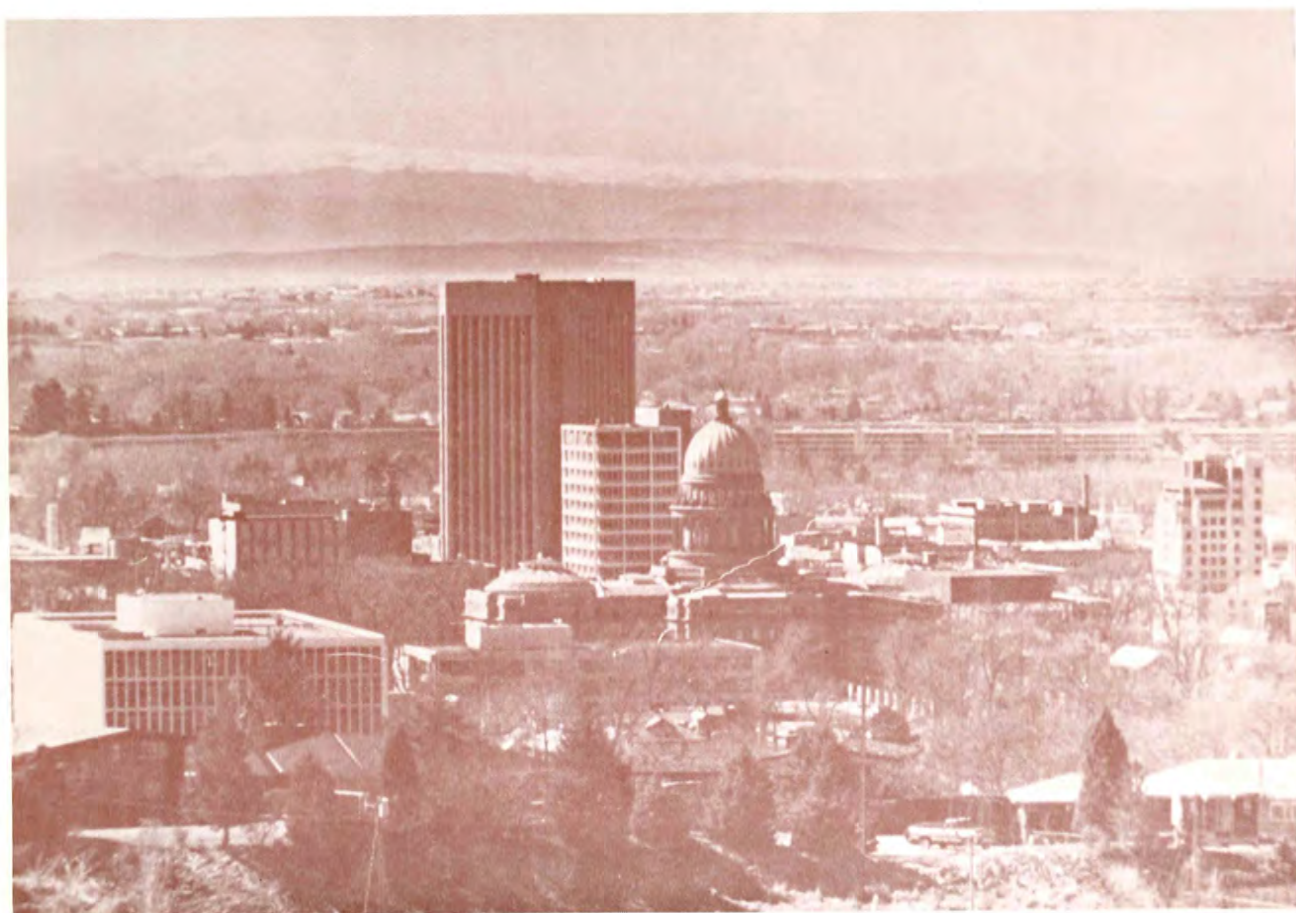
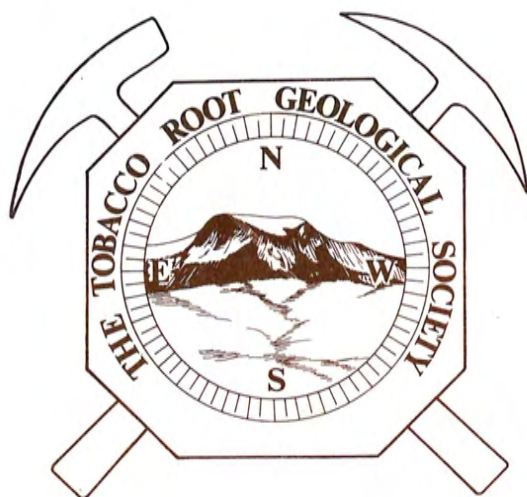




Guidebook of the 9th Annual Field Conference
August 1 - 4, 1984 Boise, Idaho



The Tobacco Root Geological Society, Inc. (TRGS) was organized in 1974 as a non-profit, scientific corporation to promote the study of the geology of the Northern Rocky Mountain Province. The organization sponsors annual conferences in the Northern Rocky Mountain Province and adjacent areas.

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Cover photography by Spencer H. Wood: Looking southwest from the Boise foothills, across the City of Boise and the State Capitol Building, and toward the snowcapped Owyhee Mountains in the background. Kuna Butte, a large basalt shield volcano of the Snake River Group is just above the tallest building in the picture. The Owyhee Mountains are mainly Late Miocene ash flow tuff sheets. Cover preparation courtesy of Wilkerson Photography, Dillon, Montana.

TOBACCO ROOT GEOLOGICAL SOCIETY

9th Annual Field Conference, 1984

GEOLOGY, TECTONICS, AND MINERAL RESOURCES
OF WESTERN AND SOUTHERN IDAHO

Boise, Idaho
August 1-5, 1984

Conference Headquarters
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Boise, Idaho 83704
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Patricia C. Beaver, Editor

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SCHEDULE OF EVENTS

Wednesday, August 1, 1984

Morning

9:00-12:00 Registration (Pre-registrants pick up registration materials).
Meeting of Officers and Executive Committee.

Afternoon

12:00-1:30 Lunch, on your own.

1:30-1:45 Welcome by Kathy Wilkerson, 1984 TRGS President. First day of
Technical Session.

1:45-2:30 Oil and gas potential and tectonics of the Idaho Thrust Belt north
of the Snake River Plain, by Jack Warne.

2:30-3:00 Coffee break.

3:00-3:45 Quaternary geology, geomorphology, and archaeology, eastern Snake
River Plain and adjacent mountains, by Wakefield Dort.

3:45-4:00 Informal discussions.

4:00-5:00 TRGS Annual Business Meeting (all members and interested non-
members are encouraged to attend).

5:00-7:00 Poster Session and Late Registration. No-Host Cocktails (with free
appetizers).

Thursday, August 2, 1984

Morning

8:00-8:45 Late registration.

8:50-9:00 Opening remarks for second day of Technical Session, by Dean
Kleinkopf.

9:00-9:45 The general geology of the Idaho Batholith, by Earl Bennett.

9:45-10:15 Rock units and deformation on the western margin of the Idaho
Batholith near McCall, Idaho, by Mel Kuntz.

10:15-10:45 Coffee break.

10:45-11:30 Geology of the Boise Geothermal area, by Spencer Wood.

11:30-12:00 Volcanic and tectonic evolution of the Bruneau - Jarbidge Eruptive
Center, southwestern Idaho, by Bill Bonnicksen.

Afternoon

- 12:00-1:30 Luncheon (included in registration fee).
- 1:30 Technical Session continues.
- 1:30-2:00 Early Triassic marine transgressions over southwest Montana - A lesson in planar hydrodynamics, by Rachel Paull.
- 2:00-2:30 Miocene pollen floras in northern Idaho, by Robert Jorstad.
- 2:30-3:00 Mississippian Copper Basin rocks in south-central Idaho: 25 years under the hammer, by Richard Paull.
- 3:00-3:30 Coffee break.
- 3:30-4:00 Eyewitness account of normal surface faulting, by Jack Pelton.
- 4:00-4:30 Structural control of groundwater eruptions and sediment boil formation in the Chilly Buttes area, Mt. Borah, Idaho earthquake, by Charles Waag.
- 4:30-4:45 Informal discussions, and announcements concerning field trips.

Evening

- 6:00-7:00 No-host cocktails.
- 7:00-8:30 Annual Banquet (no speaker).

Friday, August 3, 1984

Morning

- 7:30-8:00 Field trip participants assemble in the parking lot of the Red Lion Motor Inn - Riverside. For this field trip and subsequent field trips: privately owned vehicles will be used; four-wheel drive vehicles are not required; field trip includes a sack lunch and soft drinks; those in a position to do so are requested to use vehicles equipped with a Citizen's Band radio (Channel 18), or an Amateur 2-meter radio.
- 8:00 Field trip No. 2 departs. Geologic Reconnaissance of the Boise Basin, to be led by Liz Matthews.

Afternoon

- 5:00 Field trip returns.

Saturday, August 4, 1984

Morning

7:30-8:00 Field trip participants assemble in the parking lot of the Red Lion Motor Inn - Riverside. See instructions for previous field trip.

8:00 Field trips depart.

Field trip No. 1 - Transition Zone near Idaho Batholith, to be led by Mel Kuntz.

Field trips No. 3 and 5 combined (one fee). Boise Geothermal Area, to be led by Spencer Wood; and Rhyolites and welded tuffs of the Idavada Group to be led by Spencer Wood.

Field trip No. 4 - Oquirrh Group in southern Idaho, to be led by Tom Yancey. This trip will continue into Sunday, August 5, and will not return to Boise.

Afternoon

5:00 Field trips return, except Field trip No. 4.

Sunday, August 5, 1984

Morning

Time to be announced at registration "An Enological Adventure"-a winetasting tour of nearby Idaho wineries, to be led by Dean Kleinkopf.

OIL AND GAS POTENTIAL AND TECTONICS OF THE IDAHO THRUST BELT NORTH OF THE SNAKE RIVER PLAIN

by John R. Warne, Consulting Geologist
Billings, MT 59101

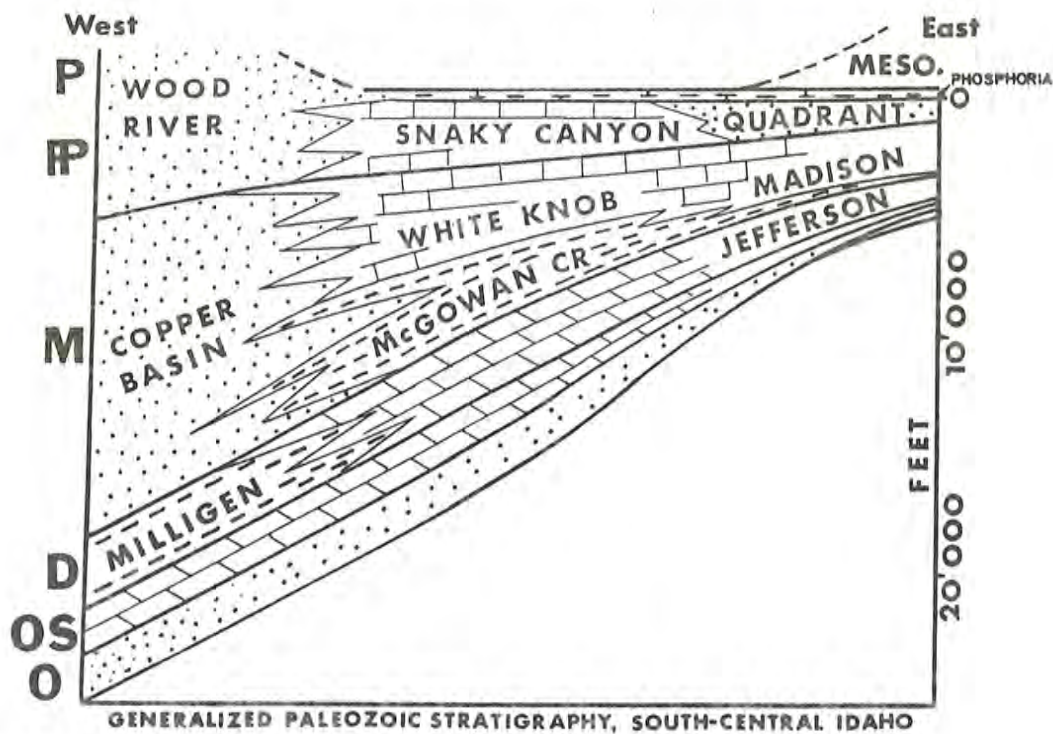
ABSTRACT

The Thrust Belt north of the Snake River Plain in south-central Idaho has the elements necessary for major oil and gas accumulations: large traps, thick reservoir rocks, top seals, rich oil-source rocks, and in at least parts of the area, a favorable temperature history. Only drilling is lacking.

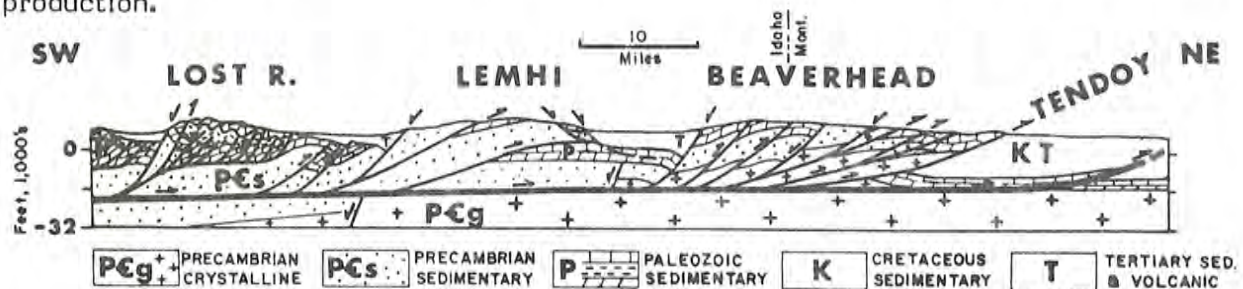
Two different oil and gas plays are in progress in the area. Some companies are looking for traps in Paleozoic rocks similar to thrust anticlines of the Utah-Wyoming Thrust Belt fairway. Others are exploring the valleys looking for stratigraphically trapped oil generated from deeply buried Tertiary sediments. No holes have been drilled to test thrust anticlines in Paleozoic strata in south-central Idaho. Only two holes have been drilled to test the Tertiary oil possibilities.

The Utah-Wyoming Sevier thrusting extended north of the Snake River Plain into southwestern Montana and south-central Idaho. After thrusting, large listric normal faults formed northwesterly trending valleys which were filled with Tertiary sediments. Styles of thrusting and resulting traps are similar to the Utah-Wyoming portion of the Thrust Belt. Paleozoic and Mesozoic strata are thrust over organic-rich Cretaceous and Permian (Phosphoria) source rocks in the eastern part of the area. Porous Paleozoic carbonates are thrust over thick organic-rich Mississippian shales in the western part of the area.

Paleozoic strata thicken westward from a normal cratonic sequence, consisting of about 1,524 m (5,000 ft) of chiefly carbonate rocks in the east, to more than 9,144 m (30,000 ft) of sandstones, conglomerates, shales and carbonates in the west. Of particular importance was the accumulation of about 914 m (3,000 ft) of organic-rich Mississippian McGowan Creek Shale in a starved basin between the Antler Uplift on the west and the craton on the east. The McGowan Creek Shale is equivalent to the Bakken Shale and lower Madison Limestone of the craton. Outcrop samples of this shale contain from .8 to 6.3 percent total organic carbon. The shale's organic richness, coupled with its great thickness, indicates that many billion barrels of oil or many trillion cubic feet of gas could have been generated, provided temperature history was favorable.



Paleotemperatures in much of the area were too hot for preservation of oil, but not too hot for preservation of gas, according to alteration of Conodonts collected by the U. S. Geological Survey. At least two important exceptions to the generally high paleotemperatures exist. The Tendoy Thrust Plate in the eastern part of the area has a Conodont alteration index of 1, which is immature. The White Knob Thrust Plate in the Pioneer Mountains west of Arco, in the southwestern part of the area, has a Conodont alteration index of 2, which is in the oil-generating range. The cooler temperature history of the White Knob Plate is confirmed by vitrinite reflectance of .45 to .64 from surface samples of the McGowan Creek Shale. The shale was just beginning to generate oil before it was brought to the surface by Sevier thrusting and subsequent erosion. Where these beds extend into the subsurface to appropriate depths, they should be generating oil and gas at the present time. Additional sampling and drilling may indicate the existence of other cooler areas. The McGowan Creek shale acts as a seal on 1,524 m (5,000 ft) of lower Paleozoic dolomite. At least 457 m (1,500 ft) of this dolomite section may have enough porosity to be an effective reservoir for oil or gas pay. South-central Idaho has the potential for giant oil and gas accumulations; however, further exploration, including drilling, will be required to convert this potential to major production.



QUATERNARY GEOLOGY, GEOMORPHOLOGY, AND ARCHAEOLOGY, EASTERN SNAKE RIVER PLAIN AND ADJACENT MOUNTAINS

by Wakefield Dort, Jr.
Department of Geology
The University of Kansas
Lawrence, Kansas 66045

Southeastern Idaho presents highly varied geomorphic areas that are closely related to complex patterns of geologic stratigraphy, structure, and history. The great Snake River Plain, locus of recurrent volcanism throughout Quaternary time, forms a prominent lowland curving across the entire width of the state. North of the eastern part of the Plain lie parallel, fundamentally fault-block mountain ranges -- from west to east the Lost River Range, Lemhi Range, and Beaverhead Mountains portion of the continental divide Bitterroot Range. Separating these north-northwesterly trending ranges are graben-like through-valleys. The northern half of the structural trough between the Lemhi and Beaverhead ranges is drained by the northwesterly-flowing Lemhi River; the southern half is drained by southeasterly-flowing Birch Creek. The intervening divide lies along an area of low hills that are collectively called Middle Ridge; Idaho Highway 28 crosses here by way of Gilmore Summit. Birch Creek Valley Trough is conveniently divisible into four parts: (1) the headwaters divide area of Middle Ridge and Gilmore Summit; (2) a broad "upper basin;" (3) a narrower area of "transverse fault blocks;" and (4) the "lower valley."

Both the Lemhi and Beaverhead Ranges are underlain by complexly folded and faulted Paleozoic strata, dominantly marine carbonates. Middle Ridge is underlain by Middle(?) to Late(?) Tertiary freshwater carbonates ("lakebeds"), tuff, and tuffaceous sedimentary rocks. All of these rock types have localized exposures in the eastern foothills of the Lemhi Range. Basalt and some rhyolite of presumed Tertiary rather than Pleistocene age, possibly equivalent to the Challis Volcanics, crop out in small areas along the foothills on both sides of Birch Creek Valley. They are well exposed in the area of "transverse fault blocks," near the middle of the valley, and cap small buttes at the southern end. Cemented fan gravel (fanglomerate) is exposed on surfaces of high, old alluvial fans, in terraced valleys dissecting younger fans, and in association with the "transverse fault blocks." Deformation by folding and faulting decreases with decreasing age of the rocks affected, but even "young" alluvial fan surfaces show minor fault-scarp development in certain areas. The topographic distribution of erratic rock types, augmented by subsurface drilling logs, clearly indicates that major fault movement of at least the western side of Middle Ridge occurred after a major, pre-Bull Lake glacial advance, perhaps during middle Pleistocene time.

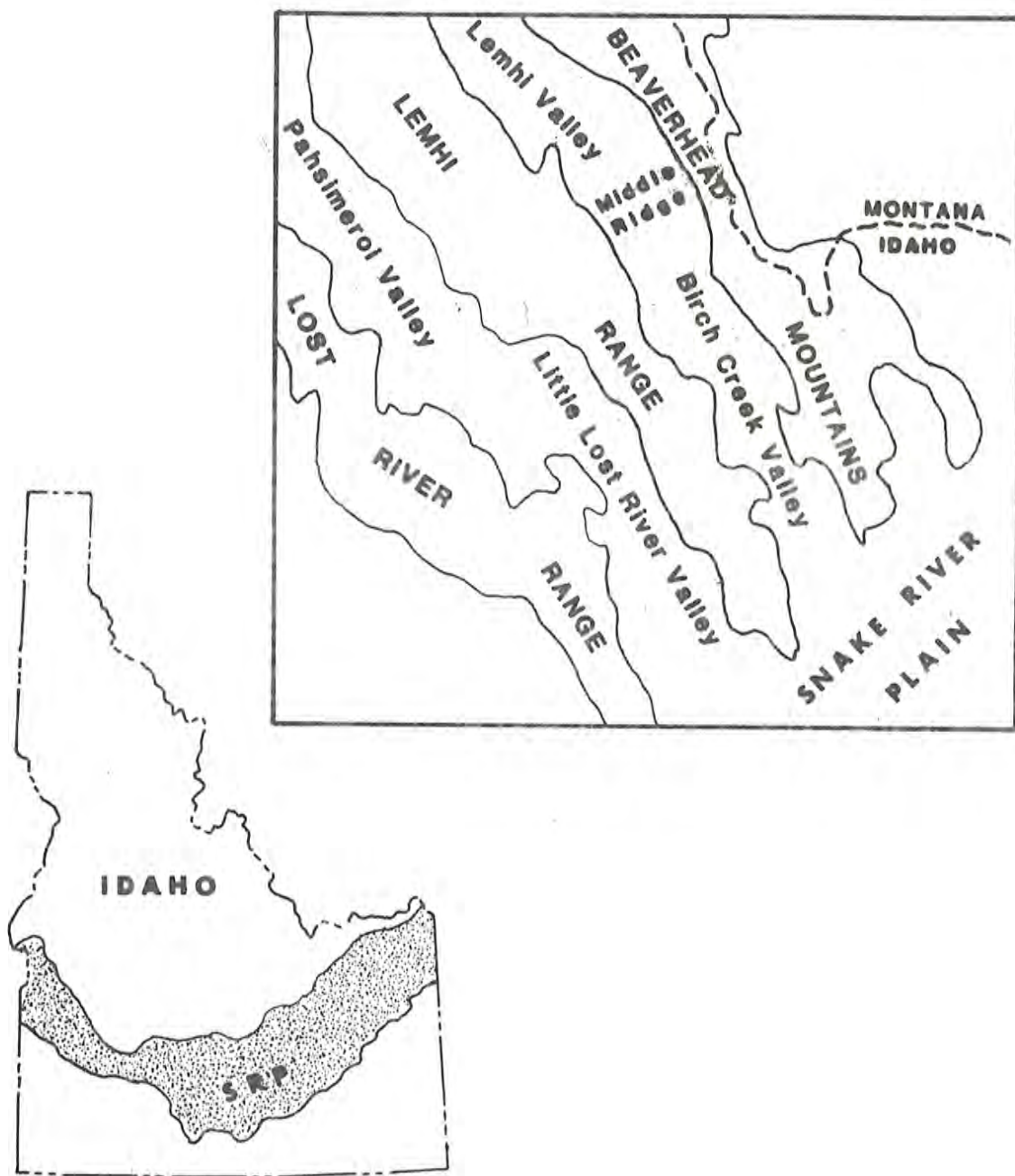


Figure 1. Index map of east-central Idaho.

Large, coalescent alluvial fans developed along both sides of the Birch Creek Trough, adjacent to the Lemhi and Beaverhead "fronts." Indeed, these constitute the most widespread landforms of the area, dominating the valley-floor scene in both the "upper basin" and "lower valley," though achieving somewhat lesser prominence in the area of "transverse fault blocks." In the upper and lower extremities of Birch Creek Valley the fans are only slightly dissected. Small remnants of higher levels are present a few feet above the most extensive surfaces and are generally limited to apex areas.

Approaching the area of "transverse fault blocks" from either end of Birch Creek Valley, general elevations of fan apexes rise, dissection increases in depth and number of channels, and the number of levels or terraces inset into the fans increases. It appears that there has been a general upbowing, greater on the western side, of the area of "transverse fault blocks," not only since the time of formation of the highest (oldest) fan surfaces, but continuing through most of Pleistocene time and perhaps into the Recent. It has been suggested by others that this warping is a buckling related to the downward movement of the Snake River Plain farther south, an explanation also offered for the origin of the Middle Ridge Divide between the Birch Creek and Lemhi River drainages, as well as for a similar divide in the through-valley west of the Lemhi Range.

Exposures on most of the higher fan remnants and in the deeper parts of lower dissected fans reveal well-cemented fanglomerate. Clasts, ranging up to medium-sized boulders, are generally rounded to subrounded. Although the fanglomerate is generally poorly sorted, the presence of a few well-sorted units, graded bedding, cut-and-fill structures, and clearly defined facies indicate deposition by flowing water, probably high-energy braided streams. Disordered mudflow or debris flow texture is notably absent. Funk (1976), who studied the Birch Creek fans in detail, concluded that they are basically composed of glacial and periglacial debris flushed out of mountain canyons by late pluvial-period streams augmented by meltwater. Fan building would therefore have been a late-glacial event. He further suggested that fan dissection was primarily an early- to full-glacial happening. The fan surfaces may have been essentially static during drier, interglacial intervals. If these interpretations are correct, the visible fan gravels, whether cemented or loose, are all of the Quaternary age.

For a number of years there have been in progress investigations by Fosberg, Hironaka, Hauxwell, Sorenson, Butler and others of the soils of Birch Creek Valley. Excavation of numerous backhoe pits has provided a general picture of soil development and variation throughout the valley. Pits at a few fortuitous locations exposed buried paleosols, mainly in the foothills zone along the base of the Lemhi Range. One locality

in the area of "transverse fault blocks" contained three paleosols in a single stratigraphic column; two paleosols are present at several places farther north. Whereas the modern soil and upper paleosols tend to be dominantly tan, the deepest paleosol is an outstanding red, indicative of climatic conditions quite different from those of today. Ages of these paleosols are at present unknown.

The northeasterly-facing side of the Lemhi Range, and equivalent slopes of ranges farther west, was subjected to several episodes of rather intense alpine glaciation during the Pleistocene Epoch. In early investigations, Dort (1962), using mainly morphologic criteria, identified deposits, plus moraines and other land forms, of "Buffalo" (or pre-Bull Lake), Bull Lake, Pinedale, and Neoglacial ages. Knoll (1977) studied the glacial and periglacial records of four canyons in the south-central Lemhi Range that had contrasting orientations, dimensions, and cirque development. On the basis of highly conservative criteria such as distinct cross-cutting or over-riding relationships of deposits or landforms, he was able to recognize multiple sub-units or pulses of the Bull Lake (3) and Pinedale (9) glaciations, as well as of the Neoglaciation (5). Additional pulses were suggested by the presence of concentric moraines that are, however, not in direct contact, and could therefore represent merely retreatal stillstands. More recently, Butler (1982) and Butler et al. (1982) devoted close attention to the glacial/periglacial record contained in sediments, soils, and land forms of two valleys adjacent to one previously studied by Knoll. A similar multi-pulse sequence was indicated. Most noteworthy was the demonstration, on the basis of stratigraphic, palynologic, and pedologic evidence, that a single prominent terminal moraine was actually composed of tills of at least three separate advances.

In a pattern that is notably similar to that found in many parts of the northern and central Rockies, true glacial deposits of Neoglacial age are restricted to a few cirques having shapes and orientations especially favorable for accumulation of snow; periglacial mass-wasting forms (rock glaciers, debris flows, talus aprons and cones) have much more extensive distribution. Pinedale terminal moraines rest on the floors of existing valleys and are located either at valley mouths, where streams debouch onto piedmont alluvial fans, or part way upvalley toward the source cirques. Bull Lake terminal moraines are generally close to or somewhat downvalley from the Pinedale termini, but shapes of these older land forms are considerably more subdued and have been dissected by postglacial erosion. Deposits attributed directly to pre-Bull Lake glaciers consist of scattered, thin veneers of erratic-bearing "gravel" or sometimes a few large, isolated erratic boulders. None of these deposits lie on valley floors; most are on crests of piedmont ridges or on pediment or alluvial-fan surfaces near the mountain front.

In addition to demonstrations of past climatic fluctuations provided by glacial and periglacial forms and deposits, and by paleosols, the mountain valleys afford clear evidence of a rather recent shift toward aridity. Perennial streams flow the full lengths of just two of the dozens of canyons incised into the flanks of the Lemhi and Beaverhead Ranges. Other valleys carry surface water through only short upper or middle reaches and do so only in the springtime or early summer. Birch Creek itself is fed by perennial springs that rise just above the "transverse fault blocks," the water apparently being forced to the surface by the northerly or upvalley face of the first tilted block. Inasmuch as these mountain canyons must have been carved by vigorous streams, a marked decrease in rainfall is indicated in relatively recent time. Accumulation of mass-wastage debris is now beginning to choke the narrowest parts of some canyon floors.

To the casual observer, the nearly level surface of the eastern Snake River Plain might suggest a history much less complex than that of the mountains to the north. This is largely illusory. It is true that fewer different processes were active on the Plain during Pleistocene time, but some of these recurred again and again. The bedrock surface is a composite product of almost innumerable volcanic eruptions, mainly of lava but including some pyroclastic debris. Most of these additions came from local vents; therefore the regional surface is a melange of many cones having very gentle slopes. All but some of the highest and youngest prominences have been blanketed by varying thicknesses of loess, thus subduing the primary topography. Finally, master drainageways from the mountains to the north, such as Birch Creek, built very extensive alluvial fans on the volcanic surface. Locally, shallow ephemeral lakes were impounded against the lava. Sand from these playas has been caught up by prevailing winds and blown toward the northeast, forming unusually long, though very low, linear dunes. Although these forms have been stabilized by vegetation near their sources, live dunes continue to migrate downwind near the northeastern edge of the Plain.

The general area of the eastern Snake River Plain and the mountainous region to the north has been the locus of extensive archaeological surveys and numerous "digs" (Swanson, 1972; and Dort and Miller, 1977). The carbonate bedrock of the Lemhi and Beaverhead Mountains is well exposed in canyon walls and on many of the steeper mountain-front slopes, and is riddled by rock shelters having a wide range of sizes. Few, if any, of these reentrants are of solutional origin; they are not the conventional forms developed in a humid climate. Rather, it appears that these are largely, if not entirely, the product of frost riving of especially susceptible bedrock zones and gravitational removal of the resulting detritus. On the volcanic plain there are small, hollow domes or blisters and lava tubes that can be entered through a place where the

top has collapsed. All of these forms that provided an overhanging roof were potential places of temporary refuge or longer occupation by aboriginal man.

Several rock shelters and caves in the foothills of both the Lemhi Range and Beaverhead Mountains have been excavated by archaeological crews, operating under the general direction of the late Earl Swanson of Idaho State University. Each was different in detail, but taken together they present a coherent record of the presence and basic life style of early man and later, Indians in the area. The prehistoric inhabitants followed a lifeway of directed nomadism determined by the seasonal availability of plant and animal resources in a variety of ecological zones. The Plain and adjacent mountain valleys supported bison from Pleistocene into early historic time; even mammoths and camels roamed the lowlands. Elk, deer, antelope, and mountain sheep were utilized, as were smaller resident mammals and birds. Streams provided fish, mollusks, and other fauna. Archaeological evidence also points to use of nuts, seeds, berries, tubers, and roots, wherever they could be found. Thus, the archaeological record, although incomplete for any given time, reflects a basic pattern of hunting and gathering, with a persistent emphasis on the taking of big game.

It appears certain that humans did not originate in North America, but entered from the Old World. Although several routes of migration are possible, the one most frequently cited is through Beringia, the isthmus that connected Siberia with Alaska during maximum glacial lowering of sea level. The time of this migration is much more controversial. Only a few decades ago, it was unthinkable to American archaeologists that man could have been in the New World for longer than perhaps 5,000 years. Today most archaeologists readily accept a residency of at least 12,000 years. Furthermore, some archaeologists and some geologists firmly believe that man has been in North America much longer.

Radiocarbon dating of charcoal and other organic material recovered from the deepest levels of rock shelters overlooking Birch Creek Valley indicates that occupation by early man began about 11,000 years ago. Fluted Folsom points have been found in association with bones of mammoth and bison near the bottom of a thick sedimentary fill in a lava tube on the Snake River Plain. Radiocarbon dating here suggests an age of almost 13,000 years before present.

It is noteworthy that dates of this antiquity would mean that early man was present during at least the waning phases of the Pinedale Glaciation. Alpine glaciers would have been present in the upper parts of most valleys along the shaded, northeastern slopes of the Lemhi Range and other mountains. Local ice caps probably covered crestral areas of sufficient flatness and extent, and between the glaciers, snow must

have been deep through much of the year. The mountains constituted very effective barriers. On the other hand, the Snake River Plain, which is now a sagebrush steppe, forbidding to many species of plants and animals, was at that time much grassier and treeline was lower.

Pinedale glacial climate gradually improved, from the human viewpoint, and became more like that of the present. Local archaeological evidence places this change in the span from 12,500 to about 7,000 years ago. This climatic trend continued, however, and the purportedly warm, dry Altithermal Period lasted to approximately 3,500 years ago, its maximum having occurred between 7,000 and 5,000 years before present. A major reversal of trend then led to the cooling of the Neoglaciation from which we are (maybe) just recovering. It should be emphasized, however, that there were many minor fluctuations superimposed on this major cycle. These are especially well indicated by the numerous stillstand and readvance moraines in some valleys of the Lemhi Range, in repeated reversals of sedimentary processes in some rock shelters, and in variations in the remains of animal and plant populations.

