HYDROGEOLOGIC FRAMEWORK OF THE GREAT BASIN REGION OF NEVADA, UTAH, AND ADJACENT STATES

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1409-B

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U.S. Geological Survey Professional Paper 1409-D

The original version of this report was published in September 1991 as a Professional Paper with the same title and number (1409-D). In November 1991, an error in the model was discovered. As a result, the model was corrected and recalibrated. This report, published in 1995, presents the revised model.

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.

Gordon P. Eaton
Director

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ILLUSTRATIONS

[Plates are in pocket]

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
square mile (mi^2)	2.590	square kilometer (km^2)

SEA LEVEL

In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly call Sea Level Datum of 1929.

HYDROGEOLOGIC FRAMEWORK OF THE GREAT BASIN REGION OF NEVADA, UTAH, AND ADJACENT STATES

By Russell W. Plume

ABSTRACT

Two major aquifer systems are recognized in the Great Basin: one system, called the carbonate-rock aquifers, is contained mostly within thick sections of Middle Cambrian to Lower Triassic carbonate rocks in the eastern Great Basin; the other system, called the basin-fill aquifers, occurs in Miocene to Holocene basin-fill deposits that are found throughout the Great Basin.

The Middle Cambrian to Lower Triassic part of the stratigraphic section in the eastern Great Basin consists of limestone and dolomite and subordinate shale, quartzite, sandstone, and conglomerate. The measured stratigraphic thickness of this part of the section ranges from 5,000 to 30,000 feet; in some places, more than 70 percent of this thickness consists of limestone and dolomite. Petroleum-well logs indicate that areally and vertically narrow zones of high porosity (possibly fault or fracture zones) occur within broader zones of low porosity. Values of hydraulic conductivity determined during previous studies and from analysis of petroleum industry drill-stem tests as a part of this study range from 0.0005 to 900 feet per day. The higher values of porosity and conductivity probably represent fault or fracture zones and the low values relatively unfractured carbonate rocks.

Lithologic and hydraulic properties of the basin fill that has accumulated in structural basins are approximately related to physiographic setting. In a typical basin, the upper and middle parts of alluvial fans and pediments are underlain mainly by poorly sorted, coarse-grained deposits, whereas lower fans and valley lowlands are underlain by increasing proportions of fine-grained deposits. In basins with a perennial or near-perennial stream, the basin fill beneath the stream flood plain has been reworked and deposited as well-sorted beds of clay, silt, sand, or gravel. Of these three groups of deposits, those of flood plains are most permeable, whereas those of upper and middle alluvial fans and pediments appear to be slightly more permeable than those of lower fans and lowlands.

The Great Basin comprises some 260 topographic basins. Each is underlain by a structural basin that may differ markedly in shape and depth from others. As part of this study, six topographic basins were evaluated in an attempt to characterize the more common geometries of structural basins and associated basin-fill aquifers. Of the six basins evaluated, maximum depths of fill range from 3,000 to 10,000 feet; two are symmetrical with respect to their topographic basins and four are asymmetrical.

Volcanic rocks of Cenozoic age are found in most mountain ranges and commonly underlie or are interbedded with basin-fill deposits. They are important aquifers in parts of the Great Basin, such as the basalt aquifers at Fallon, Nevada, and Pavant Valley, Utah, and tuff and lava-flow aquifers in south-central Nevada. However, volcanic rocks can also be poorly permeable, such as those that underlie Railroad Valley, Nevada.

Precambrian crystalline basement, the overlying upper Precambrian and Lower Cambrian clastic sedimentary rocks, and Jurassic to Tertiary granitic rocks may be some of the principal barriers to ground-water flow in the eastern Great Basin. Aeromagnetic data indicate that granitic rocks or crystalline basement (and by inference, the overlying clastic rocks) underlie parts of the region and confine ground-water flow both laterally and vertically. Directions of regional ground-water flow appear to be affected by these bodies when their tops are at altitudes comparable to water levels simulated in a computer model that was done as a separate part of the overall study. Elsewhere, the locations of several large springs seem to be related to these barriers.

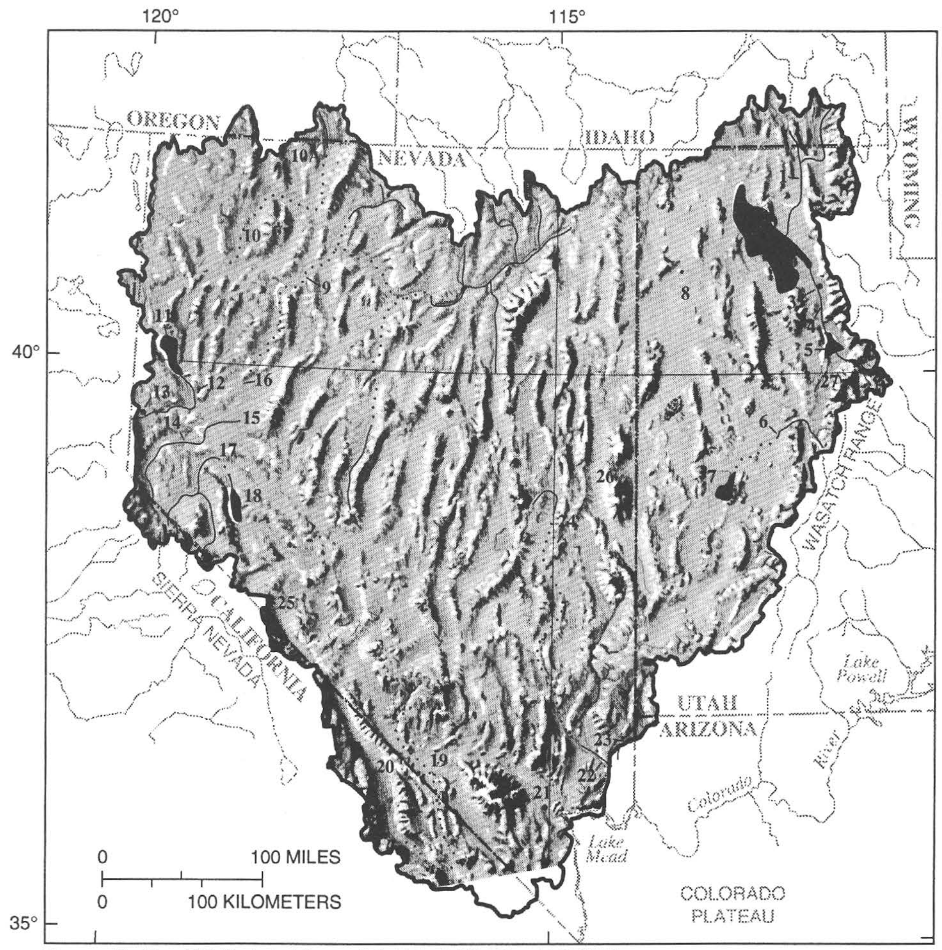
A general hypothesis that can be proposed on the basis of the analysis of aeromagnetic data is that broad magnetic highs represent areas where the transmissivity of regional aquifers may be reduced because of the potential shallow presence of granitic rocks or crystalline basement and the overlying upper Precambrian to Middle Cambrian clastic sedimentary rocks. In contrast, broad magnetic lows represent areas where the transmissivity of regional aquifers may be relatively high because of the increased depths to granitic rocks or crystalline basement.

Most basin-fill aquifers in the Great Basin are hydraulically connected to carbonate-rock aquifers or to other basin-fill aquifers; in fact, only a few hydraulically isolated basins have been identified. The most common type of connection in the eastern Great Basin is that of basin-fill and carbonate-rock aquifers. Evidence for this type of hydraulic connection comes mainly from observations in valleys where the extent of ground-water discharge either greatly exceeds or is much less than would be anticipated considering the area of the topographic basin. The most common type of hydraulic connection in the western Great Basin is basin fill that separates adjacent basins along a low divide. Hydraulic connections are provided by permeable bedrock in several basins in southwestern Nevada, but are relatively rare elsewhere. Large perennial streams also hydraulically connect basin-fill aquifers in the Great Basin.

INTRODUCTION

The Great Basin Regional Aquifer-Systems Analysis (RASA) encompasses most of the Great

Basin region in Nevada, Utah, California, Oregon, Idaho, and Arizona—an area of about 140,000 mi^2 (fig. 1). The study began in 1980 and is part of a program described in the foreword for evaluating the major regional aquifer systems in the United States. An aquifer system is defined by Poland and



Base modified from U.S. Geological Survey digital data, 1:100,000 and 1:250,000
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian - 114°

EXPLANATION

STREAM—Dotted where ephemeral

LAKE

STATE BOUNDARY

STUDY AREA BOUNDARY

SELECTED PHYSIOGRAPHIC AND CULTURAL FEATURES

1. Bear River	**10A**. Quinn River	**19**. Amargosa River
2. Great Salt Lake	**11**. Pyramid Lake	**20**. Death Valley
3. Salt Lake City	**12**. Truckee River	**21**. Las Vegas
4. Jordan River	**13**. Reno	**22**. Muddy River
5. Utah Lake	**14**. Carson River	**23**. Virgin River
6. Sevier River	**15**. Carson Sink	**24**. White River
7. Sevier Lake	**16**. Humboldt Sink	**25**. Boundary Peak
8. Great Salt Lake Desert	**17**. Walker River	**26**. Wheeler Peak
9. Humboldt River System	**18**. Walker Lake	**27**. Mt. Nebo
10. Black Rock Desert		

FIGURE 1.—Index map showing location of Great Basin Regional Aquifer-System Analysis (RASA) study area and selected physiographic and cultural features.

others (1972, p. 2) as "a heterogeneous body of intercalated permeable and poorly permeable material that functions regionally as a water-yielding hydraulic unit; it comprises two or more permeable beds separated at least locally by aquitards that impede ground-water movement but do not greatly affect the regional hydraulic continuity of the system." Harrill and others (1983, p. 2) define a regional aquifer system as an areally extensive set of aquifers that are linked in some way. Two groups of aquifers in the Great Basin generally fit these definitions. One group is present mainly in Paleozoic and early Mesozoic carbonate rocks that underlie most of eastern Nevada, western Utah, and parts of southeastern California and southern Idaho (fig. 2). This group of aquifers, called the carbonate-rock aquifers, fits the definition of a regional aquifer system because of its large areal extent. It consists of smaller flow regions bounded, to a limited extent, by geologic features described later in this report.

The other group consists of the basin-fill aquifers that are found throughout the Great Basin. A total of 260 hydrographic areas have been identified in the study area (Harrill and others, 1988), and each generally corresponds to a topographic basin and its underlying basin-fill aquifer (fig. 2). Individual basin-fill aquifers may be hydraulically isolated from similar aquifers in adjoining valleys, or they may be connected either by a stream or by ground-water underflow through basin fill or consolidated rocks. In addition, many of the basin-fill aquifers in the eastern Great Basin are hydraulically connected to other basin-fill aquifers by flow through underlying carbonate-rock aquifers.

PURPOSE AND SCOPE

The overall objective of this report is to characterize and describe the hydrogeology of regional aquifer systems in the Great Basin. More specific purposes are (1) to group the many different formations and rock units in the Great Basin into a few regional hydrogeologic units, (2) to describe the lithology, areal extent, and water-bearing character of each hydrogeologic unit, (3) to identify those units that are primarily responsible for storing and transmitting ground water in regional aquifer systems, (4) to identify those units that constitute barriers to ground-water flow, and (5) to determine, to the extent possible, the subsurface geometry of regional aquifers and their boundaries.

The scope of the study was strongly affected by differences between the two major aquifer systems in the region. The focus of study regarding the eastern Great Basin was primarily to define the distribution of units that constitute aquifers and those that constitute barriers to regional ground-water flow. For purposes of this part of the study, broad geologic features of the eastern Great Basin were considered more important than site-specific geologic features or ones of small areal extent that have little or no influence on regional ground-water flow.

In contrast, the focus of study regarding the basin-fill aquifer system was on several site-specific examples, because even generalized discussion of every individual basin in the Great Basin was beyond the scope of the study. The approach was to characterize the hydrogeology of selected basins and use these as examples of the overall hydrogeology of the basin-fill aquifer system. Consequently, only features common to many basins were described; features peculiar to one or a few were not included.

METHODS

This study involved compilation and analysis of existing data, which consist of the results of previous geologic studies made in the Great Basin and of petroleum-exploration and geophysical studies in the eastern Great Basin.

Geologic data for the hydrogeologic map (pl. 2) were compiled from the state geologic maps of Nevada, Utah, California, Idaho, and Oregon (Stewart and Carlson, 1978; Hintze, 1980; Jennings, 1977; Bond, 1978; and Walker, 1977, respectively) and from the Geologic Map of North America for the northwest corner of Arizona (North American Geologic Map Committee, 1965).

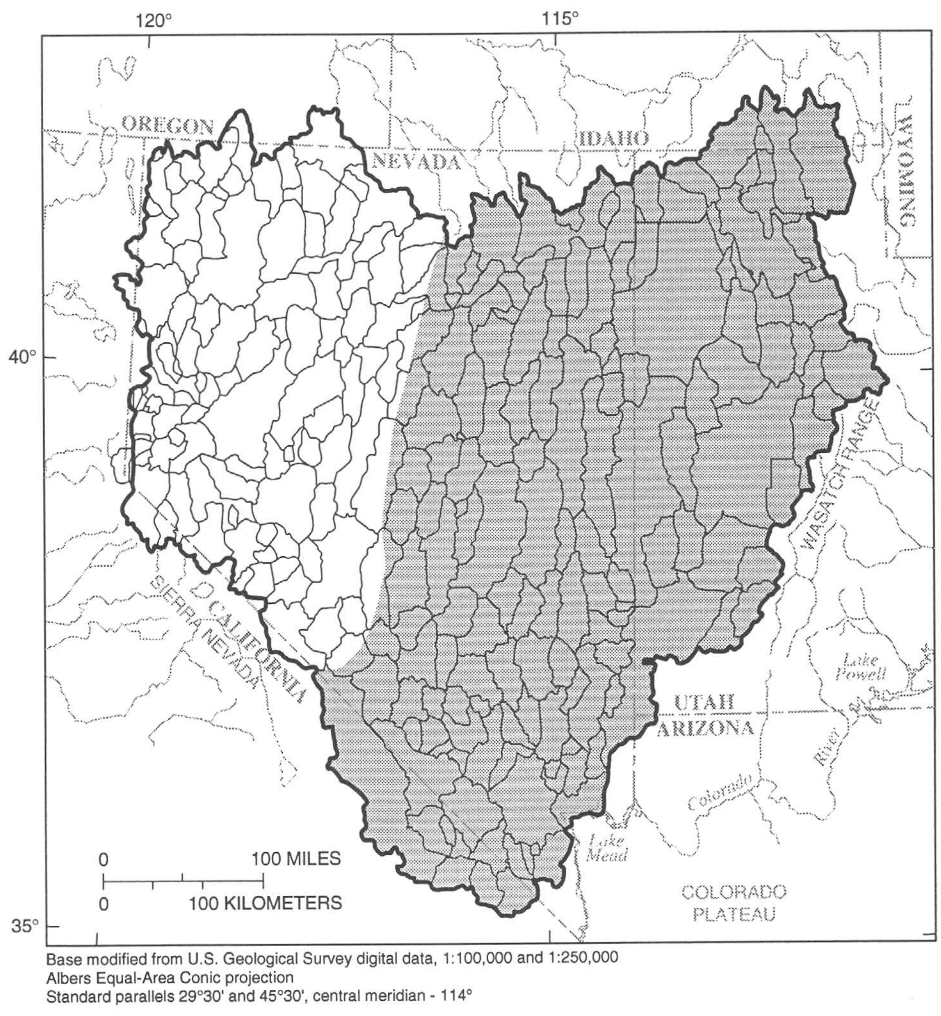
Petroleum exploration in the eastern Great Basin has generated data available through private sources and the Nevada Department of Mineral Resources. Lithologic and geophysical logs of selected petroleum-exploration wells have been compiled into composite logs by American Stratigraphic Company (AMSTRAT). These logs are an important source of subsurface information tabulated in this report, such as lithology, depth to tops of formations, and rock porosity.

The Nevada Department of Mineral Resources is a repository for data generated for each petroleum-exploration well drilled in the State. These data, also tabulated in this report, include lithologic and geophysical logs, locations of water-bearing and lost-circulation zones, water quality, and, most important for this study, results of drill-stem tests.

DRILL-STEM TESTS

The petroleum industry uses drill-stem tests to determine the hydraulic properties of an interval of a formation that is of potential economic interest. Test results consist of a report made by a well-service company to the owner of the well. In some reports, the data are fully interpreted, whereas in others only the data are presented and interpretation is left to the client. All the data available for drill-stem tests in the eastern Great Basin were interpreted for this study using the same set of techniques and assumptions (see appendix 1).

A later section of this report discusses hydraulic conductivities determined from drill-stem tests for some of the different hydrogeologic units in parts of the eastern Great Basin. These tests, like any aquifer test, have certain limitations that must be remembered when interpreting and using the data. Most of these limitations and assumptions were reviewed by McKay and Kepper (1988, p. 12–16). For most aquifer tests, the density and viscosity of ground water are assumed to be one. In deep holes such as those drilled by the petroleum industry, however, these assumptions may not be valid. Reasons include high temperatures in deep boreholes



Base modified from U.S. Geological Survey digital data, 1:100,000 and 1:250,000
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian - 114°

EXPLANATION

- CARBONATE-ROCK PROVINCE
- BASIN BOUNDARY
- STUDY AREA BOUNDARY

FIGURE 2.—Basin boundaries and extent of Paleozoic and early Mesozoic carbonate rocks in Great Basin region.

and changes in the compositions of formation fluids, both of which can result in estimated flows into the drill stem that are in error. Because of these and other uncertainties, values of hydraulic conductivity in this report are reported to one significant figure.

Another limitation of the drill-stem test as a method for estimating aquifer properties is that the objectives of petroleum exploration are different from those of a hydrogeologic study. Drill-stem tests are commonly made at depths of several thousand feet or more. Although the test results may accurately reflect formation properties at the test interval, the results do not necessarily reflect hydraulic properties of the same unit at shallower depths.

AEROMAGNETIC DATA

An initial hypothesis formed early in this study was that certain rock types in the eastern Great Basin act as potential barriers to regional ground-water flow in Paleozoic and early Mesozoic carbonate rocks. These potential barriers include Precambrian crystalline basement (metamorphic and granitic rocks) in fault contact with carbonate rocks, the overlying bodies of upper Precambrian and Lower Cambrian quartzite, sandstone, and shale that are in fault or depositional contact with carbonate rocks, and Mesozoic and Cenozoic granitic intrusive rocks that are in intrusive or fault contact with carbonate rocks. Winograd and Thordarson (1968) recognized the importance of the upper Precambrian and Lower Cambrian quartzite, sandstone, and shale as barriers to regional flow in parts of southern Nevada. Aeromagnetic data for the eastern Great Basin were obtained for the purpose of defining the subsurface extent of these possible barriers.

These aeromagnetic data are part of a larger digital data set covering the entire Basin and Range physiographic province (Hildenbrand and others, 1983). This data set is a mosaic of many different aeromagnetic surveys that were flown at differing times, altitudes, and flight-line spacings. The methods used to reduce these data sets and merge them into one are described elsewhere (Hildenbrand and others, 1983). The barometric altitude for the merged data is 12,500 ft, and the Earth's main magnetic field has been removed. The data are gridded at an interval of 1.2 mi (2.0 km) for purposes of further reduction and analysis (see appendix 2).

PREVIOUS WORK

Geologic studies done in the Great Basin are too numerous to mention individually. The geologic maps mentioned in the previous section represent compilations of the many different studies and are the principal sources of geologic data used for this report. Other important sources of geologic data include the Stratigraphic Committee of the Eastern Nevada Geological Society (1973) and Stewart (1980). Other specific sources are cited in the text.

Hydrologic studies in the Great Basin have been limited mostly to studies of individual ground-water basins and to a few regional studies that have focused mostly on the carbonate-rock aquifers of eastern Nevada and western Utah. These regional studies include those by Eakin (1966), Winograd and Thordarson (1968, 1975), Eakin and others (1976), Hess and Mifflin (1978), and Dettinger (1989). As a result of the Great Basin RASA, the geometry of part of a carbonate-rock aquifer in eastern Nevada has been defined (Plume, 1984); the Fish Springs flow system of western Utah has been described (Carlton, 1985); the general hydrogeology of parts of northwest Utah and adjacent areas has been described (Gates, 1984); a mathematical model of ground-water flow in the eastern Great Basin has been developed (Prudic and others, in press); and generalized hydrogeology, water levels, and locations of major flow systems have been described (Thomas and others, 1986; Harrill and others, 1988; Plume and Carlton, 1988).

WELL-NUMBERING SYSTEM

Well locations given in this report are based on surveys of public lands in Nevada and Utah. The formats of locations differ slightly between the two States because different base lines and meridians were used for the surveys. Well locations for the two States are described briefly below.

Well numbers in Nevada used in this report are based on the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each well number consists of the township, preceded by an N or S to indicate location north or south of the base line; the range, preceded by an E to indicate location east of the meridian; and a section number and letters designating the quarter section, quarter-quarter section, and so on (A, B, C, and D indicate the northeast, northwest, southwest, and southeast quarters, respectively).

For example, well N4 E64 7DC is in the southwest quarter of the southeast quarter of section 7, township 4 north, range 64 east, Mount Diablo base line and meridian.

Well locations are described similarly in Utah, but that State is divided into four quadrants of unequal area by the Salt Lake base line and meridian. The quadrants are designated A, B, C, and D, respectively, beginning with the northeast and proceeding in a counterclockwise direction. The first part of a well location is in parentheses with quadrant, township, and range indicated in that order. The second part consists of the section number and letters indicating position within the section just as they do for Nevada. For example, the well (C-26-17) 15D is located in the southwest quadrant of Utah in the southeast quarter of section 15, township 26 south, range 17 west.

ACKNOWLEDGMENTS

Much of the subsurface geologic and hydrologic data used for this study came from the files of the Nevada Department of Mineral Resources. The staff of that agency was very helpful in locating data and allowing the use of their copy machine. Their assistance is greatly appreciated. The staff of the Branch of Regional Geophysics, U.S. Geological Survey, Denver, Colo., provided aeromagnetic data and computer software for processing the data. In particular, I acknowledge the assistance of Thomas G. Hildenbrand, Robert P. Kucks, and Michael W. Webring; without their patient advice and assistance, an important part of this study could not have been completed.

GEOGRAPHIC SETTING

The Great Basin, a region of internal drainage and north-south-trending mountains and basins, occupies the northern part of the Basin and Range physiographic province. The Great Basin is bounded on the east by the Wasatch Range and Colorado Plateau and on the west by the Sierra Nevada (Fenneman and Johnson, 1946). To the north and south, however, the Great Basin is not as well defined. The north boundary generally separates an area where drainages terminate in the Great Basin from an area farther north drained by tributaries of the Columbia River (Fenneman, 1931, p. 327; Fenneman and Johnson, 1946). The south boundary crosses part of southeastern California and southern Nevada (Fenneman and Johnson, 1946). As just defined, the Great Basin includes most of Nevada and western Utah and parts of southeastern and northeastern California, south-central Oregon, southeastern Idaho, and the northwest corner of Arizona.

