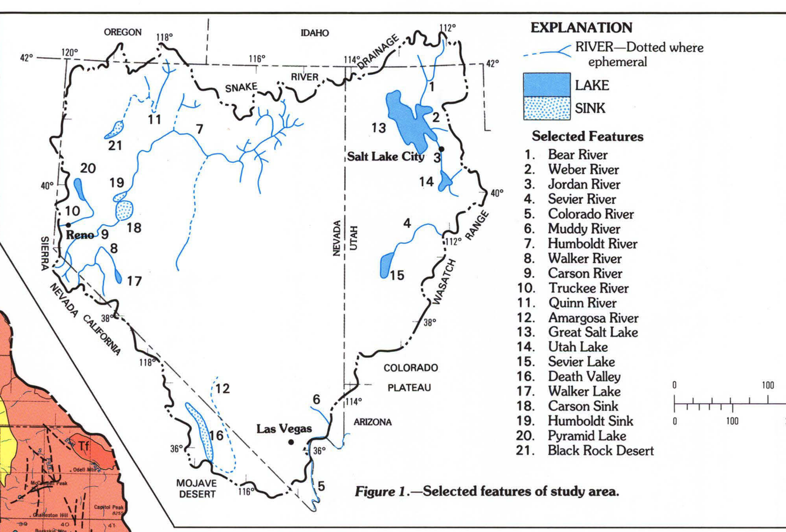



*Figure 1.*—Selected features of study area.