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THE GENERAL GEOLOGY OF THE IDAHO BATHOLITH

by Earl H. Bennett
Idaho Geological Survey
University of Idaho, Moscow, ID 83843

ABSTRACT

The Idaho Batholith in central Idaho has been divided into two lobes: the Bitterroot Lobe to the north and the Atlanta Lobe to the south. Recently completed studies by the U. S. Geological Survey, including the Selway-Bitterroot Wilderness study and the Challis CUSMAP program, indicate several differences between the two lobes.

The Atlanta Lobe is divisible into two major groups of plutonic rocks: one of Mesozoic age and one of Tertiary age. The Mesozoic group is also divisible into two major types: an older group of tonalite-to-granodiorite plutons along the western and eastern borders of the lobe, and a younger group of biotite granodiorite grading to 2-mica granite intrusives that form the massive core of the lobe. The older group may also form a northwest-trending belt of intrusions across the Challis 2⁰ map. The older tonalites have characteristics of I-type granitoids, and the younger granodiorite-to-2-mica core rocks appear to be S-type granitoids.

The biotite granodiorite, 2-mica granite plutonic core is intruded into the older tonalite plutons. The older rocks have ages clustering at 85 to 95 m.y., and the younger core rocks are clustered at 72 m.y.

Molybdenum mineralization at Thompson Creek (Pat Hughes Stock) and at Little Boulder Creek (White Cloud Stock) may be related to late-stage differentiates of the older tonalite-granodiorite suite. No ore deposits of Mesozoic age have been associated with the younger core rocks.

The older tonalite-to-granodiorite plutons have been mapped along the western border and in the northeast part of the Bitterroot Lobe. The core of the lobe is, for the most part, massive granodiorite that exhibits only slight changes in petrology and chemistry throughout. The Bitterroot Lobe has been described as a "core complex" and is about 55 m.y. old based on K/Ar dating.

The Tertiary plutonic system has intruded both lobes of the batholith and consists of a distinctive bimodal suite of granite and quartz monzodiorite plutons that may be comagmatic. The granites are anorogenic (A-type) and probably related to extensional tectonics. The Tertiary intrusives are closely related to units in the Challis Volcanics, and to equivalent hypabyssal dike complexes, such as the Idaho Porphyry Belt. Most, if not all, of the epithermal precious metal deposits in the Atlanta lobe are believed to be Tertiary in age and related in some way to the intrusive-volcanic rocks.

The Trans-Challis Fault Zone (TCFZ) is a major structural province discovered during the Challis CUSMAP project. The zone extends from the southwest to the northeast corners of the Challis 2⁰ map. It is the extension of the Great Falls Lineament that crosses Montana just west of the Boulder Batholith. Major faults south of the TCFZ trend northwest, and structures north of the zone trend northeast. The zone is a major crustal discontinuity that may provide clues to the structural evolution of the Pacific Northwest in the early-to-middle Tertiary.

ROCK UNITS AND DEFORMATION ON THE WESTERN MARGIN OF THE IDAHO BATHOLITH NEAR MCCALL, IDAHO

by Cathryn C. Allen
Division of Geological and Planetary Sciences
California Institute of Technology, Pasadena, California 91125
and Mel A. Kuntz
U.S. Geological Survey, M.S. 913
Box 25046, Denver Federal Center, Denver, Colorado 80225

ABSTRACT

Geologic mapping in the McCall area shows the following sequence of rocks from east to west (IUGS classification): (1) massive-to-weakly foliated biotite and two-mica granite, (2) hornblende-biotite tonalite and biotite granodiorite, (3) the Goose Creek intrusive and metamorphic unit, and (4) the Granite Mountain intrusive and metamorphic unit (both informal names). The granites (1) are part of the core of the Idaho Batholith. These granites intrude hornblende-biotite tonalite and biotite granodiorite (2) which forms the western border of the batholith. The tonalite-granodiorite has a strong north-south trending, steeply dipping foliation that is primarily an igneous fabric, but which has been modified locally by later deformation. The tonalite-granodiorite contains sheets of metasedimentary rocks.

The Goose Creek unit (3) consists of porphyritic biotite granodiorite interlayered with amphibolite, gneiss, schist, metasedimentary rocks, and less commonly with lenses of mafic and ultramafic rocks. The Goose Creek unit contains a strong north-south trending, steeply dipping, mylonitic foliation with associated isoclinal folds, and downdip lineations. This suggests that the unit was the locus of deformation involving relative vertical movement. The deformation extends into the tonalite-granodiorite (2) and the Granite Mountain unit (4) and obscures any primary features of contacts between these units.

The Granite Mountain unit consists of epidote-bearing tonalite, granodiorite, trondhjemite, and gneiss, and non-epidote bearing schist, tonalite, gneiss, and minor metasedimentary rocks. This unit has a north-south trending, steeply dipping foliation manifested in metamorphic, igneous, and mylonitic fabrics. Lineations are vertical to moderately dipping, and folds are isoclinal to open. Isotopic and petrologic data suggests that this unit may be part of the Permian-to-Jurassic oceanic terrain to the west.

The north-south trending fabrics in all rock units apparently formed over a protracted interval of time. The fabrics may be related to the accretion of the Seven Devils arc or to the generation and emplacement of the Idaho Batholith.

VOLCANIC AND TECTONIC EVOLUTION OF THE BRUNEAU-JARBIDGE ERUPTIVE CENTER, SOUTHWESTERN IDAHO

by Bill Bonnichsen
Idaho Geological Survey
University of Idaho, Moscow, Idaho 83843

ABSTRACT

The Bruneau-Jarbridge eruptive center in southwestern Idaho is a 95-by-55 km (59-by-34 mi) structural basin on line with, and southwest of, the eastern Snake River Plain. The eruptive center lies in eastern Owyhee County, within the region bounded by 115° and 116° west longitude and by 42° and 42°45' north latitude. During the late Miocene, a sequence of nine or more welded ash-flow tuff cooling units, (the Cougar Point Tuff), eight-to-twelve large-to-enormous rhyolite lava flows, and a succession of olivine tholeiite basalt flows from forty or more shield volcanoes erupted from the region occupied by this basin. Much of the subsidence of the interior of the Bruneau-Jarbridge eruptive center is believed to have occurred during or just after the eruption of the voluminous Cougar Point Tuff, perhaps between eleven and ten million years ago. The resulting basin was subsequently filled by rhyolite lava flows, basalt flows, and lacustrine and fluvial sediments. The only remaining topographic vestige of the basin's original physiographic form is the Grasmere escarpment along its western side. The eruptive center probably contains one or more buried calderas.

At several localities along its southern and western sides, the boundary of the eruptive center is denoted by a combination of down-to-the-north or east faults of small displacement, a moat zone filled with sediments and basalt, and lateral transitions from older welded ash flows outside of the basin, to younger rhyolite lava flows within it. The southern and western margins of the eruptive center follow the curved portion of the intense positive aeromagnetic anomaly that approximately coincides with the southern side of the central Snake River Plain. The eastern and northern margins of the eruptive center are buried beneath younger geologic units, primarily basalt flows. The location of this buried portion of the margin has been defined by a combination of additional aeromagnetic anomalies, fault trends, basalt volcano locations, and the position of a large, relatively elevated region underlain by rhyolite, located farther to the northeast.

The Bruneau-Jarbridge eruptive center formed at the site of one of the major nodes of silicic ash-flow tuff volcanism that developed during the evolution of the Snake River Plain-Yellowstone National Park, a southwest-to-northeast, time-transgressive volcanic province. After the eruptive center had developed as a structural

and physiographic basin, and had been partially filled with large, typically 10-cubic-kilometer rhyolite lava flows and intercalated sedimentary materials, its northeastern side was disrupted by rifting and subsidence along northwest-trending faults. At that time, the northeastern part of the basin was inundated by enormous rhyolite lava flows, with volumes in the 50- to 200-cubic-kilometer range. This was the end of the silicic stage of volcanism, and this event overlaps the time during which basaltic volcanism began in the area. Subsequently, but still early within the time interval of basaltic volcanism, the initial physiographic basinal form of the eruptive center had been replaced by a regional northward slope, similar to that in the area today. This is demonstrated by the persistent northward flow direction for most of the outflow sheets from the basalt shield volcanoes along the southern side of the central Snake River Plain.

EARLY TRIASSIC MARINE TRANSGRESSIONS OVER SOUTHWEST MONTANA - A LESSON IN PLANAR HYDRODYNAMICS

by Rachel K. Paull and Richard A. Paull
Department of Geological and Geophysical Sciences
The University of Wisconsin-Milwaukee
P. O. Box 413
Milwaukee, WI 53201

ABSTRACT

Age assignments, based on conodonts from the Lower Triassic Dinwoody Formation, provide a time framework for studying the initial Mesozoic marine transgression into southwestern Montana. Biostratigraphic analysis indicates that the first Early Triassic (Griesbachian) transgression was geologically instantaneous over more than 8000 square miles (12,875 sq. km.) of present-day Montana. The rapidity of this flood, physical and lithologic evidence, and the nearly conformable relations of Permian and Triassic rocks throughout the region suggest the eroded Permian surface was a nearly featureless plain of very low relief. Sedimentologic analysis indicates that basal Dinwoody deposition occurred in shallow marine waters that graded westward from inner-shelf to outer-shelf environments. Conodont biofacies studies support the lithofacies interpretations.

The depositional edge of the Dinwoody to the east is gradational into marginal marine red beds of the Chugwater Group. Information on the configuration of the Dinwoody Basin to the north and west was removed by erosion, but the seaway was open to the south. Relations to the west are enigmatic in that sections thicken in this direction, but strandline conditions are indicated by lithologic and paleoecologic analyses. Apparently, sedimentation and subsidence remained in balance, and shallow marine conditions persisted in westernmost Montana until the final retreat of the Early Triassic seas.

Red beds assigned to the Woodside Formation prograded over the Dinwoody Formation from the north and east during later Griesbachian and Dienerian time. This intermittent marine-to-nonmarine interlude ended with another rapid Early Triassic (Smithian) transgression from the south, which initiated deposition of the Thaynes Formation. Lithologic and paleontologic characteristics of the lowermost part of this unit document a return to shallow, inner-shelf marine environments over much of the study area. The record of Early Triassic deposition in southwestern Montana ended when the sea retreated from the continental margin of North America.

MIocene POLLEN FLORAS IN NORTHERN IDAHO

by Robert B. Jorstad
Department of Geology
Eastern Illinois University, Charleston, Illinois 61920

ABSTRACT

Recent palynological studies warrant recognition of an Early Miocene-aged Coniferae-Mixed Dicotyledoneae-Pteridophyte Palynomorph Assemblage Zone and the Clarkian Stage. Recognition is also warranted for a Middle Miocene-aged Fagaceae-TCT-Platanus Palynomorph Assemblage Zone and an Oviattian Stage in northern Idaho. Use of the term "Latah Flora" should be restricted to fossil assemblages from the Oviattian Stage.

INTRODUCTION

Miocene plant megafossils have been known to occur in northern Idaho for over half a century. Investigation of these plant megafossil assemblages, often termed the "Latah Flora" has been done by Knowlton, 1926; Ashlee, 1932; Berry, 1934; Brown, 1937; and Gillette, 1940. More recently, Smiley and others (1975) and Smiley and Rember (1979, 1981) have published reports of their investigations at the Clarkia Fossil Locality in northern Idaho. The only studies of Miocene pollen in northern Idaho are: (1) a preliminary report by Gray (in Smiley and others, 1975), (2) Jorstad's (1983) palynostratigraphic investigation, and (3) Gray's (in press) study of the Clarkia Fossil Locality. The purpose of this report is to announce these recent palynological discoveries and relate them to the Miocene pollen stratigraphic record in northern Idaho.

METHODS

Samples of clay and silt were taken from sedimentary interbeds with known stratigraphic positions at the locations indicated in Figure 1. Table 1 shows the stratigraphic position of the sample sites in relation to the basalt stratigraphy of the

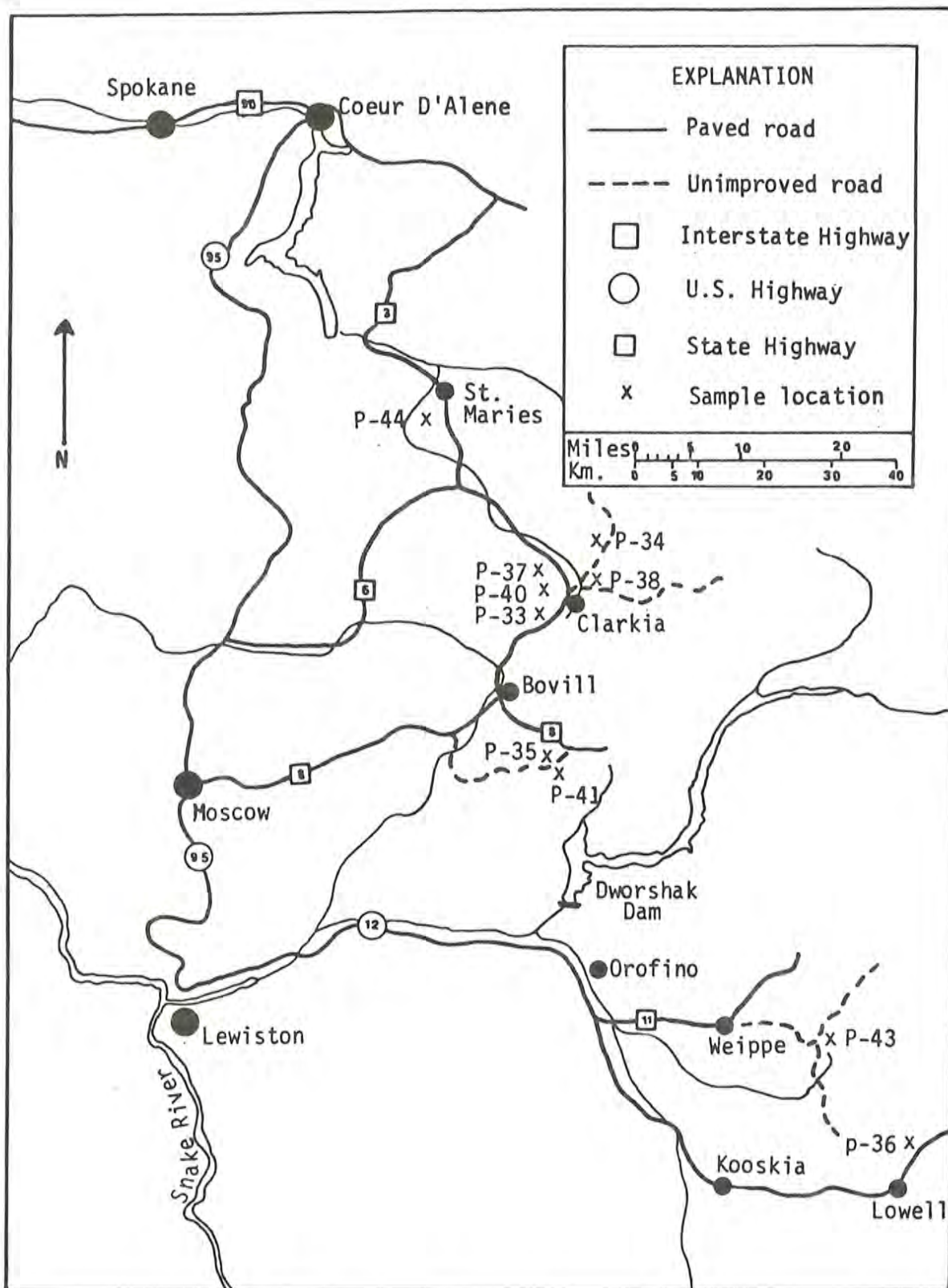


Figure 1. Map showing locations of studied Miocene pollen assemblages in northern Idaho.

Columbia Plateau as used by Swanson and others (1979) and Hooper (1982). The "P-" numbers are the University of Idaho paleobotanical fossil site numbers. Fossil pollen was extracted, using an acetolysis technique similar to Doherty's (1980), with the grains then mounted in glycerine jelly. A Zeiss universal microscope at 600X to 1,000X was used to identify the plant microfossils, in most instances to the genus level. Statistical significance is achieved by having a minimum of 200 identified grains per sample (Leopold and Wright, in press). The relative pollen frequency (RPF) was then calculated to the 1% level (Tschudy, 1973) and tabulated in Table 2. Samples lacking statistical significance are noted on Table 2. Two sites in the Clarkia Basin were sampled at different stratigraphic levels; these are designated P-33.1 through P-33.6 and P-34.1 through P-34.3.

Table 1. Stratigraphic position of Early and Middle Miocene pollen floras in northern Idaho.

my	pollen flora	associated basalt
12	Oviatt Creek (P-35, P-41) Rover Siding (P-44)	Priest Rapids* Priest Rapids* & Eckler Mountain*
15	"Latah Flora"	Columbia River Basalt Group
16	Musselshell Creek (P-43) Jungle Point (P-36)	Grande Ronde Grande Ronde Imnaha Basalt
20	Emerald Creek (P-37, P-40) Clarkia (P-33, P-34, P-38)	

* Part of the Wanapum Basalt

Table 2. Relative pollen frequency (RPF) of studied Miocene pollen assemblages in northern Idaho.

Taxon	G#	Clarkia Basin										Oviatt Creek		Other Localities		
		.1	.2	P-33		.5*	.6	P-34		37	P-40	-P		44	P-	
				.3	.4			.1	.3			35	41*		36	43
CRYPTOGAMS																
Gleicheniidites		2	11	X		9	9	1	3		3	6	5			
Lygodium			1									2				
Polypodiaceae	+	1	13	2		22	18	5	14	11	4	10		2	2	11
Sphagnum			X								X					
CONIFERS																
Abies	+	21	20	30	11	4	X	9	19		X	X	3	X		12
Larix		X	1	1	2	4	X	1	1					X	2	4
Picea	+	38	14	11	5		3	40	22	20	54	5		X	4	X
Pinus	+	15	7	1	1		4	10	12	7	16	2	14	1		X
Podocarpus		X	1		X			X	1							
Pseudotsuga	+		X	X	1	4	X	X	X				X			2
TCT	+	1	12	5	47	23	44	6	7	18	8	16	25	9	35	39
MONOCOTYLEDONS																
Gramineae	+	1		X	2	7	1	X		2			2	X	2	X
DICOTYLEDONS																
Acer	+	1	X	1	X		X	X	X			X	3			
Alnus	+	1	1	X	2	2	1	2	3	7	X	3	2	2	2	
Betula	+	8		9	2	1	2	4	5			3		2		6
Carpinipites	+	X	X				X				X		2	1		
Caryites	+	1	1	3	4		2	2	X		1	8		X	4	
Castaneoideae	+	1	3	3	3	4	1	X	2	4	1	11	4	13	2	12
Corylus	+			X												
Elaeagnaceae	+															
Engelhardtia	+			X			X				X					
Fagus	+	X	1	13	1	2	1	2		4			5	3	6	4
Fraxinus	+	1				1	X		X				2	X		
Ilexpollenites	+						1									
Juglans	+		1	1	X			2	1	9			3	1	6	
Liquidambar	+												X			
Liriodendron	+					2							X			
Magnolia	+			X		2			1	4		X				
Myrica	+								2		X	X				
Myriophyllum-pollenites			X										X			
Platanoidites	+		6	5	4	2	3	5	2	7	4	9	2	36	4	
Pterocarya	+				1		X	1	1		X	1			2	
Quercus	+	2	3	10	8	5	4	7		7	7	10	20	19	28	7
Rhamnacidites	+				X	1										
Rhus?	+				X											
Salixpollenites						1							4	1		
Tilia	+	X	X	3	2				X		X	1	2	X	2	X
Ulmus/Zelkova	+	X	1	X			X	X	1		X	12	2		2	

(+) reported by Gray, in Smiley and others (1975) or by Gray (in press) from site P-33

* not enough grains to be statistically significant

X present but less than 1% of sample

DISCUSSION

Clarkia Basin Assemblages: The fossil assemblages from Clarkia Basin sites (P-33; P-34; P-37; P-38; P-40) are: (1) rich in conifer pollen, (2) contain abundant and diverse dicot pollen, and (3) often have a sizeable component of pteridophyte (fern) spores. Jorstad (1983) proposed that these assemblages represent arboreal pollen from a high elevation Mixed-Coniferous Forest being mixed with pollen from a lower elevation Mixed-Mesophytic Forest. The fossils from the Clarkia Basin sites were deposited prior to the extrusion of the Columbia River Basalt Group as evidenced by the cross-cutting relationship and radiometric date (approximately 22 my; Smiley and Rember, 1979) of the dike at site P-34. Jorstad (1983) proposed that other northern Idaho assemblages with a similar floristic composition and age be included chronostratigraphically in the Clarkian Stage and biostratigraphically in the Coniferae-Mixed Decotyledoneae-Pteridophyte Palynomorph Assemblage Zone. Table 3 outlines Jorstad's (1983) stratigraphic proposals.

Table 3. Jorstad's (1983) proposed chronostratigraphic and biostratigraphic zonation in northern Idaho.

Time	Chronostratigraphic		Biostratigraphic
	N. American Mammalian	Pollen	Pollen Assemblage Zone
Middle Miocene	Barstovian 12.5-16.5 my*	Oviattian	Fagaceae-TCT- <u>Platanus</u>
Early Miocene	Hemingfordian 16.5-21.5 my*	Clarkian	Coniferae-Mixed Dicotyledoneae- Pteridophyte

*duration of stage from Armentrout, 1981.

Oviatt Creek and other sites. Oviatt Creek, Rover Siding, and the other studied sites have fossil assemblages that are floristically dissimilar to the Clarkia Basin assemblages. These fossil assemblages: (1) have a high proportion of Fagaceous pollen, (2) have a large and fairly diversified dicot component, (3) often have a large amount of Platanus (sycamore) pollen, and (4) are typically low in conifer pollen, with the exception of TCT. Fagaceous pollen is that of members of the Fagaceae which includes Fagus (beech), Pseudofagus, Quercus (oak), and the subfamily Castaneoideae (the tan oaks). TCT is an artificial taxon that is used to designate members of the Taxodiaceae, Cupressaceae, and Taxaceae; the pollen of these families is very difficult to assign to the genus level. Jorstad (1983) proposed that these assemblages represent a temperate hardwood forest, perhaps similar to that which now exists in southern Illinois and the neighboring region. These sediments and fossils were deposited penecontemporaneously with the extrusion of the Columbia River Basalt Group, based on the association of these fossil sites with named members of the Columbia River Basalt Group (Table 1). Jorstad (1983) proposed that other northern Idaho fossil assemblages of similar floristic composition and age be included biostratigraphically in the Fagaceae-TCT-Platanus Palynomorph Assemblage Zone and chronostratigraphically in the Oviattian Stage. The association of the classical "Latah Flora" with the Columbia River Basalt Group places the "Latah Flora" in the Oviattian Stage, in terms of chronostratigraphic relations, and precludes inclusion of the Clarkia Fossil Locality specimens in the "Latah Flora."

CONCLUSIONS

1. Early Miocene pollen assemblages in northern Idaho can be floristically differentiated from Middle Miocene pollen assemblages; this floristic dissimilarity provides the basis for recognition of a Coniferae-Mixed Dicotyledoneae-Pteridophyte Palynomorph Assemblage Zone.
2. Early Miocene sediments in northern Idaho are recognizable based on their fossil pollen content and chronostratigraphically represent the Clarkian Stage.
3. Middle Miocene pollen assemblages in northern Idaho can be floristically differentiated from Early Miocene pollen assemblages; this floristic dissimilarity provides the basis for recognition of a Fagaceae-TCT-Platanus Palynomorph Assemblage Zone.
4. Middle Miocene sediments in northern Idaho are recognizable based on their fossil pollen content and chronostratigraphically represent the Oviattian Stage.
5. The "Latah Flora" is a general term that should be used only in reference to fossil plant assemblages from the Oviattian Stage.

ACKNOWLEDGEMENTS

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**MISSISSIPPIAN COPPER BASIN ROCKS IN SOUTH-CENTRAL IDAHO:
25 YEARS UNDER THE HAMMER**

by Richard A. Paull
Department of Geological and Geophysical Sciences
The University of Wisconsin-Milwaukee
P. O. Box 413
Milwaukee, WI 53201

ABSTRACT

M. Ray Thomasson documented the existence of great thicknesses of coarse terrigenous and carbonate turbidites in the Pioneer, Boulder, and White Knob Mountains of south-central Idaho in 1959. He also attributed the provenance of these deposits to a previously unrecognized northward extension of the Antler Orogenic Belt. During the next twenty-five years, more than one hundred geologists studied, pondered, speculated, mapped, remapped, published, and republished on aspects of these rocks. As part of this effort, all occurrences of Copper Basin rocks were located and mapped at least once, and as often as seven times in certain areas. Considering the intensity of this activity within a northwesterly trending belt about 130 km (80 mi) long and 20 km (12 mi) wide, it would appear there was not much more to learn.

Analysis of previous studies, however, discloses there is little agreement about Copper Basin rocks, and generally accepted concepts are limited to the following: (1) the rocks are allochthonous and occur in one or more thrust plates; (2) Copper Basin rocks moved at least 30 km (18 mi) in an easterly direction from an unknown location; (3) all thrusts and folds dated with a moderate degree of certainty are post-Paleozoic and pre-Eocene, with only one episode of deformation positively documented; (4) multiple sources for turbidite deposits, coupled with variations in sediment supply and depositional conditions, resulted in vertical repetitions and lateral changes in lithologies; (5) although lithologies are variable, at least partial stratigraphic sequences are recognized in some areas; (6) ages based on widely scattered fossil collections range from Early to Late Mississippian (late Kinderhookian to Chesteran); and (7) a minimum thickness of about 3000 m (9840 ft) of rock is present.

Controversial or poorly understood aspects of Copper Basin rocks include: (1) age assignment, thickness, and acceptable stratigraphic units to unravel structural uncertainties and provide factual information for regional studies; (2) location of the Antler highland and the associated Muldoon foredeep basin at the time of formation; and (3) time framework and source of terrigenous and carbonate turbidites.

Thus, after twenty-five years of intensive effort, there is no consensus about age, thickness, sedimentological parameters, structure, and location of the original depositional site of Copper Basin rocks. Although significant progress toward

understanding the age, character, and relations of associated rock units in south-central Idaho can be documented, it is apparent that little has been learned about Copper Basin rocks since the pioneering insights of Thomasson. A cynic might quote the humorist who observed: "Researchers have already cast much darkness on the subject, and if they continue their investigations, we shall soon know nothing at all about it". The reality of the situation involves the limited and discontinuous nature of exposures, variability of the depositional record, structural complexities, and rugged topography, but it also reflects how the geology was done. Recognition of what is unresolved about Copper Basin rocks can make the next twenty-five years more productive.

EYEWITNESS ACCOUNT OF NORMAL SURFACE FAULTING

BY J. R. PELTON, C. W. MEISSNER, AND K. D. SMITH

Normal surface faulting associated with the Borah Peak, Idaho earthquake (preliminary M_s 7.3) of 28 October 1983 was witnessed in the vicinity of Arentson Gulch by two elk hunters, D. Hendriksen and J. Turner of Boise, Idaho. On the morning of the earthquake, the hunters were traveling in a four-wheel drive vehicle on a dirt road (Figure 1) with Hendriksen driving. Another pair of hunters, Mr. and Mrs. William Knox of Challis, Idaho, were on foot in the same area. Mr. Knox was to the northwest and on a hill above Hendriksen and Turner, and was driving elk toward his wife who was waiting near some power lines in a narrow valley (Figure 1). At 8:06 a.m. local time (14:06 UTC) the earthquake occurred, while Hendriksen and Turner drove their vehicle northeastward at a slow rate of speed (about 5 mph). A prominent fault scarp formed about 20 m directly in front of the vehicle, with the vehicle on the downthrown side (Figure 2). We interviewed Hendriksen and Turner at this site on the evening of 28 October and again at this site on the morning of 29 October. Hendriksen alone was interviewed at Boise State University on 8 November and 30 November. The 29 October interview and portions of the 8 November interview were tape-recorded and transcribed. Excerpts from these transcriptions and an interpretation of the events are given below. Observations made during the surface faulting by Mr. and Mrs. Knox are documented by Wallace (1984).

TRANSCRIPTION—29 OCTOBER

The following comments are excerpts taken in order from the complete transcription. Clarifying notes have been added in parentheses. The symbol ?---? is used where a short phrase was garbled.

Hendriksen: OK, I got about to this point right here (20 meters from the fault scarp), and all of a sudden I did feel light-headed and I just lost my equilibrium. I felt like I was going to pass out. I was just about ready to tell John at that time, "There's something wrong with me, John," and soon after that, right after that, it just started shaking like crazy. The Bronco was off the ground completely, it was just rocking like this, and right soon after that the bank (Figure 3) dropped (the fault scarp formed) and I was hanging on to the steering wheel. I looked over to John and he was just flying in the passenger seat, he was between the two seats trying to get up. And, he was saying, "What's going on?," or something like that, it was to that effect. I wasn't about to answer because I didn't know. I was looking out the window, at John, just looking all around, not knowing what was going on. I looked out the window and this ground right to my left here (Hendriksen meant the ground adjacent to the driver's side of the vehicle) was opening and closing, and I was really terrified at that. I figured it was going to open up and drop us right in. And, it happened, I don't know, probably in a span of 10 or 15 seconds, that it was violent.

Turner: It was hard to say, it seemed like a long time, yet I am sure it was a very short time.

Hendriksen: But it seemed like an awfully long time, and as soon as it violently stopped I went for the gear, reverse. And there was nothing there. I don't know

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why. My wheels weren't turning or nothing. I thought there was something happened to the Bronco. We talked about a driveline or something like that snapped on us.

Turner: We both felt at the time that maybe we had driven into a sinkhole, just too much weight and it just caved in ahead of us. We really didn't have any real feeling of anything other than our immediate selves.

Hendriksen: Yeah, looking indirectly (more or less directly) ahead at the time, I wasn't looking too much to the left until it stopped. Then I looked down the ridge and saw that it sunk, on both sides. I knew at that time it was an earthquake.

Pelton: Did you notice whether the fracture ripped across in that direction (northwest), or in that direction (southeast), or just dropped straight down?

Turner: That's funny. Because for us it really dropped straight down, but after we thought about it, the people (Mr. and Mrs. Knox) we talked to on the hill, I thought it came this way (southeast to northwest), the lady (Mrs. Knox) we talked to said she thought it came this way (northwest to southeast). So, we really couldn't tell you to be honest.

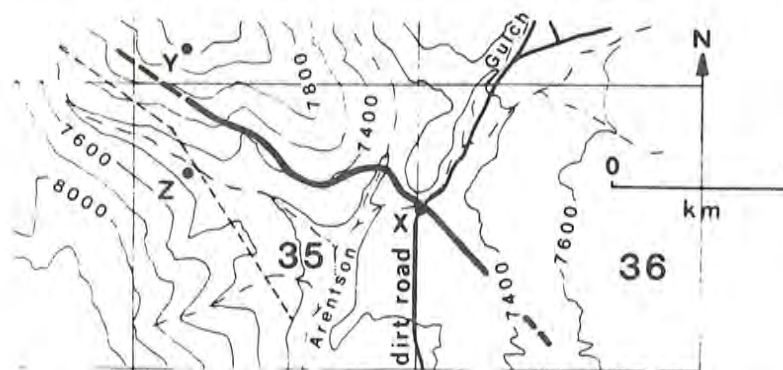


FIG. 1. Map showing Arentson Gulch area (see USGS Dickey Peak, Idaho, quadrangle, 7.5-minute series, T11N, R21E, sec 35 and 36). Heavy line is main fault scarp mapped from preliminary data; thin lines are topographic contours with contour interval 200 feet; dashed line is route of power lines; dash-dot lines are intermittent streams. Observation points during earthquake shown by black dots: X, Hendriksen and Turner in vehicle; Y, Mr. Knox; Z, Mrs. Knox. The main fault scarp shown here is part of the Arentson Gulch splay from the Lost River fault.

Pelton: You say you did notice the ground opening and closing around you?

Hendriksen: Especially at the time of the, right after, the bank (Figure 3) had dropped (to form the scarp). The ground right to my left (as before, Hendriksen meant the ground adjacent to the driver's side of the vehicle) here was just shaking violently, especially right over here, ?---? view right here to the left, and it was just like this.

Pelton: How far would you say it was opening and closing?

Hendriksen: Probably not extreme, probably two or three inches, or not much more than that.

Pelton: Something like this crack right here? (Pelton indicated a crack with a two- or three-inch horizontal gap between the edges.)

Hendriksen: Almost exactly like that, but I wasn't too sure it was going into something that the whole vehicle might just drop into. [On 30 November, Hendriksen told us that the ground in the rupture zone (Figure 2) was "gapping two or three feet," while near the vehicle cracks were opening and closing about six inches.]

