STUDIES OF GEOLOGY AND HYDROLOGY IN THE BASIN AND RANGE PROVINCE, SOUTHWESTERN UNITED STATES, FOR ISOLATION OF HIGH-LEVEL RADIOACTIVE WASTE

CHARACTERIZATION OF THE BONNEVILLE REGION, UTAH AND NEVADA

U.S. Geological Survey Open-File Report 84-744

In press as Professional Paper 1370-G

This is Chapter G of an eight-chapter Professional Paper series being prepared by the U.S. Geological Survey in cooperation with States in the Basin and Range province.

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DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

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CONVERSION FACTORS

For use of readers who prefer to use U.S. Customary units, conversion factors for terms used in this report are listed below.

U.S. Customary units and troy weights are used in the "Mineral and Energy Resources" section of this report where such terms are widely accepted and utilized by the mineral and energy fuel industries.

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic hectometer	810.7	acre-foot (acre-ft)
cubic kilometer (km^3)	0.2399	cubic foot (ft^3)
liter (L)	0.2642	gallon (gal)
	Mass	
megagram (Mg) or metric ton	1.102	short ton (2,000 lb)
	Temperature	
degree Celsius (^{o}C)	$^{o}F = 9/5\ ^{o}C + 32$	degree Farhrenheit (^{o}F)
	Chemical Concentration	
milligrams per liter (mg/L)	About 1	parts per million

STUDIES OF GEOLOGY AND HYDROLOGY IN THE BASIN AND RANGE PROVINCE, SOUTHWESTERN UNITED STATES, FOR ISOLATION OF HIGH-LEVEL RADIOACTIVE WASTE

CHARACTERIZATION OF THE BONNEVILLE REGION, UTAH AND NEVADA

Edited by

M. S. Bedinger, K. A. Sargent and William H. Langer

ABSTRACT

The Bonneville region of the Basin and Range province in west-central Utah and adjacent Nevada, includes several basins lying south of the Great Salt Lake Desert. Physiographically, the region consists of linear, north-trending mountain ranges separated by valleys, many of which are closed basins underlain by thick sequences of fill. Surface drainage of open basins and ground-water flow is to the Great Salt Lake Desert. In structure and composition the ranges are faulted Paleozoic rocks, locally intruded by Mesozoic and Tertiary plugs and stocks. In the southern and northeastern parts of the region, volcanic rocks are widespread forming a large part of some mountain ranges. The Paleozoic sedimentary rocks include great thicknesses of carbonate rocks which compose a significant aquifer in the region.

Media considered to have potential for isolation of high-level radioactive waste in the region include intrusive rocks such as granite; ash-flow tuff; and basalt and basaltic andesite lava flows. These rock types, basin fill, and possibly other rock types, may have potential as host media in the unsaturated zone. Quaternary tectonism in the region is evidenced by seismic activity, local areas of above normal geothermal heat flow, Quaternary faulting, late Cenozoic volcanic activity, and active vertical crustal movement.

The Bonneville region is part of a large ground-water flow system that is integrated partly through basin-fill deposits, but largely through an underlying carbonate-rock sequence. The region includes several topographically closed basins with virtually no local surface discharge that are drained by the underlying carbonate rock aquifer; closed basins with local surface discharge by evapotranspiration; and basins open to the Great Salt Lake Desert which discharge by ground-water underflow and evapotranspiration. The carbonate-rock aquifer discharges to large springs in the Desert and in basins tributary to the Desert. The climate is arid to semi-arid with greatest precipitation in the mountain ranges. Most recharge probably occurs by infiltration of runoff as it leaves the mountains, although some recharge probably occurs directly to the carbonate rocks in the mountain areas. The concentration of dissolved solids in ground water is generally less than 500 mg/L. Dissolved solids increases in the Great Salt Lake Desert and in major valleys adjoining the Desert. The predominant chemical constituents in ground water are calcium, magnesium and sodium bicarbonate. Chloride type water is associated with the higher dissolved-solids content of water in and near the Great Salt Lake Desert.

The majority of the mineral occurrences in the Bonneville region are of Tertiary age containing metal-bearing deposits.

INTRODUCTION

By

M.S. Bedinger and K.A. Sargent, U.S. Geological Survey

Background and Purpose

A study by the U.S. Geological Survey to evaluate potential geohydrologic environments for isolation of high-level radioactive waste in the Basin and Range physiographic province of the southwestern United States was begun in May, 1981 with the introduction of the study to the Governors of eight Basin and Range States--Arizona, California, Idaho, Nevada, New Mexico, Oregon, Texas, and Utah, and respective Indian tribes in those States. Accordingly, these States were invited to participate in the study by designating an Earth scientist to serve on a Province Working Group with the U.S. Geological Survey--membership of the working group follows the title page. State representatives have provided consultation in selecting guidelines, assembling geologic and hydrologic data, and assessing such information to identify environments that meet the guidelines for further study.

The guidelines for evaluation of the regions and the rationale for the treatment and the basis for geohydrologic characterization of the regions are given in Chapter A of this Professional Paper (Bedinger, Sargent, and others, 1985). The evaluation of the regions is given in Chapter H (Bedinger, Sargent, and Langer, 1985). The titles of chapters in this series are as follows:

A - Basis of characterization and evaluation

B - Characterization of the Trans-Pecos region, Texas

C - Characterization of the Rio Grande region, New Mexico and Texas

D - Characterization of the Sonoran region, Arizona

E - Characterization of the Sonoran region, California

F - Characterization of the Death Valley region, Nevada and California

G - Characterization of the Bonneville region, Utah and Nevada

H - Evaluation of the regions

These chapters are integrated and contain a minimum of repetition. The reader needs to consult Chapters A and H, and the appropriate regional Chapters B through G in order to achieve a complete understanding of the characterization and evaluation of and individual region.

Additional background information on this study is given in reports on the province phase of characterization and evaluation by Bedinger, Sargent, and Reed (1984), Sargent and Bedinger (1985) and Bedinger, Sargent, and Brady (1985).

This report, Characterization of the Bonneville region, Utah and Nevada, Chapter G, is one of six reports characterizing the geology and hydrology of the regions of study in the Basin and Range province. Chapter G is divided into six separately authored sections: (1) Introduction; (2) geology; (3) host media; (4) Quaternary tectonism; (5) ground-water hydrology; and (6) mineral and energy resources. Although the report was prepared under the general guidelines set by the Province Working Group, the scop of individual sections is established by their respective authors.

This chapter provides the geologic and hydrologic framework necessary to evaluate the Bonneville region for relative potential for isolation of high-level radioactive waste. Because of the limited and specific goals of the project, emphasis is placed on the characteristics of the region that relate to waste isolation.

The results of this study are not based on original data; no new field work was conducted specifically for this project. It is not intended to be a definitive report on the geologic and hydrologic aspects of the region, but it provides a general summary of published and unpublished data that are available.

Geographic Setting

The Bonneville region is in the northeastern part of the Basin and Range province and covers most of west-central Utah and a thin strip of adjacent Nevada (fig. 1). The region physiographically consists of linear, north-south trending mountain ranges separated by valleys, many of which are closed basins. The relief between the valleys and adjoining mountains is generally 1,000 to 1,500 m, but locally may be as much as 1,800 m. Figure 2 shows the west face of the House Range with a relief of 1,230 m above Tule valley. The view northward from the House Range to Fish Springs Range is shown in figure 3. The Great Salt Lake Desert forms the lowest basin at about 1,300 m above sea level and no basin flats exceed 1,800 m in elevation. Mountains cover about a third of the region and reach their maximum elevation at Wheeler Peak (3,982 m) in the Snake Range of Nevada. Piedmont-gravel fans cover areas between ranges and basins. Fans are more extensive in the Bonneville region than in higher parts of the Basin and Range province.

In structure and composition the ranges are mostly complexly faulted Paleozoic rocks locally intruded by Mesozoic and Tertiary plugs and stocks. In the southern and northeastern parts of the region, volcanic rocks are widespread forming most of some mountain ranges.

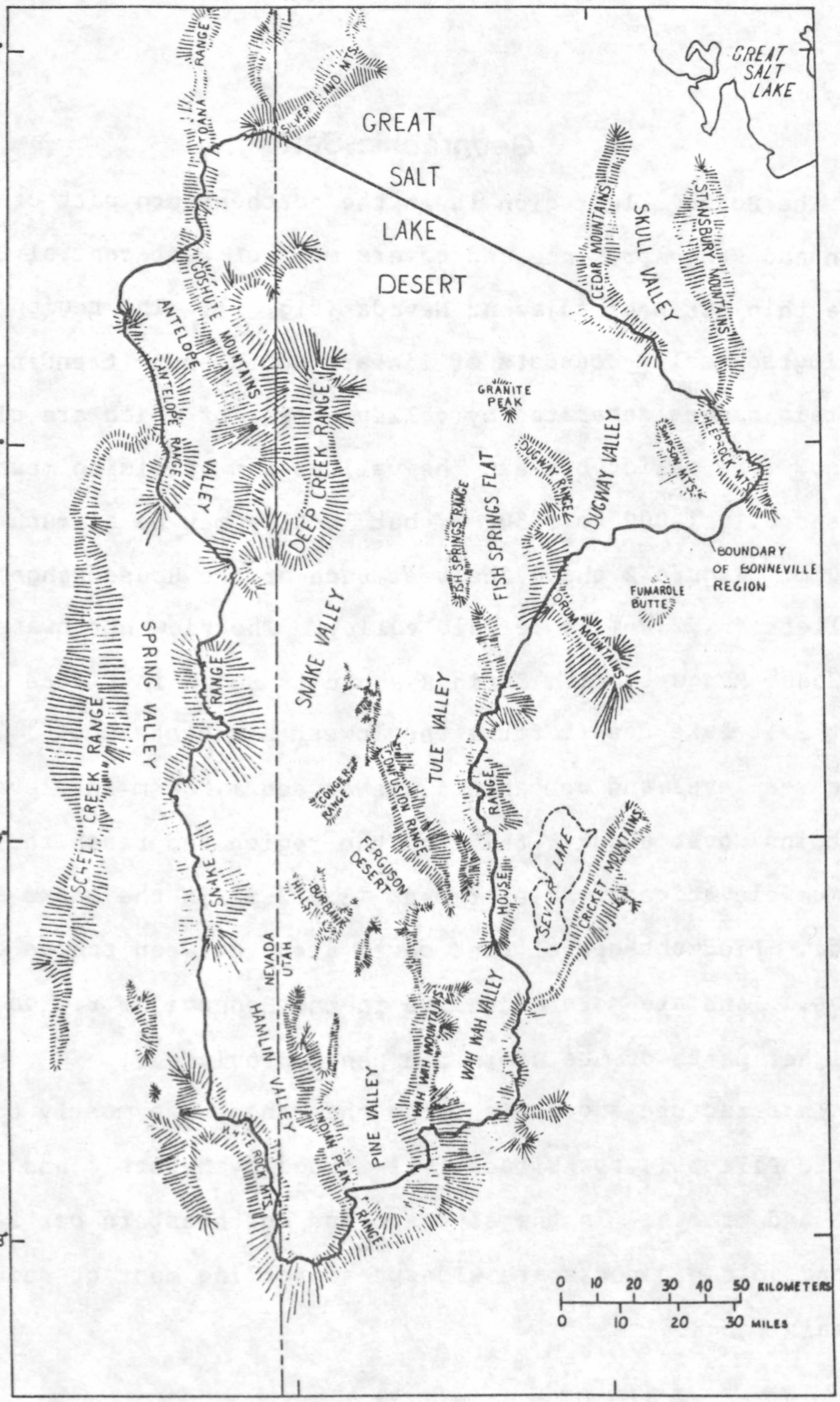

Figure 1.-- Physiographic features of the Bonneville region and vicinity, Utah and Nevada.

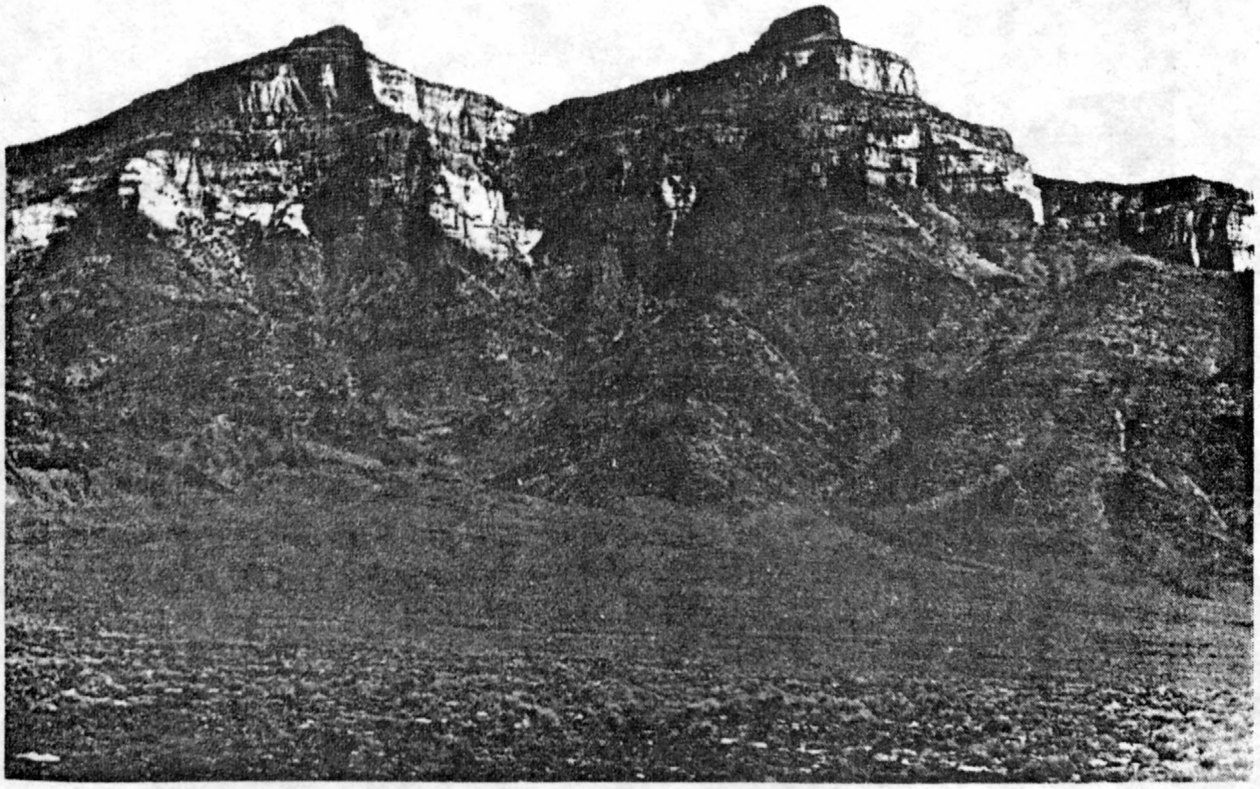

Figure 2.--View from Tule Valley of the west face of the House Range showing interbedded thick Cambrian carbonate rocks and thin shales overlying the Prospect Mountain Quartzite. In descending order, the stratigraphic units are: Swasey Limestone (topmost knobs), Whirlwind Formation (shaley limestone bench), Dome Limestone (cliff former), Chisholm Shale (bench), Howell Limestone (cliff former), Tatow Member of the Pioche Shale (silty carbonate rocks), Pioche Shale (lower part), and Prospect Mountain Quartzite. Tatow Knob, the highest point in the photograph (2,602 m), is 1,230 m above the valley floor. Photograph by C. D. Walcott (1903).

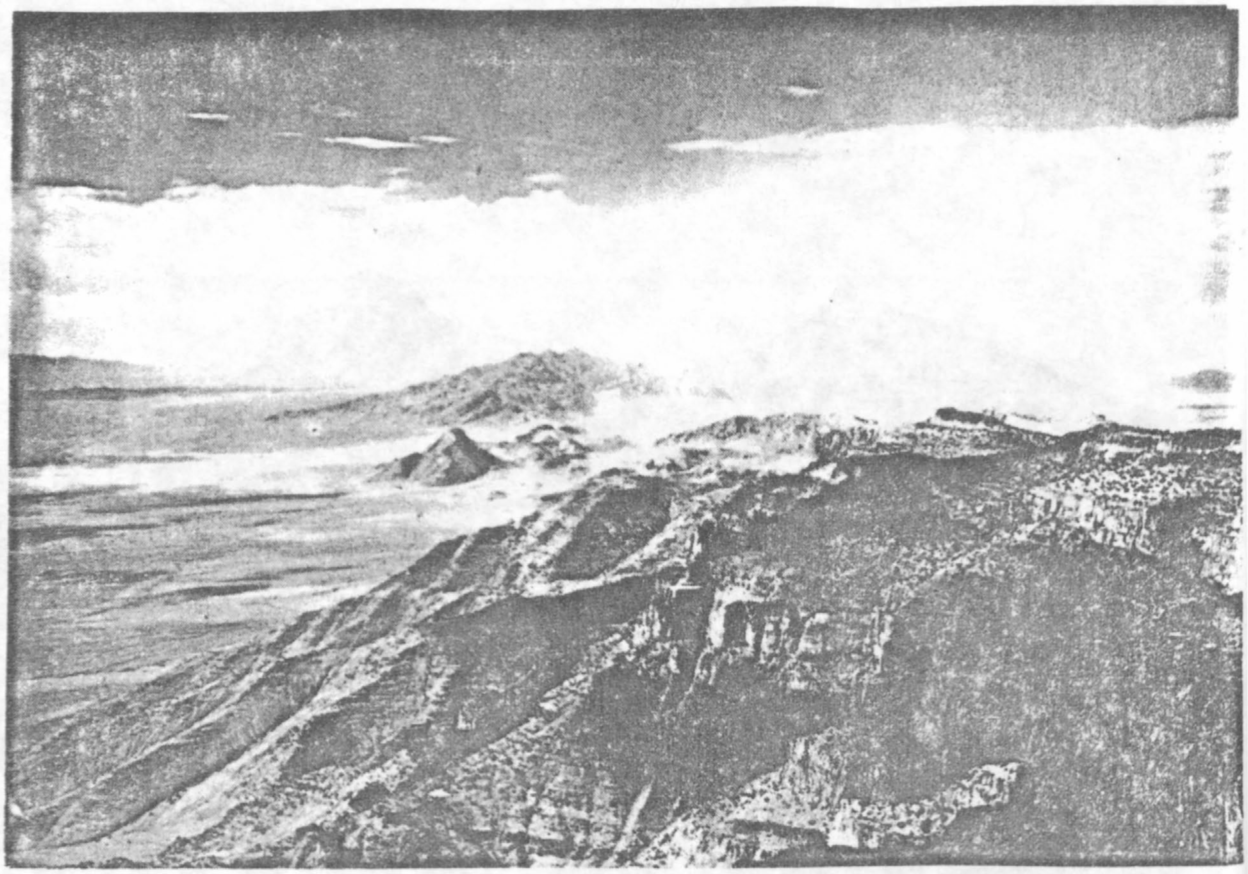

Figure 3.--View north from Tatow Knob in the House Range with Tule Valley on the left; Fish Springs Range, central distance; Fish Springs Flat, middle right; and Granite Mountains on horizon, on right. The Great Salt Lake Desert lies to the north beyond Fish Springs Range. Thick carbonate beds of Cambrian age in the House Range, foreground, are fractured and contain solution channels. Photograph by W. D. Johnson (1901).