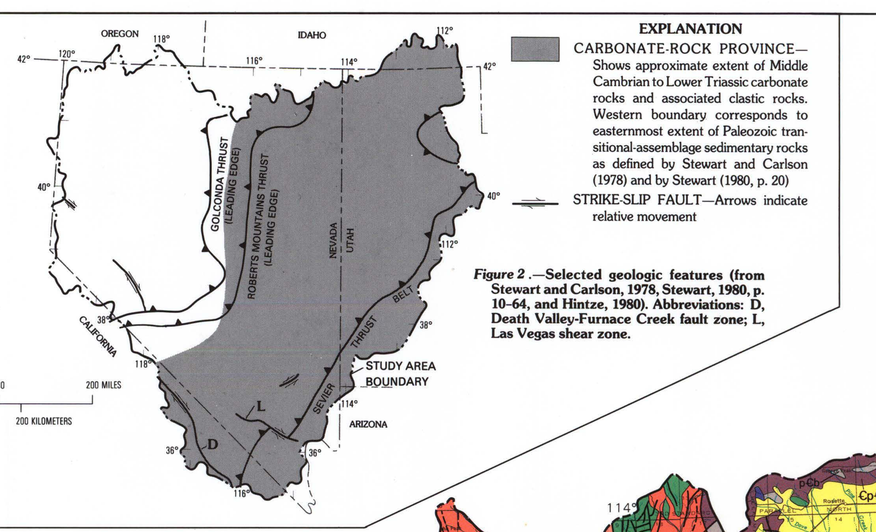
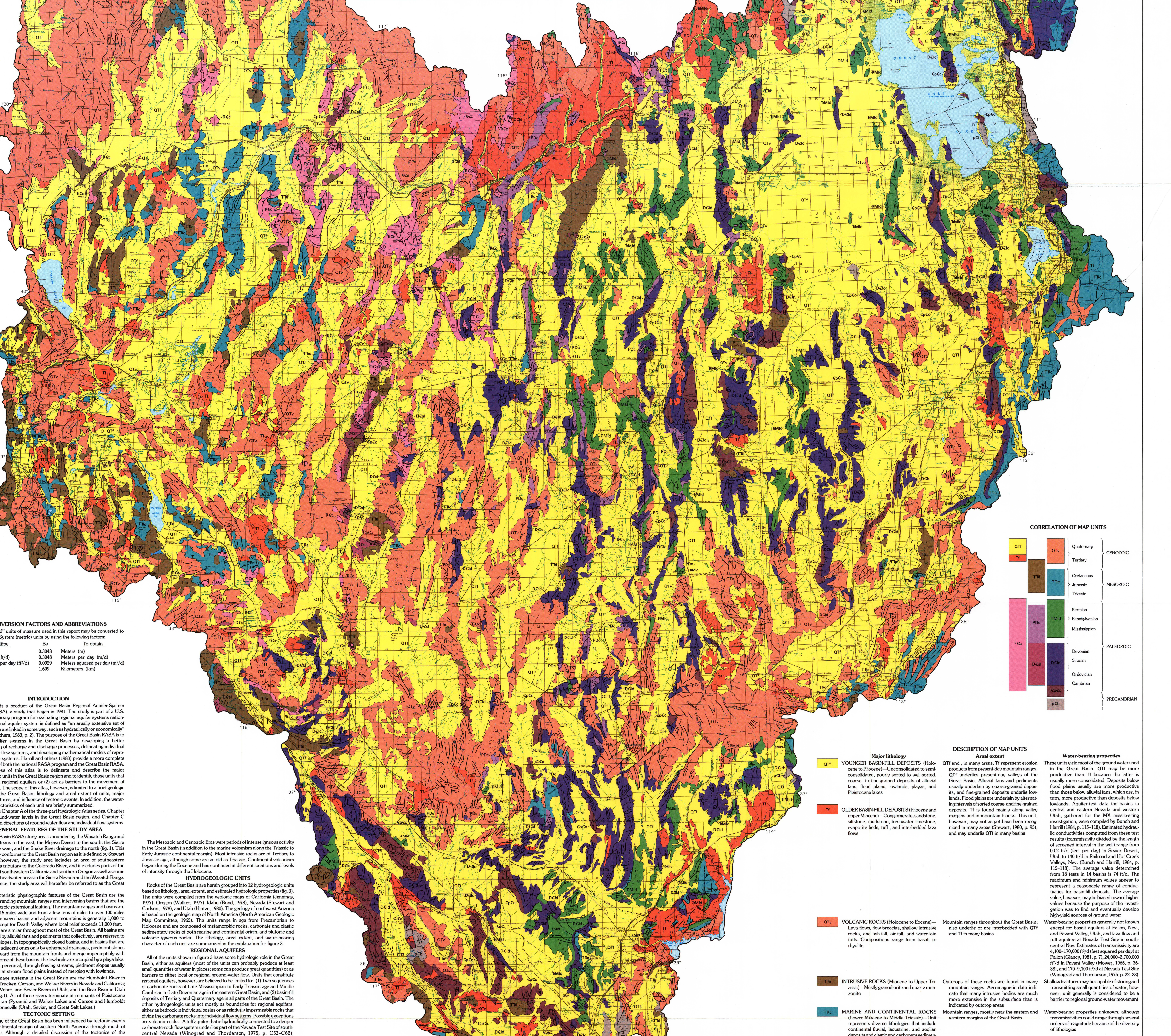



*Figure 2.*—Selected geologic features (from Stewart and Carlson, 1978; Stewart, 1980, p. 10-64; and Hintze, 1980). Abbreviations: D, Death Valley-Furnace Creek fault zone; L, Las Vegas shear zone.




## CONVERSION FACTORS AND ABBREVIATIONS

"Inch-pound" units of measure used in this report may be converted to International System (metric) units by using the following factors:

| Multipy | By | To obtain |
|---|---|---|
| Feet (ft) | 0.3048 | Meters (m) |
| Feet per day (ft/d) | 0.3048 | Meters per day (m/d) |
| Feet squared per day ($ft^2/d$) | 0.0929 | Meters squared per day ($m^2/d$) |
| Miles (mi) | 1.609 | Kilometers (km) |

## INTRODUCTION

This atlas is a product of the Great Basin Regional Aquifer-System Analysis (RASA), a study that began in 1981. The study is part of a U.S. Geological Survey program for evaluating regional aquifer systems nationwide. A regional aquifer system is defined as "an areally extensive set of aquifers which are linked in some way, such as hydraulically or economically" (Harrill and others, 1983, p. 2). The purpose of the Great Basin RASA is to evaluate aquifer systems in the Great Basin by developing a better understanding of recharge and discharge processes, delineating individual ground-water flow systems, and developing mathematical models of representative flow systems. Harrill and others (1983) provide a more complete background of both the national RASA program and the Great Basin RASA.