The Great Basin RASA study area (figs. 1, 2) mostly conforms to the Great Basin region as defined above. The west boundary of the study area generally follows the California-Nevada State line, although to the southwest the study area also includes the Death Valley area of southeastern California. The east boundary follows the westernmost extent of the Wasatch Range and the Colorado Plateau. The north boundary includes two small basins of southern Oregon within the study area and excludes the part of northeastern Nevada drained by the Owyhee River, a tributary of the Snake River. The south boundary includes parts of Nevada drained by the Colorado River and excludes the southernmost part of the State. Hereafter, the study area is referred to as the Great Basin.

The dominant topographic features of the Great Basin are the north- to north-northeast-trending mountains and intervening basins. The mountains usually are from 5 to 15 mi wide and the basins from 10 to 20 mi wide. The only significant exception to the north-northeast trends is an area mostly in western Nevada from the Colorado River on the south to the Pyramid Lake area on the north where the trends are more irregular. This area, called the Walker Lane belt (Stewart, 1988, p. 684–686), is discussed in more detail in a later section of the report.

Land-surface altitudes in the Great Basin range from 282 ft below sea level at Death Valley to 13,140 ft at Boundary Peak in the White Mountains along the west side of the Great Basin, 13,063 ft at Wheeler Peak in the Snake Range of eastern Nevada, and 11,877 ft at Mount Nebo in the Wasatch Range. Altitudes of basin floors are from about 4,000 to 6,000 ft except in the southern Great Basin, where they range from below sea level (Death Valley) to about 2,500 ft. Altitudes of mountain crests are from 5,000 to 8,000 ft, although parts of some mountain ranges exceed 10,000 ft. The central Great Basin of eastern Nevada and westernmost Utah is an area of relatively high altitude (at least 5,000–6,000 ft) whereas the eastern, western, and southern parts of the Great Basin are areas of relatively low altitude (Simpson and others, 1986). The regional sinks of the Great Basin (Great Salt Lake Desert, Sevier Lake, Black Rock Desert, Pyramid Lake, Humboldt Sink, Carson Sink, Walker Lake, and Death Valley on fig. 1) are in the areas of lower altitude at the ends of major drainage systems and, in the eastern Great Basin, of regional ground-water flow systems. The mountainous areas of the Great Basin, including the Sierra Nevada and Wasatch Range along its margins, receive as much as 40 in. of precipitation per year. A fraction of this precipitation is the principal source of ground-water recharge in the Great Basin.

The Great Basin is normally thought of as a region of internal drainage with no outlets to the Pacific Ocean. This characterization is correct except for parts of southwestern Utah, eastern and southeastern Nevada, and northwestern Arizona, which are drained by tributaries of the Colorado River. These tributaries are the Virgin River in Utah, Arizona, and Nevada, and a drainage system in eastern and southeastern Nevada (fig. 1) that begins with the White River, ends with the Muddy River (both perennial streams), and for 200 mi in between is a desert wash with only ephemeral flow. In the rest of the Great Basin, basins are either topographically closed or connected to other basins by perennial or ephemeral streams. In most basins, ephemeral streams (desert washes) and an occasional perennial stream carry runoff from mountains onto alluvial fans and pediments and, rarely, to the lowlands.

Several extensive drainage systems (in addition to tributaries of the Colorado River) are in the Great Basin. These systems are dominated by perennial streams that terminate at sinks or at lakes that are remnants of Pleistocene Lakes Bonneville and Lahontan. Two exceptions are the Amargosa River in south-central Nevada and southeastern California, which terminates at Death Valley, and the Quinn River in northwestern Nevada, which terminates at the Black Rock Desert; both of these streams are ephemeral.

Except for the Humboldt River, which originates in northeastern Nevada and terminates at the Humboldt Sink in western Nevada, all other large perennial streams originate in headwater areas beyond the east and west boundaries of the Great Basin. Three major drainage systems enter the Great Basin from the Sierra Nevada and terminate in western Nevada. They are the Truckee River, which terminates at Pyramid Lake; the Carson River, which terminates at Carson Sink; and the Walker River, which terminates at Walker Lake. Three such systems also enter the Great Basin from the Wasatch Range. They are the Sevier River, which terminates at Sevier Lake; and the Bear and Jordan Rivers, which terminate at Great Salt Lake. The Jordan River begins at Utah Lake, which, in turn, is fed by smaller streams that originate in the Wasatch Range.

GEOLOGIC SETTING

SEDIMENTARY ROCKS

LATE PRECAMBRIAN TO EARLY MESOZOIC TIME

The Great Basin was the site of the ancient continental margin of what is now western North America from as early as late Precambrian time, through the Paleozoic and into the early Mesozoic (Stewart, 1980, p. 14–60). The principal tectonic feature of that margin was the Cordilleran geosyncline, in which tens of thousands of feet of marine sedimentary and volcanic rocks accumulated. The geosyncline consisted of two main parts: (1) a miogeosynclinal basin (now the eastern Great Basin) in which clastic and carbonate rocks were deposited on the continental shelf, and (2) a eugeosynclinal basin (now the western Great Basin) in which chert, fine-grained clastic rocks, and marine volcanic rocks were deposited on the continental slope and rise.

These depositional environments were disrupted by the Late Devonian and Mississippian Antler orogeny (Stewart, 1980, p. 36) and by the Late Permian and Early Triassic Sonoma orogeny (Stewart, p. 55-59). During each orogeny, eugeosynclinal deposits were thrust eastward (in modern coordinates) over miogeosynclinal deposits of approximately equivalent age along the Roberts Mountains thrust (Antler orogeny) and the Golconda thrust (Sonoma orogeny). As a result of these orogenies, highlands formed off the coast of western North America (now central Nevada) and were sources of clastic material that was deposited in basins to the east and west.

The Great Basin today can be separated into eastern and western areas based on the distribution of facies of upper Precambrian to lower Mesozoic rocks (pl. 1). The boundary between these two areas (long-dashed line on pl. 1) approximately marks the change from continental shelf to continental slope and rise deposits in the Great Basin. The line generally conforms to the westernmost extent of carbonate rocks (eastern assemblage rocks as defined by Stewart and Carlson, 1978).

The western area includes the approximate western one-third of the Great Basin and is characterized by marine sedimentary rocks that consist of chert, shale, siltstone, sandstone, and subordinate limestone and marine volcanic rocks of Paleozoic and early Mesozoic age (pl. 1). These rocks are not always at their original sites of deposition, especially in central Nevada where they structurally overlie, along the Roberts Mountains and Golconda thrusts, rocks of approximately equivalent age that were deposited farther east. Because of these and other structural complications, parts of the stratigraphic sections are missing and total thicknesses are uncertain.

The eastern two-thirds of the Great Basin is characterized by alternating sedimentary sequences that are dominated either by clastic rocks (mostly sandstone, shale, and conglomerate) with minor limestone and dolomite, or by carbonate rocks (limestone and dolomite) with minor clastic rocks. The overall sequence is relatively consistent throughout the eastern Great Basin (pl. 1) and, from oldest to youngest, consists of (1) clastic rocks (mostly quartzite, sandstone, and shale) of late Precambrian and Early Cambrian age that rest on Precambrian crystalline basement, (2) carbonate rocks (limestone and dolomite) that range in age from Middle Cambrian to Late Devonian or Mississippian, (3) clastic rocks (mostly shale, sandstone, and conglomerate) of Late Devonian to Pennsylvanian age, (4) carbonate rocks (mostly sandy and silty limestone, sandstone, and dolomite) of Pennsylvanian and Early Permian age, (5) clastic rocks (sandstone and shale) of Pennsylvanian age in the Bear River Range of Utah and Idaho and of Permian age in the rest of the eastern Great Basin, and (6) carbonate rocks (mostly sandy limestone) of Permian and Early Triassic age.

Generally, the overall thickness of carbonate-rock sequences exceeds that of clastic-rock sequences in the eastern Great Basin, especially for the Middle Cambrian to Lower Triassic parts of the stratigraphic section. Proportions of carbonate rocks in this part of the section may be as much as 70 percent in the Bear River Range and 90 percent in the East Tintic Mountains (percentages compiled as part of this study from Stratigraphic Committee of the Eastern Nevada Geological Society, 1973). Thicknesses of the Middle Cambrian to Lower Triassic parts of the stratigraphic section in the eastern Great Basin range from about 5,000 ft in the central Mormon Mountains to 17,000 ft in the Pilot Range and nearly 30,000 ft in the House and Confusion Ranges (pl. 1).

MESOZOIC ERA

The present-day Great Basin was still the site of the Cordilleran geosyncline at the beginning of the Mesozoic Era. Consequently, continental shelf deposits (mostly sandy limestone, sandstone, and shale) of Early Triassic age are found in the eastern Great Basin and deep-water deposits of similar age characteristic of the eugeosyncline (chert, shale, siltstone, and marine volcanic rocks) are found in the western Great Basin. By Middle Triassic time, however, the continental margin had shifted westward (Speed, 1978, p. 255) so that the eastern Great Basin was an area of continental deposition and the western Great Basin an area of shelf and slope marine environments. Rocks of Middle Triassic to Early Jurassic age consist of sandstone, shale, and freshwater limestone in the eastern Great Basin and marine volcanic rocks, deep-water clastic rocks, and shallow-water clastic and carbonate rocks in the western Great Basin.

The continental margin of western North America again shifted westward in Middle Jurassic time (Speed, 1978, p. 262), and what is now the Great Basin became an area of continental deposition. However, the size and distribution of basins and highlands during this time is uncertain and undoubtedly differed over large areas. Rocks of Middle Jurassic to Cretaceous age are found mostly near the east and west margins of the Great Basin, but are relatively sparse near the center. They include shale, sandstone, conglomerate, freshwater limestone, and continental volcanic rocks.

CENOZOIC ERA

Continental sedimentary rocks continued to accumulate in basins of uncertain size and distribution into the middle or late Tertiary. These rocks consist mostly of conglomerate and sandstone with lesser amounts of freshwater limestone and evaporite beds. In addition, they are interbedded with volcanic rocks of similar age.

The size and distribution of sedimentary basins began to change drastically as early as Oligocene time (Axen and others, 1987, p. 355; Gans and others, 1987, p. 671). This change coincided with the onset of extensional faulting that began to form the present-day mountain ranges and basins of the Great Basin. The clastic deposits that accumulated while mountains and basins formed are collectively referred to as basin-fill deposits. They range in age from middle Miocene or earlier through Holocene and consist of unsorted to sorted clay, silt, sand, gravel, and boulders.

Some of the early basins appear to have had little or no relation to present-day basins (Stewart, 1980, p. 92). For instance, middle Miocene and Pliocene deposits commonly are found in mountainous areas above nearby younger deposits (pls. 2, 3). By the late Pliocene, however, the present distribution of mountains and basins was established, and the deposits of that age and younger are found mostly in basins. Characteristics of basin-fill deposits, including their lithology and geometry within basins, are discussed in a later section.

IGNEOUS AND METAMORPHIC ROCKS

PRECAMBRIAN TIME

The oldest rocks found in the Great Basin are metamorphic rocks (mostly gneiss and schist) and granitic rocks of Precambrian age, commonly referred to as Precambrian crystalline basement. These rocks are exposed at and near the south and northeast margins of the Great Basin and at Granite Peak at the south side of the Great Salt Lake Desert. Otherwise these rocks have not been found in the rest of the Great Basin. Where exposed, however, Precambrian crystalline basement is overlain by upper Precambrian and Lower Cambrian clastic rocks of marine origin (see previous section), which are widely distributed in the eastern Great Basin. For this reason, crystalline basement has been inferred to extend as far west as central Nevada (Stewart, 1980, p. 9–11). The subsurface distribution of crystalline basement in some parts of the eastern Great Basin is discussed in a later section using interpretations of aeromagnetic data.

MESOZOIC AND CENOZOIC ERAS

Intrusive igneous rocks in the Great Basin represent a wide range of compositions (alaskite occurs in the Sulphur Spring Range of central Nevada and a gabbro lopolith occurs in the Stillwater Range of west-central Nevada); however, the dominant compositions of stocks and larger intrusive bodies are granodiorite and quartz monzonite (Stewart and Carlson, 1978; Hintze, 1980). The oldest intrusions are of Triassic age and are found in parts of western Nevada in Esmeralda County; otherwise, intrusive rocks, especially larger bodies, in the Great Basin range in age from Jurassic to Tertiary. Outcrop areas of these rocks range in size from a few square miles to more than 100 mi^2. Interpretation of aeromagnetic data (discussed below) indicates that the subsurface extent of some intrusions is even larger.

CENOZOIC ERA

The most recent period of volcanism in the Great Basin began during the Eocene and has continued at differing intensities into the Pleistocene and possibly Holocene. Volcanic rocks range in composition from basalt to rhyolite and include siliceous ash-flow and air-fall tuffs, flows and flow breccias and shallow intrusive rocks.

Volcanic rocks can be found in nearly every mountain range of the Great Basin. On a regional scale, however, one or more broad belts of volcanic rocks extend across parts of the Great Basin, each representing a distinctive range of compositions and origins (Stewart and others, 1977, p. 67–71). Volcanic rocks also underlie and are interbedded with basin-fill deposits in much of the Great Basin, because volcanism preceded the extensional faulting that formed the mountains and basins and continued as basin-fill deposits accumulated.

STRUCTURAL FEATURES

The Great Basin is a structurally complex region that is not yet fully understood. During parts of the Paleozoic, Mesozoic, and possibly early Cenozoic, it was an area of tectonic compression, and since the middle to late Tertiary, it has been an area of tectonic extension. These different phases of compression and extension were directly related to tectonic events that occurred along the continental margin of western North America, even after that margin had shifted west of what is now the Great Basin.

The dominant tectonic events of Paleozoic and early Mesozoic time were the Late Devonian and Early Mississippian Antler orogeny and the Late Permian and Early Triassic Sonoma orogeny. The major structural features of these two orogenies are the Roberts Mountains thrust (Antler orogeny) and the Golconda thrust (Sonoma orogeny).

The dominant tectonic event of Mesozoic age in the Great Basin was the Sevier orogeny, which resulted in compression of the Earth's crust along a belt that extends from southern Idaho, through central and western Utah, southern Nevada, and southeastern California. The age of this orogeny extends from Middle Jurassic to early Tertiary (Coney and Harms, 1984, p. 552). In Utah, the Sevier orogenic belt consists of an imbricate stack of thrust plates that have moved eastward distances of 80 to 100 mi (Tooker, 1983, p. 71). As many as six individual thrust plates are recognized in the vicinity of Salt Lake City (Morris, 1983, p. 76–77). Each plate is bounded by a thrust fault along its sole and leading edge and by transcurrent faults along its sides (sometimes referred to in the literature as transverse or tear faults). Some of these transcurrent faults have components of right-lateral slip and others have components of left-lateral slip. In the southern Great Basin, the orogenic belt is composed of four major thrust plates (Wernicke and others, 1988, p. 1741–1747).

A structural feature of the Great Basin that may be related to more than one period of deformation is the metamorphic core complex. These features are found at scattered locations within the cordillera of western North America from Mexico to Canada. Two are recognized within the Great Basin, although others probably will be recognized as research continues. They are the Ruby Mountains and Snake Range metamorphic core complexes, located in northeastern and east-central Nevada, respectively (Coney, 1980, p. 10). Another, the Albion-Raft River-Grouse Creek core complex, is located along the margin of the Great Basin in northwestern Utah and south-central Idaho. The complexes are characterized by a ductilely deformed metamorphic-plutonic basement (referred to as the infrastructure) that is overlain by an unmetamorphosed terrane (referred to as the suprastructure) that is brittlely deformed along younger-over-older, low-angle extensional faults. These two zones are separated by a surface of dislocation called a decollement or detachment that apparently is characteristic of all core complexes (Coney, 1980, p. 15). The age of these features has been a matter of controversy, with estimates ranging from Jurassic to Miocene (Stewart, 1980, p. 80, 83). However, the origin of metamorphic core complexes has more recently been explained as a process that began during the Sevier orogeny. During this time (Middle Jurassic to early Tertiary), the complexes formed in the Earth's crust in response to compression, but were exposed by extensional faulting that began during Oligocene time (Coney and Harms, 1984, p. 552).

The dominant structural features of Cenozoic age in the Great Basin are the fault-block mountains and basins that formed as a result of extensional faulting that began as early as Oligocene time (Coney and Harms, 1984, p. 552; Gans and others, 1987, p. 671) and that has continued in places to the present (Hamilton, 1988, p. 51). High-angle normal faults traditionally were perceived as the mechanism by which mountains and basins formed. Recently, however, faulting mechanisms have been determined to be more complex than this, involving more than one type or style of normal faulting. Three types of normal faults are now recognized: (1) high-angle normal faults, (2) listric normal faults that curve and flatten with depth, and (3) low-angle normal faults that generally have placed younger rocks over older ones and are commonly referred to as "detachments." These three types of faults have been found in all parts of the Great Basin.

The Walker Lane belt (Stewart, 1988) was briefly described earlier in this report as an area mostly in western Nevada of irregular topographic trends that contrast with the more regular north-northeast trends observed in the rest of the Great Basin. The belt is a structurally complex zone characterized by several structural blocks, each with styles of deformation and structural features that do not extend to adjacent blocks (Stewart, 1988, p. 686). In addition to these structural blocks, other structural features of the Walker Lane belt are (1) strike-slip faults, with both right-lateral and left-lateral senses of displacement, that are found within some blocks and are boundaries for others, (2) high-angle normal faults that bound one or both sides of mountain ranges, (3) large-scale oroflexural folds, and (4) detachment faults and metamorphic core complexes (Stewart, 1988, p. 695–699). Understanding of the Walker Lane belt is further complicated by the ages of some of the structures, which range from Mesozoic to late Cenozoic (Stewart, 1988, p. 700–705).

HYDROGEOLOGY

The Great Basin is underlain by consolidated rocks and unconsolidated to semiconsolidated deposits that range in age from Precambrian to Cenozoic. Some constitute regional aquifers of the Great Basin, and others constitute barriers to ground-water flow that confine aquifers both vertically and laterally. Still other rocks and deposits, volcanic rocks for example, can function as aquifers in some areas and barriers in others. The six hydrogeologic units described in this section of the report are an attempt to group these rocks and deposits into a few units, each comprising either a regional aquifer system or the barriers that confine ground-water flow in the systems. The units, in order of increasing age, consist of (1) basin-fill deposits of Pliocene to Holocene age, (2) basin-fill deposits of Miocene and Pliocene age, (3) sedimentary and igneous rocks of late Precambrian to Quaternary age in the western Great Basin, (4) sedimentary and igneous rocks of Middle Triassic to Quaternary age in the eastern Great Basin, (5) carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age in the eastern Great Basin, and (6) metamorphic, igneous, and sedimentary rocks of late Precambrian and Early Cambrian age in the eastern Great Basin. The two regional aquifer systems in the Great

Basin consist of the two units of basin fill (basin-fill aquifers) and carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age (carbonate-rock aquifers). The other units mostly function as barriers to flow, although several exceptions to this are described below.

The rationale for this grouping of units is based on what is presently known about the water-bearing characteristics of rocks and deposits in the region. Units that span large intervals of geologic time and include many different lithologic categories are poorly understood and probably have a large range of water-bearing characteristics. As understanding of the hydrogeology of the Great Basin improves, such units will be further subdivided.

REGIONAL AQUIFERS

MIDDLE CAMBRIAN TO LOWER TRIASSIC CARBONATE ROCKS

The eastern Great Basin is underlain by thick sections of marine sedimentary rocks that can be broadly separated into two parts: an upper part of Middle Cambrian to Lower Triassic carbonate and minor clastic sedimentary rocks, and a lower part of upper Precambrian and Lower Cambrian clastic sedimentary rocks (part of metamorphic, igneous, and sedimentary rocks of late Precambrian and Early Cambrian age described later in this section). The carbonate and clastic sedimentary rocks constitute an extensive hydrogeologic unit that underlies the entire eastern two-thirds of the Great Basin (pls. 1, 2). The unit is bounded to the east by the Wasatch Range and Colorado Plateau, to the north by volcanic uplands south of the Snake River Plain, to the south by structural relief on Precambrian crystalline basement, and to the west by increasing proportions of clastic rocks and chert in the stratigraphic section through central Nevada (long-dashed line on pl. 2). Of these boundaries, the western one is most uncertain because the east-to-west change from stratigraphic sections dominated by carbonate rocks to those dominated by clastic rocks is gradual. This western limit (adopted for this report) is the westernmost extent of Stewart and Carlson's (1978) carbonate (eastern) assemblage that consists of Paleozoic limestone, dolomite, shale, quartzite, and sandstone.

Middle Cambrian to Lower Triassic carbonate rocks consist mostly of thick sequences of limestone and dolomite—sometimes cherty, silty, or sandy—that are separated by relatively thin sequences of shale, siltstone, sandstone, and conglomerate. Specific formations and general lithologic types that constitute this unit are listed in table 1 (following "References Cited"). The overall stratigraphic thickness of this hydrogeologic unit, at the localities shown on plate 1, ranges from about 5,000 ft in the central Mormon Mountains in southeastern Nevada, to 17,000 ft in the Pilot Range along the Utah-Nevada border, to nearly 30,000 ft in other parts of the eastern Great Basin. However, stratigraphic thickness can be misleading and does not necessarily indicate the depth to which ground water circulates, because (1) structural deformation of the section can result in apparent thicknesses that differ markedly from true stratigraphic thickness and (2) the carbonate rocks may not be permeable throughout their entire stratigraphic thickness.

A regional aquifer system, called the carbonate-rock aquifers (Dettinger, 1989, p. 5–7), is composed mostly of the carbonate rocks just described. The aquifer system is generally bounded laterally by the areal extent of the carbonate rocks defined above. The base of the aquifer system is more uncertain, but is believed to be quartzite and shale of the underlying hydrogeologic unit (metamorphic, igneous, and sedimentary rocks of late Precambrian and Early Cambrian age) or poorly permeable or impermeable carbonate rocks at great depths. As just defined, the carbonate-rock aquifers include the upper and lower carbonate aquifers and upper clastic aquitard of Winograd and Thordarson (1975, p. 10–11) for the south-central Great Basin and the upper and lower parts of the carbonate-rock aquifer and intervening clastic sedimentary rocks of Plume and Carlton (1988) for the eastern Great Basin. These detailed subdivisions of the carbonate-rock aquifers were not used for the present report because the clastic sedimentary rocks (upper clastic aquitard of Winograd and Thordarson), though locally thick, constitute a relatively thin part of the overall stratigraphic section in some places (pl. 1). Moreover, rocks that represent the upper and lower carbonate aquifers of Winograd and Thordarson commonly are in fault contact over much of the region (Plume and Carlton, 1988) and probably are hydraulically connected to differing degrees.

The principal openings that store and transmit ground water in the carbonate-rock aquifers are fractures and joints that may have been solution widened to different degrees. Solution channels (also referred to as conduits or caverns) develop along fractures or fracture zones and are appreciably wider than fractures or joints. Solution-widened fractures and joints range in width from less than an inch to a few inches, whereas solution channels can range in width from inches to tens of feet in an extreme case such as the cavern at Devils Hole in the Ash Meadows area of southern Nevada. Winograd and Thordarson (1975, p. 19) concluded that fractures and joints are mainly responsible for storing and transmitting ground water in the carbonate rocks of south-central Nevada, whereas caverns are of minor importance. However, evidence of caverns or at least impressively widened fractures has been reported in the eastern Great Basin. The presence of such features is usually indicated by a bit drop during drilling or losses of drilling fluid. Two examples follow: (1) An exploration well being drilled by the U.S. Geological Survey in limestone of the Pennsylvanian age Bird Spring Formation in southern Nevada intersected an opening several feet wide at a depth of 478 ft (Berger and others, 1988, p. 12). (2) Petroleum-exploration wells commonly experience severe losses of drilling mud at different depths,[1] although it usually is not clear whether these zones represent actual caverns. Caverns are found at land surface in different parts of the Great Basin including the Worthington Mountains, Snake Range, and Spring Mountains of Nevada and the House Range of Utah. Some are a discharge point for local ground-water flow such as caverns in the Spring Mountains; others represent discharge points for regional ground-water flow such as the cavern at Devils Hole; and others do not appear to be presently acting as conduits for any type of ground-water flow. Although they undoubtedly affect both local and regional ground-water flow to some extent, the importance of solution channels is poorly understood.