Acknowledgments

This report and the other reports in this series were prepared in cooperation with the States of Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah. Each of these States were represented by members of the Basin and Range Province Working Group. The cooperating agencies in each State and members and alternates of the Province Working Group are given following the title page. Frank E. Kottlowski of New Mexico, Susan L. Tingley of Nevada, and Don R. Mabey of Utah, alternate members of the Province Working Group, contributed significantly to the regional phase of the study. The following individuals provided continuing advice and assistance to the Basin and Range Province Working Group and in overall planning and execution of the work in preparation of this series of reports: John W. Hawley and William J. Stone of the New Mexico Bureau of Mines and Mineral Resources; Robert B. Scarborough of the Arizona Bureau of Geology and Mineral Technology; T.L.T. Grose of the Nevada Bureau of Mines and Geology and the Colorado School of Mines; George Dinwiddie and George I. Smith of the U.S. Geological Survey. The authors acknowledge the review and insights into the ground-water hydrology offered by Harry D. Goode, consultant to the Utah Geological and Mineral Survey, and Joseph S. Gates of the U.S. Geological Survey.

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GEOLOGY

By K. A. Sargent, U.S. Geological Survey

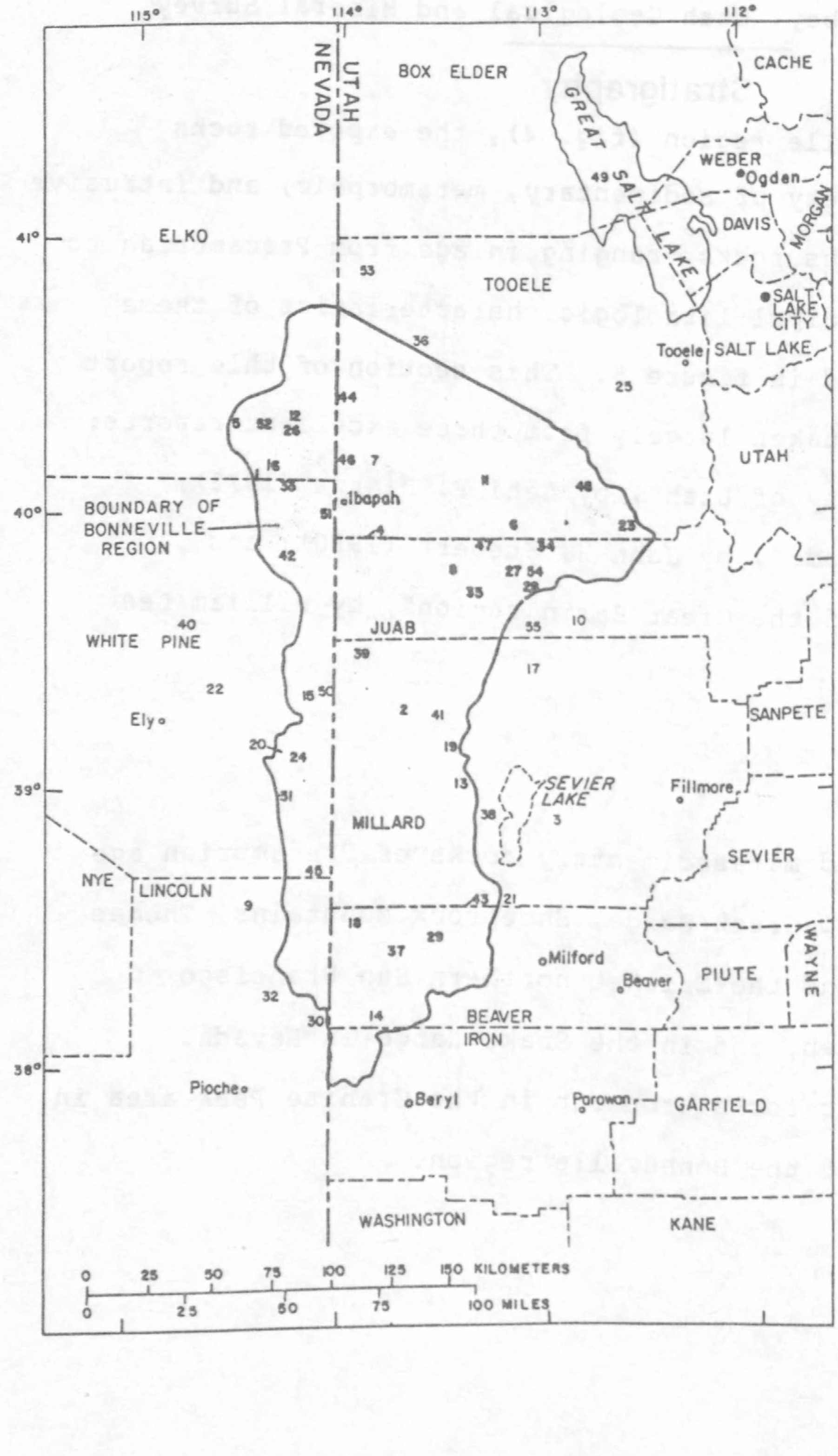
and Don R. Mabey, Utah Geological and Mineral Survey

Stratigraphy

In the Bonneville region (fig. 4), the exposed rocks include a wide variety of sedimentary, metamorphic, and intrusive and extrusive igneous rocks, ranging in age from Precambrian to Holocene. The principal lithologic characteristics of these rocks are summarized in figure 5. This section of this report on stratigraphy is taken largely from three excellent reports: (1) "Geologic history of Utah", by Lehi F. Hintze (1973); (2) "Geology of Nevada", by John H. Stewart (1980); and (3) "Stratigraphy of the Great Basin region", by William Lee Stokes (1979).

PRECAMBRIAN

Sedimentary and metasedimentary rocks of Precambrian age crop out in the Deep Creek Range, Sheeprock Mountains, Thomas and Dugway Ranges and the Cricket-northern San Francisco Mountains all in Utah, and in the Snake Range in Nevada. Precambrian granitic rocks crop out in the Granite Peak area in the northern part of the Bonneville region.



EXPLANATION

1 Antelope Range
2 Confusion Range
3 Cricket Mountains
4 Deep Creek Range
5 Dolly Varden Mountains
6 Dugway Range
7 Dutch Mountain
8 Fish Springs Range
9 Fortification Range
10 Fumarole Butte
11 Granite Peak
12 Goshute Mountains
13 House Range
14 Indian Peak Range
15 Kern Mountains
16 Kingsley Mountains
17 Little Drum Mountains
18 Mountain Home Range
19 Notch Peak
20 Sacremento Pass
21 San Francisco Mountains
22 Schell Creek Range
23 Sheeprock Mountains
24 Snake Range
25 Stansbury Mountains
26 Sugar Loaf Peak
27 Thomas Range
28 Topaz Mountain
29 Wah Wah Mountains
30 White Rock Mountains
31 Wheeler Peak
32 Wilson Creek Range

33 Antelope Valley
34 Dugway Valley
35 Fish Springs Flat
36 Great Salt Lake Desert
37 Pine Valley
38 Sevier Desert
39 Snake Valley
40 Steptoe Valley
41 Tule Valley
42 Tippett Valley
43 Wah Wah Valley

44 Blue Lake Springs
45 Big Spring
46 Deep Creek
47 Fish Springs
48 Government Creek
49 Great Salt Lake
50 Kern Mountain Spring
51 Deep Creek Valley
52 Antelope Valley
53 Bonneville Salt Flats
54 Spor Mountain
55 Drum Mountains

Figure 4.--Geographic index map for the Bonneville region, Utah and Nevada.

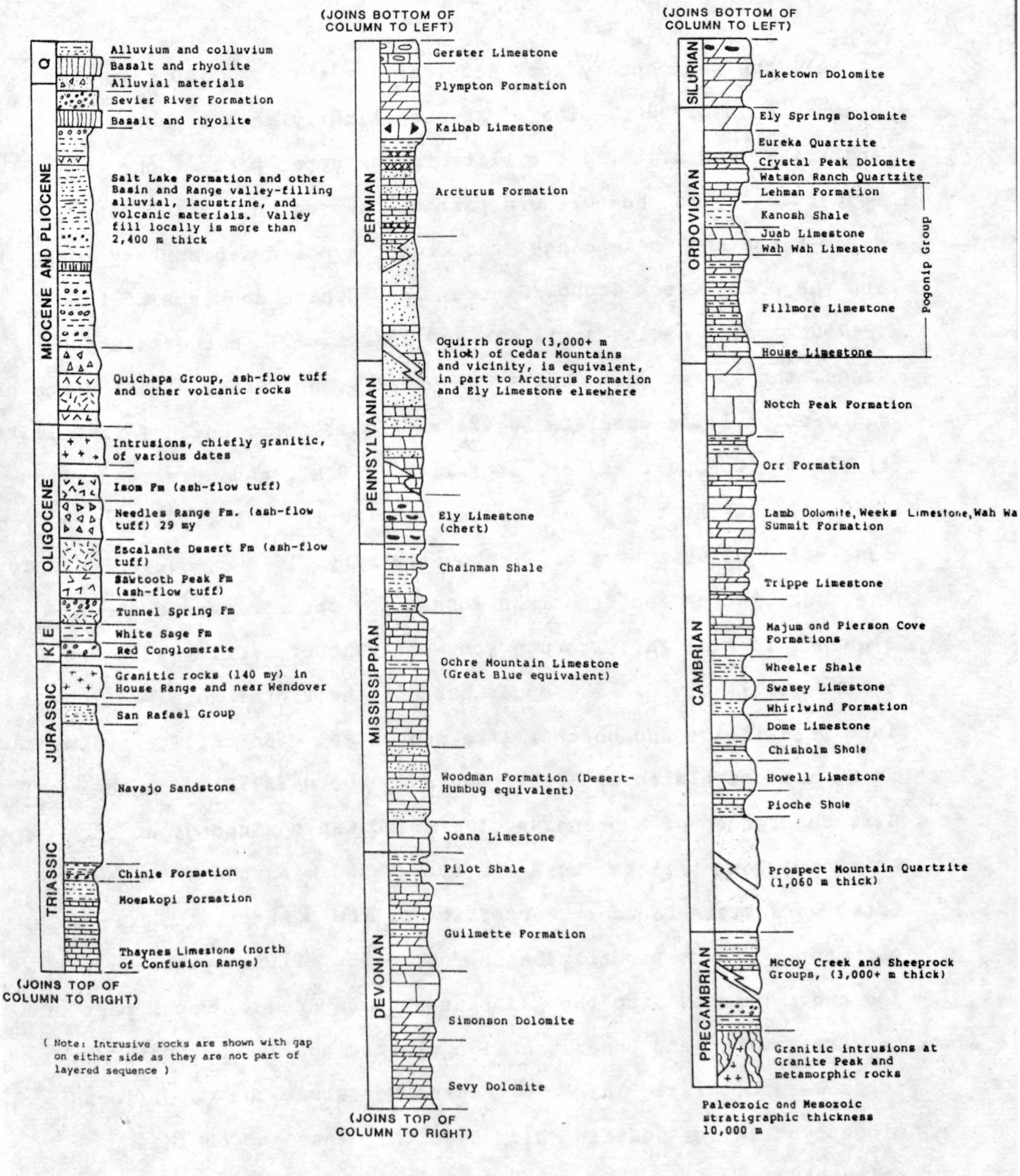


Figure 5.--Principal lithologic units and their ages in the Bonneville region, Utah and Nevada. From Hintze (1980).

All the sedimentary rock sections are thick, 1,100 m to greater than 3,700 m. The rocks are slightly metamorphosed argillite, quartzite, and tillite in the upper part of the Proterozoic. In the northern part of the region, in the Deep Creek Range and Snake Range, the oldest exposed sedimentary rocks are the McCoy Creek Group (Hintze, 1980) which consists of thick (3,750 m) alternating argillite and quartzite. In the Sheeprock Range, the lowest part of the Sheeprock Group (Hinze, 1980) contains 825 m of phyllite overlain by 425 m of quartzite, Dutch Peak Tillite (1,220 m) (Cohenair, 1959), argillite (760 m), and more quartzite (460 m). At the top of the Proterozoic is the Mutual Formation consisting of 60 m of argillite overlain by 215 m of quartzite. To the south in the San Francisco Mountains, the sedimentary rock sequence is similiar although somewhat thinner. Crittenden and others (1971) divided the upper part of the Proterozoic section into pre-tillite and post-tillite sequences. Pre-tillite sedimentary rocks are correlated by Crittenden and others (1972) with the Belt Supergroup of Montana and the Grand Canyon Supergroup of Arizona. Post-tillite rocks are correlated with the Windermere Group of western Canada. Deposition of the post-tillite sedimentary rocks probably began 750 to 850 million years (m.y.) ago and continued into the Cambrian in some areas. Upper part of the Proterozoic and Lower Cambrian clastic marine sedimentary rocks were deposited in great thicknesses along the Cordilleran miogeosyncline of western North America. The axis of the thickest deposition lies near the Utah-Nevada boundary (Stewart, 1972). Diamictites, such as the Dutch Peak Tillite, may represent a Late Proterozoic period of glaciation in western North America.

Precambrian leucocratic granite of Granite Peak crops out in the northernmost part of the Bonneville region in Utah. Fowkes (1964) reports that the rock is extensively jointed and cut by numerous pegmatite dikes and quartz veins. The granite is in contact on the south with a large mass of biotite gneiss. Both the granite and biotite gneiss are shown as Early Proterozoic age. These are the oldest exposed rocks in the region and may be of equivalent age to Early Proterozoic quartzite and schist in the Ogden, Utah area.

PALEOZOIC

Cambrian

Cambrian strata are widely distributed in the Bonneville region. They fall into a definite sequence: basal sandstone or quartzite (Prospect Mountain and Tintic Quartzites, has a maximum thickness of 3,100 m in the Drum Mountains, but is generally about 1,000 m thick), overlain by a thin Pioche Shale (45 to 150 m thick), followed by a thick (1,800 m) carbonate sequence (generally limestone below, dolomite above). Thick mottled muddy limestones and thinly laminated stromatolitic dolomites were deposited in very shallow marine waters which deepened westward. The total thickness of Cambrian rocks exceeds 3,000 m (and locally more than 3,700 m). They are thickest along a broad trough extending north-northeastward from about 38^{o} north latitude at the Utah-Nevada boundary to the Utah-Idaho border north of the Great Salt Lake.

Ordovician

Ordovician strata are thick in the Bonneville region. Areas of greatest deposition nearly coincide with the Cambrian zone of abrupt thickening which is west of the central Utah craton in the Nevada-Utah miogeocline. Ordovician rocks may be divided into a consistent three-fold succession of: (1) Lower Ordovician clastic limestones; (2) Middle Ordovician quartz sandstones; and (3) Upper Ordovician dolomites. Two subbasins developed in the Ordovician, the Ibex basin in the south where as much as 1,550 m of Ordovician strata were deposited, and the North Utah basin (outside the Bonneville region) where as much as 1,700 m of Ordovician is present. The northeast trending Tooele arch separates the two basins (fig. 6).

Lower Ordovician limestone generally contains a large percentage of fine quartz sand and silt, and the limestone itself is commonly clastic. The carbonate units commonly contain intraformational conglomerate where newly deposited silty limestone layers are believed to have been eroded by tidal flat currents and redeposited as pebbles at nearly the same location.

Thicknesses of these Lower Ordovician shallow-water limestones are as great as 1,200 m; they comprise the lower two-thirds of most of the Ordovician stratigraphic sections.