The purpose of this atlas is to delineate and describe the major hydrogeologic units in the Great Basin region and to identify those units that (1) constitute regional aquifers or (2) act as barriers to the movement of ground water. The scope of this atlas, however, is limited to a brief geologic overview of the Great Basin: lithology and areal extent of units, major structural features, and influence of tectonic events. In addition, the water-bearing characteristics of each unit are briefly summarized.

This atlas is Chapter A of the three-part Hydrologic Atlas series. Chapter B shows ground-water levels in the Great Basin region, and Chapter C shows inferred directions of ground-water flow and individual flow systems.

## GENERAL FEATURES OF THE STUDY AREA

The Great Basin RASA study area is bounded by the Wasatch Range and Colorado Plateaus to the east; the Mojave Desert to the south; the Sierra Nevada to the west; and the Snake River drainage to the north (fig. 1). This area generally conforms to the Great Basin region as it is defined by Stewart (1980, p. 7); however, the study area includes an area of southeastern Nevada that is tributary to the Colorado River, and it excludes parts of the Great Basin of southeastern California and southern Oregon as well as some mountainous headwater areas in the Sierra Nevada and the Wasatch Range. For convenience, the study area will hereafter be referred to as the Great Basin.

The characteristic physiographic features of the Great Basin are the north-south trending mountain ranges and intervening basins that are the result of Cenozoic extensional faulting. The mountain ranges and basins are commonly 5-15 miles wide and from a few tens of miles to over 100 miles long. Relief between basins and adjacent mountains is generally 1,000 to 5,000 feet, except for Death Valley where local relief exceeds 11,000 feet.

Landforms are similar throughout most of the Great Basin. All basins are characterized by alluvial fans and pediments that collectively, are referred to as piedmont slopes. In topographically closed basins, and in basins that are connected to adjacent ones only by ephemeral drainages, piedmont slopes extend basinward from the mountain fronts and merge imperceptibly with lowlands. In some of these basins, the lowlands are occupied by a playa lake. In basins with perennial, through-flowing streams, piedmont slopes usually are truncated at stream flood plains instead of merging with lowlands.

Major drainage systems in the Great Basin are the Humboldt River in Nevada; the Truckee, Carson, and Walker Rivers in Nevada and California; the Jordan, Weber, and Sevier Rivers in Utah; and the Bear River in Utah and Idaho (fig.1). All of these rivers terminate at remnants of Pleistocene Lakes Lahontan (Pyramid and Walker Lakes and Carson and Humboldt Sinks) and Bonneville (Utah, Sevier, and Great Salt Lakes.)

## TECTONIC SETTING

The geology of the Great Basin has been influenced by tectonic events along the continental margin of western North America through much of geologic time. Although a detailed discussion of the tectonics of the continental margin or of the Great Basin is beyond the scope of this report, a brief review of some of the tectonic features and events that have influenced the hydrogeologic framework of the Great Basin is appropriate.

The continental margin of western North America was located in what is now central Nevada from late Precambrian to Early Triassic time (Stewart, 1980, p. 35–40 and 55–59). During that period, marine clastic and carbonate rocks were being deposited on the continental shelf and slope (in what is now the eastern Great Basin) and fine-grained sediments, cherts, and marine volcanic rocks were being deposited farther west in the deep-ocean basin (in what is now the western Great Basin).

These depositional environments were disrupted during Late Devonian or Early Mississippian time by what is referred to as the Antler orogeny (Stewart, 1980, p. 36), and again in Late Permian or Early Triassic time by the Sonoma orogeny (Stewart, 1980, p. 55–59). Both orogenies resulted in eastward thrusting of deep-ocean deposits over slope and shelf deposits of approximately equivalent age along the Roberts Mountain thrust (Antler orogeny) and along the Golconda thrust (Sonoma orogeny) (fig. 2). As a result, highlands persisted off what was then the coast of western North America from as early as Late Devonian through Early Triassic time, and they were the source of much of the clastic sediments deposited on the continental shelf (eastern Great Basin) during that time.