As a result of this and other hydrologic studies, hydraulic properties of the carbonate-rock aquifers have been estimated for different parts of the eastern Great Basin. The hydraulic properties directly measured are porosity, transmissivity, and hydraulic conductivity.

Three types of porosity have been recognized in carbonate rocks in south-central Nevada—intercrystalline, vug, and fracture, the third being most important to the movement and storage of ground water (Winograd and Thordarson, 1975, p. 14–40). Typical fracture porosities determined from laboratory measurement of core samples range from zero to 1 percent and average 0.1 percent, whereas fracture porosities estimated from geophysical logs range from zero to as much as 28 percent, although the upper limit is usually closer to 10 percent (Winograd and Thordarson, 1975, p. 18–19; D.L. Berger, U.S. Geological Survey, oral commun., 1989). An effective porosity of 9 percent was determined for Paleozoic dolomite at the Nevada Test Site of southern Nevada using measurements of Earth tides and barometric fluctuations (Galloway, 1986, p. 942).

Values of porosity recorded on AMSTRAT logs of petroleum-exploration wells drilled in the eastern Great Basin are summarized in table 2 (following "References Cited"). Values range from zero to more than 20 percent,[2] although the upper limit of the range is usually less than 10 percent. Identified porosity types include fracture, vuggy, intercrystalline, and intergranular (see table 2 for definitions of porosity types). The logs indicate that fracture porosity in limestone and dolomite is distributed as relatively thick intervals of low porosity (less than 1 percent) and thin intervals of higher porosity (5–10 percent or more). Intervals of high porosity range in thickness from a few tens of feet to usually not more than 100 ft and are separated by sequences of consistently low porosity that are hundreds to thousands of feet thick.

Thin sections of limestone and dolomite from two widely separated areas of Nevada were examined with a petrographic microscope in an effort to obtain a qualitative understanding of types and degrees of small-scale porosity. These thin sections represent outcrop samples from eastern Nevada (White Pine and Egan Ranges) and southern Nevada (Arrow Canyon Range and Meadow Valley Mountains). They were taken from formations that range in age from Cambrian to Permian, but they do not represent a complete stratigraphic section. Since only nine samples were examined, no firm conclusions can be drawn concerning widespread relations of microscopic porosity to a particular stratigraphic unit or to properties such as grain size or lithology. However, the thin sections showed that certain types of porosity are prevalent at a microscopic scale in rocks that otherwise appear to be unfractured.

Two types of porosity were recognized in the thin sections: intercrystalline voids and fractures. The former may represent either primary or secondary porosity, whereas the latter represents secondary porosity. Porosity due to intercrystalline voids is usually much less than 1 percent and prob-

[1]Examples are available from the files of the Nevada Department of Mineral Resources.

[2]Porosities estimated from geophysical logs become increasingly uncertain when values are very low (Keys and McCary, 1971, p. 70; Winograd and Thordarson, 1975, p. 19). Consequently, values listed as zero could represent actual porosities of a fraction of a percent or more.

ably does not represent effective porosity because the voids do not appear to be connected.

Fracture porosity appears to be the most important type at a microscopic scale. Two generations of fractures are visible in most of the thin sections. The first generation consists of fractures that are linear and usually completely filled with secondary calcite or dolomite. The second generation consists of irregular or even sinuous fractures that are open to differing extents either because of dissolution of earlier filling or because they have not yet been completely filled. Rounded corners at fracture intersections may be evidence for solution widening. In addition, opposite sides of many fractures rarely look like they would fit together. On the basis of visual estimates, fracture porosities range from less than 1 percent to a few percent, although in one sample the porosity was an estimated 10 percent.

The transmissivity of carbonate-rock aquifers has been measured at several sites in the eastern Great Basin. The methods used include both single- and multiple-well aquifer tests done in connection with hydrologic studies at or near the Nevada Test Site of south-central Nevada, the MX-siting program, and petroleum exploration. Few, if any, tested wells are fully penetrating, so that the values of transmissivity determined from the tests represent a tested interval of the aquifer rather than the complete saturated thickness. The results of these tests are presented in this report as hydraulic conductivities determined by dividing the computed transmissivity by the thickness of aquifer tested.

The carbonate-rock aquifers have been more extensively tested at the Nevada Test Site and vicinity than at any other place in the eastern Great Basin. Even so, the number of tests is relatively small in relation to the size of the eastern Great Basin. Ten tests made in limestone and dolomite of Cambrian to Devonian age produced values of hydraulic conductivity that range from 0.7 to 700 ft/d, with mean and median values of 80 ft/d and 6 ft/d, respectively (Winograd and Thordarson, 1975, p. 22–23).

Four wells were drilled and tested in carbonate-rock aquifers in parts of eastern Nevada in connection with the MX-siting program (Bunch and Harrill, 1984, p. 119). Values of hydraulic conductivity determined from these test results range from 0.1 ft/d in Steptoe Valley (Pennsylvanian and Permian limestone) to 900 ft/d in Coyote Spring Valley (Mississippian Monte Cristo Limestone). The mean and median values are 200 ft/d and 9 ft/d, respectively.

Eight drill-stem tests have been made in the carbonate-rock aquifers. Test locations are, for Nevada, Railroad Valley (two tests), White River Valley (three tests), Jakes Valley (one test), and Independence Valley (one test), and, for Utah, Parowan Valley (one test). Values of hydraulic conductivity computed from the eight tests range from 0.0005 to 0.1 ft/d with mean and median values of 0.01 ft/d and 0.001 ft/d, respectively.

Values of hydraulic conductivity for the carbonate-rock aquifers, listed above, range from 0.0005 to 900 ft/d, a range of seven orders of magnitude in 23 relatively widespread aquifer tests. The mean and median values are 80 ft/d and 0.8 ft/d, respectively. This range indicates that these aquifers are very heterogeneous. One possible explanation is that fault, fracture, or cavernous zones represent the higher values and relatively unfractured rocks and sandstone and shale represent the lower values. The greatest of the values (900 ft/d) was obtained from an aquifer test made in a well drilled near a fault zone in Coyote Spring Valley, Nev. The presence of the fault is inferred from recent geologic mapping (Dwight Schmidt, U.S. Geological Survey, written commun., 1986) and from analysis of gravity data (Donald H. Schaefer, U.S. Geological Survey, oral commun., 1986). Another possible explanation is that values determined from drill-stem tests are lower than values determined from other aquifer tests because drill-stem tests commonly are made at depths of several thousand feet or more, where permeabilities may be reduced because of overburden pressure.

The results are not necessarily contradictory, because the objectives of the investigations were different: Hydrologic investigations in the Nevada Test Site area were concerned mostly with identifying and quantifying the extent of the ground-water resource in the area; the objectives of the MX-siting program were to find high-yield sources of ground water; and the objectives of petroleum exploration are to find hydrocarbons, and, as a consequence, zones that might yield large quantities of water are not necessarily of interest.

The AMSTRAT logs analyzed for this study indicate that zones of high porosity are usually less than 100 ft thick and are separated by hundreds to thousands of feet of rock with low porosity. Possible interpretations are that (1) zones of low porosity identified on the AMSTRAT logs are characterized by the types of microscopic porosity seen in thin sections and presumably by low values of hydraulic conductivity, and (2) zones of high porosity and hydraulic conductivity are restricted to relatively narrow fault or fracture zones in the midst of the much larger zones of low porosity.

In addition to the aquifer tests done at wells in different parts of the eastern Great Basin, estimated transmissivity has been computed for the carbonate-rock aquifers using Darcy's Law:

$$T = \frac{Q}{i \times w}$$

where

T = aquifer transmissivity, in feet squared per day;

Q = underflow through the aquifer, in cubic feet per day;

i = gradient of the potentiometric surface, in feet per foot; and

w = aquifer width, in feet.

Using values of underflow estimated from water budgets, estimated aquifer widths, and gradients computed from water-level measurements, Eakin (1966, p. 266) computed values of transmissivity of 30,000, 20,000, and 30,000 ft^2/d for the carbonate-rock aquifer at the north and south ends of White River Valley and the middle part of Coyote Spring Valley, Nev., respectively. A similar approach was used to revise the estimates for the White River Valley area (Plume, 1984, p. 624). In this case, the form of Darcy's Law used was

$$T = \frac{\Delta Q}{i \times \Delta w}$$

where

T = aquifer transmissivity, in feet squared per day;

ΔQ = change in underflow through the aquifer, in cubic feet per day;

i = gradient of the potentiometric surface in feet per foot (same values as used in Eakin, 1966, p. 266); and

Δw = change in aquifer width, in feet.

The rationale for this approach was that the width of the carbonate-rock aquifer in White River Valley narrows in the direction of ground-water flow as a result of the southward convergence of granitic intrusive bodies on both sides of the valley. Analysis of aeromagnetic data was used to estimate a change in aquifer width (Δw) of 80,000 ft (Plume, 1984, p. 624). Furthermore, the reduced cross section of flow in the aquifer results in a reduction of underflow (ΔQ) that is manifested by the discharge of large springs at Preston, Nev. (Plume, 1984, p. 624). Total discharge from the springs was a uniform rate of 1.3×10^6 ft^3/d (Eakin, 1966, p. 263). Using this value for ΔQ, 80,000 ft for Δw, and 0.0012 for i (Eakin, 1966, p. 266), the revised value of regional transmissivity for the carbonate-rock aquifer in White River Valley is 14,000 ft^2/d. These values represent approximate bulk transmissivities for the carbonate-rock aquifer because the methods used to compute them rely on estimates of aquifer geometry and specific flux rather than the results of an aquifer test.

MIOCENE TO HOLOCENE BASIN-FILL DEPOSITS

Aquifers, mostly in basin-fill deposits of Miocene to Holocene age, collectively compose another aquifer system in the Great Basin, here referred to as the basin-fill aquifers. Each hydrographic area in the region is underlain by a structural basin filled with thousands of feet of clastic material eroded from the adjacent mountains. The deposits in each basin contain an aquifer that may be (1) bounded by impermeable consolidated rocks of the structural basin, (2) hydraulically connected to a similar aquifer by basin-fill deposits or permeable consolidated rocks, or (3) hydraulically connected to carbonate-rock aquifers in the eastern Great Basin.

Two general features of any basin-fill aquifer in the Great Basin must be understood as completely as possible before the hydrogeologic framework of that basin can be considered to be even partly defined. The first is the lithology of the deposits, which includes such properties as the degree to which they are sorted and the degree to which coarse- and fine-grained deposits are interbedded and interfingered. The other feature is the geometry of the structural basin in which the deposits accumulated. The former is important because it is helpful for quantifying the hydraulic properties of the basin-fill aquifer. The latter is important because the bedrock basin may or may not act as a boundary for the aquifer depending on the properties of the bedrock.

Lithology and Hydraulic Properties of Deposits

Basin-fill deposits shown on plates 2 and 3 consist of two hydrogeologic units: an older unit of upper Miocene and lower Pliocene deposits and a younger one of upper Pliocene to Holocene deposits. The older basin fill consists of semiconsolidated to consolidated deposits of conglomerate, sandstone, siltstone, claystone, freshwater limestone, evaporite, and interbedded volcanic rocks. This unit is found along basin margins, less commonly near basin centers, and as isolated outcrops in mountain ranges, sometimes at altitudes that are several thousand feet higher than corresponding deposits in an adjacent basin. The older basin fill includes such stratigraphic units as the Salt Lake Formation in western Utah, Horse Springs, Muddy Creek, and Panaca Formations in southern and eastern Nevada, the Humboldt Formation in northeastern Nevada, and the Truckee, Coal Valley, and Esmeralda Formations in western Nevada (table 1). Older basin fill is inferred to underlie younger basin fill in most valleys, although its distribution is not well understood.

The basins in which the older basin fill accumulated were precursors to modern-day basins and appear, in some cases, to have been larger or of different shape than the modern ones (Stewart, 1980, p. 92). The best evidence for this is the numerous examples, shown on plate 2, where outcrops of older basin fill occur high in mountain ranges and several thousand feet lower along the margins of an adjacent valley. Assuming that these deposits underlie the valleys at differing depths, the required offsets can amount to more than 5,000 ft. This suggests that some of the earliest basins were larger than many of those today and that as modern-day basins formed, the deposits of Miocene and Pliocene age were uplifted along with older rocks as part of a mountain block.

Younger basin-fill deposits consist of unconsolidated to semiconsolidated and unsorted to poorly sorted clay, silt, sand, gravel, and boulders and usually make up the uppermost part of the fill in most basins. The subsurface extent of the younger basin fill, however, is uncertain because it is difficult to distinguish from the older basin fill solely on the basis of well logs. In addition, the distinction between the older and younger basin fill has not always been emphasized in geologic studies and the relations of the units are not always easy to understand (Stewart, 1980, p. 95). Consequently, the younger and older basin-fill deposits are collectively referred to as basin-fill deposits hereafter.

Fluvial and lacustrine deposition are the dominant processes that have controlled the accumulation of basin fill in the Great Basin. The most important agent is the intermittent storm, which produces flood water that carries clastic material eroded from consolidated rocks in the mountains to areas of deposition on adjacent alluvial fans, pediments, and basin lowlands or playas. Over time (Miocene to Holocene), runoff from these storms has resulted in the accumulation of thousands of feet of fill that consists of unsorted to poorly sorted coarse-grained deposits along basin margins and mixtures of coarse- and fine-grained deposits beneath lowlands. Lacustrine deposition also has been an important process at various times since the middle Miocene and has occurred on a large scale as recently as the last 10,000 years (Pleistocene lakes Lahontan and Bonneville).

The lowlands of some basins are partly occupied by the flood plain of a perennial stream that is part of or tributary to the stream systems shown on figure 2. Basins drained by these stream systems occupy about 34 percent of the Great Basin (Thomas and others, 1986). In addition, several topographically closed basins have streams that are perennial or near-perennial. The extent of flood-plain deposits can be estimated with reasonable confidence at land surface because the drainages characteristic of fans, pediments, and adjacent lowlands are approximately at right angles to the basin axis and end at the edge of the present flood plain. The lateral extent of flood-plain deposits becomes uncertain at depth, however, because flood plains migrate laterally through time, with the result that deposits of fans, pediments, and lowlands are complexly interfingered with adjacent flood-plain deposits. Most flood-plain deposits are well sorted in comparison with adjacent deposits because they have been reworked and redeposited by the stream. They consist of interbedded sequences of well-sorted clay, silt, sand, and gravel, where individual beds range in thickness from a few feet to as much as 10 or 20 ft.

Generalized lithologic logs (fig. 3) are available for wells completed in basin-fill deposits in 14 basins as part of the MX-siting program (well locations are shown on fig. 4). The general physiographic setting of each well was determined from topographic maps as a part of this study, and the order of the 17 logs, from left to right on figure 3, progresses from upper fan to basin lowland (none of the valleys has a perennial or near-perennial stream). The logs provide a rational basis for making generalized characterizations that should apply to basin fill in most areas except for flood-plain deposits.

The logs confirm that deposits are predominantly coarse toward valley margins and become increasingly finer basinward, although coarse deposits can extend beneath valley lowlands. More commonly, however, deposits are more heterogeneous beneath lowlands and lower fans and consist either of interbedded coarse and fine deposits or of unsorted to poorly sorted mixtures of the two.

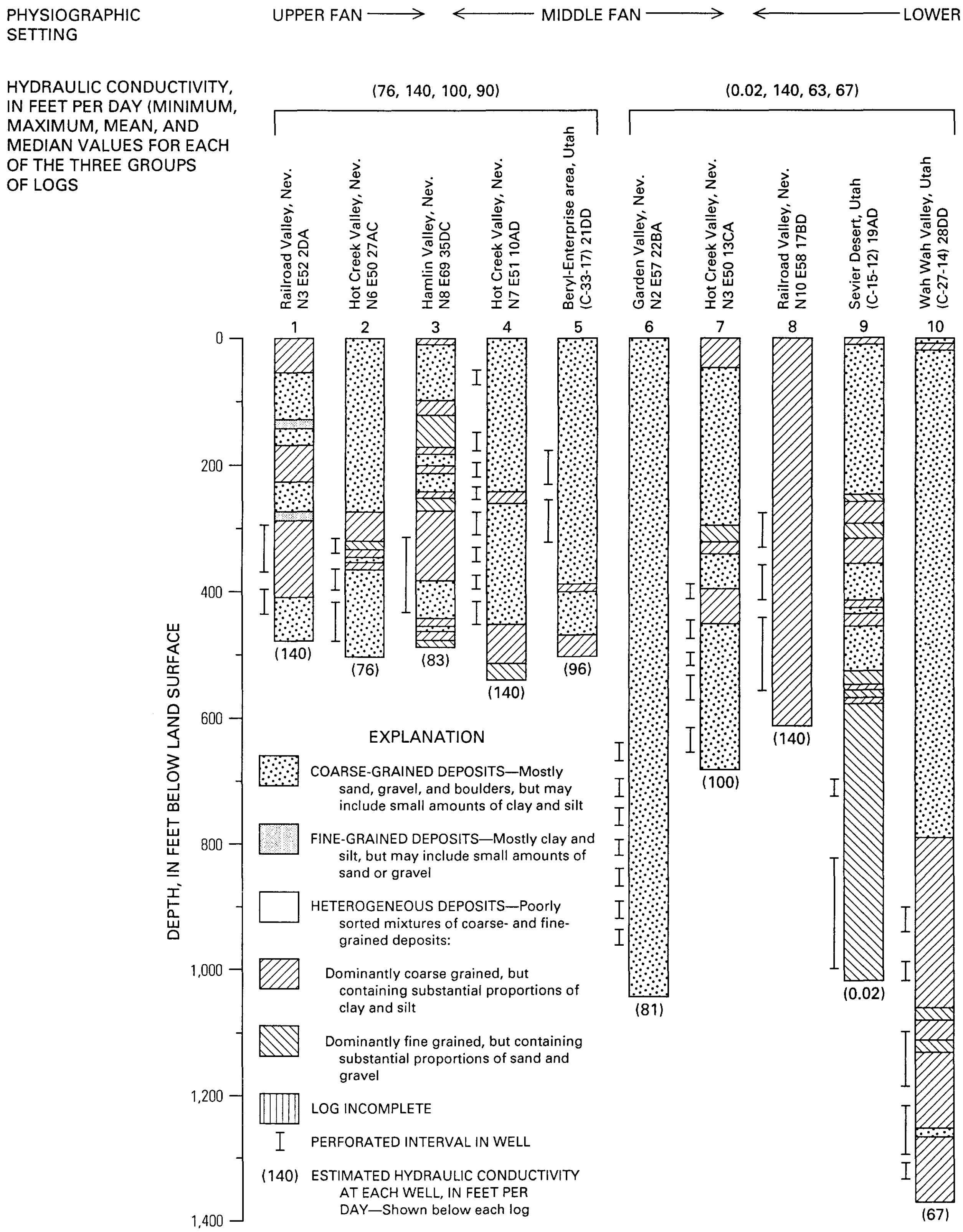


FIGURE 3.—Generalized lithologic logs, physiographic settings, and estimated hydraulic conductivities for basin-fill deposits in 14 basins in eastern Nevada and western Utah. Numbers above logs refer to well localities shown in figure 4. Data sources: Lithology from unpublished well logs; values of hydraulic conductivity from Bunch and Harrill (1984, p. 115–118).

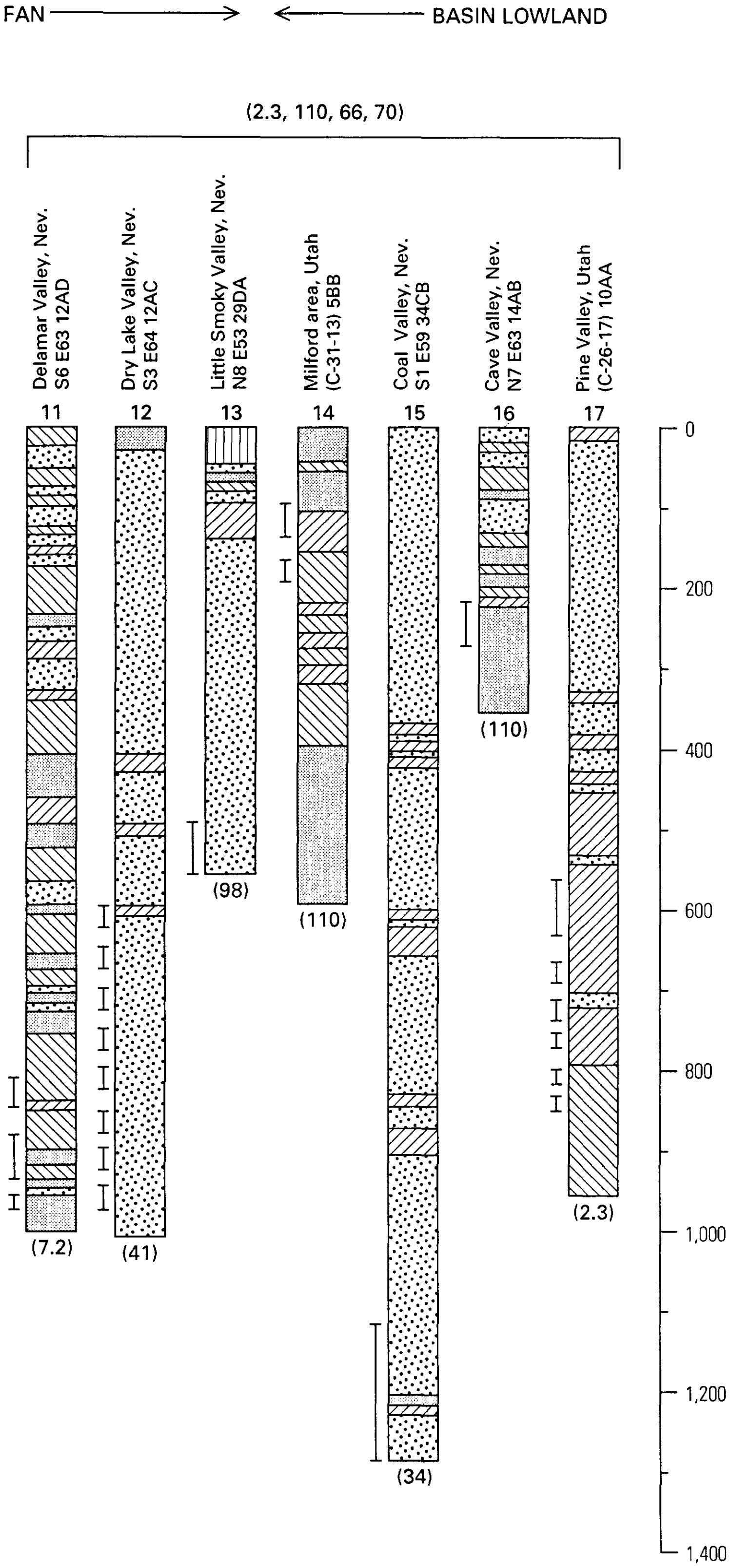


FIGURE 3.—Continued.