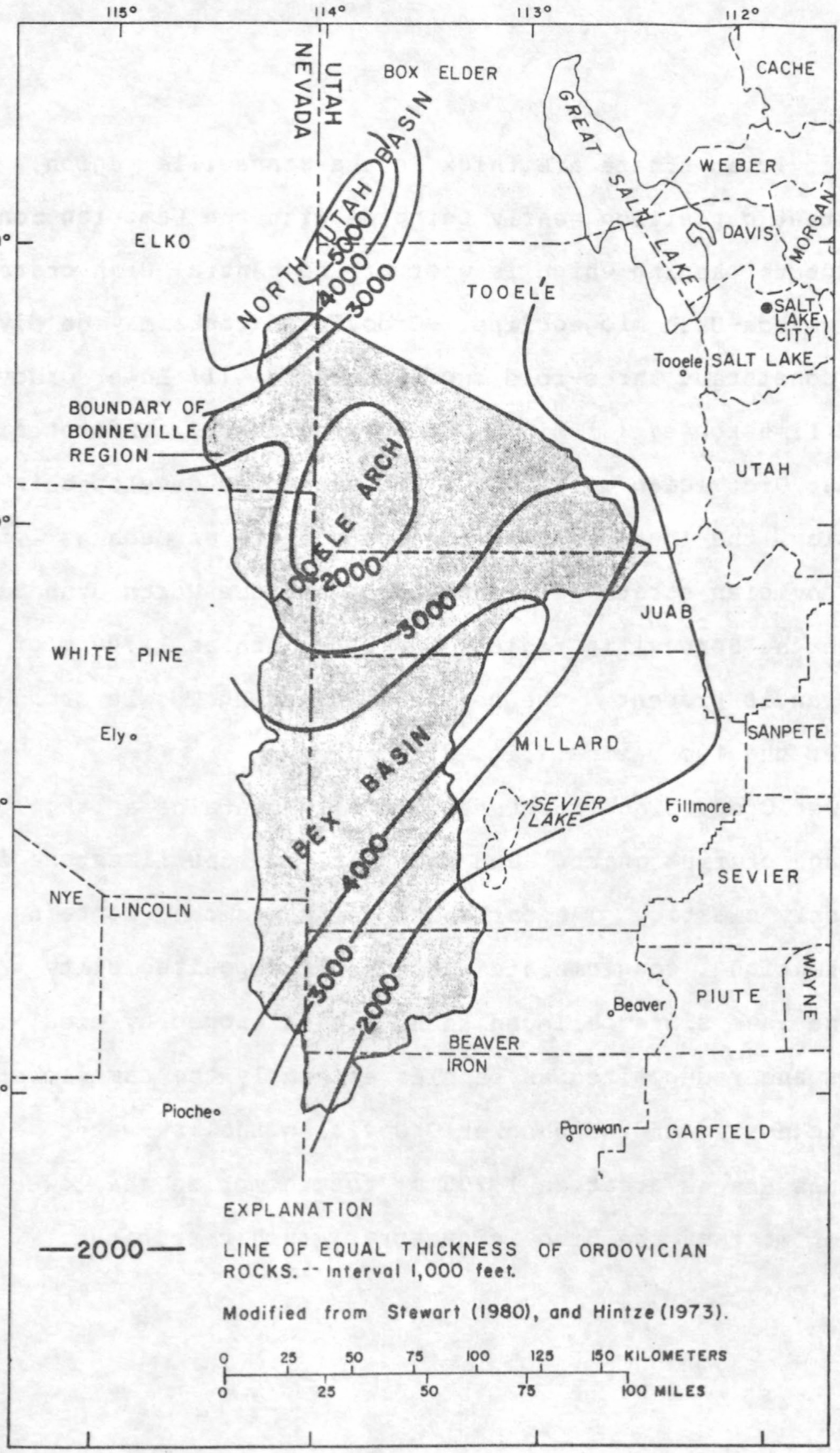


Figure 6.--Isopachs of Ordovician rocks and basins of deposition separated by the Tooele arch, in the Bonneville region and vicinity, Utah and Nevada. Thicknesses in feet. Modified from Stewart (1980), and Hintze (1973).

Middle Ordovician quartzites (Eureka and Swan Peak Quartzites) form distinctive orange-brown cliffs, sandwiched between gray and black underlying and overlying carbonate rocks. The quartzite is thickest in the Ibex basin (275 m) and North Utah basin (about 365 m), but is not present on the Tooele arch.

Upper Ordovician dolomites (Fish Haven and Ely Springs Dolomites) are uniform, dense, cliff-forming units. These strata are thickest, about 215 m, in the Ibex basin.

Silurian

Silurian stratigraphy consists of one lithology, dolomite, assigned mostly to the Laketown Dolomite and part of the overlying Sevy Dolomite. Silurian strata are thin in eastern and southern parts of the Bonneville region, but attain thicknesses as great as 400 m in the Ibex and North Utah basins.

Devonian

Devonian rocks attain their maximum thickness (1,800 m) in the axis of a miogeocline which trends northeastward through the Bonneville region. They thin drastically eastward onto the craton which is less than 160 km to the east. The Devonian rocks show continuous marine deposition in western Utah and eastern Nevada. In Late Devonian time however, the Stansbury Uplift, a mini-orogeny developed at the same location as the Tooele arch, caused the development of an erosional surface which cut out part of the earlier deposited Devonian and, east of the Bonneville region, beveled off rocks as old as Lower Cambrian. As much as 520 m of coarse conglomerate, the Stansbury Formation, was laid down in the vicinity of the uplift.

Rocks of Devonian age include, in ascending order (thicknesses are approximate), the upper part of the Sevy Dolomite (150 m), the Simonson Dolomite (3,000 m), Guilmette Formation composed of dolomite, siltstone, and limestone (1,200 m) and the Pilot Shale, which in this region is dolomite, limestone and sandstone (150 m).

Mississippian

The Oquirrh basin developed in the northern part of the Bonneville region in Mississippian time. The basin is in about the same location as the earlier Devonian Stansbury Uplift and the Ordovician-Silurian Tooele arch. In the Mississippian Period the area became a shallow but steadily subsiding basin.

To the west in central Nevada, the Antler orogenic highland developed and the Roberts Mountain thrust was emplaced in Late Devonian and Early Mississippian time. From the Antler orogenic highlands, terrigenous detrital sediments accumulated in the foreland basin located east of the orogenic belt. The Bonneville region borders this foreland basin and the Nevada portion received Antler flysch deposits of fine-grained sediment which had their origin to the west. Just to the east of the flysch deposits, still in the Bonneville region, the Oquirrh basin was mainly receiving thick shelf-carbonate deposits.

The Oquirrh basin received over 1,800 m of sedimentary rocks, largely carbonate but locally siltstone, sandstone, and some thick shales. The Bonneville region has a complex Mississippian depositional history. Much of the area has the following sequence: Lower Mississippian strata consisting of the upper part of the Pilot Shale and Fitchville Formation (150 m) overlain by the Joana and Gardison Limestones (120 m); and Upper Mississippian consisting of the Great Blue Formation (460 m), mostly limestone, but with a thick shale sequence in the middle, and the Chainman and Manning Canyon Shales (460 m) sequence of mud and fine sand. To the west in Nevada, the Chainman is overlain by the Diamond Peak Formation (sandstone and limestone). The southern part of the Bonneville region was uplifted in late Mesozoic and although most, if not all, of the Mississippian rocks were stripped from the upper plate, the possibility exists that upper Paleozoic rocks may be present in a lower plate.

Pennsylvanian

In Pennsylvanian time the Oquirrh basin continued to dominate the depositional history of western Utah. In the Sheeprock Mountains at the northeast end of the Bonneville region the marine Oquirrh Group or Formation (limestone and sandstone) is over 2,900 m thick. Elsewhere in the region the Pennsylvanian limestones and sandstones are much thinner (Ely Limestone, 425 to 610 m). Identifying the source of the sands comprising the Pennsylvanian in this region is somewhat of a puzzle. They are clean, fine-grained and quartzose. Their source must have been substantial, considering the large quantity deposited. Bissell (1959) suggested that some of it came from the Antler Orogenic Belt of central Nevada.

Permian

The Oquirrh and Ely basins dominated the depositional history of western Utah and eastern Nevada in Permian time. More than 1,770 m of carbonate, sandstone, minor gypsum and chert were deposited in the area of the Deep Creek Mountains and the Confusion Range, which were then part of the Ely basin. At the northern end of the Bonneville region, the Oquirrh basin received over 2,150 m of limestone and sandstone as the upper part of the Oquirrh Group (limestone and sandstone), the Kirkman Limestone, the Grandeur Formation (limestone and sandstone), Meade Peak Member of the Phosphoria Formation and the Franson Member of the Park City Formation (cherty limestone).

MESOZOIC

Triassic

The Lower Triassic Thaynes Limestone represents the last marine deposit in the western Utah and eastern Nevada miogeocline. In the Confusion Range, the Thaynes consists of more than 575 m of limy shales. Farther north in the Deep Creek Range only about 15 m of the Thaynes Limestone is present.

Jurassic

The only Jurassic sedimentary rocks exposed in the region occur in the southern Wah Wah Mountains at the southeastern edge of the Bonneville region. Here some Navajo Sandstone of Triassic(?) and Jurassic age is exposed as a window through an overriding thrust plate of Cambrian rocks.

Coarse-grained granitic rocks occur as stocks, plutons, and small intrusive bodies in the Bonneville region of Utah and Nevada. In Utah two bodies have been radiometrically dated. A quartz-monzonite stock lies at the northern part of the region near the north end of the Deep Creek Mountains, and its southern part has been dated at 152 m.y. by Stacey and Zartman (1976). To the south in the House Range, a porphyritic quartz monzonite dated at 143 m.y. by Armstrong and Suppe (1973) intrudes Cambrian sedimentary rocks. In the southern Snake Range in Nevada near Wheeler Peak, five quartz-monzonite bodies of Jurassic age intrude Precambrian metasedimentary and Cambrian sedimentary rocks. More than 50 radiometric ages have been run on these rocks. Lee and others, (1970) believe these rocks to be 156 to 160 m.y. in age. The only other dated Jurassic stock is located in the Goshute Mountains near Sugar Loaf Peak. Here a quartz-monzonite stock that intrudes Devonian sedimentary rock was reported to have an age of about 140 m.y. (Schilling, 1965). Other undated intrusive bodies may be of Jurassic age, but also may be as young as Tertiary age. These intrusions are designated as Tertiary-Jurassic granitic rocks (TJgr) by Stewart and Carlson (1978) on the Nevada State Geologic Map.

Cretaceous

No Cretaceous sedimentary rocks are known in the Bonneville region; several Cretaceous plutons however, have been reported in the Nevada part of the region. In the northern Antelope Range of Nevada, for example, monzonite and syenite stocks intrude Permian limestone and shale; the largest stock has been reported as 125 m.y. old by Schilling (1965). In eastern White Pine County, Nevada, a relatively large pluton in the Kern Mountains is of possible Cretaceous age. Radiometric ages on this pluton however, are 23 m.y. (Miocene), 48 m.y. (Oligocene), and 72 m.y. (Cretaceous), as reported by Hose and others (1976). Fission-track work by C. N. Naeser of the U.S. Geological Survey (written commun., 1970, as cited by Hose and others, 1976) gave an age of 40 m.y. Other granitic bodies in the Bonneville region are possibly of Cretaceous age, but none have been dated as Cretaceous.

TERTIARY

Paleocene and Eocene

Sedimentary rocks of early Tertiary age include a 180-m-thick red siliceous conglomerate of the White Sage Formation in the Deep Creek Mountains of Utah, and a few small exposures of Sheep Pass Formation (conglomerate, limestone, mudstone, siltstone, shale, and sandstone) in the southern Snake Range of Nevada.

The volcanic history of the Bonneville region began in late Eocene or early Oligocene time with the eruption of intermediate composition pumice breccia and thick lava flows of pyroxene andesite, hornblende rhyodacite, and biotite quartz latite. Thin layers of air-fall tuff and non-welded pumice breccia are intercalated with these lava flows. It is difficult to obtain thicknesses for these rocks, but Hose and others (1976) estimate at least 600 m of lower Tertiary volcanics in the nearby Schell Creek Range in Nevada. The initiation of volcanism in this area was placed by Hose and others (1976) at about 38 m.y., near the beginning of the Oligocene Epoch, and continued intermittently until about 17 m.y.

Intrusive granitic rocks of early Tertiary (Paleocene and Eocene, 38-65 m.y.) age are rare in the Bonneville region. Only two intrusive bodies are known, both in the northern part of the Bonneville region. One is near Dutch Mountain in Utah where a quartz monzonite stock has been dated by Stacey and Zartman (1976) at 38 m.y. The other is in the Antelope Range in Nevada along the Elko-White Pine County line. Here a quartz-monzonite stock that intrudes Cambrian limestone has a reported age between 33 and 41 m.y. (Schilling, 1965; McKee and Marvin, 1976). An isotopic date of 48.2 m.y. from the pluton in the Kern Mountains indicates that it may be early Tertiary, but other dates of 23 m.y. and 72 m.y. shows that its true age is uncertain.

Oligocene

Oligocene sedimentary rocks are rare in the Bonneville region and are restricted to a few thin units within thick sequences of silicic lava flows and tuffs. The sedimentary rocks probably represent deposition between volcanic eruptions. A few sedimentary exposures occur in the southern Snake Range in north-eastern Lincoln County, Nevada. None are known in the Utah part of the Bonneville region, but they probably exist as areally-limited beds intercalated with volcanic rock.

At about 34 m.y. ago, the character of volcanic activity changed in the Great Basin. Voluminous eruptions of quartz latitic and rhyolitic ash-flow tuffs and lava flows began and continued through the Oligocene and much of the Miocene Epochs until about 17 m.y. ago. In the southern Bonneville region, great thicknesses of these older lava flows and tuffs accumulated. The most widespread sequence of ash-flow tuffs in the Bonneville region belongs to the Needles Range Formation, which spreads over more than 34,000 km^2 in southwestern Utah and eastern Nevada. Measured thicknesses of this unit exceed 400 m in the Fortification Range in Nevada and 900 m in the Mountain Home Range of Utah. It reaches a maximum thickness of about 2,500 m in the Indian Peak Range of Utah. Best and others (1979) believe that much of the Needles Range Formation was extruded from the Indian Peak cauldron which has its center near Indian Peak. Elsewhere in the southern part of the Bonneville region, buried volcanic centers or calderas are the probable source of other lava, ash-flow tuff, and laharic breccia, such as the Tunnel Spring Tuff, Sawtooth Peak Formation, Escalante Desert Formation, and the Isom Formation. To the north, the Thomas, Keg, and Desert calderas (just north of the Sevier Desert, on the eastern edge of the Bonneville region) gave rise to other thick ash flows: The Mount Laird Tuff, as much as 500 m thick in Dugway Valley, the Dell Tuff, about 180 m thick, and the crystal tuff member of the Joy Tuff, also about 180 m thick; in the northern part of the Little Drum Mountains, laharic breccia as much as 460 m thick has been reported by Leedom (1974).

Basaltic and andesitic lavas of Oligocene age are relatively sparse in the Bonneville region. Intrusive granitic rocks of Oligocene age (about 25-37 m.y.) have been dated in the northern Snake Range of Nevada. Here quartz monzonite and granodiorite stocks have ages of 25 and 31 m.y. (Lee and others, 1970), and cut sedimentary rock types of Paleozoic age. The Indian Peak stock in the Indian Peak Range of Utah is probably Oligocene. This stock is quartz monzonite porphyry and intrudes intra-cauldron ash-flow tuffs of the Needles Range Formation dated at about 29 m.y. (Grant and Best, 1979). Small dioritic intrusions in the Wah Wah Range may be of Oligocene age.

Pliocene and Miocene

Pliocene and Miocene sedimentary rocks are widespread and locally very thick in the Bonneville region. They commonly occur in down-faulted blocks and for the most part were probably deposited during or after the development of basin-range structure. These rocks contain a wide variety of fluvial and lacustrine deposits, usually along with large amounts of volcanic debris. They are generally light-colored conglomerate, sandstone, siltstone, mudstone, and limestone. Ash-flow and air-fall tuffs are commonly intercalated with fluvial and lacustrine sediments. The thickness of the Pliocene and Miocene sedimentary rocks ranges from about 15 to about 90 m in most exposures but locally have been found to be from 1,500 to 2,150 m thick, as at Sacramento Pass in the southern Snake Range, and substantial thicknesses underlie many of the Cenozoic basins. Farther south in Lincoln County, Nevada, the Panaca Formation is at least 425 m thick, and equivalent rocks elsewhere are probably even thicker. The Panaca Formation consists largely of lake beds of siltstone and clay shale.

In Utah, the Salt Lake Formation consists of valley-filling alluvium, volcanic materials, and lacustrine deposits of Miocene and Pliocene age. The unit is poorly exposed in the Bonneville region but exceeds 300 m in thickness to the east under the Sevier Desert. No doubt the Salt Lake Formation or rocks of similar age and lithology, are as thick as several hundred meters in many valleys of the Bonneville region.

Early to middle Miocene and Pliocene volcanism is concentrated in two areas of the Bonneville region. To the north, just west of the Thomas Range at Spor Mountain, thick silicic lava flows (500 m), tuff breccia, and a few thin (60 m) ash flows were extruded about 21 m.y. ago. In the southern part of the Bonneville region, thick rhyolitic tuffs and lava flows continued to pile up in the southern Indian Peak Range, eastern Mountain Home Range, and eastern Wah Wah Mountains (all in Utah) and in the Wilson Creek Range in Nevada. Locally, as much as 760 m of dacitic and rhyolitic lavas and 120 m of ash-flow tuff (Condor Canyon Formation of the Quichipa Group, 21-24 m.y.) are present in the Indian Peak-Mountain Home Ranges. Farther east in the Wah Wah Mountains, nearly 600 m of quartz latitic lava flows and 400 m of ash-flow tuff were extruded about 21 to 24 m.y. ago. In this area, Lemmon and Morris (1979) also mapped the basalt of Brimstone Reservoir. This unit, about 150 m thick, was dated by Best and others (1980) at 13.3 m.y. In the Wilson Creek Range in Nevada, as much as 300 m of Miocene ash-flow tuff is shown by Ekren and others (1977). It is uncertain which Miocene formations comprise this thickness, but distribution maps of Cook (1965) indicate the thickest unit may be the Leach Canyon Tuff.

Near the end of the Miocene, as much as 700 m of upper Miocene alkali-rhyolitic domes and flows were extruded at Topaz Mountain in the Thomas Range (Lindsey, 1982). This episode, at about 6.5 m.y., marks the last major silicic extrusive event in the Bonneville region. Andesitic and dacitic flows were extruded in the lowlands west of the Fish Springs Range. Here a date of 4.7 m.y. is shown by Luedke and Smith (1978), whereas Morris (1978) shows these flows as Oligocene. Other minor scattered upper Miocene and Pliocene volcanics occur northeast of the Wah Wah Mountains and in the Deep Creek Mountains.

