	568.	29	82	85	32	50	69	69	41	69	77	79	999	77	0	245.7	94.43	0.34	5.66	0.0	0.32	0.01	0.01	0.22	0.0	0.0	1.29	1.37	0.79	0.22	-0.51	0.00034	0.0
2N	2W	34BDA1	1892.	48	89	91	39	58	47	47	42	59	97	98	999	59	0	238.1	27.12	0.04	2.49	0.0	0.99	0.04	0.05	0.12	0.0	0.0	0.89	2.46	0.67	0.15	-0.63	0.00152	0.0
2N	2W	34CDA1	378.	30	70	75	20	38	58	58	104	96	999	999	999	0	0	54.7	8.26	0.31	5.74	0.0	3.22	0.12	0.12	0.20	0.0	0.0	1.89	5.56	0.69	0.11	-0.62	0.00211	0.0
2N	2W	34DAA1	378.	31	80	84	30	49	13	13	34	13	999	73	999	0	0	293.8	3.31	0.00	15.19	0.0	19.75	0.30	0.64	0.48	0.0	0.0	1.02	6.04	0.77	0.20	-0.54	0.00055	0.0
1N	3W	1BBC1	30.	21	115	114	65	87	78	58	232	139	999	226	999	0	0	8.4	1.26	0.57	65.16	0.0	120.84	0.79	0.60	0.32	0.0	0.0	0.48	13.93	1.46	0.87	0.15	0.01483	34.7
1N	3W	12BAB1	757.	29	124	121	73	96	217	72	249	160	999	193	999	0	0	7.1	6.58	0.52	3.10	0.0	7.45	0.15	0.13	0.05	0.0	0.0	0.21	6.49	1.44	0.86	0.13	0.01393	26.4
1N	3W	12BA 1	0.	32	0	0	0	0	193	73	201	193	999	999	999	0	0	12.1	13.41	0.51	0.0	6.41	0.0	0.07	0.06	0.04	0.0	0.0	3.61	4.14	0.0	0.0	0.0	0.0	24.6
1N	3W	13AAA1	1892.	20	104	104	54	74	61	61	194	125	999	204	999	0	0	13.2	1.56	0.37	110.17	0.0	98.76	0.64	0.80	0.88	0.0	0.0	1.38	14.84	1.34	0.74	0.03	0.00824	0.0
1N	2W	3CBB1	1885.	20	91	93	41	61	54	54	208	144	215	152	214	97	97	11.0	2.32	0.57	17.69	0.0	28.44	0.43	0.24	0.15	0.0	0.0	1.28	20.30	1.16	0.56	-0.16	0.00188	0.0

T_1 = SILICA TEMP ASSUMING QUARTZ EQUILIBRIUM AND CONDUCTIVE COOLING (NO STEAM LOSS)
T_2 = SILICA TEMP ASSUMING QUARTZ EQUILIBRIUM AND ADIABATIC EXPANSION AT CONSTANT ENTHALPY (MAX STEAM LOSS)
T_3 = SILICA TEMP ASSUMING EQUILIBRIUM WITH α CHRISTOBALITE
T_4 = SILICA TEMPERATURE ASSUMING EQUILIBRIUM WITH CHALCEDONY AND CONDUCTIVE COOLING (NO STEAM LOSS)
T_5 = NA-K-CA TEMP
T_6 = NA-K-CA TEMP CORRECTED FOR MG
T_7 = NA-K TEMP
T_8 = NA-K-CA TEMP CORRECTED FOR PCO_2
T_9 = FOURNIER-TRUESDELL MIXING MODEL 1 TEMP (QUARTZ-NO STEAM LOSS)
T_{10} = FOURNIER-TRUESDELL MIXING MODEL 2 TEMP (QUARTZ-STEAM LOSS)
T_{11} = FOURNIER-TRUESDELL MIXING MODEL 1 TEMP (CHALCEDONY-NO STEAM LOSS)
%9 = PERCENT COLD WATER IN T9 CALCULATION
%11 = PERCENT COLD WATER IN T11 CALCULATION
999 = HOT WATER TEMPERATURE CALCULATION NOT POSSIBLE
0 = DATA NOT AVAILABLE FOR CALCULATION
0.0= DATA NOT AVAILABLE FOR CALCULATION

TABLE 4-5
(Continued)

Spring/Well Identification Number & Name	Discharge (est.) (1/min)	Measured Surface Temperature (°C)	Aquifer Temperatures and Percentage of Cold Water Estimated from Chemical Geothermometers (see footnotes) T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	%9	%11	Atomic Ratios: Sodium/Potassium Na/K	Sodium/Calcium Na/Ca	Magnesium/Calcium Mg/Ca	Calcium/Fluoride Ca/F	Chloride/Boron Cl/B	Chloride/Fluoride Cl/F	Calcium/Sodium Ca/Na	Molar Ratios: Calcium/Bicarbonate Ca/HCO_3	Chloride/Carbonate & Bicarbonate Cl/(CO_3 + HCO_3)	Ammonia/Chloride NH_4/Cl	Ammonia/Fluoride NH_4/F	Chloride/Sulfate Cl/SO_4	√Calcium/Sodium $\sqrt{Ca}$/Na	Free Energies of Formation of: Quartz ΔG Quartz	Chalcedony ΔG Chalcedony	Amorphous Silica ΔG Amorphous	Partial Pressure of CO_2 Gas (atmospheres) PCO_2	R= Magnesium/(Magnesium + Calcium + Potassium) Mg/(Mg+Ca+K) *
1N 2W 3CBB1	1135.	20	90	92	40	59	50	50	192	50	198	146	157	97	96	13.5	1.69	0.55	51.75	0.0	58.85	0.59	0.43	0.37	0.0	0.0	0.97	19.69	1.16	0.56	-0.15	0.00067	0.0
1N 2W 3CB 1	0.	21	0	0	0	0	16	16	162	16	999	999	999	0	0	20.4	0.58	0.18	0.0	182.79	0.0	1.72	0.98	0.18	0.0	0.0	1.30	40.60	0.0	0.0	0.0	0.0	0.0
1N 2W 3CB 1	0.	21	0	0	0	0	55	55	211	55	999	999	999	0	0	10.7	2.32	0.58	13.40	38.08	21.33	0.43	0.24	0.15	0.0	0.0	1.29	20.30	0.0	0.0	0.0	0.0	0.0
1N 2W 3DBB1	568.	20	89	91	39	58	49	49	176	127	182	139	132	97	95	16.7	1.48	0.47	124.48	0.0	91.75	0.67	0.77	1.03	0.0	0.0	1.23	17.44	1.16	0.56	-0.15	0.00214	0.0
1N 2W 4ADA1	38.	17	120	118	69	91	0	0	0	0	999	330	999	0	0	0.0	7.21	0.53	0.0	0.0	0.0	0.14	0.10	0.05	0.0	0.0	5.74	7.17	1.57	0.97	0.26	0.00627	0.0
1N 2W 4DA 1	2631.	22	0	0	0	0	39	39	154	39	999	999	999	0	0	23.0	2.62	0.46	0.0	3.39	0.0	0.38	0.23	0.09	0.0	0.0	1.08	18.04	0.0	0.0	0.0	0.0	0.0
1N 2W 5BBC1	946.	23	76	80	26	45	40	40	164	40	999	999	999	0	0	20.0	1.86	0.21	21.73	0.0	39.72	0.54	0.36	0.19	0.0	0.0	0.94	19.38	0.90	0.31	-0.41	0.00032	0.0
1N 2W 5CAB1	378.	23	91	93	41	61	56	56	161	56	170	135	127	94	92	20.8	1.96	0.36	56.75	0.0	101.78	0.51	0.84	0.46	0.0	0.0	0.63	11.97	1.10	0.51	-0.21	0.00059	0.0
1N 2W 5CB 1	0.	22	0	0	0	0	34	34	146	34	999	999	999	0	0	26.4	2.16	0.59	0.0	4.73	0.0	0.46	0.30	0.12	0.0	0.0	1.06	18.52	0.0	0.0	0.0	0.0	0.0
1N 2W 6ADD1	378.	25	93	95	43	63	59	59	158	118	172	136	128	93	91	21.7	3.87	0.25	9.86	0.0	12.53	0.26	0.22	0.17	0.0	0.0	1.17	10.80	1.12	0.53	-0.19	0.00332	0.0
1N 2W 6AD 1	4542.	24	0	0	0	0	74	74	149	74	999	999	999	0	0	25.1	8.57	0.27	0.0	3.73	0.0	0.12	0.11	0.06	0.0	0.0	1.62	6.74	0.0	0.0	0.0	0.0	19.0
1N 2W 6CAA1	1135.	24	85	88	35	54	50	50	179	124	109	103	999	90	0	16.1	2.16	0.24	18.22	0.0	27.50	0.46	0.34	0.22	0.0	0.0	0.90	17.18	1.03	0.44	-0.28	0.00328	0.0
1N 2W 7ADC1	1892.	26	121	119	70	92	93	93	186	140	999	200	999	0	0	14.7	7.63	0.19	10.72	0.0	6.32	0.13	0.13	0.22	0.0	0.0	1.62	6.56	1.44	0.85	0.13	0.00389	12.8
1N 2W 8AB 1	0.	23	0	0	0	0	38	38	140	38	999	999	999	0	0	28.9	2.82	0.24	0.0	3.39	0.0	0.35	0.26	0.01	0.0	0.0	0.12	15.48	0.0	0.0	0.0	0.0	0.0
1N 2W 8ACB1	1892.	21	84	87	34	53	43	43	178	127	99	99	999	92	0	16.4	1.03	0.22	110.17	0.0	115.88	0.97	1.10	1.03	0.0	0.0	1.29	20.72	1.06	0.46	-0.25	0.00176	0.0
1N 2W 8DDD1	1514.	18	97	99	47	67	55	55	140	102	999	209	999	0	0	28.7	1.54	0.75	356.16	0.0	267.61	0.65	1.07	1.40	0.0	0.0	1.05	9.80	1.29	0.69	-0.02	0.00650	0.0
1N 2W 9AAA1	30.	22	72	76	22	40	48	48	132	48	999	999	999	0	0	33.2	5.23	0.15	22.57	0.0	16.22	0.19	0.16	0.23	0.0	0.0	3.94	10.62	0.85	0.26	-0.46	0.00094	0.0
1N 2W 9BBA1	1514.	22	76	80	26	45	44	44	158	121	999	999	999	0	0	21.9	2.41	0.27	37.83	0.0	36.25	0.41	0.35	0.36	0.0	0.0	1.16	16.27	0.93	0.33	-0.38	0.00138	0.0
1N 2W 9CCB1	757.	24	85	88	35	54	60	60	156	115	109	103	999	90	0	22.3	3.16	0.27	27.16	0.0	23.39	0.32	0.35	0.40	0.0	0.0	1.21	10.43	1.03	0.44	-0.28	0.00402	0.0
1N 2W 9DDD1	38.	16	108	107	57	78	247	52	333	185	999	349	999	0	0	3.3	1.49	0.67	5.90	0.0	54.52	0.67	0.23	0.02	0.0	0.0	0.54	16.17	1.45	0.84	0.13	0.01212	35.4
1N 2W 10BA 1	0.	21	0	0	0	0	35	35	175	35	999	999	999	0	0	17.0	1.84	0.69	0.0	21.33	0.0	0.54	0.26	0.11	0.0	0.0	1.26	25.03	0.0	0.0	0.0	0.0	0.0
1N 2W 11AAA1	568.	18	98	100	48	68	60	60	208	142	999	213	999	0	0	11.1	2.71	0.70	17.87	0.0	25.86	0.37	0.22	0.15	0.0	0.0	1.19	17.40	1.30	0.70	-0.01	0.00285	0.0
1N 2W 16CBA1	2649.	18	84	87	34	53	52	52	167	116	120	110	75	97	94	19.0	1.62	0.45	17.32	0.0	26.62	0.62	0.53	0.34	0.0	0.0	0.67	14.43	1.11	0.51	-0.20	0.00460	0.0
1N 2W 16CB 1	0.	26	0	0	0	0	52	52	176	52	999	999	999	0	0	16.8	1.31	0.61	0.0	86.02	0.0	0.76	1.05	1.21	0.0	0.0	1.16	15.96	0.0	0.0	0.0	0.0	0.0
1N 2W 16CB 1	0.	20	0	0	0	0	51	51	166	51	999	999	999	0	0	19.4	1.51	0.58	79.50	135.57	65.58	0.66	0.93	1.11	0.0	0.0	1.11	14.53	0.0	0.0	0.0	0.0	0.0
1N 2W 17DA 1	0.	22	0	0	0	0	64	64	165	64	999	999	999	0	0	19.6	3.08	0.63	0.0	94.60	0.0	0.32	0.33	0.55	0.0	0.0	1.72	10.39	0.0	0.0	0.0	0.0	0.0
1N 2W 17DCC1	946.	21	90	92	40	59	60	60	200	130	182	139	132	96	95	12.2	1.03	0.82	232.72	0.0	180.89	0.97	1.19	1.51	0.0	0.0	1.00	16.08	1.15	0.55	-0.16	0.00645	0.0
1N 2W 17DC 1	0.	23	0	0	0	0	70	42	206	70	999	999	999	0	0	11.3	2.09	0.96	0.0	190.41	0.0	0.48	0.39	0.44	0.0	0.0	0.98	13.53	0.0	0.0	0.0	0.0	46.7

Observations

Figures 4-11, 4-12, and 4-13 are plots of quartz, chalcedony and α-christobalite calculated aquifer temperatures versus magnesium corrected Na-K-Ca calculated temperatures, respectively, obtained from Table 4-5. Fournier and others (1979) used plots of this nature to determine probability of mixing or chemical disequilibrium conditions. Provided that cation ratios remain unchanged, waters that plot on or near the equal temperature line are generally considered to be unmixed waters in chemical equilibrium with aquifer constituents. Substantial departure from the line (above) may represent waters which have either: (1) undergone evaporation, or (2) have dissolved excess silica from aquifer constituents. Waters that plot below the equal temperature line may be mixed waters or waters that have lost dissolved silica or calcium by precipitation.

To facilitate interpretation of the chemical geothermometers, a $\pm$ 5°C temperature interval of confidence has been drawn parallel to the equal temperature lines of figures 4-11 through 4-13. The $\pm$ 5°C confidence window was picked as this represents a 5% maximum error in silica analyses for the sample with the highest reported silica concentration, i.e., 94 mg/l. Silica analyses, although generally within 5% of actual values constitutes the greatest uncertainity in the analytical procedures for any of the geothermometers used in this report. This confidence interval may also represent a reasonable limit of agreement between the silica and Na-K-Ca chemical geothermometers brought about by water chemistry variability which may occur at various depths and localities even in systems where waters are considered to be homogenous, unmixed and in chemical equilibrium with aquifer constituents.

As shown by figure 4-11 (quartz calculated aquifer temperatures), most waters plotted fall a considerable distance above the equal temperature line. Only one data point (2N-3W-35caa1) falls near (within $\pm$ 5°C) the equal temperature line. Data from another well (2N-2W-21cbc1) plots below the equal temperature line.

Figure 4-12 (chalcedony calculated aquifer temperatures) is a considerable improvement over figure 4-11. Most data points are approximately equally distributed above and below the equal temperature line. Most agreement or close agreement in chalcedony and Na-K-Ca chemical geothermometers occurs between 42 and 60°C.

Figure 4-13 (α-christobalite calculated aquifer temperatures) indicates most of the plotted waters found on lines 1 and 2 of figures 4-4 through 4-6 now fall below the equal temperature line as mixed waters should. Some of the well waters that are mixed, according to the isotope data, still fall above the equal temperature line. Data from several wells plot on, or within 5°C, of the equal temperature line. These data points occur within the 42° to 60°C temperature range.

As shown by the equal temperature diagrams, there is considerable scatter in the geothermometeric data and a wide range of aquifer or permeable zone temperatures are predicted. Predicted temperatures range from about 60° to nearly 140°C on the quartz diagram (figure 4-11), from about 30° to 100°C on the chalcedony diagram (figure 4-12) and from about 15° to nearly 80°C on the α-christobalite diagram. In this area, in the predicted temperature ranges, the general shape of the plotted field and relative positions of plotted points are nearly the same on each diagram. The predicted temperatures for each point on the chalcedony diagram (figure 4-12) relative to the quartz (figure 4-11) are depressed by about 30°C. For the α-christobalite diagram (figure 4-13) relative to chalcedony diagram

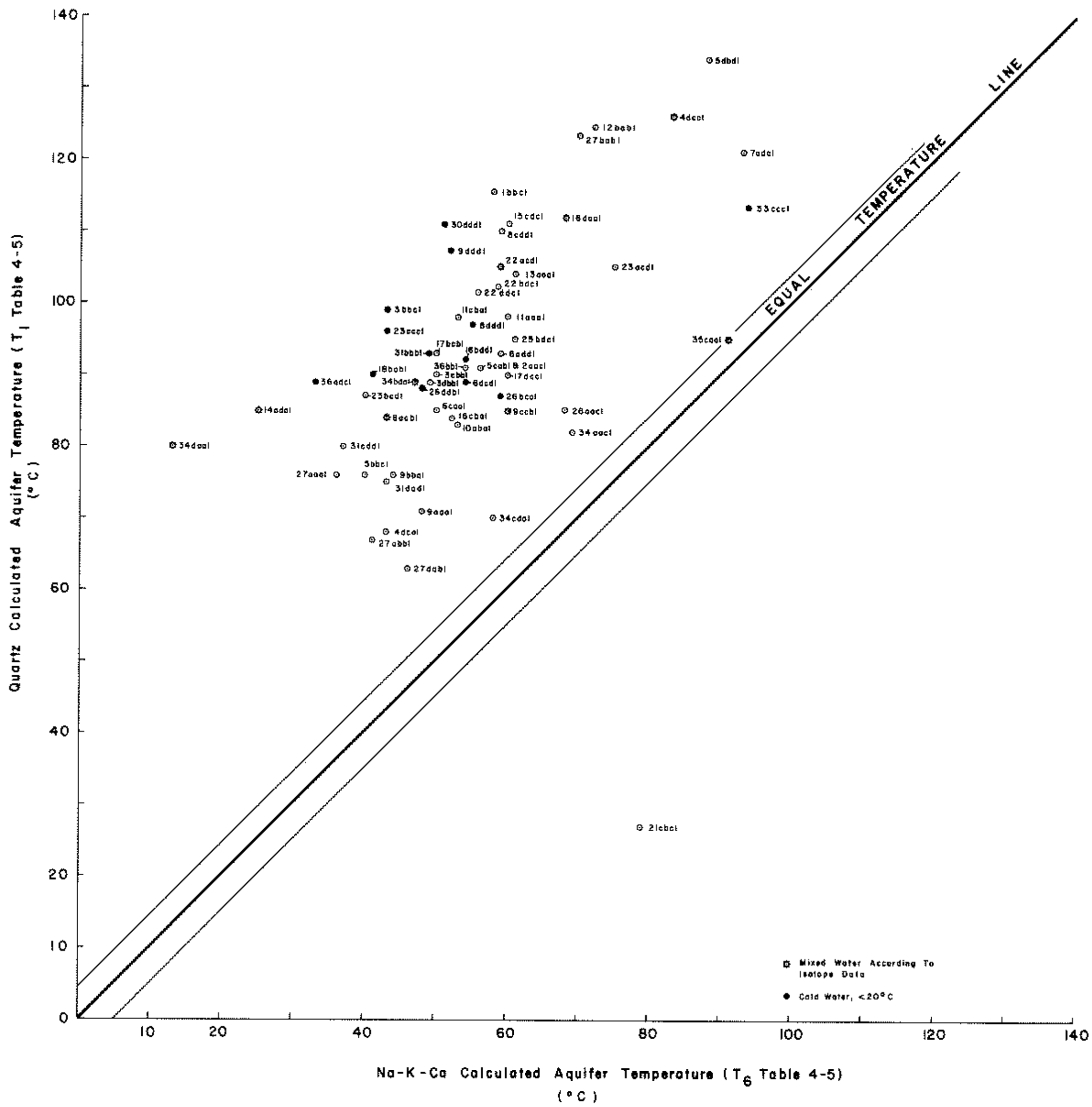

FIGURE 4-11. Equal temperature graph showing quartz versus magnesium corrected Na-K-Ca chemical geothermometer.

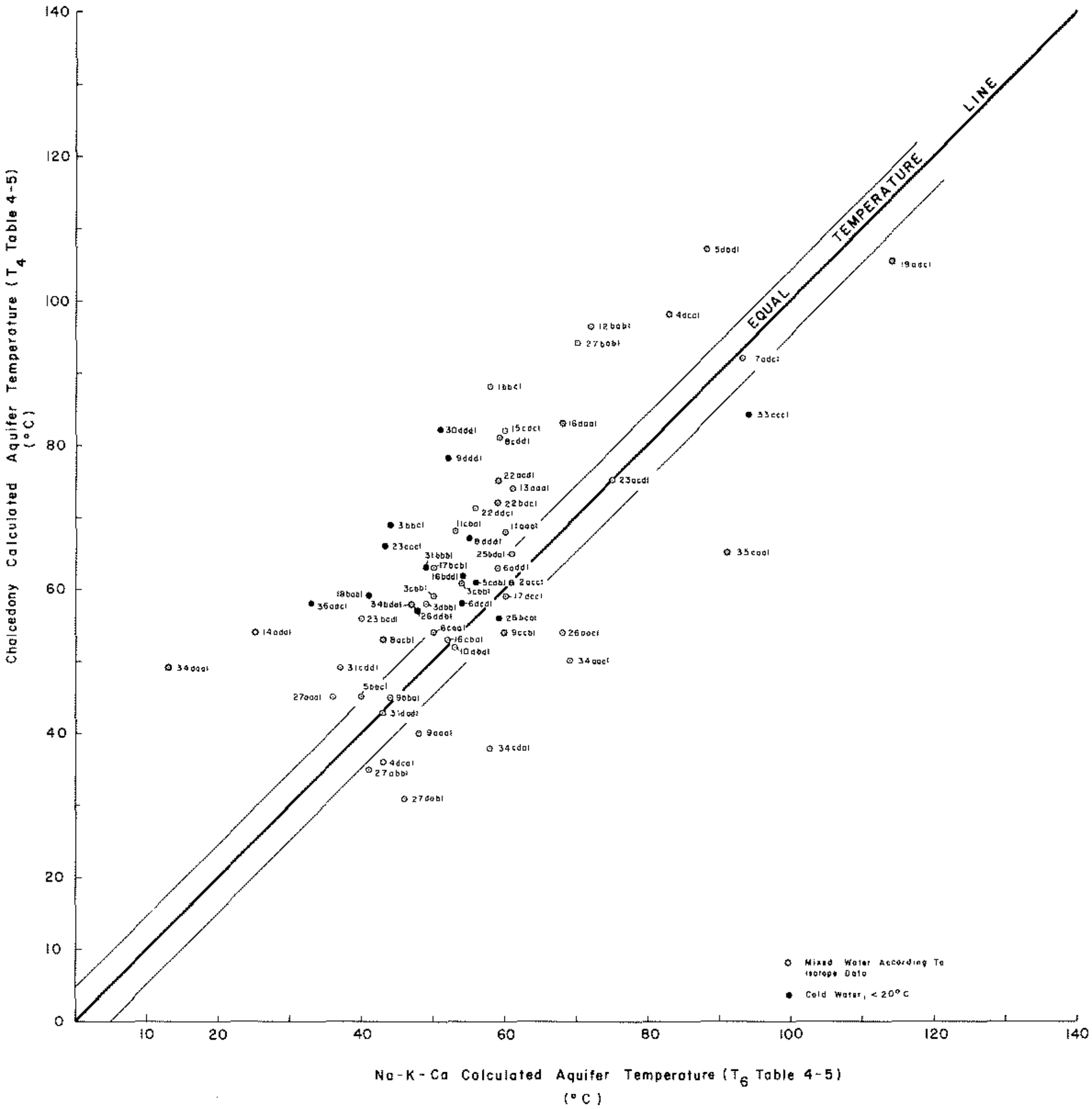

FIGURE 4-12. Equal temperature graph showing chalcedony versus magnesium corrected Na-K-Ca chemical geothermometer.

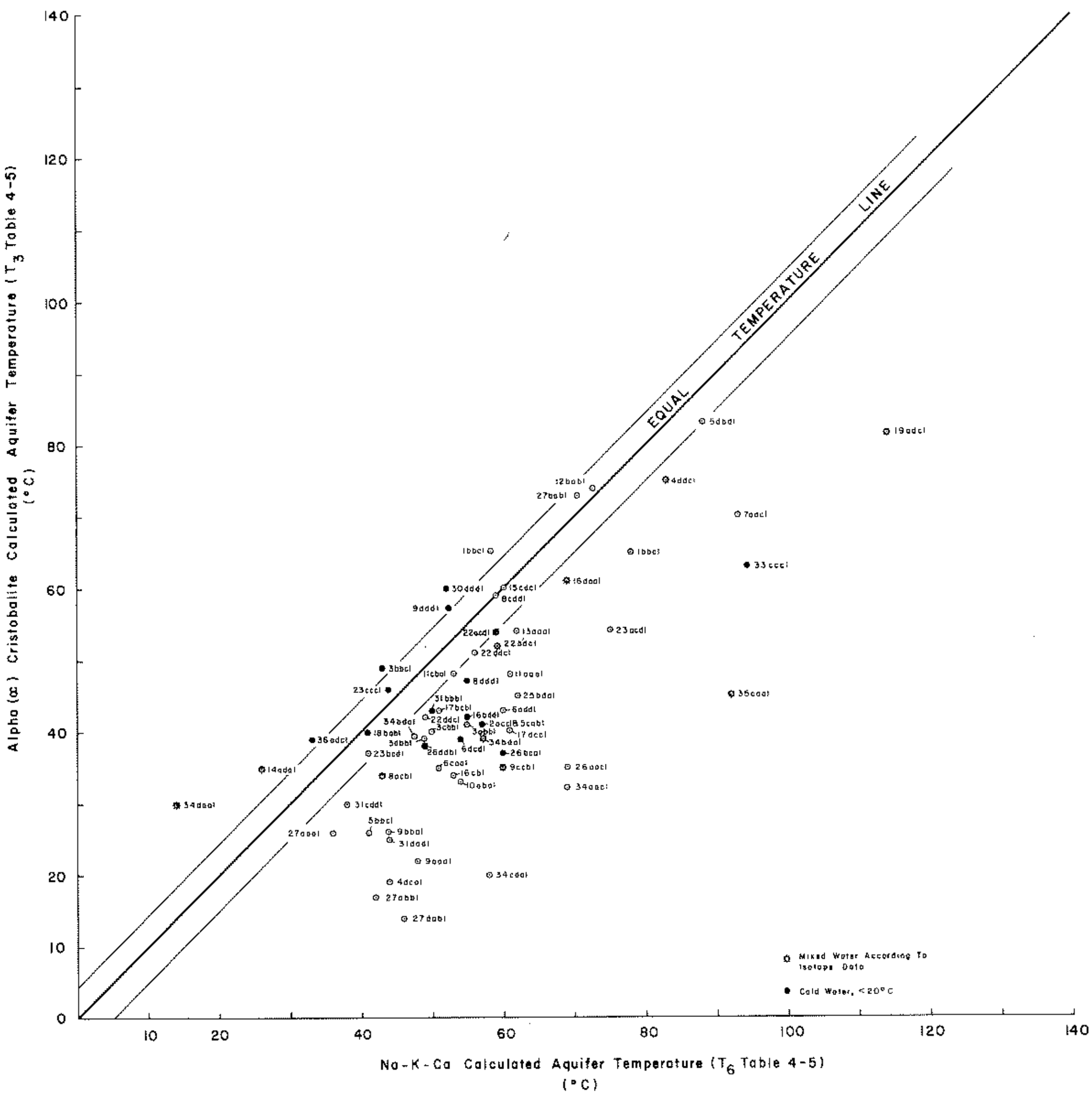

FIGURE 4-13. Equal temperature graph showing α-christabolite versus magnesium corrected Na-K-Ca chemical geothermometer.

ure 4-12), the temperatures are depressed only by about 15°C. This merely reflects the nearly parallel nature of the solubility of silica curves on the diagrams of Fournier and Rowe (1965) in this temperature range.

Discussion

The geochemical data should be interpreted in light of what is known of the geology and hydrology of the geothermal system discussed in Chapters 2 and 3, the heat flow data of Chapter 5 of this report and the possible constraints imposed by the isotope data (first part of this chapter). These discussions exemplify a complex, stacked, compartmentalized and/or hydrologically interconnected geothermal system(s) completely or nearly completely separated hydrologically from the overlying, shallow, complex, cold water hydrologic system. Thermal waters may move upward into shallower, cooler aquifers or permeable zones, as first proposed by Russell (1903), and for the most part, cool conductively during upward migration (see figure 4-14). Although some mixing of thermal and nonthermal water in aquifers undoubtedly occurs, most mixing of thermal with nonthermal water is thought to take place within well bores due to well construction.

In hydrologic systems such as discussed, it is not surprising that the chemical geothermometers predict widely variable temperatures. This variability could be due to several causes including: (1) conductive cooling with and/or without conservation of rock-water chemical equilibria, (2) mixing of various waters with and/or without conservation of rock-water chemical equilibria, and (3) combinations of all of the above. In view of the uncertainties involved, and lack of specific chemical, exact temperature, and isotope data from individual aquifers within the thermal and non-thermal systems, interpretations of the geochemical data is difficult at best, probably uncertain and should be viewed as tentative and subject to refinement as more data become available.

Figure 4-11 is interpreted to indicate that for most waters sampled, there is more reported silica in solution than can be explained by assuming quartz equilibrium, or cation equilibrium changes. Exceptions might be well 2N-3W-35caa1, which plots close to the equal temperature line, or water from this well could contain silica in equilibrium with chalcedony or α-christobalite and be mixed with cooler water as suggested by the isotope data. Isotopic data for well 2N-2W-34bda1 (measured surface temperature 48°C), which plots near the center of the cluster of points, suggests this well is a mixed water with 54% being cold water of Reynolds Creek type (figure 4-4). The high measured surface temperature of this well suggests a source deeper than the "blue clay" aquifer. A chemical mixing model for this well (Table 4-5, column T_9) indicates 97°C maximum temperature of the hot water component with 59% of the water being cold, in good agreement with isotopic data for mixing and, temperature wise, within the known temperature range for thermal waters at depth in the area (Chapter 3).