Hydraulic conductivities of basin-fill deposits differ, both laterally and vertically, due to changes in lithology of the deposits. Since lithology and sorting of basin-fill deposits appear to be related to physiographic setting, a similar relation between physiographic setting and hydraulic conductivity might exist also. Along with the logs, figure 3 shows hydraulic conductivities computed from results of aquifer tests made at each of the wells (data from Bunch and Harrill, 1984, p. 115–118). Individual values are shown below each log. The range of conductivity values for the 17 wells (0.02 to 140 ft/d) is probably reasonable for basin-fill deposits that have not been reworked by a perennial stream, although fine-grained deposits in some areas may have values that are less than the smallest values shown. The mean and median values for all 17 wells are 78 and 83 ft/d, respectively.

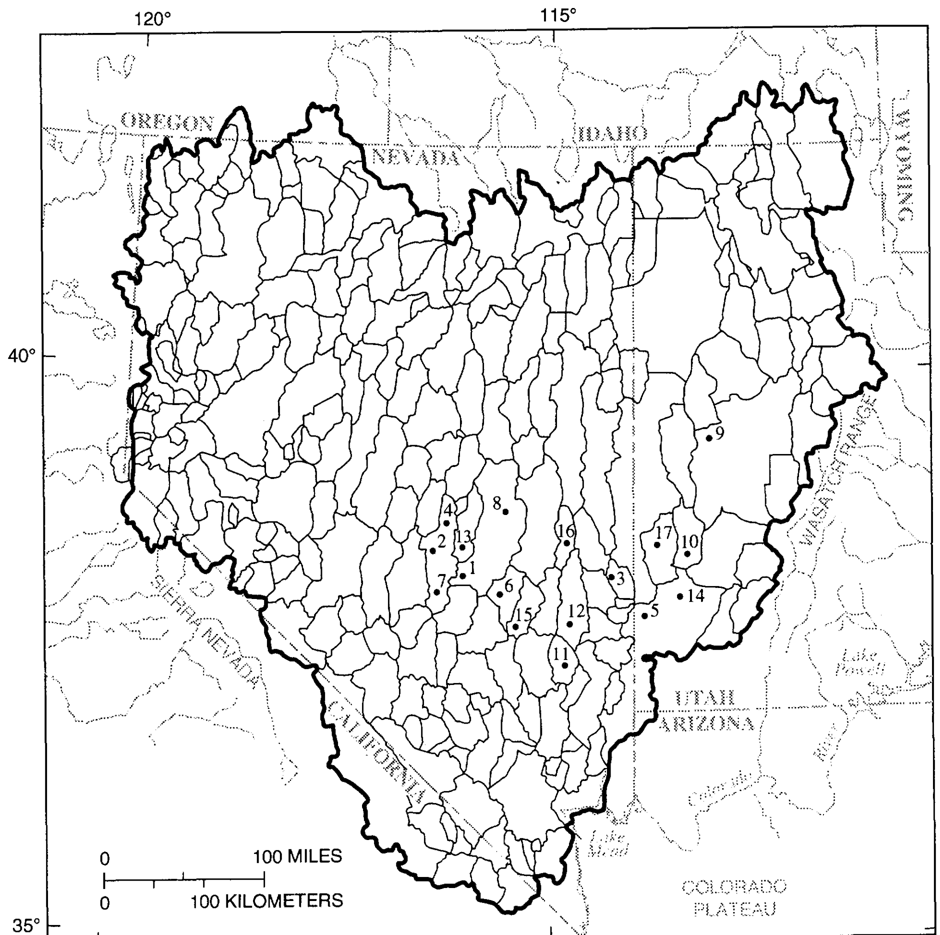
Ranges of hydraulic conductivity were compiled for broad physiographic settings (fig. 3). The data show that values of hydraulic conductivity are restricted to a narrow range of 76 to 140 ft/d, with mean and median values of 103 and 90 ft/d, for the six wells on middle and upper parts of alluvial fans or pediments where coarse materials predominate. Values of hydraulic conductivity on lower fans (five wells) and valley lowlands (six wells) have much broader ranges, 0.02 to 140 ft/d and 2.3 to 110 ft/d, respectively, with mean values of about 63 and 66 ft/d and median values of 67 and 70 ft/d. The broader ranges of hydraulic conductivity on lower fans and lowlands are not surprising considering the increased heterogeneity of basin-fill deposits in these parts of the basins. In spite of the broad ranges of values, however, there is a basinward trend toward lower values of hydraulic conductivity. This suggests that the deposits should be most permeable toward basin margins and less permeable within broader ranges near the basin axis.

Similar trends for lithology and hydraulic conductivity probably apply to basins with a perennial or near-perennial stream, except for those deposits of past and present stream flood plains. Flood-plain deposits typically are sorted to well sorted and consist of discrete beds of clay, silt, sand, or gravel. Beds of sand and gravel undoubtedly yield most of the water to a well. The hydraulic properties of flood-plain deposits were evaluated by Bredehoeft and Farvolden (1963, p. 210) at 22 wells in four valleys of north-central Nevada (Boulder, Paradise, Reese River, and Whirlwind Valleys). Values of hydraulic conductivity determined from aquifer tests at these wells range from 16 to 1,100 ft/d, with mean and median values of 130 and 68 ft/d, respectively. The median value of 68 ft/d is comparable with median values for basin fill beneath lower fans and lowlands (67 and 70 ft/d) discussed earlier; however, the mean value and range of values for flood-plain deposits indicate that they can be much more productive aquifers than those deposits that have not been reworked by a stream.

Geometry of Structural Basins in which Deposits Accumulated

A total of 260 hydrographic areas, each generally corresponding to a prism of basin fill and the underlying structural basin composed of consolidated rocks, are recognized in the Great Basin (Harrill and others, 1983, p. 5; Thomas and others, 1986). These basins formed as a result of extensional faulting that began during Oligocene time. Geometries of structural basins range from simple to complex depending on the styles of faulting that formed them. Thicknesses of fill generally range from zero at basin margins to at least several thousand feet, and thicknesses exceed 10,000 ft in a few areas such as the Black Rock Desert and Dixie Valley, Nev. (Schaefer and others, 1983, p. 27; Schaefer, 1983, p. 11).

Six basins were selected to present the more common features of structural basins in the Great



Base modified from U.S. Geological Survey digital data, 1:100,000 and 1:250,000
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian - 114°

EXPLANATION

——— BASIN BOUNDARY

▬▬▬ STUDY AREA BOUNDARY

• WELL—Number corresponds to well log in figure 3

FIGURE 4.—Index map showing location of selected water wells referred to in this report.

Basin. These particular basins were selected primarily because they are some of those few in the Great Basin in which the geometry of the bedrock basin has been defined. The basins are Carson, Dixie, Las Vegas, Railroad, and Spring Valleys, Nev., and Jordan Valley, Utah (pl. 3). Published results of gravity surveys were used to define the bedrock basins of Jordan, Dixie, Las Vegas, and Carson Valleys (Mattick, 1970; Schaefer, 1983; Plume, 1989; Maurer, 1985). The bedrock basin of Spring Valley was defined from detailed interpretations of seismic-reflection data (Gans and others, 1985), and that of Railroad Valley was defined from deep-borehole data as a part of this study.

These basins probably do not include every basin shape that occurs in the Great Basin; however, they are believed to represent some of the more common geometries of structural basins. One conclusion that can be drawn from the six basins shown on plate 3 is that the structural basin in any valley cannot be assumed to be symmetrical with respect to the topographic basin. Two broad types of basin geometries are shown on plate 3. One type consists of structural basins that are relatively symmetrical with respect to their topographic basins, and the other type consists of asymmetrical basins. Dixie Valley, Nev., and Jordan Valley, Utah, are examples of symmetrical basins that are bounded by range-front faults along each side. Maximum depths are more than 3,000 ft for Jordan Valley (Mattick, 1970, p. 123) and about 10,000 ft for Dixie Valley (Schaefer, 1983, p. 11).

The other four basins shown on plate 3 (Carson, Railroad, Spring, and Las Vegas Valleys, Nev.) are asymmetrical. Two, Las Vegas and Railroad Valleys, each consist of a relatively deep structural basin beneath one side of the topographic basin and a gently basinward sloping bedrock surface that extends 5-10 mi from the mountain front on the opposite side. The deep structural basin in Las Vegas Valley is bounded to the east by a normal fault at the base of Frenchman Mountain, on the west by a normal fault that may be marked by escarpments in the basin fill, and to the north by vertical movement on the Las Vegas shear zone (Plume, 1989, p. 21). The maximum depth of the basin beneath the north part of Las Vegas Valley is more than 5,000 ft (Plume, p. 20). Railroad Valley is similar in cross-sectional shape to Las Vegas Valley, although the shallow bedrock surface on its west side does not extend as far east and the deep structural basin (more than 7,000 ft) is more elongate.

Other asymmetrical basins can consist of several fault blocks. Two such basins are Spring and Carson Valleys, Nev. The structural basin beneath Spring Valley consists of three west-dipping fault blocks that are part of the Snake Range to the east. The basin is bounded to the west by the Schell Creek Range fault block. The resulting bedrock basin is deepest near the west margin (about 7,000 ft) and progressively shallower toward the east margin.

Carson Valley, Nev., is underlain by at least three fault blocks between the principal mountain blocks of the Sierra Nevada to the west and the Pine Nut Mountains to the east. These three blocks have formed a pair of basins separated by a shallow horst of bedrock. The main structural basin of Carson Valley lies adjacent to the Sierra Nevada and is as deep as 5,000 ft (Maurer, 1985, p. 5). The smaller bedrock basin adjacent to the Pine Nut Mountains is as deep as 2,900 ft (Maurer, p. 5).

Seismic-reflection data for other valleys in Nevada and western Utah (Anderson and others, 1983) indicate that basin geometries can be more complex than the simple ones shown on plate 3. In spite of this, however, the basic shapes defined by Anderson and others (1983, p. 1067) can generally be categorized as either relatively symmetrical or as asymmetrical.

CENOZOIC VOLCANIC ROCKS

Except for Middle Cambrian to Lower Triassic carbonate rocks and Miocene to Holocene basin-fill deposits, other hydrogeologic units in the Great Basin generally confine the movement of ground water. The more notable exceptions are Cenozoic volcanic rocks which, in the next section, are included as parts of sedimentary and igneous rocks of Precambrian to Quaternary age in the western Great Basin and sedimentary and igneous rocks of Middle Triassic to Quaternary age in the eastern Great Basin.

Cenozoic volcanic rocks occur extensively throughout the Great Basin, and there are few mountain ranges in which at least some volcanic rocks are not present. In addition, volcanic rocks underlie many valleys. The 69 petroleum-exploration wells that are shown on plate 2 were drilled in 35 valleys in the eastern Great Basin. Of these wells, 25 penetrated volcanic rocks in 18 of the valleys (table 2). These volcanic rocks range from intervals of tuff or lava 20 to 30 ft thick that are interbedded with basin-fill deposits to sequences of tuff, 3,000 to 4,000 ft thick, that are the bedrock for some structural basins. Volcanic rocks also are prevalent in mountains and underlie or are interbedded with basin-fill deposits in the western Great Basin.

Volcanic rocks have been recognized as aquifers in relatively few areas in spite of their prevalence in the Great Basin. These areas include the Fallon area of western Nevada (Glancy, 1986), the Nevada Test Site of southern Nevada (Winograd and Thordarson, 1975), central Nevada (Fiero, 1968), southeastern Nevada (Emme, 1986), and Pavant Valley of western Utah (Mower, 1965). Basalt flows interbedded with basin-fill deposits are important aquifers at Fallon and Pavant Valley. Hydraulic conductivities computed from aquifer tests of the wells that tap these basalts range from 130 to 3,100 ft/d at Fallon (Glancy, 1986, p. 18) and from 370 to 46,000 ft/d at Pavant Valley.[3] Features that store and transmit water in these very permeable basalts probably are fractures and to a lesser extent vesicles at Pavant Valley (Mower, 1965, p. 38) and zones of poorly consolidated cinders, rubble at tops of flows, and fractures at Fallon (Glancy, 1986, p. 15).

Volcanic-rock aquifers at the Nevada Test Site consist of lava flows and ash-flow tuffs (Winograd and Thordarson, 1975, p. 31–37). The lava flows store water primarily in fractures and the tuffs in interstitial pores. Hydraulic conductivities of these volcanic-rock aquifers range from 1.5 to 17 ft/d (Winograd and Thordarson, p. 22–23). In addition, hydraulic heads within these volcanic rocks indicate that ground water moves downward into underlying carbonate-rock aquifers (Winograd and Thordarson, p. 53–62).

Volcanic rocks that underlie basin-fill deposits in Railroad Valley, Nev., have been more extensively explored and tested than anywhere else in the Great Basin because these rocks are the primary reservoir for petroleum in the area. Exploration for petroleum in nearby parts of Nevada has also focused, in part, on volcanic rocks. Porosities of volcanic rocks, determined from geophysical logs, can range from nearly zero to as much as 20 percent, although the highest porosities are usually less than 10 percent (table 2). The most common porosity types listed in table 2 are intercrystalline and fracture. The results of 54 drill-stem tests at 18 wells in volcanic rocks in Railroad Valley and 1 in White River Valley produced hydraulic conductivities that range from 0.000001 to 0.3 ft/d. The mean and median values are 0.02 and 0.0004 ft/d, respectively. These values of hydraulic conductivity suggest that volcanic rocks in east-central Nevada are almost impermeable, although, as noted earlier, drill-stem tests may underestimate aquifer properties. In contrast, values determined from aquifer tests in other parts of the Great Basin indicate that basalt aquifers may contain some of the most permeable rocks in the region.

[3]For Fallon, hydraulic conductivity was computed by dividing measured transmissivity by the difference between total well depth and depth to top of basalt. All wells were finished in basalt and cased to top of basalt (Glancy, 1986, tables 1, 3). For Pavant Valley, hydraulic conductivity was computed by dividing transmissivity measured at wells pumping from the basalt aquifer (Mower, 1965, table 8) by an average thickness for the basalt of 65 ft (Mower, 1965, pl. 3).

BARRIERS TO REGIONAL GROUND-WATER FLOW

Ground-water flow in regional aquifer systems in the Great Basin is affected by a wide variety of rocks called barriers to ground-water flow. The effects of these barriers are to confine ground-water flow, not only in the vertical direction but, just as important, in the horizontal direction. These barriers partly form boundaries between flow regions (as defined by Prudic and others, in press) and constitute zones of low permeability in the carbonate-rock aquifers. They also constitute the structural basins that contain basin-fill aquifers in the western Great Basin and to a lesser extent the eastern Great Basin. Three hydrogeologic units shown on plate 2 probably are potential barriers: (1) sedimentary, igneous, and metamorphic rocks of Precambrian and Early Cambrian age in the eastern Great Basin, (2) sedimentary and igneous rocks of Middle Triassic to Quaternary age in the eastern Great Basin, and (3) sedimentary and igneous rocks of Precambrian to Quaternary age in the western Great Basin.

EASTERN GREAT BASIN

Sedimentary, igneous, and metamorphic rocks of Precambrian and Early Cambrian age in the eastern Great Basin consist of Precambrian crystalline basement (metamorphic and igneous rocks) overlain by upper Precambrian and Lower Cambrian quartzite, sandstone, and shale (pl. 2 and table 1). The sedimentary rocks are exposed in most of the eastern Great Basin except for parts of central Nevada, whereas outcrops of crystalline basement are restricted to southeastern California and parts of southern Nevada and northwestern Utah; however, crystalline basement has been inferred to underlie the entire eastern Great Basin as far west as central Nevada (Stewart, 1980, p. 9–11).

Few aquifer tests have been made in rocks of this unit and, except for a well at Mormon Mesa, it has not been penetrated by petroleum test wells in the eastern Great Basin. Wherever the sedimentary rocks are exposed, they appear to be highly fractured, especially the quartzites. This was noted by Winograd and Thordarson (1975, p. 39–40), although they also noted that adjacent shales have been squeezed into fractures and thus partly seal off any secondary permeability due to the fractures. On the basis of limited aquifer tests, examination of outcrops, and on laboratory tests of core samples, Winograd and Thordarson (p. 41–43) concluded that sedimentary rocks of late Precambrian and Early Cambrian age have low transmissivity and impede regional movement of ground water in southern Nevada. The underlying Precambrian basement is probably almost impermeable.

Sedimentary and igneous rocks of Middle Triassic to Quaternary age (pl. 2 and table 1) consist of marine sedimentary rocks (mostly sandstone and shale) of Triassic and Jurassic age, continental sedimentary rocks (conglomerate, sandstone, shale, and freshwater limestone) of Jurassic to Tertiary age, granitic intrusive rocks (mostly granodiorite and quartz monzonite) of Jurassic to Tertiary age, and volcanic rocks of Tertiary and Quaternary age. Rocks of this unit are found throughout the eastern Great Basin and occur to some extent in every mountain range in the region. Parts of the unit are the dominant rock types in some mountain ranges. The hydraulic properties of this unit probably range through several orders of magnitude because of differences in lithology and structural deformation. These properties are generally not known except for volcanic rocks in parts of the Great Basin (see previous section).

Sedimentary, igneous, and metamorphic rocks of Precambrian and Lower Cambrian age and sedimentary and igneous rocks of Middle Triassic to Quaternary age are potential barriers to regional ground-water flow where they are in fault, depositional, or intrusive contact with rocks of regional-aquifer systems. Thus, the rocks of these two units can form parts of structural basins in which basin-fill aquifers are contained, and they can form boundaries for flow regions (as defined by Prudic and others, in press) and zones of low permeability in carbonate-rock aquifers. In addition, quartzite, sandstone, and shale of upper Precambrian and Lower Cambrian age may act as a lower boundary for carbonate-rock aquifers where ground water circulates to sufficient depth. The importance of the quartzite, sandstone, and shale as a potential barrier to regional ground-water flow also was recognized by Winograd and Thordarson (1968, p. 46–47). However, the importance of any of the rocks as barriers to flow cannot be fully understood because their subsurface extents are not always indicated by study of outcrops or geologic maps. Precambrian crystalline basement and Jurassic to Tertiary granitic rocks both contain magnetic minerals, and the magnetization contrasts between these and adjacent, less magnetic, rocks are generally sufficient that the subsurface geometry of the bodies (Precambrian crystalline basement and Jurassic to Tertiary granitic rocks) can be approximated by analyzing aeromagnetic data. The source of aeromagnetic data used for this study and methods used to reduce and analyze it are described in the introduction and in appendix 2.

Plate 4 is an aeromagnetic map of the eastern Great Basin that also shows estimated altitudes of, and depths to, tops of sources for major magnetic anomalies and outcrop areas of rocks presumed to be the principal magnetic sources in the region. These sources are Precambrian crystalline basement, Jurassic to Tertiary granitic rocks, and Tertiary and Quaternary volcanic rocks—hereafter referred to as crystalline basement, granitic rocks, and volcanic rocks, respectively. In addition to these sources, others can be locally important. For example, the Eleana Formation of Mississippian age in south-central Nevada produces anomalies that initially were believed to be due to a granitic source; however, the anomalies have been shown to result from an argillite unit (fine-grained sedimentary rock) that is part of the formation (Baldwin and Jahren, 1982, p. 8). Similar occurrences in the eastern Great Basin have not been reported, but could be more common than is currently recognized. Nevertheless, the most common source rocks for magnetic anomalies in the region are believed to be those listed above. Plate 4 also shows outcrop areas of upper Precambrian and Lower Cambrian clastic sedimentary rocks, which presumably were deposited everywhere on crystalline basement.

Patterns of magnetic anomalies differ over large areas of the eastern Great Basin and can be attributed, in part, to outcrop areas of different magnetic source rocks; however, the differences cannot always be attributed to sources exposed at land surface, and also must be due to subsurface sources. The eastern Great Basin is subdivided into five broad areas, each with characteristic patterns or types of magnetic anomalies (areas 1–5 on pl. 4).

The southern Great Basin (area 1, pl. 4) is characterized by mostly long-wavelength anomalies, many of which are oriented northwest-southeast. Some of these anomalies are closely associated with outcrops of granitic rocks and others with outcrops of crystalline basement. In other parts of area 1, however, anomalies cannot be attributed to specific sources either because source rocks are not exposed nearby or because more than one source is exposed. Source depths estimated from measurements of horizontal magnetic gradients (see appendix 2) range from land surface to 8,000–10,000 ft.

The magnetic effects of volcanic rocks are illustrated by the short-wavelength anomalies in area 2 that are superimposed over broader anomalies. This area generally corresponds to a broad east-west belt of volcanic rocks that extends from southwest Utah and widens into south-central and central Nevada (pl. 4). Except for scattered outcrops of granitic rocks, some of which cover substantial areas, volcanic rocks constitute the predominant magnetic source rock exposed in the area. Area 2 can be roughly divided in half by a north-south-trending area of few anomalies called a magnetically "quiet" zone (Stewart and others, 1977, fig. 5). This zone corresponds to an area of relatively few outcrops of volcanic rocks.

Several long-wavelength anomalies are evident in area 2, although each is partly obscured by the magnetic effects of volcanic rocks. The most prominent long-wavelength anomaly is a west-southwest-trending magnetic high that extends across southwestern Utah into adjacent parts of Nevada just north of latitude 38° N. The southern edge of this anomaly coincides with the Blue Ribbon lineament, an east-west-trending structural zone that crosses southwestern Utah and extends an uncertain distance into southeastern Nevada (Rowley and others, 1978, p. 177, 188–189). The magnetic high is defined by steep magnetic gradients and by a series of outcrops of Tertiary granitic rocks along or near the north side that suggest the source either is a large pluton or a series of smaller, closely spaced granitic intrusions. However, extensive outcrops of upper Precambrian and Lower Cambrian clastic sedimentary rocks suggest a relatively shallow depth to crystalline basement in the region. Thus, the sources for this anomaly may be the younger granitic rocks and crystalline basement. Source depths, estimated from the steep magnetic gradients along the north and west sides of the anomaly, range from 1,000 to 4,000 ft (pl. 4).

Another long-wavelength anomaly located in the Nevada Test Site area (southwest part of area 2) is also poorly defined, again because of the effects of volcanic rocks. This high is bounded by steep magnetic gradients on its north and northeast sides and by lesser gradients on its south and west sides that suggest an approximate depth of 1,000 ft. Sources for this high may be granitic rocks or crystalline basement, although neither is exposed near the anomaly. The anomaly does, however, overlie part of the Timber Mountain–Oasis Valley caldera complex (see Byers and others, 1976, p. 3, for location of complex).

In addition to the two broad highs, a number of smaller magnetic highs occur in area 2; these are relatively intense and of longer wavelengths than the numerous anomalies associated with volcanic rocks. Sources for these anomalies may be both granitic rocks and crystalline basement. Estimated source depths range from land surface to 5,000 ft.

Another area of magnetic anomalies that extends across Utah into east-central Nevada is defined as area 3 on plate 4. This area is more irregular than the one defined by area 2 and it trends more to the northwest. Outcrops of magnetic source rocks in area 3 consist of volcanic rocks and granitic rocks except for an outcrop of crystalline basement at Granite Peak near the south edge of the Great Salt Lake Desert; outcrops of upper Precambrian and Middle Cambrian clastic sedimentary rocks, however, suggest that crystalline basement may be relatively shallow over parts of the area.