Intrusive granitic rocks of Miocene and Pliocene (25-2 m.y.) age are rare in the Bonneville region. One reported age for the Kern Mountain pluton was 23 m.y., but other dates on the same pluton (48 m.y. and 72 m.y.) put doubt on its actual age. Reported ages for the Ibapah stock, a large body in the Deep Creek Range, were 18.7 and 22 m.y., but a third age of 71 m.y. indicates this altered biotite adamellite stock could be much older. The stock is intensely fractured by six sets of joints. Other Tertiary intrusive bodies in the region may be of Miocene and Pliocene age, but because no dates have been run on them, no exact age can be assigned.

QUATERNARY AND QUATERNARY AND TERTIARY

Extensive unconsolidated to partly consolidated sedimentary rocks form a veneer over more than half of the Bonneville region. These sediments are in the form of Quaternary and Quaternary and Tertiary lake and playa deposits, alluvial fans, colluvium, and stream alluvium. To a lesser extent the upper Cenozoic deposits form landslides, beach ridge deposits, and sand dunes. Materials in these deposits grade from large toreva and other landslide blocks, to coarse gravel and boulders near mountain fronts, to fine silt, clay and locally some evaporitic deposits in valley flats and playas. For the most part the thickness of Quaternary sediments is less than a hundred meters, but in a few areas thicknesses may approach 300 m.

Quaternary basalts and andesites in or near the Bonneville region are limited to one location just outside the area, east of the Little Drum Mountains, at Fumarole Butte. Here a shield volcano composed primarily of basaltic andesite and covering about 100 km^2 has been dated at 0.88 m.y. (Peterson and Nash, 1980). No intrusive rocks of Quaternary age are known in the Bonneville region.

SUMMARY OF TECTONIC EVENTS

Precambrian tectonic setting

Evidence of the early tectonic setting of the Bonneville region is recorded in sedimentary and metasedimentary rocks of late Precambrian and Early Cambrian age. Stewart (1980) reports shallow-water terrigenous detritus, mainly quartzite, argillite, and siltstone, being deposited to thicknesses between 3,000 and 6,000 m. Studies of cross-stratification in the coarser-clastic units indicate dominantly westward transport. Stewart interprets the sediments as continental shelf deposits laid down in the Cordilleran miogeosyncline at what was then the western margin of North America.

Early and middle Paleozoic tectonic setting

During early and middle Paleozoic time the region continued to subside with the deposition of shallow-water sediments in a westward thickening wedge along the western margin of North America. In Ordovician time two well-defined northeast-trending depositional basins formed: The Ibex basin and the North Utah basin separated by the Tooele arch (fig. 6). These structures persisted through the Silurian. In the Devonian, a mini-orogeny, called the Stansbury disturbance, renewed emergence of the area of the Tooele arch and an unconformity developed which beveled downward to rocks as old as Lower Cambrian east of the Bonneville region. Coarse conglomerate, the Stansbury Formation, formed near the uplift and Devonian sands spread out from the distal edges of the conglomerate.

By Late Devonian and Early Mississippian time the Antler orogeny was dominant to the west in central Nevada. Deep-water siliceous sediments and volcanic assemblage rocks were being uplifted and moved eastward over shallow-water carbonate rocks along the Roberts Mountain thrust for as much as 145 km. This orogeny created the Antler highland from which coarse-flysch sediment was shed to both the east and the west. The Bonneville region, more than 150 km to the east, received some fine-grained sediment from this highland, but the dominant lithology was still carbonate and shale. The Oquirrh basin began to form in the northern Bonneville region near the end of Mississippian time. Here, over 1,800 m of sedimentary rocks, largely limestone, was deposited in the Mississippian Period alone.

Late Paleozoic and Early Triassic tectonic setting

For the Bonneville region, the tectonic setting from middle Mississippian to Early Triassic changed only in the configuration and size of depositional basins. The deepest part of the Oquirrh basin migrated eastward and received as much as 4,000 m of Pennsylvanian and nearly 3,000 m of Permian marine sediments. Also in Pennsylvanian and Permian time, the Ely basin, located southwest of the Oquirrh basin along the Nevada-Utah line, had formed. It received as much as 600 m of sediment in Pennsylvanian time and as much as 1,770 m in Permian time. The Thaynes Limestone represents the last marine invasion in the Bonneville region. In the southern Ely basin 580 m of Lower Triassic Thaynes Limestone is preserved. By the end of the Triassic, more than 10,000 m of sedimentary rocks had been deposited in the Bonneville region.

Mesozoic tectonic setting

Marine deposition ended in the early Mesozoic when the large-scale north-northeast-trending Sevier orogenic belt became active. Most of eastern Nevada and western Utah were in this belt of large-scale overthrusting, folding, and general uplift which lasted from Middle Jurassic to the end of the Mesozoic. Thick wedges of Upper Jurassic and Cretaceous detritus were shed to the east and southeast from the uplift. Metamorphic terrane within the Bonneville region related to the Sevier orogeny is found in the Kern and Deep Creek Mountains, and the northern Snake Range near the Utah-Nevada border. In the Snake Range, the geology is complex, but consists of a metamorphosed core overlain by a nonmetamorphic allochthonous sequence. This area has been called a metamorphic core complex, one of a series in a north-trending zone across the western United States. The underlying rocks consist of upper Precambrian and Cambrian siliciclastic and carbonate rocks of low metamorphic grade and weak schistosity. A subhorizontal tectonic discontinuity or decollement separates the metamorphic complex from the overlying unmetamorphosed overthrust rocks. The date of the metamorphism is not clear, but perhaps is as early as Jurassic and continued into Tertiary time. Metamorphism is present in the older rocks of the Kern and Deep Creek Mountains, but here the Snake Range decollement is not well expressed. Some of the largest granitic bodies in the region were intruded in Jurassic time (Stewart, 1980).

Cenozoic tectonic setting

In Paleocene and Eocene time, much of western Utah and eastern Nevada was elevated and shedding continental sediments to the east and south. In late Eocene or early Oligocene time, explosive volcanism started with extensive eruptions of ash-flow tuffs and intermediate composition lavas, and numerous granitic stocks were emplaced. In western Utah, the Oligocene igneous activity occurred in three west-trending belts beginning in the north. The northern belt, which extends westward from Park City, Utah, is north and northeast of the Bonneville region. The middle (Tintic) belt extends into the northern part of the Bonneville region, and the southern (Marysvale and Pioche) belt is in the southern part of the region. Magnetic data indicate that within these igneous belts intrusive rock is much more abundant in the subsurface than in outcrop. A nearly continuous batholith appears to underlie much of the Marysvale and Pioche belt. In Miocene and Pliocene time, volcanism continued. By middle Miocene, crustal extension and block faulting started to shape the Bonneville region into the basin and range patterns similar to the ones seen today. Sedimentation began in the basins in the Miocene and has continued to the present. Basins commonly are underlain by sedimentary and volcanic rocks of Miocene and Pliocene age, concealed by Quaternary alluvium and lake beds. In addition to the local basin-and-range structure, a major regional depression, the Lake Bonneville Basin, developed in northwestern Utah. By Holocene time, this basin had a topographic closure of over 300 m and periodically contained major lakes.

Structural Geology

Two major tectonic events contributed to the structural history of the Bonneville region: (1) Thrust faulting and folding during the Sevier orogeny in Middle Jurassic to early Tertiary time; and (2) middle to late Cenozoic regional extension and block faulting sometimes called the Basin and Range event or orogeny.

THRUST FAULTING

Eastward-directed thrust faults and related folds of the Sevier orogeny affected the pre-Tertiary rocks of the Bonneville region. The structural style varies from place to place depending in part on the physical characteristics of the rocks involved and in part upon the location within the effected belt. The Precambrian and lower Paleozoic sequence is generally composed of more massive and seemingly more competent quartzites and carbonate rocks. The upper Paleozoic rocks, while having great thicknesses of carbonate rock, also contain a large percentage of shale which is relatively soft and incompetent. The oldest important structural feature in the area is a large low-angle fault complex found in the Snake Range, Kern Mountains, and Deep Creek Range. This low-angle fault or detachment has been called the Snake Range decollement. It is well exposed in many places and extends throughout the Snake Range, which is more than 80 km long and more than 25 km wide. The lower plate is cut by intrusive bodies that locally metamorphosed the country rock. Rocks in the lower plate are Middle Cambrian or older and are only moderately faulted. Rocks in the upper plate are Middle Cambrian or younger and complexly faulted, but are not cut by intrusives. The style of thrusting in the upper plate is that of younger over older so that the succession in ascending order is generally correct but large slices are cut out thereby greatly attenuating the geologic section. In addition, the upper plate shows a higher density of normal faults than the lower plate. This resulted in a horst and graben structure, a style compatible with development by horizontal tension during at least part of the Sevier orogeny.

Further east, the style of thrusting changes with older (lower Paleozoic and Precambrian) rocks over younger (upper Paleozoic and Mesozoic) rocks. In this area, several thrusts have been mapped at the surface and more have been identified in reflection seismic data. A Consortium for Continental Reflection Profiling (COCORP) seismic reflection profile (Allmendinger and others, 1983) extending east from the Snake Range reveals a series of remarkably continuous low-angle reflectors extending to depths of 15 to 20 km. These reflections may represent major detachments developed during the Sevier orogeny. Windows in the thrust plates as far west as the Wah Wah Mountains reveal Mesozoic rocks underlying Paleozoic rocks. The possibility exists that the Paleozoic and Precambrian rocks cropping out in the eastern and central part of the Bonneville region are in thrust sheets overriding Mesozoic sedimentary rocks.

FOLDS

Folds are surprisingly scarce in the region and appear to be restricted largely to structural troughs. The trends of principal folds within the structural trough areas, as in the Confusion Range in Utah and west of the region in the Butte structural trough, generally parallel the axis of the trough. In these two examples, both folds and axes have a northerly trend. The folds are formed in upper Paleozoic rocks that contain thick incompetent units. They are believed to have formed during late Mesozoic to early Cenozoic time. During folding in the Confusion Range, two decollement-type faults developed. Rocks in the thrust plates glided toward the structural trough axis forming complex secondary folds and lobes (Hose, 1977).

BASIN-AND-RANGE FAULTING

The topography of the Basin and Range province is one of north-south-trending elongate mountain ranges flanked by nearly flat-bottomed valleys or basins. This pattern was formed by the Basin and Range orogeny which began about 17 m.y. ago in response to regional extension. The vertical displacement on these faults ranges up to more than 4,500 m. Movement along these faults is the primary cause of earthquakes in the region. Stewart (1971, 1978) recognizes three basic models of basin-and-range structure. These are: (1) A system of structural blocks rotated along curving, downward flattening listric faults; here the uptilted part of the block forms the mountains and the downslope area is the valley; (2) simple horsts and grabens; and (3) a system of elongate rhombohedral blocks formed by fragmentation of the upper crust by high-angle faults. There is no unanimous opinion on which model is dominant over the province, one or more models are likely relevant in any given area. In western Utah, the seismic reflection and earthquake data strongly suggest that the listric style is dominant. Many basin and range faults flatten at depth and appear to merge with the older, low-angle thrust faults. Apparently the current extension of the upper crust in this region is occurring along the same structures that formed during crustal shortening in Mesozoic time. Most of the earthquakes occur at shallow depths with 90 percent shallower than 10 km. The Bonneville region lies west of the intermountain seismic belt, but earthquakes are recorded in the region and evidence of local Quaternary faulting exists.

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POTENTIAL HOST MEDIA FOR RADIOACTIVE WASTE

By

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Potential host media for a mined repository for isolation of high-level radioactive waste in the Bonneville region, Utah and Nevada include intrusive rocks such as granite; ash-flow tuff, especially where densely welded and having thickness greater than 100 m; and basalt and basaltic andesite lava flows where greater than 100 m thick. In addition, basin-fill deposits and possibly other rock types have potential as host media in the unsaturated zone. Salt and other evaporitic deposits are not known to have potential as host media in this region. Plate 1 shows the outcrop areas of potential host media and areas believed to have thick unsaturated zones in the Bonneville region.

Intrusive Rocks

Granitic rocks in the Bonneville region occur as widely scattered, mostly small exposures. The rocks are of Mesozoic, Tertiary and Precambrian age and are summarized by Jenness (1984a).

The Indian Peak Quartz monzonite stock of Tertiary age crops out in the southern part of ground-water unit BV-01. It is heavily altered to propylite. The Cactus stock, a quartz monzonite tabular intrusive of Tertiary age, crops out in the San Francisco Mountains of southeastern part of ground-water unit BV-01. A 143-m.y.-old (Mesozoic) porphyritic quartz monzonite intrusive crops out north of Notch Peak in northeastern part of ground-water unit BV-01. The southwestern part of the mass is a sill and the main part is an extensively jointed stock. Jurassic and Cretaceous to Tertiary quartz monzonite intrusive rocks crop out in the Snake Range of northwestern part of ground-water unit BV-01 and southwestern part of ground-water unit BV-02. The area is believed to be part of a metamorphic core complex and is probably underlain by a regional-detachment fault. Some of the granite has been metamorphosed to a gneiss, perhaps during thrusting.

Outcrops of intrusive rocks in western part of ground-water unit BV-02 in the Kern Mountains are Tertiary and Cretaceous granodiorite and quartz monzonite having steep north-south trending fractures. The Ibapah stock of Tertiary age (18 to 22 m.y.) crops out in the Deep Creek Range at the junction of ground-water units BV-02 and BV-04. The mass, a quartz monzonite intrusion, is reported to be intensely fractured. The Gold Hill stock, in units BV-02 and BV-04, also a quartz monzonite, is in the northern part of the Deep Creek Range. The stock is composed of both Jurassic (152 m.y.) and Tertiary (40 m.y.) intrusive masses. Surface exposures of the stock locally show three planes of fracturing (fig. 7) and deep weathering.

Two stocks crop out in the eastern part of ground-water unit BV-03. To the southeast, Tertiary granitic intrusive rocks form much of Desert Mountain. Magnetic surveys indicate the stock may have intruded part of a large caldera. The other stock is the Sheeprock granite of Tertiary age in the Sheeprock Mountain. This stock is cut by numerous joint sets. No description is available for a third small intrusion in the northeastern part of ground-water unit BV-03.

Figure 7.--Outcrop of quartz monzonite showing three fracture planes, east of Gold Hill, Deep Creek Range, Tooele County, Utah. Photograph by M. S. Bedinger (1984).

A small Tertiary quartz monzonite stock of uniform texture crops out in the Kingsley Mountains in west-central part of ground-water unit BV-04. Two quartz monzonite stocks occur east of Antelope Valley in ground-water unit BV-04. The one southwest of Sugar Loaf Peak is of Jurassic age, and the one on the divide between ground-water units BV-04 and BV-05 at the Nevada-Utah border is Tertiary to Jurassic in age. In the Dolly Varden Mountains of northwestern part of ground-water unit BV-04, monzonites and syenites of Tertiary and Cretaceous age crop out.

Tuffaceous Rocks

The southern Bonneville region was the site of extensive volcanism in Oligocene and Miocene time. Exposed, and probably buried, calderas gave rise to sequences of ash-flow tuff that may exceed 5,000 m in aggregate thickness. Ash-flow tuffs in the Mountain Home, and Indian Peak Ranges in southern part of ground-water unit BV-01 are the thickest in the region. The Needles Range Tuff was extruded from a caldera complex in the Indian Peak Range and accounts for more than 2,500 m of the tuff in that area. Ash-flow tuff thickness in the White Rock Mountains of Nevada in southwestern part of ground-water unit BV-01, and the San Francisco Mountains of Utah in southeastern part of ground-water unit BV-01 are approximately 500 to 1,000 m thick respectively. Scattered small outcrops of ash-flow tuff 500 m thick crop out in central part of ground-water unit BV-01. Aggregate tuff thicknesses decrease to the north away from the calderas complex in the Indian Peak Range.

In the north half of the Bonneville region parts of the Thomas, Dugway Valley, Keg, and Desert calderas are present in southern and southwestern part of ground-water unit BV-03. Sections with as much as 1,000 m of ash-flow tuff may be present in and near the calderas, but flows become very thin short distances away from their source areas. Ash-flow tuffs in the Bonneville region are summarized by Roggensack and Jenness (1984).

Basaltic Rocks

Basalt flows of Miocene age with total thicknesses as much as 150 m crop out at the south end of Wah Wah Valley in southeastern part of ground-water unit BV-01.

Numerous small erosion remnants of basalt flows as much as 60 m thick crop out west and southeast of the Fish Springs Range in ground-water units BV-02 and BV-03. Basaltic rocks of the Bonneville region are summarized by Jenness (1984b).

Argillaceous Rocks

Shales and other argillaceous units are common and widely distributed throughout the Bonneville region (see Johnson, 1984). Shales thicker than 150 m are known in Precambrian, Cambrian, Ordovician, Devonian and Mississippian, and Triassic sections. Because of the structural complexities caused by folding and faulting, argillaceous rocks in the region do not appear to be favorable as host rocks. It is presumed, however, that the rocks would serve as sorptive zones for radionuclides and would slow traveltimes of ground-water flow from a repository to its discharge area.

Thick slate and argillite occur in the Sheeprock and McCoy Groups of Precambrian age (Hintze, 1980) in ground-water units BV-01, BV-02, BV-03, and BV-04. Other thick shales occur in ground-water units BV-01, BV-02, and BV-04 in Cambrian Pioche Shale Ordovician Kanosh Shale, Mississippian and Devonian Pilot Shale and Mississippian Chainman Shale. In the Confusion Range more than 570 m of Triassic Thaynes Limestone, containing thick claystone and siltstone, is present, but is highly faulted.

Unsaturated Zone

Practically all the ranges in the region have unsaturated zones that are probably greater than 150 m thick.