The Great Basin continued to be tectonically active during the Mesozoic and the Cenozoic. It underwent compression during Mesozoic and possibly early Tertiary time, and then extension from early or middle Miocene through Holocene time (Stewart, 1980, p. 76 and 105–121). The continental margin of western North America shifted to what is now western Nevada by the Late Triassic (Speed, 1978, p. 255) so that the eastern Great Basin was an area of mostly subaerial erosion and deposition and western Nevada was an area of mixed marine environments in which clastic and carbonate sedimentary rocks and marine volcanic rocks were deposited. By the Middle Jurassic, the continental margin had shifted farther west (Speed, 1978, p. 262) and the entire Great Basin was an area of subaerial erosion and fluvial and lacustrine deposition. Although these processes continued through the Cenozoic, the size and distribution of basins and highlands drastically changed in early or middle Miocene time with the onset of extensional faulting that formed the north-south trending mountains and valleys of the Great Basin. At that time, basin-fill deposits began to accumulate, and they have continued to do so through the Holocene.

Structural features of Mesozoic age include: (1) thrust faults and regional folds in western and north-central Nevada; (2) thrust faults along the Sevier thrust belt in southern Idaho, central and southwestern Utah, southern Nevada, and southeastern California (fig. 2); (3) low-angle faults in eastern Nevada; and (4) right-lateral strike-slip faults in western Nevada and southeastern California (Stewart, 1980, p. 76–87). Dominant structural features of Cenozoic age are the extensional normal faults that are commonplace throughout the region. Many are high-angle, whereas others are listric (that is, they are curved and tend to flatten with depth). In addition, low-angle detachment faults have been recognized in parts of eastern Nevada and western Utah. These faults appear to act as surfaces that truncate high-angle faults and into which listric faults merge.

The Mesozoic and Cenozoic Eras were periods of intense igneous activity in the Great Basin (in addition to the marine volcanism along the Triassic to Early Jurassic continental margin). Most intrusive rocks are of Tertiary to Jurassic age, although some are as old as Triassic. Continental volcanism began during the Eocene and has continued at different locations and levels of intensity through the Holocene.

## HYDROGEOLOGIC UNITS

Rocks of the Great Basin are herein grouped into 12 hydrogeologic units based on lithology, areal extent, and estimated hydrologic properties (fig. 3). The units were compiled from the geologic maps of California (Jennings, 1977), Oregon (Walker, 1977), Idaho (Bond, 1978), Nevada (Stewart and Carlson, 1978), and Utah (Hintze, 1980). The geology of northwest Arizona is based on the geologic map of North America (North American Geologic Map Committee, 1965). The units range in age from Precambrian to Holocene and are composed of metamorphic rocks, carbonate and clastic sedimentary rocks of both marine and continental origin, and plutonic and volcanic igneous rocks. The lithology, areal extent, and water-bearing character of each unit are summarized in the explanation for figure 3.

## REGIONAL AQUIFERS

All of the units shown in figure 3 have some hydrologic role in the Great Basin, either as aquifers (most of the units can probably produce at least small quantities of water in places; some can produce great quantities) or as barriers to either local or regional ground-water flow. Units that constitute regional aquifers, however, are believed to be limited to: (1) Two sequences of carbonate rocks of Late Mississippian to Early Triassic age and Middle Cambrian to Late Devonian age in the eastern Great Basin, and (2) basin-fill deposits of Tertiary and Quaternary age in all parts of the Great Basin. The other hydrogeologic units act mostly as boundaries for regional aquifers, either as bedrock in individual basins or as relatively impermeable rocks that divide the carbonate rocks into individual flow systems. Possible exceptions are volcanic rocks: A tuff aquifer that is hydraulically connected to a deeper carbonate-rock flow system underlies part of the Nevada Test Site of south-central Nevada (Winograd and Thordarson, 1975, p. C53–C62), and basalt aquifers are interbedded with basin-fill deposits at Fallon, Nev. (Glancy, 1981, p. 12) and at Pavant Valley, Utah (Mower, 1965, p. 23). Considering their widespread occurrence, volcanic rocks may prove to be important aquifers in other parts of the Great Basin.