Hendriksen: That one guy (Mr. Knox) said that when he was up on the hill here, he was up on the top of the ridge, we didn't even know they was around at the time, she (Mrs. Knox) was down there by those poles (the power line). He was up on top and they had jumped them (the elk) from the other side, and they were in the process of jumping them (the elk) too at the time. He said he felt the same sensation (the dizziness felt by Hendriksen), that he thought at first he was having a heart

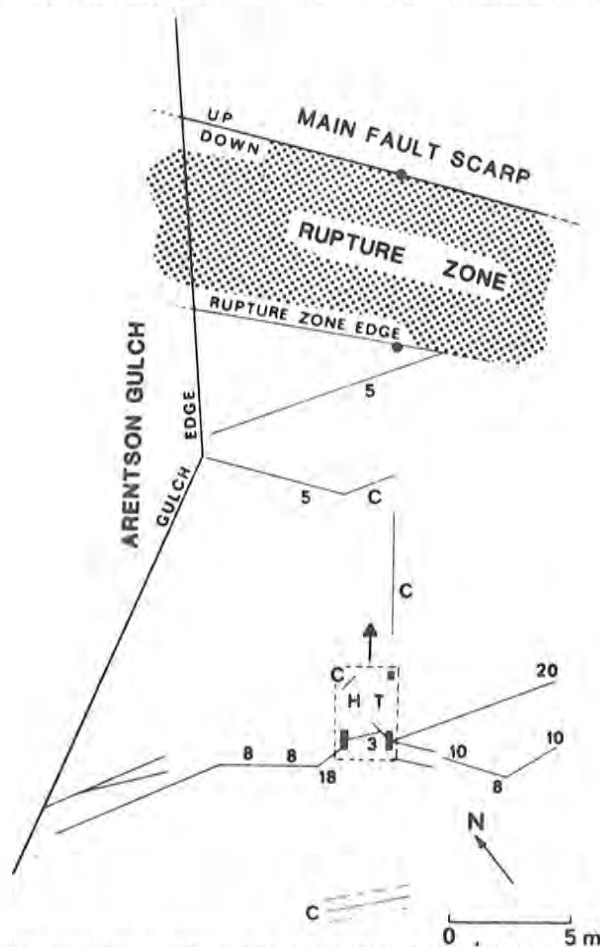


FIG. 2. Map showing position of vehicle relative to rupture zone. Vehicle outline given by dashed line; direction of vehicle travel at time of earthquake given by heavy arrow. Positions of Hendriksen and Turner given by H and T, respectively. Rear tire impressions are the solid rectangles. Right front tire impression is the solid square. Light lines are open or closed ground cracks; numbers indicate horizontal gap in centimeters for an open crack; C indicates closed crack. Many of these cracks also showed relative vertical movement. Trace of cracks is more irregular than shown. Vertical offset between black dots is about 1.8 m. Rupture zone is area of jumbled blocks of earth adjacent to main fault scarp and is probably an asymmetric graben. Map made with tape and compass on 29 October 1983.

attack, light-headed, and he said he went to the ground. He said he didn't want to fall and hurt himself. He went to the ground and he sat down and the same thing happened (the violent motion) to him. He was grabbing on to the brush up there because he was coming down the hill and he said he's probably got finger marks into the hillside coming down the hillside.

TRANSCRIPTION—8 NOVEMBER

On 8 November, Hendriksen told us that the preceding account left out important details concerning crumbling and sinking of the ground just prior to the formation

of the fault scarp. He also said that the violent motion that he experienced did not precede the actual formation of the fault scarp, as one would infer from the 29 October interview. He gave us what he considers to be a more accurate description of what actually happened during the earthquake. We feel that this second version is adequately summarized by the following excerpts.

Hendriksen: OK, upon approaching the immediate area where the fault had dropped, there was a slight uphill slope with a small indentation probably a foot to a foot and a half. (Just prior to the earthquake the vehicle was traveling up a slight slope which had a shallow depression in it, see Figure 3.) The first feeling I had was the light-headedness, like I was going to pass out, and this lasted 1 to 2 seconds, approximately. Immediately after this, the next sensation was what felt like or looked like shock waves, I don't know what it was or whether I was passing out or what. But it was the sensation of closing your eyes and fluttering your eyes, it was about the same sensation. And, immediately, immediately after this, was the bank (Figure 3) crumbling before us, sinking just like we were going into a sinkhole, and

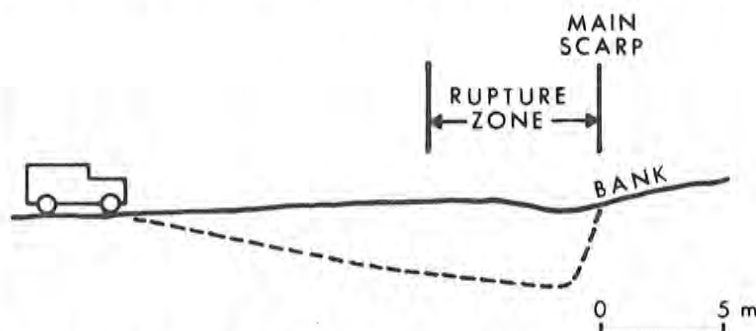


FIG. 3. Sketch of sinkhole profile and vehicle position made with assistance of D. Hendriksen. View looking northwest. Horizontal and vertical scales equal. Solid line is ground profile before earthquake. Dashed line is ground profile showing sinkhole just prior to formation of main scarp and onset of violent motion.

within a span of probably a second, or maybe a little bit more, not much, the Bronco appeared like it was going to fall within a sinkhole approximately six to ten feet (Hendriksen meant 6- to 10-feet deep, an estimate based on his perception of the depth at the time. We could not identify any object outside the vehicle that might serve as a reference scale other than sagebrush plants which were 2- to 3-feet high), and it was like we were on the edge of it. At about the time I thought we were possibly going to slide into the hole, it was nothing to be real scared about at the time, there was no noise, it was just, just motion (the crumbling and sinking), (then) it (the surface faulting) made the abrupt move, it just dropped, just snapped off, we went back down, and it (the scene) looked similar to what the quake (the fault scarp) looks like afterwards, except we went into the violent, at the time we shook, or I mean at the time that we snapped off, that's when the quake went into its most violence and that's when the noise came in. And it was deafening, a deafening rumble. And that approximately lasted 10 to 15 seconds, just violent shaking. And that was pretty much it, outside of the earth opening and closing, that was basically it.

Pelton: Don, would you describe the time between when you first felt dizzy and when you first began to see these shock waves that felt like fluttering your eyes?

Could you describe that a little bit, once again, with a little more detail?

Hendriksen: OK, I was just about to the point where I felt like there's something seriously wrong with me, and it was, like I said, it was about a 1- or 2-second span there, it was just like the whole thing was going out on me, and it was like I said, it was just like fluttering your eyes with your eyes closed, it was just about the same thing, and then it just all cleared up prior to the actual sinking and the motion afterwards. But that's as close as I can put it to, just on the verge of almost blacking out, and like again I don't know if that was shock waves coming through or whether it was just me on the verge of passing out, and at the time I was going to tell John at that time, "There's something wrong with me", and I didn't have time, I was just amazed by what was happening before us, and I just, you know, that's about it.

It is important to point out that during the dizziness and fluttering sensation, Hendriksen did not have the perception that he was in motion or that the ground was in motion, even though he uses the term shock wave, a term which he did not use in the 29 October interview and which he may have picked up from us or newspaper accounts of the earthquake. The following excerpt is clear on this point.

Pelton: (During the dizziness and fluttering sensation) Was the vehicle vibrating at all at that point?

Hendriksen: No, there was no motion, no shaking, no nothing at that time. There was really no real violence, until, completely after it (the sinkhole) sank down and when we made the abrupt drop. That seemed to be it (the start of the violent motion).

The following excerpts provide a few more details on the formation of the sinkhole.

Pelton: And then (after the fluttering sensation), things cleared up, and shortly after things cleared up in your mind, then you noticed the sinking and the crumbling in front of you, and was it really like a round hole, or was it like a valley forming all the way across the road and extending to both sides?

Hendriksen: My immediate (view) was just visually in front of me, approximately, my peripheral vision (may have been) somewhat (involved), but immediately I was concentrating (ahead), I could see things out to the side doing the same thing, and it . . . , I was more concerned about going into the hole immediately in front of us, I was concentrating directly on probably what we're seeing right here, about, on this picture here (Figure 4), that immediate area (the foreground in the photo up to the fault scarp) was just falling down in. I think it probably could have (fallen in), I don't know.

Pelton: And you think the vehicle was actually tilted down?

Hendriksen: Yes, I do. Because I remember, I think my natural reaction was, I went to the brake and was bracing myself just like I was going to fall off a cliff, just about ready to go in.

Pelton: When the hole was forming in front of you, did you feel like the vehicle was rising up and tilting in, or just tilting in, or can you make that distinction?

Hendriksen: I felt somewhat like we had risen, we were on a slight rise, but more so like we were just on the edge, ready to fall in. And I couldn't really, it looked like at times we were at least even, or possibly a little bit above what we were looking at prior to that time, but it was really hard to distinguish that. I don't know, it was more like being right on the edge of a cliff, the ground giving way right on the edge of a cliff, and getting ready to fall in, about the time I thought we were going (in), that's when it dropped (the fault scarp formed).



FIG. 4. Photograph from color slide of fault scarp taken by Hendrikson about 30 minutes after earthquake; taken from position occupied by right front tire of vehicle during earthquake. Near edge of rupture zone (Figure 2) is indicated by white dots.

DISCUSSION AND CONCLUSIONS

The sequence of events is of considerable importance: the dizziness grading into a fluttering sensation felt by Hendriksen, followed immediately by a return to clarity and the crumbling and sinking of the ground to form a 2- to 3-meter-deep sinkhole in front of the vehicle, and then the abrupt formation of the fault scarp and simultaneous onset of violent motion. The account suggests a minimum time of 2 to 3 seconds between the onset of dizziness and the formation of the fault scarp.

We interpret the dizziness and fluttering sensation experienced by Hendriksen to be the result of the arrival of seismic waves generated at the point of initial rupture. The preliminary epicenter is 30 km south of Arentson Gulch (R. B. Smith, University of Utah, personal communication). If we assume a *P*-wave velocity of 5 km/sec and a rupture velocity of 3 km/sec, then the first seismic waves would precede the rupture by 4 seconds (more if focal depth is taken into account). This simple calculation is reasonably consistent with the estimated minimum time (2 to 3 seconds) between the onset of the dizziness and the formation of the fault scarp. Hendriksen did not notice any ground motion during this period (other than the sinking and crumbling), and this could have been the result of his being in a moving vehicle or a wavelength-frequency combination for the seismic waves which would keep him from noticing motion. Another excerpt, not given above, indicates that Hendriksen was driving and looking straight ahead, while Turner, who did not feel dizzy, was looking down at the floorboards of the vehicle. We believe this difference plus the tendency for some people to be more sensitive to motion than others may account for the fact that Turner did not feel dizzy.

The sinking of the ground to a depth of 2 or 3 meters in the vicinity of the

impending fault scarp is especially interesting. The shape and location of the sinkhole was sketched by us with the help of Hendriksen on 30 November (Figure 3). Hendriksen emphasized that the sinkhole was not a vertically-sided graben-like structure; it was asymmetric and smoothly tapered to its deepest point. If the sinkhole is drawn to scale with a maximum depth of 3 meters (Figure 3), then the sinkhole edge near the vehicle does not appear to be steep enough to prompt Hendriksen's remark: "... like being right on the edge of a cliff ..."; the slope leading from the vehicle into the sinkhole shown in Figure 3 is about 15 degrees. In any case, the fault scarp formed on the side of the sinkhole that was opposite the vehicle, and was a very abrupt event. The sinkhole disappeared with the formation of the fault scarp, but numerous ground cracks, some open and some closed, were mapped by us in the vicinity of the scarp (Figure 2). These observations suggest that finite strain associated with the impending rupture developed rapidly across the fault and gave Hendriksen and Turner the impression that a sinkhole was forming. However, the evidence for actual formation of the sinkhole is not conclusive, and we cannot rule out the possibility that seismic ground motion somehow created an illusion of sinking.

The direction of rupture propagation was probably not reliably observed because of the close-in nature of the observation point and the fact that Hendriksen was focusing his attention straight ahead. The direction sensed by Mrs. Knox contradicted the direction which Hendriksen and Turner arrived at after they "thought about it". We did not interview Mr. and Mrs. Knox, but their account is summarized by Wallace (1984, this issue).

The position of the vehicle could be reliably determined because three tires left depressions in the dirt road from the violent rocking (see Figure 2). The front tires were 20 meters from the fault scarp which had a vertical offset of about 1.8 meters where it crossed the road. The back tires left especially deep depressions because an open crack about 7-cm-wide extended across the road directly beneath the rear wheels. Other cracks ran across the road near the vehicle's position (Figure 2), and some of these must have been visible from the driver's position. However, we did not find evidence for the cracks adjacent to the vehicle on the driver's side which, according to Hendriksen, were opening and closing about 5 to 15 cm.

Hendriksen and Turner did not have any formal training in the earth sciences, yet they provided a remarkable account of what must have been a very frightening experience. Both men were 28 years old at the time of the earthquake.

ACKNOWLEDGMENTS

We wish to thank D. Hendriksen and J. Turner for patiently answering our countless questions, and for supplying the photograph used in Figure 4. R. A. Page, D. M. Boore, and R. E. Wallace made many helpful suggestions to improve the manuscript. This research was supported by National Science Foundation Grant CEE-840-3585.

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DEPARTMENT OF GEOLOGY AND GEOPHYSICS
BOISE STATE UNIVERSITY
BOISE, IDAHO 83725

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**STRUCTURAL CONTROL OF GROUNDWATER ERUPTIONS AND
SEDIMENT BOIL FORMATION IN THE CHILLY BUTTES AREA,
MT BORAH, IDAHO EARTHQUAKE**

C. J. Waag
Department of Geology & Geophysics
Boise State University
Boise, Idaho 83725

The October 28, 1983, Mt. Borah, Idaho earthquake (M_s 7.3) produced more than 40 spectacular sediment boils and sinkholes near Chilly Buttes in the Big Lost River Valley. The buttes, approximately 3.7 km (23 mi) from the epicenter, are within the downthrown valley block and are exposures of a bedrock-high of late Paleozoic carbonates which underlie the Tertiary and Quaternary alluvium. The bedrock within the buttes is probably the White Knob Limestone (personal communication, Betty Skip, USGS). It is folded into a large open antiform, which is intensely fractured, especially in the hinge. The fractures strike $N15^{\circ}$ - 20° W, parallel to the axial surface and are widened by solutioning of the limestone.

As a result of the seismic shaking, groundwater erupted (1) as geysers directly from the fractures in the bedrock, (2) into a veneer of alluvium overlying the limestone on north Chilly Butte where it caused piping, and (3) up through the valley alluvium north and east of north Chilly Butte, forming sediment boils. All of the eruptions show a strong alignment parallel to fracture sets within the carbonate bedrock. The most common and strongly developed orientation is $N15^{\circ}$ - 20° W; however, a $N45^{\circ}$ W orientation is evident in the sediment boils north of the buttes.

The eruptions emitted directly from the bedrock occurred at elevations as high as 30 m (100 ft) above the valley. Elutriation of all but the largest clasts from the fissures and washouts in the coarse slope colluvium indicates that the geysering occurred in relatively large volumes, and at high velocities and pressures.

On the north slope of the butte, where a veneer of alluvium overlies the carbonate, the water piped a number of tunnels in the alluvium. The tunnels trend $N15^{\circ}$ W, parallel the fracture set in the carbonate, and are locally collapsed, forming interconnected

collapse holes or tunnel skylights. In one tunnel the alluvium has an obvious sheared fabric striking N15°W and dipping 80°W, that can be traced along the tunnel. Slight depressions are commonly developed above the sheared zones and contain an abundance of sagebrush. The roots of the sagebrush grow in a preferred alignment within the sheared alluvium and are exposed in the tunnels. Compaction of the alluvium into the underlying carbonate solution channels, and perhaps jiggling and piping during earlier quakes, probably caused the planar fabric and topographic lows to form. Whatever their origin, the weak zones and their planar fabric clearly predate the October 28 quake. Several of the tunnels can be traced to topographically lower areas where piped alluvium burst to the surface, causing washouts. One of the tunnels exits into a large washout, which exposes a fault in the carbonate and colluvium. Evidently, the surge of water was directed through the carbonate solution channels along the fault and up into the sheared alluvium, where it piped a 25 m (82 ft) tunnel. Apparently the groundwater encountered higher permeabilities within the shear zones, and pressure was partially dissipated through piping laterally, rather than erupting directly at the surface.

In the valley, about 300 m (1000 ft) northwest of north Chilly Butte, five large sandboils and several smaller ones erupted. The larger of these boils appears to have formed at the sites of earlier sinkhole-lakes shown on the Chilly Buttes Quadrangle. The fracture porosity and permeability systems that fed those lakes undoubtedly acted as the conduits for the eruptions which formed the sand boils.

The large boils are aligned N45°W, and obviously reflect an important fracture direction in the underlying carbonates. The smaller boils are also aligned; however, their orientation is along the more common N15°-20°W direction. The two alignments intersect near the center of the row of large boils. The largest sinks are about 16-18 m (52-60 ft) in diameter and are slightly elliptical; having their long axes in the alignment direction. A coalescing apron of sand, having an average width of 30 m (100 ft), links the larger sinks. At the inner edge of the sinks the sand has an average thickness of

.5 m (1.6 ft) thinning to about 15 cm (.5 ft) at its distal edge. The sediment within these boils ranges from very fine to coarse sand, but is well sorted, having an average sorting coefficient of 1.44.

In the valley adjacent to the southeast side of north Chilly Butte approximately twenty-five sediment boils and several sediment fissures erupted. Here the fissure eruptions and sediment boils again show strong structural control and are aligned along the N15°W direction. Several of the boils are also elliptical, having their long axes aligned parallel to, and continuous with, fissure eruptions. Five of the boils erupted through sinkholes that were present prior to the quake. According to unsubstantiated local information, three of the sinkholes developed about the same time as the Hebgen Lake earthquake. The other two sinkholes formed ten to eleven years ago. Although all of the sediment boils formed in response to the October 28 quake, they also show some evidence of collapse subsequent to the eruption.

In contrast to the sand boils north of the buttes, those east of the buttes contain a wide spectrum of grain sizes, ranging from clay to cobbles, and the stratigraphy seems to reflect more variable depositional conditions. In all of these boils, multiple sedimentary units can be recognized. Gradational and distinct or abrupt contacts between the units are common. The bases of many of the sedimentary units are marked by scour and fill structures, and other erosional features or diastems. In general, the basal sedimentary unit is well sorted, fine grained, and non-laminated to poorly laminated. The middle and upper units are poorly sorted, coarser grained, and commonly contain cross-bedding and graded beds. The uppermost or final depositional units are very well sorted, finest grained, and contain ripplemarks and mudcracks. The sedimentary characteristics of these boils indicate that deposition was by surging flow, and that the surge increased in intensity until the final phases, at which time the intensity of the flow waned rather abruptly.

The well-sorted basal unit is especially interesting when considered in conjunction with an eyewitness account of the sediment-boil activity. Mr. Del Clark, manager of the San Felipe Ranch, arrived at the sand boil field east of the buttes just a few minutes after the quake occurred. He observed that muddy water from the new springs around the base of the buttes had already flooded the road; however, the boils were blowing sand with no water present. According to Mr. Clark, the water did not erupt through the boils until after they blew sand and air. Then the mixture of water and sediment erupted. He estimated that the various spouts reached heights ranging from 4 to 6 m (13-20 ft). According to Mr. Clark's estimates, the duration of the sediment-water-mixture eruption was about three to four minutes. After that, the boils flowed muddy water.

Judging from the sedimentary characteristics, and from Mr. Clark's observations, it is possible that the basal unit is aeolian. It seems likely that negative dilation of the carbonate and alluvial aquifer systems would cause expulsion of air both as a direct consequence of the dilation, and indirectly as a result of the groundwater pressure wave migrating through the aquifer. Perhaps the initial surge of air caused expansion or inflation of the alluvium. Once inflated, the surge of air through the porous media may have fluidized the sediment elutriating the fine fraction and depositing the basal unit. Perhaps the diastem at the top of the basal unit not only represents a break in the sedimentation, but also a change in the medium of deposition. The overlying units being considerably coarser grained, reflect the increased surge of groundwater expelled from the aquifer systems, principally the carbonate, by the near field seismic waves. The water surge apparently hydrauliced and perhaps caused local spontaneous liquefaction of the alluvium and deposition of the upper units.

In the walls of several of the collapsed boils, clastic dikes are exposed. Grain sizes within the dikes are variable ranging from sand to gravels. The dikes, which cut both the old valley fill and newly erupted material, are vertical to nearly vertical, and

are deposited in the N15°-20°W fracture set. Large, well-established sagebrush roots present in the fractures with the clastic dikes again indicate that the fractures were present prior to the quake. A shallow seismic refraction survey in the valley, east of the base of north Chilly Butte, suggests that the depth to carbonate bedrock in the area of those sediment boils is probably somewhere between 24 and 53 m (80-175 ft), and the carbonate bedrock slopes gently eastward (Pelton, J. R. and others, 1984). This indication that the valley fill is relatively shallow, and the strong similarity of orientations of fractures within the carbonate and the alluvium, suggests that the fractures in the alluvium have propagated upward from the carbonate. Small Holocene and historic movements on N15°-20°W trending fractures within the carbonate have probably been imprinted on the alluvium. Higher permeabilities within these weak zones have encouraged greater groundwater movement and root growth. During the October 28 quake, the fractures and shear zones acted as important conduits for the escape of groundwater and the hydrauliced sediment. The source of expelled groundwater in the Chilly Buttes area is thought to have been primarily from the carbonate aquifer underlying the alluvium.

ACKNOWLEDGEMENTS

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A NEW BOUGUER GRAVITY ANOMALY MAP OF IDAHO

By Viki L. Bankey and M. Dean Kleinkopf
U. S. Geological Survey
Box 25046, DFC, MS 964
Denver, CO 80225

ABSTRACT

A new Bouguer gravity anomaly map of Idaho has been prepared by the U. S. Geological Survey in cooperation with the Idaho Bureau of Mines and Geology. Data compiled from over 24,000 gravity stations were obtained primarily from the Defense Mapping Agency, the National Geophysical Data Center of the National Oceanographic and Atmospheric Administration (NOAA), the U. S. Geological Survey, and the Idaho Bureau of Mines and Geology (Bonini, 1963). Using the method of Plouff (1977), terrain corrections were made radially from each station to a distance of 165 kilometers using digital terrain files. The map contour interval is 5 milligals. The map scale is 1:500,000, making this map suitable for direct comparison with existing state aeromagnetic and geologic maps.

Bonini (1963) described large geologic regions that were delineated by his Bouguer gravity anomaly map: the Snake River Plain, the Idaho Batholith, and the Columbia River Plateau. This new map, with much greater station control, shows local details in the gravity field that were not present on Bonini's map. The bowl-shaped positive anomaly of the Snake River Plain is narrow and steep in the west, but the amplitude and gradient of this anomaly decrease eastward and local features modify the anomaly. Similarly, the large, complex, negative anomaly of the Idaho Batholith contains a central cluster of small, local, positive anomalies. The positive gravity anomaly of the Columbia River Plateau, which reaches its maximum in Washington, is a broad feature which also covers most of the northwest panhandle of Idaho; this part of the anomaly is composed of smaller gravity highs interrupted by areas of lower gravity.

Derivative and wavelength-filtered maps made from Fourier analysis of the Bouguer gravity anomaly data (Hildenbrand, 1983) enhance subtle gravity features and help identify lithologic and structural boundaries.

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GEOLOGIC MAP OF THE NORTHERN PART OF
THE LOWER VALLEY QUADRANGLE, CARIBOU COUNTY, IDAHO

by Hans Peter Oberlindacher
and R. David Hovland
Bureau of Land Management
Boise, ID 83704

ABSTRACT

The mapped area encompasses 100 square km (38.6 square mi) in the northern part of the Lower Valley 7-1/2-minute quadrangle in Caribou County, Idaho. Marine sedimentary units, ranging from the Upper Mississippian Monroe Canyon Limestone to the Lower Triassic Portneuf Limestone of the Thaynes Formation, consist of a maximum 2,737 m (8,980 ft) succession of limestones, sandstones, siltstones, dolomites, phosphorites, and cherts. The Meade Peak Phosphatic Shale Member of the Lower Permian Phosphoria Formation contains economic phosphate resources. The fossil records indicate major unconformities for the uppermost Mississippian, the Lower and Upper Pennsylvanian, and the Upper Permian.

Pliocene or Pleistocene basalts rest unconformably upon sedimentary units as young as Triassic in the mapped area. Quaternary deposits consist of unconsolidated colluvium, alluvial fans, older alluvium, and younger alluvium along modern stream courses.

The mapped area is in a structurally complex transitional zone between the extreme eastern part of the Basin and Range physiographic province (dominated by Cenozoic block faulting), and the western part of the Middle Rocky Mountains physiographic province (dominated by Cretaceous thrust faulting and folding). The area is entirely within the upper plate of the Late Cretaceous Meade Thrust. Structural features within the area are imbricate thrust faults, sub-parallel north-to-northwest trending folds, east-west trending tear faults, and north-to-northwest trending high-angle faults. The tear faults have apparent left-lateral offsets up to 3 km (1.9 mi). Geologic relationships within the area suggest the following sequence of events: folding prior to, or synchronous with, thrusting; imbricate thrusting; tear faulting; high-angle normal faulting; and Pliocene or Pleistocene volcanism.

The Mississippian-to-Triassic sedimentary rock sequence was deposited on a shallow shelf between an emergent craton to the east and the Antler Orogenic Belt to the west. The depositional environments for the marine sedimentary strata range from shallow open-marine to supratidal.

**IDAVADA SILICIC VOLCANICS OF BENNETT MOUNTAIN AND THE
EASTERN DANSKIN MOUNTAINS
SNAKE RIVER PLAIN, IDAHO**

By S. H. Wood, Boise State University, Boise, ID 83725
and J. N. Gardner, Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

Bennett Mountain is comprised of a 500-m (1640-ft) section of rhyolite (71-72 percent silica) of the Idavada Group, which overlies pre-Cenozoic granitic rock and patches of Eocene Challis volcanics. The sequence of magnetic polarity in this section is a basal reversed unit, a normal unit, a reversed unit that is K/Ar dated by Armstrong et al. (1980) at 11.6 ± 0.6 my, a thin normal unit, and an upper, thin, canyon-filling reversed unit. The entire section is downfaulted to the SW, 200 m+ (656 ft) along N-NW trending normal faults. The Bennett Mountain block is overlapped by a 250 m+ (820 ft) sequence of normal-polarity rhyolite units that underlies most of the eastern Danskin Mountains.

Twelve flow units are distinguished on the basis of: (1) size and abundance of plagioclase phenocrysts; (2) a vertical zonation of flow banding and sheeting that becomes more steeply inclined upward and folded at the top of a flow; (3) vitrophyres commonly at the bottom and top of a flow; and (4) magnetic polarity measured with a field magnetometer. Eutaxitic and pyroclastic textures are absent except locally at the distal ends of flows. Phenocrysts are mostly andesine, minor cpx and iron ores, but some contain minor opx and fayalite. Primary hydrous mafic minerals are absent. Xenocrysts of microcline and embayed quartz are rare. These rocks are similar to densely welded ash-flow tuffs described by Ekren et al. (1980) in the Owyhee Mountains to the south across the Snake River Plain. Evidence presented here is consistent with the proposal by Ekren et al. (1978) that these magmas erupt and spread as extremely hot ash flows and then revert to high-viscosity lava flows. Eruption of relatively hot and dry rhyolite magma, contemporaneously with major faulting, suggests a deep-seated origin for Idavada magmas, related to rifting and development of the western Snake River Plain.

REVIEW OF LATE CENOZOIC TECTONICS, VOLCANISM, AND SUBSURFACE GEOLOGY OF THE WESTERN SNAKE RIVER PLAIN, IDAHO

by Spencer H. Wood
Department of Geology and Geophysics
Boise State University, Boise, Idaho 83725

Late Cenozoic development of the Snake River Plain as an east-west arcuate structural depression interrupting the north-south structural fabric of the North American Cordillera remains something of an enigma to investigators of North American Cenozoic tectonics. Three other major geologic provinces border the western plain area: the Basin and Range province, the Columbia River Plateau, and the High Lava Plains province of east-central Oregon (Fig. 1). All four provinces developed their distinctive characteristics in Miocene time.

The main episode of Columbia River Basalt volcanism occurred largely in the middle Miocene between 17 and 13 m.y. ago. The basalt erupted from north-northwest trending fissure vents in eastern Oregon and westernmost Idaho and flooded and filled basins in southeastern Washington and covered low country of northeastern Oregon and adjacent Idaho. These basalts are of limited compositional range and are mainly of tholeiitic or high-alumina compositions (Swanson and others, 1975; Hooper, 1982; and Christiansen and Lipman, 1972).

Basin and Range topography and associated volcanism began in central Nevada about 22 m.y. ago and was well defined by north-northwest and north-south block faulting 13 to 10 m.y. ago (Stewart, 1978). Prior to 22 m.y. ago, volcanism in the Basin and Range province was distinctly calc-alkalic in character, apparently in response to magma systems generated by a subduction system along the Pacific margin of central North America. Since middle Miocene time, the province has produced mostly alkaline volcanic rocks of either basaltic or high-silica rhyolitic composition and remarkably little rock of intermediate composition. This has been called bi-modal volcanism in reference to the two compositional end members of volcanic rocks (Christiansen and Lipman, 1972; Christiansen and McKee, 1978). Bi-modal volcanism of the Basin and Range has typically involved linear fissure eruptions of basalt and large circular caldera systems that result from the voluminous eruptions of rhyolitic magma that are emplaced as widespread ash-flow tuff sheets. Many of these caldera systems have had extensive hydrothermal activity and have become mineralized with precious metals (Shawe and others, 1978).

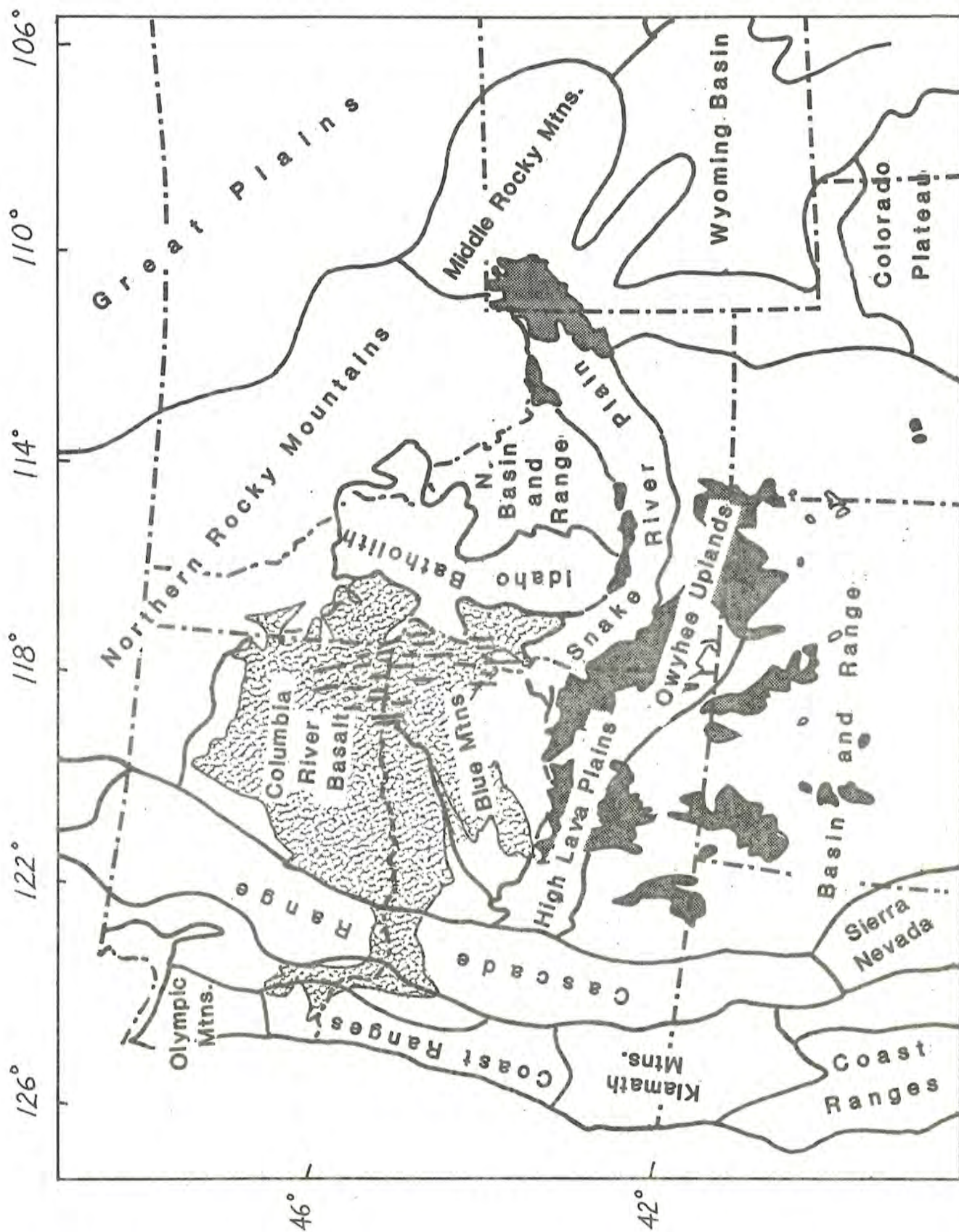


Figure 1. Tectonic provinces of the northwestern United States. Dark stippled areas are late Cenozoic rhyolite (<17 m.y) after Stewart and Carlson (1979). Area underlain by the Columbia River basalt (Grande Ronde and Imnaha Formations, 14-17 m.y) are shown by irregular shaded pattern after Swanson and Wright (1981). Dark NW-trending lines show the dike swarms from which most of the Columbia River basalt erupted.