The discordance between the isotope data (which suggests mixing) for well 2N-2W-34bda1 and the equal temperature plot of figure 4-11 (which suggests excess silica or changes in cation ratios) can most easily be explained by assuming an increased sodium/potassium ratio brought about by decreased potassium. For these waters, a general rule of thumb is an increased sodium or calcium or decreased potassium content, effectively lowers the calculated Na-K-Ca aquifer temperature causing the data point to plot to the left of the equal temperature line. Water from well 2N-2W-34bda1 has the lowest dissolved potassium content of any well sampled in the Nampa-Caldwell area and has a higher sodium/

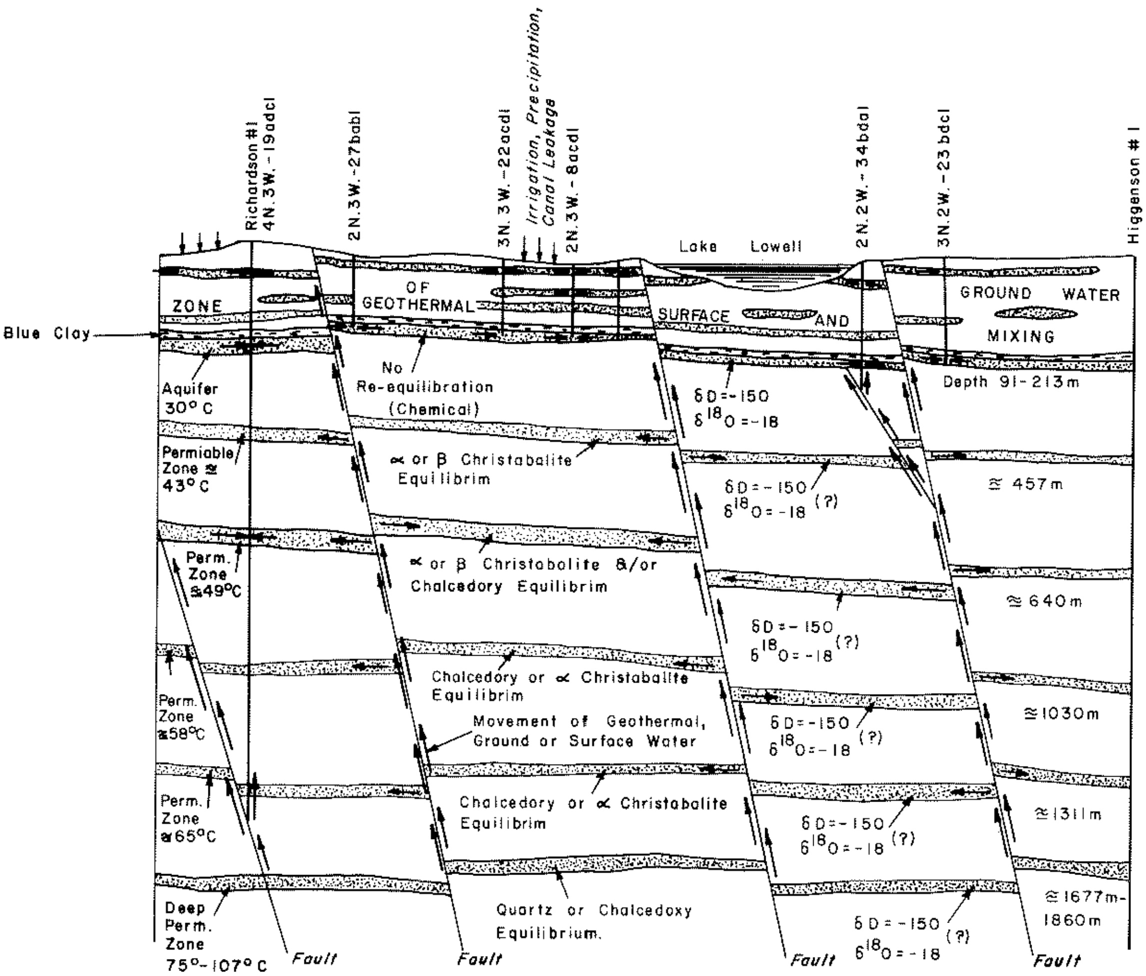

FIGURE 4-14. Idealized 2 dimensional cross section across the Nampa-Caldwell area depicting conceptual model of the hydrologic system.

potassium ratio than all but two wells (see tables 4-3 and 4-5). A Na-K-Ca calculated aquifer temperature for water from well 2N-2W-34bda1, using an adjusted higher potassium value comparable with other well waters, results in a temperature nearly identical to quartz mixing model 1 (column T_9, Table 4-5). Lower sodium/potassium ratios and higher potassium content appears normal for the geothermal waters in this area; therefore, adjusted cation ratios from mixing or precipitation due to loss of potassium may not be the cause of most of the other high predicted temperatures shown on figure 4-11. Figure 4-15a shows the generalized effects of changes in cations on the Na-K-Ca chemical geothermometer in this area.

Figure 4-12 indicates that waters from many of the wells may have more reported silica than can be explained by chalcedony equilibrium or have undergone cation equilibrium changes. Those falling on or near the equal temperature line of figure 4-12 might be in equilibrium with chalcedony and unmixed. These waters could be from an aquifer or permeable zone of the indicated temperature. Aquifer temperatures which are near the equal temperature line of figure 4-12 do fall within the measured minimum temperature range of permeable zones delineated by temperature logs from oil and gas drilling (see Chapter 3, this report). This data indicates that thermal aquifers or permeable zones of the required temperatures to explain the equilibrium temperatures plotted on figure 4-12 exists beneath the Nampa-Caldwell area, but that these temperatures are not high enough, in general, to account for high silica contents unless silica species other than quartz is postulated as controlling the silica content.

Figure 4-13 indicates that for water from many wells, the isotope ratio data and geothermometry can be brought into closest agreement by making a generalization that dissolved silica in most mixed thermal waters may have been in equilibrium with α-christobalite. Data from a few wells plot near the equal temperature line. These might represent unmixed well waters, i.e., well water 2N-3W-27bab1. Again, these temperatures fall within the range of minimum temperatures from temperature logs from permeable zones delineated by oil and gas well drilling. Data points from several mixed waters (according to isotope data) still fall above the equal temperature line and these might represent well water with silica in equilibrium with β-christobalite or amorphous silica or represent cation changes.

Well 2N-3W-27bab1 would appear to be most appropriate to obtain reliable information on aquifer temperatures in the Nampa-Caldwell area since the isotope data indicate that water from this well is unmixed. The apparent convergence of data in the cation field in the trilinear diagram (figure 4-9), and relatively good agreement between α-christobalite (72°C) and the magnesium corrected Na-K-Ca (cation) geothermometer (70°C) (a 2°C temperature difference, columns T_3 and T_6, Table 4-5) may mean little change in cations for water from well 2N-3W-27bab1, and that these might be within acceptable limits. However, a discharge of 757 l/min from this well, and a moderate depth of 195 m (640 ft) indicate water being pumped to the surface rapidly enough that there could be very little (1° or 2°C at most) change in temperature of the water in the well bore (no conductive cooling since the water left the "blue clay" aquifer). Consequently, the measured surface temperature of the well water (30°C) should be a good indicator of actual aquifer temperatures from the "blue clay" aquifer. In addition, the uniformity of isotope versus temperature data suggests uniform temperature for this aquifer over fairly large areas. Consequently, aquifer temperatures probably are not much greater or less than 30°C anywhere in this aquifer. Thermal water may be migrating upward, along faults or joints, from a deeper aquifer or permeable zone of about

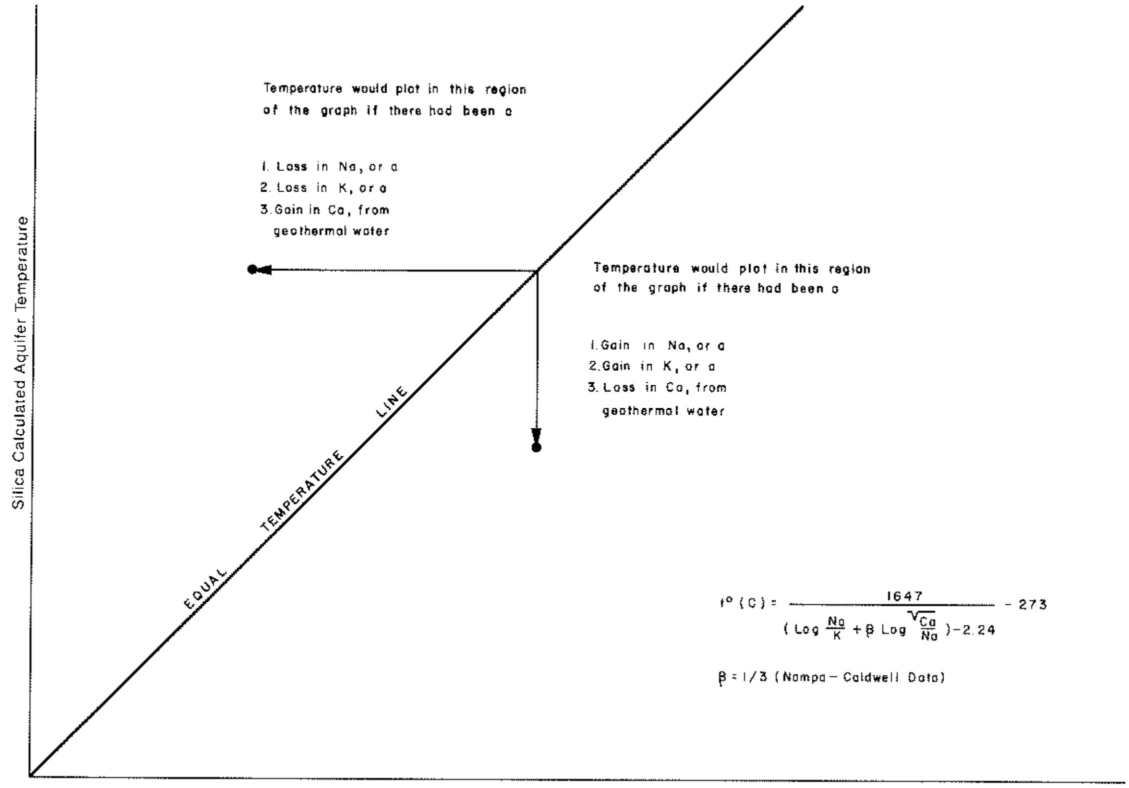

Figure 4-15a

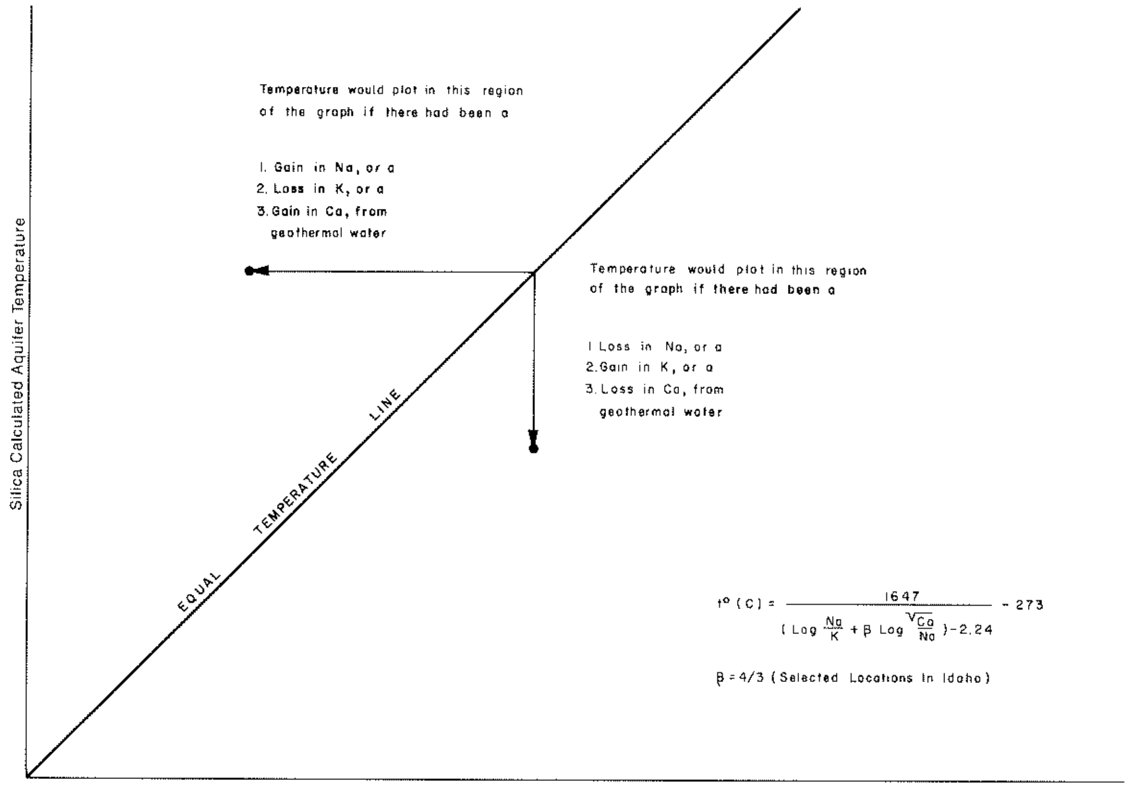

FIGURE 4-15. Graph showing generalized effects of change in cations on the Na-K-Ca chemical geothermometer in the Nampa-Caldwell area.

70°C or higher and cooling by conduction to about 30°C as it ascends into the aquifer within the "blue clay." Heat flow data of Chapter 6 (this report) indicates 70°C temperature would be reached at depth only below about 1000 to 1500 m (3,300 to 5,000 ft). The fact that in only a few instances did mixing model calculations give believable results, indicates most waters in the area have undergone conductive cooling to a significant degree, before mixing, or, equilibrium changes. The variability in the chemical data underscores the complex nature of the geothermal and cold water systems in this area.

Table 4-6 lists wells whose waters yield calculated aquifer temperatures that plot near the equal temperature lines of figures 4-12 and 4-13, with their measured surface temperatures. Those with measured surface temperatures near 30°C (within about 3° to 5°C, i.e, water from wells 2N-3W-27bab1, 2N-3W-23acd1 and 1N-3W-12bab1) may be most likely to represent unmixed geothermal waters that equilibrated chemically near given aquifer temperatures in various compartmentalized permeable zones before migration into the "blue clay" aquifer. Water from the three above mentioned wells do have similar $Cl/CO_3 + HCO_3$ ratios from .05 to .09 indicating these waters are from the same aquifer.

In conclusion, calculated subsurface temperatures (from table 4-6) are comparable to those measured during oil and gas drilling operations and may indicate thermal waters from certain warmer compartmentalized thermal aquifers or permeable zones retain chemical equilibrium in some instances during residence within the blue clay aquifer at temperatures of about 30°C.

TABLE 4-6
Well Waters Plotting On Or Near The Equal Temperature Lines
Of Figures 4-12 and 4-13 Showing Their Measured Surface and Aquifer Temperatures

Figure 4-12

Well Identification No.	Measured Surface Temperature (°C)	Chalcedony Aquifer Temperature (°C)	Na-K-Ca (Mg corrected) Aquifer Temperature (°C)
3N-3W-26bca1	17	56	59
3N-2W-10aba1	38	52	53
2N-3W-23acd1	28	75	75
2N-2W- 2acc1	30	61	56
2N-2W-31dad1	22	43	43
1N-2W- 5bbc1	23	45	43
1N-2W- 5cab1	23	56	56
1N-2W- 6add1	25	63	59
1N-2W- 6caa1	24	54	50
1N-2W- 7adc1	26	92	93
1N-2W- 9bba1	22	45	44
1N-2W-16cba1	18	53	52

Figure 4-13

Well Identification No.	Measured Surface Temperature (°C)	α-Christobalite Aquifer Temperature (°C)	Na-K-Ca (Mg corrected) Aquifer Temperature (°C)
4N-4W- 5dbd1	24	83	88
3N-2W-23bcd1	31	37	40
3N-3W-23ccc1	12	46	43
2N-3W- 8cdd1	22	59	59
2N-3W-11cba1	21	48	53
2N-3W-15cdc1	26	60	60
2N-3W-22acd1	27	54	59
2N-3W-22ddc1	27	51	56
2N-3W-27bab1	30	72	70
2N-2W-18bab1	14	40	41
1N-3W-12bab1	29	73	72

CHAPTER 5 — HEAT FLOW

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GENERAL STATEMENT

The theoretical three-dimensional expression of the generation, transportation, and storage of heat in the earth's crust is given by the formula:

$$\nabla \cdot q = - A + p'c'\hat{v} \cdot \nabla \theta \ + pc\frac{\delta\theta}{\delta t} \qquad (1)$$

(Lachenbruch and Sass, 1977), where

q = conductive flux vector

A = heat generation

p,p' = density of static and moving material, respectively

c,c' = heat capacity of static and moving material, respectively

θ = temperature

t = time

v = vertical (seepage) velocity of volume flux of water or magma

z = depth

It is convenient in geothermal studies to simplify interpretations by using quasi-one-dimensional models in which Equation (1) becomes

$$\frac{\delta\theta}{\delta z} = = A = p'c'v' \frac{\delta\theta}{\delta z} + pc\frac{\delta\theta}{\delta t} \qquad (2)$$

In the western Snake River Plain, a heat source from the radioactive minerals wihin the underlying and surrounding silicic batholith is recognized. Previous studies have determined that the contribution to regional heat flow by these radioactive minerals is 0.3 HFU (Brott and others, 1976). Regional heat flow is refracted away from poorly conductive graben-filled sediments (3.0 TCU) of the Snake River Plain towards the more thermally conductive silicic intrusives (6.0 TCU). This reduces the amount of heat energy transmitted from the mantle. The amount of energy refracted is approximately equal to the amount contributed by the radioactive decay within the sediments. These variables cancel one another.

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The following formula is derived from Equation [1] when the sign convention is reversed, radioactive decay is absent, no convection occurs, and one-dimension is considered.

$$q = K \frac{\Delta\theta}{\Delta z} \qquad (3)$$

where

q = heat flow

K = thermal conductivity

θ = temperature

z = depth

In this investigation, Equation (3) was used for calculation of heat flow values. Two basic sets of data are required for determination of heat flow: (1) the temperature gradient or change in temperature with depth $\frac{\Delta\theta}{\Delta z}$

(2) the thermal conductivity of the rock units through which the gradients are measured (K of equation 3). The anticipated results of this heat flow study include information on the earth's energy balance and processes associated with generation, transport and storage of the heat.

The basic unit of measurement in heat flow is the "Heat Flow Unit" (HFU), 1 HFU = 10^{-6} calories/cm^{2}sec. Heat flow is, therefore, a measurement of heat energy (microcalories = 10^{-6} calories) passing through a unit area (cm^2) of the earth per unit of time (seconds). Temperature gradients in this text are measured as °C/km. The basic thermal-conductivity measurement is the "Thermal Conductivity Unit" (TCU), 1 TCU = 10^{-3} calories/cm/sec°C or the amount of heat energy (millicalories = 10^{-3} calories) that pass through a unit length (1 cm) in a unit period of time (1 second) at a given temperature (°C). As various dimensional systems are used, Table 1-1 gives the conversions.

The range of observed heat-flow values is normally between between 1.0 and 2.0 HFU with highs between 2.0 and 3.0 and lows between 0.5 and 1.0 FHU. However, heat-flow values can span several orders of magnitude, especially where convective transport of heat brings high temperatures near the earth's surface.

PREVIOUS WORK RELATED TO HEAT FLOW

The western Snake River Plain is located within the "Cordilleran Thermal Anomaly Zone" (Roy and others, 1972), where there is an overall heat flow of about 2.0 HFU. Regional differentiation of the heat-flow values in the western United States has been outlined by Lachenbruch and Sass (1977) and is presented in figure 5-1. The plate tectonic evolution of the western Snake River Plain graben is discussed by Atwater (1970). A rift structure and deep-seated left-lateral strike-slip displacement of 40-50 miles has been proposed by Warner (1975). The fact that the structural evolution differed between the eastern and western Snake River Plain has been proposed by Bonnichsen and Travers (1975) and LaFehr (1962). Consistent with these models is Brott and others' (1978) proposal of a migrat-

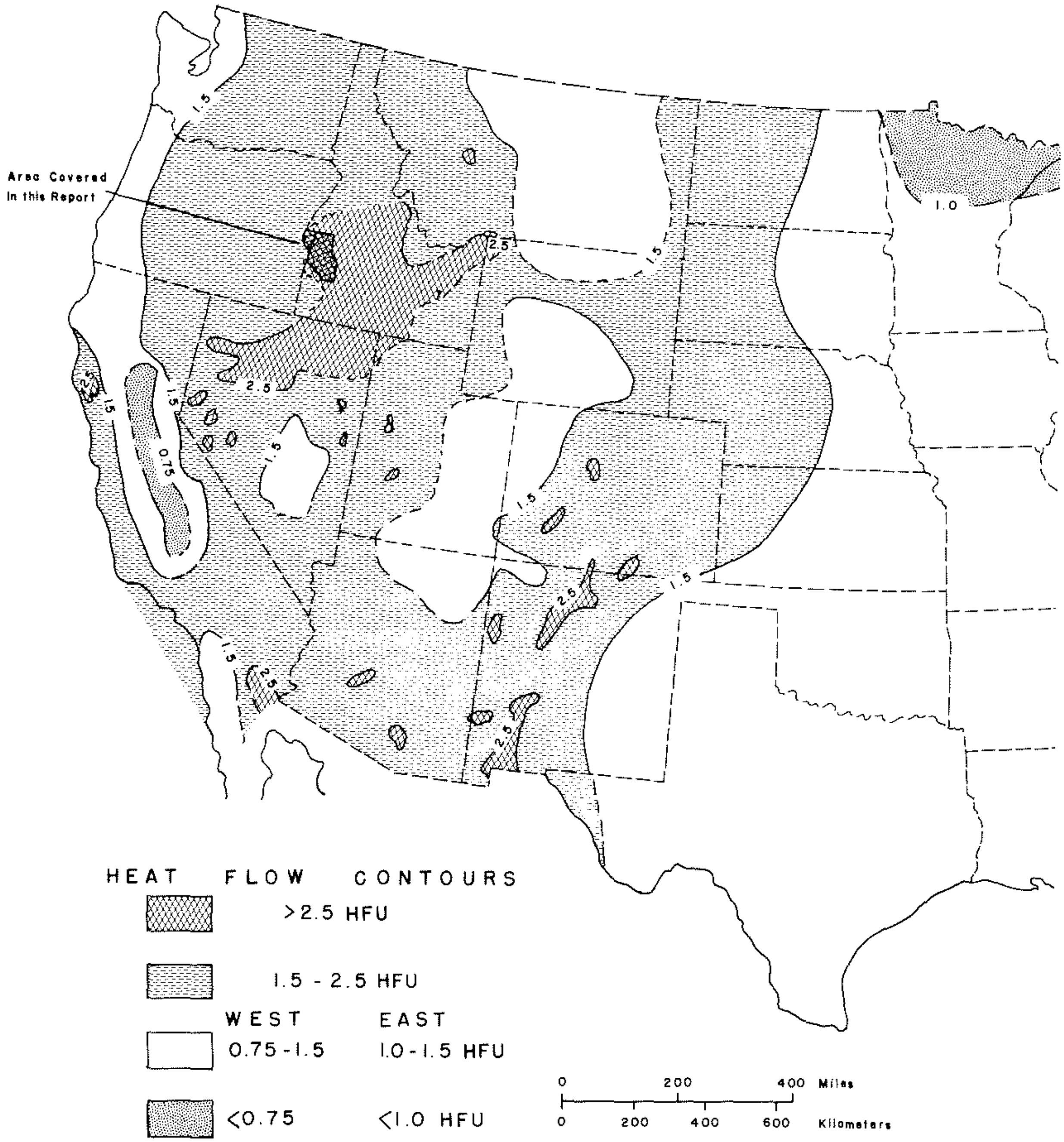

FIGURE 5-1. A generalized heat flow contour map of the western United States. From Lachenbruch and Sass (1977).

ing thermal anomaly which began in the westernmost portion of the plain (near the Idaho-Oregon border) approximately 12.5 million years ago and migrated eastward to its present location near Yellowstone Park. Armstrong and others (1975) have proposed similar models based on an eastward decrease in the K/Ar dates of the volcanic rocks.

The present crustal configuration is shown by geophysical methods to be extraordinarily thin (Pakiser, 1963), approximately 5-10 kilometers, when compared to the Basin and Range Province to the south where the upper crust has a thickness (P-wave velocity layer of 6.7 km/sec) of approximately 30-40 kilometers. However, a lower anomalously thick crust, approximately 28 kilometers, is present beneath the western Snake River Plain and has been proposed by Brott and others (1978) to be the result of a mafic intrusion some 12.5 million years ago. Gravity measurements reveal patterns of isogal lines which trend in the same direction as the plain. Two-dimensional gravity models across the plain suggest that fissure zones filled with basalt exist beneath the predominantly sedimentary layers of the Idaho Group. This model seems to fit well with LaFehr's proposal of an en echelon structure (1962) and with Lachenbruch's (1977) model of an extending Basin and Range lithosphere. If this model is valid, the effect on the local heat flux would be great and would be related to the intrusion of high temperature mafic dikes that provide deeply rooted conduits to shallower depths. A contour map of the heat-flow values measured in this investigation shows trends similar to isogal maps of the area. Correlation of high gravity and low heat flow has been reported by Decker and Smithson (1975) in the Rio Grande Rift and by Brott and others (1976) in the Snake River Plain. Here in the western Snake River Plain, high gravity anomalies also overlie areas which have low heat flow. At present, there is no explanation for this phenomena. The western Snake River Plain has been grouped into recognized hydrothermally induced systems of known geothermal-resource areas such as the Battle Mountain area in northern Nevada and the Yellowstone system in western Wyoming. Recognizing that hydrothermal activity would most likely play a major role in the heat-flow patterns of the western Snake River Plain, the author has exercised caution in preparing the models which assume only conductive heat transport. A detailed map of the distribution of heat-flow values determined during this investigation is presented in figure 5-2. This heat-flow contour map outlines general trends in the heat-flow values recorded by the author. It is interesting to note that the values recorded by Brott and others (1978) in this area follow the same patterns. An interpretation of this pattern is given in the chapter on temperature distribution.

Classic theoretical studies of heat flow in solids by Carslaw and Jaeger (1959) have been used to produce models of heat flow in Basin and Range structures (Blackwell and Chapman, 1977). These models appear to support field data collected for this investigation and are discussed more thoroughly in the chapter on local interpretations.

DATA ACQUISITION

To obtain a heat-flow measurement at a specific drill hole, it is necessary to measure the earth's thermal gradient and to assess the thermal conductivity of the rock unit through which the gradients were measured. The more accurate the measurements are and the better the knowledge of geology and hydrology, the more precise a heat-flow measurement will be. In this section, a brief overview is presented of the type and accuracy of instrumentation which was used and the methods of field surveys, sample acquisition and determination of thermal conductivity.

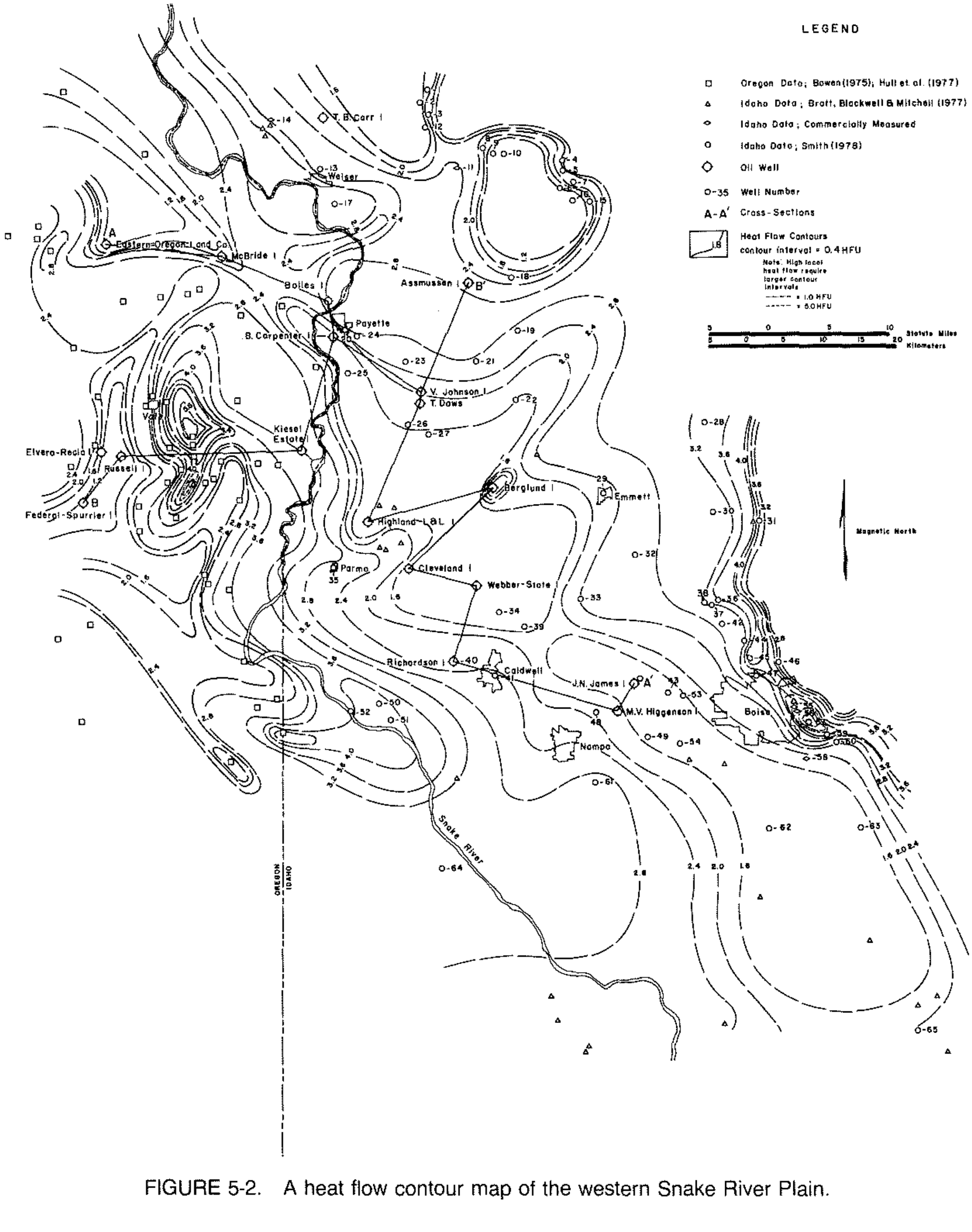

FIGURE 5-2. A heat flow contour map of the western Snake River Plain.

All logs run in this survey were made with a Fenwal Thermistor Probe connected to a digital meter by a 680 meter (2,200 foot) four-conductor cable. The digital meter is a portable unit which measures the electrical resistance in the cable and thermistor, subtracts the cable resistance and displays the result on the output screen in milliohms. A set of polynomial coefficients relate pairs of resistance values and temperatures which are documented in probe tables. The manufacturer calibrates the probe by comparing it to a platinum thermometer element in still water. The accuracy of these readings is approximately 0.02 degrees centigrade. A design feature of the instrument permits cable resistance to be measured separately. Such measurements were recorded at the top and again at the bottom of each well to reveal any irregularities in the cable resistance indicating leaks or faulty readings.

Temperature measurements were taken at five-meter intervals from the surface downwards. Wall-rock temperatures for measurements made above the water table were determined by taking several timed measurements and extrapolating the results to infinite time, as discussed by Parasnis (1971). A program for determining the asymptotically-approached temperatures was written for a TI-59 portable calculator and allowed calculations to be made in the field.

As might be expected, gradients within a drill hole varied due to thermal-conductivity changes between rock units. Theoretically, the heat flow should remain the same. In wells assumed to be undisturbed by groundwater movement, an accuracy of between 10 and 15 percent for heat-flow values between units was observed. These results are relatively good considering the accuracy of the thermal-conductivity measurements is near this limit.

THERMAL CONDUCTIVITY

The divided bar technique, which has been used in thermal conductivity mesurements of samples taken in this study, has been refined by several authors (Birch, 1950; Sass and others, 1971). The apparatus used in this investigation consists of a "stack" composed of the sample cylinder, a copper disk at each end of the sample followed by pyrex glass plates and, again, two wafers of copper. Four differential thermocouples are used to measure differences of temperature across the three poor conductors two of pyrex and one of rock. A temperature differential across the apparatus is produced by circulating water above and below the "stack" with styrofoam insulation surrounding the "stack" to prevent heat loss or gain from adjacent air. The sample can be placed directly in the stack if it is a solid core type with the ends polished to ensure good thermal contact. If the sample is of cuttings, these can be placed in a cell 0.63 cm long fitted to machined copper bases. When the core or the cell is placed in the stack and an axially-directed force applied to decrease resistance at the contacts, the circulating fluids are heated and cooled until there is a drop of about 7 degrees centigrade across each of the glass wafers. As the conductivity of the samples varies between two and three times that of the pyrex, the difference in temperatures across the sample is between 2 degrees centigrade and 3 degrees centigrade.

To a first approximation, the ratio of conductivity of rocks to pyrex is equal to the ratio of the mean potential (produced by the differential thermocouples) across the glass samples to the mean potential across the rock (Birch, 1950). The absolute conductivity of pyrex is known from earlier work (Birch and Clark, 1940) to be 0.00296 calories/cm sec deg at 30 degrees centigrade.

When the sample is of fragments, calculation of the bulk thermal conductivity is somewhat more involved than that for solid cores. However, investigations by Sass et al. (1971) have shown that the error incurred in using rock fragments instead of solid rock core is probably within 10 percent. The difference in procedure involves the use of a cell in the stack to hold the rock fragments rather than the solid core.