The carbonate rocks constitute a regional aquifer system that underlies the eastern part of the Great Basin (fig. 2). This aquifer system consists of several major flow systems (Harrill and others, 1983, p. 9) which are bounded by plutonic rocks that have intruded the carbonate rocks, by faults that juxtapose relatively impermeable units against the carbonate rocks, and by ground-water divides. Similar boundaries probably partition the major flow systems into smaller ones.

The two carbonate-rock units (see above) are separated stratigraphically by Upper Devonian and Mississippian clastic rocks (see footnote 1 in the explanation for fig. 3) that may locally restrict flow between the two units; however, the two carbonate-rock units are commonly in fault contact with each other, and thus are probably connected hydraulically in most areas. For this reason, the carbonate-rock aquifer is believed to consist of the two units of carbonate rocks (TRMld and D€ld) and the intervening unit of clastic rocks (lower part of PDc, fig. 3). The stratigraphic thickness of this combined unit is generally more than 20,000 feet (Stratigraphic Committee of the Eastern Nevada Geological Society, 1973). Its saturated thickness is probably less than its stratigraphic thickness in most areas, however, because significant secondary and tertiary permeability may not develop throughout the whole interval, especially at great depths. For practical purposes, the base of the carbonate-rock aquifer is considered to be the top of upper Precambrian and Lower Cambrian clastic rocks (€p€c), although the actual base may be much shallower.

Basin-fill aquifers of the numerous valleys in the Great Basin, which are dominated by unconsolidated to semi-consolidated deposits, constitute a regional aquifer system because of the similarities between basins and because these aquifers are the most important and most developed source of ground water in the region. Some basins are topographically and hydrologically closed by impermeable bedrock and others are part of multi-basin flow systems connected by perennial streams or by flow through the basin fill or permeable bedrock. Basin-fill deposits usually range in thickness from zero at margins of valleys to several thousand feet in valley lowlands. However, the deposits in some valleys, such as the Black Rock Desert and Dixie Valley in western Nevada, are as thick as 10,000 feet (Schaefer, 1983, p. 11; Schaefer and others, 1983, p. 27). The permeable material in many basins in Utah commonly is restricted to the upper 1,500 feet of basin fill (J.S. Gates, U.S. Geological Survey, written commun., 1985), and a similar situation may exist in the rest of the Great Basin. Well yields within the basin fill seem to be related to physiographic setting in most valleys. For instance, piedmont slope deposits generally are more productive than valley-lowland deposits, and flood-plain deposits generally are more productive than piedmont slope deposits. However, these are general observations that do not apply in all valleys. The hydraulic properties of basin-fill deposits (see explanation, fig. 3) can differ greatly over short distances in any valley, both laterally and vertically, because of abrupt changes in grain size, and the degree of sorting and consolidation.

## ALTITUDE DATUM

The term "National Geodetic Vertical Datum of 1929" replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The geodetic datum is derived from a general adjustment of the first-order leveling networks of both the United States and Canada. For convenience in this report, the datum is referred to as "sea level."

*Figure 3.*—Hydrogeology

SCALE 1:1 000 000

25 0 25 50 MILES

25 0 25 50 KILOMETERS

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## EXPLANATION

CONTACT—Dashed where approximately located or uncertain

HIGH-ANGLE FAULT—Dashed where approximately located; dotted where concealed. Many are Cenozoic extensional faults, including listric faults (that is, faults that curve and flatten with depth)

THRUST FAULT—Dashed where approximately located; dotted where concealed. Barbs on upper plate. Also includes some low-angle extensional faults in eastern Nevada

STRIKE-SLIP FAULT—Dashed where approximately located; dotted where concealed. Arrows indicate relative movement