Several major groups of rhyolite ash-flow tuff sheets occur along the northern edge of the Basin and Range province in Idaho and Oregon for which the calderas are not clearly evident. These groups are typically late Miocene in age and are associated with broad structural basins over 100 km in their longest dimension and containing at least 1200 meters of volcanic and sedimentary fill since late Miocene time. Examples are the Harney Basin of the High Lava Plains province of southeastern Oregon (Walker and Nolf, 1981) and the Snake River Plain. Silicic volcanic rocks of these areas are typically high in silica and potassium. They are notably lacking in extensive hydrothermal alteration and precious metal mineralization either because such features have never been unroofed or because the magma-water systems never evolved. The phenocryst assemblage of most of these rocks is also similar in that hydrous mafic phases such as biotite and hornblende are notably absent. The rocks typically contain abundant andesine to oligoclase-plagioclase phenocrysts and microphenocrysts of clinopyroxene and magnetite. Alkali feldspars, sanidine, quartz, and minor amounts of orthopyroxene and fayalite olivine occur in some units. The Idavada Group is composed largely of welded ash-flow tuff sheets with the above characteristics.

The oldest rhyolites of the Idavada Group are situated in an area along the Oregon-Idaho border (117°E). Armstrong and others (1975) show that the rhyolites of the group become systematically younger east to Yellowstone National Park where large Quaternary-aged calderas, young rhyolite, modern hydrothermal activity, and geophysical evidence attest to the dormant volcanic system (Christiansen and Smith, 1981). A general facies relationship of volcanic and sedimentary fill has also shifted from west to east across the plain so that in any local section one sees (from oldest to youngest): (A) silicic volcanic rocks, mostly ash flow deposits with minor basalt and sediment intercalations; (B) basalt flows with minor intercalated sediment and local silicic volcanic rocks; and (C) lacustrine and fluvial sediments complexly interstratified with basalt flows (Armstrong and others, 1975). The systematic-age decrease of the Snake River Plain rhyolites to the east has been interpreted by many as a record of the continental lithosphere sliding over a fixed "hot spot" in the mantle at an average rate of 3.5 cm/yr. This hypothesis is analogous to the age progression in basalts forming the Hawaiian Islands-Emperor Seamount chain in the north-central Pacific Ocean. This concept gained wide acceptance until MacLeod and Walker (1976) reported that rhyolites of the High Lava Plains province of eastern Oregon become systematically younger to the west at a rate of 3 cm/yr, a pattern diametrically opposite to that observed in southern Idaho. The Oregon system terminates at the north-south trending Cascade Range of dormant and active calc-alkaline magma systems. The age progression through

eastern Oregon now casts doubt upon the simple "hot spot" hypotheses. No widely accepted kinematic model presently exists to explain both sets of K/Ar age dates on silicic volcanism, although the tectonics of the region have been recently reviewed by Brott and others (1978), Christiansen and McKee (1978), and Smith (1978). Although few of these late Cenozoic volcanic areas have been studied and little comparative petrography and geochemistry exists for the rhyolites, the general similarities cited above appear to be valid except for the dormant volcanic systems at the east and west ends.

Public and proprietary subsurface data is available for much of the western Snake River Plain, some of which is reviewed by Wood and Anderson (1981). We still lack a good understanding of the margins of the western plain, largely because of a lack of geologic mapping, although mapping by Ekren and others (1980), Wood and Burnham (1983), and Wood and Garder (1984) have added new information. It is the purpose of this review to point out some aspects of recent economic interest in the western plain and the more important findings from the subsurface data. A full synthesis and interpretation remains to be done.

Thickness of the Cenozoic volcanic and sedimentary fill in the western Snake River plain is at least 4.3 km (14,000 ft) as demonstrated by the section penetrated by the J.N. James No. 1 exploratory well (Halbouty-Chevron, 1976) located about 16 km (10 mi) west of Boise. The well bottomed in a section of volcanics of intermediate composition and of unknown age (Fig. 3-4). Notable is the 2100-m (7000-ft) section of basalt beneath the 728 m (2390 ft) depth, and the absence of a clearly identifiable section of Idavada rhyolitic or tuffaceous rocks. The well drilled a structural high with 700 m (2100 ft) of relief (Fig. 6-7). The structure trends NW-SE and shows up on the regional gravity maps as a +20 milligal anomaly.

The lacustrine and fluvial fill above the volcanic acoustic basement reaches a thickness of about 1700 m (5600 ft) at the western end of the seismic line in Figure 6 near Caldwell, Idaho. This deep trough of Idaho Group sediments extends NW into the Ontario, Oregon area where a similar section is encountered in deep drilling and seismic data (Wood and Anderson, 1981; Applegate and Donaldson, 1979).

The natural gas and geothermal water potential of the Cenozoic sedimentary section has attracted a number of exploration ventures in recent years. Geothermal gradients from deep wells are shown in Figure 5, and the wells are located on Figure 2. The most successful geothermal operation has been for space-heating in the City of Boise (Wood and Burnham, 1983).

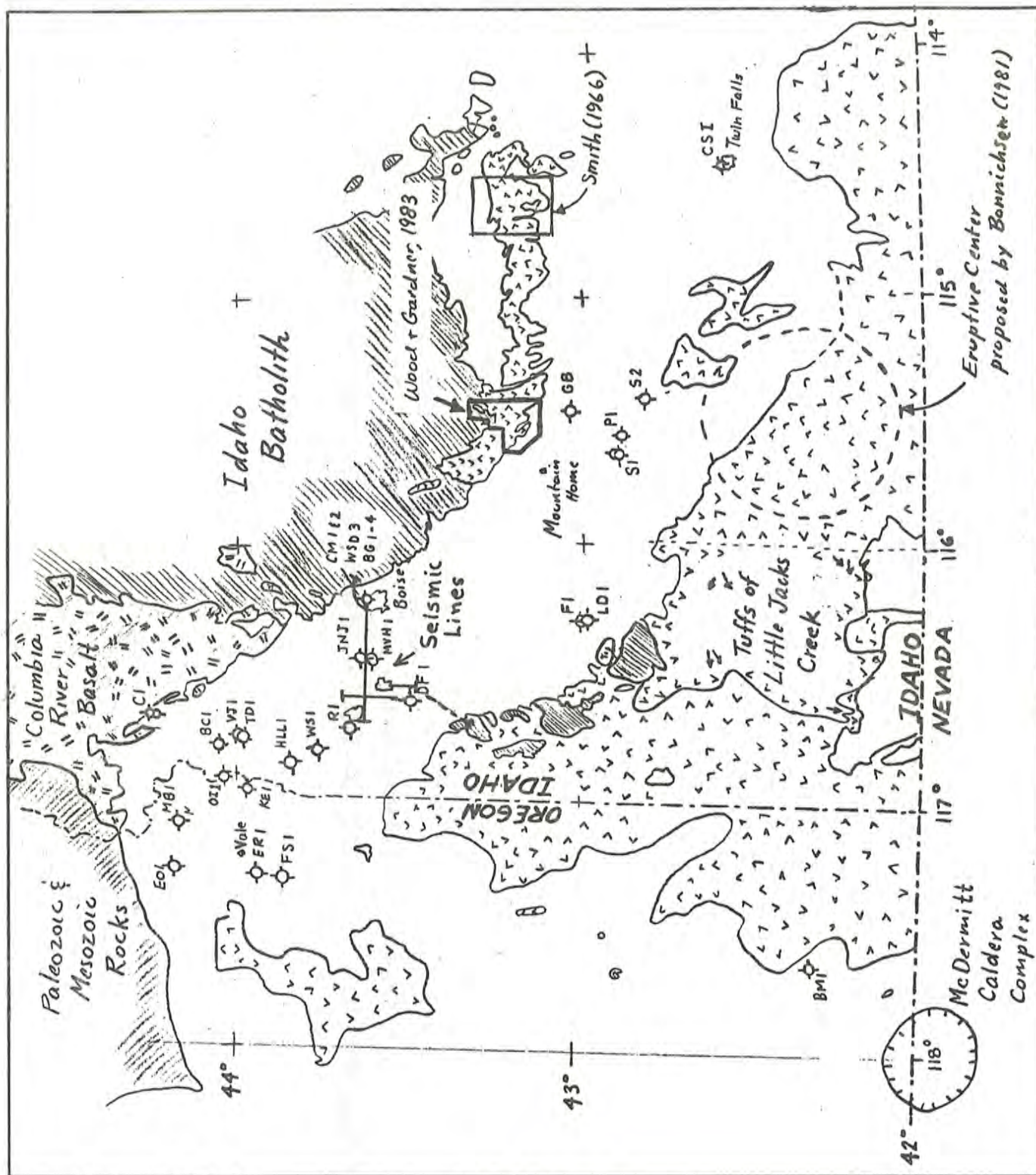
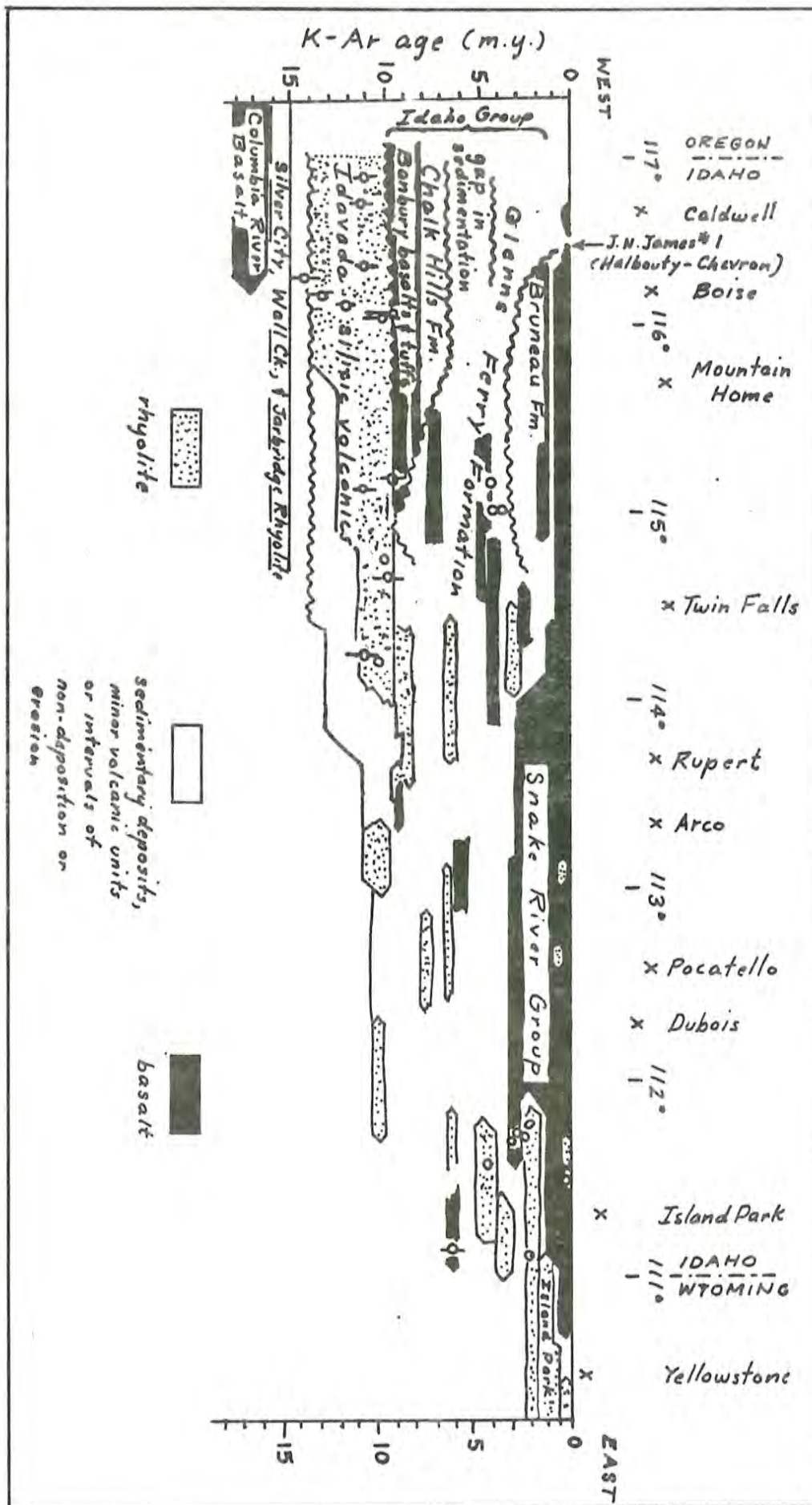


Figure 2. Map showing location of east-west seismic section (Fig. 6) from Boise to Caldwell, and north-south line through Nampa to the Deer Flat No. 1 well Champlin Oil Co., 1980) and extended to the south margin of the plain from surface mapping (Fig. 7). Also shown are locations of deep geothermal and petroleum exploration wells as of 1981. Area shaded with NE-trending lines is the outcrop area of Mesozoic granitic rocks. Area shaded with small "v's" is covered with a carapace of rhyolitic volcanic rocks of late Cenozoic age.

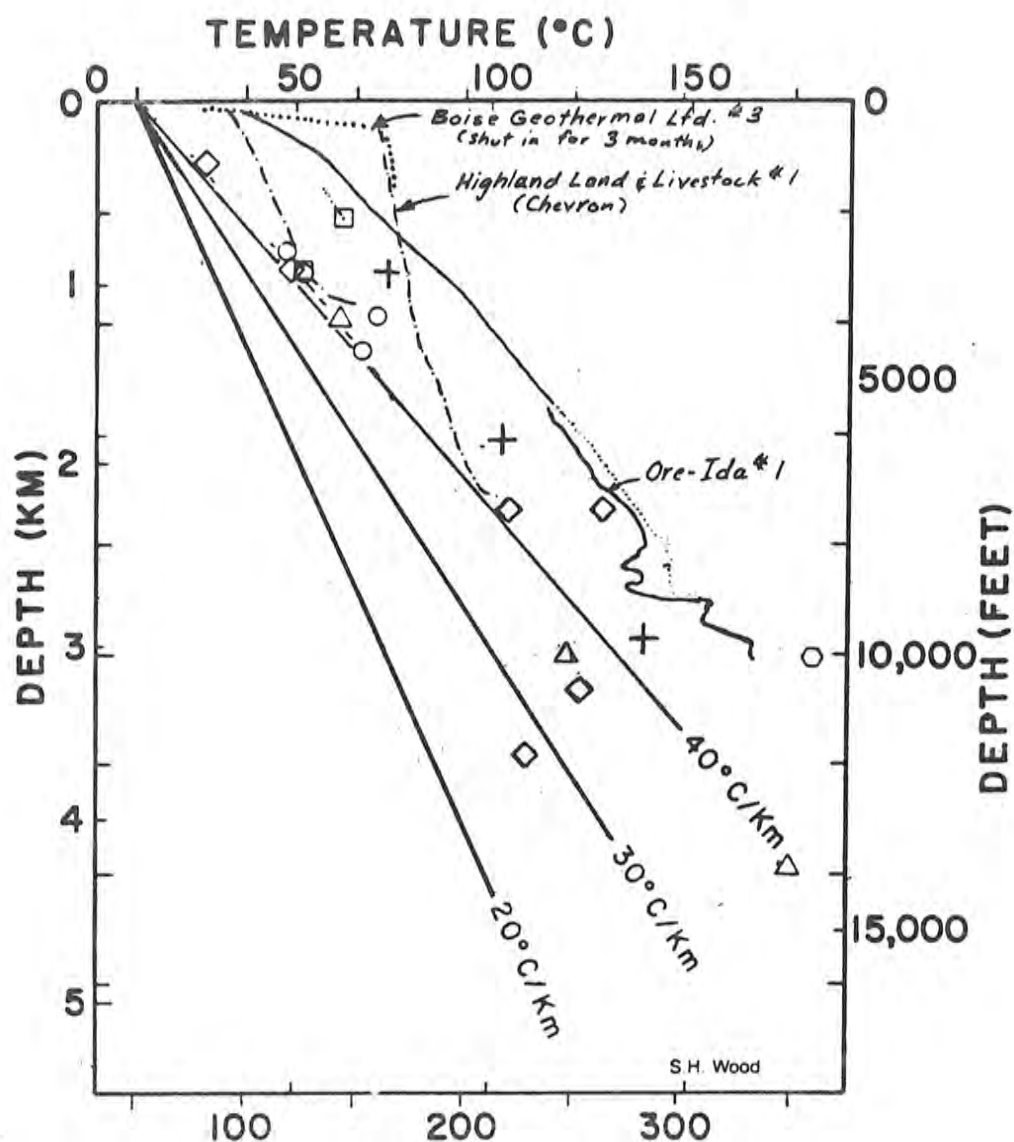
Figure 3. Space-time profile along the Snake River Plain, Idaho showing the eastward migration of rhyolite volcanism and accompanying facies relationships across the plain (modified from Armstrong and others, 1980 and 1975). Open circles are K/Ar dates as of 1980 reported by Armstrong. Diagram has been modified west of 116°E to be consistent with stratigraphy in this paper. The interval of Idavada Rhyolites is absent in the J.N. James well and is thin on the NW margin of the plain. Age dates west of 116° are mostly from the Owyhee Uplands.



DEPTH (feet)	AGE	GROUPS & FORMATIONS	LITHOLOGY	DESCRIPTION	DEPTH (meters)
		Snake River Group		Terrace gravels of the Boise River drainage	
	Pleistocene	Upper Idaho Group (Glenns Ferry Formation)		Basalt, dark gray, Titanite-augite, plagioclase, and olivine. 2 flows, 3 to 15 m thick, confined to Indian Creek and Lake Lowell areas	
1000				Silty sand, light brown, fine grained, poorly sorted	
	Plio-Pleistocene	Lower Idaho Group		Claystone, medium brown to light gray (Blue clay in water-well driller's logs)	
		(Chalk Hills & Poison Creek Formations, undifferentiated)		Silt, sand, and claystone, light brown to light gray. Electric logs indicate sands are fair aquifers	500
2000				Sand, gray, very fine to medium grained, fair sorting. Electric logs indicate good aquifer.	
				Siltstone, gray-green	
3000		Basalt I (mostly olivine basalt)		Basalt, dark gray to black, abundant olivine	
4000				Tuff & tuffaceous siltstone, light green, with abundant fragments of light pinkish brown rhyolitic tuff.	1000
				Basalt, as above with tuff and siltstone between flows	
5000				Sand, white, very fine to medium grained, well sorted, arkosic. (Contains tarry oil and gilsonite in the J.N. James no. 1 well).	
				Sand, siltstone, tuff, and welded tuff, interbedded.	1500
				Basalt, black, pyroxene & plagioclase	
6000	Pliocene & Miocene	Basalt II		Sand, very fine to coarse grained & silica cemented sandstone	
7000				Sand, white to light brown, very fine to fine grained, poorly sorted	2000
8000		Basalt III		Basalt, altered to a dark green, zeolite in amygdulae.	
9000				Sandstone, gray-white, arkosic with lithic fragments, very fine to coarse grained, moderately sorted.	
				Siltstone, light to dark brown, laminated, interbedded with moderately sorted arkosic sandstone	2500
				Basalt, black, zeolite in amygdulae.	
				Welded tuff, very colorful, grey-brown-green, quartz and plagioclase phenocrysts.	
				Basalt, black to dark green interbedded with vitric and lithic tuffs.	
				Basalt, black to dark green, massive thick flows chalcidony and zeolite in amygdulae.	
10,000				Sandstone, white to cream, fine to coarse grained tuffaceous.	3000
				Tuff, light to medium grey, welded in part, ashy in part, quartz and feldspar phenocrysts, and altered glass. Interbedded gray-brown clay and brown siltstone.	
				Sandstone, milky-white, poorly sorted, clayey.	
11,000		Sucker Creek Formation		Tuff, as above.	
12,000				Tuff, dark green to gray and lavender, partly hard vitric and lithic tuff. Interbedded with light and dark brown siltstone	3500
13,000		Rhyolites & welded tuffs		Basalt, dark gray to dark green, abundant euhedral plagioclase laths, subhedral olivine(?)	
				Rhyolite-dacite tuff, mottled gray-lavender, quartz and olivine(?) phenocrysts	
				Interbedded vitric and lithic tuffs and grey to lavender welded tuffs, spherulitic in part, pyroxene, amphibole, and quartz phenocrysts.	4000
14,000	Miocene (?)	Older Latites & Basalts, undivided		Latite and Andesite and Dacite (?) flows & tuffs, phenocrysts of amphibole and biotite.	

S.H. Wood

Figure 4. Columnar section showing lithologies encountered in the 14,000 ft. J. N. James #1 exploratory well Halbouty-Chevron drilled in 1976 near Meridian, Idaho. Descriptions of cuttings are from the mud log on file with the state petroleum engineers office.



SUBSURFACE TEMPERATURE (° F)

- △ J.N. James #1 (14,000 Ft. = 4267.2 m., T.D.)
- - - Higgenson #1 (3609 Ft. = 1100 m., T.D.)
- Richardson #1 (3048 Ft. = 929 m., T.D.)
- Webber - State #1 (4528 Ft. = 1380.1 m., T.D.)
- ◇ Highland L & L #1 (11,395 Ft. = 3637.8 M., T.D.)
- Ore - Ida #1 (10,035 Ft. = 3064.5 m., T.D.)
- + Deer Flat #1 (9,300 Ft. = 2958 m., T.D.)
- ... Boise Geothermal #3 (1897 Ft. = 578 m.)

Figure 5. Temperature profiles from selected deep wells in the western Snake River Plain. Points are maximum temperatures from electric logs. Continuous lines are from temperature logs.

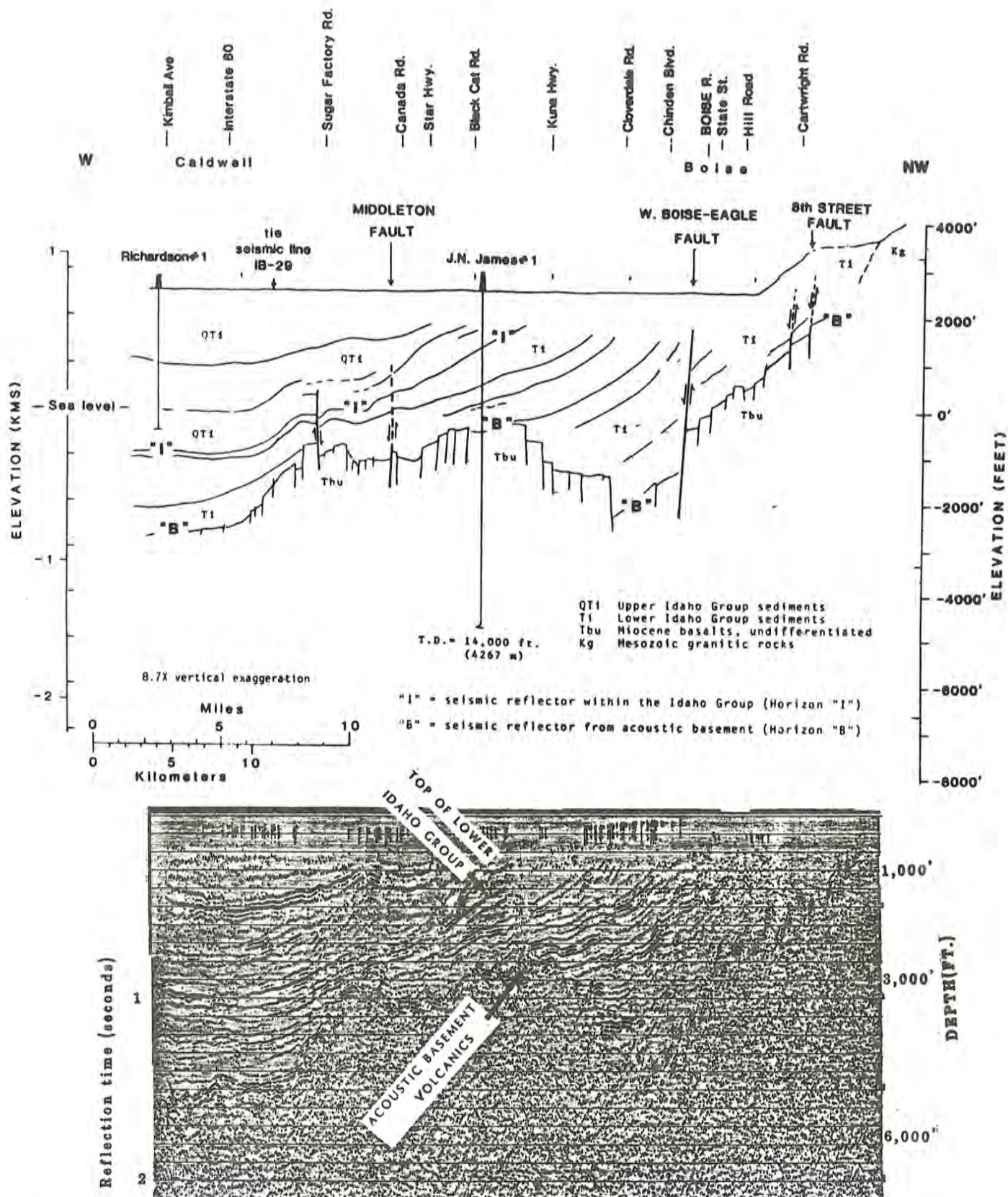


Figure 6. Reflection seismic section and interpretation along an east-west line from Boise to Caldwell, Idaho. Location of section is shown in Figure 2.

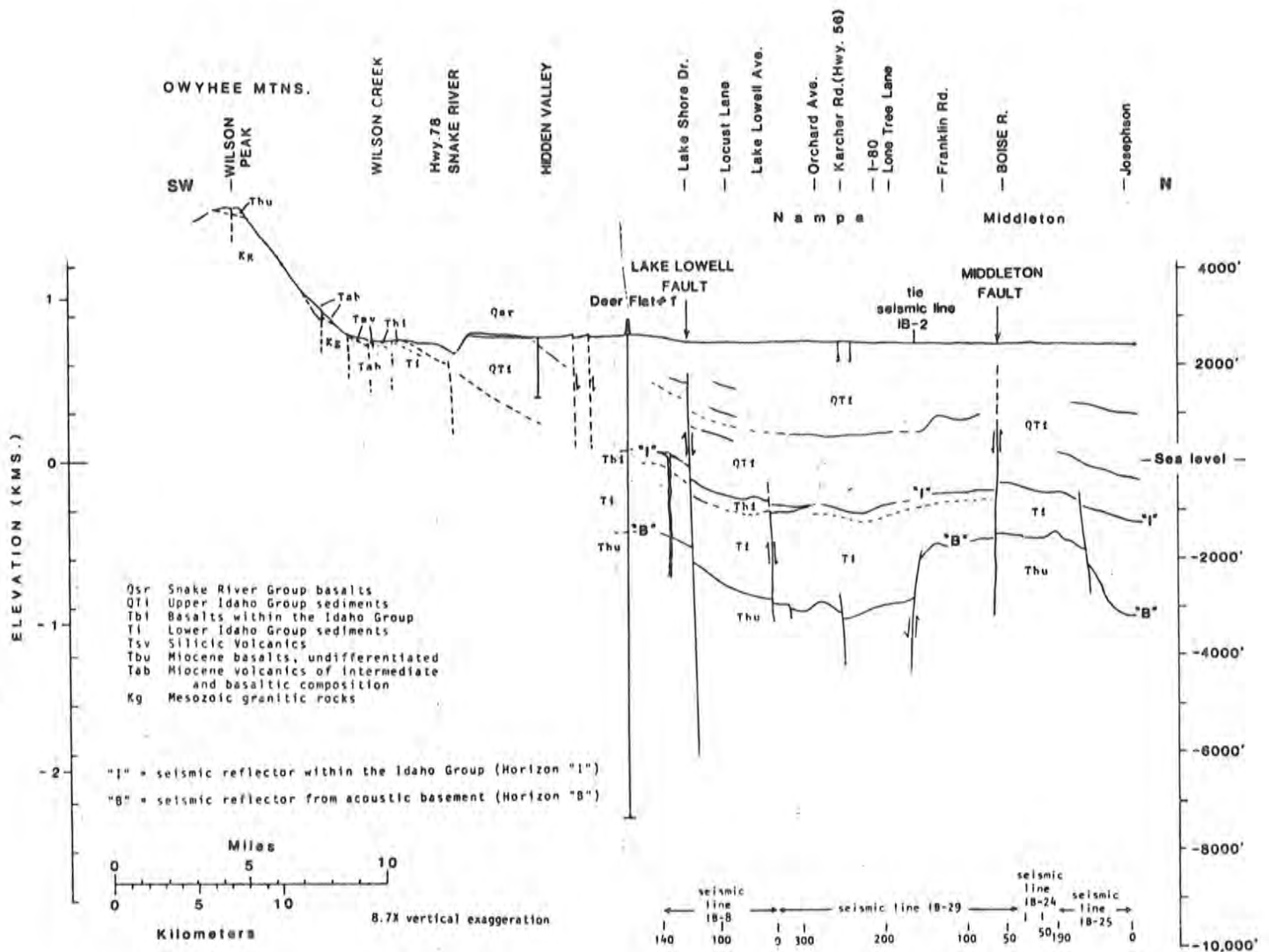


Figure 7. Line-drawing interpretation of a north-south seismic reflection line from Middleton, through Nampa, to the Owyhee Mountains. Geology south of the Deer Flat #1 well is from Ekren and others (1979) and unpublished mapping by S. Wood.

Petroleum exploration dates back to the turn of the century and has resulted in a number of natural gas "blowouts" and other less spectacular shows summarized in Newton and Corcoran (1963). None of the flows could be sustained for a long enough time to be economic, but under favorable market conditions, and the fact that gas occurs within the upper 2500 feet in the Ontario-Payette area, these prospects are still of interest. Almost every deep exploratory well encountered gas in the section from 1500 to 7500 feet. Sanyal and others (1980) have reported on log analyses of shows in the recent 10,000-ft well drilled in Ontario, Oregon. Needed is a study of the subsurface facies of the various sedimentary units to understand the significance of natural gas and also geothermal and cold water resources in the section.

The late Cenozoic fluviatile, lacustrine, and volcanic rocks in the southeast Oregon and westernmost Idaho part of the plain have been explored for the past three years for epithermal precious metal deposits (Gray and others, 1983), after discovery of several "jasperoid-like" paleo-hot spring deposits with significant gold values, particularly in rocks mapped as the Deer Butte Formation by Kittleman and others (1967).

The western Snake River Plain has many interesting prospects and problems to be explored in the future. Whether your interest is gold, hot water, petroleum, regional geology, tectonics, trout fishing; or scenery, we hope you enjoy your visit here, and possibly come back to contribute to the understanding of this region.

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**GEOLOGY OF THE BOISE GEOTHERMAL AREA,
GEOLOGIC ROAD LOG (1984); WITH COMMENTS ON GEOTHERMAL GROUNDWATER**

by Will L. Burnham
3220 Victory View Drive
Boise, Idaho 83725
and
Spencer H. Wood
Department of Geology and Geophysics
Boise State University, Boise, Idaho 83725

FIELD TRIP ROUTE IS SHOWN ON FIGURE 1.

Distance

0.00 mi Parking area at North side of Old State Penitentiary Museum compound,
(0.00 km) behind the Bishop House. Looking north across the south boundary of
Section 12, T. 3N, R. 2E (indistinct fence line) at the ridge slope and the
newly refurbished well house for BSWD (Boise Warm Springs Water
District) wells. The well house contains the original two wells drilled in
1890 for hot water at a prominent hot spring, seep, and marsh area (Wells,
1971). The wells were quickly placed in service to provide space heating
and domestic hot water for homes and businesses, as well as a Natatorium.
Demand for space heating has varied over the years because of the
convenience of gas and electric heat, but current records show that the
wells service some 200 connections. Both wells were redeveloped and
partly reconstructed at various intervals, principally in about 1930. Other
wells have been drilled near these from time to time, but none have been
as successful as the original. The wells are each about 400-to-410 feet
(122-to-125 m) deep, are 31 feet (9 m) apart, and are cased with 12-inch
(30.5-cm) steel pipe to a depth of 160 feet (49 m). Below 160 feet (49
m) the wells are about 9 inches (23 cm) in diameter and are uncased.
Information about the subsurface materials drilled is sketchy, but it is
probable that 160 feet (49 m) marks the base of potentially collapsible
sediments and the top of more stable volcanic rock (see attached diagrams
and cross-sections, Fig. 2). Borehole television inspection in 1980 indicated
hard, fractured rock to about 370 feet (113 m), then coarse conglomerate
to the bottom. Geologic mapping and other well data indicate the rock
is rhyolite.