The theory used in correlating solid rock and rock fragment bulk thermal conductivities is expressed in the equation:

$$K_r = K_w \frac{D^2 K_c}{d^2 K_w} - \frac{D^2 - d^2}{d^2} \frac{K_p}{K_w}^{\frac{1}{1-\phi}} \qquad (4)$$

where:

K_r = conductivity of nonporous rock

K_w = thermal conductivity of liquid water (1.46 mcal/cm sec centigrade at 25°C)

D = outer diameter of cell wall

d = inner diameter of cell wall

K_c = measured conductivity of cell and contents

K_p = thermal conductivity of plastic cell wall

ϕ = volume fraction of water in cell

When the manufacturer's constants are introduced into the preceding formula, it converts to:

$$K_r = 1.46\ (0.815\ K_c - 0.104)^{\frac{1}{1-\phi}} \qquad (5)$$

where K_r is determined by knowing the measured thermal conductivity and the percentage of volume occupied in the cell by rock fragments.

Thermal-Conductivity Results

The results of the thermal-conductivity analyses of samples taken within the area covered in this investigation are shown on Table 5-1 and statistically presented by the histograms of figures 5-3 and 5-4. The procedure described in the preceding section produces

TABLE 5-1
Heat Flow Data Of The Western Snake River Plain

Well No.	Well Location	North Latitude	West Longitude	Elevation of Well Head (Meters)	Depth of Hole (Meters)	Range of Geothermal Gradient (Meters)	Geothermal Gradient (°C/km)	Thermal Conductivity ("in situ") (Millical/ cm/Sec °C)	Heat Flow (Uncorrected) (Microcal/ cm/Sec)	Thermal Conductivity Samples: No.	Type	Lithology
1	12N/4W/23CCA	44 21'	116 47'	817.1	76.2	15 - 77	59.5	2.98 ± 0.32	1.77	13	Cuttings	SAND/CLY/[BSLT]
2	12N/4W/27DBC	44 20'	116 47'	731.7	76.2	55 - 77	43.8	3.29 ± 0.37	1.44	13	Cuttings	CLAY/[BSLT]
3	12N/4W/35CDC	44 15'	116 47'	743.9	76.2	40 - 77	59.6	3.66 ± 0.79	2.18	13	Cuttings	[SAND/CLY]
4	11N/2W/22DBB	44 16'	116 33'	1036.6	76.2	15 - 77	92.8	2.90 ± 0.27	2.70	13	Cuttings	[SAND/CLY]
5	11N/2W/27ACD	44 15'	116 33'	1036.6	76.2	0 - 25	127.6	2.25 ± 0.08	2.87	13	Cuttings	[SAND/CLY]
6	11N/2W/34CCB	44 14'	116 34'	1064	76.2	10 - 77	38.6	2.91 ± 0.52	1.12	13	Cuttings	[SAND/CLY]
7	11N/2W/35BDD	44 14'	116 32'	1054.9	76.2	45 - 65	72.6	3.55 ± 0.31	2.58	12	Cuttings	SAND/CLY/[BSLT]
8	11N/3W/16DAA	44 17'	116 41'	1112.8	76.2	50 - 77	44.0	3.75 ± 0.93	1.65	13	Cuttings	[SAND]/CLY/BSLT
9	11N/3W/22AAD	44 16'	116 40'	1112.8	76.2	40 - 77	28.0	3.25 ± 0.20	0.90	13	Cuttings	SAND/CLY/[BSLT]
10	11N/3W/23ABD	44 15'	116 39'	1152.4	76.2	30 - 77	18.4	3.72 ± 0.31	0.68	13	Cuttings	[SAND/CLY]
11	11N/3W/29BDD*	44 16'01''	116 43'49''	807.9	2439	2043 -2439	36.5	6.01 ± 0.50#	2.19			GRANITE
12	11N/4W/2CCC	44 18'	116 47'	718.0	76.2	20 - 55	47.5	3.19 ± 0.09	1.52	13	Cuttings	SAND/CLY/[BLST]
13	11N/5W/29BAD	44 15'51'	116 57'53''	679.9	71.0	10 - 71	53.1	4.17	2.21	1	Cuttings	SAND
14	11N/6W/3BD*	44 09'36''	117 02'50''	722.6	611.3	97.6- 414.6	71.0	3.49 ± 0.90#	2.48			SAND/CLY
15	10N/2W/1DDD	44 13'27''	116 30'44''	1105.2	38.0	20 - 77	44.0	2.73 ± 0.58	1.22	9	Cuttings	[SAND/CLY]/BSLT
16	10N/2W/2CCD	44 13'27''	116 32'50''	1079.3	76.2	20 - 65	31.6	3.46 ± 0.57	1.59	13	Cuttings	SAND/CLY/[BSLT]
17	10N/5W/9BAC	43 59'32''	116 56'32''	646.3	34.0	15 - 25	106 (?)	2.79 ± 0.51#	2.96			[CLAY]
18	9N/3W/12BCA	44 08'02''	116 38'51''	811.0	435.0	195 - 435	67.0	2.79 ± 0.51#	1.87			[CLAY]
19	9N/3W/36DDB	44 04'07''	116 38'07''	817.4	333.4	230 - 334	96.0	2.79 ± 0.51#	2.68			[CLAY]
20	9N/5W/34CDA	44 04'14''	116 55'22''	655.5	64.0	30 - 64	57.0	4.82	2.75	1	Cuttings	[SAND]
21	8N/3W/16DBD	44 02'09''	116 47'19''	700.0	442.0	10 - 442	97.0	2.79 ± 0.51#	1.57			[CLAY]
22	8N/3W/36CAD	43 56'12''	116 38'37''	840.9	415.0	140 - 335	45.0	3.49 ± 0.90#	1.57			[SAND/CLY]
23	8N/4W/16BDA	44 02'05''	116 49'17''	695.1	295.0	15 - 295	89.3	2.79 ± 0.51#	2.49			[CLAY]
24	8N/5W/2BAD	44 03'53''	116 54'11''	754.6	54.0	45 - 54	89-111	2.56	2.28-2.84	1	Cuttings	[SAND/CLY]
25	8N/5W/22ACA	44 01'17''	116 55'06''	673.8	45.0	30 - 40	27.6	3.77 ± 0.19	(0)	2	Cuttings	[SAND]
26	7N/4W/9ACD	43 57'37''	116 49'10''	694.4	31.1	20 - 30	41.4	4.45	1.84	1	Cuttings	[SAND]
27	7N/4W/14BCD	43 56'16''	116 47'16''	704.3	27.5	10 - 25	(0)	4.35	(0)	1	Cuttings	[SAND]
28	7N/1E/10DCD	43 57'32''	116 19'48''	780.5	64.0	30 - 64	130.0	2.55	3.32	1	Cuttings	[CLAY]
29	6N/1W/4AAD	43 52'37''	116 29'38''	725.3	72.0	10 - 72	66.3(?)	3.49 ± 0.90#	2.31			
30	6N/1E/15DDD	43 51'08''	116 18'45''	1344.5	33.2	20 - 33	49.4	6.00 ± 0.87	2.98	10	Core	[GRANITE]
31	6N2E/29ACC	43 50'	116 15'	1294.8	150.3	10 - 150.3	60.5	6.57 ± 0.09	4.0	4	Core	[GRANITE]
32	5N/1W/3ABD	43 48'15''	116 26'23''	838.4	32.0	15 - 32	77.4	3.39	2.62	1	Cuttings	[SAND]
33	5N/2W/26AAA	43 44'42''	116 33'12''	777.4	73.3	45 - 70	57.0	4.24	2.42	1	Cuttings	[SAND]
34	5N/3W/35DBB	43 44'01''	116 40'11''	762.0	56.6	10 - 57	36.2	3.88	1.41	1	Cuttings	[SAND]
35	5N/5W/9BDB	43 47'14''	116 56'41''	675.3	117.0	10 - 117	68.2(?)	3.73 ± 0.05	2.54	2	Cuttings	[SAND]

TABLE 5-1
(Continued)

Well No.	Well Location	North Latitude	West Longitude	Elevation of Well Head (Meters)	Depth of Hole (Meters)	Range of Geothermal Gradient (Meters)	Geothermal Gradient (°C/km)	Thermal Conductivity ("in situ") (Millical/ cm/Sec °C)	Heat Flow (Uncorrected) (Microcal/ cm/Sec)	Thermal Conductivity Samples No.	Type	Lithology
36	5N/1E/26BAC	43 44'49''	116 18'28''	926.8	133.0	65 - 125	82.2	4.41	3.63	1	Cuttings	[CLAY]
37	5N/1E/27BDD	43 44'47''	116 19'41''	902.4	99.0	55 - 100	85.7	3.88	3.33	1	Cuttings	[CLAY]
38	5N/1E/27DAA	43 44'32''	116 18'53''	850.6	69.0	35 - 69	89	3.43	3.05	1	Cuttings	[CLAY]
39	4N/2W/6BCB	43 42'55''	116 37'49''	739.3	30.0	(0)	(0)	(0)	(0)			
40	4N/3W/19ADC	43 40'15''	116 44'14''	711.9	650.0	(0)	(0)	(0)	(0)			[CLAY]
41	4N/3W/27AAC	43 59'32''	116 40'31''	731.7	48.0	20 - 48	72.4	3.49 + 0.90#	2.53			[SAND/CLAY]
42	4N/1E/2ADB	43 43'02''	116 17'51''	902.4	82.0	10 - 40	70.7	4.15	2.93	1	Cuttings	[SAND]
43	4N/1E/31CCC	43 38'04''	116 23'24''	789.6	49.3	35 - 49	22.0(?)	4.31	0.95	1	Cuttings	[SAND]
44	4N/2E/7CAA	43 41'54''	116 15'50''	902.4	31.6	10 - 25	93.8	3.49 + 0.90#	3.27			[SAND/CLY]
45	4N/2E/19AAA	43 40'38''	116 31'29''	856.7	169.0	30 - 130	100.0	4.78	4.78	1	Cuttings	[SAND]
46	4N/2E/22BCD	43 40'15''	116 12'31''	887.0	80.0	10 - 80	61.3	3.49 + 0.90#	2.14			[SAND/CLY]
47	4N/2F/29ACC	43 39'25''	116 14'21''	814.4	123.0	15 - 123	91.7	3.49 0.90#	3.20			[SAND/CLY]
48	3N/1W/7BCB	43 31'43''	116 30'42''	797.7	14.0	10 - 14	(0)	(0)	(0)			
49	3N/1W/23DBB	43 35'57''	116 25'22''	821.6	51.8	40 - 50	22.0	4.42	0.97	1	Cuttings	[SAND]
50	3N/4W/6BBC	43 37'36''	116 52'10''	785.0	60.0	35 - 50	91.3	4.64	4.24	1	Cuttings	[SAND]
51	3N/4W/8CDC	43 36'14''	116 50'39''	731.7	62.6	40 - 62	87.3	4.67	4.08	1	Cuttings	[SAND]
52	3N/5W/3DDC	43 37'10''	116 55'12''	682.9	21.0	15 - 20	104.4	3.49 + 0.90#	3.64			[SAND/CLY]
53	3N/1E/5ABB	43 37'59''	116 21'43''	797.3	25.0	15 - 25	45.2	3.49 + 0.90#	1.58			[SAND/CLY]
54	3N/1E/29BBB	43 34'29''	116 22'21''	807.9	85.0	45 - 80	34.0	3.49 + 0.90#	1.19			[SAND]
55	3N/2E/11BAB*	43 37'06''	116 11'03''	835.4	372.6	35 - 114	225.4	2.99 + 0.55	6.73	24	Core	[CLY/RHYOLITE(?)]
56	3N/2E/11BAD*	43 37'01''	116 10'55''	844.5	391.2	45.7- 137.2	361.8	2.99 + 0.55	10.8			[CLY/RHYOLITE(?)]
57	3N/2E/13ACC	43 35'55''	116 09'38''	850.6	222.0	40 - 55	506 (?)	4.11	20.8	1	Cuttings	[SAND]
58	3N/2E/36AC	43 33'20''	116 09'16''	884.2	195.7	98 - 140	49.2	3.49 + 0.90#	1.72			[SAND/CLY]
59	3N/3E/20DDB	43 35'02''	116 07'38''	875.0	161.9	20 -1602	308.9	2.98	9.20	1	Cuttings	[SAND]
60	3N/3E/28BB	43 34'27''	116 06'44''	878.0	73.9	25 - 74	86.6	2.79 + 0.51#	2.42			[CLAY]
61	2N/1W/7BBC	43 31'43''	116 30'42''	777.4	29.8	20 - 25	82.2	3.62 ± 0.85	2.97			[BASALT]
62	2N/2E/33ABB	43 28'23''	116 13'17''	922.3	162.5	30 - 125	58.9	3.95	2.32	1	Cuttings	[SAND]
63	2N/3E/35BBC	43 28'11''	116 04'22''	1070.0	332.0	120 - 180	73.3	3.92	2.87	1	Cuttings	[SAND]
64	1N/4W/13BAC	43 25'39''	116 45'56''	777.24	27.0	5 - 25	111.0	2.79 + 0.51#	3.10			[CLAY]
65	2S/1E/23AAD	43 50'08''	115 47'10''	963.0	235.0	210 - 235	70- 81.1	3.29	2.3 -2.67	1	Cuttings	[SAND]/BASALT

NOTE: Symbols used in the table are explained in by the following: * = gradients measured by other surveys; # = no samples taken, thermal conductivity assigned from harmonic means of dominant rock type (see histograms, Figures 5 and 6); and 0 = gradient information to disturbed to be useful. ? = questionable data.

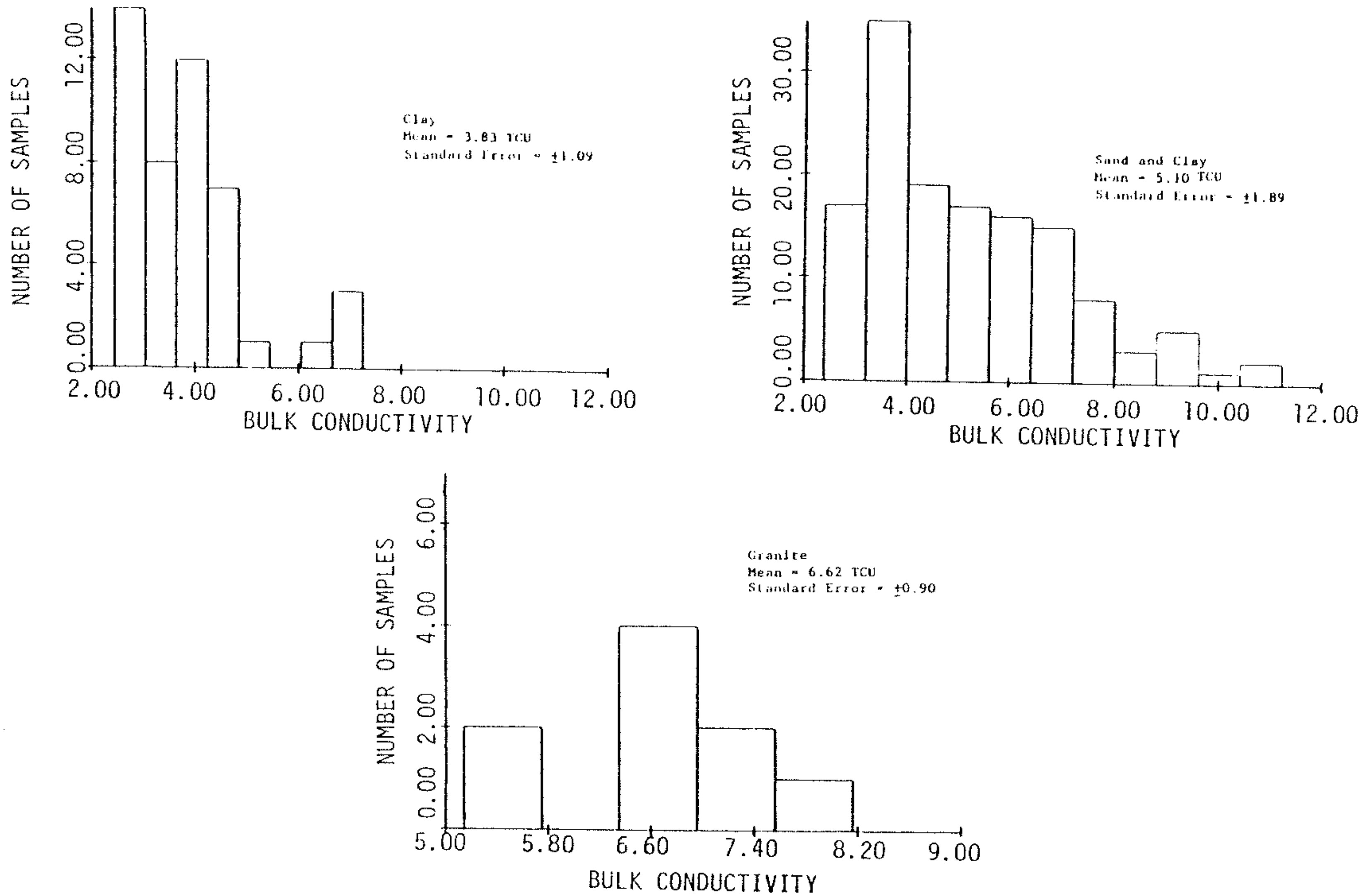

FIGURE 5-3. Bulk thermal conductivity histograms; clay, sand and clay, and granitic rock.

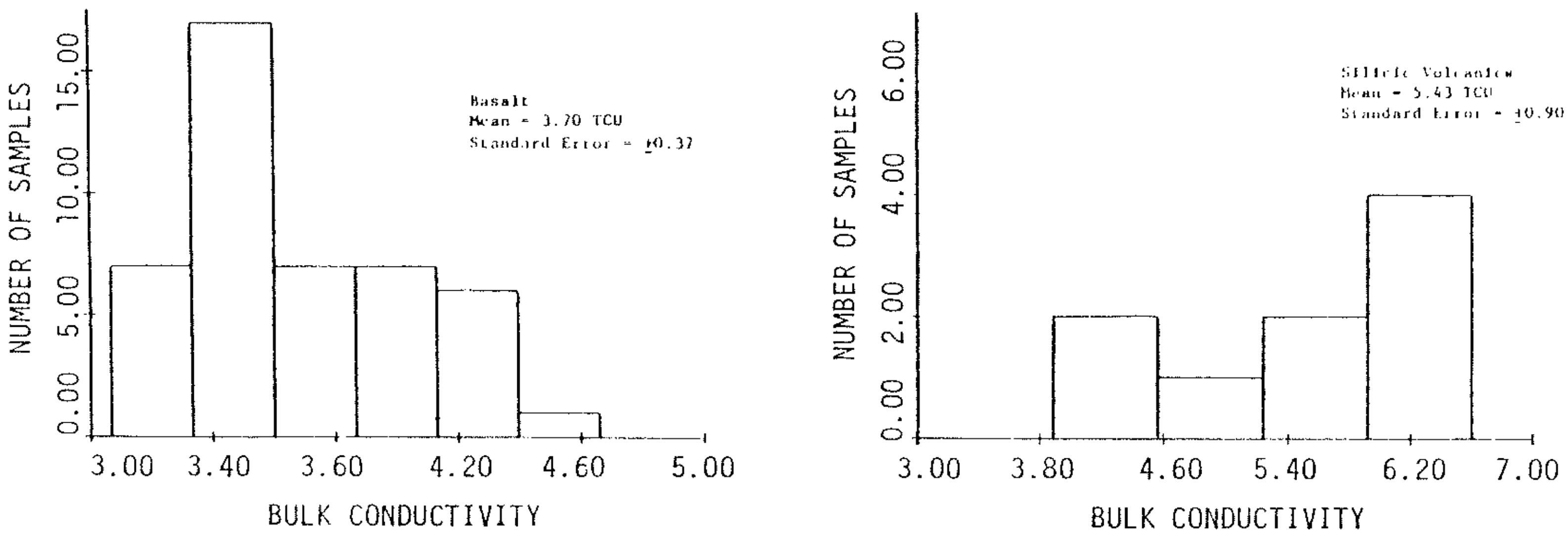

FIGURE 5-4. Bulk thermal conductivity histograms; basalt and silicic volcanic rocks.

TABLE 5-2
Bulk Thermal Conductivity Results

Investigator	Basalt	Granite	Silicic Volcanics	Sand & Clay	Clay
1. Smith	3.7 ± 0.38*	6.67 ± 0.95	5.43 ± 0.90	5.10 ± 1.9	3.83 ± 1.11
2. Brott	4.5 ± 0.50	6.50 ± 0.30	4.83 ± 0.27	6.00 ± 8	3.60 ± 4.0
Change of 1. from 2.	18% less	18% more	12% more	15% more	6% more
Combined Average	4.03 ± 1.06	6.49 ± 1.57	4.83 ± 0.27	5.20 ± 1.84	3.78 ± 0.98
Assumed Porosity	10%	5%	5%	30%	30%
Calculated "in situ" Value	3.62 ± 0.85	6.01 ± 0.50	4.54 ± 0.24	3.49 ± 0.90	2.79 ± 0.51
Number of Samples					
Smith	45	9	9	138	46
Brott	16	24	16	15	15
Total	61	33	25	153	61

NOTE: *4.83 ± .27 = mean ± one standard deviation.

results considered as the bulk conductivity of the samples or the thermal conductivity which would exist without regard for porosity of the samples. To convert this to "in situ" thermal conductivity a formula proposed by Woodside and Messmer (1961) is used. It is:

$$K_i = (K_b)^{1-\phi} (K_w)^{\phi} \tag{6}$$

where:

K_w = thermal conductivity of water

K_i = "in situ" thermal conductivity

K_b = bulk conductivity of the sample

ϕ = porosity of the rock unit

After determination of the harmonic mean of the bulk conductivity, an estimate of the "in situ" volume fraction occupied by water was made. This estimate is an unmeasured quantity and subject to error. Estimates were prepared from porosity studies of cores acquired in oil-well drilling operations (Newton and Corcoran, 1963) and from reports by authors on average porosities of rock types (Heiland, 1968). Results were in relatively good agreement with other authors who have worked in surrounding areas (Brott and others, 1976; Bowen and Blackwell, 1975). A statistical comparison with Brott's results is given in Table 5-2.

GEOHYDROLOGY

The inclusion of this section on the groundwater environment of the area has a threefold purpose: first, to integrate known geohydrologic data into the observed heat-flow configuration; second, to emphasize that some of the subsurface heat distribution is related to permeability of formations; and third, to make some generalizations about the regional and several local groundwater flow systems in the geological makeup of this area. A detailed investigation of the western Snake River Plain's geohydrology is beyond the scope of this study.

For the purpose of a geohydrologic discussion, the western Snake River Plain has been separated into five sections, each of which is treated separately though they may all be hydrologically interconnected. A summary of the water-bearing characteristics of the formations is presented in figure 5-5.

The subareas are: (1) the Boise Front and highlands forming the northeastern boundary of the plain, (2) the Boise River Valley, (3) southern Ada and western Elmore counties, (4) the southern Canyon County area, and (5) the Weiser River Basin.

The highlands forming the northeastern boundary of the western Snake River Plain are considered recharge areas, although the amount of groundwater recharge transmitted to formations in the plain is considered small. Mohammad (1970) and Savage (1958, 1961) mapped the rock units contacting the Idaho Batholith as predominantly the Idaho Group. The water-bearing features of this sedimentary formation are highly variable, but it is known to produce confined aquifers at lower elevations. Ralston and Chapman (1970) suggest that

PERIOD	SERIES		GROUPS	FORMATIONS	WATER BEARING CHARACTERISTICS
QUATERNARY	RECENT		SNAKE RIVER GROUP	Surficial Deposits	Local permeability high in gravel and sand alluvium. Irregularity and local extent of beds caused some beds to have low yields.
QUATERNARY	PLIESTOCENE	UPPER	SNAKE RIVER GROUP	Younger Terrace Gravels (Boise Area) Lower Mesa Gravels (Weiser Area) Upper Mesa Gravels (Weiser Area)	Terrace and mesa gravels permit infiltration of meteoric water and moderate to high yields where below watertable.
QUATERNARY	PLIESTOCENE	UPPER	SNAKE RIVER GROUP	Basalt of Snake River Group	High permeability because of jointing. An important aquifer south of Nampa.
QUATERNARY	PLIESTOCENE	UPPER	SNAKE RIVER GROUP	Older Terrace Gravels (Boise Area)	High permeability permits good groundwater recharge, entirely above watertable where mapped.
QUATERNARY	PLIESTOCENE	MIDDLE LOWER	IDAHO GROUP	Glens Ferry Formation Chalk Hills Formation Banbary Basalt (Grassy Mt. Basalt) Poison Ck. Formation	Porosity and permeability highly variable, chief source of artesian water in western Snake River Plain. Some water is warm.
TERTIARY	PLIOCENE	UPPER MIDDLE LOWER	IDAHO GROUP		
TERTIARY	PLIOCENE	LOWER		Idavada Volcanics / Deer Butte Formation	Permeability is generally low, commonly contains warm water under artesian pressure. Probable source by interformational leakage of hot artesian water in the vicinity of Boise.
TERTIARY	MIOCENE	UPPER		Late Columbia River Basalt	Permeability unknown but probably similar to other Columbia River Basalt.
TERTIARY	MIOCENE			Payette Formation	Permeability generally low, sandy beds in the westernmost part of the Snake River Plain yields small to moderate amounts of artesian water.
TERTIARY	MIOCENE	MIDDLE		Early Columbia River Basalt	Permeability unknown.
CRETACEOUS		UPPER MIDDLE		Idaho and Owyhee Batholiths	Permeability generally low except were jointed or faulted. Infiltration is considered low.

FIGURE 5-5. Geologic column of the western Snake River Plain. Adapted from Savage (1958, 1961); Corcoren, et. al. (1962); Malde and Powers (1962) and Mundorf, et. al. (1974).

the granite and its weathered products are not good recharge units. Most recharge to the western Snake River Plain shallow groundwater system comes from other sources, such as meteoric waters falling directly on the plain, recharge from the rivers, and irrigation (Mundorf and others, 1964; Nace and others, 1957; Thomas and Dion, 1974).

The Boise Front is a recharge area for the Boise Valley shallow groundwater system. Isopiestic contours indicate that groundwater flows from the highlands toward the Boise River and subsequently in the direction of the westward-flowing river. The Idaho Group is a source for moderately deep artesian water in the Boise Valley. The deeper formations of the Payette sediments and Columbia River Basalts (Owyhee Volcanics) are generally low in permeability, but contain deep regional artesian groundwater resources (Nace and others, 1957). However, little is known about these systems, and deeper aquifers have only been penetrated by oil well exploration holes. Groundwater is retrieved normally from shallow wells in the Boise River Valley as water tables are shallow. Irrigation in this area has had a significant impact on the local water table, because more water is recharged than the area is able to discharge, and there has been a resultant increase in water-table elevation. Because of the variability of the underlying strata, much of the irrigation water moves laterally and reenters the drainage networks rather than the deep aquifer systems. Within this area infiltration and lateral migration are thought to reduce temperature gradients and, consequently, the heat flow measured in shallow bore holes (less than 30.5 meters; 100 feet).

The Mountain Home Plateau is southeast of the Boise Valley area, and Nace and others (1975) suggest the existence of a groundwater divide between the two areas. Ralston and Chapman (1970) suggest that recharge is mainly through exposed basalts in the higher regions to the northeast and from infiltration to the plain. Groundwater movement is generally southwestward toward the Snake River where the groundwater is discharged as springs. The water table is deep in this area, irrigation minimal, and some perched water tables exist. Recharge and discharge are low, and irrigation has been restricted by the lack of surface water and the depth to groundwater. Alterations of thermal gradient measurements in this area due to surface infiltration are minimal. A special problem noted in taking measurements of deep wells in this area was the tendency of air to be blown from the borehole in the morning and sucked into the borehole in the afternoon. The temperature measurements above the water table were distorted considerably by this phenomenon (see figure 5-6).

The shallow groundwater movement of southern Canyon County is known to occur primarily within the sand and gravel layers of the Idaho Group. The Snake River Basalts have high permeability, but are located predominantly above the water table. A groundwater divide is postulated to run near the southern edge of Lake Lowell and continues in a general northwestward direction (Stevens, 1962). From this divide, groundwater flows approximately southwestward and northeastward. Recharge is principally from surface infiltration. The deep rock units do contain permeable zones which are often artesian. Recharge to the deep zones has been suggested as coming from the south in the Owyhee Mountains. Discharge from leaky aquifers is thought to be a source of some of the recharge for the overlying aqui-

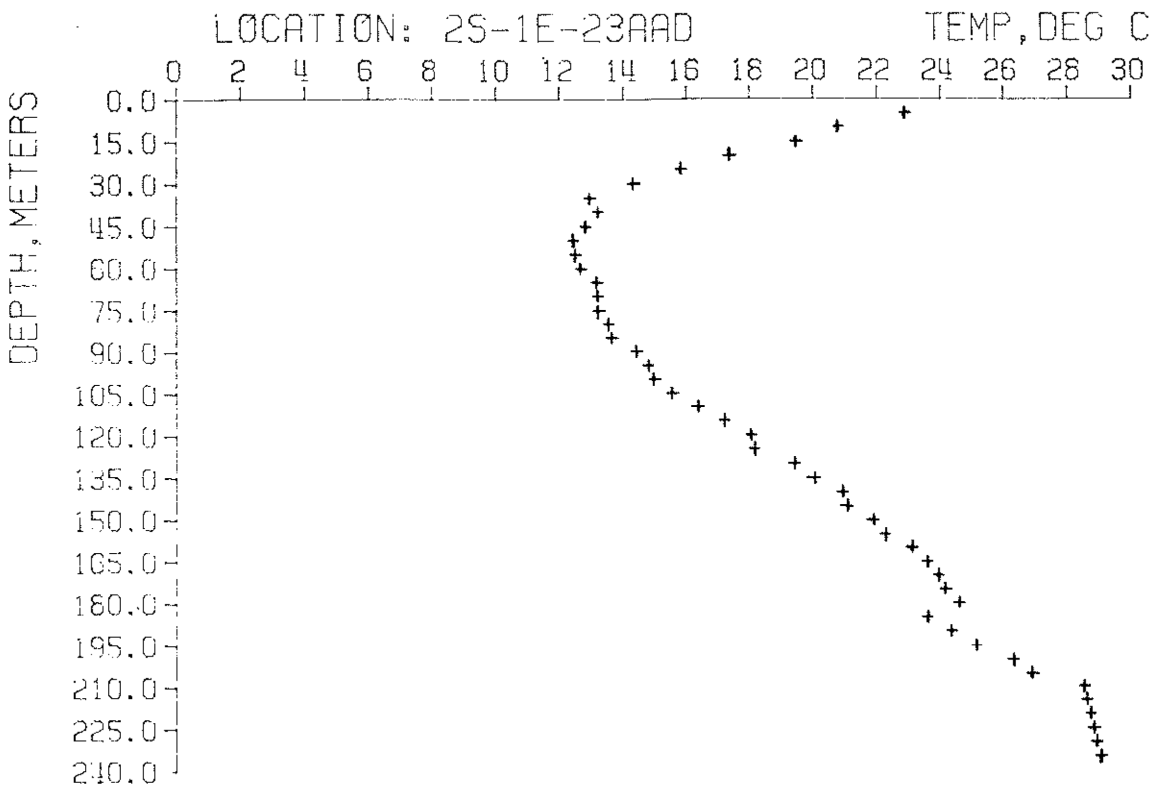

FIGURE 5-6. Temperature profile of well No. 65.

fers. The major groundwater movement within the area is in the shallow aquifers which are largely recharged from the surface. Shallow thermal gradients would be expected to be altered by irrigation-induced recharge. Deep temperature gradients would be expected to show a truer temperature distribution where they are unaffected by deep artesian discharge.