BOUNDARY OF STUDY AREA

## DESCRIPTION OF MAP UNITS

| Unit | Major lithology | Areal extent | Water-bearing properties |
|---|---|---|---|
| QTf | YOUNGER BASIN-FILL DEPOSITS (Holocene to Pliocene)—Unconsolidated to semi-consolidated, poorly sorted to well-sorted, coarse- to fine-grained deposits of alluvial fans, flood plains, lowlands, playas, and Pleistocene lakes | QTf and, in many areas, Tf represent erosion products from present-day mountain ranges. QTf underlies present-day valleys of the Great Basin. Alluvial fans and pediments usually underlain by coarse-grained deposits, and fine-grained deposits underlie lowlands. Flood plains are underlain by alternating intervals of sorted coarse- and fine-grained deposits. Tf is found mainly along valley margins and in mountain blocks. This unit, however, may not as yet have been recognized in many areas (Stewart, 1980, p. 95), and may underlie QTf in many basins | These units yield most of the ground water used in the Great Basin. QTf may be more productive than Tf because the latter is usually more consolidated. Deposits below flood plains usually are more productive than those below alluvial fans, which are, in turn, more productive than deposits below lowlands. Aquifer-test data for basins in central and eastern Nevada and western Utah, gathered for the MX missile-siting investigation, were compiled by Bunch and Harrill (1984, p. 115–118). Estimated hydraulic conductivities computed from these test results (transmissivity divided by the length of screened interval in the well) range from 0.02 ft/d (feet per day) in Sevier Desert, Utah to 140 ft/d in Railroad and Hot Creek Valleys, Nev. (Bunch and Harrill, 1984, p. 115–118). The average value determined from 18 tests in 14 basins is 74 ft/d. The maximum and minimum values appear to represent a reasonable range of conductivities for basin-fill deposits. The average value, however, may be biased toward higher values because the purpose of the investigation was to find and eventually develop high-yield sources of ground water |
| Tf | OLDER BASIN-FILL DEPOSITS (Pliocene and upper Miocene)—Conglomerate, sandstone, siltstone, mudstone, freshwater limestone, evaporite beds, tuff, and interbedded lava flows | | |
| QTv | VOLCANIC ROCKS (Holocene to Eocene)—Lava flows, flow breccias, shallow intrusive rocks, and ash-fall, air-fall, and water-lain tuffs. Compositions range from basalt to rhyolite | Mountain ranges throughout the Great Basin; also underlie or are interbedded with QTf and Tf in many basins | Water-bearing properties generally not known except for basalt aquifers at Fallon, Nev., and Pavant Valley, Utah, and lava flow and tuff aquifers at Nevada Test Site in south-central Nev. Estimates of transmissivity are 4,100–170,000 $ft^2/d$ (feet squared per day) at Fallon (Glancy, 1981, p. 7), 24,000–2,700,000 $ft^2/d$ in Pavant Valley (Mower, 1965, p. 36-38), and 170–9,100 $ft^2/d$ at Nevada Test Site (Winograd and Thordarson, 1975, p. 22–23) |
| TTRi | INTRUSIVE ROCKS (Miocene to Upper Triassic)—Mostly granodiorite and quartz monzonite | Outcrops of these rocks are found in many mountain ranges. Aeromagnetic data indicate that many intrusive bodies are much more extensive in the subsurface than is indicated by outcrop areas | Shallow fractures may be capable of storing and transmitting small quantities of water; however, unit generally is considered to be a barrier to regional ground-water movement |
| TTRc | MARINE AND CONTINENTAL ROCKS (Lower Miocene to Middle Triassic)—Unit represents diverse lithologies that include continental fluvial, lacustrine, and aeolian deposits and clastic and carbonate sedimentary rocks and volcanic rocks of marine origin | Mountain ranges, mostly near the eastern and western margins of the Great Basin | Water-bearing properties unknown, although transmissivities could range through several orders of magnitude because of the diversity of lithologies |