The wells are both artesian, and will flow at the well house floor (elev.
2,765 ft., 843 m) if not pumped. They have been in continuous use since
1891 and still yield water at the original temperature of 170-172°F (78°C).
To prevent overtopping during summer shutdown, each well casing is tapped
near the top by a line that feeds into the distribution pipeline. The best
available information indicates that static water level has declined a few
feet during the 90-year period--perhaps as much as 18 feet (6 m) (see
Lindgren, 1898). Yield of each well is limited by depth of pump setting
which is at the 160-foot (49-m) casing base. The west well is slightly
the better of the two, and will yield at least 1,200 gpm (gallons per
minute) or 4543 liters per minute when pumped alone. Drawdown
interference between wells is large, and maximum yield with both pumps
operating is only slightly greater than 1,200 gpm (4543 lpm). Average

discharge during the peak of the winter heating season is about 800 gpm (3028 lpm). Average for the season is nearer 500 gpm (1893 lpm). Well tests in 1980 prior to installation of the present pumps gave indicated aquifer transmissivity and storativity values of about 15,000-25,000 gpd/ft. (56,781-94,635 lpd/m) and 1.5×10^{-4} , respectively. In an attempt to increase yield and number of service connections a cable-tool hole was drilled to a depth of 595 feet (181 m) (from elev. 2,785 ft, 849 m) about 650 feet (198 m) northwest of these wells in 1982. This latest well (BWSWD #3) penetrated a fault plane at about 315 feet, (96 m), then was drilled in hard, dense rhyolitic rock to 471 feet (144 m). A white clay occurs to 487 feet (148 m), then pinkish, quartz-rich rhyolite to the bottom at 595 feet (181 m). Insufficient yield and water temperature of about 145°F (63°C) makes the well unusable for planned purposes. It is presently equipped with a water-level recorder to monitor annual trends and the effect of pumping at the producing wells (see attached hydrograph, Fig. 3).

The attached sketch and cross-section of the ridgeslope (Fig. 2), and the stratigraphic chart (Fig. 4) identify the principal geologic features of this geothermal site. The wells are in, or very near, at least one of three distinct fault planes that strike along the ridge base (Fig. 5) and dip 65° to 80° south. The northernmost fault is immediately north of BWSWD #3 and is the one cut by the well at about 315 feet (96 m). The middle fault trace is sub-parallel and trends about through the production wells. The third, and apparently largest, fault offset is on a plane again sub-parallel and trending just behind the old penitentiary, beneath the parking area. The tabular blocks between the faults are tilted to the northwest about 12°, forming ramps on the down-dropped sandstone surfaces as seen to the right of the well house. The ridge face behind the well house is a moderately eroded fault scarp, exposing sandstone and siltstone along the crest, resting on a thin greenish-gray claystone, all sediments of the lower Idaho Group (see stratigraphic chart attached, Fig. 4). The claystone is unconformable on porphyritic basalt that, in turn, laps unconformably against the higher of the two rhyolitic rock outcrops to the west, or left (locally referred to as Castle Rock). Large (several centimeters) phenocrysts of feldspar occur in the basalt, as well as zeolite, calcite, and opaline secondary deposits. The basalt occupies the same stratigraphic position as basalt flow units at the base of the basaltic tuff unit (Tbt) found in outcrops throughout the area and in the geothermal wells at Military Reserve and Capitol Mall. The remainder of the scarp face is composed of two distinctive rhyolitic rock types (Tsv₁ on stratigraphic chart, Fig. 4,5), best seen in and around the two prominent outcrops of "Castle Rock." The higher and larger mass is a stoney rhyolite flow, or densely welded rhyolite tuff, displaying well-developed sheet jointing, the orientation of which suggests a tight asymmetrical anticlinal fold whose axis plunges gently north. This is the outcrop described as a laccolith by Lindgren in his 1898 report, and argued over by geologists ever since. There is now good evidence to indicate that the exposure represents only the draping of the lower Idaho Group sandstone (Til) over the rhyolite, with a large erosional unconformity between.

The core of the nearer, smaller outcrop is the same stoney rhyolite,

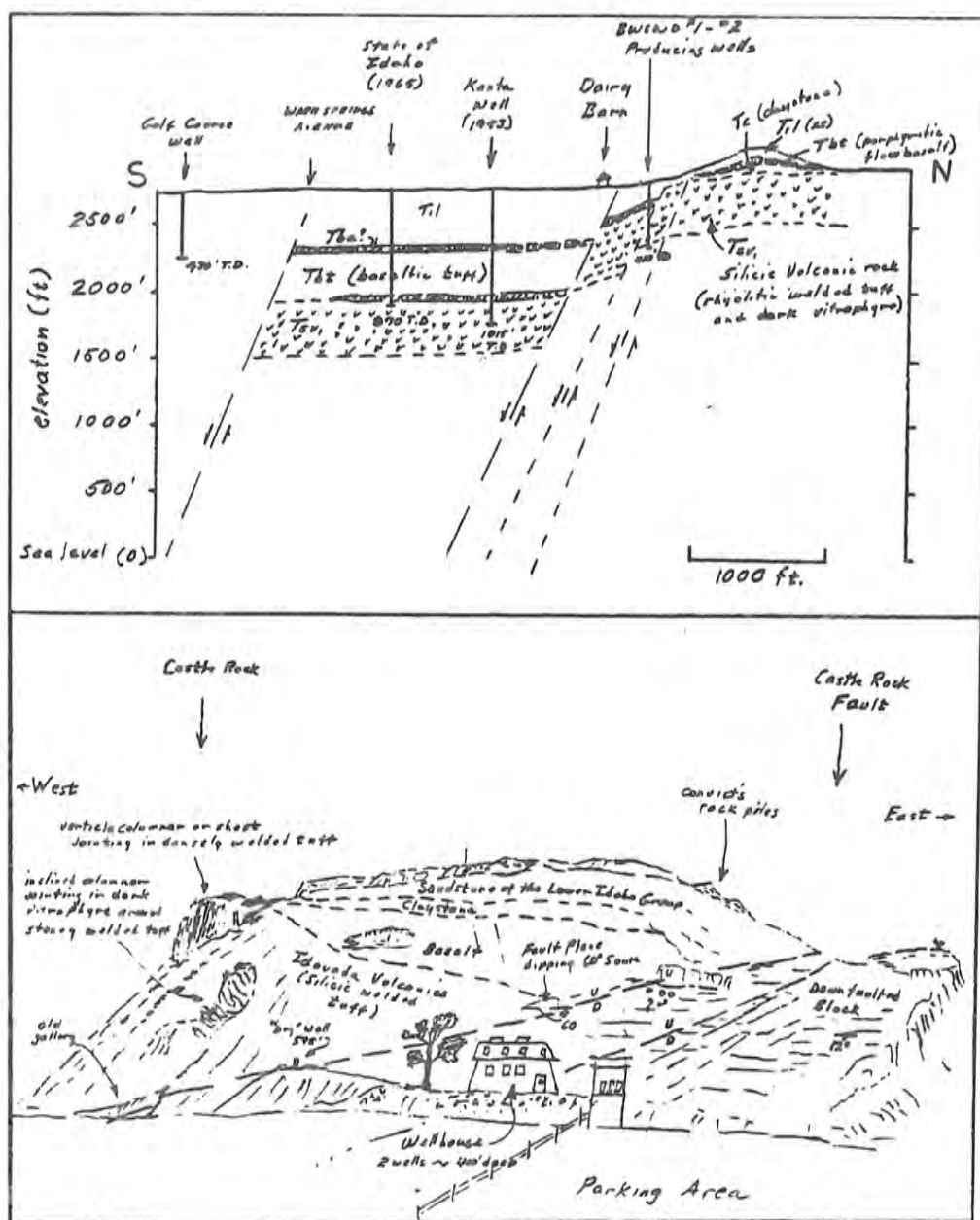


Figure 2. Sketch and generalized Cross-Section across east end of ridge behind old State Penitentiary and BWSWD wells showing geologic units and fault displacement.

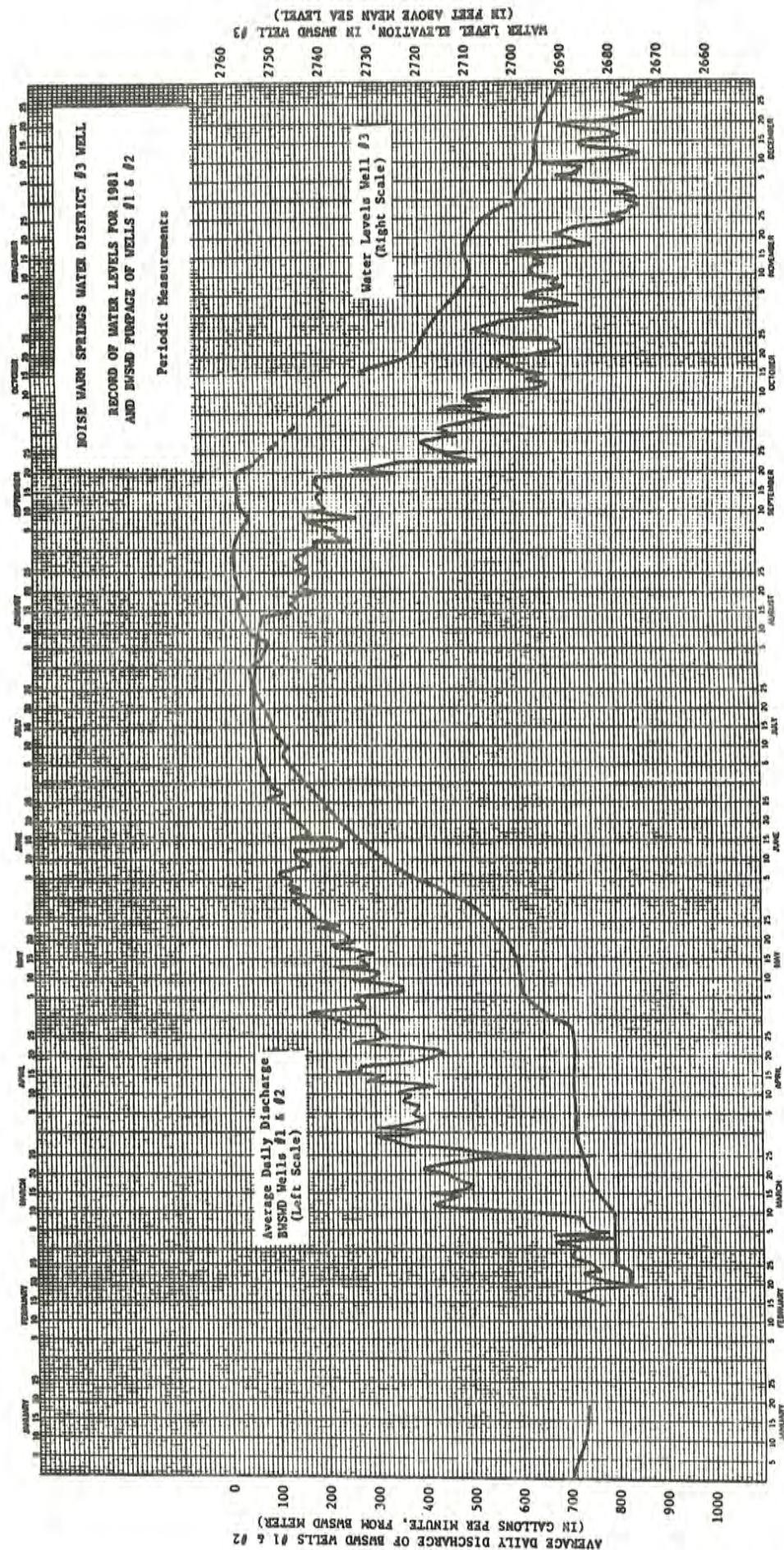


Figure 3. Boise Warm Spring Water District #3 well. Record of water levels for 1981.

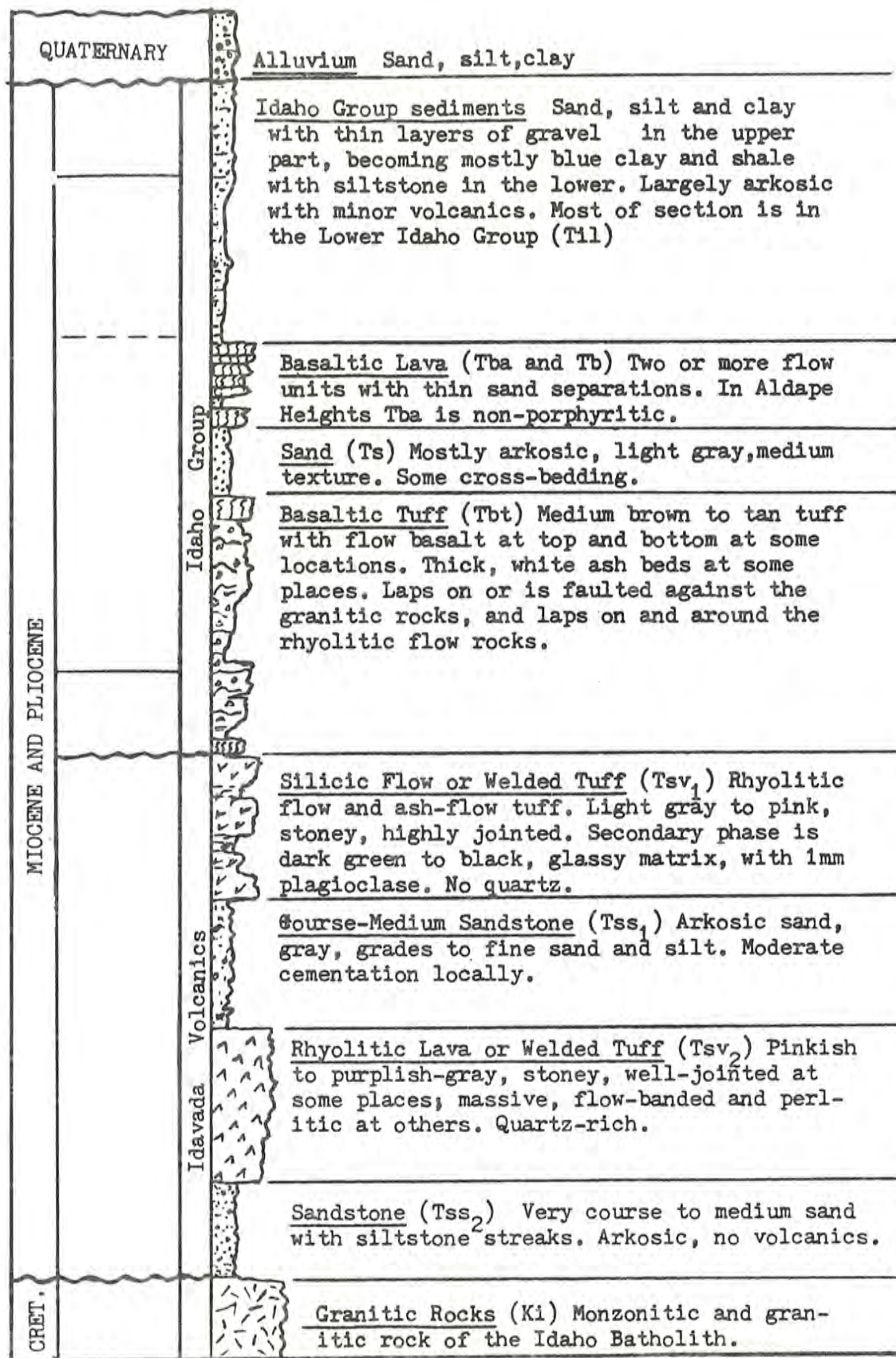
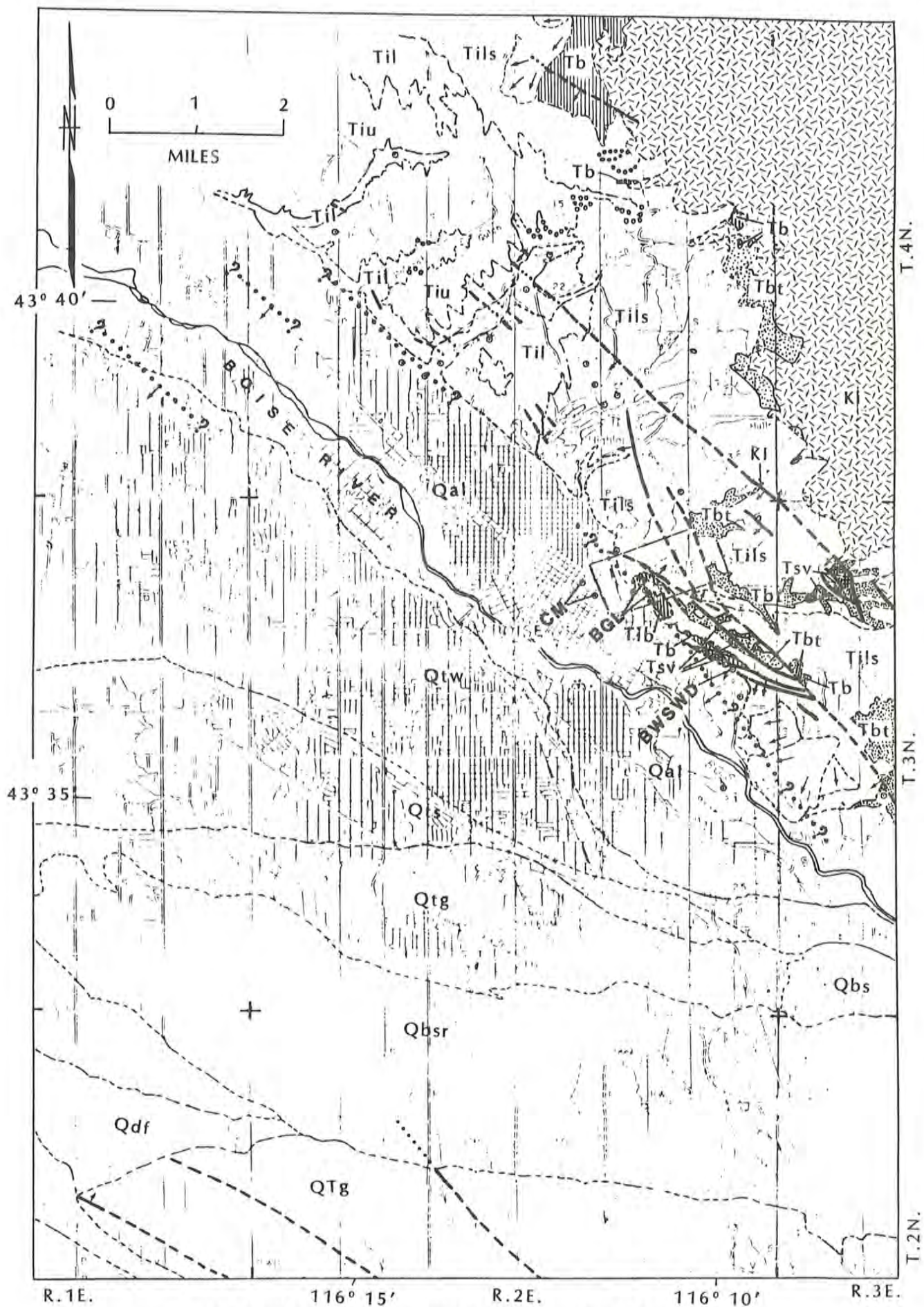


Figure 4. Stratigraphic and lithologic sequence of the principal rock units seen in outcrop within the foothills, and in the geothermal wells near Boise.



GEOLOGIC MAP OF BOISE, IDAHO

EXPLANATION

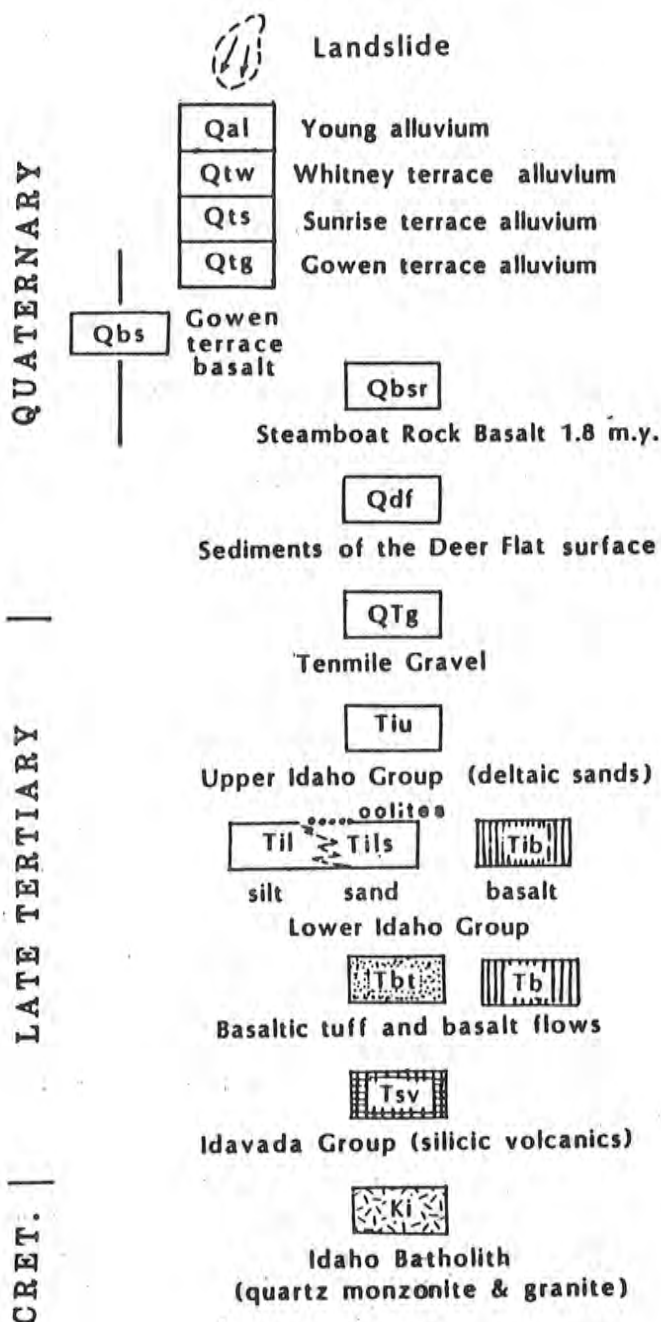


Figure 5. Geologic map of the Boise, Idaho area, and location of the principal producing wells of the geothermal system. Faults are shown with a solid line where the trace can be mapped from surface exposure and offset beds. Exposed fault planes where dip can be measured are shown with a small arrow indicating dip direction. All faults have normal displacement. Dashed line indicated inferred location of fault where exposures are poor. Dotted line indicates a buried fault trace located by seismic reflection surveys, by ground magnetometer surveys, from well logs, or a location inferred by extending a surface outcrop beneath a younger depositional unit. Question mark indicates a projection of the fault trace beyond geophysical or other subsurface control.

although the jointing is oriented more to the northwest and the fold upside down. Surrounding this outcrop is a dark green or brown to nearly black, porphyritic rhyolitic vitrophyre. Plagioclase phenocrysts in the glassy matrix are about 1 to 1.5 mm (.04 to .06 in.) in size. The rock displays large hexagonal joint columns, oriented perpendicular to the plane of faulting.

Fragments that appear to be derived from the stoney rhyolite may be seen near the contact with that rhyolite as inclusions in the vitrophyre. An excellent exposure of hydrothermally altered and leached rhyolitic rock occurs along the northernmost fault plane immediately north of BWSWD #3. Also, the two stoney rhyolite outcrops are separated by a north-trending zone of hydrothermal alteration and silicification.

Finally, the fault group displayed here marks the southern boundary of a triangular horst block that underlies most of the Foothills East Subdivision area, across the ridge to the north of this locality, and extends northwestward beyond Military Reserve Park. Displacement of the rhyolitic rocks across this fault group is indicated to be at least 800 feet (243 m), down to the south. A recent well drilled in the down-thrown block (the Kanta well at the SE corner of the old prison compound) reached rhyolite at about 790 feet (241 m) below elevation 2,765 ft. (843 m), which matches closely the log of a second well to the southeast (State Old Pen well). A second new well drilled for Boise City Parks Dept. in the open flat about 600 ft. (183 m) south of "Castle Rock" also reached top of rhyolite at 700 ft. (213 m) below land surface elevation, 2,735 ft. (834 m). Although this shows a rhyolite offset of at least 800 ft. (243 m), the top of the overlying basaltic rock sequence is offset only about 550 to 600 ft. (168 m to 183 m).

In this structural block, faulted down at least 800 ft. (243 m) below "Castle Rock", the maximum temperature of water from the three known hot-water wells in the block is at least 10 degrees F (-12°C) less than that of the BWSWD wells. The reason may be both because of mixing with cold near-surface water, and because of lateral distance of the wells from major fault planes.

- 0.35 mi.
(0.56 km) Stop sign. Intersection with Warm Springs Avenue (Hwy 21), turn right. The subsurface trace of the principal Boise Front Fault (Foothills Fault of Hollenbaugh) is believed to pass at about this point and trend about parallel to Warm Springs Avenue to the left. This fault further displaces the rhyolite down to the south.
- 0.60 mi.
(0.97 km) Trolley House Restaurant and School on left. Immediately behind is a Boise City swimming pool. This is the site of the Natatorium, which was a major user of BWSWD well water until the 1950's. Continue on Warm Springs Avenue.
- 1.10 mi.
(1.77 km) Locust Street. Turn right toward foothills. At least 200 homes along Warm Springs Avenue and the first two blocks here on the north side use the BWSWD well water for space heat and for domestic hot water. The water is delivered through either a meter or an adjustable orifice. Spent water is discharged to the sewer or to canals leading to the Boise River (See map; BWSWD distribution system, Fig. 7). Recently some spent water

	SERIES	GROUPS AND FORMATIONS		
		South of Snake River	Boise Area	
Pleistocene	Recent	Snake River Group**	<u>Alluvium</u>	
	Upper		Melon Gravel*	<u>Terrace Gravel</u>
			Bancroft Springs Basalt*	Boise River
			Sand Springs Basalt	Whitney
			Crowsnest Gravel*	Sunrise
			Thousand Sprgs. Basalt**	Gowen
			Sugar Bowl Gravel*	<u>Snow River Basalt</u>
			Madson Basalt	(Unconformity)
	Middle	Idaho Group**	<u>Black Mesa Gravel*</u>	
	Lower		Bruneau Formation*	<u>Tennile Gravel</u>
Tuana Gravel*			<u>Upper Idaho Group</u>	
Glenns Ferry Formation*			Glenns Ferry Formation	
Upper			<u>Lower Idaho Group</u>	
Middle	Chalk Hills Formation*		<u>Basaltic Tuff</u>	
Pliocene	Lower	Banbury Basalt		
		Poison Creek Formation		
		(West) Idavada Volcanics* (East)	<u>Idavada Volcanics</u> Tertiary Sandstones	
Miocene	Upper and Middle	Undifferentiated rocks	(Unconformity)	
Eocene-Cretaceous			<u>Idaho Batholith</u>	

*New stratigraphic names

**Old stratigraphic names, redefined

Figure 6. Upper Cenozoic stratigraphic units of the western Snake River Plain proposed by Malde and Powers (1962), and as adapted for the Boise geothermal area.

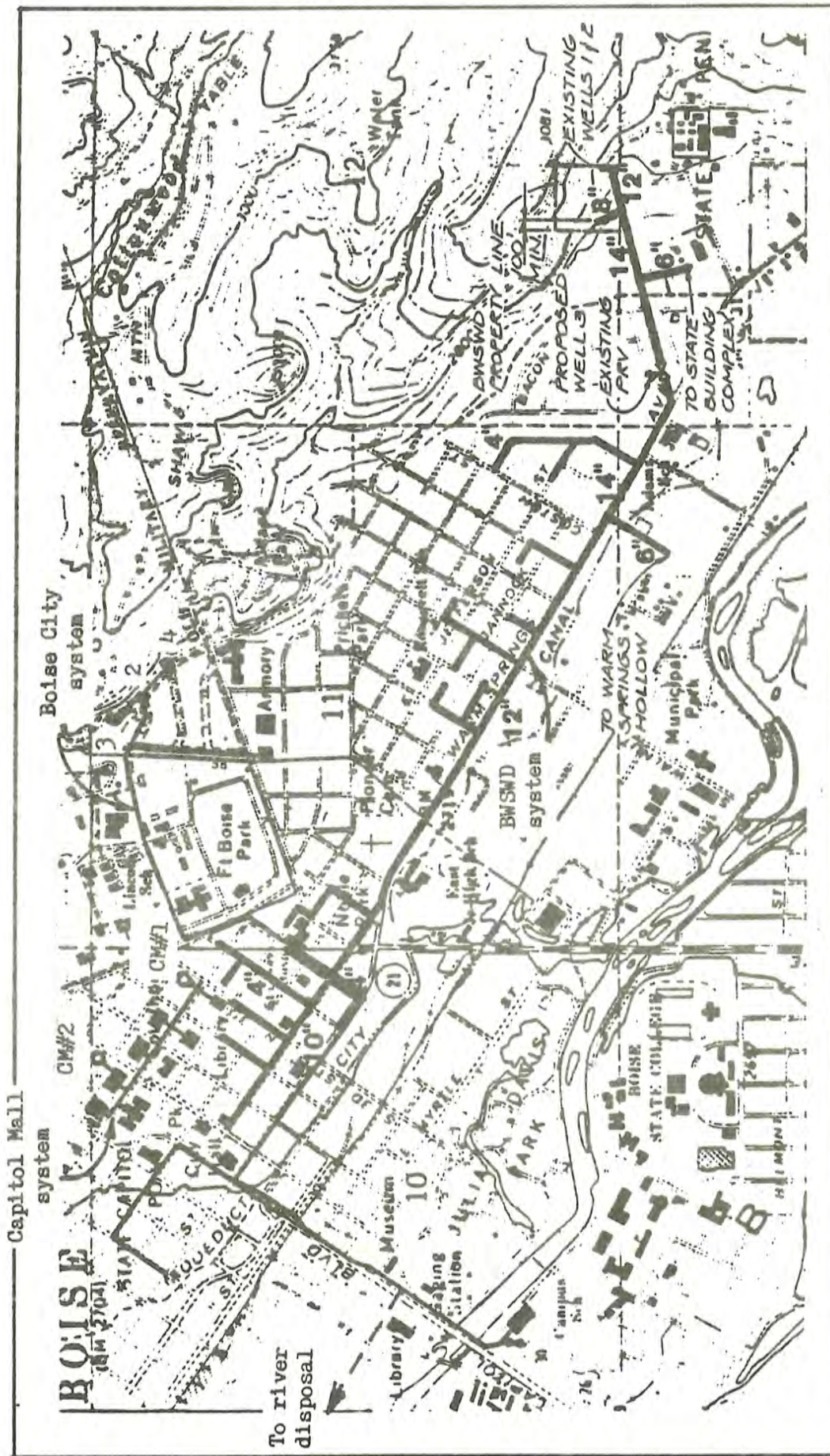


Figure 7. Distribution and service areas for the three separate geothermal systems in place in Boise. The Boise City and Boise Warm Springs Water District systems are inter-tied. The Capitol Mall system serves State of Idaho facilities, and is a separate closed system.

has been diverted for use in experimental prawn culture before final discharge.

- 1.45 mi.
(2.33 km) Locust Street crosses the principal faults of the Boise Front about here. Cross onto the horst block. Immediately ahead is thin alluvium on basalt at the base of the basaltic tuff unit.
- 1.60 mi.
(2.57 km) Turn right onto Shenandoah and enter Foothills East Subdivision.
- 1.80 mi.
(2.89 km) The knob on the left is capped by lower Idaho Group Sandstone (Til) overlying porphyritic basalt. Sandstone overlies flow basalt under the ridge coming into view on the right, leading up to "Castle Rock." The horst block is broken in this vicinity by internal normal faults, with displacements of a few feet to tens of feet. The faults trend mainly NW and dip steeply. Continue around Shenandoah St.
- 2.10 mi.
(3.38 km) Intersection with Rimrock Street on left. The multiple dwelling units ahead on the right are about on one of the northeast boundary faults of the horst block. Several sub-parallel normal faults, down to the northeast, are present in this vicinity and trend SE through the large depression on the right. The faults bring lower Idaho Group sediments down against basaltic tuff, flow basalts, and older lower Idaho Group sediments.
- 2.30 mi.
(3.70 km) Turn right on Shaw Mtn. Road. Immediately after the turn, Shaw Mtn. Road crosses the trace of the principal northeast boundary normal fault of the horst block. The fault trace is covered by unfaulted terrace gravel here, but strata of the block immediately ahead (NE) are down, relative to those of this block. The down-faulted, graben-like block is narrow at this southeast end, and widens to the northwest. It is tilted several degrees northwest.
- 2.50 mi.
(4.02 km) Bear left on Shaw Mtn. Road.
- 2.60 mi.
(4.18 km) Descending the south wall of Cottonwood Creek Canyon. A good view of the nearly flat-lying, brown, basaltic tuff unit, overlain by light gray sand, is ahead just beyond the ranch house in the canyon on the left. Just ahead, the road crosses a second main zone of normal faults of the Boise Front zone of faulting. Although not well exposed along the road here, these faults are clearly traced both to the northwest and southeast, and mark the northeast boundary of the graben block just crossed. Trend of the faults is about N38°W with a steep SW dip. Throw is down to the SW, such that the basaltic tuff exposed beyond the house is found in wells this side of the fault at greater depths.
- 3.00 mi.
(4.82 km) Cross cattleguard, then Cottonwood Creek. On ridge point at northeast side of tributary from the right, basaltic tuff is overlain by white sand (Ts), which in turn is unconformably overlain by Quaternary bouldery terrace alluvium (Qg). The white sand is Tertiary and everywhere in this vicinity marks the contact between basaltic tuff (Tbt) and the lower Idaho Group sediments. The Quaternary gravel above is a terrace deposit and is not known to be faulted within the foothills, and marks an ancestral Cottonwood Creek drainage system. It is traceable from terraces at the

present mouth of Cottonwood Creek, to an elevation of about 3,500 ft. (1067 m) in upper Picket Pin Creek ahead.