The Weiser groundwater movement is significantly affected by the Columbia River Basalts which underlie much of the area. Considering the Weiser River Basin as a whole, the principal recharge occurs in the bordering highlands and movement is toward the Snake River (Young, 1977). Interfingering of the Payette Formation with the Columbia River Basalt and the occurrence of numerous structural features, including faults, synclines, and anticlines may produce boundaries to groundwater flow (Newcomb, 1972). The predominance of basalts in the vertical cross section of the area is illustrated in figure 5-7 in wells northwest of Weiser (well No. 14), where most of the 610 m (2,000 ft) depth is volcanic, and east of Weiser (well No. 11) where 2,000 m (6,560 ft) of basalt were encountered in a 2,439 m (8,000 ft) hole. Thus, groundwater movement, both hot and cold, could have substantial vertical and horizontal components.

TEMPERATURE DISTRIBUTION

Gradients

Three sources of interference with ideal linear temperature gradients were found during the course of this study. The first is air circulation in vesicular basalt (e.g., well No. 65, figure 5-6). Although the amount of temperature-gradient distortion was large, the phenomena which produce this condition (low water tables and thick sequences of vesicular basalt) seem to be relatively rare in the western plain.

The second effect on temperature gradients occurs in areas of intense irrigation. Figure 5-8 illustrates the results obtained from wells located through the center of the plain in an area of low recorded heat flow where irrigation is prevalent. The average gradient of these wells is 12°C/km which is much less than the 78°C/km average of all wells measured. Calculated heat flows from deeper oil wells (437-4,268 m; 1,500-14,000 ft), in the same central plain area, average 1.88 HFU, whereas, the average heat-flow values from the shallower wells (60-90 m; 200-300 ft) averaged 1.13 HFU. An 0.7 HFU deficit is observed in the thermal budget. It is suggested that this "washed-out value" is caused by the vertical infiltration and lateral migration of irrigation- and meteorically-derived groundwater. Lachenbruch and Sass

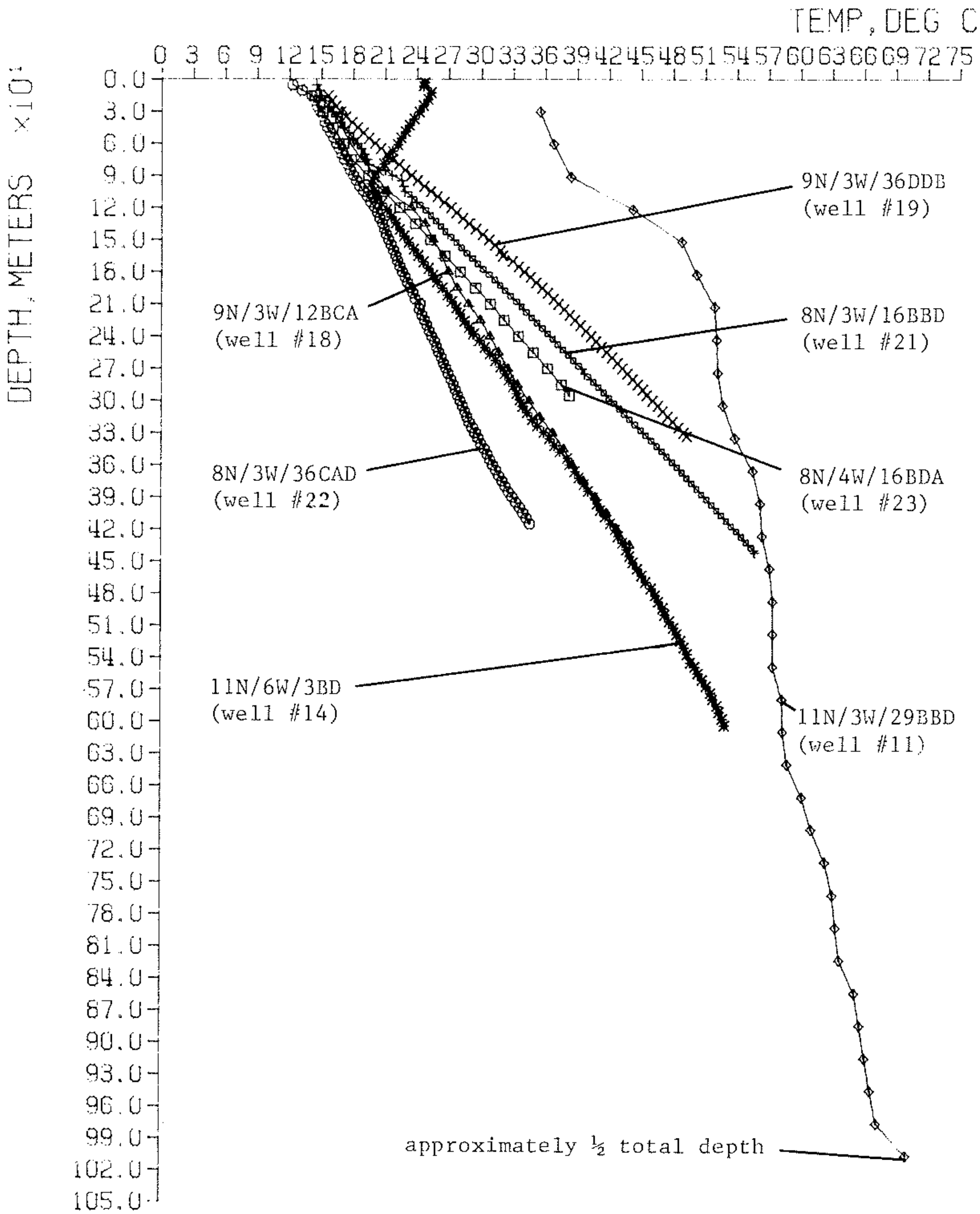

FIGURE 5-7. Temperature profile of wells measured in the Weiser-Crane Creek area.

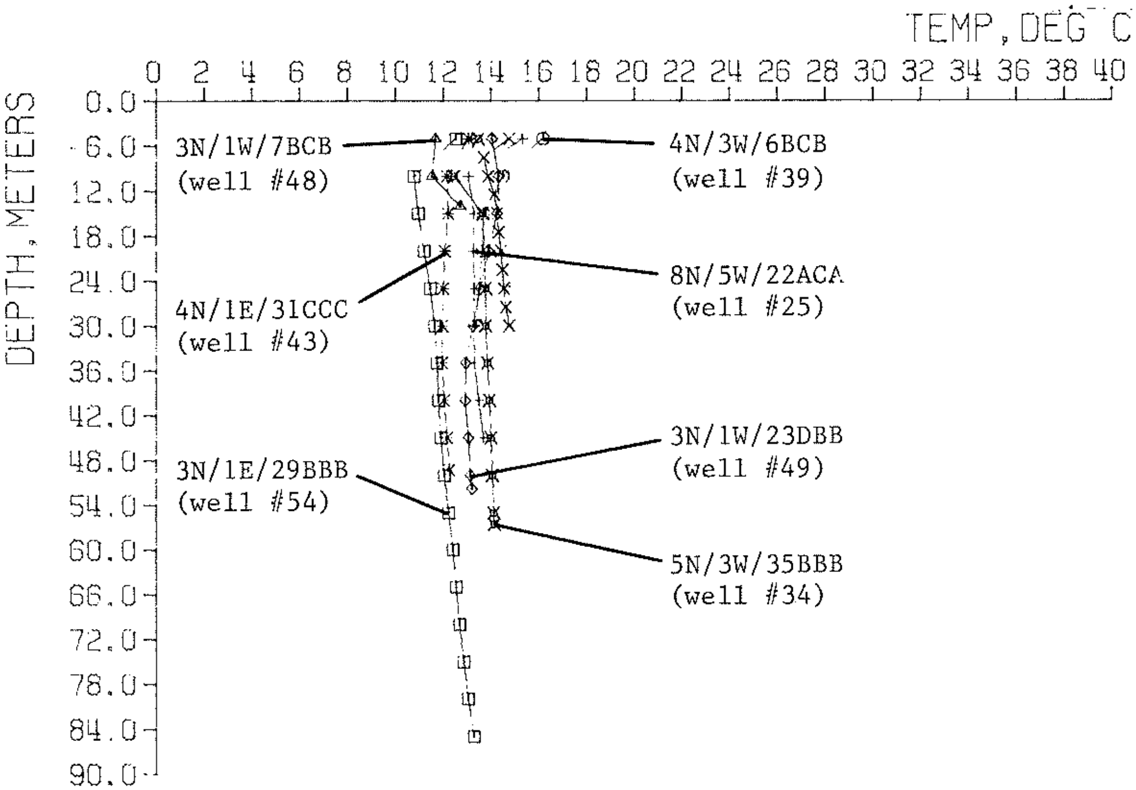

FIGURE 5-8. Thermal gradients measured in wells affected by surface water infiltration.

(1977) suggest a general formula for determining the alteration of a heat-flow value caused by mass movement (magma or groundwater) within the earth.

$$\frac{qZ_1}{qZ_2} = e^{(\Delta Z/s)} \tag{7}$$

where:

qZ_1 = boundary (1) heat flow

qZ_2 = boundary (2) heat flow

Z = thickness of layer

V = velocity of groundwater movement

s = K/p'c', characteristic distance with sign of V (or) generally:

$s(\text{feet}) = \frac{100}{V\ (ft/yr)} =$ for sediments with K = 3 TCU

$s(\text{feet}) = \frac{200}{V\ (ft/yr)} =$ for "rock" with K = 7 TCU

K = thermal conductivity of rock unit

Rearranging and substituting, the formula becomes:

$$V\left(\frac{ft}{yr}\right) = \frac{[100\ (\text{or})\ 200]\ 1n\ \frac{qZ_1}{qZ_2}}{\Delta Z} \tag{8}$$

Assuming the thickness of sediments altered by infiltration to be 152 meters (500 feet), a vertical infiltration velocity of 3.05 cm/yr (0.1 ft/yr) is obtained which seems reasonable.

The third observed distortion of the temperature gradients is associated with convecting groundwater movement. Lachenbruch and Sass (1977) demonstrate that an upward vertical movement of groundwater with a velocity of 30.48 cm/yr (1.0 ft/yr) can increase the surface heat flow by 150 HFU. Examples of this phenomenon in the western Snake River Plain are the restricted zones of high heat-flow values along the fault zones. These zones are located near the northeastern boundary of the plain where anomalous values of 20 HFU exist and along a fault zone described by Bowen and Blackwell (1975) on the western end of the plain where anomalous values of over 6 HFU exist. For well No. 11 (figure 5-7) in the

Weiser-Crane Creek area, a surface heat flow of 2.53 HFU was calculated from gradients measured through a clay cap covering a thick sequence of basalt. Although less anomalous than the fault-zone anomalies, good geologic control and temperature measurements suggest that convection both upwards and downwards is occurring (see section on local interpretations, Weiser-Crane Creek cross section).

Isogeothermal Surfaces

As an aid to visualizing the deep heat-energy distribution in the western Snake River Plain, two vertical cross sections have been adapted from Newton and Corcoran's work (1963). These cross sections show lithologic information gathered from oil wells drilled throughout the sedimentary basin. The correlations of major stratigraphic units are based on previous work (Newton and Corocoran, 1963). Continental fluviatile and lacustrine deposits interfingered with basalt flows yield inter-well correlations of only general character, but the areal extent and depth coverage of the information is good. One well, J.N. James No. 1, penetrates over 4,267 m (14,000 ft) into the interbedded sediments and basalts. This well is located near the eastern boundary of the investigated area. The Highland L&L No. 1 well is located near the western edge of the area of investigation and, geologically, near the western end of the Snake River basin. This well is 3,659 m (12,000 ft) deep and is a good reference point to which correlations from wells in eastern Oregon can be made. Temperature profiles from deep oil and gas wells in the western Snake River Plain are given in figure 3-3 of this report.

The steps followed in developing the isogeothermal surfaces shown in figures 5-9 and 5-10 were as follows: (1) known lithology was plotted on the cross sections, (2) temperatures recorded on well logs were plotted, (3) heat-flow values were assigned to each well selected from the heat-flow contour map (figure 5-2), (4) isogeothermal surfaces were calculated using the formula: heat flow = (thermal conductivity) x (temperature gradient) or:

$$\Delta t = \frac{(\Delta d)\ (q)}{K} \tag{9}$$

where:

Δt = change in temperature (°C)

q = heat flow (HFU)

K = thermal conductivity (TCU)

Δd = change in depth (kilometers)

and (5) calculations were verified by comparison with known temperatures in the wells.

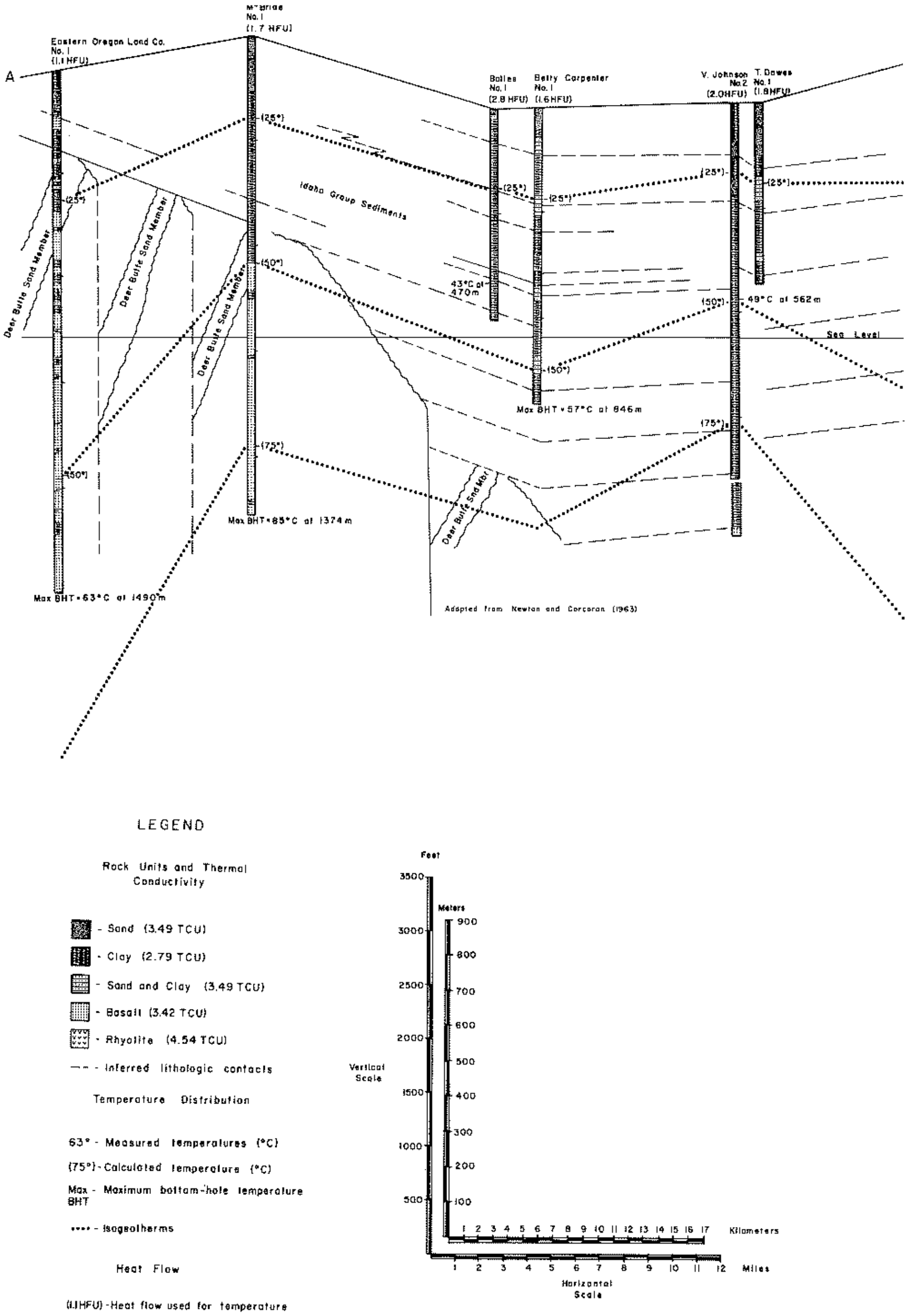

FIGURE 5-9. Cross section A-A' showing isogeothermal horizons. Lithology adapted from Newton and Corcoren (1963).

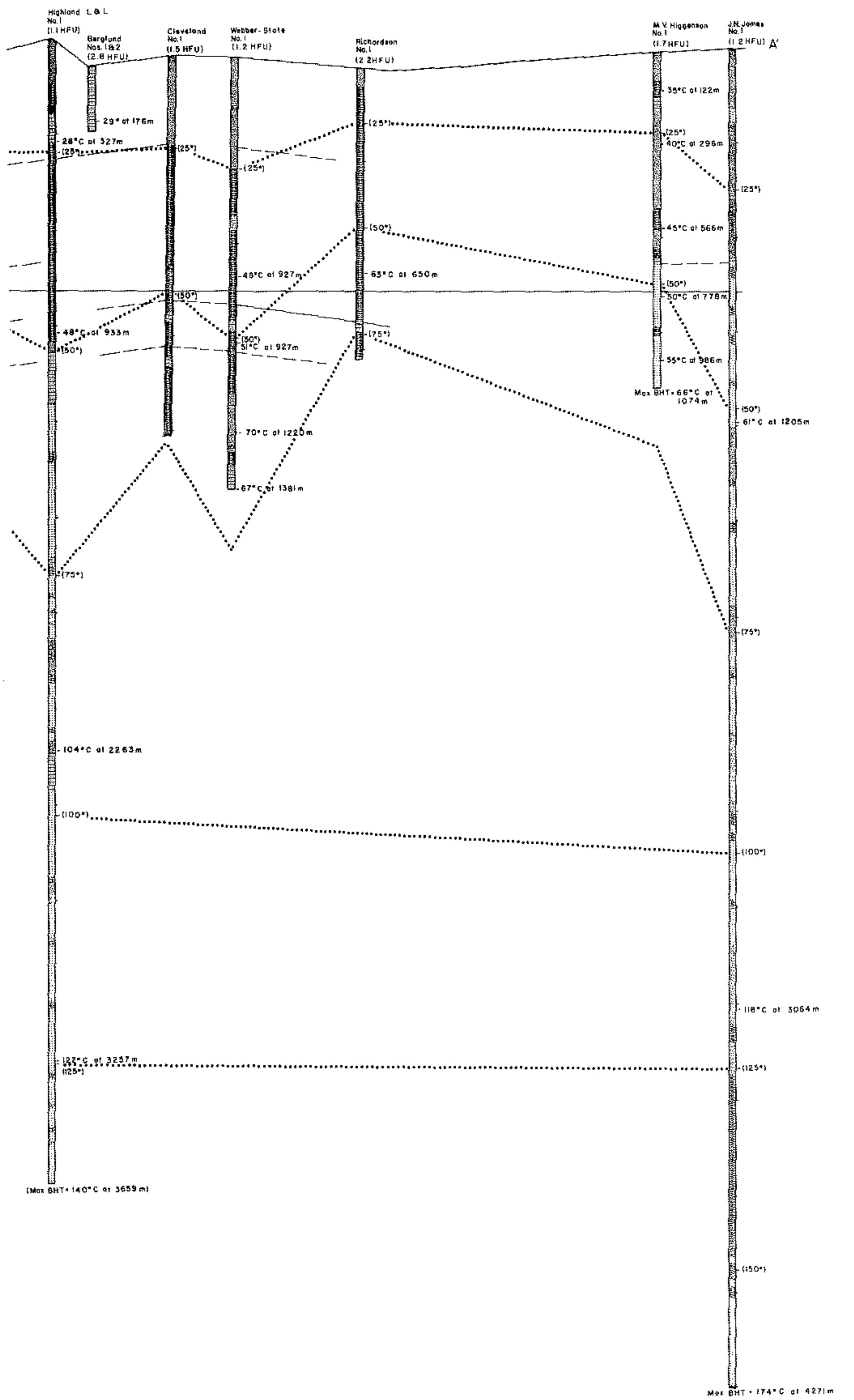

FIGURE 5-9. Cont.

Several factors were assumed in developing the model described above. First, the values of heat flow assigned to each well were derived from regional trends, not from direct measurements. These values are a "most reasonable" guess as the heat-flow values seem to form a specific trend which is also seen in the gravity isogal lines and the geologic framework of the basin. Second, the calculations of temperatures were made on the assumption that the temperature distribution was a function of conductive heat transfer, disregarding the convective heat transfer which has been demonstrated to be a factor in certain portions of the plain. Finally, the lithologic units were divided into five thermal-conductivity groups which correlate with the five major rock types and for which thermal-conductivity values were derived by the author and previous investigators of this and surrounding areas. The samples for this work were selected from well cuttings, outcrop samples, and drill cores of formations which were thought to be represented in the deeper wells. Variations in mineral composition, porosity, and structural environment may have effects on certain isogeothermal surfaces in certain locations.

To substantiate the preceding assumptions, the results of the temperature calculations were plotted on the cross sections and compared with the temperatures measured during the geophysical surveys run at the time of the drilling (see Table 5-3 and figure 3-3, this report). Although the results of this procedure did not reproduce the temperatures measured by the oil companies, in most instances the calculated temperatures and the measured temperatures are remarkably close. A possible source of error could be that temperature distribution is not only a function of thermal conductivity, but also of fluid movement, both natural and that occurring from drilling operations. Upward groundwater movement would tend to crowd the isogeotherms nearer to the surface, as illustrated in the Higgenson No. 1 oil well. Downward groundwater movement would tend to spread out the isogeotherms, as illustrated in the lower basalt section of the Christensen A-1 geothermal-exploration well (well No.11, figure 5-7).

The cross sections present a regional view of the heat-energy distribution in the western Snake River Plain. They do not attempt to predict variations caused by artesian flow between aquifers or structurally-induced temperature variations on a site-specific basis. Models of three specific areas are discussed in the next section on local interpretations.

TABLE 5-3
Oil Well Data — Western Snake River Plain

	Depth of Temperature Measurement		Maximum Temperature Recorded		Calculated Heat Flow	Date Drilling	Date Temp.
	(Meters)	(Feet)	(Deg C)	(Deg F)	(HFU)	Completed	Logged
Assmussen #1	1,224.7	4,017	131.2	270	2.5	4/20/56	4/20/56
Berglund #1	175.6	576	29.4	85	2.8	5/13/28	6/28
Bolles #1	469.5	1,540	43.3	110	2.0	(?)	3/03/55
B. Carpenter #1	846.0	2,775	57.2	135	1.6	2/01/55	2/19/55
Chrestensen A-1	2,437.8	7,996	162.8	325	2.4	12/12/77	12/13/77
T. Daws #1	513.7	1,685	37.8	100	1.8	7/19/55	7/30/55
E. Ore. Lnd. co. #1	1,490.2	4,888	62.8	145	1.1	1955	6/08/5
Federal #1	1,933.6	6,539	90.6	195	1.2	(?)	12/31/54
Highland L & L #1	3,256.7	10,682	122.2	252	1.2	5/73	5/02/73
J. N. James #1	4,270.4	14,007	174.4	346	1.4	9/22/76	9/22/76
V. Johnson #2	572.0	1,876	48.9	120	2.0	(?)	5/13/55
McBride #1	1,373.5	4,505	85	185	1.7	1956	1/12/57
Recla #1	1,405.8	4,611	62.2	144	1.2	1950	8/13/50
Reins Estate #1	1,480.5	4,856	124.4	256	2.0	(?)	6/30/75
Richardson #1	650	2,132	63.2	145.7	2.2	1/24/56	7/30/78
Webber State #1	1,380.2	4,527	66.7	152	1.4	3/29/56	3/30/56
Weiser Strat #1	609.8	2,000	52.9	127.2	2.2	(?)	(?)

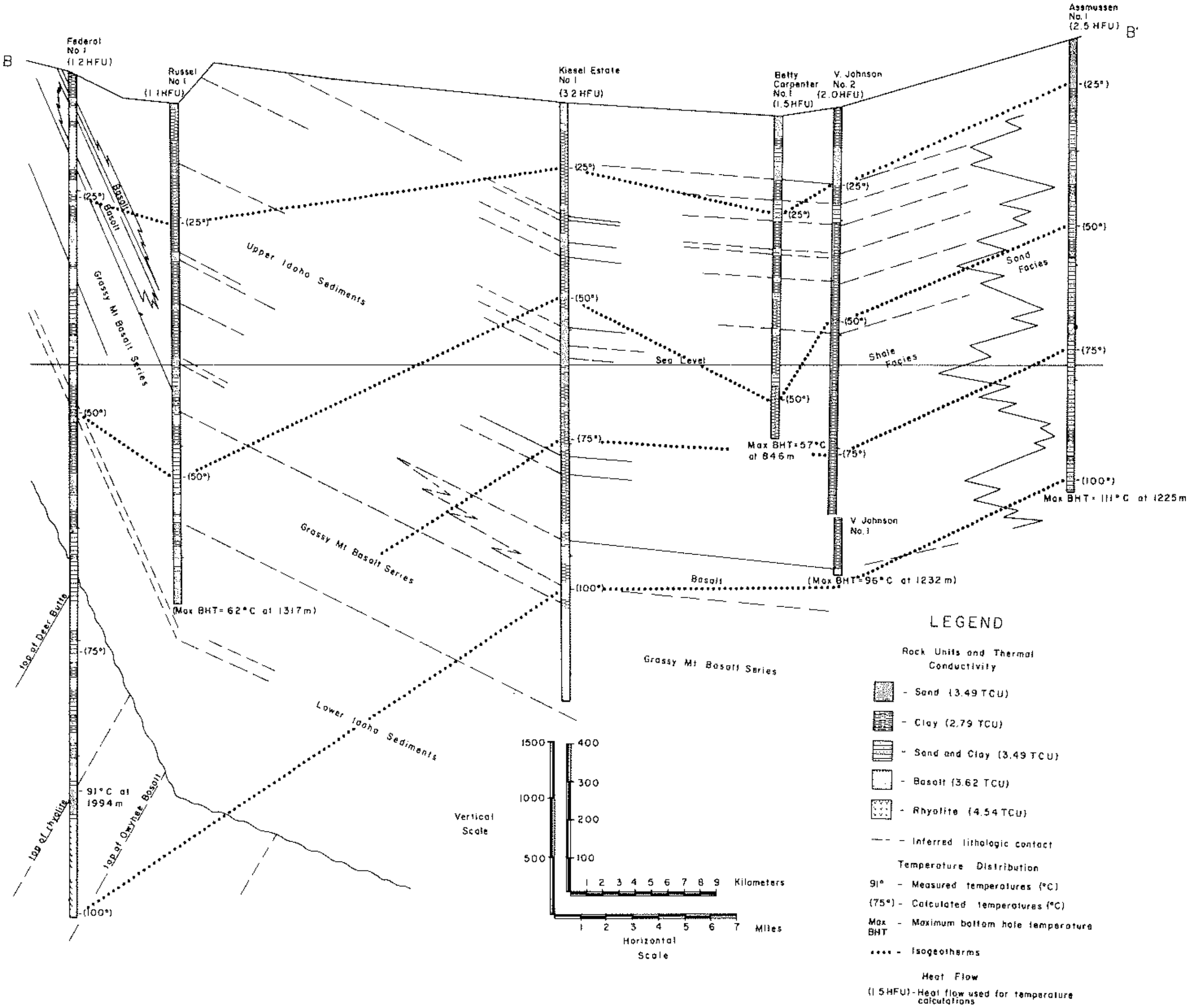

FIGURE 5-10. Cross section B-B' showing isogeothermal horizons. Lithology adapted from Newton and Corcoren (1963).

LOCAL INTERPRETATIONS

Boise Front Cross Section

The area to be discussed in this section is centered over the highest heat-flow values recorded in this investigation as well as the highest published values of surveys made in and around the western Snake River Plain. The objective is to present a model which would explain the presence and distribution of the high heat flow values.

The geology of the Boise Front has been investigated and mapped by several authors (see figure 5-11). Malde (1959) and Hill (1963) identify a northwest-trending normal fault zone that occurs at the base of the Boise Front. This fault zone displays a displacement of at least 2,744 m (9,000 ft). Savage (1958) shows several short orthogonally-oriented faults which reflect general lineament trends detected by Day (1974) on his satellite imagery lineament map of Idaho (see also figure 4-2, this report). Similarly, Mohammed (1970) found normal faults running nearly perpendicular to each other in the approximate locations of Savage. The surface geology has been mapped by Mohammed (1970), Savage (1958) and Nace and others (1957).

Detailed deep subsurface stratigraphy is not well understood in this area. From descriptions of the Glenns Ferry Formation (Malde and Powers, 1962), it would appear to rest upon the Idaho Batholith and consist of a collection of nonindurated complexly intertonguing lacustrine and fluvial deposits. The facies are rarely continuous and proposed relations have been determined only by detailed stratigraphic study. A thick arkose facies might be expected because of the proximity and relative position of the batholith. Fence diagrams produced by Mohammed (1970) show that many of the faults have small displacements, on the order of 2 to 30 m (7 to 100 ft). This suggests that the displacement reported by Malde (1959) would be en echelon in character and further complicate correlations. A detailed lithologic study in the immediate vicinity of Boise (Smith, 1977) confirms that the bed of the Glenns Ferry Formation near the northwest-trending fault area have little lateral consistency. The presence of a steeply dipping nonconformity, recognized by Malde (1959) and Thomas and others (1974) as occurring between the sediments and the batholith, seems to be supported by logs from a hole drilled by Boise Oil Company at Section 27, T.4 N, R.3 E, which reaches a depth of 637 m (2,090 ft) without encountering basement.

The cross section presented in this text is intended to show the ground elevation, temperature isogeotherms, and structure. As suggested by Birch (1950) and Blackwell and Steele (1977), the isogeotherms appear to parallel the ground surface (figure 5-12). The relationship of the isogeotherms to stratigraphy might be considered important. A highly conductive formation would have a tendency to spread the temperature out vertically as indicated by Equation [3], and, if a specific heat flow is to be maintained in the vertical direction, the thermal gradient must decrease.

The two dominant lithologic units in this area are sand and clay, which have been determined to have mean thermal conductivities of 3.49 TCU and 2.79 TCU, respectively (see Table 5-2). Thus, the mean difference in thermal conductivities between formations is only 0.66 TCU which results in a heat-flow variation of 20 percent. This is much less than the 1,000 percent variation of heat flow recorded in the area. The isogeothermal patterns thus are assumed to be predominantly a product of convective heat transfer. The apparent convergence of the isogeothermal lines of well No's. 56 and 59 (figure 5-12) are considered to

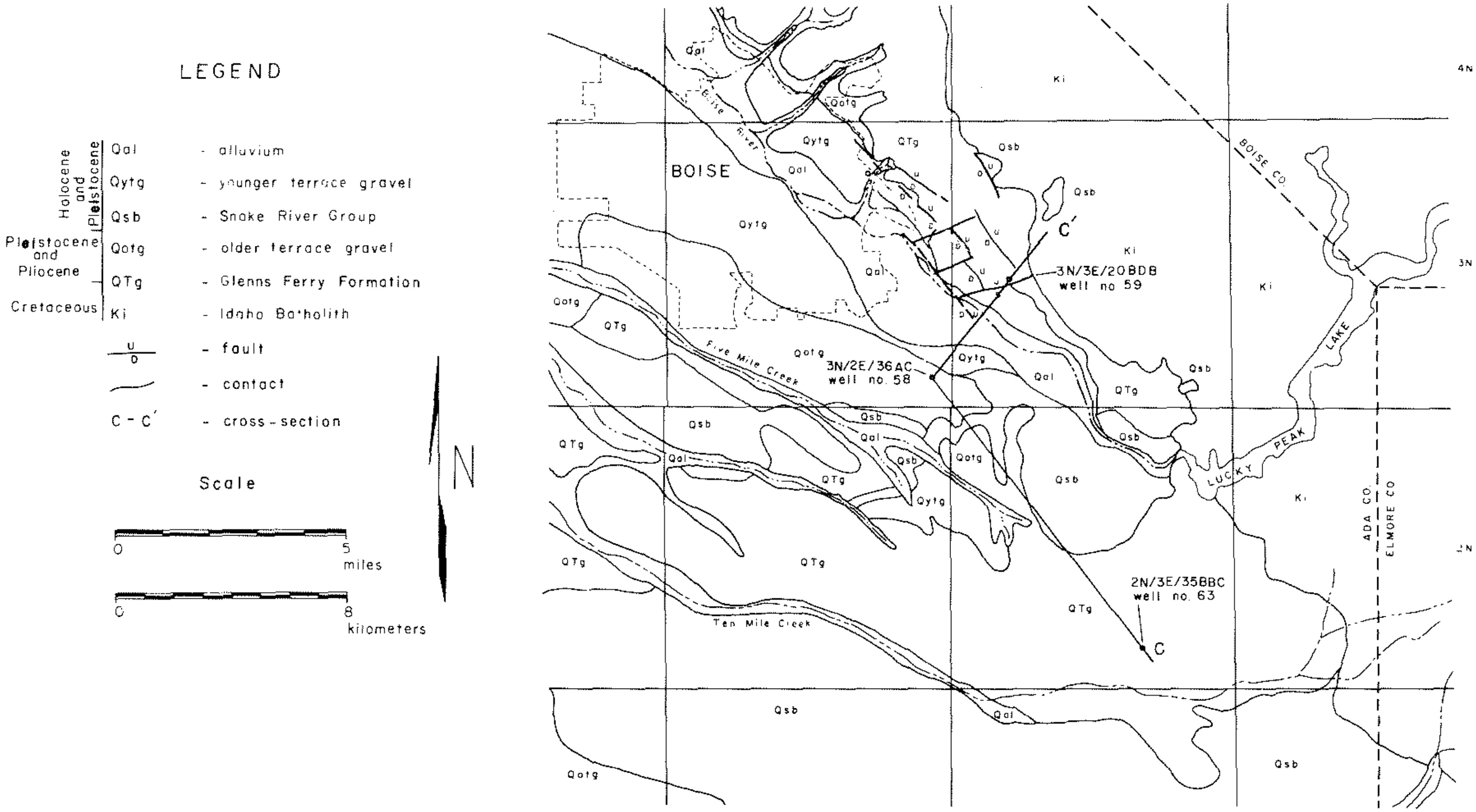

FIGURE 5-11. Generalized geologic map of the Boise Front area. Adapted from Nace, et. al. (1957); Savage (1958); Young, et. al. (1977).