With few exceptions, magnetic anomalies in area 3 are of long wavelengths. In west-central Utah, a large magnetic high with several smaller associated anomalies extends west-southwest from near the Wasatch Range. The data used for plate 4 do not extend far enough to delineate the easternmost extent of this anomaly, but the aeromagnetic map of Utah (Zietz and others, 1976) indicates that it does not extend to the Wasatch Mountains. Estimated depths to the source for this anomaly range from 1,000 to 3,000 ft.

Magnetic anomalies in the western part of area 3 (eastern Nevada and western Utah) are oriented north-south or east-west. Sources for these anomalies are probably a combination of granitic rocks and crystalline basement. Outcrops of granitic rocks are common in this part of area 3, as are outcrops of upper Precambrian to Middle Cambrian clastic sedimentary rocks, which suggest relatively shallow depths to crystalline basement. North-south-oriented anomalies align with mountain ranges in the western part of area 3, although the anomalies are not necessarily centered on the ranges. For instance, the anomaly aligned with the Egan Range in eastern Nevada is centered over the west side of the mountain range and the east side of White River Valley. Estimated source depths range from at or near land surface at a few widely scattered anomalies to as much as 10,000 ft at the weak anomaly in the Snake Range.

Two magnetic highs in the northern part of area 3 partly coincide with the Silver Island and Newfoundland Mountains; estimated source depths are at 1,000 ft and land surface, respectively. The source in the Newfoundland Mountains appears to be granitic rocks. A broader northwest-oriented magnetic high farther south is not closely associated with any mountain blocks except for Granite Peak at the south edge of the Great Salt Lake Desert, where a steep magnetic gradient is centered over a large outcrop of crystalline basement. In addition, granitic rocks are exposed near the southwest side of the anomaly. Estimated depths to the source for this large anomaly are land surface at Granite Peak and 2,000 ft along the Nevada-Utah State line.

The northern part of the eastern Great Basin can be divided into two parts that consist of northeastern and north-central Nevada (area 4, pl. 4) and northwestern and north-central Utah and south-central Idaho (area 5, pl. 4). Area 4 is generally a magnetically "quiet" area with broad, low-amplitude highs separated by broad lows. These anomalies include three very weak ones associated with the Ruby Mountains metamorphic core complex, which are discussed in further detail below. The most prominent anomaly is linear and trends southeast from the general vicinity of Battle Mountain across the southwest side of the area. This anomaly closely coincides with a similarly trending belt of faults and outcrops of volcanic rocks referred to as the Oregon-Nevada lineament (Stewart and others, 1975). Sources for this anomaly may be both basaltic rocks along a crustal rift (Stewart and others, 1975, p. 267) and granitic rocks along or near the anomaly. The estimated depth of the source at the south end of Pine Valley is 6,000 ft.

Two principal magnetic features of area 5 are broad southeast-trending highs associated with crystalline basement and granitic rocks. Estimated source depths are 10,000 ft for the easternmost high and land surface for the westernmost. Another broad high extends from near the Wasatch Range southwestward to the Stansbury Mountains south of latitude 41° N. The estimated depth to the source for this high is 5,000 ft.

The Snake Range and Ruby Mountains metamorphic core complexes (see previous section) are in the southern part of area 3 and north-central part of area 4, respectively. Magnetic anomalies associated with the Snake Range are of relatively low amplitude and are oriented north-south and east-west. Those highs associated with the Ruby Mountains are even weaker and are oriented in a north-northeast direction. The reasons for the weakness of these anomalies are unclear because both complexes are characterized by extensive outcrops of granitic rocks and, in the Snake Range, by outcrops of upper Precambrian and Middle Cambrian clastic sedimentary rocks that suggest shallow depths to crystalline basement. One possible reason for the weak anomalies might be that the depth to the Curie temperature in the Earth's crust (the temperature at which rocks become demagnetized) might be relatively shallow over core complexes. Another reason might be simply that the granitic rocks associated with these core complexes are only weakly magnetic.

The foregoing discussion of magnetic anomalies in the eastern Great Basin is not intended to be a rigorous analysis of their geologic implications in the region. As stated previously, the intent is to define features that might influence regional ground-water flow. Hence, the anomalies that are of most interest are ones with sources that appear to be of large extent. Smaller sources are of interest where they can be defined, but their potential influence on regional ground-water flow probably is more localized and, for purposes of this study, of lesser interest.

A general hypothesis that can be proposed on the basis of the analysis of aeromagnetic data is that broad magnetic highs represent areas where the transmissivity of regional aquifers may be reduced because of the potential shallow presence of granitic rocks or crystalline basement and the overlying upper Precambrian to Middle Cambrian clastic sedimentary rocks. In contrast, broad magnetic lows represent areas where the transmissivity of regional aquifers may be relatively high because of the increased depths to granitic rocks or crystalline basement.

WESTERN GREAT BASIN

Sedimentary and igneous rocks of Precambrian to Quaternary age form structural basins throughout the western part of the Great Basin (pl. 2 and table 1). The rocks of this unit include a broad lithologic range: (1) marine chert, shale, siltstone, sandstone, conglomerate, limestone, dolomite, and volcanic rocks of Precambrian to Jurassic age, (2) fluvial and lacustrine shale, siltstone, sandstone, conglomerate, and limestone of Cretaceous and Tertiary age, (3) granitic rocks, mostly quartz monzonite and granodiorite, of Triassic to Tertiary age, and (4) volcanic rocks of Tertiary and Quaternary age.

The hydraulic properties of this hydrogeologic unit have not been measured except for volcanic and granitic rocks in the Lemmon Valley area north of Reno in western Nevada and basalt flows interbedded with basin-fill deposits in the Fallon area of western Nevada (see earlier section). Hydraulic conductivities of some of the rocks in this unit estimated from the results of drillers' aquifer tests in Lemmon Valley range from 0.3 to 20 ft/d (Harrill, 1973, p. 20). Harrill (p. 19) concluded that fractured volcanic and granitic rocks are capable of yielding small quantities of ground water to wells, although he generally considered the consolidated rocks in the area to be nearly impermeable. However, the hydraulic properties of the unit undoubtedly range through several orders of magnitude because of the wide range of lithology and potential for structural deformation. The unit forms structural basins for basin-fill aquifers.

REGIONAL GROUND-WATER FLOW

CARBONATE-ROCK AQUIFERS

The eastern Great Basin is underlain by a thick stratigraphic section of Middle Cambrian to Early Triassic age in which carbonate rocks are the dominant lithology. These rocks contain the carbonate-rock aquifers that are recharged by high-altitude snowmelt and that discharge at large springs scattered throughout the eastern Great Basin and at several large sinks, including the Great Salt Lake Desert in northwestern Utah, Sevier Desert in west-central Utah, Railroad Valley in east-central Nevada, the Colorado River in southeastern Nevada and northwestern Arizona, and Death Valley in southeastern California. The movement of ground water toward these discharge areas is partly affected by poorly permeable rocks that can either force ground water to the surface as spring discharge or result in convoluted directions of regional flow. These rocks, called barriers to ground-water flow, include Precambrian crystalline basement in fault contact with carbonate rocks, the overlying upper Precambrian and Lower Cambrian clastic sedimentary rocks in fault or depositional contact with carbonate rocks, and Jurassic to Tertiary granitic intrusive bodies in fault or intrusive contact with carbonate rocks (pl. 2 and table 1). Outcrop areas of barriers to ground-water flow are shown individually on plate 4 and as one unit on plate 5. In addition, plate 5 shows areal extents in the subsurface, and estimated altitudes of, the tops of crystalline basement and granitic intrusive rocks determined from analysis of aeromagnetic data (previous section and pl. 4). The plate also shows five regions of deep ground-water flow and general directions of flow in each region, both based on a computer model done as a part of the Great Basin RASA (Prudic and others, 1993). The five regions are called the Bonneville, Upper Humboldt River, Railroad Valley, Death Valley, and Colorado River regions, respectively (Prudic and others, 1993).

The flow model was conceptualized as two layers: a lower layer of deep ground-water flow, mostly in carbonate rocks, and an upper layer of shallow ground-water flow in basin-fill deposits and consolidated rocks of mountain ranges (Prudic and others, 1993). The final distributions of transmissivity simulated for both layers were dependent only on water levels and distributions and amounts of recharge and discharge (Prudic and others, 1993). The final results were not dependent on distributions of rocks believed to represent barriers to ground-water flow that are described in this report.

Comparison of the model results (Prudic and others, 1993, fig. 24) with locations of barriers indicates that deep ground-water flow and, to a lesser extent, shallow flow are affected by some of the barriers. Several barriers coincide with or are near boundaries of deep-flow regions (pl. 5). In addition, simulated deep ground-water flow moves around barriers, and low values of transmissivity computed for the upper model layer generally correspond to outcrops of crystalline basement and the overlying clastic sedimentary rocks (Prudic and others, 1993). Specific examples where ground-water flow is inferred to be affected by barriers are discussed in the following paragraphs.

The Bonneville Region of deep ground-water flow (Prudic and others, 1993, fig. 24) covers most of western Utah and parts of eastern and northeastern Nevada (pl. 5). The western boundary of the region coincides with an area of high land-surface altitudes (Simpson and others, 1988) and high regional flow potentials (Harrill and others, 1988). Deep ground-water flow in the region is toward the Great Salt Lake and Sevier Deserts, in northwestern and west-central Utah, respectively. The altitude of the potentiometric surface in the region ranges from 4,250 ft at Great Salt Lake to more than 6,000 ft near the western boundary.

The distribution of barriers to flow, either in outcrop areas or as subsurface magnetic bodies (pl. 5), may provide a basis for subdividing the

Bonneville Region into smaller flow areas. The tops of several of the magnetic bodies are at altitudes comparable to those of the regional potentiometric surface (Prudic and others, 1993, figs. 23, 24). Even when the magnetic bodies are much deeper, however, the potential presence of at least several thousand feet of overlying clastic sedimentary rocks could produce effective barriers to ground-water flow.

The elongate body in central Utah between Utah Lake and the Sevier River is a good example. Middle parts of the body are at altitudes near or above altitudes of water levels for deep ground-water flow in the region, whereas altitudes of the west end of the body are more than 2,000 ft lower. However, outcrops of upper Precambrian and Lower Cambrian clastic sedimentary rocks (pls. 4, 5) suggest that the barrier is much shallower and probably affects both deep and shallow ground-water flow. In fact, the boundary between two shallow-flow regions (Prudic and others, 1993, fig. 23) crosses the area underlain by this potential barrier to ground-water flow.

The large northwest-trending magnetic body near the Nevada-Utah border about 10 mi south of Wendover, Nev., helps explain the location of Blue Lake Springs. The altitude of the top of the body near these large springs is estimated to be at 3,000 ft, which is 1,000–2,000 ft lower than the potentiometric surface for deep ground-water flow in the area (Prudic and others, 1993, fig. 24). The body is believed to consist of crystalline basement and to be overlain by several thousand feet of clastic sedimentary rocks. Ground water moving from eastern Nevada to the Great Salt Lake Desert is inferred to move upward along the barrier and discharge at the springs. Although not shown by flow directions, ground water also is inferred to move around the north and south sides of the barrier.

Deep ground-water flow in the Upper Humboldt River Region is from the north and south toward the river. The effects of barriers to ground-water flow are generally not evident in the region except for the Ruby Mountains metamorphic core complex and the elongate magnetic body in the west part of the region. The boundary between this region and the Bonneville Region is underlain, in part, by the Ruby Mountains metamorphic core complex (pl. 5). No prominent magnetic bodies are associated with this core complex (pl. 4); however, the presence of upper Precambrian and Lower Cambrian clastic sedimentary rocks and Jurassic to Tertiary granitic rocks at altitudes well above nearby water levels (pl. 5 and Prudic and others, 1993, figs. 23, 24) indicates that the complex is a barrier to both deep and shallow ground-water flow.

The effects of the elongate magnetic body in the southwestern part of the Upper Humboldt River Region on ground-water flow are not obvious anywhere in the region. However, the body may affect flow in Kobeh Valley. Ground water in the valley discharges as evapotranspiration along valley lowlands (Rush and Everett, 1964, pl. 1), although much of the discharge occurs toward the west side of the valley in areas that are topographically higher and upgradient from the east side. One would expect evapotranspiration to be greatest in the eastern parts of the valley (James R. Harrill, U.S. Geological Survey, oral commun., 1991). The inference here is that granitic intrusions associated with the magnetic body might be shallow enough to impede the eastward movement of ground water. The magnetic anomaly associated with the body, however, is weak in the Kobeh Valley area, and no attempt was made to estimate a depth to source. The potential hydrologic effects of the body cannot be fully evaluated until more detailed hydrologic and geologic data are available.

Railroad Valley is a sink for deep ground-water flow in a relatively small part of east-central Nevada. The effects of barriers to flow are generally not evident except for two subsurface magnetic bodies along parts of the eastern boundary of the region. The tops of the two bodies are at estimated altitudes of 8,000 ft in the White Pine Range and 6,000 ft in the Quinn Canyon Range. The two bodies probably affect both deep and shallow ground-water flow, although neither body is large enough to affect flow over a large area.

The Colorado River and Death Valley regions of deep ground-water flow (pl. 5) are similar for two reasons: (1) ground water generally moves from north to south in each region over distances of 100 mi or more, and (2) magnetic bodies, some of large extent, underlie each region, but seem to play a minor part as boundaries. Some of the magnetic bodies are at altitudes comparable to nearby water levels (Prudic and others, 1993, figs. 23, 24). Even the deeper bodies can form a substantial barrier to ground-water flow if overlain by a thick section of upper Precambrian and Lower Cambrian clastic sedimentary rocks.

The hydrologic effects of barriers in both regions seem to be those of impeding ground-water flow, resulting either in convoluted directions of horizontal flow or vertical flow that discharges as large springs. Ground-water flow in both regions presumably would be more directly toward Death Valley and the Colorado River were it not for the barriers shown on plate 5.

Three groups of large springs provide evidence for the hydrologic effects of barriers in the two regions. The springs in White River Valley near the north end of the Colorado River region (pl. 5) were described earlier in this report as part of a discussion of a method used to compute the bulk transmissivity of the carbonate-rock aquifers. The discharge at the springs appears to be the result of a decrease in aquifer cross section in the direction of flow caused by the southward convergence of granitic intrusions along the east and west sides of White River Valley (Plume, 1984, p. 624).

Muddy River Springs, farther south in the same region, provide a similar example. The springs are directly between magnetic bodies beneath the Sheep and Arrow Canyon Ranges to the southwest and Mormon Mountains to the northeast. Crystalline basement is the source for the body in the Mormon Mountains (pl. 4) and also may be the source for the body beneath the Sheep and Arrow Canyon Ranges. In addition, crystalline basement undoubtedly is overlain by upper Precambrian and Lower Cambrian clastic sedimentary rocks that range in thickness from about 1,000 ft at Mormon Mountain to more than 10,000 ft in the Spring Mountains about 25 mi south of the Sheep Range (pl. 1). The combined effects of crystalline basement and clastic sedimentary rocks at relatively shallow depths are to reduce the cross-sectional area of flow in carbonate-rock aquifers in the area and force ground water to land surface as spring discharge.

The springs at Ash Meadows, 30 to 40 mi northeast of Death Valley, provide a third example. In this case, however, subsurface magnetic bodies do not appear to be near enough to the springs to account for such a large discharge area, although upper Precambrian and Lower Cambrian clastic sedimentary rocks are exposed nearby (pl. 4). A geologic section of the Ash Meadows area (Dudley and Larson, 1976, p. 10) shows that the clastic sedimentary rocks gradually rise in the direction of ground-water flow and reach a relatively shallow level near the springs. Thus, the springs at Ash Meadows may be the result of a reduced aquifer cross section caused by gradual thinning of the aquifer in the direction of ground-water flow.

There seems to be little doubt that the barriers shown on plate 5 are capable of impeding ground-water flow in the eastern Great Basin, although the hydrologic effects discussed in this part of the report are based mostly on geologic and hydrologic inference. The barriers cause ground water to follow convoluted paths and, at least in some instances, to discharge at large springs. The barriers, however, exert only a minor influence as boundaries of the flow regions defined by Prudic and others (1993, figs. 23 and 24). Perhaps some of the barriers are more important at smaller scales.

The question that remains unanswered is what geologic features, if any, do constitute boundaries of flow regions. The answer probably will require an improved understanding of the influence of extensional faulting in the region. A number of geologic studies in the past 10 years (Coney, 1980; Coney and Harms, 1984; Gans and others, 1985; Wernicke and others, 1985, 1988; Axen and others, 1987; Hamilton, 1988) have refined the traditional concepts of normal faulting in the Great Basin. Instead of simple horsts and grabens bordered by high-angle normal faults, the region has undergone tectonic extension involving low-angle, high-angle, and listric normal faults. As a result, parts of the Great Basin are underlain by thick, laterally continuous sections of carbonate rocks and other parts by isolated blocks of carbonate rocks (Dettinger, 1989, p. 13). On the basis of several recent geologic studies, Dettinger identified the central third of southern Nevada as a north-south corridor of thick and continuous carbonate rocks that constitute the regional carbonate-rock aquifers (1989, p. 13). Thus, other corridors of thick and continuous carbonate rocks may be identified in the eastern Great Basin as the geologic understanding of the region improves.

BASIN FILL

EASTERN GREAT BASIN

Each structural basin in the eastern Great Basin contains a basin-fill aquifer that can be hydraulically connected to an adjacent basin by way of either basin-fill deposits or permeable consolidated rocks, although the latter condition is more common. The hydraulic connection may be effective where the structural basin consists mostly of Middle Cambrian to Early Triassic carbonate rocks. The connection may not be effective where the structural basin consists of Middle Triassic to middle Tertiary sedimentary and igneous rocks or of Precambrian and Lower Cambrian metamorphic, igneous, and sedimentary rocks (pl. 2). With few exceptions, almost all basins are hydraulically interconnected in the eastern Great Basin (Harrill and others, 1988). These basin-fill aquifers and permeable consolidated rocks of mountain ranges constitute the upper layer of the ground-water model for the eastern Great Basin (Prudic and others, 1993) discussed in the previous section.

In a few basins, the extent of the hydraulic connection can be inferred mostly from hydraulic heads or from the presence or absence of discharge areas such as springs, wet playas, and areas of phreatophytes. For instance, ground-water levels in Jakes Valley in east-central Nevada are deep in spite of the high mountains surrounding the valley that receive large amounts of winter precipitation that is potential recharge. The inference is that recharge enters carbonate rocks in the mountain block and moves laterally and downward, partly into the basin fill, before entering deeper carbonate rocks. Valleys such as Jakes Valley receive substantial recharge, but natural discharge occurs as underflow through basin fill and carbonate rocks rather than as springs or as evapotranspiration along the valley floor (Eakin, 1966, p. 261); for practical purposes, the recharge is directly entering a regional flow system. Other examples of these types of valleys in the eastern Great Basin include Pine and Wah Wah Valleys, Utah (Stephens, 1976, p. 11–17; 1974, p. 26–27).

In some parts of the eastern Great Basin, regional ground-water flow moves from carbonate rocks into basin-fill deposits. Such an area usually is a basin with large areas of phreatophytes, large springs, or a playa with water levels at or near land surface. The common characteristic of such basins is that recharge from the surrounding mountains would not be expected to produce the large amounts of natural discharge that are observed. Examples include regional sinks such as the Great Salt Lake Desert, Sevier Desert, Death Valley, and Railroad Valley and smaller areas such as Pahranagat and White River Valleys and Ash Meadows, Nev., and Tule Valley, Utah.

WESTERN GREAT BASIN

The western part of the Great Basin is similar to the eastern part in that few basins are hydrologically closed (see pl. 2; Thomas and others, 1986; Harrill and others, 1988, for locations of basins discussed below). Examples of closed basins include Gabbs, Monte Cristo, Smith Creek, and Edwards Creek Valleys. The most common means of hydraulic connection in the western Great Basin is by way of basin fill that underlies low topographic divides between adjacent basins. An example of this type of basin is Dixie Valley in west-central Nevada, which receives underflow from Pleasant and Jersey Valleys to the north and Fairview, Stingaree, Cowkick, and Eastgate Valleys to the south. A similar example is Soda Spring Valley in southwestern Nevada, which receives underflow from Garfield Flat and loses underflow to Walker Lake Valley and Rhodes Salt Marsh. Basins connected by streamflow (fig. 1) also are connected by underflow through basin fill.

Hydraulic connections provided by permeable bedrock are less common and occur mostly in southwestern Nevada (Harrill and others, 1988) in an area referred to as "the south-central Marsh Area" (Thomas and others, 1986). Fractured volcanic rocks are thought to provide the hydraulic connection in this area that includes Huntoon, Teels Marsh, Columbus Salt Marsh, and Clayton Valleys, and the southern end of Big Smokey Valley (Thomas and others, 1986; Harrill and others, 1988).

SUMMARY AND CONCLUSIONS

This study was done as part of the Great Basin RASA, which in turn is part of a larger program for evaluating the Nation's ground-water resources. The overall goal of the study was to describe the hydrogeologic framework of the Great Basin. Specific objectives were (1) to group the many different formations and rock units in the Great Basin into a few hydrogeologic units, (2) to describe the lithology, areal extent, and water-bearing character of each unit, (3) to identify those units that are primarily responsible for storing and transmitting ground water within regional aquifer systems, (4) to identify those units that function as barriers to regional ground-water flow, and (5) to determine, to the extent possible, the subsurface geometry of aquifers and their boundaries.

Two aquifer systems were recognized in the Great Basin at the beginning of this study: one mainly within Middle Cambrian to Early Triassic carbonate rocks in the eastern Great Basin and the other within Cenozoic basin-fill deposits found in every basin of the Great Basin. The two systems are hydraulically connected in the eastern Great Basin to an extent that is still not completely understood. The two may actually constitute one complex flow system; however, they are described separately in this study mainly because the approaches used to develop an understanding of the hydrogeologic framework of each were significantly different. The approach used for carbonate rocks in the eastern Great Basin was to deal with large-scale hydrogeologic features of the region; features that affect local ground-water flow were not emphasized. In contrast, the approach used for basin-fill aquifers was to use site-specific knowledge of these aquifers in a few basins in order to broadly define properties believed to be common to many; it was beyond the scope of this study to define the hydrogeologic framework of every basin-fill aquifer in the Great Basin. Cenozoic volcanic rocks may constitute a third aquifer system in some areas, but in others may instead function as a barrier to regional flow.

Six hydrogeologic units were identified in the Great Basin for purposes of this study. The water-bearing characteristics of these units are highly variable: in some areas, a particular unit might be capable of storing and transmitting large quantities of water, whereas in other areas it might be a barrier to ground-water flow. In spite of this variation, however, three of the units probably function mostly as regional aquifers and the other three as barriers to regional flow. The regional aquifers are in Middle Cambrian to Lower Triassic carbonate rocks in the eastern Great Basin and in two units of Cenozoic basin-fill deposits that occur throughout the Great Basin.

The Middle Cambrian to Lower Triassic stratigraphic section in the eastern Great Basin is dominated by limestone and dolomite, although thinner intervals of clastic rocks occur throughout the section. The stratigraphic thickness of this part of the section differs throughout the eastern Great Basin; measured thicknesses range from 5,000 to 30,000 ft. Although stratigraphic thickness is useful for estimating the potential extent, at depth, of carbonate rocks, it can be misleading for estimating aquifer depths because of the structural complexity of the region.