| TR€c | MARINE SEDIMENTARY AND VOLCANIC ROCKS (Lower Triassic to Lower Cambrian)—Unit consists of deep-water clastic rocks, chert, and volcanic rocks | Structurally overlies units of approximately equivalent age along the Roberts Mountains and Golconda thrusts in central Nevada (fig. 2) | Water-bearing properties unknown. Probably does not store or transmit much water |
| PDc | CLASTIC ROCKS (Upper Permian to Upper Devonian)—Shale, sandstone, and conglomerate[1] | Eastern Great Basin | Water-bearing properties largely unknown. Presumed to act as a local barrier to flow between TRMld and D€ld |
| TRMld | CARBONATE ROCKS (Upper Triassic to Lower Mississippian)—Limestone, commonly silty or sandy, and lesser amounts of dolomite, shale, siltstone, and sandstone. This unit is generally more clastic than D€ld. In parts of central Utah, proportion of clastic rocks may exceed that of carbonate rocks | Eastern Great Basin | Forms upper part of carbonate-rock aquifer. Water-bearing properties largely unknown. Estimated to be similar to those of D€ld at the Nevada Test Site (Winograd and Thordarson, 1975, p. 30–31) |
| D€sl | CARBONATE AND CLASTIC ROCKS (Middle Devonian to Middle Cambrian)—Thin bedded to laminated, sandy to silty limestone, sandstone, siltstone, and shale | Central Nevada | Water-bearing properties largely unknown. May be similar to those for units TR€c, TRMld, and D€ld |
| D€ld | CARBONATE ROCKS (Middle Devonian to Middle Cambrian)—Limestone and dolomite, with lesser amounts of shale, sandstone, and quartzite | Eastern Great Basin as far west as central Nevada | Forms lower part of carbonate-rock aquifer. Estimates of transmissivity are as follows: from 170–5,200 $ft^2/d$ at Nevada Test Site (Winograd and Thordarson, 1975, p. 22); 14,000 $ft^2/d$ in White River Valley, Nev. (Plume, 1984, p. 624); 200 $ft^2/d$ in Steptoe Valley, Nev., 13,400 $ft^2/d$ in Dry Lake Valley, Nev., 400 $ft^2/d$ in Garden Valley, Nev., and 40,000 and 250,000 $ft^2/d$ in Coyote Spring Valley, Nev. (Bunch and Harrill, 1984, p. 119) |
| €p€c | CLASTIC ROCKS (Lower Cambrian and upper Precambrian)—Quartzite, shale, siltstone, sandstone, limestone, and dolomite. Metamorphosed in some areas | Eastern Great Basin | Considered impermeable by Winograd and Thordarson (1975, p. 11). Significant secondary permeability probably does not develop below the older unit of carbonate rocks D€ld, (so this unit €p€c) may form a base for the carbonate-rock aquifer of the eastern Great Basin. Barrier to regional flow where it is in fault contact with the carbonate rock |
| p€b | BASEMENT ROCKS (Precambrian)—Gneiss, schist, gneissic granite, and granite | Outcrops near southern, southeastern, and northeastern boundaries of Great Basin. May underlie eastern Great Basin as far west as central Nevada (Stewart, 1980, p. 9–11) | Probably not capable of storing or transmitting much water. Barrier to regional flow where it is in fault contact with the carbonate-rock aquifer |

[1]This unit mostly represents erosion products from the Antler and Sonoma highlands and from a continental source farther east (Welsh and Bissell, 1979, p. Y21). These deposits accumulated from Late Devonian through Mississippi time in eastern Nevada and western Utah. Farther west, however, the deposits appear to have accumulated through the Permian. This distinction is important because the unit stratigraphically separates TRMld and D€ld in eastern Nevada and western Utah.

Base from U.S. Geological Survey
State maps 1:1,000,000

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1988

Geology from North American Geologic Map Committee (1965), Jennings (1977), Walker (1977), Bond (1978), Stewart and Carlson (1978), and Hintze (1980); modified by R.W. Plume and S.M. Carlton, 1983

# HYDROGEOLOGY OF THE GREAT BASIN REGION OF NEVADA, UTAH, AND ADJACENT STATES

By
Russell W. Plume and Stephen M. Carlton

1988

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