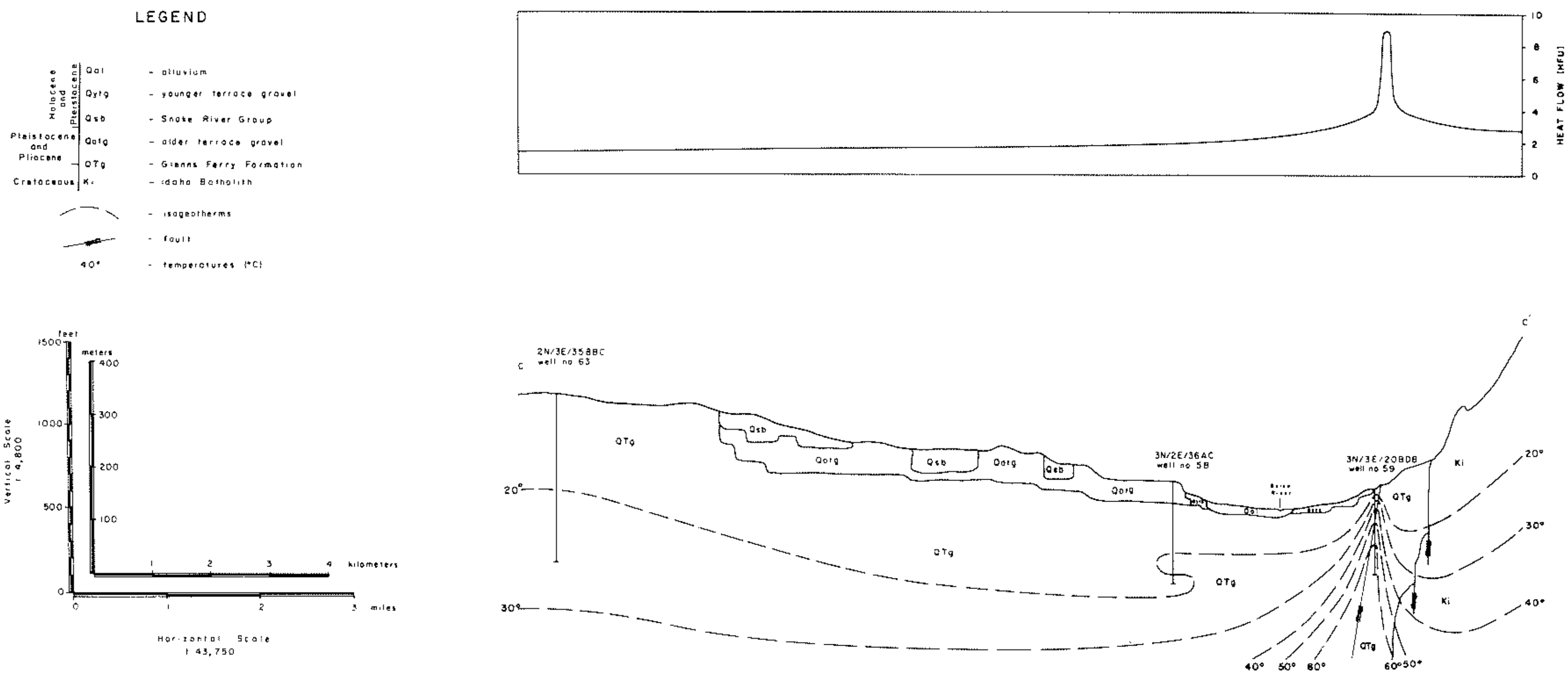

FIGURE 5-12. Cross section C-C' showing isogeothermal horizons.

reflect classic isogeothermal line depression of normal fault, Basin and Range-type convective geothermal systems, as modeled by Blackwell and Chapman (1977), and of a fault-dominated convection system as mapped by Grindley (1970). Also, Randall (1974) postulated that isogeotherms showing the effects of structure suggest that the emplacement of the heat source must be of sufficient age for structure and stratigraphy to exercise that effect. This seems to agree with Brott's et al. (1976) heat source emplacement model of 12.5 million years and stands in contrast to Randall's Salton Sea emplacement model of 16,000 years which showed no isogeothermal alterations by either structure or stratigraphy.

Well No. 56 was reported as being artesian (Idaho Geothermal Development Projects Annual Report for 1976) as are other wells in the Boise Front area. With the multiple clay lenses within the Glenns Ferry Formation and a high-elevation recharge area available, this phenomenon is easily visualized. Domenico and Palciauskas (1973) model such a "forced convective system" and observe that convective losses on the recharge side of the midline of flow are just balanced by convective heat gains on the discharge side of the midline. They also note that heat flow at the surface is a manifestation of the geothermal gradient and is greater in groundwater discharge areas then in recharge areas. The Boise Front is easy to visualize as being a near-vertical conduit system for confined aquifers which makes it a focal point for discharge.

The work of Brott and others (1978) on the western Snake River Plain shows an anomalous jump in heat-flow values at the boundary between the Plain and the highlands. A partial explanation of this jump is the refraction of heat away from the volcanics and sediments of low thermal conductivity towards the intrusive material of high thermal conductivity. Thus, an explanation of the higher than normal heat flow along the Boise front area may relate, in part, to refraction.

Description of a Temperature Gradient Well near Caldwell, Idaho [Richardson Well No. 1 (4N-3W-19adc1)]

This gradient description aids the understanding of the geohydrology in the Nampa-Caldwell area and demonstrates the information that can be gained from temperature-gradient surveys.

The well in question was abandoned as an oil prospect, is open to the surface and is flowing. It is presently used as a stock watering well. At the surface, water is discharging at 39 degrees centigrade. The profile recorded (see figure 5-13) shows that the gradient is nearly isothermal for the first 90 meters, which would be expected in an artesian thermal well. However, at an approximate depth of 110 meters, the gradient changes sharply and the temperature reaches 46.5 degrees centigrade and the gradient again becomes vertical. This behavior of the temperature depth profile might best be explained by a flow of 46.5 degrees centigrade water rising in the well under hydraulic potential and contacting a shallower series of cold aquifers. The water cools by mixing as it rises, until it reaches a temperature of approximately 39 degrees centigrade, the discharge temperature.

Below 130 meters, the gradient again remains essentially isothermal for 210 meters. At 340 meters, a sudden jump occurs in the temperature from the isothermal flow of 46.5 degrees centigrade to 57 degrees centigrade. This 9.5 degree centigrade jump is neither preceded nor followed by a gradual temperature change and is suggested to coincide with the intersection of the rising 57 degrees centigrade water and a thin, very cold aquifer at

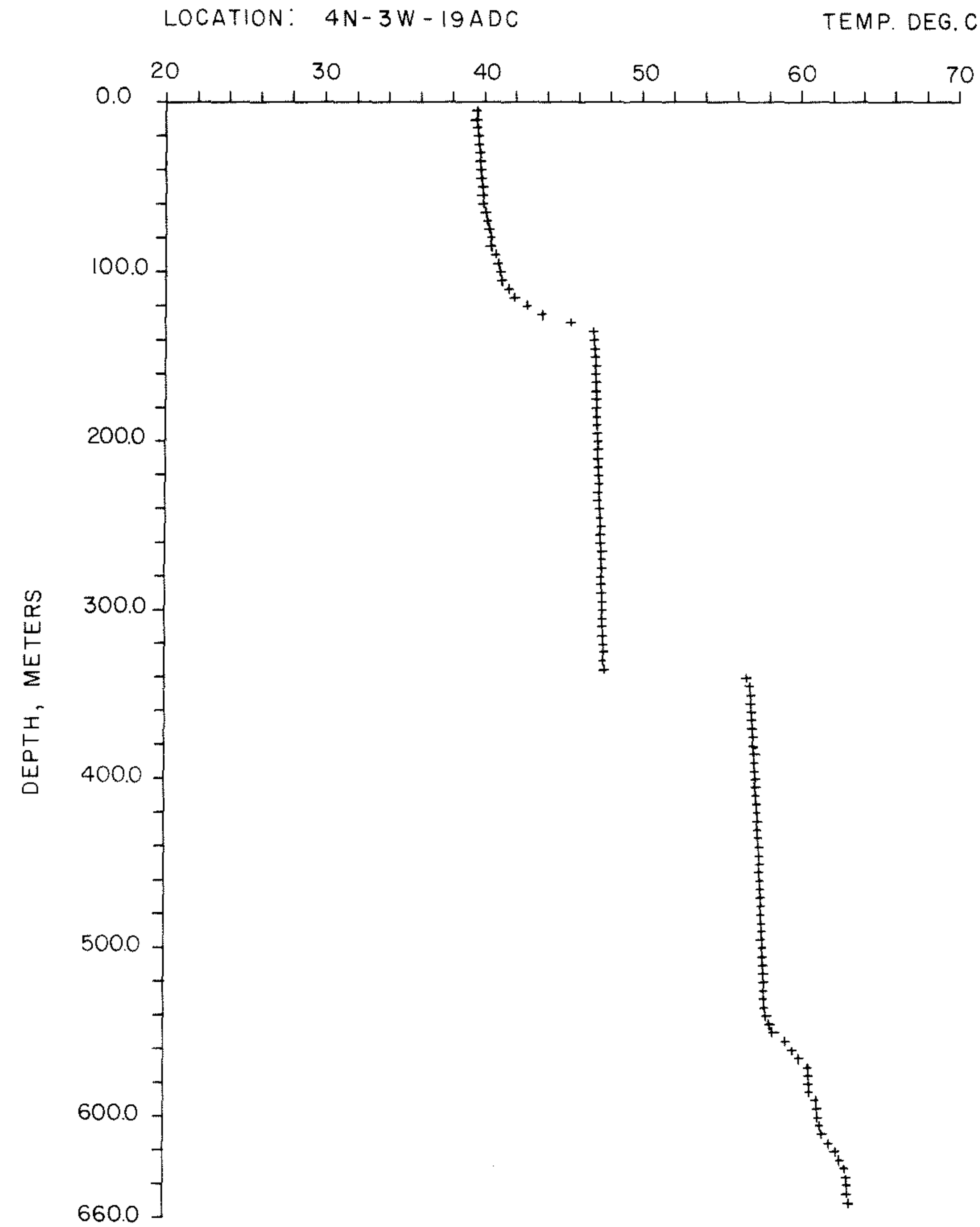

FIGURE 5-13. Temperature-depth profile of well #40, Richardson No. 1 well near Caldwell, Idaho.

approximately 340 meters. Below 340 meters, the profile is again vertical down to 540 meters, where the gradient begins to "stairstep" downwards suggesting various small hot water aquifers and possibly, near the base, the artesian flow.

It was noted from profiles of non-artesian wells in this area, that the geothermal gradient averaged 78°C/km. Thus, the Richardson No. 1 well should have a natural temperature of about 57 degrees centigrade near the 540 meter depth, which it does. This suggests that the bottom of the long isothermal gradient is near the bottom of the artesian water. It might also be noted that the gradient below 540 meters is about 54°C/km, somewhat below the regional gradient and possibly indicating that the aquifer may be a heat source for the geothermal gradients in the overlying strata. A problem in the development of this system may be the absence of large quantities of hot water because the flow at the well head is 75 liters/minute and well logs indicate the lithology is mostly lake muds and shales.

Weiser-Crane Creek Cross Sections

Located in the northeastern extremity of the western Snake River Plain study area, the Weiser-Crane Creek area has been the subject of previous geothermal investigations. Heat-flow values for this area were considered good because of the high quality of temperature profiles obtained from holes specifically drilled for geothermal investigations. Also, multiple samples of rock units were retrieved from various depths to enhance the accuracy of thermal-conductivity knowledge of this area.

The rock units are predominantly Idaho Group, Columbia River Basalts and the Payette Formation (see figure 5-14). The oldest rock unit is represented by the Idaho Batholith which is exposed 12 miles to the east. The Columbia River Basalts (Miocene) and associated interbedded sediments (Payette Formation) are in contact with the intrusive and appear to overlie the batholith beneath the Weiser-Crane Creek area (figure 5-7) where well No. 11 (11N-3W-29bbd1) reveals the contact at a depth of 2,220 m (7,280 ft). Overlying the Miocene basalts and sediments is the Idaho Group (Pliocene-Pleistocene) which dips to the west and southwest.

Structurally, the area contains numerous anticlines and synclines which trend in a northwest-southeast direction. The hole (well No. 1) is drilled near the crest of an anticline. The cross section (figure 5-15) shows that the Columbia River Basalt-Payette Formation sequence is exposed at the surface near the northwest end of the profile. However, 7 miles to the south, an oil well over 1,220 m (4,000 ft) deep remains within the Idaho Group for its entire depth. This suggests that the basalts and the interbedded sediments dip steeply beneath this thick sequence of Idaho Group sediments, as was indicated by Kirkham (1931a, 1931b, 1931c) from surface geology. Another possibility is that the northwest-trending fault zone extends up from the Boise Front area to downfault the Idaho Group against the Columbia River Basalts.

In figure 5-15, plotted isogeotherms show that near-surface topography affects the subsurface temperatures causing the isogeotherms to parallel the ground surface. In the Christensen A-1 well, No. 11, the isogeotherms appear to be crowded beneath the Payette Formation which overlies the basalts. This is interpreted to be an expression of upward-moving groundwater convecting deep temperatures toward the surface. Farther to the south, the temperatures of holes drilled in the Idaho Group indicate very little groundwater movement (linear temperature gradients) and the isogeotherms are evenly distributed.

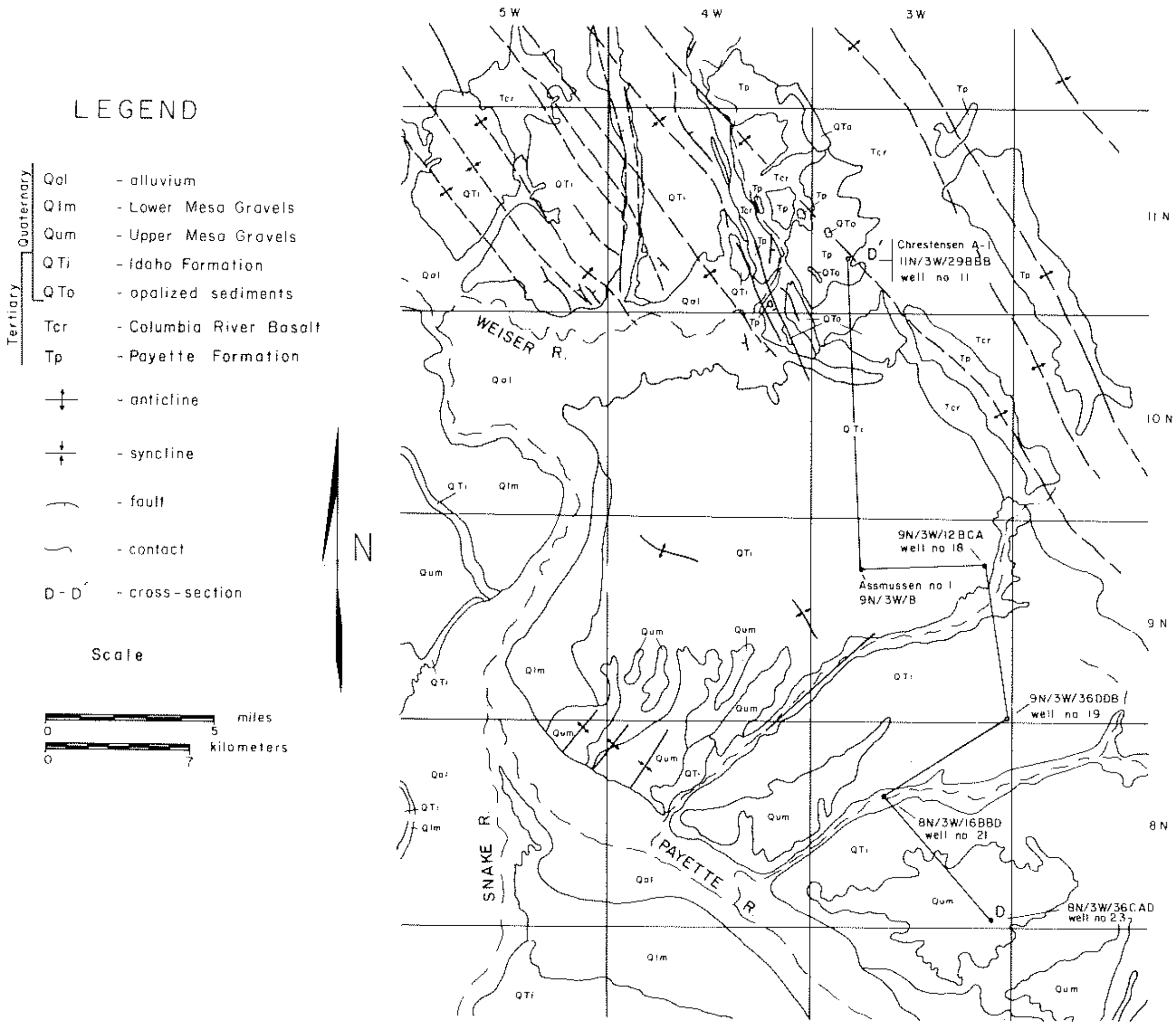

FIGURE 5-14. Generalized geologic map of the Weiser-Crane Creek area and location of D-D' section. Adapted from Kirkham (1931); Savage (1958); Young, et. al. (1977).

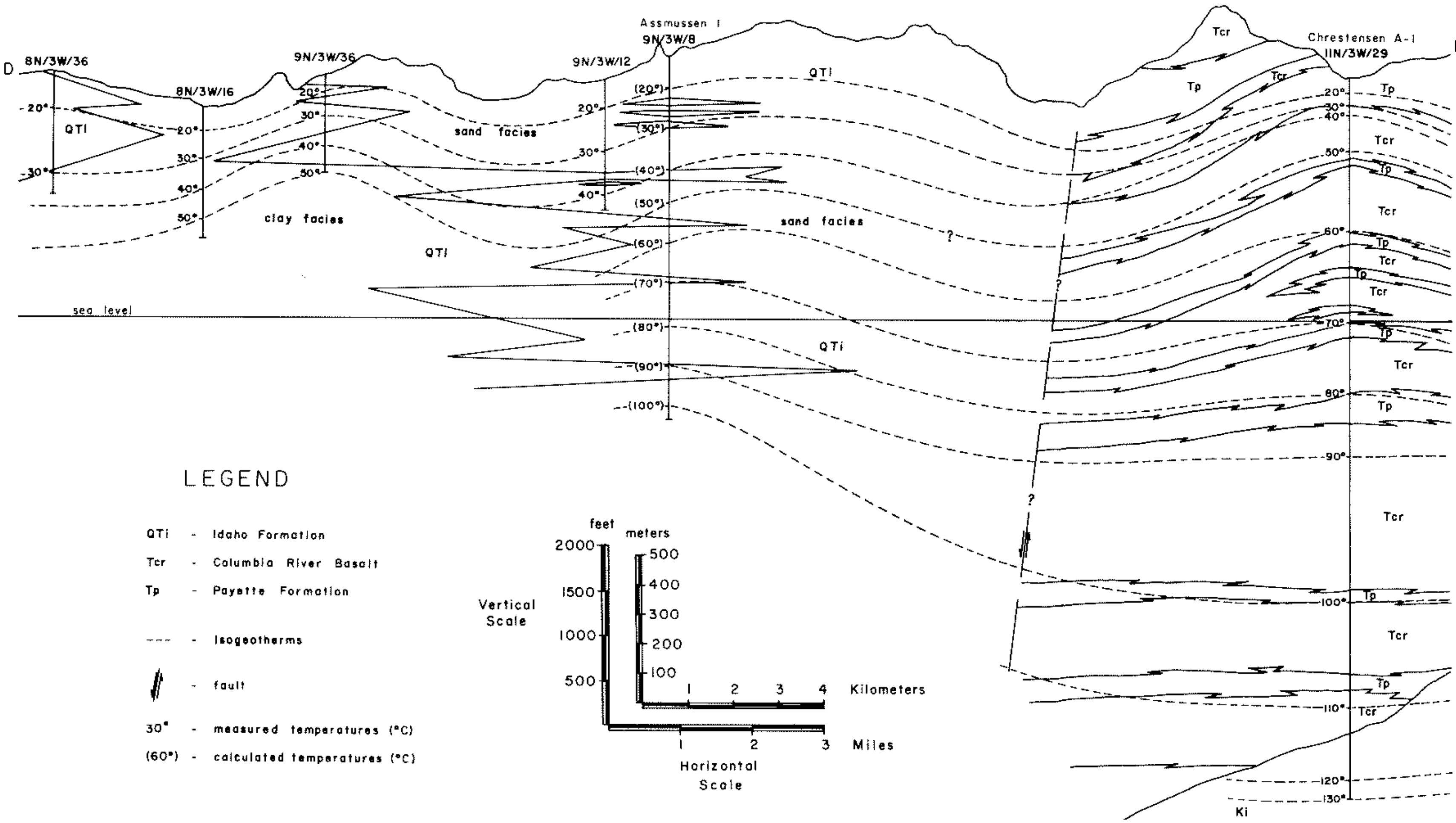

FIGURE 5-15. Cross section D-D' in the Weiser-Crane Creek area.

Figure 5-7 shows a comparison of deep temperature gradients acquired within the Weiser-Crane Creek area. This group of profiles has nearly the same geothermal gradient and, with one exception, is considered to have been made in formations which have little or no groundwater movement. Near the surface, well No. 14 (11N-6W-3bd1) displays a negative gradient to a depth of 120 m (400 ft), an effect which is assumed to be caused by infiltration of meteroic or irrigation water from the surface. At depths below 120 m (400 ft), the gradients are nearly linear and range from 51°C/km to 91°C/km, a range of values which is within 20°C/km of the average of 78°C/km for the western Snake River Plain. The temperature profile in well No. 11 (11N-6W-3bd1) from the same region, displays a profile which is markedly different. Groundwater movements within the basalts are interpreted as the cause of this distorted profile. In the section on temperature distribution, calculations of the vertical groundwater velocity are given as 1.5 cm/yr (0.05 ft/yr) upward in the upper portion (250-1,000 m; 800-3,280 ft) of the well and 0.73 cm/yr (0.024 ft/yr) downwards in the lower portion (2,150-2,380 m; 7,052-7,806 ft). The system is complex with several convection cells contributing to the temperature distribution.

As a rough check on these calculations, the maximum temperature of surface hot-spring water in the Weiser-Crane Creek area was determined by geothermometry to be an average of 140°C (285°F). From the temperature profile, this would put the origin of the hot water at a depth in excess of the drilled depth of (maximum bottom hole temperature was 127°C, 261°F) 2,439 m (8,000 ft). Assuming an average vertical velocity of 1.13 cm/yr (0.037 ft/yr) and a reservoir depth of 2,744 m (9,000 ft), the time for a complete infiltration-to-discharge cycle would be on the order of 500,000 years. Rightmire, Young, and Whitehead (1976) conducted an oxygen isotope study of the springs in the Weiser-Crane Creek area. The results of their analyses suggest the water was introduced into the groundwater system during a period of colder climate. The introduction of meteoric water during the cooler Pleistocene Period would coincide with the oxygen isotope results and groundwater velocity calculations.

In conclusion, the groundwater appears to cause a great deal of alteration in the temperature distribution of the Weiser-Crane Creek area. The temperature profiles from areas of poor groundwater circulation appear to have much higher gradients than those of the more permeable areas; however, the near-surface temperatures in formations which allow circulation are much higher and have lower gradients at depth. It thus appears that a local source of heat is not present beneath the high-gradient holes. Instead, the cap over the hydrothermal reservoir restricts shallow circulation of the hot water, whereas, in areas of high permeability above the same reservoir, the higher temperatures are carried closer to the surface by convecting hot water. The rock unit distributions taken from well logs and the relative ages of the rocks (figure 5-15) indicate that the Columbia River Basalts and the interbedded Payette Formation were faulted and lie beneath the Idaho Group, where geothermometry and gradient data indicate the maximum reservoir temperature would exist. The reservoir would lie beneath more than 1,200 m (4,000 ft) of sediments. The continuation of this geothermal system beneath the western Snake River Plain is subject to speculation. Oil wells drilled through the Idaho Group and into underlying basalts have not recorded anomalously high temperatures (see figures 5-9 and 5-10).

CHAPTER 6 - GEOPHYSICS

By
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James K. Applegate[2]
and
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INTRODUCTION

Much of the western Snake River Plain is relatively flat and featureless, being mantled by Quaternary sediments and basalt flows. Subsurface structural and stratigraphic situations in older rocks, favorable for geothermal resources, can only be explored by geophysical methods or drilling. One hundred thirty two km (82 mi) of proprietory seismic reflection profiles were purchased by the Idaho Department of Water resources and interpreted by S.H. Wood and J. K. Applegate. One 38km (24 mi) long line was reprocessed using a detailed, high-technology approach at the W.M. Keck Research Laboratory of the Geophysics Department, Colorado School of Mines under supervision of Dr. J. K. Applegate. Eight proprietory magnetotelluric soundings were purchased from Great Basins Petroleum and interpreted by P.R. Donaldson. An aeromagnetic survey of the area using one-half mile line spacing was flown by Aerial Geophysics, Inc. A detailed gravity survey with 0.8 km (0.5-mile) station spacing was completed and interpreted by Olson (1980) of Brigham Young University.

In addition to these site-specific studies, regional gravity maps of southern Idaho by Mabey (1976) and of eastern Oregon by Lillie and Couch (1979) are compiled in figure 2-1. Resistivity soundings are currently being obtained and interpreted as profiles across the plain by R. Bisdorf (U.S. Geological Survey, Denver) and should be released in 1982 (Jerry Lindholm, 1981, personal communication).

Seismic reflection profiling, magnetotelluric soundings and resistivity surveys appear to be the most useful in locating structure and anomalous resistivity to depths of about 2 km (1.25 mi). Regional gravity and magnetics delineate the larger structures and thick basalt accumulations under the plain. Magnetotelluric soundings are useful for determining the general structure of thick units of contrasting resistivity at depths far greater than those investigated by seismic reflection and resistivity methods. Unfortunately, detailed gravity and magnetics yield ambiguous results and appear to be responsive to near surface irregularities of basalt flows. While detailed gravity and magnetics have been very useful in locating faults in other areas, the faulted layers with contrasting susceptibilities or densities are apparently too deep in the area to allow resolution of structure.

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SEISMIC REFLECTION PROFILES

The seismic reflection method is by far the most successful geophysical method for exploring the structure and lithology of subsurface formations. Faults, folds, and tilted rocks are located with precision where they are intersected by the line of profiling. Because successful production of geothermal water is commonly from fractured zones associated with faulting, or from permeable layers of volcanic or sedimentary rock, the reflection method is particularly applicable to exploring for the subsurface indications of geothermal resources in the western plain. The major limitation of the reflection method in the western plain is the relatively shallow acoustic basement of Miocene volcanic rocks ranging in depth from about 600 to 1800 m (2000 to 6000 ft). Below this acoustic basement subsurface information is not obtained by conventional seismic reflection techniques.

The Idaho Department of Water Resources acquired 132 km (82 mi) of common-depth point (CDP) seismic-reflection profiles traversing the Boise-Nampa-Caldwell area of the western Snake River Plain (Table 6-1). One hundred seventeen km (72 mi) are 2400% CDP Vibroseis coverage obtained in 1971 and 1972 by Chevron, U.S.A. Field data were recorded from tandem Vibroseis sources utilizing a 16 second, 56-7 Herz (Hz) sweep. Vibrator points were 50 m (165 ft) apart. The recording spread was 48 geophone groups (using 8 Hz GSC-10D geophones), spaced 50 m (165 ft) apart, usually in a split spread configuration: 1,484.4 m (4,867 ft), 326.9 m (1,072 ft), 326.9 m (1,072 ft), and 1,484.4 m (4,867 ft). Data were recorded by the Texas Instruments digital field system (DFS) III. A 16 km (10 mi) line of 1200% CDP Vibroseis data was acquired from Anschutz Exploration, Ltd. Data were recorded and processed by Delta Exploration Company in 1972. The field system used tandem Vibroseis units with a 14-46 Hz sweep. The recording filters were 48 Hz/out. The geophone group interval was 100 m (320 ft). The remainder of the recording parameters are not known.

Record sections originally processed by Chevron Geophysical services for Standard Oil of California and by Delta Exploration for Anschutz were interpreted by S.H. Wood and J.K. Applegate without further reprocessing. Chevron Line IB-2 extending from the Boise foothills to just east of Caldwell was reprocessed under the supervision of J.K. Applegate at the Colorado School of Mines (CSM) W.M. Keck Exploration Research Laboratory (ERL).

The original Chevron data is of good quality. Numerous good reflectors can be traced within first 0.5 to 1.8 seconds of record. Resolution of the shallow geologic section (0.2 to 0.4 seconds) on the profiles is only poor to fair because of the wide-angle of shallow reflections from the long-offset recording spread and the low gain on the early part of the record.

The Anschutz data, by comparison, is of fair to poor quality. It is likely that the deconvolution operator in the original processing was poorly designed. Because of the "leggyness" of reflectors, faults cannot be identified with certainty. This data might be improved by reprocessing; however, the line did not suggest faulting, therefore, the Anschutz line was not reprocessed.

In order to recover the shallow data and to take advantage of the considerable improvement in reflection data processing techniques since the 1972 date of the sections furnished by Chevron, line IB-2 was reprocessed at the W.W. Keck Exploration Research Laboratory at CSM. The original 21-track field tapes from Chevron were commercially copied onto 9-track tapes. The field data were received in a demultiplexed and vertically stacked format. At this point, CSM/ERL undertook processing.