Variations in porosity and hydraulic conductivity of the carbonate rocks appear to be related to differences in the degree to which the rocks are fractured. Porosity estimates range from almost zero to as much as 20 percent, although values usually do not exceed 10 percent. Logs for petroleum-exploration wells indicate that zones of relatively high porosity are narrow and are interspersed with broader zones of low porosity. Hydraulic conductivities of Middle Cambrian to Lower Triassic carbonate rocks have been estimated from the results of aquifer tests done at 23 relatively widespread wells in the eastern Great Basin. Values range from 0.0005 to 900 ft/d. The higher values of porosity and hydraulic conductivity may be restricted to narrow fault or fracture zones and the lower values to intervening less fractured rock.

Cenozoic basin-fill deposits have been accumulating in the Great Basin since about middle Miocene time. These deposits consist of older (late Miocene and early Pliocene) sandstone, siltstone, claystone, freshwater limestone, evaporites, and interbedded volcanic rocks that began to accumulate as the earliest basins formed. These deposits usually are exposed along valley margins and also constitute the deeper fill in many, if not all, basins. Younger deposits, of Pliocene to Holocene age, consist of unconsolidated clay, silt, sand, gravel, and boulders, and are found in every basin in the Great Basin. The two units are not easily distinguished from each other in many valleys, especially in the subsurface.

Lithologic and hydraulic properties of basin-fill deposits appear to be approximately related to their physiographic setting in valleys. On upper to middle alluvial fans and pediments, the deposits are generally coarse; on lower fans and valley lowlands, in contrast, they consist of interbedded coarse and fine materials or heterogeneous mixtures of the two. Hydraulic conductivities determined at 17 aquifer tests range from 0.02 to 140 ft/d. Hydraulic conductivity appears generally to decrease basinward. In basins with perennial or near-perennial streams, sediments in part of the lowlands have been reworked and deposited in the stream flood plain as sequences of well-sorted beds of clay, silt, sand, or gravel. These deposits are typically more permeable than the poorly sorted ones beyond the flood plain. Hydraulic conductivities of flood-plain deposits measured at 22 wells in four valleys of north-central Nevada range from 16 to 1,100 ft/d.

Geometries of bedrock basins were evaluated for six topographic basins in the Great Basin. They probably do not account for every basin shape in the region, but they are thought to represent the more common shapes. Two of the basins—Dixie Valley in Nevada and Jordan Valley in Utah—are relatively symmetrical and maximum estimated depths are 10,000 ft and 3,000 ft, respectively. The other four basins are not symmetrical. Two basins, Las Vegas and Railroad Valley in Nevada, are underlain by a deep bedrock basin (5,000 and 7,000 ft, respectively) near one side of the valley and a shallow (1,000 ft or less) sloping bedrock surface on the other side. Spring Valley, Nev., is underlain by an asymmetrical basin that is deepest (7,000 ft) along its west side adjacent to the Schell Creek Range and becomes gradually shallower to the east. Carson Valley, Nev., is underlain by at least three fault blocks that have formed a pair of bedrock basins (2,900 and 5,000 ft deep, respectively) that lie along the east and west sides of the topographic basin. One conclusion that can be drawn from the few basins described is that a bedrock basin cannot be assumed to be symmetrical with respect to its topographic basin.

Cenozoic volcanic rocks are found in most mountain ranges in the Great Basin and underlie or are interbedded with basin-fill deposits in many valleys. Volcanic rocks are recognized as aquifers at Fallon, Nev., and Pavant Valley, Utah (basalt aquifers), and at the Nevada Test Site (tuff and lava-flow aquifers). Hydraulic conductivities determined from tests of these aquifers range from 1.5 to 46,000 ft/d. The basalt aquifers are especially productive. In contrast, hydraulic conductivities determined from drill-stem tests in Railroad Valley, Nev., indicate that tuffs in that valley can be very impermeable (hydraulic conductivities determined from drill-stem tests range from 0.000001 to 0.3 ft/d). Volcanic rocks may prove to be regionally important aquifers because they are so widespread in the Great Basin; however, they are also capable of functioning as barriers to regional ground-water flow in some areas.

Hydrogeologic units that probably form barriers to regional ground-water flow are Precambrian and Lower Cambrian sedimentary, igneous, and metamorphic rocks in the eastern Great Basin, Middle Triassic to Quaternary sedimentary and igneous rocks in the eastern Great Basin, and upper Precambrian to Quaternary sedimentary and igneous rocks in the western Great Basin. The former two are potential barriers to regional flow in carbonate-rock aquifers and also form structural basins along with Middle Cambrian to Lower Triassic carbonate rocks in the eastern Great Basin. Structural basins in the western Great Basin are underlain by upper Precambrian to Quaternary sedimentary and igneous rocks.

Precambrian crystalline basement (metamorphic and igneous rocks) and overlying upper Precambrian and Lower Cambrian quartzite, sandstone, and shale are barriers to ground-water flow where they are in fault or depositional contact with carbonate-rock aquifers. In addition, they may act as a base for the flow system in parts of the Great Basin where circulation extends to the base of the carbonate rocks. Middle Triassic to Tertiary clastic sedimentary rocks, Jurassic to Tertiary granitic intrusive rocks, and Tertiary and Quaternary volcanic rocks also are believed to be barriers to flow where they are in fault, depositional, or intrusive contact with carbonate rocks. Precambrian crystalline basement, upper Precambrian and Lower Cambrian clastic sedimentary rocks, and Jurassic to Tertiary granitic rocks are believed to be especially effective as barriers. Their subsurface extent can be inferred in many parts of the eastern Great Basin from study of geologic maps of the region, but such an approach does not adequately define that extent.

Aeromagnetic data were analyzed to aid in identifying bodies of Precambrian crystalline basement and Jurassic to Tertiary granitic intrusions that presumably are the principal sources for long-wavelength magnetic anomalies in the eastern Great Basin. In addition, the subsurface presence and extent of upper Precambrian and Lower Cambrian clastic sedimentary rocks could be inferred because these rocks overlie crystalline basement.

Barriers to ground-water flow are scattered throughout the eastern Great Basin. Over much of the region, these barriers are at altitudes comparable to water levels simulated as part of a computer model of ground-water flow. The barriers coincide with, or are in close proximity to, boundaries between regions of deep ground-water flow as defined by other studies. However, the barriers do not form continuous boundaries for any of the flow regions. The barriers do form zones of low transmissivity that impede ground-water flow, resulting in convoluted directions of flow and in upward flow that discharges at large springs. Such springs include Blue Lake Springs in western Utah, Muddy River Springs in southeast Nevada, the springs at Ash Meadows in southwest Nevada, and those near Preston in east-central Nevada.

Basin-fill aquifers are hydraulically connected to carbonate-rock aquifers in the eastern Great Basin and to other basin-fill aquifers throughout the region. Few basins are hydrologically closed. Excessive depths to water in some basins and large discharge areas in others provide evidence for connections between basin-fill and carbonate-rock aquifers in eastern Nevada. For instance, water levels in some basins are so deep that ground water does not discharge as evapotranspiration even though local recharge is sufficient to produce it; in others, observed discharge exceeds amounts that would be expected to be produced from local recharge. In either type of basin, the inference is that basin-fill aquifers are part of regional flow systems. Basin-fill aquifers in the western Great Basin are hydraulically connected by perennial streams and by ground-water underflow through alluvium and, less commonly, through permeable bedrock between adjacent valleys.

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TABLES 1 AND 2; APPENDIXES 1 AND 2

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*

[Rock and stratigraphic units, lithologies, and thicknesses compiled from Stratigraphic Committee of the Eastern Nevada Geological Society (1973), Stewart and Carlson (1978), Hintze (1980), and Stewart (1980). Abbreviations: ft/d, feet per day]

Hydrogeologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
			Basin-fill deposits, entire Great Basin			
Younger basin-fill deposits	Quaternary and Tertiary	Holocene to upper Pliocene	Younger basin-fill deposits.	Unconsolidated to semiconsolidated deposits of alluvial fans and pediments (unsorted to poorly sorted silt, sand, gravel, and boulders); valley lowlands and playas (poorly sorted clay, silt, sand, and gravel); and stream flood plains (sorted to well-sorted intervals of silt and clay or sand and gravel).	Uncertain but probably as much as 2,000 to 3,000 feet in most valleys, and as much as 10,000 feet in some.	Younger and older basin-fill deposits, collectively referred to as basin fill, constitute basin-fill aquifers and yield much of the ground water used in the Great Basin. Aquifer-test data for 17 wells in 14 basins in central and eastern Nevada and western Utah (see figs. 3 and 4), collected for MX siting investigation, are as follows: Estimated hydraulic conductivities (transmissivity divided by length of screened interval in well) range from 0.02 ft/d in Sevier Desert, Utah, to 140 ft/d in Hot Creek and Railroad Valleys, Nev. (Bunch and Harrill, 1984, p. 115-118). Average value is 78 ft/d. Maximum and minimum values appear to be a reasonable range of conductivities for basin-fill deposits, exclusive of flood-plain deposits. Average value, however, may be biased toward higher values because purpose of investigation was to find and eventually develop high-yield sources of ground water. Hydraulic conductivities of flood-plain deposits measured at 22 wells in north-central Nevada range from 16 to 1,100 ft/d, with a mean of 130 ft/d (Bredehoeft and Farvolden, 1963, p. 210).
Older basin-fill deposits	Tertiary	Lower Pliocene to middle Miocene	Esmeralda, Coal Valley, and Truckee Formations in western Nevada; Humboldt Formation in northeastern Nevada; Panaca Formation in southeastern Nevada; Muddy Creek Formation in southern Nevada; Salt Lake Formation in western Utah.	Semi-consolidated to consolidated fanglomerate, sandstone, siltstone, mudstone, limestone, and interbedded volcanic rocks.		

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydro-geologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
			Consolidated rocks, western Great Basin			
Sedimen-tary, volcanic, and intrusive rocks	Quaternary and Tertiary	Pleistocene to Eocene	Volcanic rocks.	Flows and flow breccias that range in composition from basalt to rhyolite and silicic ash-flow, air-fall, and water-laid tuffs.	Thickness of individual units can reach 3,000 feet. Composite thickness of volcanic rocks in some areas probably as great as 10,000 feet.	Different parts of this unit are poorly permeable bedrock for structural basins in the western Great Basin. Consequently, these rocks act as boundaries for basin-fill aquifers. Localized conditions of relatively high permeability occur within the unit, especially within volcanic rocks. A basalt aquifer, interbedded with younger basin-fill deposits, at Fallon, Nev., has hydraulic conductivities estimated to range from 130 to 3,100 ft/d.
	Tertiary to Triassic		Intrusive rocks.	Predominantly quartz monzonite and granodiorite.		
	Tertiary to Jurassic		Continental sedimentary rocks.	Conglomerate, sandstone, siltstone, shale, and freshwater limestone. Units of Tertiary age locally tuffaceous or interbedded with volcanic rocks.	Thickness of individual units differs from area to area. Can be several thousand feet.	
	Jurassic to Precambrian		Marine sedimentary and volcanic rocks.	Shale, siltstone, sandstone, quartzite, conglomerate, chert, limestone, and lava flows including pillow lavas.	Thickness of individual units can be as much as 10,000 feet. Composite thicknesses change rapidly and are not well known.	

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydrogeologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
Consolidated rocks, eastern Great Basin						
Sedimentary and igneous rocks	Quaternary and Tertiary	Pleistocene to Eocene	Volcanic rocks.	Flows and flow breccias that range in composition from basalt to rhyolite and silicic ash-flow, air-fall, and water-laid tuffs.	Individual units as thick as 3,000 feet; composite thickness of these rocks may be 10,000 feet; however, entire section rarely is present in any area, except perhaps along southeastern and eastern boundary of Great Basin.	Unit is poorly permeable barrier to regional ground-water flow where in fault, depositional, or intrusive contact with carbonate-rock aquifers. In addition, rocks of this unit and other consolidated rocks in eastern Great Basin are bedrock for structural basins. Notable exceptions to general impermeability of these rocks are Cenozoic volcanic rocks. Basalts interbedded with younger basin-fill deposits in Pavant Valley, Utah, have estimated hydraulic conductivities that range from 370 to 46,000 ft/d. Lava flows and tuffs at Nevada Test Site in south-central Nevada have hydraulic conductivities that range from 1.5 to 17 ft/d. Volcanic rocks that underlie Railroad Valley, Nev., are much less permeable, with hydraulic conductivities of 0.000001 to 0.3 ft/d.
	Tertiary to Jurassic		Intrusive rocks.	Predominantly quartz monzonite and granodiorite.		
	Tertiary to Triassic		Continental sedimentary rocks.	Fluvial and lacustrine shale, siltstone, sandstone, and conglomerate. Freshwater limestone and eolian sandstone. Units of Tertiary age are commonly tuffaceous and contain interbedded volcanic rocks.		
Carbonate and clastic sedimentary rocks	Triassic	Lower	Moenkopi Formation	Siltstone, sandstone, and interbedded limestone and gypsum.	1,600-2,300 feet	Unit contains carbonate-rock aquifers in eastern Great Basin. Ground water is transmitted mostly along joints and fractures. Estimates of hydraulic conductivity range from 0.0005 to 900 ft/d. Higher values represent fault or fracture zones and low values relatively unfractured rock. Unit also constitutes parts of some structural basins.
			Thaynes Formation	Limestone and calcareous siltstone and sandstone.	Few hundred to 3,000 feet	

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydro-geologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
	Permian	Upper and Lower	Kaibab Limestone, Toroweap Formation, Park City group in eastern Nevada; Phosphoria Formation, Park City Group in central and western Utah.	Cherty limestone, dolomite, sandstone, and shale.	1,000 to 15,000 feet	
		Lower	Pequop Formation, Arcturus Formation, Rib Hill Sandstone of east-central Nevada; Coconino Sandstone, Hermit Shale, Queantoweap Sandstone of McNair (1951) in southeastern Nevada; Arcturus Formation, Diamond Creek Sandstone, and Kirkman Limestone in western and central Utah.	Siltstone, sandstone, limestone, dolomite, and gypsum.		
	Permian and Pennsylvanian		Garden Valley and Carbon Ridge Formations, Carlin Canyon, Beacon Flat, Buckskin Mountain, and Strathearn Formations of Fails (1960) in east-central and northeastern Nevada; Riepe Spring Limestone of Steele (1960) and Ely Limestone in eastern Nevada; Bird Spring Formation and Callville Limestone in southern Nevada; Oquirrh Group in western and central Utah.	Sandy and silty limestone, conglomerate, and siltstone in east-central Nevada; limestone dolomite, siltstone, and sandstone in eastern and southern Nevada and western Utah, and sandstone and limestone in central Utah.		
	Pennsylvanian	Middle and Lower	Tomera and Moleen Formations.	Limestone, sometimes cherty or sandy, and conglomerate.		
	Pennsylvanian and Mississippian		Diamond Peak Formation in east-central Nevada.	Conglomerate.	600-3,800 feet	

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydro-geologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
	Mississippian		Chainman Shale and Joanna Limestone in eastern Nevada; Monte Cristo and Sultan Limestones in southern Nevada; Eleana Formation in south-central Nevada; Chainman and Manning Canyon Shales, Great Blue and Ochre Mountain Limestones, Woodman and Humbug Formations, Deseret and Gardison Limestones, and Fitchville Formation in western and central Utah.	Shale, siltstone, and limestone in eastern Nevada; limestone, dolomite, sandstone, and chert in southern Nevada; shale, sandstone, and conglomerate in south-central Nevada; and limestone, dolomite, sandstone, and shale in western and central Utah.	400-5,000 feet	
	Mississippian and Devonian		Pilot Shale	Shale.	75-950 feet	
	Devonian		Guilmette Formation, Simonson and Sevy Dolomites in eastern Nevada and western Utah; Devils Gate Limestone and Nevada Formation (former usage) in east-central Nevada; and Pinyon Peak Limestone, Victoria Formation, and Simonson and Sevy Dolomites in central Utah.	Dolomite, limestone, and subordinate sandstone and quartzite.	From less than 500 feet to 6,000 feet.	
	Silurian		Lone Mountain and Laketown Dolomites and Roberts Mountain Formation in eastern Nevada; Laketown Dolomite in western and central Utah.	Dolomite.	From 0 to more than 1,000 feet.	

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydrogeologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
	Ordovician		Ely Spring and Fish Haven Dolomites, Eureka and Swan Peak Quartzites, Crystal Peak Dolomite, Pogonip Group, and Garden City Formation in eastern Nevada and western Utah; Fish Haven Dolomite and Opohonga Limestone in central Utah.	Limestone, dolomite, shale, and quartzite.	0 to 5,000 feet	
	Cambrian	Upper and Middle	Windfall Formation, Dunderberg Shale, Hamburg Dolomite, Secret Canyon Shale, Geddes Limestone, and Eldorado Dolomite in northern and eastern Nevada; Nopah, Bonanza King, and Carrara Formations in southern Nevada; Notch Peak, Orr, Weeks, and Lamb Formations, Marjum Limestone, Wheeler Shale, Swasey Limestone, Whirlwind Formation, Dome Limestone, Chisholm Shale, Howell Limestone in western Utah; and Ajax Dolomite, Opex Formation, Cole Canyon Dolomite, Bluebird Dolomite, Bowman Limestone, Herkimer Limestone, Dagmar Dolomite, Teutonic Limestone, and Ophir Group in central Utah.	Limestone, dolomite, shale, and siltstone.	500 to 8,000 feet	

TABLE 1.—*Stratigraphic and hydrogeologic units of Great Basin*—Continued

Hydrogeologic unit	System	Series	Rock or stratigraphic unit	Major lithology	Range in thickness	Water-bearing characteristics
Metamorphic, igneous, and sedimentary rocks	Cambrian and Precambrian		Pioche Shale, Osgood Mountain and Prospect Mountain Quartzites and McCoy Creek Group of Misch and Hazzard (1962) in northern and eastern Nevada; Zabriskie Quartzite, Wood Canyon Formation, Stirling Quartzite, and Johnnie Formation in southern Nevada; Pioche Shale, Prospect Mountain Quartzite, and McCoy Creek Group of Misch and Hazzard (1962) and Sheeprock Group of Christie-Blick (1982) in western Utah; and Tintic and Brigham Quartzites, Mutual Formation, Blackrock Limestone, and Pocatello Formation in central and northern Utah.	Quartzite, siltstone, conglomerate, and minor limestone and dolomite.	Less than 500 to more than 20,000 feet	Unit, in part, forms flow-region boundaries and, where flow circulates deeply enough, lower boundary of carbonate-rock aquifers. Unit also is bedrock, in part, for some structural basins.
	Precambrian		Crystalline basement.	Granitic rocks and metamorphic rocks including gneiss, schist, gneissic granite, amphibolite, migmatite, pegmatite, and marble.		

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*

Data source: American Stratigraphic Company logs indicated by (A) followed by their log number. All other numbers are Nevada State Department of Mineral Resources file numbers.
Land-surface altitude: Datum is sea level.
Well depth: Listed depths were measured along the well bore from land surface. If a well bore deviates from vertical, the listed depth is greater than the true vertical depth and may be uncertain by as much as several hundred feet.
Depth interval: Datum is land surface. Listed depths were measured along the well bore. If a well bore deviates from vertical, the listed depth is greater than the true vertical depth.
Lithology: Abbreviations: anhy, anhydrite; cgl, conglomerate; clyst, claystone; dol, dolomite; gvl, gravel; ls, limestone; mrlst, marlstone; qtzt, quartzite; sd, sand; sh, shale; sltst, siltstone; ss, sandstone; volc, volcanic rocks.
Porosity type: Abbreviations and definitions: e, earthy--loosely aggregated particles, having the properties of earth or soil; f, facture--porosity resulting from presence of openings produced by breaking or shattering of otherwise less pervious rock; o, oolitic--porosity associated with pore spaces between oolites which are small (0.01-0.1 inch) round accretions of calcite, silica, or other minerals; p, pinpoint--minute, isolated pores smaller than 0.002 inch; u, unknown; v, vuggy--porosity due to small openings larger than 0.002 inch and interconnected by minute fractures; x, intercrystalline--pores between individual crystals, interfragmental, and intergranular--primary pores between mineral grains or rock fragments that constitute a sedimentary rock (Bates and Jackson, 1987, p. 205, 257, 461, and 728; Levorsen, 1967, p. 97-127).
Remarks: For tops of hydrogeologic units, assume younger basin-fill deposits at land surface and older basin-fill deposits not identified unless noted otherwise. Hydrogeologic units are described in detail in text, table 1, and on plate 2.