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QUATERNARY TECTONISM

By

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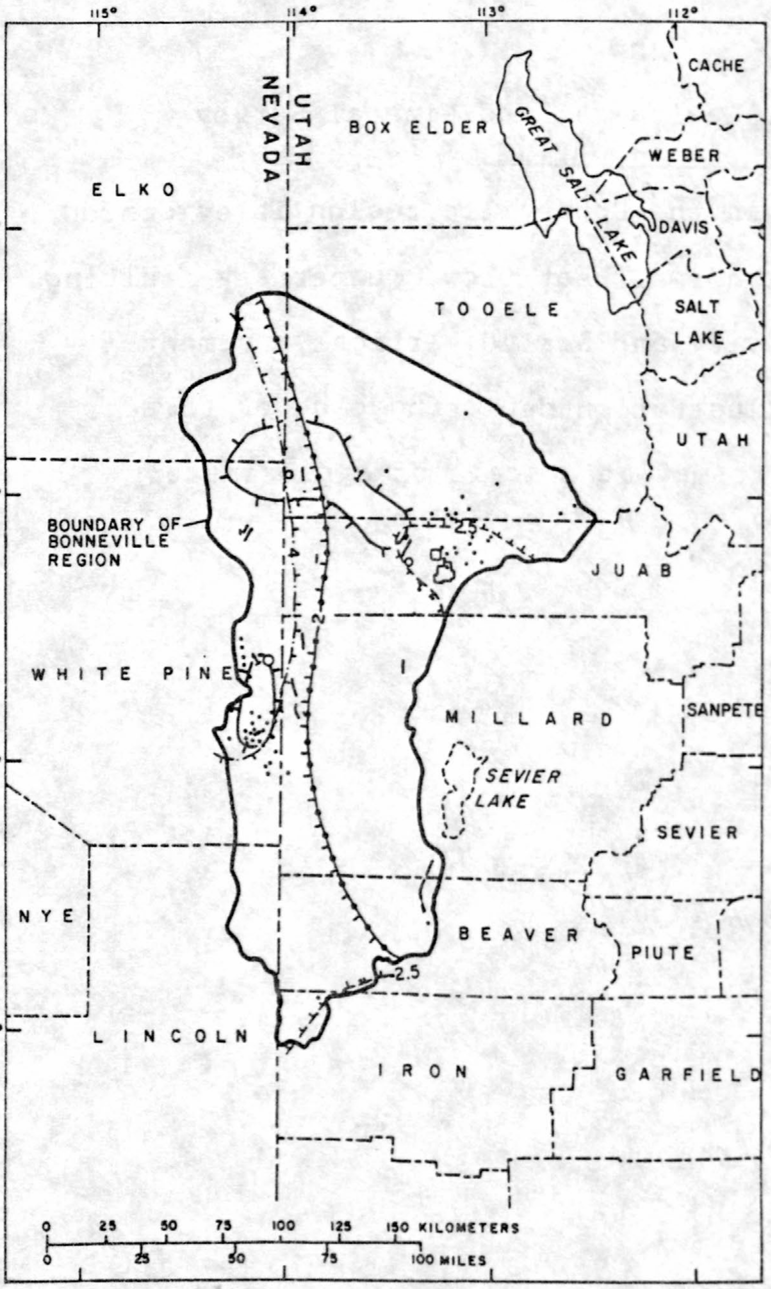
Quaternary tectonism in the Bonneville region is evidenced by seismic activity, above normal heat flow, Quaternary faulting, late Cenozoic volcanic activity and active vertical movement. Figure 8 is a composite illustration depicting each of these features in a generalized format at a scale of approximately 1:2,500,000.



EXPLANATION

- EPICENTER OF EARTHQUAKE OF MAGNITUDE LESS THAN 4 RICHTER SCALE AS DEFINED BY ASKEW AND ALGERMISSEN, 1983
- EPICENTER OF EARTHQUAKE OF MAGNITUDE 4-5 RICHTER SCALE AS DEFINED BY ASKEW AND ALGERMISSEN, 1983
- EPICENTER OF EARTHQUAKE OF MAGNITUDE 5-6 RICHTER SCALE AS DEFINED BY ASKEW AND ALGERMISSEN, 1983
- LINE OF EQUAL STRAIN RELEASE IN EQUIVALENT MAGNITUDE 4.0 EARTHQUAKES PER 823 SQUARE KILOMETERS.-- Hachures on side of lesser strain release
- QUATERNARY FAULT
- HEAT-FLOW MEASUREMENT SITE WITH HEAT-FLOW READING IN EXCESS OF 2.5 HEAT-FLOW UNITS
- LINE OF EQUAL HEAT-FLOW.-- Hachured on side of lesser heat flow
- UPWARD CRUSTAL MOVEMENT IN METERS PER 10,000 YEARS.-- Hachured on side of lesser movement
- UPWARD CRUSTAL MOVEMENTS IN MILLIMETERS PER YEAR.-- Hachured on side of lesser movement

Figure 8.--Quaternary tectonic features.

Seismicity

The Bonneville region lies west of the intermountain seismic belt and only a few dozen earthquakes have been reported for the region (Richins, 1979). Most occurred in two swarms; one in late 1963 and early 1964 was west-central, in the Snake Range of Nevada with a maximum Richter magnitude (surface wave) of 3.9. The other was in the northeast near the Thomas Range in 1974, 1975 and 1976 with a maximum Richter magnitude of 2.2 (fig. 8). All but three earthquakes in the region are less than Richter magnitude 4. The largest earthquakes are two Richter magnitude 4.3 events. One in 1894 apparently was near the young fault scarps on the east side of the Fish Springs Range. The other was near the Nevada-Utah line near Ibapah, Utah in 1915. The swarm of earthquakes in the west-central part of the region may be associated with the Snake Range decollement, a low-angle detachment surface, recently discussed by Allmendinger and others (1983). Contours showing the greatest strain release in the region are centered on the earthquake swarm in the Snake Range and on the earthquake near Ibapah (Algermissen and others, 1983) (fig. 8). The scattered swarms of earthquakes in the northeastern part of the region affect the symmetry of the contour around Ibapah.

Heat Flow

Approximately 10 heat-flow readings are reported in the Bonneville region (Sass and others, 1976; John H. Sass, U.S. Geological Survey, written commun., 1982). Most of the values are typical of the northern Basin and Range province averaging about 2 HFU. Heat-flow values over 2.5 HFU occur in Fish Springs Flat and coincide with the swarm of earthquakes in the northeastern part of the region (fig. 8). The highest heat-flow value in the region, 9.29 HFU, reflects a local geothermal anomaly.

Quaternary Faulting

Nakata and others (1982) show widely scattered north- and northeast-trending, late Quaternary (less than or about 500,000 years old) faults (fig. 8). One set of three faults, designated 10,000 years old or less, occurs on the east side of Fish Springs Range and west of the earthquake swarm in the northeast part of the region.

Late Cenozoic Volcanic

No volcanic rocks younger than about 2 m.y. are believed to crop out in the region. However, Fumarole Butte, a Quaternary basalt center, lies about 16 km to the east outside the Bonneville region in the Sevier Desert.

Vertical Crustal Movement

Gable and Hatton (1983) show that the eastern half of the Bonneville region is rising at a rate of 2 to 4 mm/yr based on geodetic-leveling data. This uplift is believed to be in a large part, due to the continuing isostatic rebound following the removal of the water load of Pleistocene Lake Bonneville. On a more regional scale, the region is rising at the rate of 2 to 4 m per 10,000 years (0.2 to 0.4 mm/yr) based on geology, geomorphology, and radiocarbon dates (fig. 8).

About 16,000 years ago, Lake Bonneville inundated much of the northeastern part of the Bonneville region with water of maximum depths of over 300 m. The weight of the water depressed the northern part of the region a maximum of about 60 m. When the water load was removed, the surface gradually rebounded (and continues to rebound today). During the period that the deep-water lake existed, numerous lake features were formed. Erosion of the basin rim during the last deep-lake cycle lowered the outlet about 90 m, thus decreasing the maximum depth of a lake that can develop with the current topography. Over the last 10,000 years, a part of the north edge of the region and the floors of closed-topographic basins have been inundated periodically by shallow lakes.

Photolineations

Recent work by Offield (T. W. Offield, U.S. Geological Survey, written commun., 1983) on linear features in the Great Basin shows that virtually no photolineations occur in Quaternary sediments in the Bonneville region. The longest photolineations are range-front faults which probably originated 15 to 20 m.y. ago, and most of which show little or no renewed movement in the last 500,000 years.

Modern Tectonics

The Bonneville region, along with the rest of the northern Basin and Range province, is extending in a generally east-west direction. No direct measure of the rate of extension within the region is available, but the relative scarcity of Quaternary fault scarps and historic earthquakes suggest that the extension rate is lower than the area to the east, nearer the border of the Basin and Range province. In response to the regional extension, vertical movement occurs along generally north-trending normal fault zones that bound the ranges. Most of these faults dip under the valleys and flatten at depth and some appear to merge with detachments related to older thrusting. Earthquakes associated with movement along these normal faults are shallow (focal depths less than 10 km). Displacment along the fault zones is likely to drop the basin rather than elevate the range. Tilting of both blocks may be extensive.

The relatively rapid depression and rebound of the land surface accompanying the increase and decrease of the depth of Lake Bonneville appears to have occurred independent of movement along the major normal-fault systems. The vertical movement related to the lake was accommodated by horizontal movement of material with a relatively low viscosity at depths below which the brittle failure associated with earthquakes occurs.

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GROUND-WATER HYDROLOGY

By

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The Bonneville region of Utah and Nevada is part of a large ground-water flow system that is integrated partly through basin-fill deposits, but largely through an underlying carbonate-rock sequence which serves as an underdrain. The region includes several topographically closed basins with no surface discharge--Pine Valley and Wah Wah Valley in ground-water unit BV-01; closed basins with surface discharge by evapotranspiration--Tule Valley in ground-water unit BV-01; Tippett Valley and Antelope Valley in ground-water unit BV-04, and drainage basins that are open to the Great Salt Lake Desert--Dugway Valley-Government Creek area, and Fish Springs Flat in ground-water unit BV-03; Snake Valley in ground-water unit BV-01; Deep Creek Valley in unit BV-04; and small valleys in ground-water unit BV-05. The climate is arid to semi-arid with annual precipitation ranging from 150 to 200 mm in the basin areas to a maximum of about 800 mm in the highest mountain ranges. Mean annual free-water surface evaporation is approximately 1,000 to 1,500 mm/yr.

Major Hydrogeologic Units

Basin fill (including alluvial material of stream valleys) occurs largely in structural basins and is as great as 2,800 m in thickness. The more permeable part of the basin fill is generally in the upper 500 m of the section. Basin fill crops out at the surface over approximately two thirds of the region. Bedrock pediment surfaces underlie the fill at shallow depths in many areas, such as in the Mountain Home Range (Needles Range), and western Tule Valley in ground-water unit BV-01, and in the Goshute Mountains in ground-water unit BV-05.

Basin fill consists mostly of nonindurated to semi-indurated sedimentary terrestrial and lacustrine deposits and volcanic rocks. The age of the deposits range from Tertiary to Holocene. The terrestrial deposits consist largely of poorly sorted to moderately sorted mixtures of gravel, sand, silt and clay that were derived largely from the consolidated rocks in the nearby mountains. The fill also locally contains fine-grained lake deposits, limestone, and evaporitic deposits; tuffaceous sediments and extrusive volcanic rocks from episodic volcanic activity; and glacial deposits from the Quaternary Period. The fill differs greatly both vertically and areally.

Volcanic rocks are grouped hydrologically as undifferentiated volcanic rocks and tuffs. Undifferentiated volcanics include flows and tuffs of Tertiary age, up to 1,200 m thick. Tuffs consist of ash-fall tuff and moderately to densely welded ash flow. Tuffs of Tertiary age occur in the southern part of ground-water unit BV-01. Their aggregate thickness is over 3,000 m.

Consolidated fine-grained clastic rocks, composed of silt and argillaceous materials of Precambrian and Cambrian age are scattered throughout the region. Thickness of the units mapped are more than 700 m. They are interbedded with other coarser sediments, and are probably discontinuous due to attenuation faulting.

Carbonate rocks are widespread in the subsurface and at the surface. They consist of limestones, massive to thinly bedded, and dolomites with silty and sandy interbeds. Carbonate rocks ranging in age from Cambrian to Triassic are commonly intensively fractured, and some units exhibit well-developed solution openings (figs. 9, 10, 11, and 12). Aggregate thicknesses of carbonate rocks range from 150 m to 7,500 m. Carbonate rocks compose an extensive aquifer that underlies much of the region.

Orthoquartzites, metamorphics and silicic intrusive rocks are exposed throughout the area, and underlie much of the region. These rocks range in age from Precambrian to Tertiary.

Ground-Water Flow Regime

The source of recharge to ground water in the region is precipitation. Most of the precipitation falls at higher elevations in the mountain ranges, but most recharge probably occurs by infiltration of runoff as it leaves the mountains and crosses permeable basin-fill deposits. Recharge to most segments of the region has been estimated in reconnaissance studies using a method developed by Eakin and others (1951, p. 79-81) for use in Nevada and modified by Hood (Hood and Waddell, 1968, p. 22-23) for use in western Utah. Discharge of ground water occurs largely to springs and by evapotranspiration in areas where the ground-water level is near the land surface.

Figure 9.--Intensively fractured limestone and shaley limestone of the House Limestone, Pogonip Group, of Ordovician age, near Skull Rock Pass, Millard County, Utah. Photograph by M.S. Bedinger (1984).

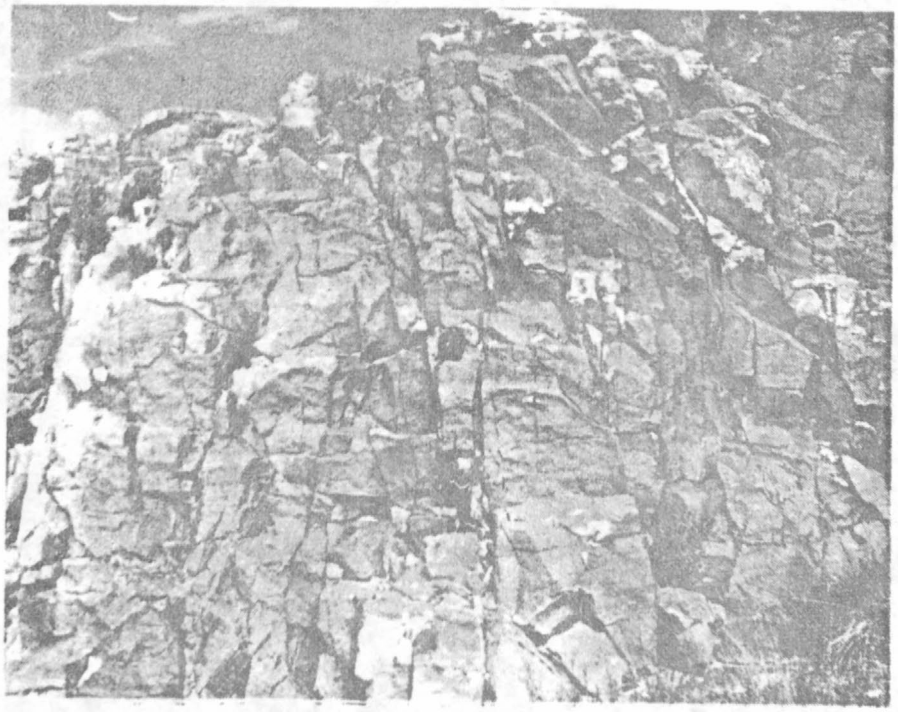

Figure 10.--Laketown Dolomite of Silurian age showing predominantly vertical fractures in the massively bedded dolomite, southern Confusion Range, Millard County, Utah. Scale is indicated by the light meter in center of photograph. Photograph by M.S. Bedinger (1984).

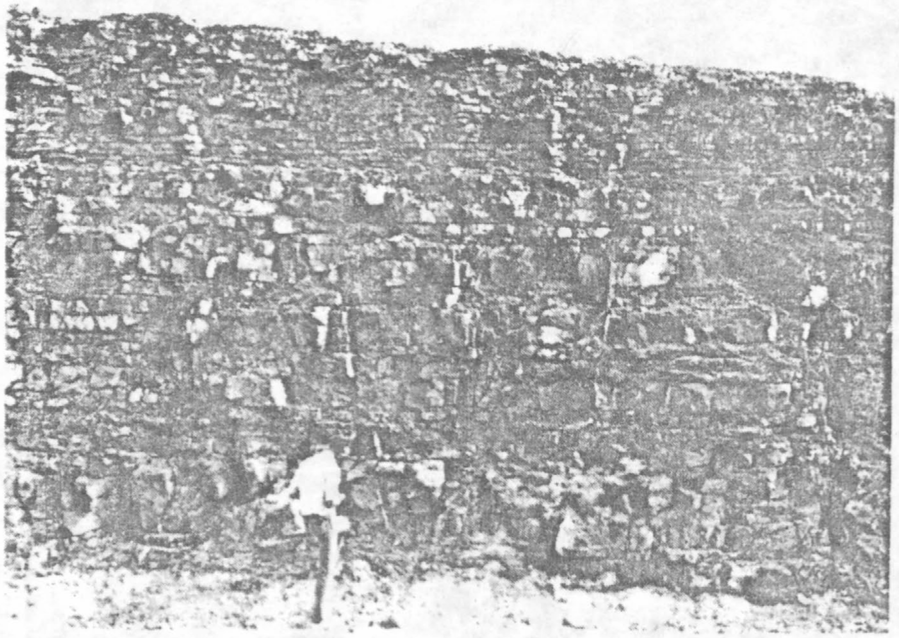

Figure 11.--Limestone beds in the Guilmette Formation of Devonian age, with fracture sets at right angles to bedding planes, southern Confusion Range, Millard County, Utah. Photograph by M.S. Bedinger (1984).