- 3.20 mi.
(5.15 km) Cross 100-ft. (30 m) offset in top of basaltic tuff, down to SW.
- 3.30 mi.
(5.31 km) Good view of basaltic tuff unit in canyon wall on south side of creek. Tuff on both sides of canyon and in the roadcuts on the left. Here the tuff is overlain by red-brown arkosic sand and silt, without the distinctive gray-to-white sand separator.
- 3.70 mi.
(5.95 km) Road crosses onto outcrop of purplish-gray, glassy, flow-banded, welded rhyolite tuff (Tsv₂). Basaltic tuff, overlain by lower Idaho Group sandy sediments, laps onto and over the rhyolite in the ridge on the left. Across the creek the basaltic tuff appears to lap onto the rhyolite. The rhyolite here is a dark vitrophyre of the lower (Tsv₂) unit shown on the stratigraphic chart.
- 3.80 mi.
(6.11 km) Stop 1. Confluence of Cottonwood Creek and Picket Pin Creek. Purplish-gray perlitic rhyolite on the point between the creeks is characteristic of similar outcrops near and surrounding the base of the Tsv₂ unit. The west edge of the rhyolite outcrop here between the creeks is beveled to a uniform, flat, bench surface some 20 or 30 ft. (6 or 9 m) above the creeks. The red-brown fluvial deposit above the bench is in the lower Idaho Group and the basaltic tuff is missing. Thus this contact marks a large erosional unconformity at this locality. The top of the basaltic tuff unit appears at, or just above, road level in the canyon wall on the north side of Cottonwood Creek, yet about 2,000 ft. (610 m) up Picket Pin Creek the top of basaltic tuff is more than 500 ft (152 m) above this point. There, as here and to the west, the tuff is nearly horizontal. The rhyolite flow of Rocky Canyon is at least 200 feet (61 m) thick, and may be as much as 400 ft. (122 m) thick. The rock is complexly flow-banded and highly fractured, varying in color from dark and glassy gray-brown to a stoney lavender-gray. It contains euhedral quartz and phenocrysts of both plagioclase and alkali feldspar. Mafic minerals are not conspicuous, but careful examination is yet to be done. Flow features suggest it may be either a densely welded ash-flow tuff or rhyolite flow. It is known to occur in the subsurface in Freestone Creek, 1.5 miles (2.4 km) northwest. Note that the top of the rhyolite exposure rises in sharp steps. Faults are not clearly evident in the gorge walls, but fracturing is intense and these are believed to represent vertical displacement. Laterally, along the mountain front in both directions, there is evidence that the third principal fault trace of the Boise Frontal Fault zone lies through this locality.
- Continue up Rocky Canyon Road.
- 4.00 mi.
(6.44 km) Note sudden offset in height of canyon walls, then immediately the near-vertical fracture patterns in the rhyolite on either wall.
- 4.30 mi.
(6.92 km) Stop 2. At upstream margin of rhyolite. On the left, north of the road in thick bushy growth, the granite of the Idaho Batholith (Ki) is in fault contact with basaltic tuff. These red-brown deposits give the color to the saddle-like swale in the contact zone between the granite and the

rhyolite. South of the creek (to the right) the basaltic tuff is clearly evident in the lower part of the canyon wall, and appears to lap against the rhyolite. A few hundred feet upstream, an old mine adit follows a fault contact between granite and basaltic tuff. The contact zone here has not been studied sufficiently to determine just how the granite, rhyolite, and basaltic tuff occur. It appears, however, that the basaltic tuff overlies or laps against the rhyolite, and that both are faulted against the granite on a contact that trends N52°W and dips toward the southwest about 72 degrees. (See geologic map sections.)

4.45 mi.
(7.16 km)

The road bends sharply left, then back 90° right. The granitic rock here is biotite bearing, but much of the rock is hydrothermally altered so it contains no visible mafic minerals. Originally it was probably a biotite quartz monzonite. In the tributary to the right, there are hydrothermal quartz veins and alteration in the granitic rock. Note the consistent joint sets or extensive fracturing in the area.

Continue up Rocky Canyon Road through the granitic rock exposures, noting the great variability in degree and orientation of jointing and fracturing. Flow basalt caps the south canyon wall ridge, lying unconformably on both the granitic rocks and basaltic tuff. Stratigraphically this basalt overlies unconformably the basaltic tuff, and is equivalent in position to the flow basalts at the top of the basaltic tuff unit at the mouth of Cottonwood Creek. The basalts of the two localities are very dissimilar in texture and mineralogy, however. Unconformably on this basalt, and on the granitic rocks of the north canyon wall, is gravelly alluvial sediment of the lower Idaho Group.

6.00 mi.
(9.66 km)

Basalt dikes cutting granitic rocks in roadcuts.

6.25 mi.
(10.06 km)

Stop 3. Turn around at mouth of Fivemile Canyon. Numerous old workings for gold in quartz veins occur up this canyon. Large outcrops with prominent jointing are seen ahead in Cottonwood Creek and on the east wall of Fivemile Canyon.

Turn vehicles around and retrace the trip. The intent now is to use this as the beginning point for a trip upward in stratigraphic sequence (and time) across most of the rocks of importance to the geothermal system and the wells. The best conceptual model at present is that recharge to the thermal water flow system occurs here and to the northeast over the jointed, fractured granitic rocks, and through the intense fracturing of the rhyolitic rocks. Consider this concept as we now backtrack through Rocky Canyon and emerge on the basaltic tuff. The tuff is widespread throughout the Boise Front and into the valley. It has very small cross-bed permeability and does not accept recharge readily. It is broken by the faults, but the basaltic composition tends to alter to clay wherever faulting has allowed contact with hydrothermal conditions. Thus, the basaltic tuff and overlying Idaho Group sediments provide a hydraulic cap to the deep circulation system in the granitic and rhyolitic rocks. We climb back out of Cottonwood Creek onto Idaho Group sediments and Qg as we return to the intersection of Shaw Mtn. Road and Shenandoah Street.

0.00 mi.

Re-set odometer to 0.0 at junction of Shaw Mtn. Road and Shenandoah.

- (0.00 km) Continue down Shaw Mtn. Road and recall that we are again on the horst block.
- 0.25 mi.
(0.40 km) Fault on right in roadcut bank of cross-bedded yellowish sand. This fault is one of the main internal structural features of the horst block. It strikes NW and dips 62° NE. A second, similar fault is visible again on the right a few hundred feet further on around the curve. The faulted sand belongs near the base of the lower Idaho Group sediments. Basaltic flow units, at the base of the basaltic tuff, outcrop a short distance below the road on the left.
- 0.60 mi.
(0.97 km) Cross contact at base of the uppermost basalt flow units in the area (Tba), designated the basalt of Aldape Heights on the stratigraphic chart. Below the road, on the left, there are exposures of a light gray sand that separates this basalt from the basaltic tuff sequence. Continue around Shaw Mtn. Road on the Aldape Heights basalt (Tba), which dips about 15° southwest.
- 0.70 mi.
(1.13 km) Looking northwest along the toe of the Boise Front and the trace of the principal faults of the Frontal Fault zone. Straight ahead are the four Boise Geothermal Limited wells, BGL-1 thru 4 and test hole BGL-1 (Beard). Three sub-parallel planes of normal faulting are known to occur along or near the break in slope, with a down-to-the-southwest throw of rhyolitic rocks totaling about 900-1,000 ft. (274-305 m) (Fig. 8,9). Throw on the basaltic tuff is about 450 ft. (137 m), and on the basalt of Aldape Heights (Tba) is about 270 ft. (82 m). The fault planes here dip about $80-85^{\circ}$ SW. This fault zone trace is the same one noted earlier beneath Warm Springs Avenue near the old penitentiary.
- 0.90 mi.
(1.45 km) Continue left on Reserve Street.
- 1.10 mi.
(1.77 km) Turn right at signal onto Mountain Cove Road. Berms on the right bound flood-control basins for Cottonwood Creek and Freestone Creek drainages. Controlled outflow is through the flume along the road, on left.
- 1.40 mi.
(2.25 km) Cross headgate structure and turn right onto dirt track up the frontal slope. Exposure at base of slope on left and around the ridge into Cottonwood Creek is the uppermost of two distinct basalt flows of the Aldape Heights basalt (Tba).
- 1.70 mi.
(2.74 km) Stop 4. Park in designated area for overlook into Cottonwood-Freestone Creeks. Walk about 200 ft. (61 m) north to picnic shelter and overlook. We are on the Quaternary terrace gravel noted earlier as we crossed Cottonwood Creek heading up to Rocky Canyon gorge. The gravel is in erosional contact here with the Tba unit that is seen in exposure across the canyon, and it caps the ridge between the creeks. This is the youngest deposit known in the area, except for the alluvium of the present stream terraces and channels. It contains cobble layers, as well as large blocks and boulders of the distinctive basalt, overlying granitic rock above the Rocky Canyon gorge, about 2.5 miles (4 km) upstream.

Looking at the north canyon wall above Mountain Cove Road, the upper flow unit of Aldape Heights basalt (Tba) is exposed in the old quarry and

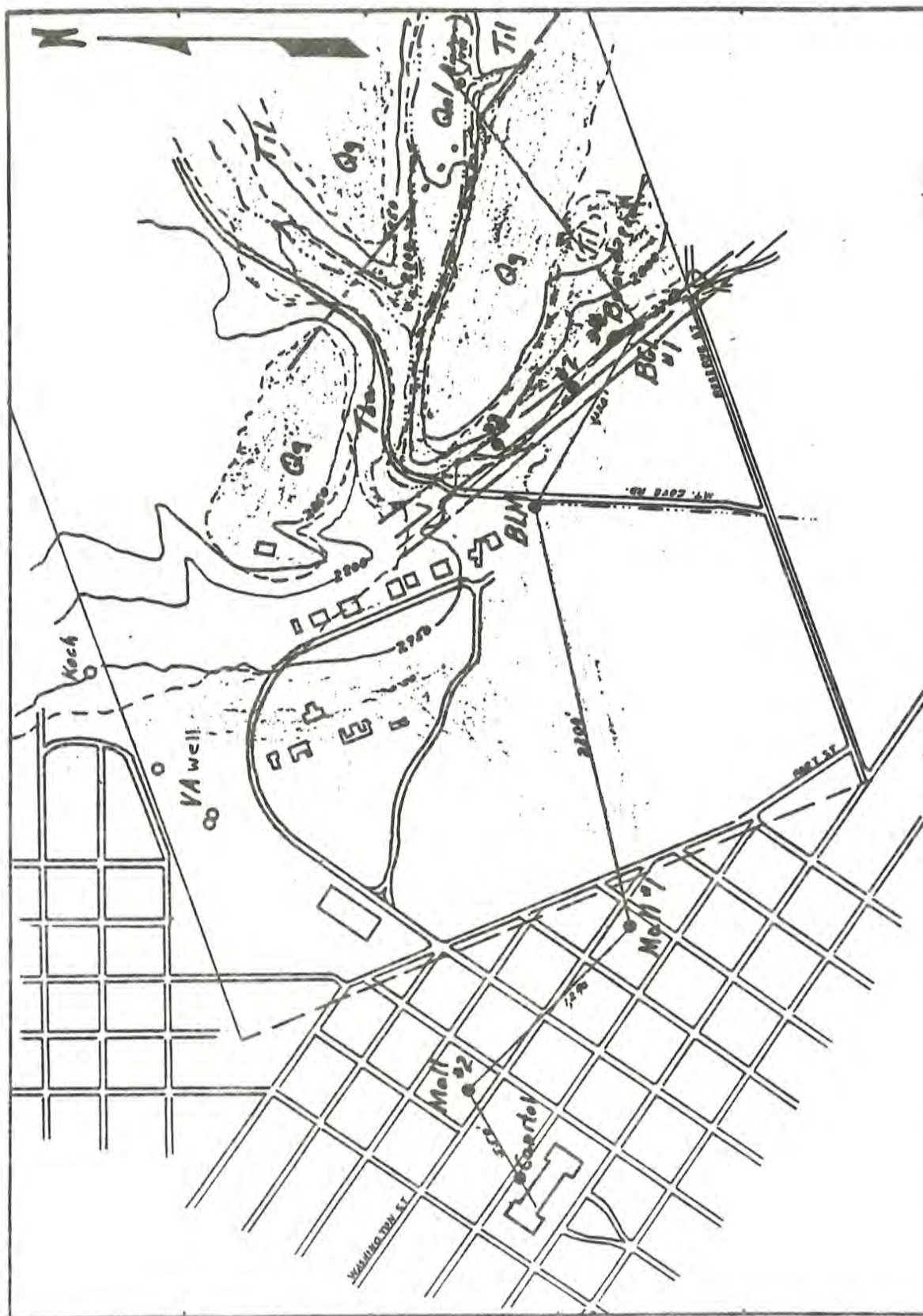


Figure 8. Generalized location map of the Capitol Mall and Military Reserve Park area, with wells, line of section (Fig. 10), and general geology.

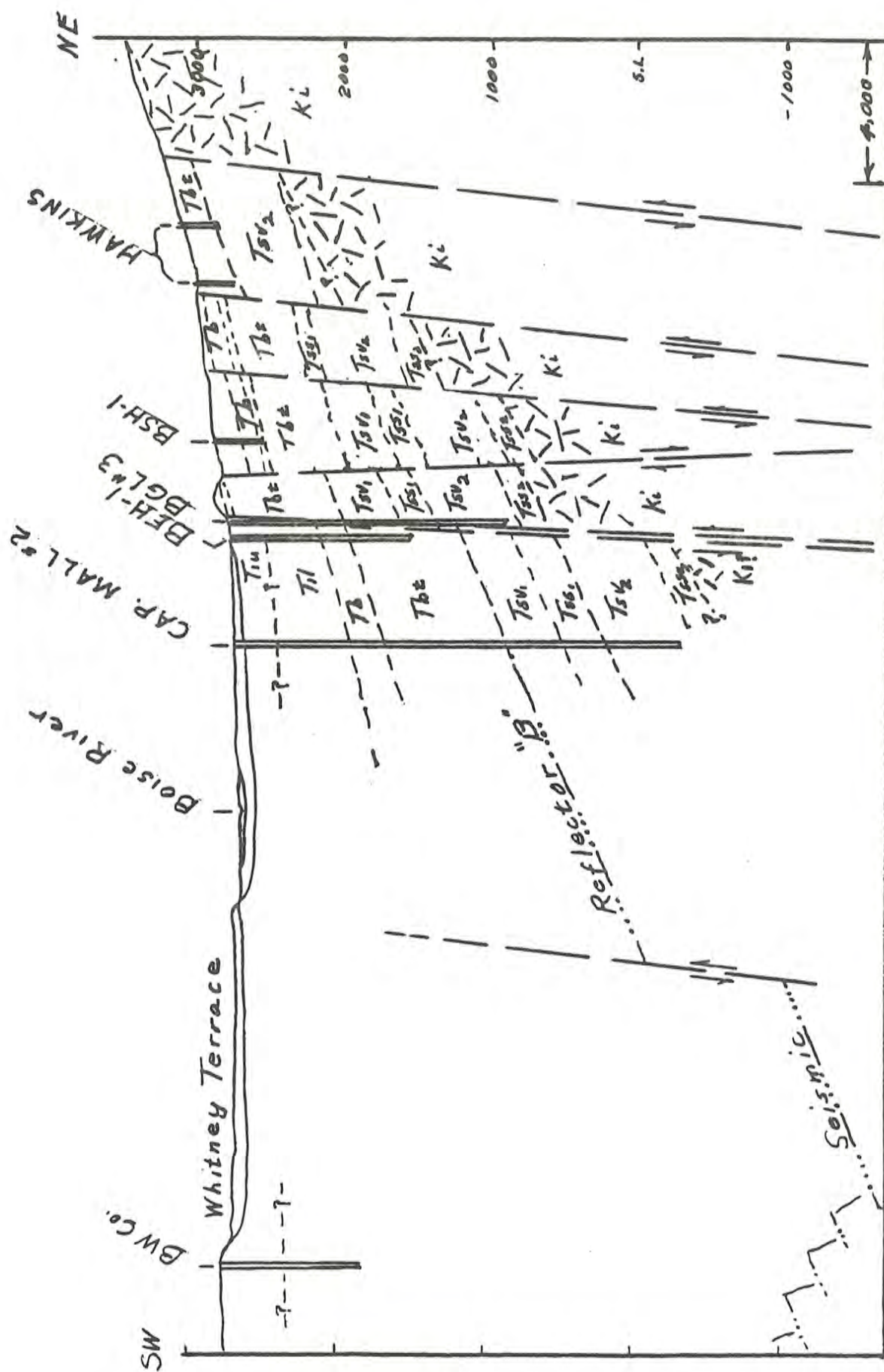
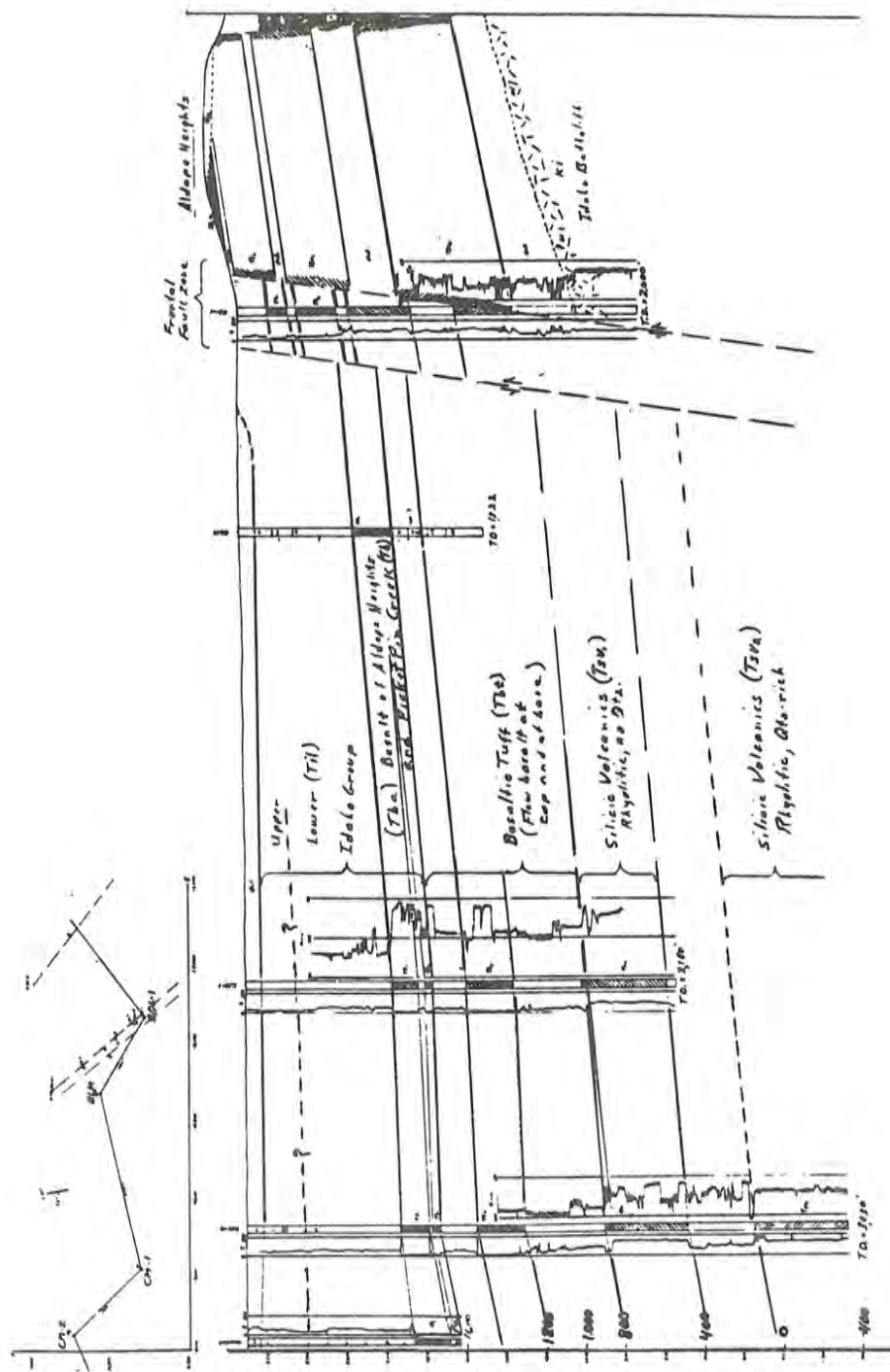


Figure 10. Correlation section from the State Capitol to Cottonwood Creek. No vertical exaggeration.



dips about 12°SW . Base of Qg is seen at the top of the exposure unconformably on the basalt. Down and to the right near the road is a thin white sand which thickens southward under our vantage point, and separates the two flow units of Tba. Up and slightly right of the sand exposure is an outcrop of sandstone striking NW and dipping only about 3 to 5 degrees SW. The sandstone belongs stratigraphically well above the basalt with which it appears here to be continuous. One of the main faults of the NE side of the horst block passes between the outcrops, trending $\text{N}58^{\circ}\text{W}$ and dipping steeply NE. The fault also cuts across the nose of the dividing ridge between the creeks before us and to the right, then can be found in a tributary draw along this side of the canyon about 1,200 ft. (366 m) upstream. Another, and the main NE boundary fault of the horst block, crosses the dividing ridge a few hundred feet farther east, and trends $\text{N}52^{\circ}\text{W}$ with a steep NE dip. The two wells noted by Lindgren in his 1898 report as being in Cottonwood Creek about 2 miles (3.2 km) above Boise were located near the south wall of the creek, just upstream (East) of the trace of this NE boundary fault of the horst. The basalt reported in those wells is the down-faulted Tba.

1.90 mi.
(3.06 km)

On switchback above well BGL-3. (See map, figure 8 for well numbers and locations.) The Tba unit is under soil cover in the roadcut here. The top of basalt is found in well BGL-3, about 80 ft. (24 m) away, at a depth of 270 ft. (82 m). This fault offset of nearly 300 ft. (91 m) is on the middle of the three fault planes along the front, striking $\text{N}38^{\circ}\text{W}$ and dipping 85°SW . The first geothermal test hole drilled in 1975 and designated BEH-1 (BLM) is located beside the nearest metal-sided building, across the road and flume toward the west, about 400 ft. (122 m) away. All three fault traces of the frontal fault zone occur between here and that well.

2.00 mi.
(3.22 km)

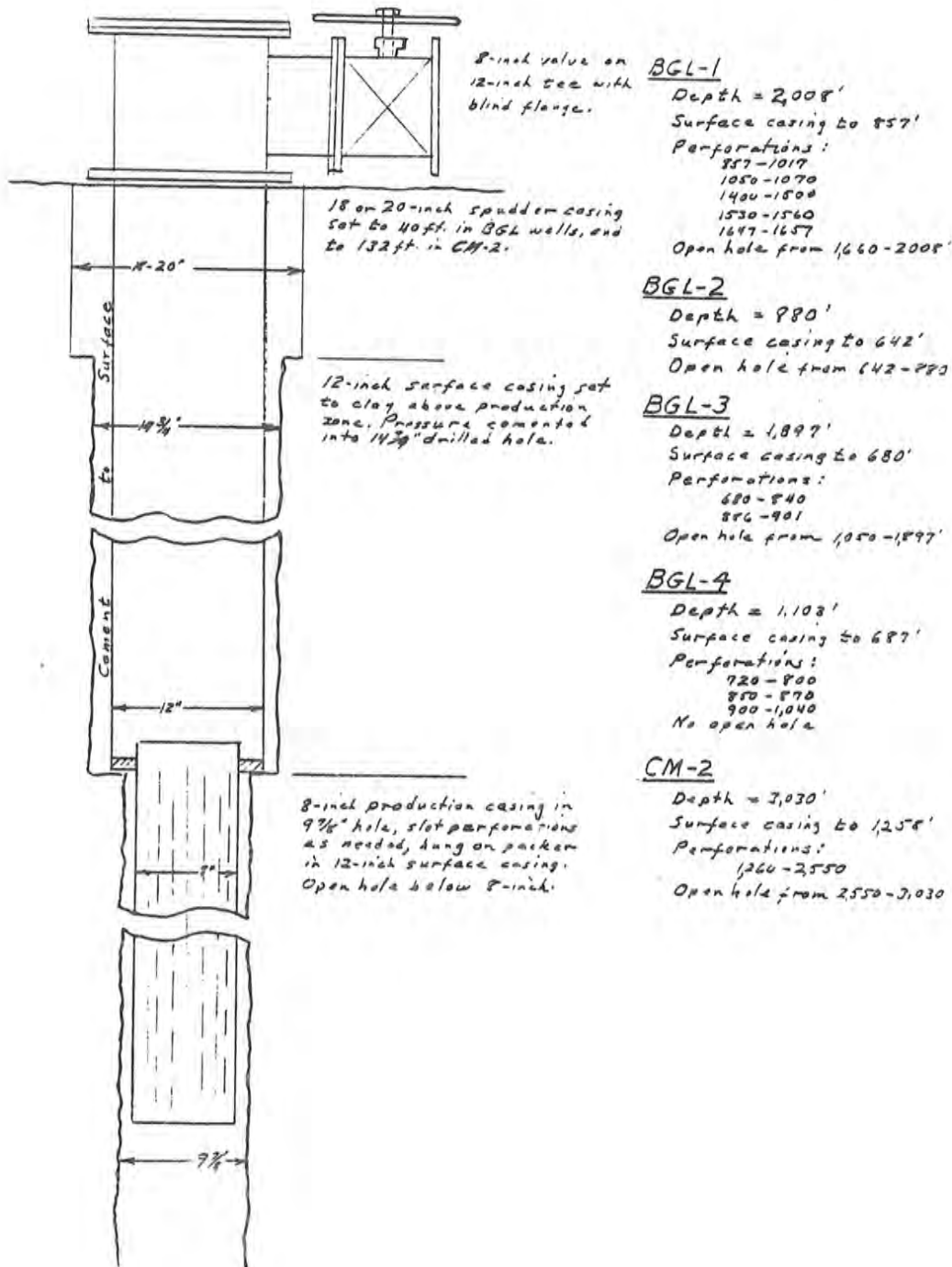
Stop 5. At Boise Geothermal Limited Well No. 2 (Fig. 8). Wells are numbered in the order drilled. Number 1 is at the SE without a shelter. The others are in concrete housings, designed for partial burial to blend with park landscaping. Most of the pertinent information on locations, well construction, yield, water temperature and quality, instrumentation, distribution system, and uses is given in accompanying maps, diagrams, and table. A few additional facts on design, construction, testing, and completion follow:

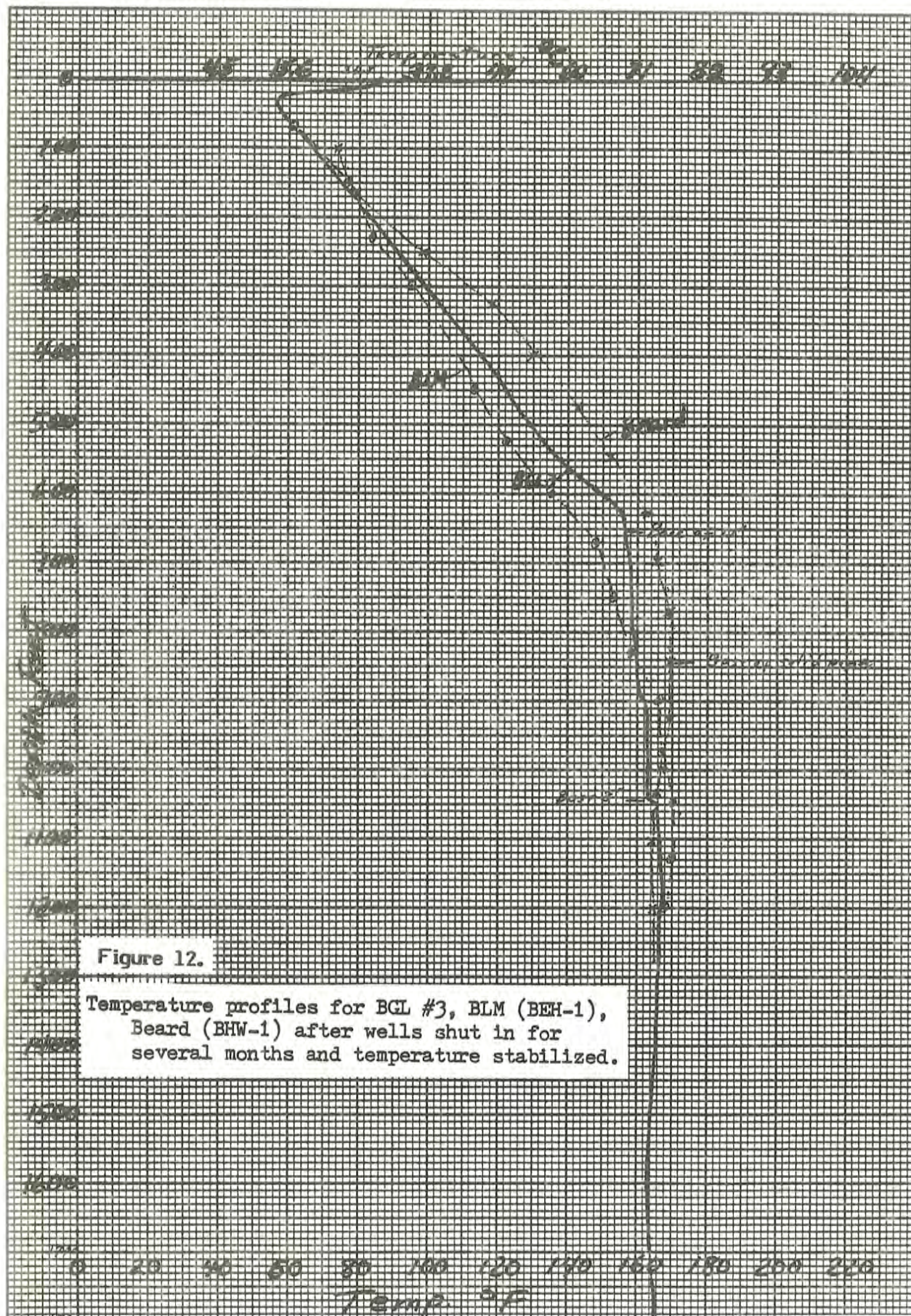
1. Data from test holes BEH-1 (BLM) and BGH-1 (Beard) restricted location to near vicinity of interpreted faults striking NW along the toe of the break in slope of the Boise Front.

2. Right-of-way and access restricted locations to roadways and berm tops within Military Reserve Park between Mountain Cove Road and the south boundary.

3. Planned uses determined a desired peak season yield of 2,000 gpm (7571 lpm) or greater. Test data from the BLM-Beard holes indicated individual well yields of 500 gpm (1893 lpm) with economically feasible drawdown. Consequently, four wells were needed to be fitted into available locations.

Figure 11. Typical well construction for Boise Geothermal Limited wells 1 through 4 and Capitol Mall well #2.





Representative Water Quality

(Geothermal & Shallow Cold Water)

	BWSWD (Westwell)	BGL-2	VA Supply	Capitol Mall #2	Barnes (Foothills)	BWCo. Centennial (Valley)	Boise River (Barber)
Specific Conductance (micromhos/cm)	378	405		415	157	208	85
pH	8.15	8.15	8.9	7.55	6.77	7.7	7.29
Temperature, °C	78	74	72	70.5	16	(Cold)	9
<u>Cations (mg/l)</u>							
Calcium	3.2	1.9		1.3	16	21	10.4
Magnesium	<0.1	<0.1		0.1	2.8	0.48	1.26
Sodium	82.6	88		79.2	10.4	23	4.4
Potassium	1.4	1.1		0.6	1.6	0.75	0.9
Silica (SiO ₂)	73.5	74		55.6	39.7	27	13
<u>Anions (mg/l)</u>							
Bicarbonate	137	138		142	83	--	46
Chloride	5.9	5.4	9	8	3.6	5	0.3
Sulfate	21.5	20	22	19	10	20	2
Fluoride	19.1	15.7	16.7	16	0.32	0.62	--

Table 1. Representative water Quality, Boise area.

4. Spacing to minimize drawdown interference between wells had to be matched to access and right-of-way, and to pipeline costs for the gathering system.