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
					Nevada			
1	(A) D-2519	6,100	6,611	5-95	ss, sltst, cgl	3-10	x	Porosities for interval 4,895 to 5,280 feet represent several basalt flows 5 to 40 feet thick. Hydrogeologic unit tops: older basin-fill deposits at land surface; top of sedimentary and igneous rocks of middle Triassic to Quaternary age not identified; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 6,444 feet (?).
N41 E60 16AB				250-505	gvl, sltst, tuff	0-4	x	
				520-680	cgl, gvl, tuff	2-12	x	
				860-1,740	cgl, gvl, tuff	0-6	x	
				2,700-2,835	tuff, sd	0-6	x	
				3,605-3,815	tuff, sd	0-6	x,f	
				4,350-4,800	tuff	4	x	
				4,895 5,280	see remarks	3-6	v,f	
				5,355 5,410	tuff	3	f	
				6,450-6,600	qtzt, clyst	0-6	f,x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
2	(A) D-2560	5,650	8,412	620-1,470	see remarks	6-12	x	Porosities for interval 620 to 1,470 feet represent sand beds 5 to 20 feet thick interbedded with clyst and for interval 3,325 to 3,855 feet represent three beds 10 to 25 feet thick of fractured limestone. Hydrogeologic unit tops: older basin-fill deposits at land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,390 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 3,110 feet.
N40 E66 8CD				3,325-3,855	see remarks	4	f	
				8,295-8,310	chert	5	f	
3	(A) D-4368	6,085	7,100	240-1,080	cgl,ss	6	x	Porosities for interval 3,440 to 4,360 feet represent sandstone beds 10 to 75 feet thick and conglomerate 120 feet thick. Hydrogeologic unit tops: older basin-fill deposits at land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,690 feet.
N40 E55 31CD				1,300-1,440	ss,cgl, clyst, tuff	0-12	x	
				2,980-3,370	ss,cgl, clyst, tuff	0-4	x	
				3,440-4,360	see remarks	0-20	x	
				4,410-6,050	ss,cgl, sltst, sh	0-6	x	
				6,370-6,950-	sltst, ss,sh	0-4	x	
4	(A) D-4513	5,750	4,460	0-1,210	cgl	6-8	x	Hydrogeologic unit tops: older basin-fill deposits at land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,210 feet; metamorphic rocks at 4,265 feet, unit unknown.
N40 E52 4AC				3,345-3,750	ss, clyst, tuff	0-6	x	
5	(A) D-2790	4,890	4,938	2,205-3,015	tuff, clyst, cgl	0-6	e,x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, land surface; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,708 feet.
N39 E69 19AA								
6	(A) 690-R	5,588	8,414	3,560-3,580	clyst	4	x	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, top not identified; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 8,190 feet.
N38 E61 21AA				4,830-4,850	clyst	4	x	
				8,200-8,210	ls	5	f	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah—* Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
7	(A) D-2746	4,390	5,465	1,495-1,605	ss, tuff	0-6	x	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,000 feet (?); carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 3,320 feet.
N37 E59 3BD				5,035-5,055	dol	3	x	
				5,125-5,140	ss	6	x	
8	(A) 348-R	5,235	4,100	3,040-3,060	sltst	4	p	Hydrogeologic unit tops: older basin-fill deposits at land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, top not identified; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 3,020 feet.
N35 E58 9AA				3,395-4,100	ls,sh	0-6	f	
9	(A) D-4724	5,596	6,070	4,570-4,695	cgl, chert	0-6	x	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, top not identified; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,235 feet.
N34 E64 13AD				5,205-5,250	ls, clyst	0-4	x	
				5,825-5,845	ls	0-4	x	
10	(A) D-2713	5,305	7,349	20-750	cgl,ss, tuff	0-20	x	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 550 feet (?); carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 3,070 feet.
N34 E57 11BB				3,075-3,235	dol	0-3	v	
				3,925-4,020	dol,ls	0-4	v,x	
11	(A) D-4907	5,600	5,569	420-2,485	cgl,ss, clyst	0-8	x	Porosities for interval 4,465 to 5,325 feet are about 4 percent for thin intervals of limestone about 5 feet thick. Hydrogeologic unit tops: older basin-fill deposits and sedimentary and igneous rocks of Middle Triassic to Quaternary age, top not indentified; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,774 feet.
N32 E67 19CC				2,730-3,075	cgl, clyst, ss	0-4	x	
				3,480-3,635	cgl, clyst	0-4	x	
				3,840-3,865	cgl, clyst	0-4	x	
				4,465-5,325	ls	see remarks	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
12	(A) 520-R	5,835	3,158	55-290	ls,sh	0-4	f	Many of the porosity intervals are less than 5 feet thick according to log. Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
N30 E64 36DA				665-1,710	dol, sltst	0-4	f,v	
				2,145-2,810	dol, sltst	0-4	f,v	
13	147	5,952	13,116	--	--	--	--	Severe circulation problems at about 4,000 feet. Limited drill-stem test data indicate that intervals 5,934 to 6,029 feet, 7,166 to 7,263 feet, and 12,640 to 12,840 feet produced large quantities of water.
N30 E60 8CB								
14	(A) D-4361	5,559	13,600	0-100	cgl	20	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,007 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 10,600 feet.
N29 E56 19AA	149			105-985	cgl, clyst	0-20	x	
				1,110-2,450	cgl, sltst sh,tuff	0-20	x	
				2,590-5,495	tuff, cgl, sltst, dol	0-20	x,v	
				6,535-6,735	sh,dol	0-6	p	
				12,010-12,300	dol,ls	0-4	x,v,p	
15	(A) D-2443	5,300	1,546	200-205	sltst	3	x	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
N28 E70 18BC								
16	(A) D-4573	5,285	10,505	1,050-1,135	cgl, clyst	0-12	x	Hydrogeologic unit tops: older basin-fill deposits, top not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, top uncertain, probably 1,000 to 1,500 feet.
N28 E52 32AB				2,135-2,145	cgl	12	x	
				2,360-2,365	cgl	12	x	
				4,745-5,540	ss, sltst, clyst	0-12	x	
				7,070-7,090	cgl	3-6	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
17	(A) D-2548	5,492	4,502	825-850	ss	4	x	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 870 feet (?); carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 2,220 feet.
N26 E70 20CB				1,320-1,350	tuff	10	f	
				1,570-1,800	tuff, cgl	0-12	v,f, x	
				1,825-2,210	cgl,ss, clyst	0-6	x	
				2,555-4,440	dol,ls, ss	0-10	v,f, x	
18	(A) D-3101	5,745	3,116	530-580	cgl	20?	u	Hydrogeologic unit tops: older basin-fill deposits, top not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,350 feet.
N26 E52 6CA				900-2,350	cgl	20?	u	
19	(A) D-4364	6,330	7,071	0-1,470	cgl,ss, clyst	6	x	Hydrogeologic unit tops: older basin-fill deposits and sedimentary and igneous rocks of Middle Triassic to Quaternary age uncertain; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,854 feet. Circulation problems below 5,880 feet.
N23 E58 35DD				1,480-1,620	cgl,ss	6-12	x	
				1,625-2,110	cgl, tuff,ls	0-6	x	
				2,215-2,960	ls,ss, sltst	0-6	x	
				3,600-4,310	sh, sltst	0-4	x	
				4,760-4,780	ss	0-5	x	
				5,750-5,855	ss, sltst	0-4	x	
20	(A) D-4571	6,103	6,500	150-1,170	cgl,ss	6	x	Hydrogeologic units tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,213 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,545 feet.
N22 E58 34AD	228			1,200-1,365	ss, sltst, tuff	0-6	x	
				1,545-2,415	cgl,ss, sltst, ls	0-20	x	
				2,425-2,915	cgl,ss	12-20	x	
				2,965-3,425	ss,sh, sltst	0-6	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity		Remarks
						Percent	Type	
21	(A) D-4557	6,030	9,263	55-255	cgl	10	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 8,010 feet (?).
N20 E63 27CC				840-1,140	clyst, ss	4	x	
22	(A) D-3558	6,266	2,978	30-220	cgl	20?	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,300 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,880 feet.
N20 E61 14DD				1,300-1,310	volc	6	v	
				1,730-1,880	ss	20?	x	
				1,880-1,960	ls,ss	20?	x	
				2,742-2,748	ls	4	f	
23	(A) 483-R	7,250	11,531	650-660	dol	4	f	Porosities for interval 2,220 to 3,230 feet due to several gypsum beds 5 to 20 feet thick. Porosities for interval 3,275 to 10,790 feet due to scattered intervals of limestone or dolomite usually less than 5 feet thick, rarely 20 feet thick. Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
N20 E60 32BB				1,270-1,280	dol	4	v	
				1,330-1,340	ls	4	v	
				1,510-1,530	dol	3	f	
				2,220-3,230	see remarks	4	x	
				3,275-10,790	see remarks	4	f	
24	(A) D-3169	6,186	6,100	1,065-1,150	clyst	3	x	Hydrogeologic unit tops: older basin-fill deposits, near 900 feet (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,031 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,889 feet.
N19 E64 17DD				3,385-3,445	tuff	3	x	
				4,600-4,625	ls	3	v	
				4,890-4,915	ls	3	x	
				6,010-6,100	ls	3	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
25	(A) D-4566	6,016	4,405	100-280	cgl	20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 4,340 feet(?).
N19 E63 21AA				730-820	cgl,ss	20?	x	
				2,000-2,090	cgl	20?	x	
				3,490-3,920	cgl	20?	x	
26	(A) D-3164	5,877	5,047	0-3,940	cgl	20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,941 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,936 feet.
N19 E55 11BC				4,065-4,100	tuff	0-10	v	
				4,955-4,985	dol	0-20	x	
27	(A) D-3719	7,438	7,620	455-3,680	ls,dol, sh	0-6	see remarks	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface. Porosity: 155 to 3,680 feet due to fractured intervals 5 feet or less thick, rarely 20 feet thick; 3,740 to 7,430 feet due to fractured intervals less than 5 feet thick to 30 or 40 feet thick.
N18 E58 21DA				3,740-7,430	dol,ls	0-20	see remarks	
				7,430-7,620	ss	0-4	x	
28	(A) D-2624	6,588	7,984	150-1,165	ss,tuff, clyst, volc	0-6	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 100 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,177 feet.
N18 E57 23AD				1,885-2,195	sh	0-6	f	
				2,825-2,905	ls	0-3	f	
				3,850-7,960	dol,sh, ss	0-6	x,f, v	
29	(A) D-3724	6,586	2,680	0-1,740	cgl,ss	12-20?	x	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,740 feet.
N16 E64 30AC				1,870-1,880	ls	6	f	
				2,075-2,680	ls,sh, sltst	0-6	f	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity		Remarks
						Percent	Type	
30	(A) 298-R	6,385	10,314	2,420-2,455	ls	0-6	f	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
N16 E56 31DA				4,015-5,605	ls,dol	0-6	f	
				6,760-6,815	dol,ls	0-4	f	
				7,940-10,250	dol	0-6	x,f,v	
31	(A) D-4559	5,759	4,750	50-830	cgl, sltst, tuff	0-20?	x	Hydrogeologic unit tops: older basin-fill deposits and sedimentary and igneous rocks of Middle Triassic to Quaternary age uncertain; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,036 feet.
N15 E66 24DA				2,400-3,920	sltst, clyst, tuff, cgl	0-20?	x	
32	(A) 355-R	7,360	5,117	260-300	ls	0-5	v	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
N15 E59 17AA				1,590-1,660	ss,sh	0-12	x	
				2,000-2,070	ss	6-12	x	
				3,995-4,050	ls	3	v	
33	(A) D-4586	6,445	4,410	2,690-3,390	ss,sh	0-20	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, land surface; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 215 feet.
N14 E60 1CB								

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
34	(A) D-2522	5,420	5,895	970-1,070	cgl,sd	4	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,460 feet.
N11 E61 27DC				1,170-1,405	sd,cgl	0-4	x	
				3,040-3,065	sd	0-4	x	
				3,135-3,220	volc	4	f,x	
				3,730-3,750	tuff	3	x	
				4,770-4,785	tuff	3	x	
				5,540-5,890	ls	0-4	x	
35	(A) D-2500	5,480	4,850	0-1,476	cgl	0-20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,476 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,520 feet.
N10 E62 19BB				2,640-2,935	ls, mrlst	0-4	p,v	
				3,230-4,340	ls, mrlst, clyst, sltst	0-10	p,v	
				4,605-4,635	ls	0-4	v	
36	(A) D-3501	5,382	4,957	0-1,050	cgl,ss	0-20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 1,050 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,735 feet.
N10 E61 10BB				2,110-2,220	ss	20?	x	
				2,260-2,360	ss	20?	x	
				2,680-2,880	ls	0-4	v	
				3,390-4,705	ls	0-4	v	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
37	(A) D-4780	4,892	7,800	430-2,295	cgl,ss	3-6	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,294 feet; carbonate and clastic sedimentarv rocks of Middle Cambrian to Early Triassic age, 7,250 feet.
N10 E57 26CD				6,670-6,775	ls,sh, sltst	0-4	v	
				6,980-7,070	ls,sh	0-4	v,f	
38	(A) D-2672	6,540	6,269	5,350-5,490	ss, sltst, dol	0-6	x	Hydrogeologic unit tops: not identified.
N9 E63 22AB								
39	(A) D-3529	5,324	6,150	1,990-2,590	ss	20?	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,703 feet.
N9 E61 9AD				3,240-3,710	ss,cgl	20?	x	
				4,010-4,060	ss	0-20?	x	
				4,310-5,510	ss,cgl	0-20?	x	
40	(A) 664-R	4,753	10,358	1,100-1,550	ss, clyst	0-20?	x	Porosities for interval 9,360 to 10,300 feet due to fractured zones less than 10 feet thick. Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 6,445 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 7,785 feet.
N9 E57 35BA				3,280-3,460	cgl, clyst	0-20?	x,f	
				6,530-7,260	tuff	0-6	f,v	
				7,310-7,620	mrlst, ls,dol, sh	0-12	f,v	
				7,860-8,710	ls,sh	0-6	f	
				9,360-10,300	dol,sh, sltst, sh	0-6	see remarks	
41	(A) D-4754	4,752	6,335	435-3,990	cgl, clyst	0-10	x	Hydrogeologic unit tops: older basin-fill deposits, not identified; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,990 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 6,100 feet.
N9 E56 26BB	197			4,360-4,760	tuff	1-5	f	
				6,145-6,305	dol	0-6	v,x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
42	(A) D-3533	5,437	7,066	1,180-1,980	ss	20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,964 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 6,434 feet.
N8 E62 17CD				2,810-3,810	ss	0-20?	x	
				6,500-6,520	ls	12	f	
43	(A) D-4704	4,735	6,142	420-740	cgl,ss, clyst	0-6	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,535 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,840 feet.
N8 E56 3BC				780-3,535	cgl,ss	1-12	x	
				4,690-4,710	ss	12	x	
				5,870-6,100	ls,sh	0-6	v	
44	(A) D-3158	6,037	7,024	110-130	cgl	20	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 706 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 6,630 feet.
N7 E64 19DD				150-160	cgl	20	x	
				260-320	ss,cgl	12	x	
				320-6,180	ss, clyst, tuff,ls	0-20?	u	
				6,795-6,895	ls	0-4	e	
45	(A) D-4579	5,219	10,473	70-2,900	cgl, mrlst, clyst	0-4	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,901 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,416 feet.
N7 E61 2CA				4,870-4,995	cgl,ss, sh,ls	0-6	x	
				6,660-7,940	ls,ss	0-6	f	
				8,115-8,200	ss	12	x	
				8,600-8,945	ss,sh	0-12	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
46	(A) D-2734	4,730	1,711	110-1,300	see remarks	0-20?	x	For interval 110 to 1,300 feet, porosities due to conglomerate intervals as thick as 300 to 400 feet. Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 430 feet (?); carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,294 feet.
N7 E55 28CA				1,525-1,600	dol,ls, sh	0-4	p,x	
47	(A) D-3546	5,202	5,690	1,620-1,790	tuff,ss	0-20?	x	Hydrogeologic unit tops: older basin-fill deposits, land surface (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 395 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 2,950 feet.
N6 E61 33DC				2,020-2,950	ss,tuff	0-20?	x	
				3,160-3,170	ls	4	f	
				4,445-4,455	ss	3	x	
				4,545-4,630	ss	3-12	x	
				4,700-4,715	ss	3	x	
48	(A) D-3700	4,716	6,553	0-1,290	ss	0-20?	x	For interval 5,295 to 6,500 feet, porosities represent fractured intervals 1 to 10 feet thick. Hydrogeologic unit tops: older basin-fill deposits, 1,300 feet (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 5,020 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,276 feet.
N6 E56 5CD				1,305-2,540	mrlst, ls,ss, clyst	0-20?	x	
				5,140-5,276	tuff,ss	0-20?	x	
				5,295-6,500	sh,ls	3-6	see remarks	
49	(A) D-3545	4,809	7,780	20-3,167	cgl,ss	0-20?	x	Hydrogeologic unit tops: older basin-fill deposits, 795 feet (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,167 feet.
N5 E55 29DB				3,675-3,795	tuff	6	p	
				4,190-4,260	tuff	4-6	p	
				6,810-6,840	ss, clyst	0-4	x	
				7,520-7,585	ss	4	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity: Percent	Porosity: Type	Remarks
50 N3 E54 36BB	(A) D-4552	6,414	8,355	0-315	tuff	see remarks	--	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, land surface. Several intervals 30 to 100 feet thick of 4 percent porosity.
51 N2 E60 19CA	(A) D-4928	4,990	7,700	150-2,480	ss,cgl	0-20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,726 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 6,718 feet.
				2,605-2,610	ss	4	x	
				2,740-2,755	ss,ls	4-6	x	
				3,275-3,315	clyst, ss	0-3	x	
				3,510-3,585	ss, clyst	0-3	x	
				4,560-4,580	tuff	0-3	f	
				7,480-7,640	ls	0-3	f	
52 S1 E60 17BB	(A) D-3504	4,940	2,439	600-790	cgl,ss	20?	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 790 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 1,490 feet.
53 S20 E66 5CC	(A) D-3530	2,033	5,919	235-365	sh, sltst, ss	0-6	x	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
				755-880	ls,dol, ss	0-5	x	
				1,185-1,400	ls	0-4	x,v	
				1,520-1,885	dol,ls, ss,anhy	0-6	x	
				1,900-2,625	ss,sh dol,ls	0-20	x	
				2,640-2,900	dol,ss, sh	0-12	x	
				3,580-4,165	dol,ls, ss,sh	0-12	x,v, o,f	
				4,600-5,885	ls,dol	0-4	x,v, o	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth inter-val (feet)	Litho-logy	Porosity Percent	Porosity Type	Remarks
					Utah			
54	(A) D-3703	4,400	4,765	340-520	basalt	0-4	v,f	Basalt from 340 to 520 feet most likely interbedded with younger basin-fill deposits. Hydrogeologic unit tops below younger basin-fill deposits cannot be identified.
(B-14-10) 23BC				520-3,520	cgl,ss	0-20?	x	
				3,830-4,750	sltst, clyst, sh	0-6	f,x, v	
55	(A) D-2499	4,828	8,967	920-940	ss	3	x	Hydrogeologic unit tops: older basin-fill deposits, 116 feet; sedimentary and igneous rocks of Middle Triassic to Quaternary age, absent (?); carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 790 feet. For interval 6,150 to 6,940 feet, porosities represent fractured limestone interval usually less than 5 feet thick. Intervals 8,439 to 8,540 feet and 8,690 to 8,950 feet produced salt water.
(B-11-5) 18DD				1,795-2,020	ss,sh	0-6	x	
				2,410-2,470	ss,sh	0-9	f	
				3,070-3,130	ss	0-7	f	
				6,150-6,940	see remarks	0-6	f	
				8,160-8,950	dol	0-6	v,x, f	
56	(A) D-4378	4,251	10,968	760-865	clyst, ss,cgl	0-20	x	Hydrogeologic unit tops: older basin-fill deposits, 220 feet (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 3,154 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 4,736 feet.
(B-10-2) 16BC				934-3,154	cgl,ss, clyst	0-20	x	
				3,255-4,736	cgl, tuff, clyst	0-20	x	
				4,736-6,290	cgl, clyst, ls	0-20	x	
				6,405-7,425	ls,dol, sltst	0-6	v,x	
				9,535-10,025	sh, sltst	0-20	x	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
57	(A) 696-R	4,240	7,918	0-460	cgl	0-20?	x	Hydrogeologic unit tops: older basin-fill deposits and sedimentary and igneous rocks of Middle Triassic to Quaternary age absent; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 460 feet.
(B-10-7) 17AC				1,495-1,540	ss	6	x	
				1,600-4,040	ss,sh	0-6	x,f	
				6,750-6,785	ls	4	v	
58	(A) D-2986	4,242	2,442	25-65	ls	0-12	o	Hydrogeologic unit tops: older basin-fill deposits, land surface; sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,104 feet.
(B-8-7) 9BD				230-280	sltst, mrlst	20	o	
				2,020-2,160	ls	0->20	f,v	
				2,220-2,440	ls	0-20	f,v	
59	(A) D-1478	8,173	6,431	0-2,760	ss	5->20	x	Hydrogeologic unit tops: older basin-fill deposits, land surface (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, absent; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 2,975 feet.
(B-2-2) 20BB				2,800-2,885	ss	0-6	x	
				3,170-3,230	dol,sh	0-6	p	
				4,115-4,145	sltst	20	x	
				4,170-4,240	sltst	20	x	
				4,415-6,405	ss	0->20	x	
60	(A) D-4597	4,635	11,270	9,845-10,415	dol	0-10	f	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 2,550 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 7,702 feet. Sedimentary and igneous rocks of Middle Triassic to Quaternary age (2,550 to 7,702 feet) consist mostly of salt beds and subordinate marlstone and claystone of the Arapien Shale.
(C-15-7) 23								

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity		Remarks
						Percent	Type	
61	(A) 453-R	5,515	6,202	235-700	ss,dol	0-6	x	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
(C-15-17) 8BA				1,805-1,850	ss,ls	0-6	x	
62	(A) 436-R	5,768	9,010	1,075-1,110	dol	0-4	x	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
(C-16-17) 8CB				5,875-5,980	dol	0-4	x	
				6,775-6,850	dol	0-4	x	
				7,895-8,080	dol	0-4	x	
				8,955-8,985	dol	0-4	x	
63	(A) D-4346	6,070	15,355	695-930	cgl,ss	0->20	x	Hydrogeologic unit tops: older basin-fill deposits, 680 feet (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 930 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 11,348 feet.
(C-20-2) 14DD				935-3,600	ss, sltst, sh,ls	0-20	x	
				3,620-6,320	cgl,ss, sh,ls	0->20	x	
				6,480-8,855	dol,ls, sh,ss	0-8	x,v	
				9,260-11,210	ss,sh	0->20	x	
				13,635-14,720	ss,dol, anhy	0-4	x	
64	(A) D-1579	6,492	8,962	40-120	ss	6-12	x	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, land surface; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 120 feet.
(C-22-4) 21DC				2,430-2,495	ls,sh	0-6	x	
				3,450-4,045	dol,sh, ss	0-7	x,v	
				4,605-5,130	dol,ss, anhy	0-6	x,v	
				5,625-6,425	dol,ls, sh, sltst	0-12	x,v	
				6,490-8,950	dol,sh	0-6	x,v	

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
65	(A) 424-R	6,226	6,955	3,005-3,620	dol	0-4	x,v	Hydrogeologic unit tops: carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, land surface.
(C-22-19) 3DB				4,365-4,400	dol	0-4	x	
				4,750-5,475	dol	0-4	x	
				6,115-6,210	ss	0-3	x	
66	(A) D-4702	6,422	7,730	2,030-2,610	ss	3-6	f	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, land surface; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 2,032 feet. For interval 2,720 to 4,110 feet, porosities represent intervals 5 to 20 feet thick of dolomite, limestone, or sandstone. Lower parts of hole from 6,170 to 7,730 feet penetrate dolomite and limestone intruded by dikes of basic igneous rock.
(C-26-6) 7BA				2,720-4,110	see remarks	4-8	v,x,f	
				4,360-6,110	dol,ls	0-8	x,f	
				6,170-7,650	dol, igneous rocks	0-20	f,x	
67	(A) D-4193	5,205	8,555	3,840-4,285	see remarks	6	f	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, uncertain; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 2,780 feet. For interval 3,840 to 4,285 feet, porosity represents intervals of limestone and dolomite less than 5 feet thick. This hole penetrates to Pioche Shale, which is at base of carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age (see table 1).
(C-26-17) 15D								

TABLE 2.—*Subsurface hydrogeologic data compiled from records of petroleum-exploration wells in Nevada and Utah*—Continued

Well number (plate 2) and location	Data source	Land-surface altitude (feet)	Well depth (feet)	Depth interval (feet)	Lithology	Porosity Percent	Porosity Type	Remarks
68 (C-36-11) 18BD	(A) D-4302	5,515	11,700	410-910	cgl	20?	x	Hydrogeologic unit tops: older basin-fill deposits, absent (?); sedimentary and igneous rocks of Middle Triassic to Quaternary age, 910 feet; carbonate and clastic sedimentary rocks of Middle Cambrian to Early Triassic age, 5,170 feet. For interval 10,210 to 11,520 feet, porosities represent dolomite intervals 10 to 50 feet thick; adjacent limestones do not appear to be porous.
				1,760-2,940	ss,ls, sltst	0-20?	x	
				3,000-5,675	ss,sh	0-12	x	
				7,280-7,360	dol	0-10	v	
				7,995-8,740	ss	0-15	x	
				9,700-9,970	dol,ss	0-4	x	
				10,210-11,520	see remarks	3-12	x,v	
69 (C-37-11) 9AA	(A) D-3982	6,498	5,995	1,025-2,440	dol,ls, anhy,ss	see remarks	v	Hydrogeologic unit tops: sedimentary and igneous rocks of Middle Triassic to Quaternary age, 110 feet. For intervals 1,025 to 2,440 feet and 5,035 to 5,590 feet, porosities of 3 to 8 percent found mostly in dolomite. Igneous intrusion (dike) at 3,290 to 3,310 feet.
				2,560-3,400	ss,sh	0-20	x	
				5,035-5,590	ls,dol, anhy	see remarks	v	
				5,900-5,990	ss	3-10	x	

APPENDIX 1.—METHODS USED TO INTERPRET DRILL-STEM TESTS

Drill-stem tests at petroleum-exploration wells provided some of the more important data used for this study because relatively few aquifer tests have been made for consolidated rocks in the eastern Great Basin. Test procedures involve emplacing inflatable packers in an exploration hole to isolate an interval of interest, and then alternately allowing fluid from that interval to flow into the drill stem (the flow period) and then shutting off the flow and recording the buildup of pressure (shut-in period). The rates of fluid production during flow periods and of pressure increase during shut-in periods can be used to calculate transmissivity, hydraulic conductivity, and the undisturbed formation pressure for the test interval.