The first step in the processing was cross-correlation. This included the correlation of the field data with the Vibroseis sweep. This results in a record that is analogous to that from an impulsive source. The next phase was the edit phase during which the records were analyzed for bad traces and the bad traces were eliminated to improve data quality. The next step involved the application of elevation statics, preliminary velocity scans, and a near offset stack. This phase of the processing includes corrections to a datum, a preliminary analysis of the velocity by the use of a constant velocity stack to determine the appropriate stacking velocity, and stacking of the data using only the near-offset traces to review data quality. In step 4, deconvolution tests were run to assess means of sharpening the signal and to remove any reverberatory affects. This step results in a sharper, more coherent signal with a broader frequency content. At processing step 5, mute tests were run to attenuate noise that might interfere with the signal during stacking procedures. The objective was to remove the noise trains and refracted energy that might stack and create apparent reflections. Also during this step, a more detailed constant velocity scan was undertaken to further improve the resolution of the velocity function with which to stack the data. In step 6, a brute stack was prepared in order to analyze the state of the data. This brute stack used the derived velocity function. The next processing step (7) included the application of automatic residual statics using the CGG (Compagnie Generale de Geophysique) program SATAN. This program attempts to improve the trace-to-trace coherency and remove static effects that remain after making elevation corrections. After the application of the automatic residual statics in step 7, a more detailed velocity scan (step 8) was run to further refine the velocity in order to enhance the signal. Step 9 was a further iteration in this loop, and automatic residual statics (SATAN) were run again to further refine and improve the data quality. The next step (10) was a refined stack using all of the derived parameters. Then during step 11, a filter test was run to determine the most applicable final filters for displaying the data. Wave migration tests during step 12 determined the appropriate migration velocities and parameters to produce a two-dimensionally migrated section. The final step produced a final stacked, migrated time section.

The processing sequence represents a detailed high technology approach to processing. More care was given to detail than might be expected in a standard commercial effort. This resulted in an improved section. This final section was displayed in various modes to improve interpretation and a migrated, depth section was also prepared. The interpreted reprocessed section is shown as a line tracing in figure 2-4. Unfortunately, the original seismic sections cannot be published at the present time because of the conditions under which the data were purchased (see note, Table 6-1).

Numerous good reflecting horizons can be tied to formations with lithology known from well data. Elsewhere the character of the reflection wavelet and the configuration of the reflection horizon can be used to infer lithology. Average velocity to a reflector obtained by the CDP method can also be inverted to give formation interval velocities characteristic of certain lithologies. Depths to reflecting horizons can be calculated from the reflection time on the profiles using average velocity information from sonic logs of deep wells or from velocities derived from CDP reflection data.

TABLE 6-1
Seismic Reflection Profiles Acquired*
By The Idaho Department Of Water Resources

Line	Length (miles)	Orientation
IB-2 (Chevron)	38	EW
IB-7 (Chevron)	12	NW-SE
IB-8 (Chevron)	5	NS
IB-24 (Chevron)	2	EW
IB-25 (Chevron)	6	NS
IB-29 (Chevron)	11	NS
Anschutz	10	NS

* Seismic sections acquired by the Idaho Department of Water Resources cannot be sold, traded, disposed of, disclosed, or otherwise made available to other parties. However, interpretations of the data by the Idaho Department of Water Resources or consultants to the Department for indications of the presence of geothermal resources can be used for any purpose whatsoever including general publication and free availability to the public. Therefore the line tracings of interpreted seismic data are available in another volume for public release. The actual seismic sections cannot be released and Chevron, U.S.A. continues to have exclusive rights to sell, trade, loan, use and otherwise make available such seismic data to other parties.

Interpreted seismic profiles are shown in figures 2-4, 2-5, and in the supplementary data report containing the line tracings. The two horizons for which structure contour maps are prepared are labeled "B", and "I". Horizon "B" is considered acoustic basement, although some deeper, but discontinous reflections are evident beneath this horizon.

The structure contour maps (figures 2-7, and 2-8) have been prepared by multiplying seismic reflection times by the same average velocity over the entire map. Although there is evidence that the velocity to a particular horizon varies somewhat over the map area (figure 6-1), the available velocity information is limited to Line IB-2, and a few wells with acoustic velocity (sonic) logs so that it could not be reliably varied over the entire map. Therefore both of the structure contour maps are truly isochron maps and differ from a structure map only by a constant factor which is the assumed velocity.

The structure contour maps are based upon widely-spaced reflection lines. Near line intersections the structural configuration and fault location are well constrained, but in the area between lines the fault location and orientation, and the structural configuration of the horizon is interpretive. The basis for connecting faults from line to line is the similarity of sense and amount of displacement where a fault crosses the line of profile. Location of a fault is exact at the line crossing, but the connections of faults are from line to line and hence the orientation of the fault is somewhat interpretive with such widely spaced lines. Built into the structure contour maps is an interpretive attempt to impose a northwest strike to the structure. This is the prevalent strike of most of the folding and faulting observed on the

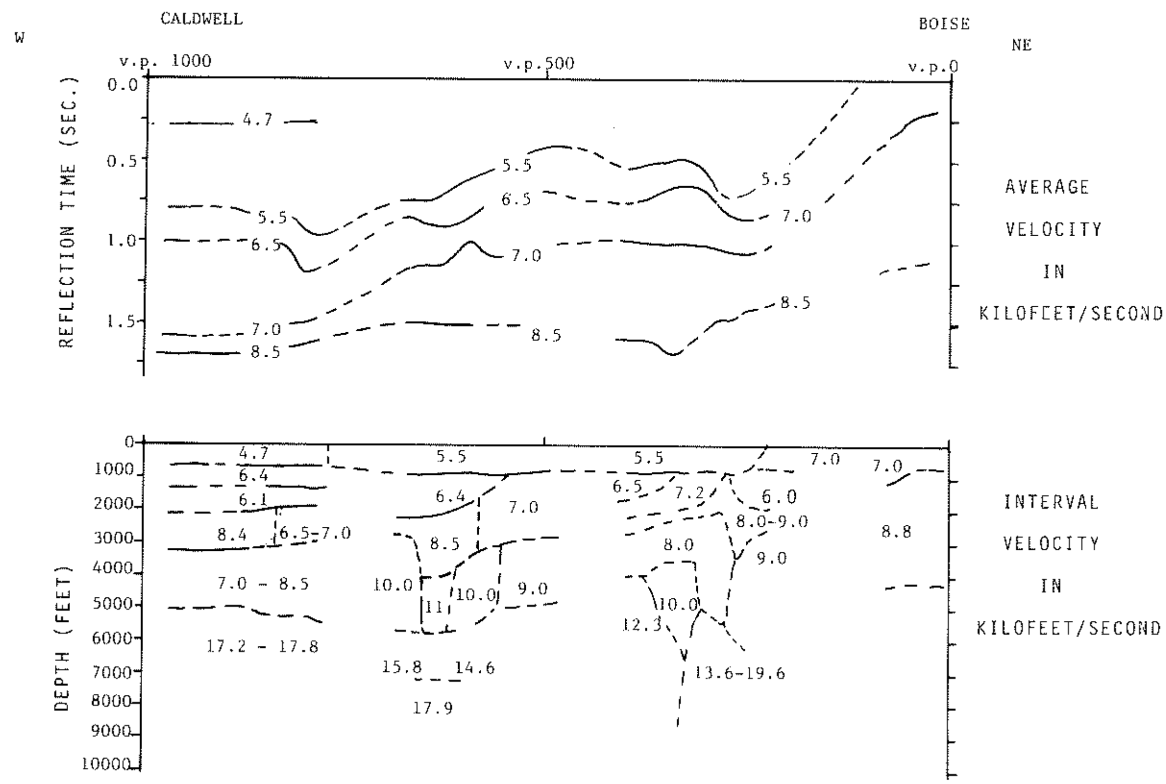

FIGURE 6-1. Profile of stacking (R.M.S.) and internal seismic velocity analysis of common depth point data on line IB-2.

surface of the plain (figure 2-6) and margins of the plain (figure 2-1), and also the configuration of gravity anomolies contoured by Mabey (1976) and Olson (1980). Some of the structure on the acoustic basement (Horizon "B", figure 2-7) could not be easily depicted with a northwest strike. A number of faults are more easily connected using a north-northwest strike. This different orientation is reasonable for faulting of Miocene-aged volcanics, for structures in the Owyhee Mountains south of the plain generally have a N10°W to N20°W orientation (McIntyre, 1972, Pansze, 1973, Ekren and others, 1981) and structures on the Miocene Columbia River Group north of the plain also have more of a north-northwest orientation (Newcomb, 1971).

Acoustic Basement

Seismic energy is reflected from interfaces of layers with contrasting velocities and/or density. At an interface with a large contrast in velocity, essentially all of the energy is reflected, and little is transmitted to deeper layers. The reflection process is analogous to the reflection of light, and an interface of high seismic impedance contrast is analogous to complete reflection by opaque or mirror material. Very strong reflections are derived from thick volcanic units beneath the Snake River Plain. The entire area examined is underlain by a thick section of basalt or other volcanic rocks of high seismic velocity that reflect almost all energy, so that deeper structure can rarely be detected on the sections. This thick reflecting layer is called "acoustic basement" because reflections from beneath it are weak or nonexistent. South of Nampa a thick volcanic unit in the shallow section also acts as a local acoustic basement. The two overlapping acoustic basements are well illustrated at the south end of Line IB-29 (figure 2-5). Seismic velocities of dense volcanic flows in the subsurface Snake River Plain are typically 4600-5500 m/s (15,000-18,000 ft/sec) whereas the overlying clastic sediments are typiclly 2100 m/s (7000 ft/sec). The "opacity" or "transparency" of a dense volcanic unit to seismic waves also depends upon its thickness, and upon the frequency of the seismic energy. In attempting to match the seismic reflection profiles to the integrated sonic logs of the J.N. James #1 and the M.V. Higgenson #1 well, it was found that the top of the basalt at 0.7 seconds (integrated time) or, 730 m (2400 ft) depth, is not exactly the acoustic basement of the reflection profiles. The wavelet identified with acoustic basement starts with a trough followed by a strong peak at about 0.8 seconds, or about 100 m (330 ft) below the top of the basalt. The stronger wavelets are commonly clipped on the processed sections.

The reflection from acoustic basement is strong, but segments are rarely continuous for more than 10 vibrator points or about 500 m (1600 ft). The irregular appearance of acoustic basement horizon suggest that it is broken up into a great number of fault blocks, and that it is also considerably eroded. Indeed, one cannot distinguish between erosional truncations of basalt reflectors and faulted basalt. Only where the fault cuts younger strata can a fault be identified with certainty. The acoustic basement and possibly the top of the basalt section would appear to be a major unconformity, for reflections from the overlying sediment merge, or appear to lap upon the relief of the acoustic basement reflector (figure 2-5).

Seismic Velocity

In addition to seismic velocity measured on sonic logs of deep wells, one also obtains information on subsurface velocity by analysis of common-depth-point seismic data. The profile of stacking (R.M.S.) velocity (obtained from this analysis) versus reflection time is shown in figure 2-4 along line IB-2. This plot shows that velocity varies laterally in the sedimentary section. The velocity of the sediment increases to the east along this line. Velocity at 0.5 seconds reflection time increases from 1,680 m/sec (5,500 ft/sec) in the deep section of sediment in the western part of line IB-2 to about 1,830 to 1,921 m/sec (6000 to 6300 ft/sec) over the structurally high basalt near Meridian and eastward to the Boise foothills. Two factors which would contribute to this velocity increase are 1) the increase in sand thickness to the east at the expense of claystone and siltstone and 2) the uplift of sediments over the structural high and eastward to the Boise Foothills.

An uplifted section of sediments would have a higher velocity, because deep burial would have produced a higher degree of compaction, compared to a section of sediment that had simply subsided to its level in the plain. If this latter explanation is preferred, it also implies uplift and erosion of a part of the section to the east in the Boise area, where the section has an anomalously higher velocity.

The plot of lateral changes of velocity (figure 6-1) also shows that a choice of 2133 m/sec (7000 ft/sec) is appropriate to convert reflection time to depth to the acoustic basement such as is done for figure 2-8.

STRUCTURE CONTOUR MAP OF HORIZON "B" (Acoustic Basement)

The structure contour map of Horizon "B" (figure 2-7) was obtained by correlating a consistent, very strong but discontinuous reflection through the network of lines. Two-way reflection times are converted to depth assuming a constant average velocity of 2,133 m/s (7,000 ft/sec) over the entire map area. Datum for all the seismic reflection data is 762 m (2500 ft) above sea level, so that the depths are below this datum and not necessarily the ground surface which varies from 700 to 825 m (2,300 to 2,700 ft) over most of the area.

The dominant feature on this map is the nose of a N50°W striking structural high that plunges step-wise along faults to the northwest. The structural high is outlined by the 1,456 m (4,800 ft) contour. The structural high is 8 to 13 km (5 to 8 mi) wide between the 1,465 m (4,800 ft) contour. The highest point detected by available seismic coverage is 854 m (2,800 ft) about 5 km (3 mi) northwest of Meridian. Axis of this high runs from the town of Meridian to the town of Middleton, where the acoustic basement lies at a depth of 1,100 to 1,220 m (3,600 to 4,000 ft)

The structural high on acoustic basement is flanked by basins, one of which encompasses the Lake Lowell-Nampa area, where acoustic basement is about 1,220 to 1,700 m (4,000 to 5,600 ft) deep, and another detected only by line IB-2 which lies between Meridian and a point at the northwest end of Chinden Boulevard by Valley View School in northwest Boise (Section 26, T. 4N, R. 1E). This latter basin probably trends northwest and is about 8 km (5 mi) wide. The structural configuration of the basin is illustrated by the section which cuts it obliquely in an east-west direction shown in (figure 2-7). Acoustic basement is deepest along the line at a point beneath the intersection of McMillan Road and Cloverdale Road (Drive on the USGS 7 1/2 min. Cloverdale quadangle maps, Section 28, T. 4N, R. 1E) where it is at a depth of 1,460 m (4,800 ft).

Structure on acoustic basement consists of both faults and dipping segments. Near the intersection of lines where orientation of faults and contours is controlled there is good evidence of two directions of faulting. An earlier set has a north-northwest orientation, whereas another set of more recent faults and folds have a more westerly strike (N45°W to N60°W).

On this map three major fault zones that cut the overlying strata are named. These are the "West Boise-Eagle Fault", the "Middleton-Meridan Fault", and the "Lake Lowell Fault". These faults have particularly good expression on the reflection profiles and have the largest displacements. The Lake Lowell and the Middleton-Meridian Faults displace acoustic basement about 120 m (400 ft). The West Boise-Eagle Fault has a displacement of about 240 m (800 ft). All faults appear to have high angle dips (60 to 80°) and normal displacements.

The map of acoustic basement (Horizon "B") can be used as a guide to the thickness of Idaho Group sediment and as an indication of the maximum drill depth to aquifers within the lower Idaho Group. Drill depths below acoustic basement will probably encounter the thick volcanic section.

STRUCTURAL CONTOUR MAP ON HORIZON "I" WITHIN THE LOWER IDAHO GROUP

The structure contour map on Horizon "I" (figure 2-8) was obtained by tracing a generally continuous reflection that is the top of a basalt flow sequence in the area southwest of Nampa. Elsewhere and over most of the map area the reflection from Horizon "I" is apparently produced by velocity contrasts between sandstone and clayey siltstone units. The basaltic nature of the reflecting beds in the southwest area is known from the very high amplitude of the reflection, and its expression as a local shallow acoustic basement over a limited area. The basaltic section was drilled by the Champlin Oil Company (Deer Flat No. 1 well) in 1981, confirming the interpretation of the seismic data. Values on the contour map are depth below a 760 m (2,500 ft) datum calculated from two-way reflection time assuming a constant average velocity of 1,829 m/sec (6,000 ft/sec).

The dominant feature of this map is the general westerly dip of the horizon. This westerly downtilt is interrupted by a number of northwest striking faults; or local steepening of dip along northwest trending zones probably associated with faulting contemporaneous with deposition.

Faulting and downwarping maintain the basin area in the Nampa-Lake Lowell area, and this area and the area to the northwest is a major basin of deposition. The basin in the Meridian-northwest Boise area was completely filled with sediment by the time of deposition of Horizon "I" (figure 2-4). The basin area north of the structural high appears to have shifted westward as shown by the north dip of the horizon at the north end of the cross section through Middleton (figure 2-5). The major northwest striking faults that cut Horizon "I" continue up into the shallower section indicating that this northwest trend of normal faulting is the recent orientation of faults in the area.

Horizon "I" is chosen in this report as a dividing horizon for the upper and lower units of the Idaho Group based on the earlier discussion of stratigraphic units (Chapter 2). Structural configuration of this horizon is the configuration expected of most of the aquifer units in the Idaho Group. The map is particularly useful for showing the location of the three major fault zones with Quaternary age offset. These fault zones are prospective areas for fracture permeability and for upward migration of hot geothermal waters.

The northwest extent of the subsurface basalt field in the south-western part of the area is shown in figure 2-6. This buried volcanic field is identified from its expression on reflection profiles IB-7, IB-8 and IB-29 (figure 2-5).

The significance of the buried basalt volcanic field within the Idaho Group to geothermal resources of the area is uncertain. If several dense brittle units occur in this section, good fracture permeability might be developed along the Lake Lowell Fault, and other faults that displace the shallow section. The area south of Lake Lowell and in the Hidden Valley area contains a number of anomolously warm water wells. Wells drilled to depths of 150 m or more (500 ft or more) in this area typically produce warm fresh water (Chapter 3 of this report). Existence of deeper permeable aquifers in this area can be better evaluated when geophysical logs of the Deer Flat No. 1 well become available.

GRAVITY SURVEY

Regional gravity surveys by Mabey (1976), Lillie and Couch (1979), and Couch (1978) are shown as a compilation of their maps in figure 2-1. The western Snake River Plain appears as a regional positive gravity anomaly with values of -120 to -70 milligals relative to values of -120 to -160 milligals in the surrounding granitic terrain. The configuration of the -120 milligal contour outlines much of the physiographic basin. This contour extends northwestward to about Weiser, Idaho where the basin apparently terminates against Mesozoic and Paleozoic rocks of lesser density associated with the core of the Blue Mountain uplift. Much of the Western Owyhee Mountains show values typical of the granitic terrain suggesting that granitic rocks extend westward to about the Oregon-Idaho border beneath a thin cover of volcanic flow rocks and sediment. West of the Oregon border is a rectangular area of relatively high values, about 30 km (19 mi) wide, with a north-south elongation extending to about Rome, Oregon. This area may be a basin controlled by north-south, basin and range faulting and filled with relatively dense volcanics that merge with those of the Snake River Plain to the north.

Configuration of gravity contours in the western plain (figure 2-1) shows that the positive anomaly of the plain is made up of several elongate ("hot-dog-shaped"), northwest trending gravity highs arranged in a crude *en echelon* pattern. The elongate anomaly of about 20 milligals in the center of the plain near Nampa and Caldwell is shown by seismic data to be produced by structural relief of the thick basalt section in the plain. The large positive anomaly in the vicinity of Mountain Home, Idaho is not explained; however, unpublished resistivity profiles by the U.S. Geological Survey indicate that resistive and dense basalt extend from the surface to considerable depth in this area.

Steep gravity gradients that appear on the margins of the plain are probably caused by large basin-margin faults where thick basalt sections are faulted against granitic rock.

A detailed gravity survey with station spacing of 0.8 km (0.5 mi) in the Nampa-Caldwell area was carried out by Olsen for a M.S. thesis at Brigham Young University. The map (figure 6-2) shows the prominant, northwest-striking gravity high that extends across and off of the map area. Shorter wavelength anomalies (figure 6-3)probably represent complexities of near-surface basalt flows of the Snake River Group. No major faults can be exactly located by this survey largely because shallow basalts are not significantly faulted, and the deep basalts with large fault offsets are over 700 m (2,300 ft.) deep and were not resolved in detail by gravity.

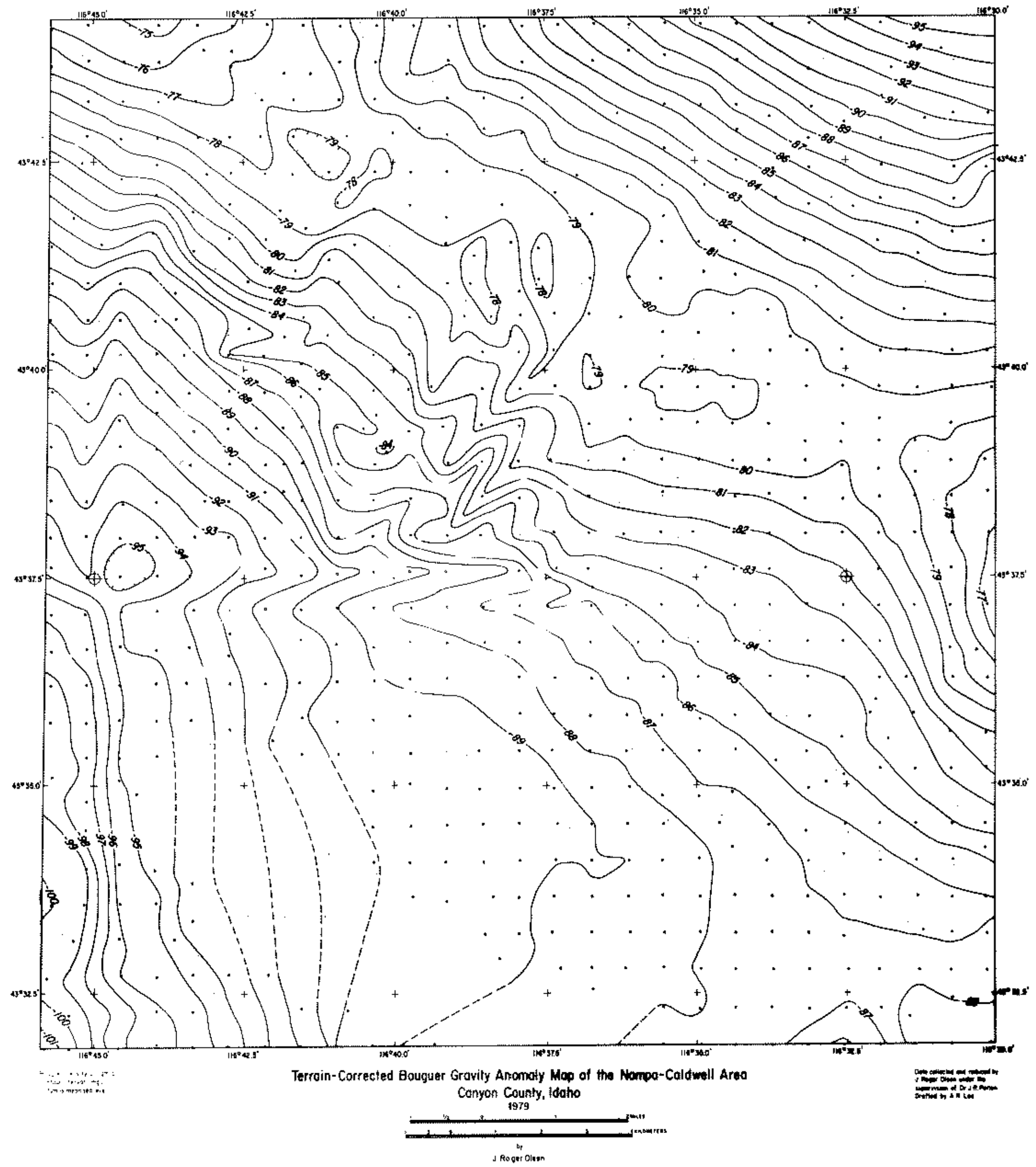

FIGURE 6-2. Terrain corrected Bourguer gravity anomoly map of the Nampa-Caldwell area. From Olsen (1980).

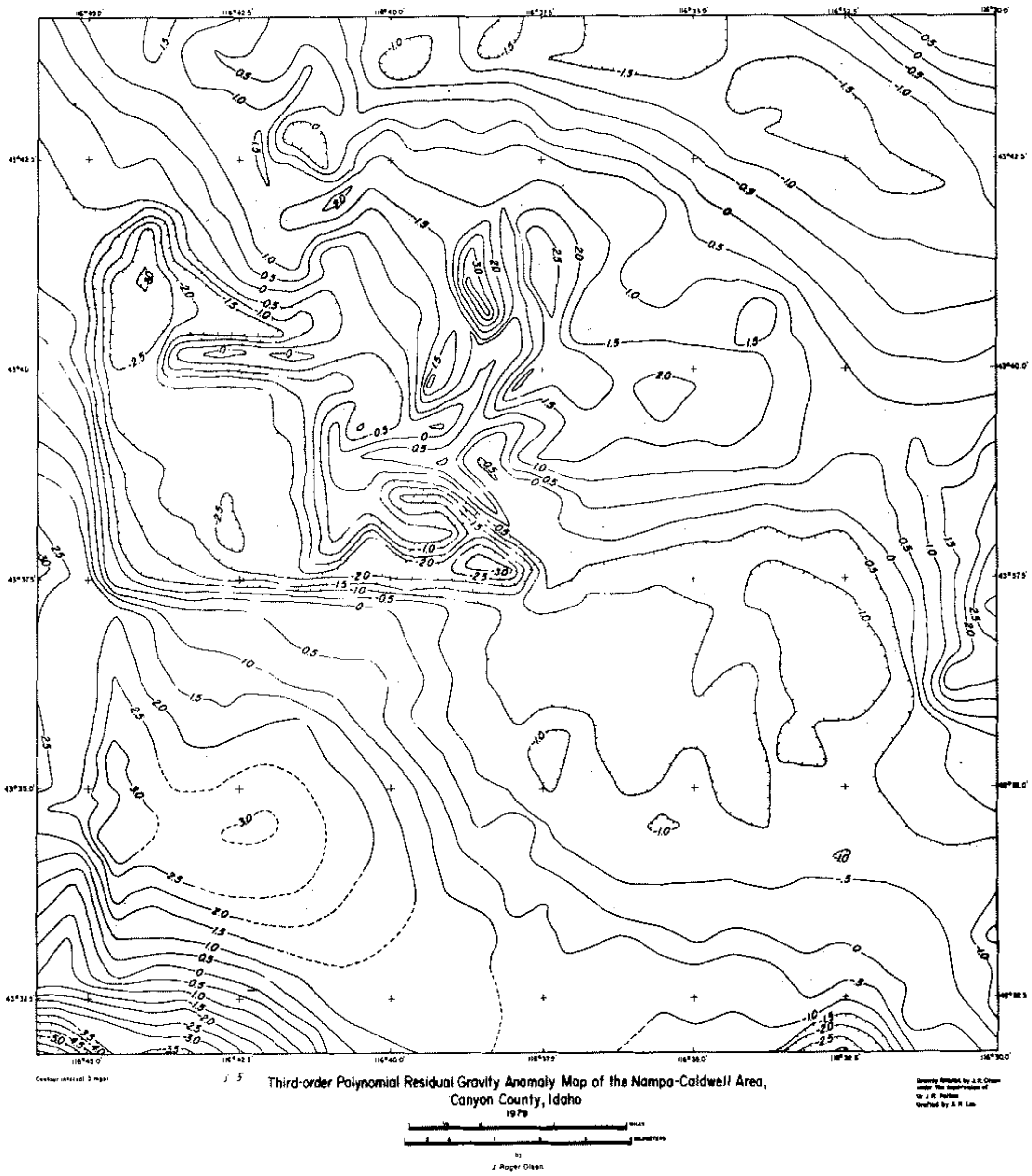

FIGURE 6-3. Third-order Polynomial Residual Gravity Anomaly Map of the Nampa-Caldwell Area, Canyon County, Idaho. From Olsen (1980).

AEROMAGNETIC SURVEY

Aerial Geophysics, Inc. (Salt Lake City, Utah) conducted an aeromagnetic survey of the Nampa-Caldwell area in June 1979. The survey was flown with a Geometrics proton-precession magnetometer (G803). Flight lines are 0.8 km (0.5 mi) apart. The magnetic contour map (figure 6-4) of the magnetic field shows a number of 200 to 400 gamma anomalies. These anomalies are 2 to 6 km (1.25 to 3.75 mi) wide and superposed upon a larger magnetic low about 7 km (4.3 mi) wide that runs through the area and off the map to the northwest and southeast. Position of the magnetic low is an area between Lake Lowell and the Indian Creek drainage in which shallow basalts of the Snake River Group are absent. It is possible that detailed modelling of the magnetic data might better define the thicker parts of the surficial basalts, but such studies have not been carried out.

In the southwest part of the map is a positive anomaly outlined by the 5000 gamma contour. Seismic reflection data shows that is an area of buried basalt vents, or shields about 3 km (1.5 mi) wide and 300 to 600 m (1,000 to 2,000 ft.) deep. It appears that aeromagnetics may be used to locate areas underlain by basalts, but that detailed modelling of the various combinations of depths and thicknesses of subsurface basalts would lead to ambiguous results, unless supported by seismic reflection and drilling data.

MAGNETOTELLURIC DATA

General

Data from 13 magnetotelluric (MT) soundings were obtained by the Geotronic's Corporation of Austin, Texas to aid in the interpretation of subsurface geology in the Nampa-Caldwell area. The data were originally obtained for the Great Basin Petroleum Company in 1978 by Geotronics. Only a portion of the original survey was purchased for this project.

Five components (three components of the magnetic field and two components of the electric field) were recorded digitally over a frequency range of 0.002 Hz to more than 200 Hz. Raw data quality as reported by Geotronics was quite good. These data were reduced to resistivity versus depth curves based on the electromagnetic skin-effect on the attenuation of a range of frequencies with depth.

Interpretation

The interpretation procedure begins with the calibration of the data with known geology, in this case data from the M.T. Halbouty-J.N. James No. 1 well. The degree of vertical control gained from this correlation exercise is very good since one of the MT sites is essentially coincident with the well. Comparisions were made with a smoothed resistivity log from the well and also with geologic formation picks.

Site to site correlation then extends this vertical control over the surveyed area in a manner which is very similar to well log correlation.

Beginning with site 8 (see figure 6-5) at the J.N. James No. 1 well, the sounding curve was scrutinized for recognizable character in the vicinity of depths where acoustic horizons had been picked from seismic sections for mapping. These points were then correlated from site to site and compared with the depths to horizons mapped from the reflection seismic data. The purpose for this was two-fold. First the comparison offers an increased confidence in mapping horizons from the MT data and second the comparisons might suggest additions or changes to the seismically interpreted structure.

The correlations obtained were all quite good and no modifications to the seismic structure maps are suggested. Shallow correlations are limited to some degree by the lack of near surface resolution inherent in magnetotellurics. Acoustic basement occurs at relatively shallow depths in this area and therefore correlations with high confidence level were not possible at all recording sites for seismic picks in the upper part of the section.

Beginning again with site 8 (J.N. James No. 1 well) interpreted geologic formation tops were picked and then correlated on a site to site basis with the other soundings. This information is summarized in cross section A-A', B-B', and C-C' (figures 6-5, 6-6 and 6-7), an interpreted structure on one of the deeper units ("Older Igneous Rocks") and an intermediate depth unit within the Columbia River Group or possibly within the Idaho Group.

From the interpreted formation tops, significant faulting at depth is very evident with the amount of apparent movement decreasing upward in the section suggesting that a large portion of the movement probably predated the shallow units. Thus, the faults shown in cross section are not shown reaching the surface and the interpreted structure map is shown for a unit which is clearly cut by the faults (figures 6-5 and 6-6). The fault pattern shown on this map is supported by seismic and surface mapping and other published and unpublished interpretations of the structural style in the area.