5. State and local laws and regulations related to geothermal wells required pressure grouting of surface casing to protect shallow cold-water aquifers, and blow-out protection when drilling the thermal zone. Such requirements dictated size, type, and capabilities of drilling equipment used. Design, discharge, and drawdown dictated size of pumps required. Size of pump dictated size of hole to be drilled to accept casing and the pressure-cemented annulus needed. Size of surface casing was further dictated by size of the production hole and casing needed, and by the possibility that at least two hole-size reductions might be needed below the surface casing. Such considerations further determined the size and type of drilling equipment.

6. Drilling deep, large diameter holes in or near fault zones anticipates hole-wall instability and loss-of-circulation problems. A carefully designed and controlled drilling mud is required. To minimize drilling mud effects on thermal water production, only bentonite clay mixed with fresh water was used where mud drilling was necessary. Conditioning additives were closely monitored and kept to a minimum. Wherever possible in the thermal water production zones, drilling was done with water only, with compressed air assistance in removing cuttings and maintaining circulation.

7. Only moderate thermal-water formation pressures were encountered, and as a rule the wells did not flow or make a significant amount of water during drilling. Each well was completed by circulating out the drilling fluid with clear water, then air lifting to reduce the column density sufficiently to initiate artesian flow. Flow was continued until the discharge was clear and stable. Well BGL-3 is located such that the wellhead elevation is above artesian pressure head. That well was air-lift pumped for completion.

8. The wells were testflowed or pumped under a variety of procedures, designed to determine both well and aquifer hydraulic characteristics, under planned production schedules and use. Testing included long-term monitoring of water-level changes in the thermal water zones at the Koch well which is drilled in the fault blocks northeast of the Frontal Fault Zone (Fig. 8). Also monitored was BSWD well #3 (Fig. 3) which is in or near the faults directly connected to the Frontal Fault Zone and the BLM test hole which is on the valleyward side of the Frontal Fault Zone. During flow tests, all wells in the vicinity completed in the thermal water zones were used as observation wells. Additionally, shallow cold-water wells nearby were monitored for possible drawdown effects.

9. Well and aquifer characteristics, as based on testing done to date, may be summarized as follows:

The wells in Military Reserve Park and valleyward in the Capitol Mall area display a seasonal static level fluctuation that matches closely both timing and magnitude of change in cold-water municipal, domestic, and irrigation wells in and near Boise. The Koch well water level fluctuates in a manner completely out of phase with

other wells, and is more in harmony with industrial and municipal supply wells within the foothills toward the northwest. BSWWD well #3 water level follows very closely the pumping times and magnitude at the two production wells near the Old Penitentiary (see attached hydrographs; Fig. 13,14).

The thermal water aquifer system at the BGL wells is well confined, with indicated storage coefficients of 10^{-4} to 10^{-3} . All wells have a barometric efficiency of about 80 to 90 percent. During the early, initial period of a test, the aquifer responds as a fault-fracture system with indicated transmissivity in the 10^6 gpd/ft. range and no-flow boundary across the faults to the northeast. Toward the southwest, the Capitol Mall and BLM observation wells indicate the aquifer responds more in the character of a granular material with transmissivity values of the order of 10^5 gpd/ft. and storativity of 10^{-3} .

There is a regional gradient of the static water level (pressure head) toward the northwest from BGL-1 to BGL-3, within the Military Reserve area. Also, toward the west-northwest between wells in Military Reserve and those at Capitol Mall. The pressure head in the thermal groundwater system is everywhere greater than either artesian or water-table levels in the cold-water aquifers of the lower Idaho Group sediments. It is therefore interpreted that the gradient in the thermal water system reflects lateral migration valleyward from the frontal faults and discharge upward by cross-bed bleeding to Idaho Group deposits at lowerhead.

Continue southeast along the line of wells to Reserve Street.

3.15 mi.
(5.07 km) Reserve Street. Turn right and proceed toward downtown Boise.

3.60 mi.
(5.79 km) Turn right on Fort Street. Cold-water wells here in the Military Reserve Park area are 400-500 ft. (122-152 m) deep. Monitored water levels in these wells do not reflect drawdown caused when flow-testing the geothermal wells. Idaho Group sediments are more than 600 ft. (183 m) thick in this vicinity.

3.80 mi.
(6.11 km) Turn left on Washington Street.

3.90 mi.
(6.28 km) On the left, the structure in the parking lot houses the State of Idaho Capitol Mall well #1. The field trip will not stop here, as it will return to this site at the end of a walking tour through the State facilities.

Continue west on Washington Street.

4.15 mi.
(6.68 km) State of Idaho parking lot on right. Enter lot and continue around to Capitol Mall well #2 well house near SE corner. This is the final stop.

Capitol Mall well #2 was drilled by the same equipment and under essentially the same specifications as the four Boise Geothermal Limited wells in Military Reserve Park. The well is 3,030 ft. (924 m) deep and

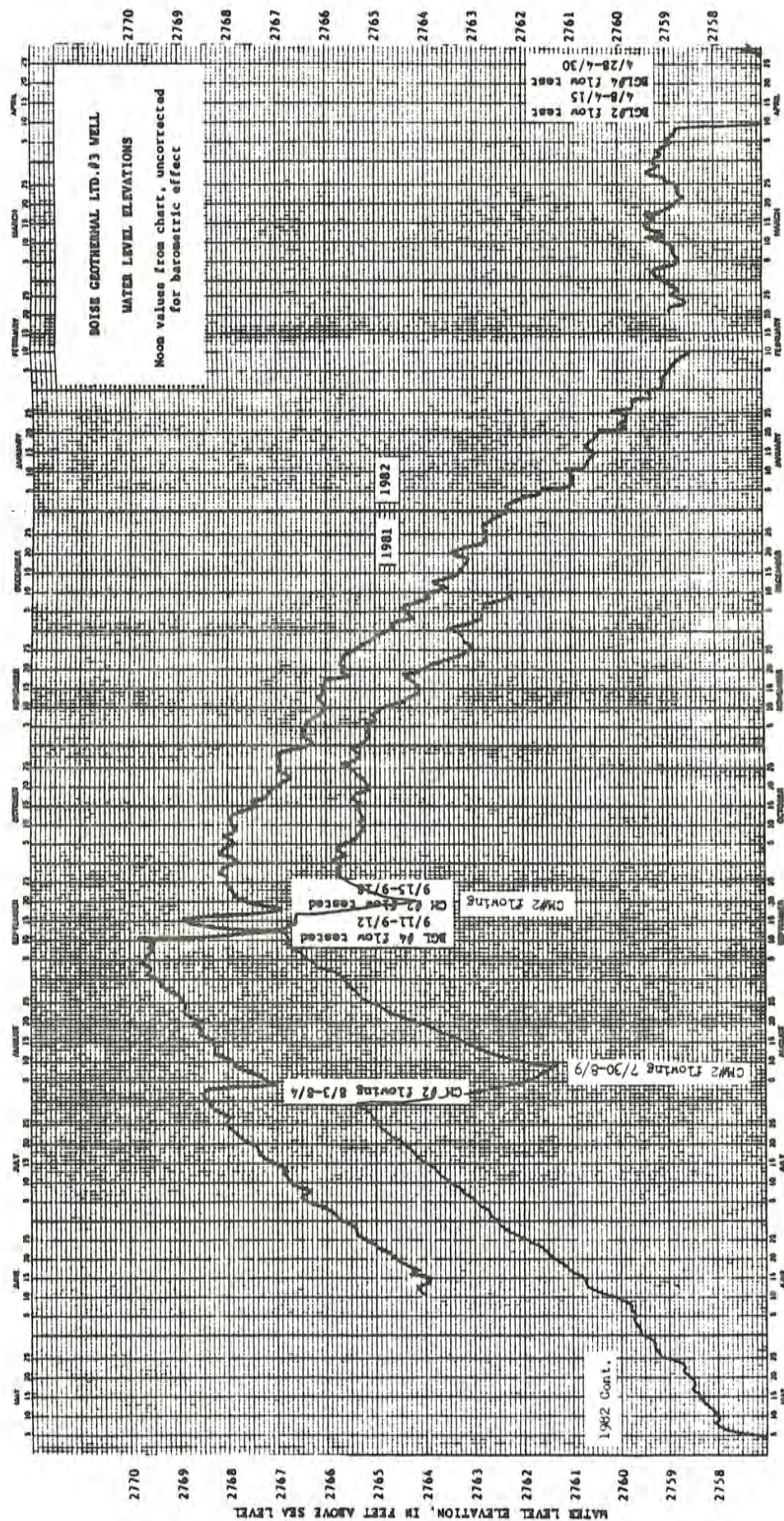


Figure 13. Boise Geothermal LTD. #3 well. Water level elevations.

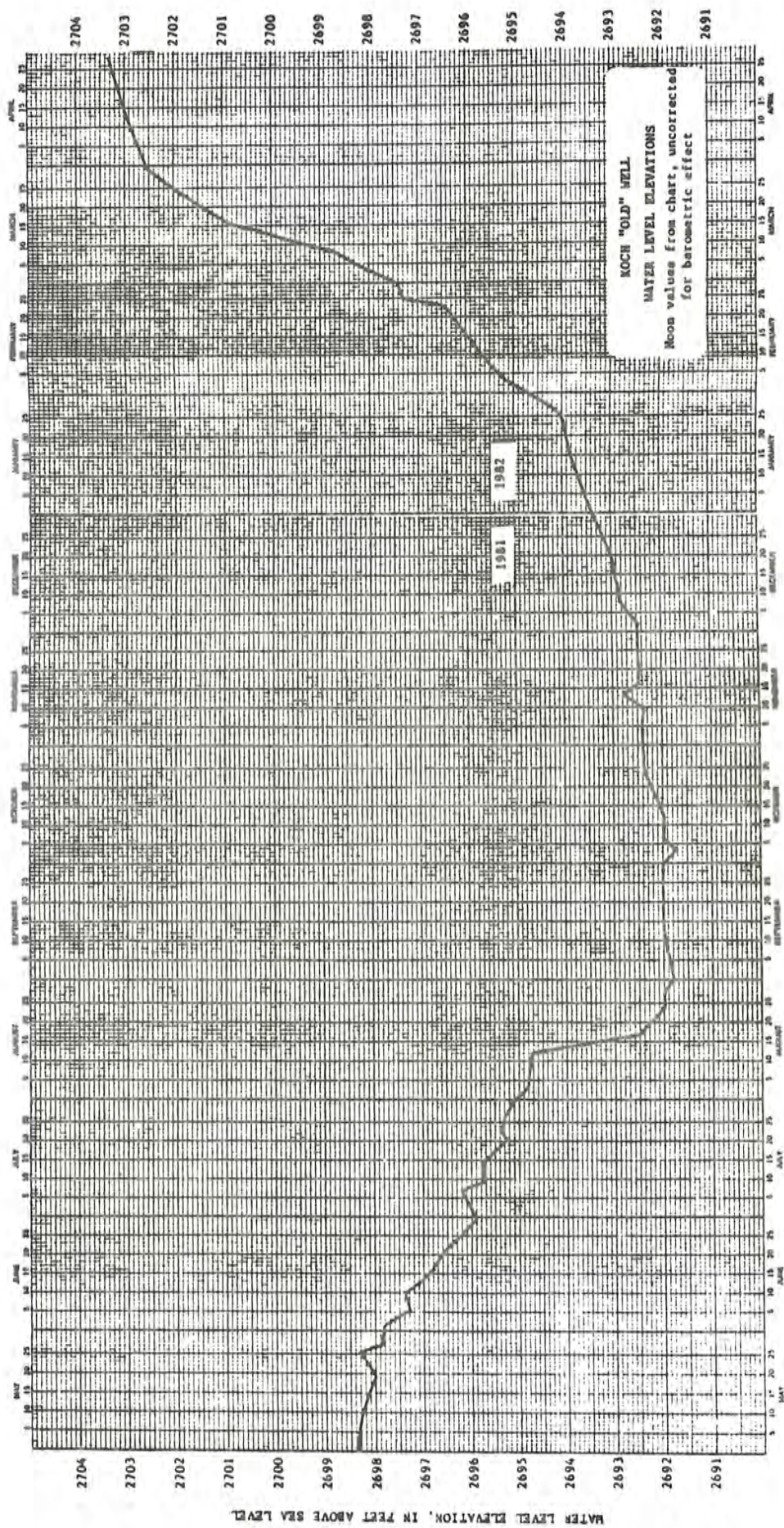


Figure 14. Koch "Old" well. Water level elevations.

bottoms in quartz-rich rhyolite (Tsv₂). Attached diagrams and correlative sections give the essentials of well construction and stratigraphic relations. Pressure cementing of the 12-inch (31-cm) surface casing was done by Halliburton Oil Well Cementing, and the suite of borehole geophysical logs was made by Schlumberger, both from Evanston, Wyoming. In addition to the geolograph record and log of cuttings, logs were run for Natural Gamma, Caliper, Induction Electrical Resistivity, Borehole Compensated Sonic, Compensated Neutron-Formation Density, and Temperature. These were used to guide production casing, perforation, and completion programs. The drilling was done with fresh water mixed with bentonite mud, and/or just fresh water and air. Artesian flow was controlled by mud until well-head valving was in place and disposal facilities were in order. Upon purging of mud from the column, flow of at least 950 gpm (3596 lpm) was obtained for initial cleanup and completion. Temperature of discharge water stabilized at 160°F (71°C), and shut-in pressure of the hot water column was about 18 psig. The water quality is similar to that from other wells, and following flow tests for data about aquifer constants, the well was equipped and placed into service for the 1982-83 heating season. Attached information sheets furnish the pertinent information about the well; the heat-exchange equipment in the State buildings, and the equipment for injection of the spent water at Capitol Mall well #1.

After viewing the well facilities, proceed with walking tour through office buildings and to Capitol Mall well #1. This well is equipped for injection of the spent thermal groundwater from well #2. Drilled under a separate State contract with light-duty rotary drilling equipment, the well is 2,153 ft. (656 m) deep and bottoms in sandstone and conglomerate (Tss₁) below the upper silicious volcanic rock (Tsv₁). The well was drilled primarily as an exploratory well and was not designed sufficiently to meet flow needs for heating the Capitol Mall. It does serve well, though, as an injection well; the receiving aquifer being the upper part of the rhyolite at about 1,700-1,800 ft. (518-548 m) (Fig. 10).

End trip at Capitol Mall #1. Re-board transportation for return.

CAPITOL MALL GEOTHERMAL FACT SHEET

I. Pump Date and Operation (Fig. 15).

- a) Production Pump P-5 - Peerless 5 stage vertical turbine, 70 foot (21 m) setting, with 2 speed 40 hp motor, rated for 750 gpm (2839 lpm) at 165 ft. (50 m) TDH on high speed and 500 gpm (1893 lpm) at 75 ft. (23 m) TDH on low speed.
- b) Injection Pump P-6 - Peerless 4 stage horizontal centrifugal rated for 750 gpm (2593 lpm) at 360 ft (110 m) TDH.
- c) Injection Pump P-7 - Peerless end suction centrifugal rated for 300 gpm (1135 lpm) at 75 ft. (23 m) TDH.
- d) Operation
 - Pump P-7 - On at temperatures below 60°F (16°C)
Off at temperatures above 60°F (16°C)
 - Pump P-5 - On at low speed at 200 gpm (757 lpm)
On at high speed at 375 gpm (1419 lpm)
 - Pump P-6 - On at 500 gpm (1893 lpm)
 - Pump P-5 - Discharge pressure controlled to 30 psig on low speed
and 50 psig on high speed.
 - Pump P-6 & P-7 - Suction pressure controlled to 10 psig

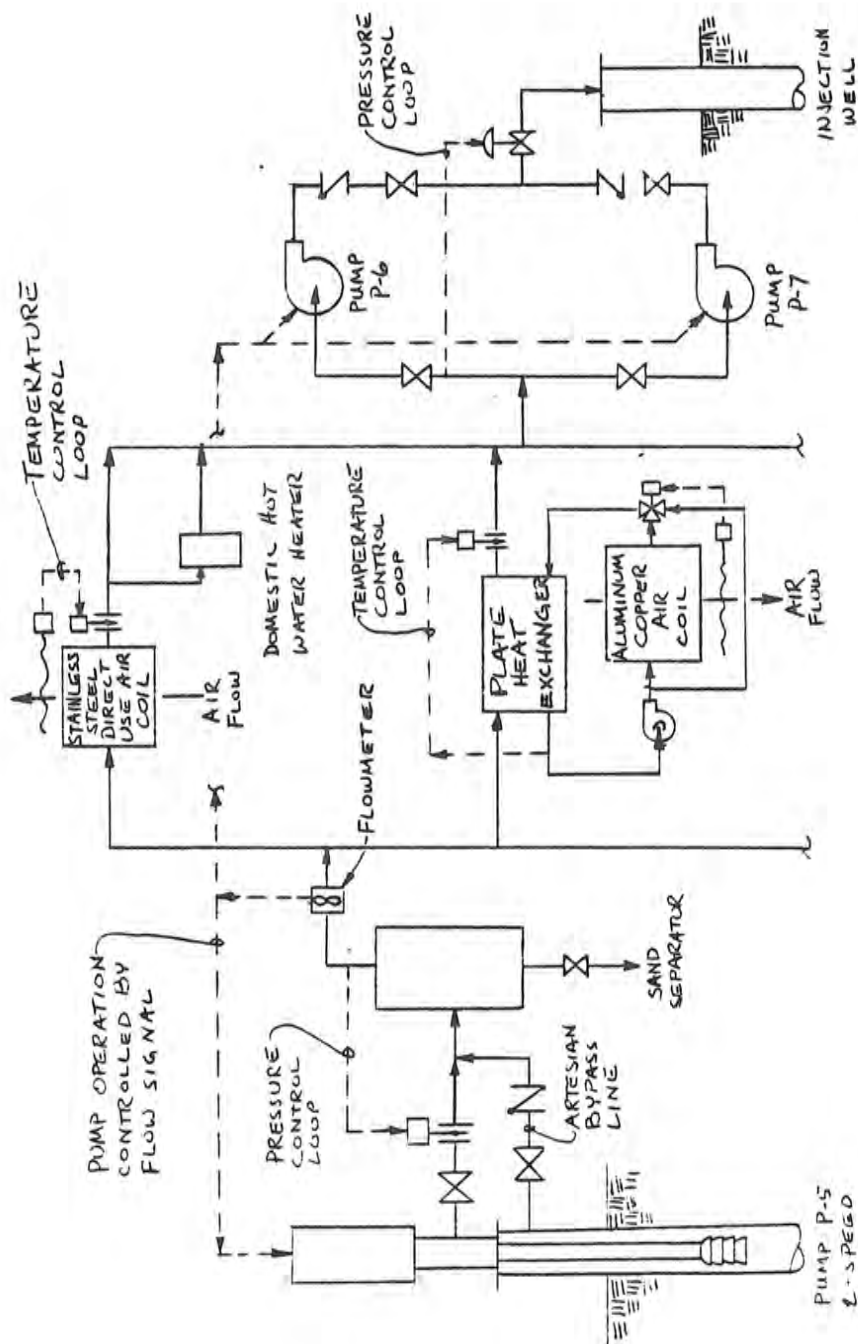
II. Pipeline

- a) Buried geothermal supply line is pre-insulated asbestos-cement, 8-inch (20 cm) size for the main line and 4-inch (10 cm) size to the Library.
- b) Buried geothermal return line is uninsulated asbestos-cement, 8-inch (20 cm) size for the main line and 4-inch (10 cm) size to the Library.
- c) Exposed geothermal piping is welded or screwed carbon steel with field applied 1-1 1/2 inch (2.5-4 cm) fiberglass insulation. Main supply and return lines are 8-inch (20 cm) size. Victaulic fittings were used in mechanical rooms and the pump stations.

III. Building Retrofits

- a) Len B. Jordan Building

97,000 sq. ft. (29,566 sq. m), 115 gpm (435 lpm) geothermal design flow, 1.71×10^6 Btuh design load. Geothermal water flows directly to stainless steel air coils which were installed upstream of the existing steam coils, which were left intact to provide back-up and peak heating. A 330,000 Btuh heat exchanger uses geothermal return water to heat domestic hot water.



PRODUCTION PUMP STATION
 BUILDING RETROFITS (TYPICAL)
 INJECTION PUMP STATION

Figure 15. Boise Capitol Mall geothermal space-heating system showing production and re-injection well installations.

b) Hall of Mirrors

145,000 sq. ft. (44,196 sq. m), 80 gpm (303 lpm) geothermal design flow, 1.12×10^6 Btuh design load. Geothermal water flows to a plate heat exchanger to heat a new closed building hot water loop. The existing steam coils were removed and replaced by hot water coils. A steam converter was installed in series with the plate heat exchanger to provide back-up and peak heating.

c) Capitol Building

127,000 sq. ft. (38,710 sq. m), 160 gpm (606 lpm) geothermal design flow, 2.32×10^6 Btuh design load. Geothermal water flows to a new plate exchanger which was installed in series with the existing steam converter in the existing closed building hot water loop. The steam converter was left intact to provide back-up and peak heating. There are several small, remote air handlers with steam coils that were not retrofitted because it was uneconomical to pipe hot water then.

d) Central Services

43,000 sq. ft. (13,106 sq. m), 60 gpm (227 lpm) geothermal design flow, 0.81×10^6 Btuh design load. Geothermal water flows to stainless steel air coils which were installed upstream of the existing steam coils, which were left intact to provide back-up and peak heating.

e) Tower

166,000 sq. ft. (50,597 sq. m), 110 gpm (416 lpm) geothermal design flow, 1.68×10^6 Btuh design load. Geothermal water flows to a new plate heat exchanger which was installed in series with the existing steam converter in the existing closed building hot water loop. The steam converter was left intact to provide back-up and peak heating. The heat exchanger was actually sized for 220 gpm (833 lpm) geothermal flow, and will be able to carry the second Tower when it is added to this structure. A 500,000 Btuh plate heat exchanger heats domestic hot water with geothermal return water.

f) Supreme Court Building

66,000 sq. ft. (20,117 sq. m), 60 gpm (227 lpm) geothermal design flow, 0.83×10^6 Btuh design load. Geothermal water flows to a plate heat exchanger which heats water in a new closed building hot water loop. The existing steam coils were removed and replaced with hot water coils. A new steam converter was installed in series with the plate heat exchanger to provide back-up and peak heating.

g) State Library

39,000 sq. ft. (11,887 sq. m), 40 gpm (151 lpm) geothermal design flow, 0.52×10^6 Btuh design load. A new plate heat exchanger was installed to heat the closed building hot water loop. One air handler had hot water coils, and the steam coils in the other air handler was replaced with hot water coils. The existing steam converter was upgraded to increase its capacity to handle back-up and peak heating for both air handlers.

h) Controls

Water flow to the air coils is controlled by the leaving air temperature, which is on a reset schedule of 75°F (24°C) supply air at 60°F (16°C) outside air temperature, and 100°F (38°C) supply at 20°F (-7°C) outside air temperature.

Geothermal water flow to the plate heat exchangers is controlled by the leaving closed building loop water temperature which is on a reset schedule of 85°F (29°C) and 60°F (16°C) outside air temperature, and 120°F (49°C) at a 20°F (-7°C) outside air temperature.

IV. Experience

The system was started up October 1, 1982. For the winter of 1982-1983 the system operated very well, although start-up problems kept the energy management system from recording as much data as was hoped for. Generally, flows were somewhat less than the design values, injection pump P-6 was not required to be used, and geothermal water return temperatures ranged from 120 to 130°F (49 to 54°C) for buildings with plate heat exchangers and 100 to 110°F (38 to 43°C) for buildings with direct use stainless steel coils.

Following is a table showing degree days and therm usage at the State of Idaho Capitol Mall gas meter.

1981 - 1982						
	Oct	Nov	Dec	Jan	Feb	Total
Degree Days	497	624	915	1,240	974	4,250
Therms	36,114	51,501	56,776	68,003	65,061	277,455
1982 - 1983						
	Oct	Nov	Dec	Jan	Feb	Total
Degree Days	432	863	1,031	897	653	3,876
Therms	14,858	15,722	21,487	31,447	20,259	103,773

Correct the 1982-1983 usage to a comparable degree day level for 1981-1982.

Corrected 1982-1983 usage = $103,772 \times 4250/3876 = 113,786$

% gas usage in '82-'83 = $113,786/277,455 = 41\%$ of '81 -'82

The State of Idaho realized a savings of approximately \$80,000 on its gas bill in 1982-1983, as compared to the same 6 months in 1981-1982.

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GEOLOGIC RECONNAISSANCE OF THE BOISE BASIN

Field Trip Log

By Elizabeth M. Mathews
U.S. Forest Service
Garden Valley, Idaho 83622

General Description of Field Trip

This all day field trip begins and ends in Boise. Beginning in the stream gravels of the Boise River drainage, the field trip route follows the Snake River basalts up Mores Creek to their contact with the granitic rocks of the Idaho Batholith below Idaho City. From Idaho City, the route turns north for a tour of the mining districts and "porphyry belt" of the Boise Basin. To return to Boise, the route follows the south and main forks of the Payette River from Garden Valley down to Horseshoe Bend, and then through a sedimentary sequence of the Payette Formation over Horseshoe Bend summit to Boise. The primary emphasis of the field trip is mining history and ore deposits; however, engineering geology is also highlighted, and subjects of general geologic interest are discussed throughout.

Logistical Information

1. Start at the entrance to the old Idaho State Penitentiary at the southeast end of Warm Springs Avenue.
2. The field trip takes all day. Some of the longer loops and side trips can be eliminated, speeding up the trip somewhat. These opportunities are pointed out in the field trip log.
3. Back road vehicles are recommended but not essential. Stops 16, 17, and 18 may need to be eliminated by those driving sedans.
4. The Placerville City Park is suggested for a lunch stop. Bring a bag lunch. Cold beverages and some snack foods are available at the Placerville store.
5. Wear field clothes and boots. Bring rock hammers, hand lenses, etc. No underground workings will be entered, so no special safety gear is required.
6. The mileage given at each station is the distance from the previous station unless otherwise noted.

Distance from
Prev. Station

Description

- Stop 1
Begin the field trip in front of the entrance to the old Idaho State Penitentiary. This area of Boise is heated predominantly by geothermal hot water. The main well is located near the base of the slope, just west of the old State Penitentiary. Some new wells have been drilled in the downtown Boise area to heat some of the newer government buildings as well. Between here and the next stop, fairly thick sections of Quaternary river terrace gravels can be seen. Along the narrow, curvey stretch of road past the golf course, small landslides periodically occur, blocking the highway.
- Stop 2
5.5 miles
(8.9 km)
Stop at the Oregon Trail historical marker. Across the river, Quaternary Snake River Basalt can be seen overlying the river sediments. To the north, the hills of the Boise ridge represent the western margin of the Idaho Batholith. Between here and Lucky Peak Dam, excellent examples of columnar jointing in the basalt can be seen along the cliffs above the highway.
- Stop 3
2.9 miles
(4.7 km)
Stop at the base of Lucky Peak Dam. A small remnant of an older flow of Tertiary Columbia River Basalt outcrops on the north side of the highway. Several exposures of these older flows are present near the margin of the batholith, where not obscured by overlying younger flows or sediments. Between here and where the highway disappears out of sight near the top of the dam, the contact between the basalt and overlying sediments, followed by the contact between the sediments and the Cretaceous rocks of the Idaho Batholith, can be seen. Granodiorite and quartz monzonite are the primary rocks of the batholith. Quartz diorite and true granite also occur in a few areas.
- Stop 4
4.5 miles
(7.2 km)
Stop at the top of Highland Summit. From here is an excellent view of a basalt flow confined to the narrow canyon below. Anderson (1947a) described this feature as follows:

"When the basalt was extruded, the valleys had been eroded nearly to their present depths, but the streams have since trenched the basalt, leaving lava-flooded terraces 100 feet high on both sides. Because the columnar joints of the basalt favored the formation of vertical cliffs, the streams flow in a canyon within a valley."
- Stop 5
2.8 miles
(4.5 km)
Stop on the south side of the Mores Creek bridge. Two distinct basalt flows are visible below in Mores Creek canyon. The lower unit is characterized by tabular structures arranged in radial patterns; the upper unit exhibits uniform columnar jointing. Between here and the next stop, roadcuts reveal several prominent basalt dikes cross-cutting the granitic rock.
- Stop 6
6.2 miles
(10.0 km)
Stop at the turnout near the recent mine workings on the southeast side of the highway. The claimant is mining gold from the gravel underlying the basalt by drifting into the gravel layer. In the early 1900's, the gravel was mined 1.8 meters (6 ft.) below the present level.

Stop 7
2.0 miles
(3.22 km)

Stop at the pullout on the northwest side of the highway. Some of the first people to mine the gravels under the basalt were the Chinese. Up the gully to the west is an old drift (cave) that was made by the Chinese in the early 1900's. In the opening is a basalt column that has broken away from the rest of the columnar structure. Note the basal conglomerate and scoria in the basalt (roof of workings). Inside the old workings is a mold of a tree that was buried by the lava. This can be seen in the roof of the workings by the main opening. Just south of this point along the west side of the highway are basalt columns that are at about a 45 degree angle to vertical. As the lava cooled, the columns formed perpendicular to the original ground surface.

Stop 8
4.1 miles
(6.6 km)

Stop at the mouth of Grimes Creek (intersection of Highway 21 and the Grimes Creek Road). The vent (or vents) from which the basalt was extruded is probably located just upstream from here, buried under the flow. The uppermost extent of the flow is less than 3 kilometers (1.8 mi.) north. The highway and Grimes Creek Road follow just below the granite-basalt contact. Grimes Creek follows a narrow valley for the next 23 kilometers (14 mi.) to New Centerville. At New Centerville, the valley opens up into a broad basin, commonly referred to as the Boise Basin. From here, there are two alternate routes to New Centerville. One is to follow Grimes Creek the entire way, and the other is via Highway 21 to Idaho City and then north on the Slaughterhouse Gulch Road to New Centerville. To follow this road log, continue on Highway 21 toward Idaho City.

Stop 9
5.1 miles
(8.2 km)

Pull off the highway onto the flat gravelled area on the southeast side of the road. This area exemplifies the extensive dredging which took place along Mores Creek beginning at the turn of the century. According to Ballard (1924) the first dredge to operate was a "2.5 cubic foot open-connected steam operated Risdon dredge (which) was built near Warm Springs about two miles below Idaho City." The dredge evidently operated continuously until it sank in 1905. A large steam-shovel dredge was also built about this time, but was abandoned when it did not prove economical. The next phase of dredging is described by Metzger (1938):

"In 1908, the W.H. Estabrook dredge was built on Elk Creek about a half mile above Idaho City. This is reputed to have been the largest dredge in the world at that time. The boat was built entirely of native Ponderosa pine. Timbers 24 inches square and over 75 feet long were sawed from logs procured at a great cost and hauled a distance of more than 25 miles by teams.

"The dredge worked down Elk Creek to the confluence with Moores Creek, and thence down Moores Creek to about the present site of Hot Springs. At this point it was turned around and worked up Moores Creek to 2.5 or 3 miles above Idaho City. It operated in all a little more than 5 years. Buckets of 13-cubic foot capacity were first used. Later on, these were replaced by 18-cubic foot buckets, which in turn were replaced by buckets of 21-cubic foot capacity. The 21-cubic foot buckets were too large and were never entirely satisfactory.

"The gravels above Idaho City on Moores Creek became gradually lower grade; and the dredge finally ceased operating about 1917. One morning about 3 years later; the caretaker went out to shovel snow from the deck and the roof and built a fire on the roof to keep warm. He failed to extinguish the fire when he left the dredge, and the next morning it was burned to the ground."

It is difficult to say how many times the gravels in this area have been reworked, first by hand methods, then later by the large floating dredges.

Stop 10
5.3 miles
(8.5 km)

Stop at Idaho City. Tour this old mining town and visit the Historical Museum. Continue northwest out of town, taking the Slaughterhouse Gulch Road to New Centerville. Note the thick alluvial and colluvial deposits along this stretch of road.

Stop 11
7.8 miles
(12.6 km)

Stop at the intersection with the Grimes Creek and Henry Creek Roads. Dredge mining in Grimes Creek began at about the same date in Mores Creek; however, more extensive dredging continued later into the century. The Centerville dredge began work in Grimes Creek about 1936. Metzger (1938) describes it as follows:

"The dredge has been in operation about 2 years. It was manufactured by the Yuba Manufacturing Co. of San Francisco and assembled near Centerville by the Olson Manufacturing Co. of Boise, Idaho. It is of all-steel construction. The bucket line consists of 79 six-foot buckets operated at a speed of 22 per minute. The dredge was designed for a higher bucket speed but in operation it had to be retarded because of insufficient jig capacity. A 7/8-inch cable is used on the ladder; a 7/8-inch cable for mooring the bow and a 3/4-inch cable for the stern. The dredge takes a 6-foot cut and makes a sweep of about 100 feet. Two steel spuds are used, one for making the step ahead and one for dredging. The rated capacity is 6,000 cubic yards in 24 hours. In June 1937 it was operating at a capacity of 4,500 cubic yards."

Some natural revegetation of the old dredge piles has started to occur here. Ponderosa Pine seems to have the easiest time reestablishing itself in this rocky, soilless environment. Continue across the bridge over Grimes Creek. A right turn at the intersection north of the bridge will lead upstream along Grimes Creek to Grimes Pass. To follow this field trip log, continue instead straight up Granite Creek northwest to Placerville. While driving this stretch of road, note the large deposits of sediment in the channel of Granite Creek, probably as a result of overloading of the creek from hydraulic operations upstream. Once the larger placer operations ceased, deposition of sediment stopped, and the creek began downcutting through the layers of sediment.