Table 3 is a tabulation of elapsed times and pressures recorded during part of a drill-stem test for a well in Independence Valley, Nev. (well 9 in table 2). The test interval was 5,295 to 5,378 ft below land surface and, according to the log for this well (AMSTRAT log D-4724), rocks of the interval consisted of limestone of the Permian Arcturus Formation (middle Cambrian to Lower Triassic carbonate and clastic sedimentary rocks). The land-surface altitude at the well was 5,596 ft. The test consisted of the following parts: (1) an initial flow period (30.2 min. duration); (2) an initial shut-in period (90.5 min.); (3) a final flow period (29.3 min.); and (4) a final shut-in period (121.3 min.). Table 3 lists times and pressures for the final shut-in period. The test interval produced 145 gal of drilling mud during the two flow periods at an average rate of 2.4 gal/min. The mud had invaded the limestone during drilling and probably was forced out by ground water because oil or gas was not discovered in this well.

The petroleum industry analyzes data such as those shown in table 3 using a technique devised by Horner (1951) and described by Earlougher (1977). The technique is analogous to the Theis recovery formula (Ferris and others, 1962, p. 100–103). The data are plotted graphically (fig. 5) so that the vertical axis represents shut-in pressure and the horizontal axis represents the logarithm of the dimensionless time term:

$$\log \frac{t_p}{\Delta t} + 1 \quad ,$$

where

t_p = time of previous flow periods, in minutes; and
Δt = elapsed time since the shut-in period began, in minutes.

The part of the resulting curve where Δt becomes large (as the horizontal axis approaches one) can be used to calculate estimated hydraulic properties of the test interval. In principle, the general form of the equation for the linear (long-term) part of the curve should be

$$P_w = P_o - 35.4 \frac{Q}{T\mu} \times \log \frac{t_p}{\Delta t} + 1 \quad ,$$

TABLE 3.—*Time and pressure data for second shut-in period during drill-stem test at petroleum-exploration well in Independence Valley, Nev. (well 9, plate 2 and table 2)*

[Data from files of Nevada Department of Mineral Resources]

Time since shut-in began (minutes)	Pressure (pounds per square inch)	Time since shut-in began (minutes)	Pressure (pounds per square inch)	Time since shut-in began (minutes)	Pressure (pounds per square inch)
1	814	16	2,095	55	2,255
2	1,292	18	2,121	60	2,262
3	1,515	20	2,140	65	2,267
4	1,650	22	2,155	70	2,272
5	1,745	24	2,168	75	2,277
6	1,819	26	2,180	80	2,281
7	1,872	28	2,189	85	2,285
8	1,915	30	2,198	90	2,288
9	1,951	35	2,215	95	2,292
10	1,982	40	2,229	100	2,295
12	2,030	45	2,239	105	2,297
14	2,067	50	2,248	110	2,299
				115	2,301
				120	2,304

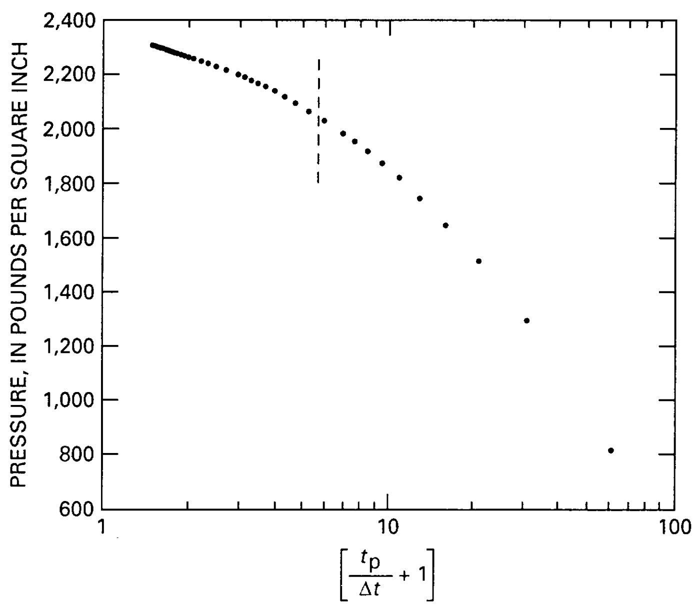


FIGURE 5.—Pressure as a function of logarithm of dimensionless time term for second shut-in period during drill-stem test at well in Independence Valley, Nev. (well 9, pl. 2 and tables 2, 4); known as Horner plot in petroleum industry (Horner, 1951; Earlougher, 1977, p. 46). Eleven data points to the right of vertical dashed line are believed to have been influenced by well-bore affects and were rejected before further analysis. t_p, time in minutes of previous flow periods; Δt, time in minutes since shut-in began.

where

P_o = undisturbed test-interval pressure, in pounds per square inch;

P_w = shut-in pressure, in pounds per square inch, in the test interval at time Δt;

Q = rate at which the test interval produced fluid during all previous flow periods, in gallons per minute;

T = transmissivity, in feet squared per day; and

μ = viscosity, in centipoise, of the test-interval fluid.

The slope of this equation, determined from the data (fig. 5), is represented by the term

$$35.4 \frac{Q}{T\mu}$$

and, if μ=1 is assumed, the transmissivity can be computed from the term because Q is known. The constant 35.4 produces values of T that are in conventional units (feet squared per day). When elapsed time (Δt) of the shut-in period is large, the curve approaches the vertical axis and the value of the intercept on that axis is called the theoretical or undisturbed formation pressure. This pressure can then be used to compute the height above the test interval at which freshwater would stand. The actual height to which drilling mud and (or) formation fluid would eventually rise in the drill stem could differ from the computed height of the potentiometric surface because of high temperatures and fluid densities. Corrections for these properties of the fluid were not made in the computations because neither property was consistently reported for all the drill-stem tests analyzed.

A useful means of obtaining the equation above for a specific drill-stem test is to visually determine from the graph (fig. 5) which of the data late in the shut-in period approximate a straight line. These data are then used to obtain a least-squares fit (by linear regression) of pressures recorded during the shut-in period against corresponding values of the logarithm of the dimensionless time term. Using this method for the data listed in table 3 and plotted on figure 5, the equation is

$$P_w = 2{,}381 - 402 \log \frac{t_p}{\Delta t} + 1 \quad ,$$

where the constants 2,381 and 402 are the theoretical formation pressure if Δt approaches infinity and the slope of the equation, respectively. Both of these values must be multiplied by 2.3 (conversion from pounds per square inch to feet of head) before being used to solve for altitude of the hydraulic head and transmissivity. The calculated values of transmissivity, hydraulic conductivity, and altitude of the hydraulic head computed from the top of the test interval are 0.09 ft^2/d, 0.001 ft/d, and 5,800 ft, respectively.

APPENDIX 2.—METHODS USED TO INTERPRET AEROMAGNETIC DATA

Interpretation of the aeromagnetic map for the eastern Great Basin (pl. 4) is difficult in some areas because of the complexity of magnetic anomalies. This complexity is caused mostly by the overlap of magnetic fields due to source bodies that have differing contents of magnetic minerals, depths, and geometries. Three rock types in the eastern Great Basin probably are the most common sources for anomalies on plate 4: Precambrian crystalline basement, Jurassic to Tertiary granitic rocks, and Cenozoic volcanic rocks. Comparison of magnetic anomalies with nearby outcrops of exposed source rocks indicates that crystalline basement and granitic rocks produce long-wavelength, high-amplitude anomalies whereas volcanic rocks produce short-wavelength, low-amplitude anomalies. Where two of these rock types (volcanic and granitic rocks for instance) are superimposed, the resulting magnetic field can be complex. The most common effect is that short-wavelength anomalies due to volcanic rocks partly obscure broader anomalies.

The subsurface geometry of source bodies for long-wavelength anomalies is considered most significant in this study because these bodies may function as barriers to regional ground-water flow. Consequently, source bodies for short-wavelength anomalies are of minimal interest, and the anomalies constitute noise that must be removed or suppressed so that long-wavelength anomalies can be better defined. Several digital processing techniques are available for accomplishing this, and each can be used to remove or suppress a certain range of anomaly wavelengths and, in effect, enhance others. Because long-wavelength anomalies are of primary interest, the data shown on plate 4 were reduced using a technique called the pseudogravity transformation. This approach has two main advantages: (1) it is a frequency filter that suppresses short-wavelength anomalies and thus enhances broader long-wavelength anomalies (T.H. Hildenbrand, U.S. Geological Survey, oral commun., 1986), and (2) it removes the dipolar effect that results from the inclination of the Earth's magnetic field so that anomalies are plotted directly over their sources (Baranov, 1957, p. 381–382). The aeromagnetic data shown on plate 4 were filtered with a computer program specifically designed for analysis of such data (Hildenbrand, 1983). The mathematical theory of the pseudogravity transformation* and its uses and limitations were discussed by Baranov (1957), Baranov and Naudy (1964), Hildenbrand (1983), and Grauch and Cordell (1987).

*Use of the pseudogravity transformation requires only the assumption that the direction of magnetization is the same for all sources.

Figures 6–8 are computer-generated maps of a small area in south-central Nevada (see inset area on pl. 4) that show the sequence of steps used to determine the subsurface geometries of source bodies for broad long-wavelength anomalies in the eastern Great Basin.

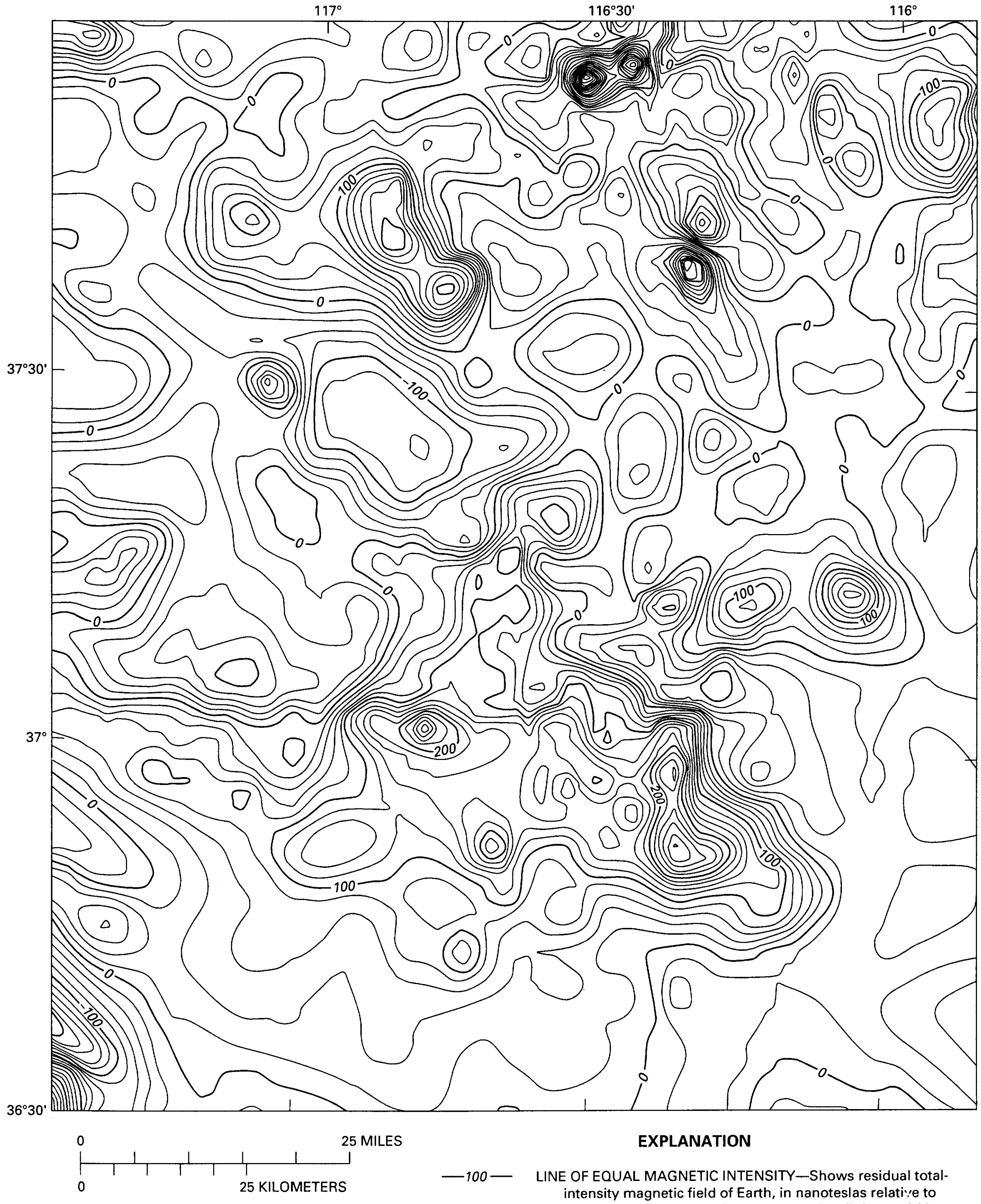
Figure 6 is an aeromagnetic map showing the total intensity magnetic field of the area. The map was taken directly from the aeromagnetic map of the eastern Great Basin (pl. 4). Some of the more prominent features on this map are the numerous short-wavelength anomalies whose sources are outcrops of volcanic rocks that occur throughout much of the area. In addition, several broader anomalies are discernible to differing extents. The largest is in the south-central part of the map area and is defined by steep magnetic gradients trending northwest and north-northeast; however, this feature is partly obscured by several short-wavelength anomalies. To the north, several other broad anomalies are generally easier to distinguish than the larger one to the south.

Figure 7 is the pseudogravity transformation of the data shown in figure 6. Comparison of these figures shows that (1) short-wavelength anomalies are suppressed and broader anomalies (presumably due to Precambrian basement or to Jurassic and Tertiary granitic rocks) are well defined, and (2) anomalies are displaced somewhat northward so that the effect of the geomagnetic field inclination at this latitude is largely eliminated.

The steepest gradients of the pseudogravity field around each anomaly are over the margins of the associated source body, assuming that the margins are vertical or near-vertical[†]. The gradients represent depositional, structural, or intrusive boundaries where magnetic rocks are in contact with relatively nonmagnetic rocks. Figure 8 is a map of horizontal gradients computed from the pseudogravity field map. The highs on figure 8 correspond to gradient maxima observed on figure 7, and consequently, delineate the margins, subject to limitations, of associated magnetic source bodies, which are shown as the shaded areas.

Approximate depths to magnetic sources also were estimated for the more prominent magnetic highs on plate 4. The method used involves two steps. First, the anomaly is visually inspected and one or more areas where it is well defined by steep gradients are selected for measurement. Second, the horizontal extent (at map scale) is measured at each area where the gradient is most intense. This horizontal distance is the approximate distance between the instrument and magnetic source, and can be converted to depth to source using the appropriate land-surface altitude and flight altitude of the magnetic survey. The method is a variation and simplified approach (T.G. Hildenbrand and H.R. Blank, U.S. Geological Survey, oral communs., 1986 and 1989) to a method developed by Vacquier and others (1951).

[†]This assumption is not always valid. For instance, the margin of a source body is offset from the associated gradient maximum if the margin does not dip vertically. For regional surveys, however, the amount of offset is generally not significant (Grauch and Cordell, 1987, p. 121).



EXPLANATION

—100— LINE OF EQUAL MAGNETIC INTENSITY—Shows residual total-intensity magnetic field of Earth, in nanoteslas relative to arbitrary datum (12,500 feet above sea level). Interval 20 nanoteslas

FIGURE 6.—Total-intensity magnetic field for area in south-central Nevada. See inset area on plate 4 for location.

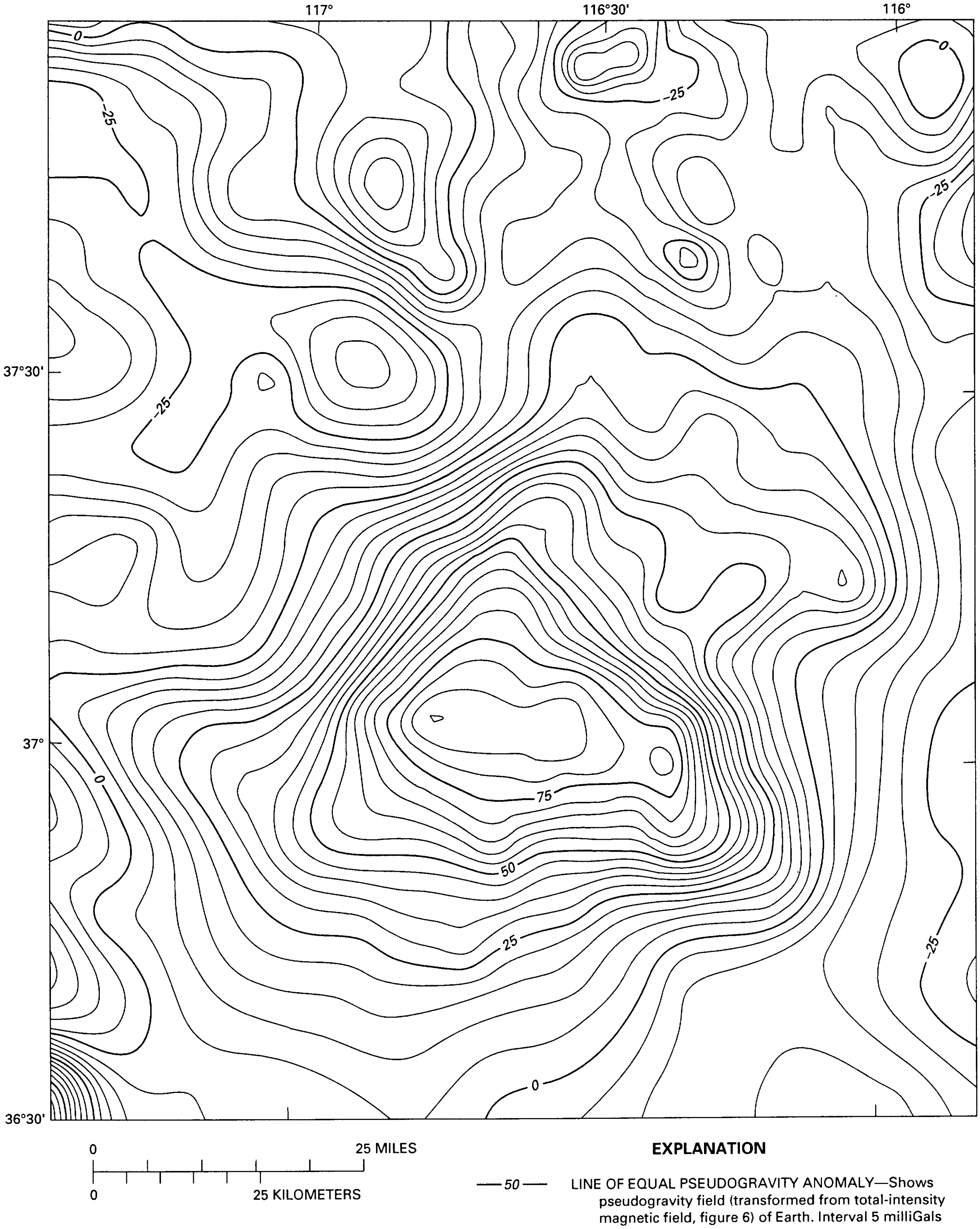


FIGURE 7.—Pseudogravity field for area in south-central Nevada. See inset area on plate 4 for location.

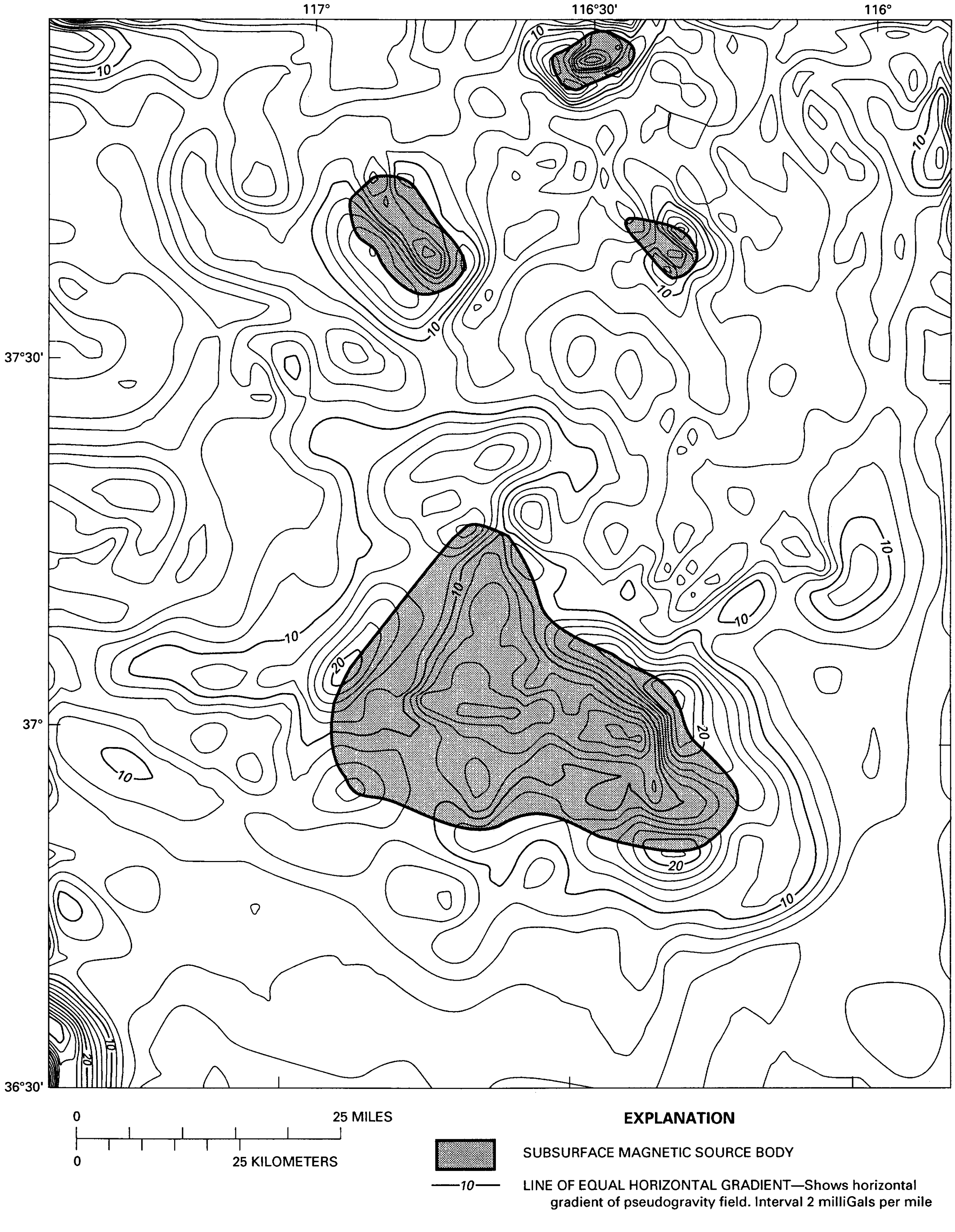


FIGURE 8.—Magnitude of horizontal gradient of pseudogravity field for area in south-central Nevada. See inset area on plate 4 for location.

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