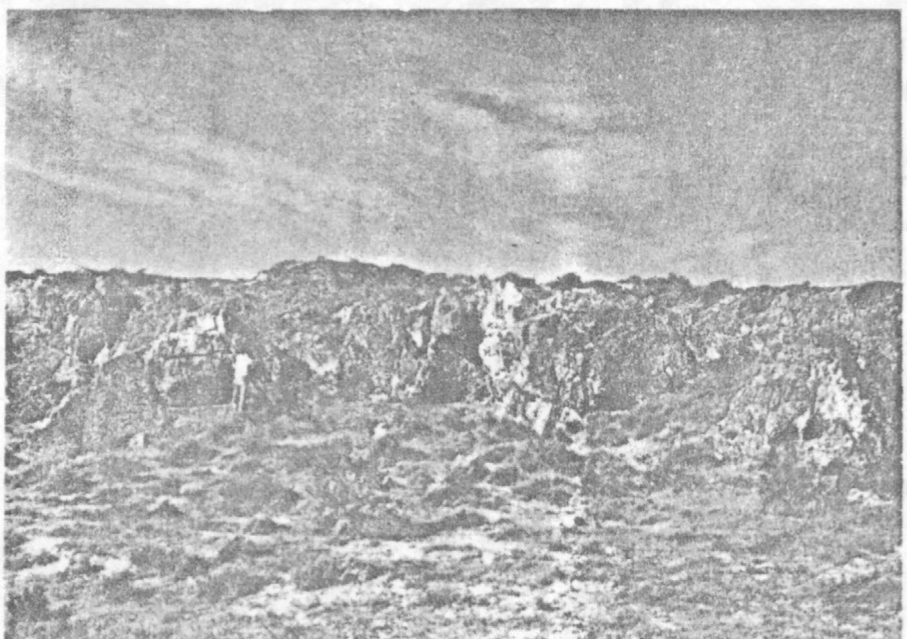

Figure 12.--The Joana Limestone of Mississippian age showing well-developed solution channels parallel to bedding near Garrison, Millard County, Utah. Photograph by M.S. Bedinger (1984).

Water budgets for the Bonneville region are given in reconnaissance reports for basins in the region and summarized in the report on the southern Great Salt Lake Desert by Gates and Kruer (1981). Gates and Kruer summarize and revise the water-budget estimates reported in previous reconnaissance reports on the basins in the region and provide estimates of water-budget components of the southern Great Salt Lake Desert. The water-budget analyses for basins in the Bonneville region show unmistakable evidence of interbasin ground-water flow, even considering that the estimation of individual water-budget components is only approximate. For example, Tule Valley has an estimated recharge rate within the basin of 9.4 hm^3/yr from precipitation. The estimated loss to evapotranspiration within the basin, based on three methods of estimation, ranges from 29.6 hm^3/yr to 69.0 hm^3/yr (Stephens, 1978). Fish Springs Flat has an estimated recharge rate of 5 hm^3/yr, and an estimated discharge rate to springs of 43 hm^3/yr (Bolke and Sumsion, 1978). In contrast, other basins indicate an excess of recharge over discharge. Pine Valley and Wah Wah Valley have estimated discharge of 8.8 hm^3/yr and 1.8 hm^3/yr, respectively, by evapotranspiration, wells, and springs. These valleys have estimated recharge rates from precipitation of 25.9 hm^3/yr and 8.6 hm^3/yr, respectively (Stephens, 1976 and 1974).

A large part of the region is underlain by a thick sequence of carbonate rocks of Paleozoic age. It is inferred that the carbonate rocks act as a regional aquifer and subdrain the Bonneville region. Recharge to the carbonate aquifer is by infiltration of precipitation in the mountain ranges and downward flow from basin-fill deposits in areas such as Pine Valley and Wah Wah Valley. Discharge from the carbonate-rock aquifer is by upward flow to basin fill and then evapotranspiration from large areas of shallow ground water and by discharge to the thermal springs in Fish Springs Flat, Tule Valley, southern Great Salt Lake Desert and probably Snake Valley.
A hypothetical regional potentiometric map for the deep carbonate rocks and contiguous rocks is shown in plate 2. The regional potentiometric surface in the carbonate rocks is inferred to be lower than the shallow water levels in the areas that contribute recharge to the carbonate rocks, and higher than the water level at the springs and in the areas of discharge from the carbonate rocks. In spite of the uncertainties of the exact head in the carbonate and contiguous rocks, the shape of the water-level contours indicating direction of flow, the altitude of the water level relative to the basin fill, and areas of discharge can be drawn with some confidence. However, the areal distribution of permeability is not known, and therefore flow in the carbonate rocks and contiguous rocks at depth is not known. It is also evident from both the water-level data in the basin fill and the water budgets for the basins in the Bonneville region and surrounding areas, that flow in the carbonate rocks extends beyond the Bonneville region. There

appears to be underflow to the Bonneville region from the Sevier Desert and the data strongly suggest the potential for underflow from basins to the west and southwest in Nevada. A summary of ground-water flow components integrating the water-level maps for the basin fill and carbonate aquifer, and estimates of recharge and discharge for the basins in the Bonneville region are given in table 1 and in plate 2. The estimates of recharge by precipitation and discharge by wells, evapotranspiration, and springs are given as reported by Gates and Kruer (1981, their table 7) except as indicated in table 1. The estimates of subsurface inflow and outflow from the basins are inferred on the basis of flows necessary to balance the water-budget estimates of recharge and discharge for each basin. The assumed distribution of subsurface flow is consistent with the hypothetical water-level potential for the carbonate and contiguous rocks at depth.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity.

[All rates are in cubic hectometers per year (hm^3/yr)].

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Dugway Valley-Government Creek area	14.8	<1.2	3.5	Mower and Feltis (1968) estimate less than 6.2 hm^3/yr subsurface inflow from the Sevier Desert through alluvium. The boundary of the area as drawn in figure 8 probably includes the recharge area of this 6.2 hm^3/yr recharge. The hydraulic gradient in the deep carbonate or other consolidated rock indicates potential for flow from the Sevier Desert beneath the Dugway Government Creek area to the Great Salt Lake Desert.	Stephens and Sumsion (1978) estimated 9.9 hm^3/yr of subsurface outflow in the basin fill to the Great Salt Lake Desert in order to balance the water-budget equation for the area. There is a low gradient in underlying consolidated rock for subsurface outflow to the Great Salt Lake Desert.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation [1/]	Discharge [1/] Evapotranspiration	Discharge [1/] Wells, seeps and springs	Subsurface Inflow	Subsurface Outflow
Fish Springs Flat	4.9	9.9	33.3	Subsurface inflow must be large to support the flow of Fish Springs because local recharge is only 4.9 hm^3/yr. Inflow must be as much as 38.2 hm^3 or more per year--some inflow probably continues to flow north to discharge to the Great Salt Lake Desert. Subsurface flow is probably from Snake Valley, Pine Valley and Wah Wah Valley by way of the Tule Valley and the Sevier Desert.	A small subsurface outflow in basin fill has been estimated by Bolke and Sumsion (1978). Additional outflow to the Great Salt Lake Desert may occur in the carbonate-rock aquifer.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Deep Creek Valley	21	14.8	2.0	Excess of recharge over discharge in Antelope and Tippett Valleys west of Deep Creek Valley and hydraulic potential from the west indicates underflow of as much as 12.3 hm^3 or more per year.	The Gates and Kruer (1981) revision of the Deep Creek Valley surface outflow is about 3.7 hm^3/yr originating in Deep Creek Valley. Additional subsurface outflow orignates from inflow from basins to the west of Deep Creek Valley. The hypothetical gradient of hydraulic head in the carbonate aquifer indicates subsurface flow would be to northern Snake Valley and to the Great Salt Lake Desert. Carbonate rocks are missing in the southern Deep Creek Mountains on the southeast margin of Deep Creek Valley where the bedrock is Precambrian sedimentary and metasedimentary rocks

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Deep Creek Valley (Con't)					Tertiary igneous intrusive rock--rocks very likely of lower hydraulic conductivity than the carbonate-rock aquifer.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Snake Valley	6/ 130.7	3/ 4/ 78.9	4/ 7/ 12.3	The potential for subsurface inflow from the west is indicated by the hypothetical potentiometric surface in carbonate and contiguous rocks. Water budgets in adjacent valleys to the west, however, do not indicate an excess of ground water and the gradient from the west is relatively low. Locally along the western boundary the carbonate rocks are not present in the section. Subsurface inflow to Snake Valley is evidently relatively small.	Hood and Rush (1965) estimated that about 12.33 hm^3/yr discharged by outflow in the basin fill to the Great Salt Desert. Outflow through the carbonate aquifer is about 27.1 hm^3/yr. However, outflow would be greater by the amount of subsurface inflow to Snake Valley from the west.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Tule Valley	9.4	39.5	<1	Discharge to springs, and by evapotranspiration in Tule Valley exceeds the local recharge. Inflow is indicated by excess ground water in adjacent valleys and hypothetical potential gradient in the carbonate-rock aquifer from the west and south. Inflow from Pine, Wah Wah, and Snake Valleys probably indicate as much as 51.8 hm^3/yr subsurface inflow and probable inflow from the Sevier Desert.	Fish Springs appears to be downgradient from Tule Valley through the carbonate-rock aquifer. Part of the underflow from adjacent valleys probably continues beneath Tule Valley to discharge at Fish Springs.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Wah Wah Valley	8.6	<1	1.1	Subsurface inflow is indicated from the carbonate-aquifer map from Pine Valley and Beryl-Enterprise and Milford areas to the south and east. Stephens (1974) estimated 3.7 hm^3/yr of recharge to Pine Valley was contributed as inflow. As much as 13.6 hm^3 or more per year may originate in Pine Valley based on the excess of recharge over discharge in the Pine Valley.	Discharge from wells, springs, and by evapotranspiration in Wah Wah Valley is very small. Discharge of most of the recharge within the valley by precipitation and underflow from the west, south, and east is by underflow principally to the north. This outflow could be 24.7 hm^3/yr (Gates and Kruer, 1981).

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation [1/]	Discharge [1/]		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Pine Valley	25.9	6.8	2.0	The hypothetical gradient in the carbonate rock indicates potential for inflow from the northern part of Snake Valley to the west.	The hypothetical gradient in the carbonate-rock aquifer indicates potential for outflow from Pine Valley (13.6 hm^3/yr) based on water-budget estimates) principally to Wah Wah Valley.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/: Evapotranspiration	Discharge 1/: Wells, seeps and springs	Subsurface Inflow	Subsurface Outflow
Tippett Valley	5/ 8.5	5/ 0	2/ <1	The hypothetical hydraulic gradient in the carbonate-rock aquifer indicates a potential for inflow from Steptoe Valley on the west.	Subsurface outflow, about 6.2 hm^3 or more per year, is to the Great Salt Lake Desert beneath Deep Creek Valley and southern Antelope Valley.
Antelope Valley	5/ 5.8	5/ <1	2/ 2	Hydraulic potential exists for flow in carbonate or other consolidated rock into Antelope Valley from Steptoe Valley on the west. Water budget studies for Steptoe Valley do not indicate a significant excess of recharge over discharge.	Antelope Valley probably loses water by subsurface outflow, about 6.2 hm^3/yr on the basis of water-budget studies. The hypothetical hydraulic gradient in the carbonate rocks indicates flow beneath Deep Creek Valley and the Great Salt Lake Desert.

Table 1.--Summary of ground-water flow components for the Bonneville region, Utah and Nevada, and vicinity--Continued.

Hydrologic Area	Recharge by Precipitation 1/	Discharge 1/		Subsurface Inflow	Subsurface Outflow
		Evapotranspiration	Wells, seeps and springs		
Southern Great Salt Lake Desert	58.0	77.7	25.9	The Southern Great Salt Lake Desert receives inflow from basins given in the table above and other adjacent basins. Subsurface inflow occurs both in the basin fill and in consolidated rocks.	None

1/ Recharge and discharge rates as revised by Gates and Kruer (1981, their table 7) except as indicated

2/ Not reported or partial estimate

3/ From Price (1979)

4/ Spring discharge included in evapotranspiraton estimate

5/ From Harrill (1971)

6/ Modified from Gates and Kruer (1981), based on revision of basin boundary in present report

7/ Estimated by J.S. Gates (U.S. Geological Survey, personal commun., 1984)

In reviewing the evidence for interbasin flow in the region, Gates and Kruer (1981) point out the disparities in recharge and discharge discussed above and shown in the water budgets for the basins (table 1 and pl. 2). Gates and Kruer suggest that the recharge to the Deep Creek Range could be one potential source for the Fish Springs group of springs. However, carbonate rocks are missing in the southern half of the Deep Creek Range and the part of the range most likely lying upgradient from the Fish Springs group of springs (pl. 2). The southern Deep Creek Range is underlain by intrusive igneous rocks and sedimentary and meta-sedimentary quartzites. There is an excess of ground water in the three basins, Deep Creek Valley, Tippett Valley, and Antelope Valley, of about 16 hm^3/yr. Some may move by underflow into Snake Valley, but most probably moves to the Great Salt Lake Desert. The regional contours on the carbonate and contiguous rocks would indicate underflow might move to Blue Lake Springs and nearby springs, and the Bonneville Salt Flats which is a major discharge area within the Great Salt Lake Desert.

Ground-Water Flow Analysis

AREAL GROUND-WATER FLOW

Areal ground-water flow was analyzed in the basin-fill deposits and in the regional carbonate aquifer. Relative ground-water traveltimes at the water table were analyzed using the procedure described in Chapter A (Bedinger, Sargent, and others, 1985). The relative velocities in the hydrogeologic units are shown in plate 3. Relative velocities are reported because site-specific data are not available for the region. The values of hydraulic properties of the units and hydraulic gradients used in estimating relative ground-water velocities are given in table 2.

Table 2.--Hydraulic properties of hydrogeologic units modeled in areal ground-water flow analysis

[K = hydraulic conductivity, in meters per day; Ø = effective porosity]

Hydrogeologic Unit	Map symbol (pl. 2)	K/Ø	Hydraulic gradient
Basin fill	a	6×10^{1}	0.005
Volcanic rocks undifferentiated	v	1×10^{-1}	.02
Ash-flow tuff	t	1×10^{-1}	.02
Fine-grained clastic rocks	f	3×10^{-9}	--- 1/
Carbonate rocks	c	1×10^{-1}	.02
Metamorphic rocks	m	2×10^{-1}	.02
Granitic rocks	g	2×10^{-1}	.02

1/ not estimated

The hydraulic gradients for the hydrogeologic units are representative gradients taken from the water-level contour map (Bedinger and others, 1984). The ratio of hydraulic conductivity to effective porosity was estimated using the values in Chapter A and modified as necessary during the verification of the cross-section and areal-flow models.

Ground-water traveltimes near the water table are shown in plate 4. Flow paths along which the relative traveltimes were calculated and major discharge areas, large springs, and evapotranspiration areas are also shown on the map. Flow at the water table in several basins is inferred to terminate by downward flow to the regional-carbonate aquifer. These areas are shown diagrammatically as diamonds in plate 2. The exact position of the downward flow is not known and may take place over a broad area in the closed basins. Traveltime in the deep aquifers was modeled for a selected geologic section using a separate digital model

CROSS-SECTIONAL MODELS

Cross-sectional models were used to analyze ground-water flow along selected flow paths. The mathematical model used in modeling flow in geologic sections is given in Chapter A of this report. The map locations of the geologic section and the model parameters and results are shown in plate 5. The value of hydraulic properties of the rock units in the geologic section used in analysis of the ground-water flow are given in table 3.

Table 3.--Hydraulic properties of hydrogeologic units used in cross-sectional models

[K = hydraulic conductivity in meters per day; Ø = effective porosity]

Hydrogeologic unit	Symbol on (pl. 5)	A-A' K	A-A' Ø
Ash-flow tuff	T	4×10^{-4}	0.35
Carbonate rocks (dense to moderately dense)	c	3×10^{-3}	0.01
Carbonate rocks (fractured or karstic)	C	6×10^{0}	0.12
Crystalline rocks (lower part of section)	g	3×10^{-7}	0.04
Coarse-grained basin fill	a	1×10^{0}	0.18
Fine-grained basin fill	A	2×10^{-2}	.32
Fine-grained clastic rocks	f	5×10^{-7}	0.22

Distribution of rock units, relative traveltimes, and stream functions are given on the cross-sectional model (pl. 5). Relative traveltimes are given in intervals of one order of magnitude from 10^1 and longer. Numbers indicate the relative time of travel from points on the line to the discharge area. Stream functions show the directions of ground-water movement and the numbers indicate the relative amount of flow in the section below the flow line.

The cross-sectional model gives a more realistic concept of the traveltime between widely spaced points in the region than does the map of traveltime at the water table. As seen from the section, the flow paths in the divide areas of the flow system dive steeply into the flow system and take the longest flow paths to the discharge areas. Relative traveltimes from the divide areas to discharge areas are as great as 10^5 to 10^7. Commonly, these longest relative traveltimes are of restricted surface area at the water table. The areas of longer relative traveltime enlarge with depth and would provide more confidence in locating an area of long traveltime at depth beneath the water table than above the water table. Broad areas of relative traveltime of 10^5 or greater exist at the water table in the cross-sectional model.

Quality of Ground Water

The quality of ground water in the Bonneville region is characterized by the areal distribution of dissolved solids (fig. 13) and predominant chemical constituents in solution (fig. 14). These maps are generalized from those of Thompson and Chappell (1984) and Thompson and Nuter (1984) that were compiled from the water-quality files of the U.S. Geological Survey (WATSTORE) and published reports. The data are mostly from non-geothermal springs and wells less than 150 m in depth and completed in alluvial and basin- fill deposits. In areas where data are not available, the water- quality parameters were estimated from the position in the ground-water flow system and the lithology of the local bedrock.

The concentration of dissolved solids is generally less than 500 mg/L. Dissolved solids increases near and in the major valleys adjoining the Great Salt Lake Desert in the northern part of the region. The greatest dissolved-solids concentration is in the Great Salt Lake Desert where the concentration is greater than 200,000 milligrams per liter.

The predominant chemical constituents in the ground water are calcium, magnesium and bicarbonate. Water of the sodium bicarbonate type is prevalent in the southern part of the region in association with the volcanic rocks. Water in which chloride is a principal cation is associated with the areas of higher dissolved-solids content.