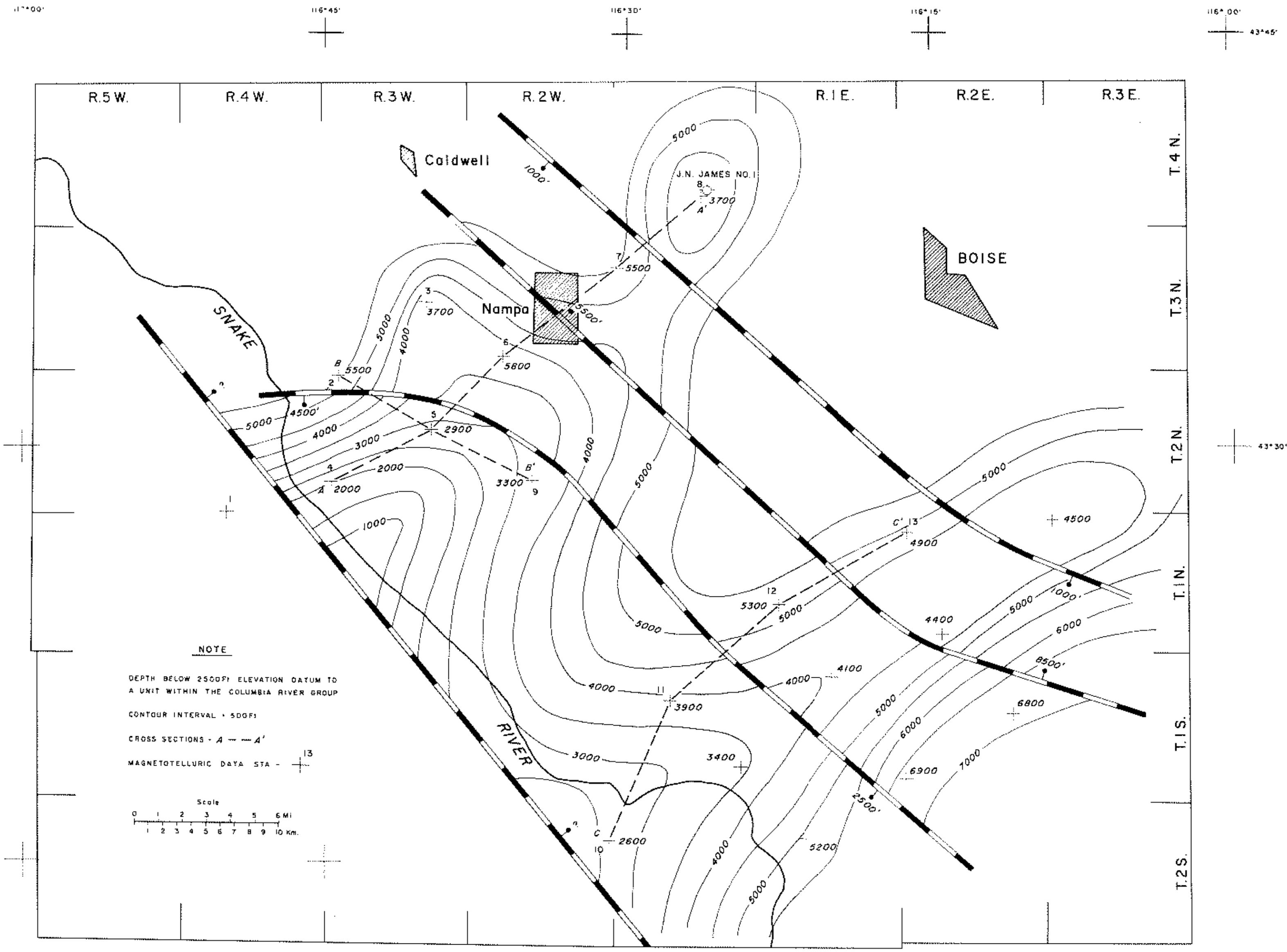

FIGURE 6-5. Structure contour map on top of "older igneous rocks" from magnetotelluric data in the western Snake River Plain.

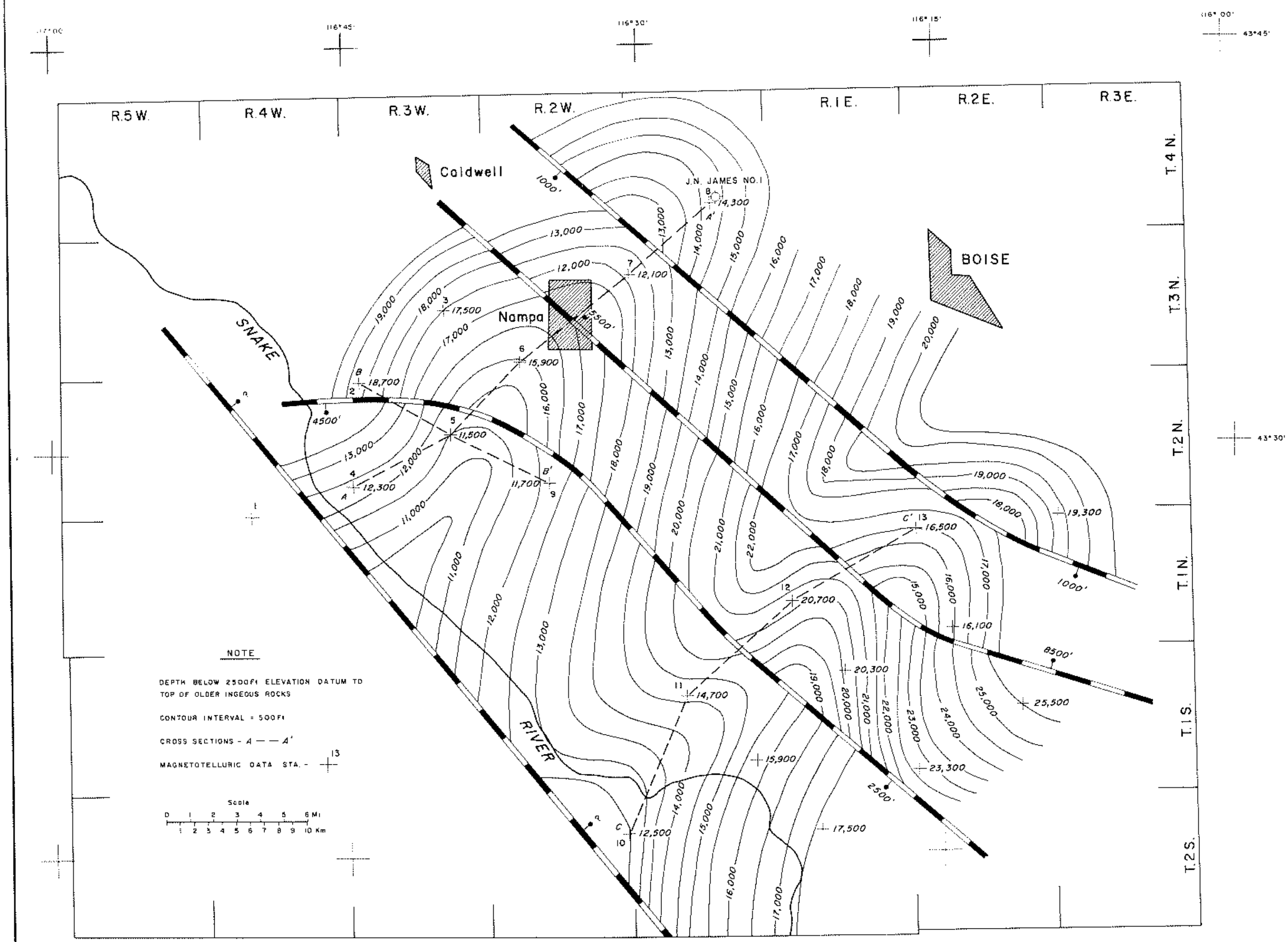

FIGURE6-6. Structure contour map on top of a horizon within the Columbia River Group from magnetotelluric data.

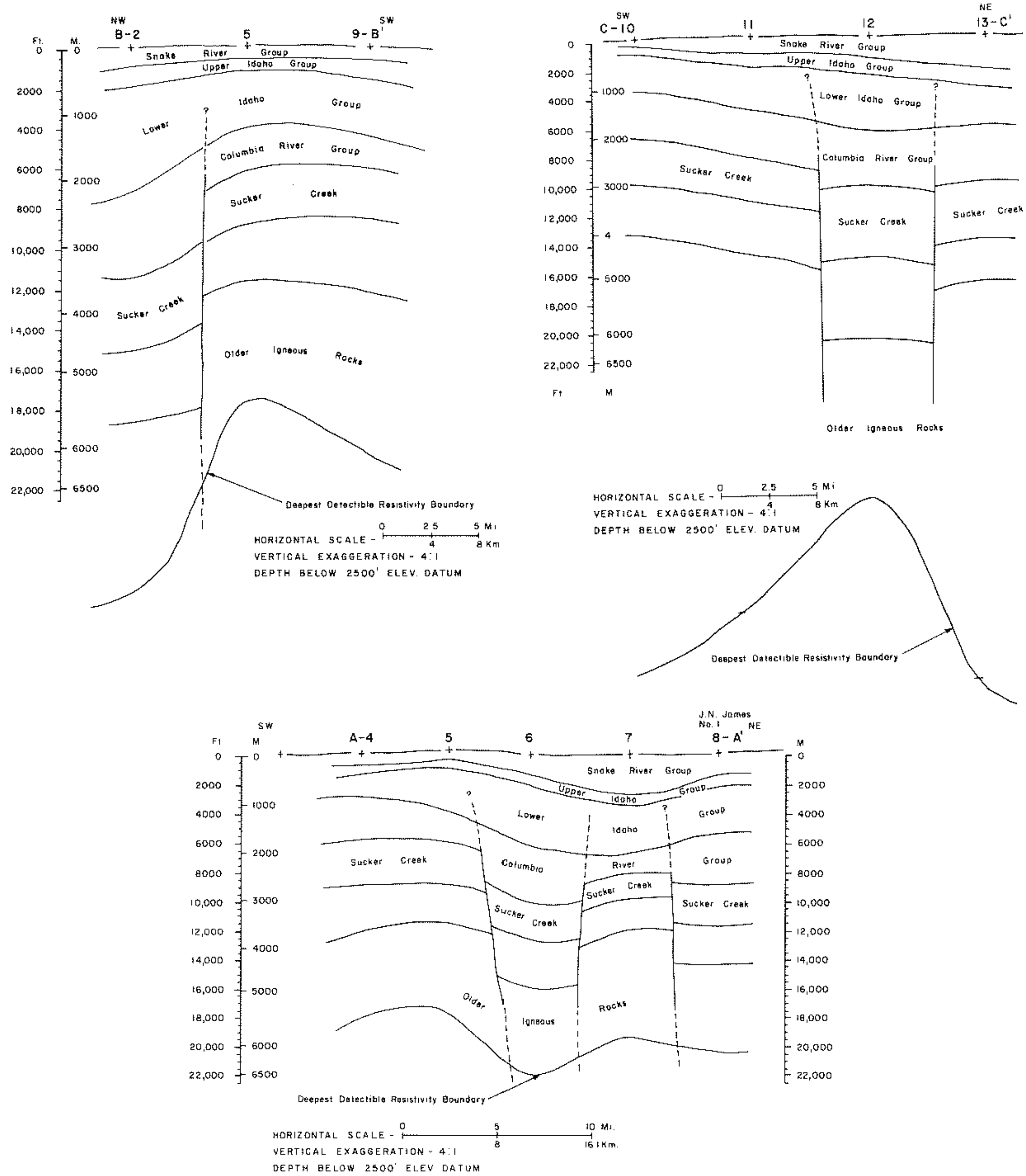

FIGURE 6-7. Cross-Section A-A', B-B' and C-C' from magnetotelluric data in the western Snake River Plain.

CHAPTER 7 - SYNOPSIS

By
John C. Mitchell[1]

APPARENT DISCREPANCIES

As can be appreciated in a report of this scope, there are several aspects of the study that appear as discrepancies. These should be clarified.

The heat flow chapter (no. 5) was completed more than a year before Wood and Anderson's Geology (Chapter 3) and the Geophysics (Chapter 6). Therefore, Smith, not having the benefit of the final interpretation on subsurface geology, used Newton and Corcoran's earlier work (1963) in Oregon and Western Idaho. These had not the benefit of the J.N. James No. 1, the Highland Livestock and Land No. 1, nor the Ore-Ida Foods No. 1 wells. The inclusion of Newton and Corcoran's stratigraphy as well as that proposed by Wood and Anderson (Chapter 2) does vividly point out that additional effort needs to be made in the western Snake River Plain to unravel the stratigraphic problems.

The reflective seismic data (Chapter 6) seems to contradict the idea of any structures being perpendicular to the Snake River Plain axis as suggested in Chapter 4 by the lineaments study. The reflection seismic lines were so oriented and located that they do not cross several of the linear features, notably L-5, figure 4-2. Other linear features perpendicular to the Plain's axis are crossed by only one purchased line. It is impossible to determine strike of any feature cut by only one line; therefore, no structures perpendicular to the Plain's axis were conclusively observed in the seismic data. Alternate hypothesis of dislocations observed on seismic data could conceivably be interpreted as northeast trending. However, the authors chose to present data only on those they felt most certain about and reject all others. Therefore, there is no conclusive evidence of the existence of the northeast trending linears other than the satellite data, and the fact that several northwest linears do coincide with seismically interpreted faults, or with suspected rift trends. Some of Mohammad's (1970) faults in the Boise front area also approximately parallel the northeast trending linears. Structures mapped from magnetotelluric data (figures 6-4 and 6-5) also trend perpendicular to the Plain's axis, and alternatively could be interpreted as fracture related. As more data becomes available on the western Snake River Plain, awareness of the possible existence of plain axis perpendicular features in the subsurface should be incorporated in its interpretation.

CONCLUSIONS

Geological, hydrological, geochemical and geophysical studies generated a great deal of additional data on the structural framework and geothermal potential of the western Snake River Plain in general, and the Nampa-Caldwell area in particular. These data are interpreted as follows:

[1] Idaho Department of Water Resources

1. The absence of a thick section of siliceous Idavada volcanic rocks in the J.N. James No. 1 well, and other deep oil and gas exploration wells, make correlation of basalt sections beneath the western Snake River Plain with sections on the Plain's margins and other areas, uncertain.

2. Within the graben-like basin known as the western Snake River Plain, geophysical studies have revealed complex basin structures. A large basin exists in the Nampa-Caldwell area, and another in the Meridian-northwest Boise area. These basins are separated by a structural high that runs from approximately Meridian to Middleton.

3. The basin structures are filled with Idaho and Snake River Group sediments, and older basalts which constitute the acoustic basement, and may contain several permeable thermal water bearing zones. These zones are located at approximate depths of 91-213 m (300-700 ft), 457 m (1,500 ft) 640 m (2,000 ft), 1,035 m (3,400 ft) 1,310 m (4,300 ft) and 1,680 m (5,500 ft). Depths may vary due to basin related geologic complexities.

4. Minimum subsurface temperatures for these six zones, estimated from temperature logs obtained during oil and gas exploration drilling in deep aquifers and water well drilling in shallow aquifers, are respective to depth; 30°C, 43°C, 49°C, 58°C, 66°C and 75°C.

5. The permeable zone encountered at 1,310 m in the J.N. James No. 1 well may be the same zone encountered at 1,860 m (6,100 ft) in the recently completed Deer Flat No. 1 well, in which 107°C water was encountered. The water rose in the well bore to within 61 m (200 ft) of the surface which indicates this permeable zone may be extensive, but may also be variable in temperature.

6. Thicknesses of these units probably vary, but estimates of thicknesses from electrical logs from the above mentioned wells appear to be 75 m (245 ft), 40 m (131 ft), 31 m (100 ft.), 100 m (330 ft), 61 m (200 ft) and 75 m (245 ft).

7. Comparison of the separation in laterlog and deep induction log traces in shallow sands [120 to 180m (400 to 600 ft) deep] from the Higgenson No. 1 well near Meridian with deeper sands [418 to 564m (1370 to 1850 ft) deep] indicates the shallow and deep sands should have similar permeability. Pump tests run on the city of Nampa No. 8 and the Nampa State School and Hospital No. 3 wells indicate transmissivities of 2,480 m^2/day (26,700 ft^2/day) and 2,000 m^2/day (21,400 ft^2/day) with a deminsion-less storativity of 6×10^{-4} for sand aquifers between 116 and 184m (380 to 605 ft) in depth. If lateral facies changes in the sand units are minor between Nampa and Meridian, the intermediate sand aquifer in the Higgenson No. 1 well should have transmissivity and storativity values similar to the shallow aquifer in the city of Nampa No. 8 and Nampa State School and Hospital No. 3 wells.

8. Unconformities within the upper Glenns Ferry Formation may mean this formation is thin, or absent in the Boise front area.

9. Geothermal waters are depleted in heavy isotopes which may mean recharge from precipitation in areas of higher elevation (geographic displacement) or during a time when the climate was colder than that prevailing today. If recharge occurred during the Pleistocene Epoch (ice age) the water is equal to or greater than 11,000 years old. Alternatively, depleted water could be the result of evaporation of river water with subsequent ^{18}O enrichment. Less likely, geothermal waters could result from semipermeable membrane clay layer fractionation processes, or from exchange of isotopic species with aquifer constituents, or result from deep seated steam separation by subsurface boiling.

10. Recharge may be taking place slowly over a long period of time, or there may be relatively little present day recharge to the thermal system.

11. Mixing of thermal and nonthermal waters may be widespread in the Nampa-Caldwell area occurring primarily within well bores due to well construction. The total effects on the geothermal and nonthermal aquifers or permeable zones due to migration and mixing of thermal and nonthermal waters on the longevity of the shallow geothermal aquifers for use as a heat source is not known.

12. Cold water recharge, for aquifers above the "blue clay", appears, from isotope data, to be from Reynolds Creek basin south of the Snake River Plain, or similar elevations, the Snake River, Lake Lowell and canals, perhaps the Payette River, Boise River and Willow Creek areas north of the Snake River Plain.

13. The thermal water appears ultimately to be coming from aquifers or permeable zones deeper than the aquifer within the "blue clay."

14. Temperatures of the aquifer within the "blue clay" appear to be only about 30°C, and may be fairly uniform over large areas.

15. Temperatures of 90' to 95°C might be obtained nearly everywhere in the area, but only by drilling to depths greater than 1500 m (5,000 ft), or perhaps at shallower depths in fault zones.

16. Thermal water of isotopic composition near δD = -150 ‰ and $\delta^{18}O$ = -18 ‰ may be widespread in the western Snake River Plain region, and may be the parent geothermal water in the Nampa-Caldwell area, the Boise area, the Bruneau-Grandview area and perhaps other areas. This indicates the water in these areas may be from the same elevation or source(s) and/or times of recharge, or the geothermal system may be interconnected.

17. The western Snake River Plain, located within the Cordillarian thermal anomaly zone (an elongate belt outlined by a 2.3 HFU contour stretching from northern Nevada through the western Snake River Plain into the eastern Snake River Plain and to the Yellowstone Park area) is a region of recognized convectively induced high heat flow outlined by a 3.0 HFU contour.

18. A temperature profile of the Richardson #1 well (4N-3W-19adcl) in the Nampa-Caldwell area also showed indications of several hot permeable zones in this area.

19. Heat flow in the Boise Front area is dominated by structurally controlled groundwater movement and models similar to theoretical basin and range heat flow distribution models with no local detectable heat source.

20. In the Weiser-Crane Creek area, temperature distribution is intensely affected by rock type and groundwater movement where sediments act as a blanket to retain high temperatures at depth. This results in low near surface temperatures, but high temperature gradients. A localized high temperature source is not suggested by the Isogeotherm distribution in this area.

RECOMMENDATIONS

The isotope data may be interpreted to indicate that thermal waters in the Nampa-Caldwell area, and indeed other areas in Idaho, including Weiser, Bruneau-Grandview and Boise areas, may be old waters (11,000 years or greater). It is not known if present withdrawals of old water are being replaced with present day recharge. If not, the thermal waters are being depleted and large scale withdrawals, i.e., for space heating or other purposes could eventually deplete the aquifer(s) to a point where further economic use is not feasible. To maximize the longevity of the resource until recharge can be proven or disproven, it is recommended that:

1. For space heating or other geothermal purposes, consideration be given to the use of down hole heat exchangers (heat exchangers located within the well bores adjacent to, or within the aquifers). These have proven practical at other localities such as Klamath Falls, Oregon. Down hole heat exchangers have two advantages;

   a. they do not deplete the water resource,

   b. there is little or no chemical pollution, as little or no geothermal water is brought to the surface.

2. Wherever possible, wells drilled for geothermal purposes should have production casing cemented solid, from the production zone to the surface, to assure the highest temperature for the intended use and to avoid mixing effects of deeper, hotter water with shallow, cooler water.

3. Investigations of effects of widespread artificial aquifer connections by well drilling on the longevity of the thermal permeable zones and their use for a heat source should be conducted.

4. Should large scale development take place, it would be advisable to establish a geochemical sampling program whereby quarterly or even monthly samples are obtained from production zones. Such information has been utilized in high temperature fields for early detection of impending production changes (volume, temperature, fluid characteristics) in geothermal wells.

5. Thief sampling of water from permeable zones isolated by packers to prevent mixing within the well bore of the Richardson No. 1 well should be made to determine deep water isotope and geochemical "finger prints."

6. Investigations to delineate possible recharge of the thermal aquifers should be undertaken to determine if recharge is presently occurring. These could include further stable isotope work in suspected recharge areas in the mountains on both sides of the Snake River Plain, tritium age dating, dating using ^{12}C, ^{13}C, and ^{14}C and inert gas methods to determine absolute age of thermal water from various thermal aquifers.

7. More work is needed to determine clay layer semi-permeable membrane effects on the stable isotope ratios in the Nampa-Caldwell area. This particular study would be in the realm of institutions with adequate research facilities for such studies.

8. Monitoring of potentiometric surfaces to detect stress effects in the aquifers and permeable zones would provide early warning of water level declines should these take place due to increased pumpage from geothermal development.

9. Stable isotope data has proved to be a very valuable tool in this investigation and should be incorporated as standard water quality data in other areal investigations where deemed appropriate. Stable isotope studies should be integrated in any groundwater study of the Boise front geothermal system.

10. Seismic risks associated with possible large scale dewatering of the geothermal system should be assessed. A seismic net (3 stations) should be set up in the Nampa-Caldwell area and another along the Boise front area to obtain background data before large scale withdrawal of geothermal water begins, and should be continued after production begins.

11. Detailed petrographic and geochemical studies of well cuttings from deep wells with comparisons to outcrops in and around the western Snake River Plain should be made for correlation purposes. This would shed more light on several stratigraphic problems. Knowledge gained could be incorporated in determining the history and origin of the Snake River Plain which would be an invaluable aid in further locating and assessing the regions geothermal resources.

12. More geophysical data within the western Snake River Plain should be purchased and interpreted to help determine the boundaries of the geothermal system(s). More geophysical information, including geophysical logging of abandoned, unused, or used wells - where access permits - in the western Snake River Plain would aid greatly in making more detailed correlation of rock units and provide more knowledge of geologic structure.

13. More detailed geologic mapping, particularly on the northern margin of the western Snake River Plain is needed to unravel the stratigraphy and correlate units. A better understanding of the geology, hydrology and geochemistry of groundwaters in and near the plain will greatly expand geologists' ability to locate and evaluate areas of geothermal potential in this region. The knowledge gained in such studies would significally aid in proper resource management and could ultimately have great benefit for the people of the entire state.

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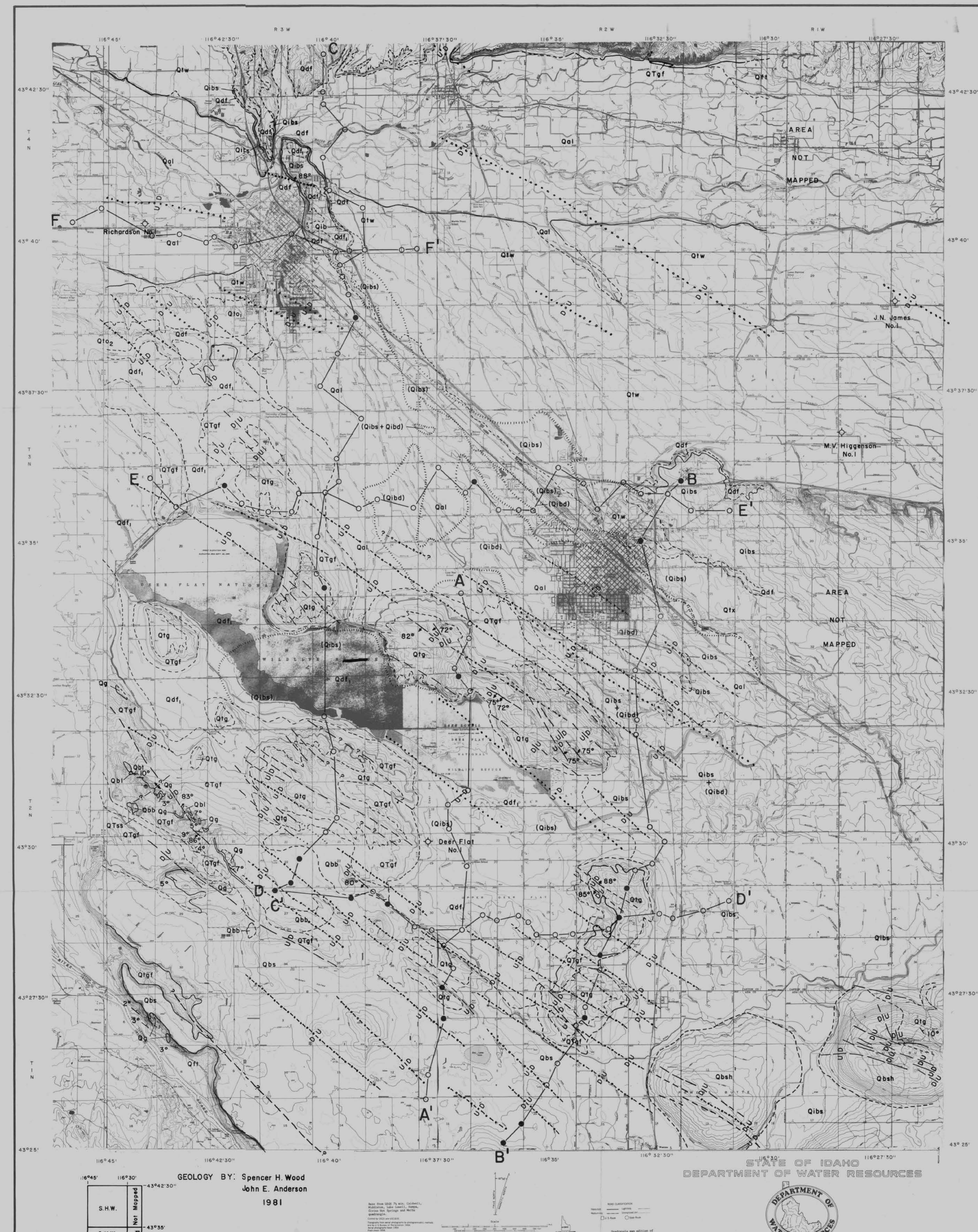
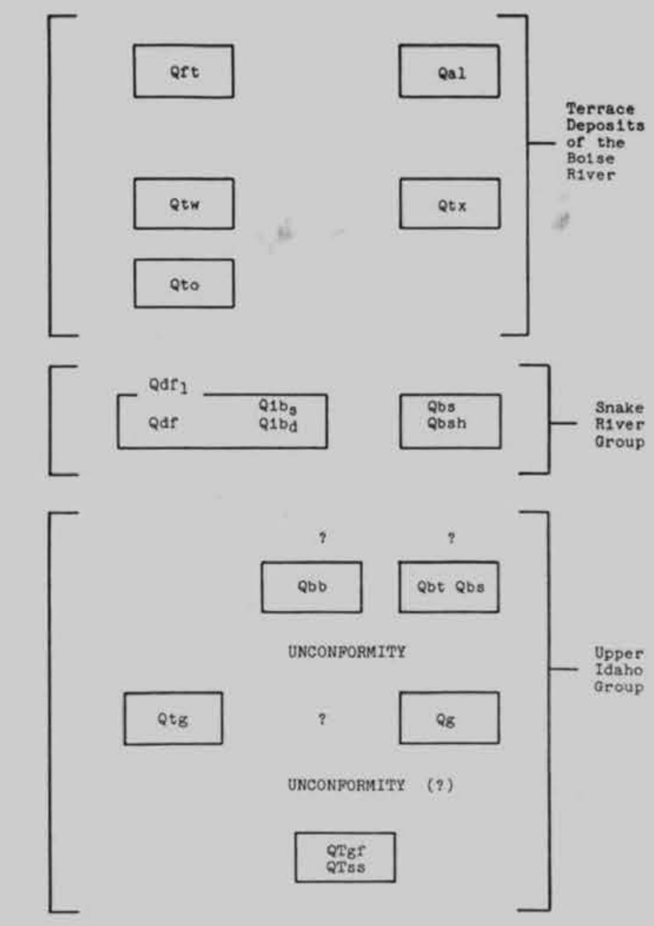


Figure 2-6.
GEOLOGIC MAP OF THE NAMPA-CALDWELL AREA

CORRELATION OF MAP UNITS



EXPLANATION

Qft

ALLUVAIL FAN AND TALUS DEPOSITS: Deposits of small alluvial fans that merge with flood plains or terraces of the Boise River and Snake River. 0 to 20 m (0 to 65 ft) thick.

Qal

RECENT FLUVIAL DEPOSITS: Deposits on the flood plain of the Boise River and Indian Creek. Locally includes low terraces within 5 m (15 ft) of the present streams.

Qtw

WHITNEY TERRACE ALLUVIAM: Gravel and sand deposits of the Whitney Terrace, a bench 10 to 20 m (35 to 65 ft) above the present Boise River flood plain. 0 to 30 m (100 ft) thick.

Qtx

TERRACE ALLUVIUM OF INDIAN CREEK: Thin sandy alluvium on a terrace level on the north side of Indian Creek that merges with the Whitney Terrace.

Qto_1 Qto_2

OLDER TERRACE DEPOSITS: Qto_1: Deposits of a terrace gravel 7 m (25 ft) above the Whitney Terrace. Terrace is preserved just west of Caldwell at an elevation of about 730 m (2400 ft). Qto_2 is an older terrace deposit standing at 750 m (2460 ft).

Qdf_1 Qdf

OLDER ALLUVIAL DEPOSITS: Widespread alluvial deposits that form the dissected upland 40 to 60 m (130 to 200 ft) above the present Boise River. Qdf_1: Undissected surface of deposit with a well cemented caliche soil horizon 0.5 to 1.2 m (1.5 to 4.0 ft) deep. Qdf: Unconsolidated fluvial deposits of cross-bedded, coars, arkosic sand with minor beds of gravel and silt. 60 to 100 m (200 to 330 ft) thick.

Qibs (Qibd) Qbs Qbsh

BASALT FLOWS OF INDIAN CREEK: Qibs: Gray, dictytaxitic, titanoaugite, plagioclase, olivine basalt occurrring as one or more flows in the Indian Creek drainage. Qibs lies within 10 m (35 ft) of the surface, and is interbedded with Qdf. Flow is 10 to 15 m (35 to 50 ft) thick. (Qibs) is shown in brackets and indicates it is present as a sursufac unit. (Qibd) is not exposed in the map area, and is shown as a concealed unit mapped from its occurrence in water wells. The flow lies 15 to 30 m (50 to 100 ft) below the surface, and is 10 to 15 m (35 to 50 ft) thick in the map area. Qib_s: Basalt flows of the Snake River Group, undivided. Qbsh: Shield volcanoes of the Snake River Group and probably the source vents of the Indian Creek flows.

Qbt Qbs Qbb

BRUNEAU FORMATION: Lacustrine deposits and basalt that outcrop along the northside of the Snake River Canyon. Qbl: horizontal, tan-white silt and fine sand. 0 to 20 m (0 to 66 ft) thick. Qbt: brown silt with palagonized basaltic ash and scoria lapilli. Qbb: Black to dark gray olivine basalt.

UNCONFORMITY

Qtg

TENMILE GRAVELS: Cobble and pebble gravel deposits with minor crossbedded arkosic, coarse, sand lenses. Clasts are almost entirely felsic porphyry and granitic rocks. 5 to 20 m (15 to 65 ft) thick.

Qg

TUANA GRAVELS· Cobble and pebble gravel depoists and coarse arkosic sand. Conspicuous clasts of silicic volcanics, granitic rocks, and trace amounts of distinctive orange quartzite and metamorphic clasts. 0 to 10 m (0 to 35 ft) thick.

UNCONFORMITY (?)