Stop 12
4.9 miles
(7.9 km)

Stop at the intersection of the Granite Creek and Harris Creek roads. From this point, the characteristic geomorphology of the Boise Basin is evident. Anderson (1947a) describes it as follows:

"Boise Basin itself may be described as bounded by higher slopes on all sides, except on the northwest where it is bordered by the deep canyon of the South Fork of the Payette River. The lowest part of the basin stands at an altitude of about 4,000 feet; the encircling ridges on the west rise above 7,000 feet, those on the south above 6,000 feet, and those on the north and east above 8,000 feet.

"The basin is somewhat elliptical in plan, and its longest dimension, from northwest to southeast, is about 16 miles; the distance across is 10 to 12 miles. A low broad divide between Grimes Creek and Moore Creek separates the basin into two parts. Except for minor gravel flats along the streams in and near the central part of the basin, the basin is composed entirely of low hills and ridges whose crests, except on the northwest, rise gradually to merge with the hills and ridges of the surrounding uplands. On the northwest, its low ridges abut abruptly against a high, steep, scarplike slope that borders an asymmetrical tilted mountain block known as Boise Ridge, which rises as much as 3,000 feet above the basin. This block has its crest near the margin of the basin, and its longer back slope is tilted to the west."

A likely explanation for the basin's unique shape and topography will become evident at a later stop. Turn right toward Placerville at this intersection. Along this stretch of road, try to guess what areas were worked by the old timers, and what areas are "virgin" (if any). Vegetation and shape of the land can give clues, but can also be deceiving.

Stop 13
1.2 miles
(1.9 km)

Stop for lunch at Placerville. Follow the signs northeast out of town toward Alder Creek Summit and Garden Valley. At .3 mile (.5 km) from the Placerville town park, turn right on the road toward Clouder and Boyles Gulch. Follow the middle fork of the road .8 mile (1.3 km). From this point, the road deteriorates rapidly. Park and walk the next quarter mile (.4 km). At the crest of the hill you will see large cliffs created by past hydraulic mining.

Stop 14
1.1 mile
(1.8 km)

Hydraulic mining was a common method of working the thick alluvial and coluvial deposits of the basin. The deposits are high enough above the creek beds, and the bedrock has a sufficient slope to efficiently dispose of the tailings. The first hydraulic mine was started near here in 1898. Most of the early operators were fresh from the gold fields of California, where this method originated. Now retrace your steps .8 mile (1.3 km) back to the intersection and take the right fork of the road up the hill to the southeast. This road will take you back towards Grimes Creek.

Stop 15
5.2 miles
(8.4 km)

Stop at the intersection with the Grimes Creek road. Here, the characteristic crescent shape of dredge piles can be seen. The coarse fraction from the dredge was discarded from a long arm called the stacker, which moved from side to side behind the dredge. As the dredge moved up or down the stream, crescent-shaped piles were deposited in roughly parallel fashion. The tips of the crescents always point in the direction the dredge was moving. Turn left (north) and

continue up Grimes Creek to Pioneerville. To follow this field trip log, turn left (west) out of Pioneerville up Big Muddy Creek (5.2 miles or 8.4 km from Stop 15). WARNING: This road often becomes slippery or even impassible after a rain. Pickup trucks or backroad vehicles are recommended. Four wheel drive may be necessary if the road is wet. To bypass this stretch, continue up Grimes Creek to Grimes Pass and pick up the field trip log at Stop 19.

Stop 16
6.5 miles
(10.5 km)

Stop along the road next to a large roadcut through highly oxidized, sheared rock. This oxidized shear zone is typical of the mineralized lodes of the Boise Basin. A zone, roughly between Quartzburg and Grimes Pass, is commonly referred to as the Boise Basin "porphyry belt" due to the occurrence of Tertiary dikes, many of which have a porphyritic texture. Sulfide mineralization associated with the dike swarm accounts for the area's productive mining history. Anderson (1947a) believes that emplacement of the dikes and lodes occurred in two episodes, beginning in the early Tertiary at the close of the Laramide Orogeny. He describes the early lodes as striking west-northwest and dipping southwest at moderate angles, and comprised of scant amounts of sulfides within a dominant quartz matrix. The later lodes, which Anderson dates from the lower Miocene, typically have a northeasterly strike, and were emplaced along nearly vertical fractures and shears. They are commonly associated with rhyolite and other "porphyrys"; and are dominated by sulfide minerals rather than quartz. These later lodes have generally been the more productive. Galena or pyrite are the chief sulfides present, with lesser amounts of sphalerite, tetrahedrite, and chalcopyrite. Anderson believes that the precious metals were added during a later, second stage of mineralization. The sheared rhyolite porphyry seen in the roadcut, although not visibly mineralized, is probably an example of a lower Miocene intrusion.

Stop 17
1.1 mile
(1.8 km)

Stop next to the old tailing ponds. The old mill for the Missouri Mine was located on the hill above the tailing ponds. It was finally dismantled about a year ago (1983) and the equipment moved down to Boise. Some mineralized rock might still be present above the millsite where ore was stockpiled.

Stop 18
.7 mile
(1.1 km)

Stop next to the portal to the main adit. Little is known of the early history of the Missouri Mine. The following is summarized (in part) from Anderson (1947a). Ore shipments from the mine were made as far back as 1906. In 1919 it was being operated by the Missouri Mine Company. The mine was closed for a period of time in the 1930's and 1940's, but was reopened in more recent years. The last season of continuous operation was the summer of 1982. Since then, the portal to the main adit has caved. Two lodes are known to cross the property, the Missouri Lode and the Silver King Lode. They both occupy prominent shear zones. The Missouri Lode strikes about N. 35° E. and dips 45° S.E. at the surface, steepening to 85° S.E. at depth. Anderson (1947a) describes the ore as follows:

"The ore at the Missouri mine is the base-metal type, and most of it consists of sulfide seams and stringers composed of about equal amounts of sulfides and quartz-carbonate gangue. The sulfides include pyrite, arsenopyrite, sphalerite, and galena, and scant amounts of chalcopyrite, and tetrahedrite or tennantite. Some free gold in grains of microscopic size is also contained in the ore. Most of the ore mined was somewhat oxidized and contained streaks with supergene wire silver and grains of argentite, the latter as a replacement of galena and tetrahedrite. Ore in the bin in 1932 consisted largely of arsenophyrite, pyrite and dark grayish and brownish black sphalerite, but the better ore is reported to have had seams of massive galena 1 to 4 inches thick, in part crushed in gouge. The arsenopyrite is more abundant locally than at any other place along the "porphyry belt" of the Quartzburg-Grimes Pass area and was introduced into the brecciated sulfide filling along with most of the quartz and carbonate. The ore deposition was accompanied by extensive sericitization and pyritization, locally silicification of the enclosing rocks, and the sulfides in part replace the altered rock."

Spend some time looking around the hillside above the adit, where tractor excavation has exposed the shear zone and surrounding country rock: Continue up the road to the top of the ridge, then turn right (northeast) on the Mineral Mountain Road towards Grimes Pass. (If this section of road is impassible, you will have to retrace your steps back to Pioneerville, then turn left and continue up Grimes Creek to Grimes Pass.)

Stop 19
1.2 miles
(1.9 km)

Stop at Grimes Pass. To the west and north lie Garden Valley and the South Fork of the Payette River. This fair-sized river is less than 2.5 kilometers (1.5 mi.) airline distance from where you are standing. The small creek in the draw to the north (Sweet Creek) represents the southernmost extent of the Payette River watershed at this point. However, the northern extent of the Payette River watershed extends nearly as far north as you can see from here. To the south lies the Grimes Creek Drainage. As you saw today, Grimes Creek is a tributary of Mores Creek, which lies 24 kilometers (15 mi.) due south. Mores Creek is, in turn, a tributary of the Boise River, which lies almost 48 kilometers (30 mi.) due south. The waters of Grimes Creek flow over 48 kilometers (30 mi.) before entering a river of a size comparable to the Payette. What could account for this lopsided drainage pattern, with the bulk of the watershed area located to the north of the major rivers?

Now look at your field trip map. Notice the large arc made by Grimes Creek as it leaves its headwaters near Pilot Peak, then bends around to head in a southwesterly direction through the Boise Basin. Note also how close Grimes Creek comes to the top of the summit here at Grimes Pass. Why doesn't Grimes Creek drain into the South Fork of the Payette River? Anderson, for one, believes that it once did, but was subsequently captured by the Boise River drainage as a result of differential uplift to the north. This would also help account for the characteristic geomorphology of the Boise Basin. His discussion follows:

"Apparently as the basaltic extrusions died away near the close of the Miocene, the igneous activity was succeeded by a mild crustal disturbance involving differential uplift to the north. The low, essentially flat surface that characterized the general region then became a tilted plain, sloping gently to the south. The differential uplift renewed the cutting power of the streams and produced marked changes in the drainage patterns. The ancestral Boise and Payette Rivers had the advantage of increased gradients and gully cut back far up the slope. These streams, favored by slope, successfully competed against the tributaries of greatly reduced gradients that joined the trunk streams from the south and that had to flow against the slope to maintain their courses. Capture of the drainage basins of the handicapped streams by those favored by surface slope was imminent, and in this way the tributaries of the Boise River robbed the Payette River of most of its drainage area, except on the north, and those joining the Payette from the north worked far up the slope against the headwater of the Salmon River. A very one-sided drainage pattern was thereby evolved. During these adjustments one of the tributaries of the Boise River captured Grimes Creek water where it entered the Payette River and has maintained this capture to the present day.

"Adjustment of the drainage to the tilted slope probably required much of Pliocene time for its completion. During this interval the uplifted surface was carved into a system of low hills and flat-topped ledges separated by relatively shallow valleys, in places as much as several hundred feet deep. The products of erosion were carried westward and probably deposited on the somewhat eroded Payette formation and basalt as beds of the Idaho formation. In the later part of the Pliocene the region stood low, and its surface resembled that of the present upland areas.

"The region was then subjected to another crustal disturbance beginning at the close of the Pliocene epoch and continuing intermittently to the present day. Elongated segments of the crust were broken into faults and the segments tilted into block mountains, of which Boise Bulge stands as a conspicuous example. The region was also differentially warped, and such intermontane depressions as Boise Basin and Garden Valley were produced partly as a result of faulting and partly as a consequence of differential uplift. The region as a whole was elevated to the levels at which it stands today.

"The general uplift greatly increased the cutting power of the main streams, and the elevated erosion surface was deeply and intricately dissected. The South Fork of the Payette River rapidly deepened its channel, particularly in the high upland east of Garden Valley and across the mountain block to the west. Grimes Creek, because of its distant connection with the Boise River, was not so materially affected by the uplift and continued on as before; but the Payette, in consequence of its steepened gradient produced by the tilting of the

faulted crustal segment against the base of Boise Ridge west of Garden Valley carved its canyon far below the level of Grimes Creek and at the same time undercut and moved back the divide, separating the two where the creek now appears to flow for nearly 3 miles in a narrow, one-sided trough high on the canyon wall.

"The warping of the low, hilly surface in Boise Basin steepened the gradients of the streams flowing down the flanks of the basin, causing them to erode deep valleys and canyons and to carve canyons of even greater depth in order to maintain their courses across the rim on the opposite side. Conditions, locally, as in Boise Basin, favored the accumulation of valuable placers but did not promote deep weathering and most of the weathered material previously formed during the Pliocene, when erosion was not nearly so active, was eroded. After Moore Creek and lower Grimes Creek had carved their canyons nearly to their present depths, basalt poured out from a vent just above the junction of the two streams and flowed southward, eventually reaching and spreading over the margin of the Snake River Plain. The district escaped the Pleistocene glaciation, but degradation was interrupted several times, probably because glaciers at the headwaters of the main rivers freed so much material that the streams could not carry all of it away and alluvium accumulated along the valley bottoms, later to be partly removed as the stream load returned to normal. The mountains thus carved out of the uplifted, faulted and warped Tertiary erosion surface now in the process of being worn away."

Continue north down toward Garden Valley. Note the large gullies which have formed as a result of concentration of runoff from the road into just a few places. The granitic rocks of the Idaho Batholith are extremely susceptible to weathering and subsequent erosion. Two solutions frequently used to prevent excessive erosion are outcropping of roads and installation of additional drainage structures. However, even these solutions are not without their own problems. Outcropping can create safety problems on steep mountainous roads, and drainage structures can prove quite costly to install and maintain. Turn left (west) at the intersection of the Grimes Creek Road and the South Fork Payette Road (3.3 miles or 5.3 km. from Grimes Pass), then continue another 5.5 miles (8.9 km.) down-river to the Alder Creek Road. Turn right and cross the bridge over the river.

Stop 20
11.6 miles
(18.7 km)

Stop at the intersection of the Alder Creek Road with the Banks-Lowman Highway. Here in Garden Valley, the South Fork of the Payette River forms a fairly broad, open valley. Upstream the valley gradually narrows. About 4.8 kilometers (3 mi.) downstream, the Middle Fork enters the South Fork from the north. Below this point, the South Fork plunges abruptly into a narrow, steep canyon. Fisher and others (1983) have mapped three north-striking faults which have a major influence on the geomorphology of the valley. To the south, the canyon of Alder Creek follows one of the faults. Two other faults influence the course of the Middle Fork of the Payette to the north. Uplift to the west along these faults has produced the rejuvenated canyon below Garden Valley.

Garden Valley itself represents a graben which was filled with alluvium as the river dropped its load in response to a reduced gradient. From here, the trip can be shortcut by turning west toward Banks and returning directly to Boise. Allow 1.5 - 2 hours for the return trip, with stops. To follow the field trip log, turn east toward Lowman. You will eventually backtrack and return to this point. Allow an extra 1.5 hours for this side trip, with stops. If you choose to skip this portion of the trip, go directly to Stop 24, measuring the mileage from this point.

Stop 21
2.4 miles
(3.9 km)

Stop at the pullout on the south side of the road across from Hot Springs Campground. Numerous hot springs along the South and Middle Forks of the Payette River and throughout the area indicate the presence of a sizeable heat source at fairly shallow depth. As meteoric water percolates through fractures and faults in the bedrock, it becomes heated and resurfaces at hot springs. In recent years, industry has shown some interest in geothermal leasing on the Boise National Forest. Na-K-Ca geothermometers and Si content indicate reservoir temperatures range from 100 - 145 degrees centigrade (212-293°F). The area is still seismically active as well. Within the past few years, several small and moderate-sized earthquakes have been recorded north of Boiling Spring on the Middle Fork of the Payette.

Two other interesting features can be seen from here. Note how the river has cut a narrow, incised canyon in this rather broad valley. This might indicate a period of little or no tectonic activity followed by a period of renewed uplift. Also note the small piles of cobbles from previous placer mining. The South Fork of the Payette was not mined as extensively as Grimes and Mores Creek were, primarily due to the large thickness of the gravels and difficulty reaching bedrock. The work which was done was mainly limited to the edges or rims of the benches where the gravel is thin. More of these workings will become evident as you continue upstream. In recent years, this river has become extremely popular with suction dredge miners.

Equipped with wet or dry suits, they use scuba gear to penetrate some of the deeper holes in the river. Some large nuggets have reportedly been extracted from cracks in the bedrock on the river bottom.

Stop 22
3.2 miles
(9.8 km)

Stop at first opportunity after the road pavement turns to gravel. The greenhouses 1/4 mile (.04 km) back on the north side of the highway are heated by geothermal hot water. A wide variety of flowers and bedding plants are grown year round. On the river below, what remains of the old Grimes Dam can be seen. This dam was built early in the century to supply power to the mines up at Grimes Pass, as well as to Pioneerville, Centerville, and Idaho City. A branch line supplied Placerville and Quartzburg. The plant consisted of two 900 kv turbogenerators. A diesel-powered generator was used to take care of heavy loads during the fall and winter, when the flow of the South Fork became too low to meet demands. The dam washed out sometime in the mid 1940's.

Stop 23
6.1 miles
(9.8 km)

Watch for the point at which the road approaches river level. Pull out on the south side of the road. Several features along the next quarter mile (.04 km) stretch of road will be discussed from this point. You may want to walk this stretch or make frequent stops between here and Big Pine Creek. The road network on the hillside in front of you was built in connection with exploration drilling for molybdenum. The most recent activity occurred in the summer of 1982. The deposit consists of small stringers of molybdenite within a rhyolitic matrix. The intrusions of Tertiary rhyolite are much more resistant than the Cretaceous quartz monzonite, and form prominent fins and ledges upstream. Little Falls, the small drop in the river, just upriver from here, cascades over these ledges. Although the area has been mostly picked over, some samples of molybdenite-bearing rhyolite might still be found near the portal to the exploration adit .1 mile (.2 km) up the road. At .4 mile (.6 km), near the far bend in the road, two mafic dikes can be seen cross-cutting granite. One of these is basalt and the other fits Anderson's (1947a) description of a lamprophyre. Thin laths of plagioclase can be seen in a dark groundmass. Alteration of the rock makes identification of individual crystals of dark minerals difficult to impossible. Note the thin seams of calcite penetrating the dike. At .5 mile (.8 km) is the intersection with the Deadwood-Scott Mountain Road. This is a good place to turn around and return to Garden Valley. You may want to drive a short distance up this road to view the extensive network of drill roads on the west side of Big Pine Creek.

Return to Garden Valley and note the mileage at the turnoff to Alder Creek. The mileage to the next stop will be measured from that intersection. Continue west toward Banks.

Stop 24
10.4 miles
(16.7 km)

Stop at the pullout on the south side of the road. The migmatite apparent in the outcrop in the north side of the road is an example of the metamorphic alteration characteristic of the western margin of the batholith. Bands relatively rich in biotite alternate with biotite-poor layers. Schmidt (1964) did a petrographic study of a cross-section through the western margin of the batholith north of here in Adams and Valley Counties. He identified five gradational belts from east to west: Quartz monzonite and granodiorite; leucocratic quartz diorite; quartz diorite gneiss; leucocratic quartz dioritic migmatite; and fine-grained migmatitic gneiss and biotite schist. The metamorphic grade increases eastward from the sillimanite zone within the gneiss and schist, to the kyanite zone within the granodiorite, with the sillimanite isograd occurring within the migmatite. Mineral assemblages also vary systematically across the gradational belts. The most significant changes are an increase in potassium feldspar from essentially zero in the migmatite, to nearly 30% in the quartz monzonite core area, and an increase in the anorthite content of the plagioclase from An₂₅ in the quartz monzonite to An₄₀ in the quartz diorite gneiss. Schmidt believes that this zonation was produced by regional synkinematic metamorphism.

and sodium metasomatism. Endomorphism also has caused a certain amount of recrystallization of quartz and potassium feldspar and adjustment of plagioclase under regional postemplacement conditions. Continue downstream to Banks (1.4 miles or 2.3 km) to the intersection with Highway 55. From this intersection you can look across the North Fork of the Payette River into Phillips Creek. Note the numerous small slumps and mudflows. Many of the more recent failures occurred during the extremely wet spring of 1982. Now turn south on Highway 55 and continue downstream along the main Payette River. Watch for the single prominent outcrop of Columbia River Basalt on the east side of the highway (10.3 miles or 16.6 km from Stop 24).

Stop 25
15.1 miles
(24.3 km)

Stop at the weigh station on the west side of the highway. Looking south past the town of Horseshoe Bend, you can see Highway 55 as it climbs Horseshoe Bend Hill. Horseshoe Bend Hill is comprised of Tertiary-aged sedimentary rocks of the Payette Formation. Pebbles (1962) describes this formation as consisting of three facies: one composed of shale and silty clay, another of sandstone and conglomerate, and the third of limestone and diatomite. Note the extremely hummocky topography, indicating extensive mass movement. The highway has been extremely difficult to maintain along this stretch. Slides have closed the road on numerous occasions, and some sections of road have necessitated constant repair as the roadbase sinks and moves downslope. After the disastrous spring of 1982, some innovative measures were initiated to stabilize two of the worst sections of road. The roadbed was excavated to below the zone of movement and replaced with a mixture of material consisting largely of sawdust. One of these new fills can be seen from here. It is located roughly one third of the way up the slope from Horseshoe Bend to the top of the ridge. Other more permanent solutions, such as relocation of Highway 55 to an entirely new location, are still being discussed. Now continue south through the town, and up Horseshoe Bend Hill. Note the wide bend the Payette River makes before heading in a westerly direction toward Emmett. The town of Horseshoe Bend derived its name from this feature.

Stop 26
5.6 miles
(9.0 km)

Stop at the pullout on the northeast side of the highway. The section of road before you has been reconstructed using sawdust fill. The highway crosses the most active part of the largest slump at this point. About .2 mile (.3 km) down the road from here, a series of pipes are being used to drain groundwater at depth from the hillside to try and reduce saturation. Immediately downslope from here, several sagponds are evident during the wetter months of the year. On the hillside to the west, two fairly recent failures are apparent in the sandstone unit. Note the more fluid nature of the older flow compared with the more recent slide. To the east, where the highway bends out of view, the shale-siltstone unit is well exposed in a large roadcut. A small exposure of this unit is also evident immediately across the highway from the pullout where you are located. Note the dip of these beds. Pebbles (1962) relates the dip of the beds to the slope failure as follows:

"An interesting feature of the landslide area adjacent to State Highway 15 (now 55) is that the stratified rocks generally dip rather steeply to the west or southwest, directions almost opposite to the general slope of the ground surface and the direction of movement of the landslides. Obviously then, the slides cannot have resulted from shear failures along the bedding surfaces between the rock strata. A similar situation exists in the Portuguese Bend landslide in the Palos Verdes Hills of California (Jour. Geology, 1960, p. 140-153) where lake beds dip landward in a direction opposite to the movement of the slide. It was concluded that access of water into these strata could have been aided by their attitude, whereby direct precipitation and runoff could enter their eroded upper ends and migrate down-dip along the more permeable beds. This same process may take place in the Payette Formation adjacent to Highway 15. The conditions here may be further aggravated by the partial entrapment of seepage water coming from the "Siphon Lakes" and other small bodies of water at higher elevations. Numerous springs and bogs in the area indicate places where this water reaches the ground surface as the result of hydrostatic pressure between relatively impermeable strata. With respect to landslides, the net effect of this entrapped water is to increase the pore-water pressure in the soil and to accelerate disintegration of the sedimentary strata."

This is the last stop of the field trip. Continue 15.5 miles (24.9 km) to the intersection of Highway 55 with Highway 44 and turn left toward Boise.

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FIELD GUIDE TO OQUIRRH GROUP AND PARK CITY GROUP
(PENNSYLVANIAN AND PERMIAN) OF THE SUBLETT RANGE, IDAHO

by Thomas E. Yancey
Department of Geology, College of Geosciences
Texas A & M University, College Station, Texas 77843-3115

Cumulative
Mileage

- 0.0 Boise, Idaho. Take Interstate 30 east toward Twin Falls, Idaho.
- 124.0 Twin Falls. Continue east on Interstate 30.
- 189.0 Yale exit. Turn south on road running beside Raft River.
- 195.0 Intersection with Heglar Canyon Road. Turn left and head toward Sublett Range.
If you miss the intersection, you will curve westward and cross the Raft River.
The Heglar Canyon Road passes between two hills, North Chapin Mt. and South Chapin Mt.
- 202.0 Heglar Crossroads. There is a single building located here. Stay on road that runs beside stream bed and continue up the canyon. A dirt road leading up the bluff on the south side of the valley is the terminus of South Heglar Canyon Road, which provides access to thick sections of Manning Canyon and Oquirrh Group sections in the area of Indian Fork Canyon.
- 206.0 Contact of Tertiary volcanics and Paleozoic strata.
- 206.2 High angle fault within Paleozoic section, separating small section of Oquirrh rocks on west from main sequence. This fault is one splay of the major fault trend along western boundary of the range.

Stop 1. Contact of Manning Canyon Fm. with Oquirrh Group, exposed in small side valley on north side of road, in center of west 1/2 of Sec. 9, T. 11 S., R. 29 E. On the up-canyon side of the fault, close to road level, are exposures to the very top of the Manning Canyon Fm. in conformable contact with the Oquirrh Group. This is probably the only exposure of the contact in the range, since the Manning Canyon is fault bounded elsewhere along the western side of the range. The contact is placed at the level of the lowest limestone in the section and occurs above 23 meters (75 ft.) of argillites. Basal Oquirrh strata are sandy, and consist mostly of calcareous sandstones and sandy limestones, with some prominent quartzite units present 30 to 60 meters (98 to 197 ft.) above base of Oquirrh Group. Above the level, quartzites are not present in the section.

Continue up canyon to prominent narrows formed by limestone ledges in SE 1/4 of Sec. 9. This is the main part of the Heglar Canyon Fm., the lowest formation of the Oquirrh Group. The formation is about 330 meters (1083 ft.) thick in this section, and of Morrowan and Atokan age. It consists mostly of limestone, along with some calcareous sandstones and argillaceous strata. Cherty limestones occur in the middle of the formation, and form the resistant cliffs at the narrows in the canyon. The Heglar Canyon Fm. includes the resistant lower limestones of the Oquirrh Group in the Sublett Range, and are separated from the upper limestones by a thick sequence of sandstones and sandy limestones. Previous reports by H. Bissel and by R. Armstrong place a basal sandstone formation between the Manning Canyon and Heglar Canyon limestones, but the sandstones in this interval are thin and not useful for mapping, and not distinct enough to designate as a separate formation. Previous mapping has confused other portions of the Oquirrh, and even some Manning Canyon strata, with the Basal Oquirrh sandstones, and is not reliable.

- 207.2 Stop 2. Conglomerate-bearing interval of lower part of Oquirrh Group, near mouth of prominent north-trending side canyon, marked by small knobs of Tertiary volcanics near road level, in S 1/2 of SW 1/4 of Sec. 10, T. 11 S., R. 29 E. Above the Heglar Canyon Fm. is a 350 meter (1148 ft.) thick interval of mixed lithology, including sandy limestone, argillaceous limestone, sandstones, siltstones, and clean limestones. The limestones form subdued ledges on the canyon walls. The base of the sequence is Atokan in age, but most is Desmoinesian in age. The most distinctive feature is the presence of conglomerate and conglomeratic limestones in a few horizons in the top of the sequence. These conglomerates have variable thicknesses along strike. Several large masses of conglomerate occur near the mouth of the side canyon, and the largest is an 18-meter (60 ft.) ledge of conglomerate exposed on the ridge, just east of the mouth of the side canyon. The conglomerate clasts are mostly chert pebbles and cobbles, but limestone clasts are present, as well as a few quartz and sandstone pebbles. Conglomerate masses pinch out laterally within short distances, but contain few sedimentary structures. They are similar in composition, occurrence, and age to conglomerates of the Hailey Fm. of the Oquirrh Group in the Wood River area of central Idaho. Above the conglomerate-bearing interval is a thick sequence of quartzose sandstones with a few limestones present, that is poorly exposed in North Heglar Canyon.

- 209.7 Stop 3. Limestones of the Trail Canyon Fm. of the upper part of the Oquirrh Group, at Lower Heglar Spring, in the mouth of Spring Canyon, NE corner of Sec. 26, T. 11 S., R. 29 E. The upper limestone interval of the Oquirrh Group is the Trail Canyon Fm., which is nearly 1500 meters (492 ft.) thick in its type area, and contains mappable sub-units. The Trail Canyon Fm. contains some Missourian strata at the base, but is mostly Virgilian and Wolfcampian in age, with the clean limestones of the middle of the formation being Virgilian in age. The best sections of the Trail Canyon Fm. are located in the type area (Trail Canyon) on the east margin of the range, and in the Indian Fork area of South Heglar Canyon. Both sections have been sampled for fusulinids, and are similar in age and lithologic sub-units.

Second Day.

Quaking Asp Mountain - South Fork Rock Creek Area.

Drive into Rockland Valley along Rt. 37. If coming from the north (American Falls) proceed to Roy (a road interesection), leave paved road, and continue straight onto gravel road, keeping close to Rock Creek. Continue 5 miles to Robinson Ranch. If coming from the south (Snowville), travel north to Holbrook, and drive north 5 miles on Rt. 37, then turn west onto gravel road leading to Meadows. Go 1-1/2 miles west, and turn right onto another gravel road at the corral. Proceed north 6 miles to Robinson Ranch.

- 0.0 Robinson Ranch. Take dirt road leading due west from ranch buildings for 3 miles up Holloway Canyon, past Quaking Asp Mountain on the south. The road is rough in places, but passable for most vehicles.
- 3.0 Head of Holloway Canyon. Turn north onto Sublett Troughs Road, and go over low saddle into South Fork Rock Creek Canyon.
- 3.5 Stop 1. Upper Oquirrh Group (Hudspeth Cutoff Fm.) and Park City Group (Grandeur Fm.) at junction of Sublett Troughs Road and South Fork Rock Creek, center of SW 1/4 of Sec. 19, T. 13 S., R. 30 E. Walk up slope on the north side of the canyon to saddle, and turn right to top of hill. The high point of the hill is formed of quartzose sandstones of the highest part of the Hudspeth Cutoff Fm. The contact between it and the overlying Grandeur Fm. occurs just west of the top of the hill, and is placed at the first carbonate to appear above the thick sandstone. The Hudspeth Cutoff Fm. is about 300 meters (984 ft.) thick and is the highest formation in the Oquirrh Group, consisting almost entirely of quartzose sandstones, with a few thin carbonates present in the middle of the formation. These sandstones are the same as those placed in the Heydlauff Fm. by Howard Cramer, as can be shown by lateral tracing of beds, and the name

Heydlauff is dropped in favor of Hudspeth Cutoff. At the base of the formation is a 150-meter (492-ft.) sequence of bedded chert, which is formed of chertified sandstones, with only a small amount of limestone present. The bedded cherts have usually been placed in the Trail Canyon Fm., but are actually sandstones replaced by chert, and therefore best placed in the Hudspeth Cutoff Fm. The bedded chert unit contains some layers with Wolfcampian fusulinids, but the remainder of the Hudspeth Cutoff has not yielded fossils. From the top of the hill to the next hill to the west is a 600-meter (1968 ft.) section of Grandeur Fm., which contains a mixture of sandstones and carbonates. The carbonates in the lower half of the formation (in this area) are dolomitized, and commonly contain nodules and stringers of white chert. The upper half of the formation contains limestones, usually fossiliferous, and occasional thin siltstones and phosphorite horizons. The entire Grandeur is Leonardian in age, and similar to Grandeur in other areas, except that it is thicker than normal.

4.2 Stop 2. Grandeur Fm. and Meade Peak Member of the Park City Group, at Sublett Troughs, SE corner of Sec. 24, T. 13 S., R. 30 E. The Meade Peak Member is exposed immediately west of Sublett Troughs, and on the hillside to the south. The Grandeur-Meade Peak contact runs northward up the small valley just north of the Troughs. The Meade Peak occupies the axis of a large syncline that trends NNW-SSE along the eastern margin of the range, with Phosphoria Fm. exposed for about 8 km (5 mi) along the syncline axis. The syncline is faulted in many places, but is not cut by thrusts of the type suggested by R. Armstrong.

4.6 Fork in road. Take dirt road north, up side canyon.

5.1 Stop 3. Phosphoria Fm. of Park City Group, at Yellowjacket Spring, at west edge of Sec. 24, T. 13 S., R. 30 E. The top of the Grandeur Fm., the Meade Peak Member, and lower part of the Rex Chert (Meade Peak and Rex Chert are members of the Phosphoria Fm.) are present in stratigraphic sequence on both sides of the side canyon here. Rex Chert caps all of the hills near the spring, and variable exposures of the Meade Peak occur on all the hillsides. The Meade Peak is mostly siltstone here, with some conspicuous intraclastic limestones in the lower part, and phosphorite scattered through it. The Rex Chert is composed entirely of bedded chert. Hills on this side of the canyon are capped by only thin layers of Rex Chert, while the high hill south of the canyon has a thick sequence of Rex Chert capping it.

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- 1976: Guidebook (of selected areas in southwestern Montana); from the 1st Annual TRGS Field Conference, held in Bozeman, Montana: Mont. Bur. Mines and Geol. Spec. Publ. 73.
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- 1978: Guidebook of the Drummond - Elkhorn areas, west-central Montana; from the 3rd Annual TRGS Field Conference, held in Missoula, Montana: Mont. Bur. Mines and Geol. Spec. Publ. 82.
- 1979: See 1977.
- 1980: Tobacco Root Geological Society 1980 Field Conference Guidebook; from the 5th Annual TRGS Field Conference, held in Spokane, Washington.
- 1981: 1981 Field Conference Guidebook; from the 6th Annual TRGS Field Conference, held in Pocatello, Idaho: Northwest Geology, v. 11, 1982.
- 1982: The overthrust province in the vicinity of Dillon, Montana, and how this structural framework has influenced mineral and energy resources accumulation; from the 7th Annual TRGS Field Conference, held in Dillon, Montana.
- 1983: Geologic and structural framework and mineral energy resources of northwest Montana; from the 8th Annual TRGS Conference, held in Whitefish, Montana.
- 1984: Geology, tectonics, and mineral resources of western and southern Idaho; from the 9th Annual TRGS Field Conference, held in Boise, Idaho.

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