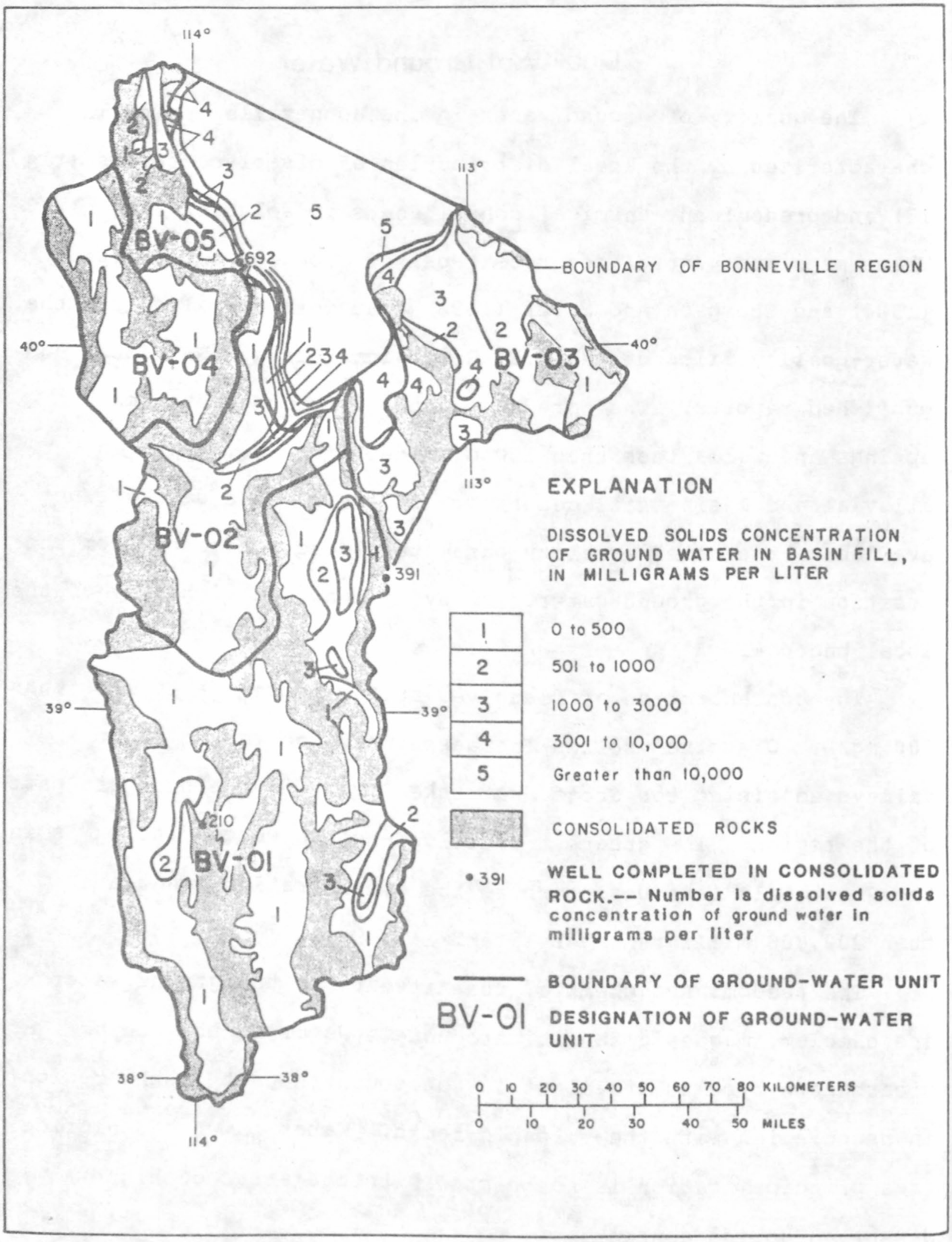

Figure 13.--Dissolved-solids concentration of ground water.

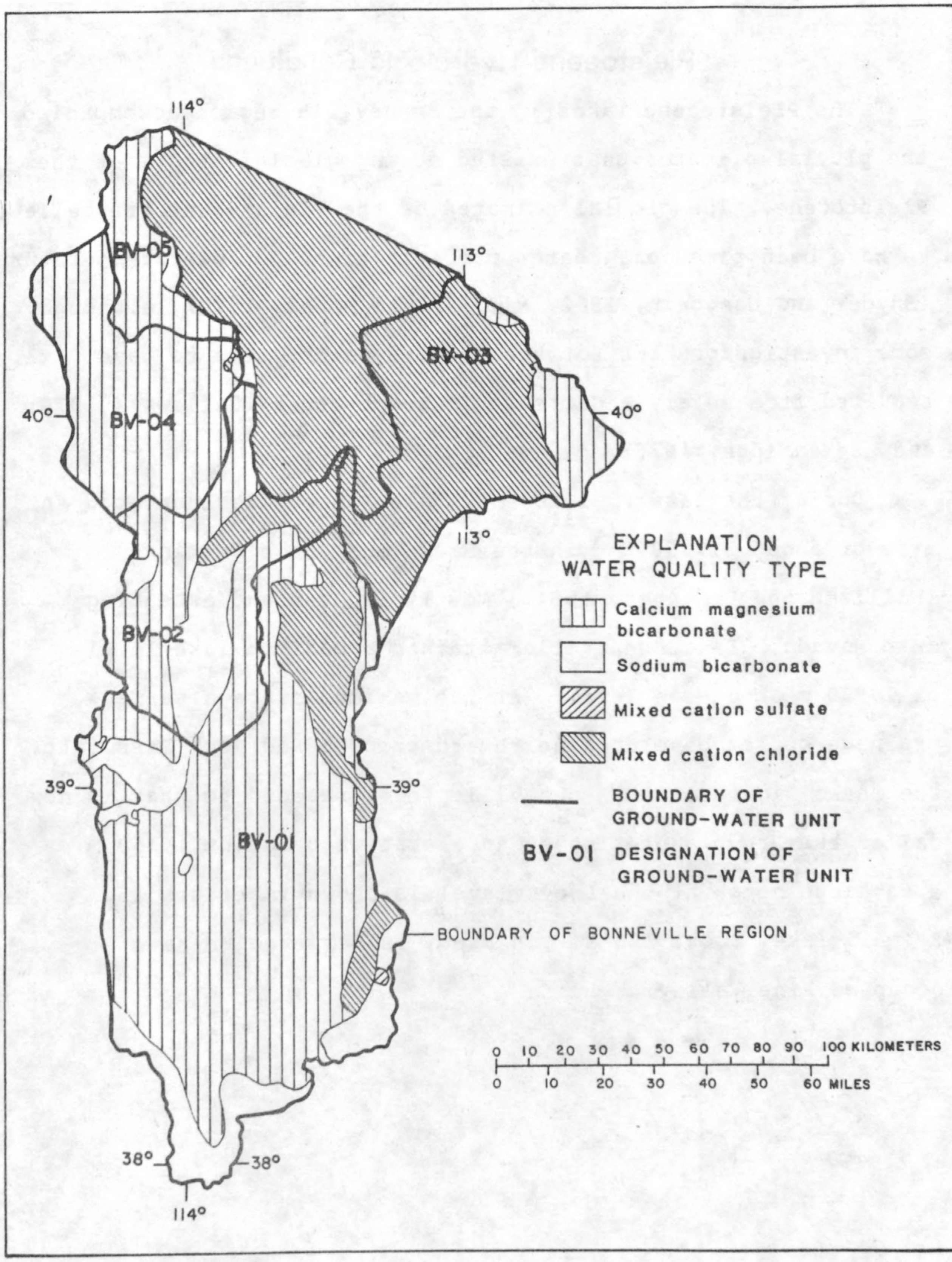

Figure 14.--Distribution of chemical types of ground water.

Pleistocene Hydrologic Conditions

The Pleistocene lakes in the Bonneville region accompanied the pluvial climates that existed during glacial stages of the Pleistocene. The glacial climates of the Pleistocene are believed to have been times of greater precipitation and lower temperature, (Snyder and Langbein, 1962; Mifflin and Wheat, 1979), although some investigators opt for the greater water yield to have resulted from solely a decrease in temperature (Galloway, 1970; and Brakenridge, 1978).

During the late Pleistocene, Lake Bonneville inundated an area of about 51,660 km^2 in the Basin and Range province (Williams and Bedinger, 1984), mostly in Utah and extending into Nevada. Lake Bonneville attained a maximum lake level of 1,550 m above sea level. At the maximum stage a surface drainage outlet developed northward through Red Rock Pass into the Snake River basin. Bonneville level receded to what is now called the Provo shoreline at an elevation of about 1,460 m. A wave cut notch at the Provo level is shown in figure 15. A small lake, about 106 km in area, is believed to have occupied Pine Valley.

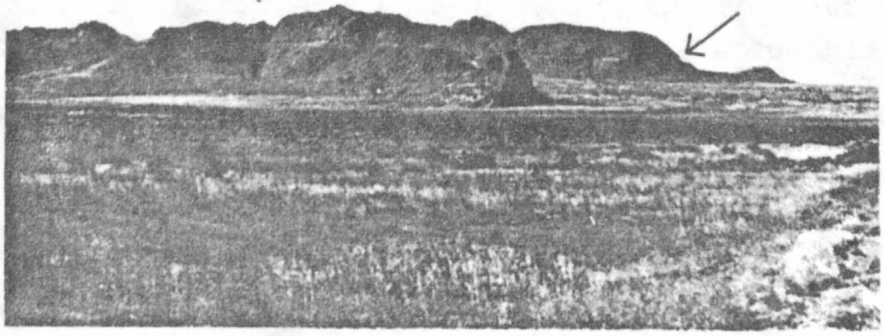

Figure 15.--Photograph of wave cut notch (arrow) of Provo level of Lake Bonneville in Tertiary volcanic rock hills south of Wendover, Elko County, Nevada. Photograph by K.A. Sargent (1984).

Recurrence of climates that existed in the Pleistocene would potentially refill Lake Bonneville to the level of the Provo shoreline and increase the rate of recharge of ground water. Refilling of Bonneville to about 1,460 m would inundate the lower Snake Valley, Tule Valley, Fish Springs Flat, and Dugway Valley--Government Creek area. Inundation of the Sevier Desert would extend into the northern end of the Wah Wah Valley.

Inundation of a larger surface area would decrease the length of many flow paths at the water table to the discharge areas. Much of the flow paths in the carbonate rocks would tend to discharge in localized zones of high permeability, as it does now at springs. Ground water in the carbonate rocks, however, might find new spring openings such as beneath the lake in Wah Wah Valley and in the lake in Pine Valley.

Increased recharge would increase the hydraulic gradient to the discharge areas and decrease the depth to water. However, depth to water would probably be greater than 150 m in many ranges.

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MINERAL AND ENERGY RESOURCES

By

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At least 38 mining districts occur in the Bonneville region of Nevada and Utah. Beryllium-bearing ores at Spor Mountain (east of Thomas Range), Juab County, and base- and precious-metal deposits in the San Francisco district, Beaver County, account for the bulk of the value of metals produced in the region to date. The Gold Hill district, Tooele County, Fish Springs district, Juab County, Utah; and the Osceola district, White Pine County, Nevada, have each produced concentrates worth a few millions of dollars. Gold is being produced presently in the Willow Springs district, Tooele County. Metallic-mineral deposits in the Bonneville region are of two main types, vein or replacement deposits of Tertiary age. Fluorspar is the principal industrial mineral commodity with significant production. Breccia pipes have been the primary source of locally important fluorspar mining. A few isolated geothermal low temperature springs and wells (water commonly less than 50 ^{o}C), are located in the Bonneville study area. A thin bed of radioactive lignite in the Heavenly Hills area, Juab County, constitutes the only presently known occurrence of coal. Several boreholes have reported shows of hydrocarbons, however, no wells have produced significant amounts of oil or gas to date.

Metallic-Mineral Resources

The resource areas in the Bonneville region are those areas delineated respectively by Wong (1982, 1983), and their locations are shown on plate 6. These areas generally indicate the limit of productive workings. The resource areas of Wong are not all inclusive and they do not indicate the extent of mineralized rock. The boundaries of the mineralized areas mentioned herein do not coincide with the limits of established metal-mining districts. These data were compiled primarily from the U.S. Geological Survey's Computerized Resource Information Bank (CRIB). The Utah Geological and Mineral Survey and Nevada Bureau of Mines and Geology currently maintain and revise this file in cooperation with the U.S. Geological Survey.

The majority of the mineral deposits in the Bonneville region are of Tertiary age. These areas of mineralization contain metal-bearing deposits that occur in diverse modes, and lie within several east-northeast-trending belts of Cenozoic volcanic and intrusive rocks (Shawe and others, 1978). These areas of igneous activity and related mineralization are aligned along zones of pronounced structural weakness (Hilpert and Roberts, 1964; Shawe and Stewart, 1976).

Many of the mineral deposits in the Bonneville region contain base and precious metals in fracture-controlled epithermal veins or replacement deposits in carbonate rocks. A few of the mineralized areas contain ores in strataform, breccia pipes or fissure deposits. The sites of the principal metal production and most extensive workings in the Bonneville region include the San Francisco and Preuss districts, Beaver County, Gold Hill district, Tooele County, Spor Mountain and Fish Spring districts, Juab County, Utah; and the Osceola district, White Pine County, Nevada. Table 4 contains a summary of the commodities and modes of occurrence for the principal mineral deposits in the Bonneville region.

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county.

Commodities in the commodities column are abbreviated as follows: Ag, silver; Al, aluminum; As, arsenic; Au, gold; B, boron; Ba, barium; Be, beryllium; Bi, bismuth; Cu, copper; F, fluorine; Fe, iron; Hg, mercury; Li, lithium; Mg, magnesium; Mn, manganese; Mo, molybdeum; Pb, lead; S, sulfur; Sn, tin; Th, thorium; U, uranium; V, vanadium; W, tungsten; Zn, zinc.
[These data are are preliminary and are subject to revision.]

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type ----	Host Rock	References
Trout Creek	13 S.	19 W.	U, Fe	Radioactive lignite -- Gossan ---------------	Tertiary gravels Limestone of Pennsylvanian Ely Formation	Thomson, 1973
	13 S.	19 W.	Cu, Fe, Mn	Veins ---------------	Quartz veins in schist of Pre-cambrian Johnson Pass sequence	Thomson, 1973
Honey Comb Hills	13 S. 13 S.	15 W. 16 W.	U, F, Be	Disseminiated -------	Tuff of Topaz Mountain Rhyolite	Cadigan and Ketner, 1982; McAnulty and Levinson, 1964; Montoya and others, 1964; Staatz and Bauer, 1950
Spring Creek	12 S.	18 W.	Pb, Zn, W, F, Be	Veins --------------	Muscovite-bearing quartz veins in dolomite of Pre-cambrian Trout Creek sequence	Everett, 1961; Thomson, 1973
	12 S. 12 S. 13 S.	18 W. 19 W. 19 W.	Pb, Zn, W, F, Ag, Au, Cu, Fe, U, Mn, Be	Veins --------------	Trout Creek sequence, Johnson Pass sequence	Butler and others, 1920; Everett, 1961; Heyl, 1963; Thomson, 1973
	14 S.	19 W.		Gossan -------------	Chainman Shale	

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type	Host Rock	References
Spor Mountain	12 S. 13 S.	12 W. 12 W.	F, U, V, Be, Li, Mg, Mn	Pipe	Lost Sheep Member of Laketown Dolomite, Floride Member of Ely Springs, Bell Hill, Member of Laketown Dolomite, Fish Haven Dolomite,	Bauer, 1952; Bullock, 1976; Chojnack, 1964; Dasch, 1967; Leedom and Mitchell, 1978; Lindsey, 1977, 1979; Lindsey and others, 1973; Meeves, 1966; Montoya, Baur, and Wilson, 1964 Shawe, 1968; Shawe and others, 1964; Staatz, 1963; Staatz and Bauer, 1950; Staatz and Carr, 1964; Staatz and Griffitts, 1961; Staatz and Osterwald, 1959; Thurston and others, 1954
				Vein	Lost Sheep Member of Laketown Dolomite, Rhyolite, Bell Hill Member of Laketown Dolomite,	
				Bedded	Tuff member of Spor Mountain Formation	

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type ----	Host Rock	References
Spring Creek	12 S. 12 S. 13 S. 14 S.	18 W. 19 W. 19 W. 19 W.	Ag, Au, Cu, Fe, U, Mn, Be	Vein ---------------- Gossan -------------	Trout Creek sequence, Johnson Pass sequence Chainman Shale	Bulter and others, 1920; Heyl, 1963; Thomson, 1973
Topaz Mountain	13 S.	11 W.	U, F	Vein ----------------	Tuff	Leedom and Mitchell, 1978; Outerbridge and others, 1960; Staatz and Carr, 1964
				Millard County		
Gordon (House Range)	25 S.	6 W.	F, S	Replacement ----------	Callvile Limestone	Bullock, 1976; Davis, 1949
				Tooele County		
Columbia	9 S. 10 S.	6 W. 6 W.	Ag, Pb, Zn, Fe, Mn	Vein ----------------	Quartzite	Bullock, 1970; Butler and others, 1920; Cohenour, 1959; Heyl, 1963

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type ----	Host Rock	References
	Township	Range				
Dugway	9 S.	12 W.	Ag, Au, Pb, Zn Cu, Fe, F	Replacement ---------	Dolomite, lime- stone, quartzite	Bullock, 1976; Butler and others, 1920; Heyl, 1963 Perry and McCarthy, 1976; Staatz and Carr, 1964
	10 S.	12 W.		Vein ----------------	Quartzite,	
Erickson	10 S	6 W.	Ag, Au, Pb, Zn, Cu, Mn, U, F.	Replacement ---------	Quartzite	Bullock, 1976; Butler and others, 1920; Cohenour, 1959; Crittenden, 1951; Heyl, 1963; Hillier, 1956; Pardee, 1922
	10 S.	7 W.				
	10 S.	8 W.				
	9 S.	9 W.				
Gold Hill (Clifton)	7 S.	17 W.	Ag, Au, Pb, Zn, Cu, Fe, Mo, W, Bi, V, Be, Ba, As, F, B	Vein ----------------	Quartz monzonite, Oquirrh Formation, Ochre Mountain Limestone	Bullock, 1970, 1976; Buranek, 1948; Butler and others, 1920; Custer, 1917; Nolan, 1935
	7 S.	18 W.				
	8 S.	17 W.				