QTgf QTss

GLENNS FERRY FORMATION: QTgf: Greenish-gray siltstone and fine sandstone. Indistinct bedding. QTss: Buff-colored, ripple-marked, crossbedded, poorly-sorted, arkosic and tuffaceous sandstone.

CONTACT

Long-dashed where approximately located. (Location of edge of Indian Creek Basalt is inferred from topography or controlled by nearest water well for which a driller's log is available); dotted contact is one concealed by a younger depositional or flow unit (The deep Indian Creek Basalt unit, Qib_d, is entirely concealed and contact is based upon reference to basalt on driller's logs).

D 75° U — — —?—?—?

Trace of fault, showing dip

Solid line with dip sympol is at an exposure of the fault plane. Dashed line is a fault location inferred from topographic expression of faultline scarps. Line of trace is queried where a fault is suggested by topography, but existance of fault is uncertain. U, upthrown side; D, downthrown side.

D U

Trace of fault inferred from seismic reflection profiles (See Figures 2-4, 2-5, 2-7, and 2-8).

D U

Trace of fault inferred by elevation changes of marker beds obtained from geologic cross sections derived from water well logs. (See Chapter 3 and Figure 3-1.)

6°

Inclined Horizontal

Strike and dip of beds.

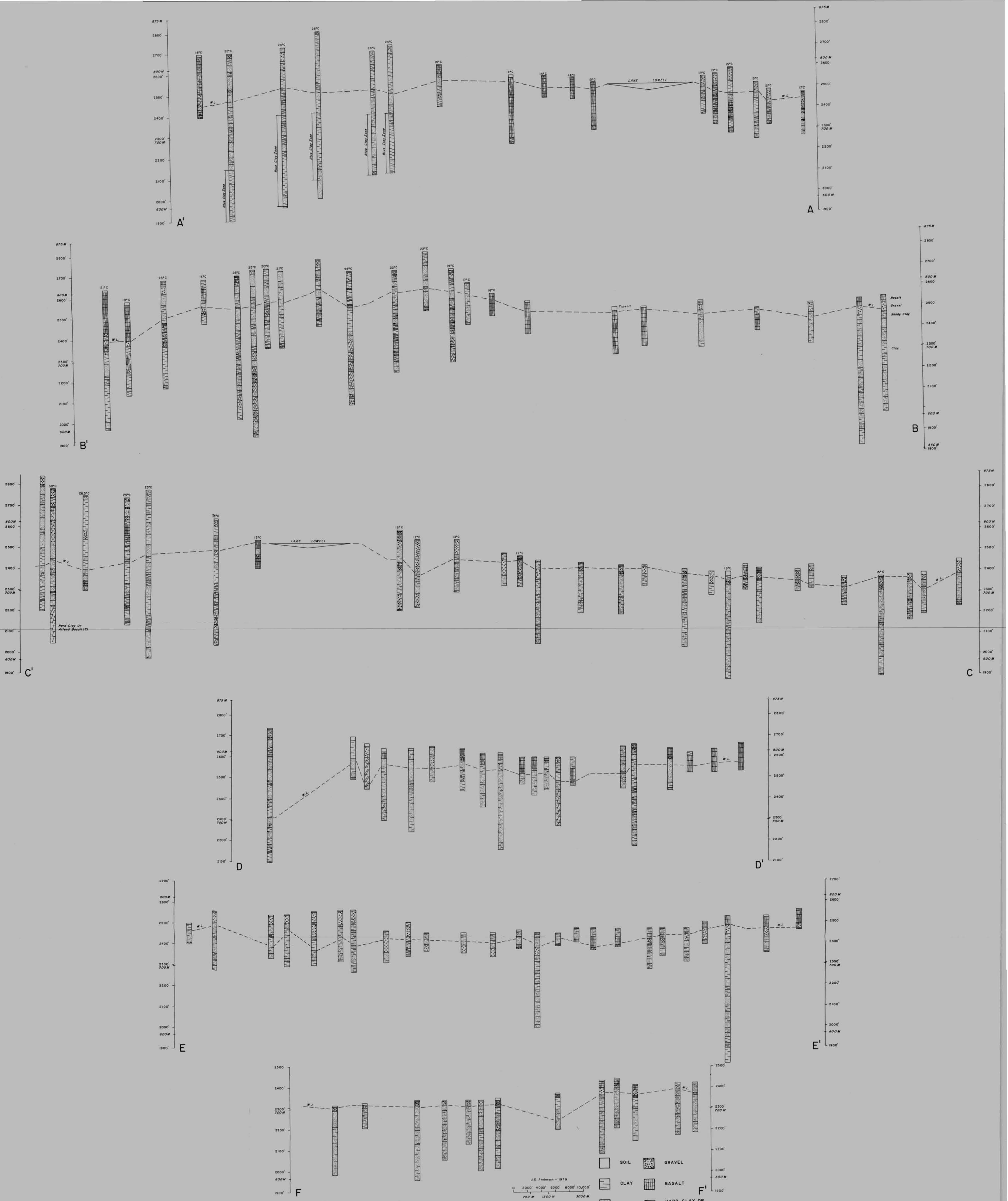
—?— — — — — —?—

Inferred anticline axès, existance uncertain.

A A'

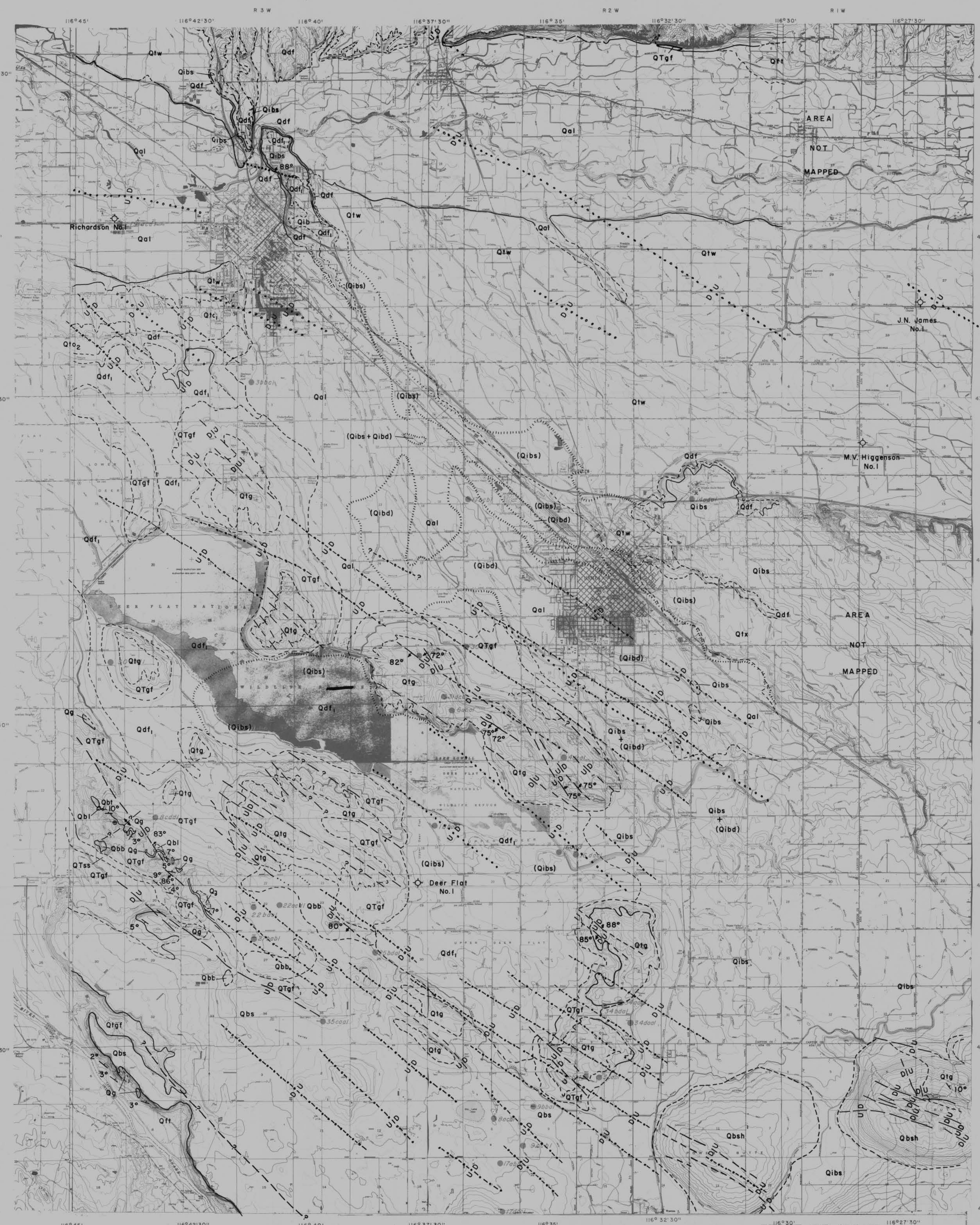
Location of water wells.

Only those wells are shown for which a driller's log was used to make geologic cross-sections shown in figure 3-1. Solid black dot represents a well for which a chemical analysis is available.



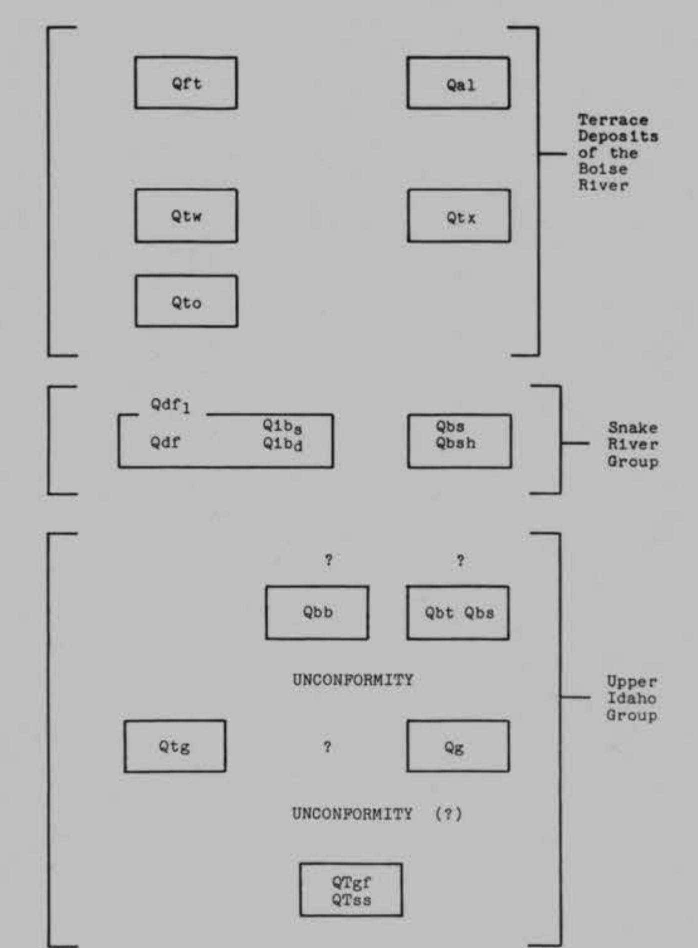
Datum is Mean Sea Level

Figure 3-1: STRATIGRAPHIC CROSS SECTIONS ACROSS THE NAMPA - CALDWELL AREA INTERPRETED FROM WATER WELL DRILLERS LOGS.



GEOLOGY BY: Spencer H. Wood
John E. Anderson
1981

CORRELATION OF MAP UNITS



EXPLANATION

Qft

ALLUVAIL FAN AND TALUS DEPOSITS: Deposits of small alluvial fans that merge with flood plains or terraces of the Boise River and Snake River. 0 to 20 m (0 to 65 ft) thick.

Qal

RECENT FLUVIAL DEPOSITS: Deposits on the flood plain of the Boise River and Indian Creek. Locally includes low terraces within 5 m (15 ft) of the present streams.

Qtw

WHITNEY TERRACE ALLUVIAM: Gravel and sand deposits of the Whitney Terrace, a bench 10 to 20 m (35 to 65 ft) above the present Boise River flood plain. 0 to 30 m (100 ft) thick.

Qtx

TERRACE ALLUVIUM OF INDIAN CREEK: Thin sandy alluvium on a terrace level on the north side of Indian Creek that merges with the Whitney Terrace.

Qto_1 Qto_2

OLDER TERRACE DEPOSITS: Qto_1: Deposits of a terrace gravel 7 m (25 ft) above the Whitney Terrace. Terrace is preserved just west of Caldwell at an elevation of about 730 m (2400 ft). Qto_2 is an older terrace deposit standing at 750 m (2460 ft).

Qdf_1 Qdf

OLDER ALLUVIAL DEPOSITS: Widespread alluvial deposits that form the dissected upland 40 to 60 m (130 to 200 ft) above the present Boise River. Qdf_1: Undissected surface of deposit with a well cemented caliche soil horizon 0.5 to 1.2 m (1.5 to 4.0 ft) deep. Qdf: Unconsolidated fluvial deposits of cross-bedded, coars, arkosic sand with minor beds of gravel and silt. 60 to 100 m (200 to 330 ft) thick.

Qibs (Qibd) Qbs Qbsh

BASALT FLOWS OF INDIAN CREEK: Qibs: Gray, dictytaxitic, titanoaugite, plagioclase, olivine basalt occurrring as one or more flows in the Indian Creek drainage. Qibs lies within 10 m (35 ft) of the surface, and is interbedded with Qdf. Flow is 10 to 15 m (35 to 50 ft) thick. (Qibs) is shown in brackets and indicates it is present as a sursufac unit. (Qibd) is not exposed in the map area, and is shown as a concealed unit mapped from its occurrence in water wells. The flow lies 15 to 30 m (50 to 100 ft) below the surface, and is 10 to 15 m (35 to 50 ft) thick in the map area. Qib_s: Basalt flows of the Snake River Group, undivided. Qbsh: Shield volcanoes of the Snake River Group and probably the source vents of the Indian Creek flows.

Qbt Qbs Qbb

BRUNEAU FORMATION: Lacustrine deposits and basalt that outcrop along the northside of the Snake River Canyon. Qbl: horizontal, tan-white silt and fine sand. 0 to 20 m (0 to 66 ft) thick. Qbt: brown silt with palagonized basaltic ash and scoria lapilli. Qbb: Black to dark gray olivine basalt.

UNCONFORMITY

Qtg

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UNCONFORMITY (?)

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D 75° U — — —?—?—?

Trace of fault, showing dip

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D / U

Trace of fault inferred from seismic reflection profiles (See Figures 2-4, 2-5, 2-7, and 2-8).

D / U

Trace of fault inferred by elevation changes of marker beds obtained from geologic cross sections derived from water well logs. (See Chapter 3 and Figure 3-1.)

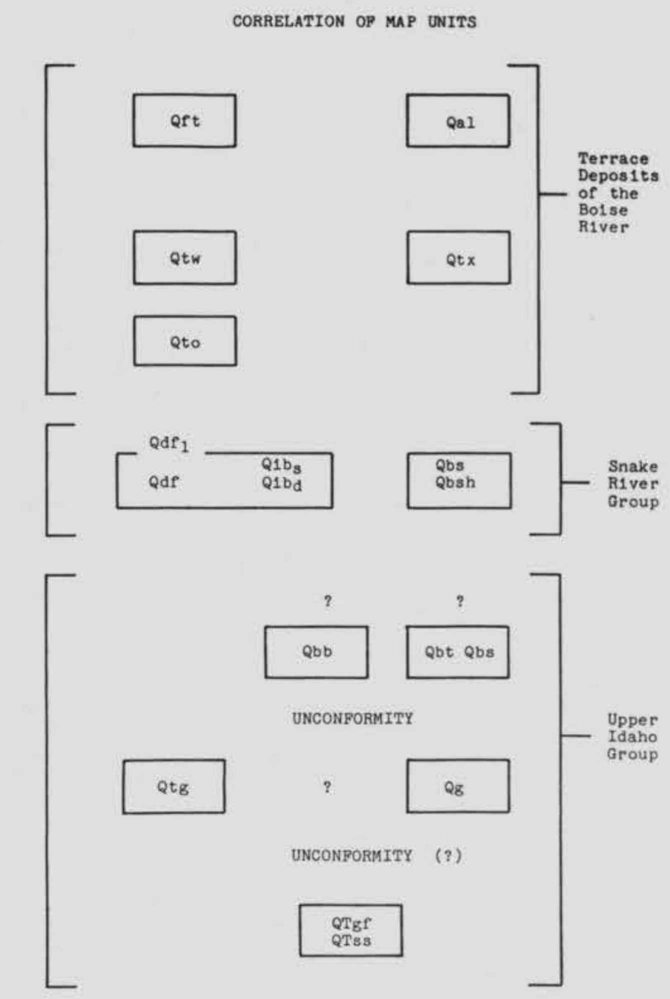
6° Inclined — Horizontal

Strike and dip of beds.

—?— — — — — —?—

Inferred anticline axès, existance uncertain.

Figure 4-3. ISOTOPE SAMPLE LOCATIONS FROM WELLS AND SURFACE WATER IN THE NAMPA-CALDWELL AREA, CANYON COUNTY, IDAHO



EXPLANATION

Qft

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RECENT FLUVIAL DEPOSITS: Deposits on the flood plain of the Boise River and Indian Creek. Locally includes low terraces within 5 m (15 ft) of the present streams.

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Qdf_1 / Qdf

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Qbt Qbs Qbb

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UNCONFORMITY

Qtg

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UNCONFORMITY (?)

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Trace of fault inferred by elevation changes of marker beds obtained from geologic cross sections derived from water well logs. (See Chapter 3 and Figure 3-1.)

6° Inclined — Horizontal

Strike and dip of beds.

Inferred anticline axès, existance uncertain.

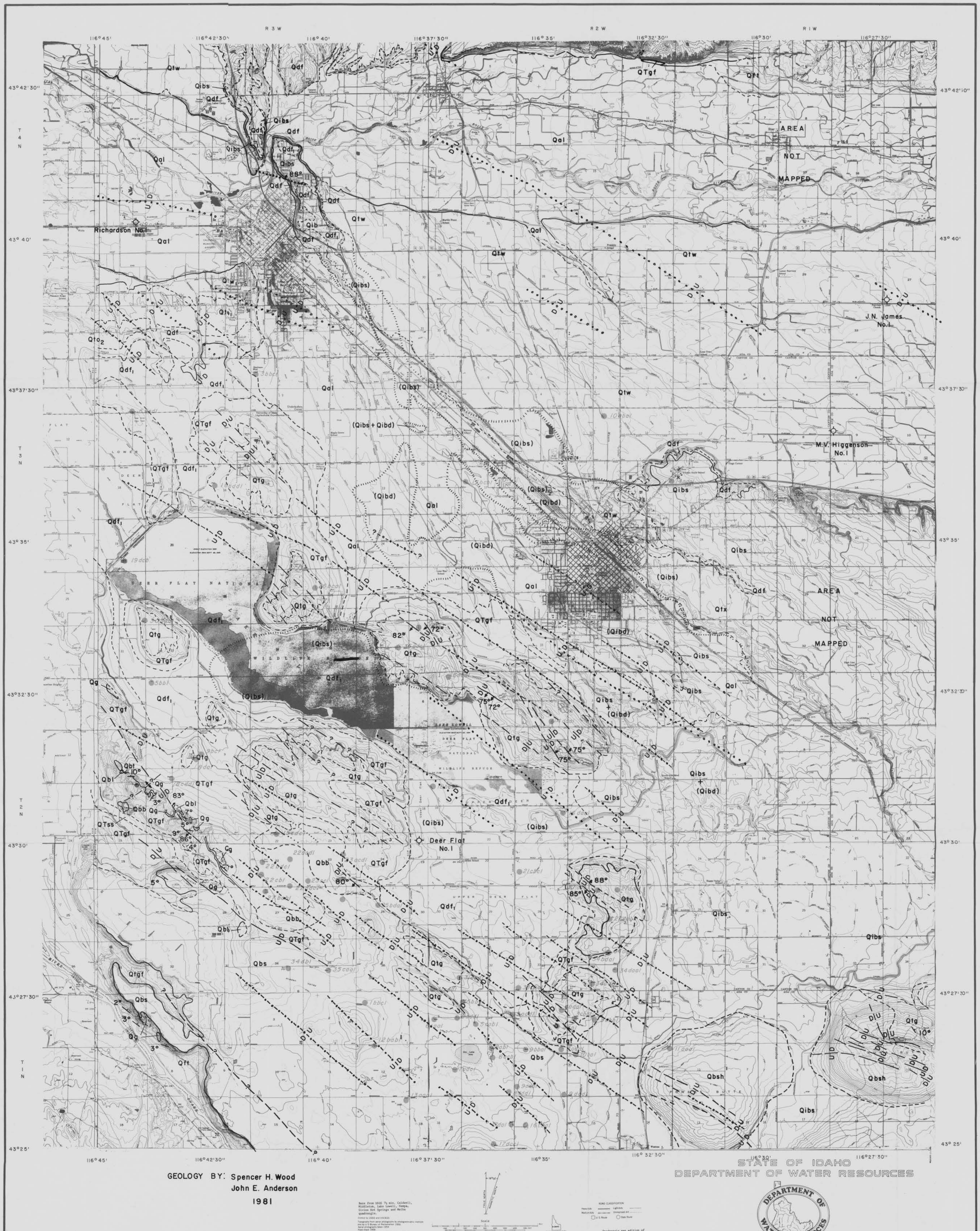
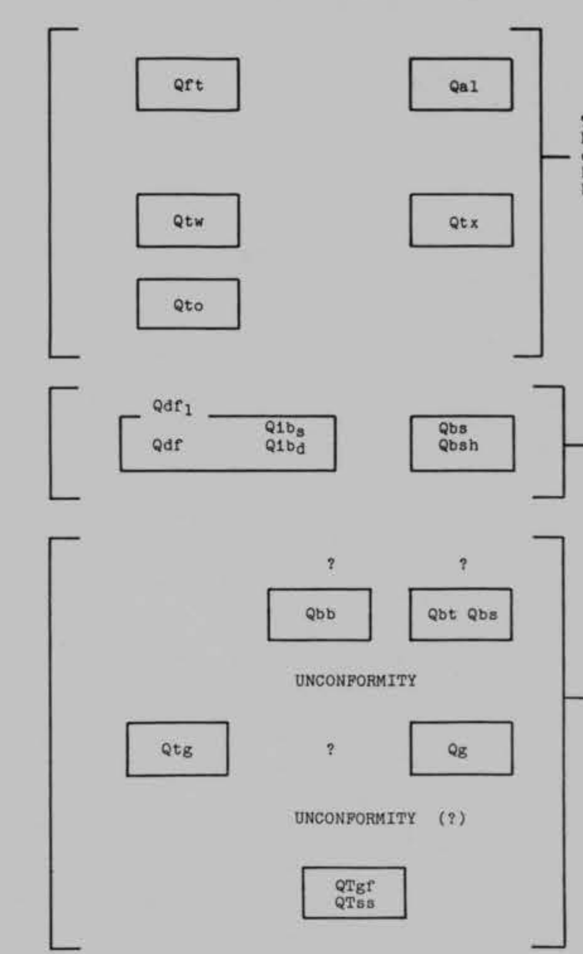


Figure 4-8. WATER QUALITY SAMPLE LOCATIONS FROM WELLS IN THE NAMPA-CALDWELL AREA, CANYON COUNTY, IDAHO



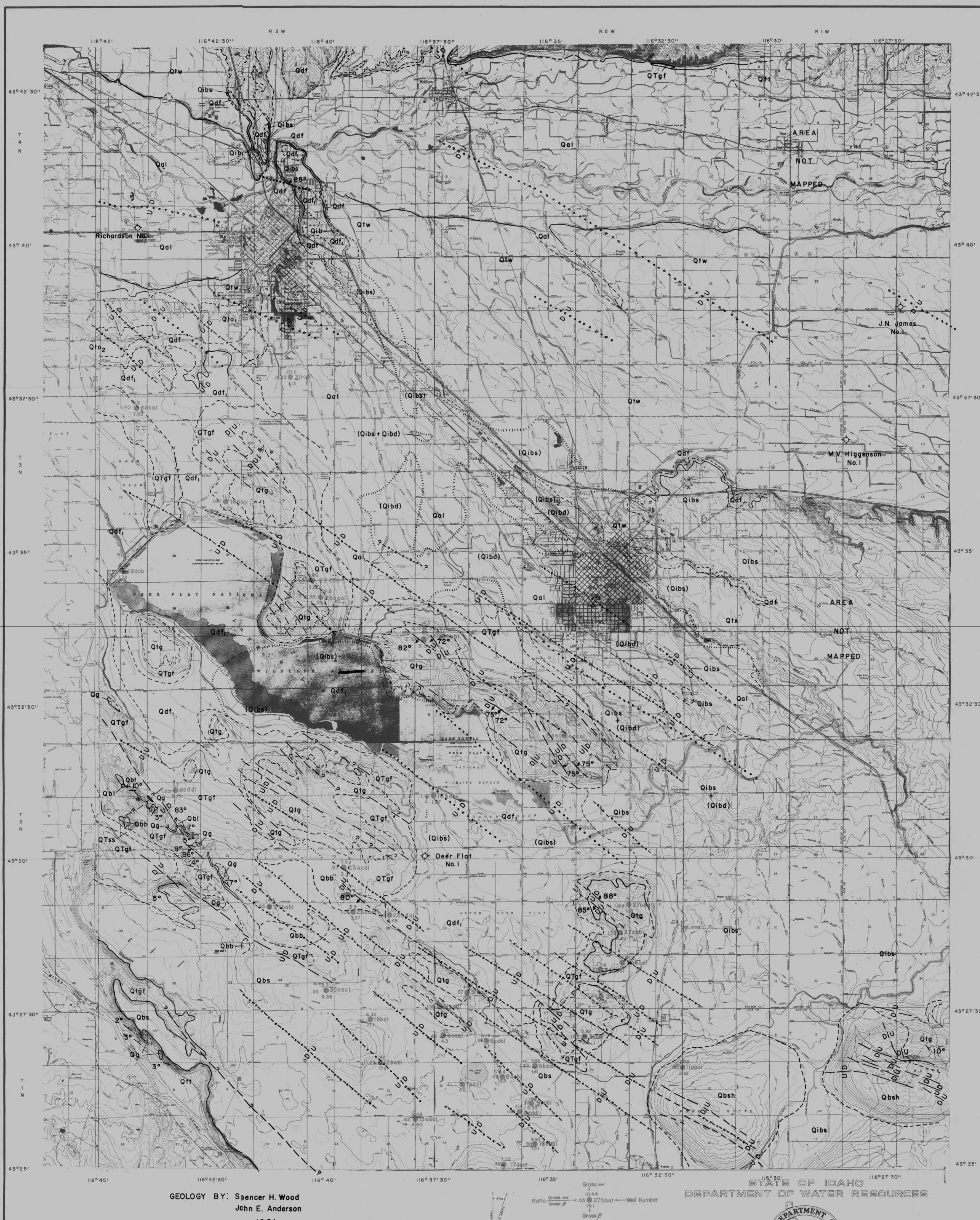


Figure 4-10. RADIOLOGICAL SAMPLE LOCATIONS FROM WELLS IN THE NAMPA CALDWELL AREA, CANYON COUNTY, IDAHO

EXPLANATION

Qft

ALLUVAIL FAN AND TALUS DEPOSITS: Deposits of small alluvial fans that merge with flood plains or terraces of the Boise River and Snake River. 0 to 20 m (0 to 65 ft) thick.

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UNCONFORMITY

Qtg

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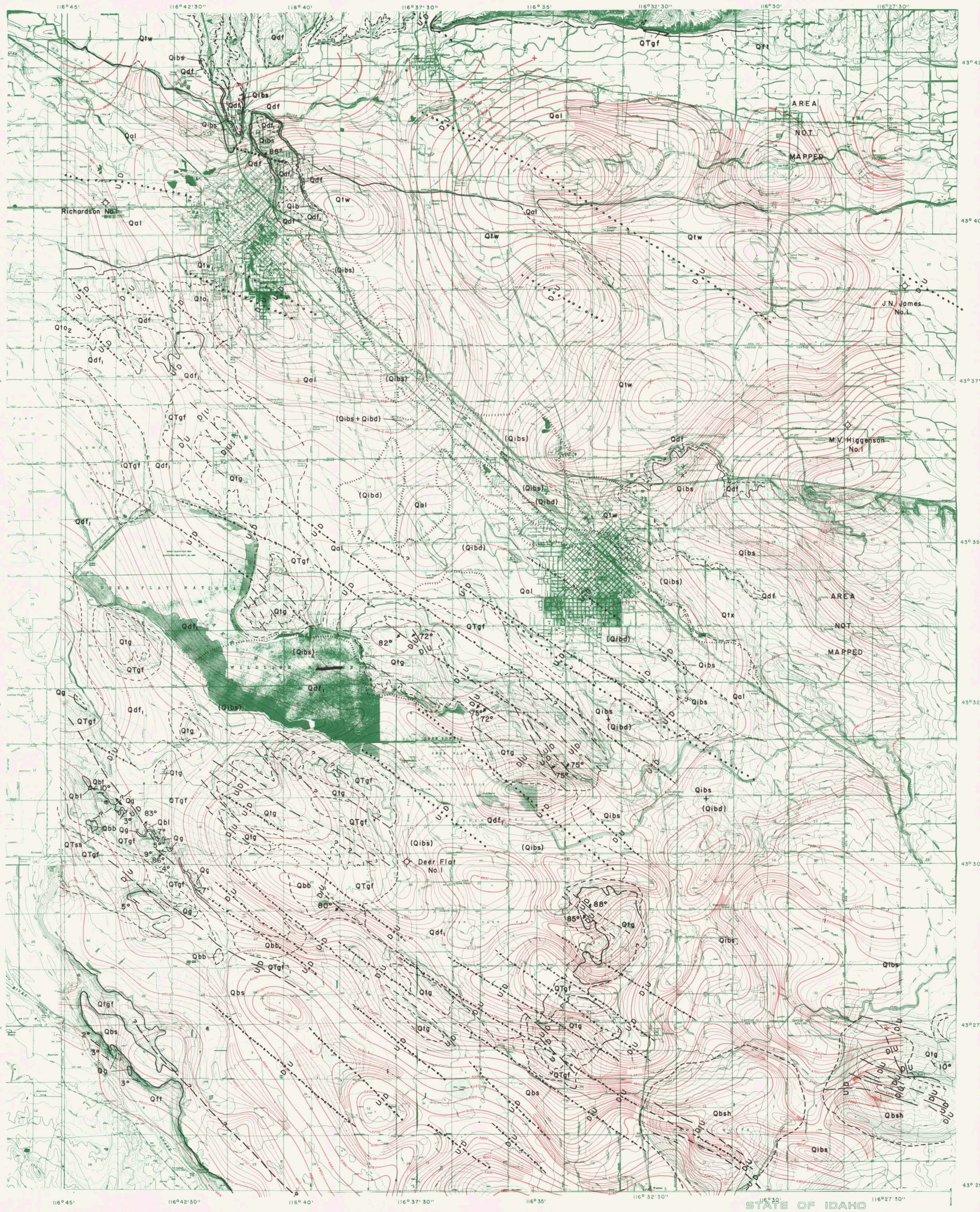
6° Inclined — Horizontal

Strike and dip of beds.

Inferred anticline axès, existance uncertain.



GEOLOGY BY: Spencer H. Wood
John E. Anderson
1981

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

CONTOUR MAP FOR
AEROMAGNETIC SURVEY
SOUTHWEST IDAHO – PROJECT
CANYON & ADA COUNTIES, IDAHO

Figure 6-4: AEROMAGNETIC MAP OF THE NAMPA-CALDWELL AREA, CANYON COUNTY, IDAHO.

CORRELATION OF MAP UNITS

Terrace Deposits of the Boise River: Qft, Qal, Qtw, Qtx, Qto

Snake River Group: Qdf_1, Qdf, Qib_s, Qib_d; Qbs, Qbsh

Upper Idaho Group: ? Qbb; ? Qbt Qbs

UNCONFORMITY

Qtg ? Qg

UNCONFORMITY (?)

QTgf, QTss

EXPLANATION

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6° Inclined — Horizontal

Strike and dip of beds.

—?— — — — — —?—

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