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type ----	Host Rock	References
	Township	Range				
Gold Hill (Continued)	8 S.	18 W.		Contact metamorphic -	Ochre Mountain Limestone	El-Shatoury and Whelan, 1970; Everett, 1961; Foshag and others, 1930; Garvin, 1966; Griffitts, 1965; Heyl, 1963; Kemp and Billingsley, 1918; Lemmon, 1964; Lemmon and Tweto, 1962; Meeves, 1966; Nolan, 1935; Perry and McCarthy, 1976; Schaller and Nolan, 1931; Thomson, 1973
	9 S.	17 W.		Replacement ---------	Oquirrh Formation	
	9 S.	18 W.		Gossan --------------	Ochre Mountain Limestone	
				Pegmatite -----------	Quartz monzonite	

Table 4.--*Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county*--Continued.

Mineralized Area	Location Township	Location Range	Commodities	Deposit type ----	Host Rock	References
Granite Peak	8 S. 9 S.	13 W. 13 W.	Ag, Pb, Cu, Fe, Be, F, mica	Vein ---------------- Pegmatite -----------	Granite Biotite granite gneiss	Bullock, 1967; Butler and others, 1920; Elevatorski, 1974; Fowkes, 1964; Hanley and others, 1950
Willow Springs	9 S. 10 S. 10 S.	18 W. 17 W. 18 W.	Ag, Au, Pb, Zn, Cu, Fe Hg, Ba, Sb	Replacement --------- Vein ----------------	Dolomite, quartzite Quartzite, dolomite, limestone	Hilpert, 1964; Nolan, 1935; Perry and McCarthy, 1976; Thomson, 1973

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type	Host Rock	References
	Township	Range				
				UTAH		
				Beaver County		
Blawn Mountain	29 S.	15 W.	Fe	Replacement	Paleozoic carbonate rocks	Bullock, 1970
				Fissure filling	do.	
	29 S. 30 S.	15 W. 16 W.	Alunite, kaolinite	Altered silicified breccia	Oligocene rhyolite	Parkinson, 1974; Thurston and others, 1954; Whelan, 1965
	29 S.	15 W.	F, U	Replacement	Brecciated intrusive topaz rhyolite	Lindsey and Osmonson, 1978; Whelan, 1965
	29 S.	16 W.	Sn	Breccia	Rhyolite	Lindsey and Osmonson, 1978

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type ----	Host Rock	References
	Township	Range				
Washington (Indian Peak)	30 S.	17 W.	F, U, Cu	Vein ----------------	Porphyritic Ignimbrite	Bullock, 1976; Everett, 1961; Frey, 1947; Thurston and others, 1954; Everett and Wilson, 1956
	30 S.	18 W.		Vein ----------------	Wah Wah Springs Tuff Member of Needles Range Formation	
Pine Grove	28 S. 29 S. 29 S. 30 S. 30 S.	16 W. 15 W. 16 W. 14 W. 15 W.	Ag, Au, Pb, Zn Cu, Fe, Mo, U, Sn, Be, Mn, F, Al, clay	Gossan -------------- Vein ----------------- Replacement ---------- Fracture filling -----	Undifferentiated limestone do. Pioche Shale-limestone Prospect Mountain Quartzite	Bullock, 1970, 1976; Crittenden, 1951; Heyl, 1963; Jones and Dunham, 1946; Miller, 1966; Perry and McCarthy, 1976 Taylor and Powers, 1959; Thurston and others, 1954; Whelan, 1965

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type ----	Host Rock	References
Wah Wah Pass	26 S.	15 W.	Fe, Mn	Replacement ---------	Cambrian limestone of the Orr and Weeks Formations	Bullock, 1970
				Fissure fillings ----	Hematite in fault gauge.	
				Pipe-like bodies ----	Adjacent to contact between diorite or quartz diorite dikes and Paleozoic carbonate rocks	
Preuss	26 S.	13 W.	Ag, Au, Pb, Cu, Ba, Fe	Disseminated --------	Cactus quartz monzonite	Butler, 1913; Emmons, 1902; Lindgren, 1910; Perry and McCarthy, 1976
	27 S.	13 W.		Breccia pipe --------	do.	
				Vein ----------------	Prospect Mountain Quartzite	
				Replacement ---------	Limestone	

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location Township	Range	Commodities	Deposit type ----	Host Rock	References
San Francisco	27 S.	13 W.	Ag, Au, Pb, Zn, Cu, Fe, W,	Contact metasomatic -	Limestone of Orr Formation	Bullock, 1976; Butler, 1913;
	27 S.	14 W.	Mo, F	Replacement ---------	do.	Butler and others,1920
				Fissure filling -----	Volcanics, quartz monzonite	East, 1966;
				Skarn ---------------	Limestone	Emmons, 1902; Everett, 1961; Hobbs, 1945; Koschman and Bergendahl, 1968; Lemmon and Tweto, 1962; McKelvey, 1973; Perry and McCarthy, 1976; Stringham, 1967; James, 1973
			Iron County			
Indian Peak	31 S.	18 W.	Ag, Au, Pb, Zn, Cu	Contact metasomatic --	Dolomite	Heyl, 1963
Stateline	32 S.	19 W.	Ag, Au, Cu, Pb, Mn	Vein ----------------	Welded Tuff	Butler and others, 1920; Koschman and Bergendahl, 1968; Thomson, 1973
	32 S.	20 W.				
	33 S.	20 W.				

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type ----	Host Rock	References
	Township	Range				
			Juab County			
Desert Mountain	12 S.	7 W.	Cu, Ba	Vein ----------------	Granite	Bulter and others, 1920; Hillier, 1956
Fish Springs	11 S.	14 W.	Ag, Au, Pb, Zn, Cu, Mo, Fe, Be, U, V, F, Mg	Replacement --------- Bedded --------------- Vein ----------------	Notch Peak Formation White tuff Bell Hill Member of Laketown Dolomite	Bullock, 1976; Buranek, 1948; Butler and others, 1920; Crawford and Buranek, 1957; Heyl, 1963; Lindsey, 1977; Montoya and others, 1964; Oliveira, 1975; Perry and McCarthy, 1976; Staatz and Bauer, 1950; James, 1973

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type ----	Host Rock	References
			NEVADA			
			Elko County			
Dolly Varden (Granite, Granite Mountain, Mitzpah)	28 N. 29 N.	66 E. 66 E.	Au, Ag, Cu, Pb Zn, Mo, Th	Contact metamorphic-- Replacement --------- Vein ----------------	Limestone, quartz monzonite Limestone Quartz monzonite	Granger and others, 1957; Hill, 1916; Lincoln, 1923; Smith, 1976
Ferber	27 N.	70 E.	Au, Ag, Cu, Pb	Vein ---------------- Porphyry Copper -----	Quartz monzonite do.	Granger and others, 1957; Hill, 1916; Lincoln, 1923; Smith, 1976
Ferguson Spring (Allegheny)	30 N.	69 E.	Au, Ag, Cu, Pb	Replacement ---------	Limestone	Granger and others, 1957; Hill, 1916; Lincoln, 1923

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type ----	Host Rock	References
Kinsley (Antelope)	26 N. 26 N.	67 E. 68 E.	Au, Ag, Cu, Pb, W, Mo	Contact Metamorphic -- Replacement --------- Vein ----------------	Limestone, quartz monzonite Limestone Dolomite	Emmons, 1910; Granger and others, 1957; Lincoln, 1923; Matson, 1947
Wendover	33 N.	70 E.	W	Unknown		Smith 1976
White Horse	28 N.	68 E.	Ag, Pb, Zn, Cu, W	Vein ----------------	Quartz monzonite	Granger and others, 1957; Hill, 1916; Lincoln, 1923; Smith, 1976
White Pine County						
Black Horse	15 N. 15 N. 16 N.	68 E. 69 E. 68 E.	Au, Ag, Pb, Cu, W, Zn	Vein ---------------- Pods ---------------- Placer --------------	Limestone, shale Conglomerate Gravel	Hose and others, 1976; Lemmon and Tweto, 1962

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location: Township	Location: Range	Commodities	Deposit type	Host Rock	References
Lexington (Lexington Canyon, Shoshone)	11 N.	69 E.	W	Vein ---------------- Placer --------------	Limestone Alluvium	Hose and others, 1976; Lincoln, 1923
Lincoln (Mount Washington, St Lawrence, Mount Wheeler)	12 N.	68 E.	W, Be, Pb, Ag, Cu, Sb,	Vein ---------------- Replacement ---------	Limestone do.	Hose and others, 1976; Stager, 1960; Whitebread and Lee, 1961
Mount Moriah	16 N. 17 N. 17 N. 17 N.	70 E. 68 E. 69 E. 70 E.	Au, Ag, Pb, Zn, Cu, W, Garnet	Placer Garnet ------- Replacement --------- Contact -------------	Creek bed Limestone Limestone, intrusives	Hose and others, 1976;
Osceola (Weaver Creek, Summit Diggins, Hogum, Willard Creek)	14 N. 14 N.	67 E. 68 E.	Au, Ag, Pb, Zn, Cu, W.	Vein ---------------- Placer -------------	Quartzite, Granite porphyry Gravel	Hose and others, 1976; Lincoln, 1923; Weeks, 1908
Red Hills	22 N.	68 E.	Pb, Ag, Cu, Au	Breccia zone --------	Limestone	Hill, 1916; Hose and others, 1976

Table 4.--Resource areas of the Bonneville region of Utah (Wong, 1983), and mineralized areas of the Bonneville region of Nevada (Wong, 1982), by county--Continued.

Mineralized Area	Location		Commodities	Deposit type ----	Host Rock	References
	Township	Range				
Snake (Bonita)	12 N. 13 N.	68 E. 70 E.	Ag, Pb, Cu, W	Vein ----------------	Quartz monzonite	Hose and others, 1976
Tungstonia (Eagle, Pleasant Valley, Kern, Regan)	20.5 N. 21 N. 21 N.	69 E. 67 E. 69 E.	Pb, Ag, Au, Cu, W, Zn, Bi, F	Vein ---------------- Replacement ---------	Limestone, granite Brecciated limestone	Couch and Carpenter, 1943; Hill, 1916; Hose and others, 1976; Lincoln, 1923

Lead, silver, copper, gold, zinc and beryllium are the principal metallic commodities with important production in the mining districts of the Bonneville region. Iron, tungsten, and molybdenum, are elements that have been produced locally in smaller amounts. The San Francisco district in Beaver County, Utah, was a major source of base and precious metals in the study area. The district contains vein and disseminated deposits in Tertiary lavas, mineralized chimneys in intermediate intrusives, and contact and fault-controlled replacement ore bodies primarily in carbonate rocks of Paleozoic age (Butler, 1913). The bulk of the value and tonnage in areas mined in the San Francisco district came from the replacement and fissure vein deposits in the Horn Silver and Beaver Carbonate mines on the east flank of the San Francisco Range. Approximately $34 million in metals were produced between 1879 and 1917 from mines in the San Francisco district and the adjacent Preuss district to the north (Butler and others, 1920).

The Gold Hill mining district is located at the northern end of the Deep Creek Range in Tooele County, Utah. The area contains numerous small vein and replacement deposits. Lead, zinc, copper, and silver were mined primarily from replacement ore bodies in the Pennsylvanian Oquirrh Formation (Nolan, 1935). Copper-bearing veins are present in a quartz monzonite stock. Lode gold veins occur in limestone near the intrusive, and tungsten mineralization is present in irregular tactite zones peripheral to the stock. Furthermore, the Mississippian Ochre Mountain limestone contains notable amounts of arsenic in two limestone replacement bodies (Nolan, 1935). Recurrent episodes of faulting contributed significantly to the small size of many of the ore zones. Production in the Gold Hill district was mainly from lode-gold deposits. At least $2 million in gold, silver, copper, lead, and zinc ores were mined between 1901 and 1927 and approximately 4,536 Mg of metallic arsenic were shipped from 1920 to 1925 (Nolan, 1935).

Gold is currently being mined by the Evelyn Limited Partnership in Goshute Canyon in the Willow Springs district. Lode gold and associated base-metal sulfides occur along an extensive silicified fracture system in the Cambrian Prospect Mountain Quartzite (Thomson, 1973). Approximately 20,000 ounces of gold were produced previously from this property (Tripp, 1984, written commun.).

Several mineralized areas occur along pronounced east-trending vein systems in the northern part of the Fish Springs Range, Juab County. The productive zones comprise small irregular replacement bodies in Ordovician and Silurian carbonate rocks, commonly near the footwall of granite porphyry dikes (Butler and others, 1920). Lead and silver ores were the primary source of production in the Fish Springs district. The gold content of the mineralized zones is low, and copper occurs chiefly in secondary minerals in the oxidized zone (Butler and others, 1920). Approximately 2.5 million ounces of silver and more than 7,258 Mg of lead were mined between 1891 and 1917, and the cumulative value of metals produced in the Fish Springs district exceeds $2.3 million (Butler and others, 1920).

Numerous thin gold- and silver-bearing quartz veins occur in quartzite in the Osceola district, White Pine County, Nevada. These lodes and several nearby placer deposits were worked continuously from 1901 to 1959 (Smith, 1976). Precious metals in the lodes and placers accounted for the principal value of metal production in the district. Small amounts of lead, zinc, and copper also were produced from the vein deposits. Approximately 550 short ton units of tungsten were mined from a pipelike replacement body in the Wheeler Formation, and from a scheelite-bearing quartz vein that cuts the Cambrian Prospect Mountain Quartzite (Smith, 1976). The tungsten deposits occur commonly near a Mesozoic(?) granitic intrusive or metadolerite dike. The combined production of metals from mines in the Osceola area is estimated to exceed $3.3 million (Smith, 1976).

The Spor Mountain district is located in Juab County, Utah, about 80 km northeast of Delta. Beryllium is economically the most important metal in the district, however, productive fluospar and uranium mines also occur in the area. The Yellow Chief mine immediately east of the district contains an estimated 90,720 Mg of uranium ore with a grade of at least 0.2 precent U_3O_8 (Bowyer, 1963; Hewitt, 1968). Extensive bertrandite-bearing ore zones with minor associated phenakite occur in thick sections of Pliocene water-laid tuff of the Spor Mountain Formation that were deposited in a lacustrine environment (Shawe, 1968). The 6- to 7-m.y.-old tuff of the Topaz Mountain Rhyolite contains less extensive zones of beryllium mineralization (Lindsey, 1981). Principal zones of beryllium mineralization are restricted to hydrothermally altered horizons containing altered clasts of Paleozoic dolomite. The Spor Mountain district contains one of the largest known non-pegmatitic resources of low-grade beryllium ore in the world (Griffitts, 1964). Several million Mg of beryllium ore with at least 0.5 percent BeO are identified in the district (Shawe, 1968).

The majority of the presently known occurrences of iron in the Bonneville region are located in Beaver County, Utah. These deposits are commonly irregular concordant replacement bodies near the contact between Paleozoic limestones and local intrusives. Less than 1.8 million Mg of combined production and resources are estimated to occur at each locality (Reeves, 1964).

Several scattered occurrences of tungsten and molybdenum are noted in the study area (Hobbs, 1945; Lemmon, 1964; and King, 1964), and these areas have produced little ore to date.

Nonmetallic and Industrial Mineral Resources

Nonmetallic industrial minerals and rocks occur throughout the Bonneville region. Excluding natural aggregates and building stone, nonmetallic industrial minerals and rocks have been mined on a small scale primarily for local use. Fluorspar is the principal industrial mineral commodity mined to date in the study area. A small amount of barite has also been produced in two localities.

The Spor Mountain district, Juab County, Utah, contains the principal productive fluorspar mines in the Bonneville region. Between 1944 and 1975 more than 204,120 Mg of fluorspar were mined principally from breccia pipes (Bullock, 1976). In addition, mines in the Washington district, Beaver County, have produced at least 18,144 Mg of metallurgical-grade fluorspar (Bullock, 1976).

A few thousand Mg of barite were produced in western Utah between 1955 and 1961 under a federally subsidized incentive program (Brobst, 1964). The bulk of the production was from the Garrick mine in the Fish Springs district, Juab County, Utah, and the Horn Silver mine in the San Francisco district, Beaver County, Utah, contributed the remainder of the ore (Brobst, 1964; Elevatorski, 1974).

Geothermal Resources

There are relatively few geothermal occurrences in the Bonneville region. Geothermal springs are located in the Snake Valley and Tule Valley west-central Millard County, and near the northern end of the Fish Springs Range in western Juab County, Utah. Wilson's Health Spring near the northern end of the Fish Springs Range has a temperature of 61°C, and this is the warmest geothermal spring in the study area (Murphy, 1980). The remaining geothermal springs in the Bonneville region of Utah have temperatures generally between 20° and 30°C. The Kern Mountains Spring and Big Spring in eastern White Pine County, Nevada, are in the only geothermal occurrences identified presently in the Bonneville region of Nevada. These springs contain warm water with temperatures less than 37°C (Garside and Schilling, 1979). No geothermal wells with temperatures in excess of 50°C occur presently in the Bonneville region of Nevada (Garside and Schilling, 1979; Murphy, 1980). Furthermore, no lands in the Bonneville region are currently classified as Known Geothermal Resources Areas (U. S. Bureau of Land Management, 1983a, 1983b).

Coal, Oil, and Gas Resources

No major coal occurrences are known at present in the Bonneville region (Doelling, 1982; Schilling, 1980). A thin bed of radioactive lignite has been prospected by a 7.6-m-deep incline in the Heavenly Hills area, western Juab County, Utah. The lignite reportedly contains from 0.01 to 0.31 percent uranium (Thomson, 1973). More than 20 hydrocarbon exploration boreholes have been drilled in the study area (Brady, 1983). Shows of oil or gas have been observed in some of these holes, however, no production has been reported to date. There are currently no Known Geologic Structures in the Bonneville region (U. S. Bureau of Land Management, 1983a, 1983b).

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Plates 1 to 6

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