GEOLOGIC AND HYDROLOGIC CHARACTERIZATION AND EVALUATION OF THE BASIN AND RANGE PROVINCE RELATIVE TO THE DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

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PART III--GEOLOGIC AND HYDROLOGIC EVALUATION

By M. S. Bedinger, K. A. Sargent, and B. T. Brady

U.S. GEOLOGICAL SURVEY OPEN-FILE REPORT 83-756

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This is Part III of a series of reports being prepared by the U.S. Geological Survey in consultation with States in the Basin and Range Province.

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CONVERSION FACTORS

English unit		Conversion factor	Metric unit
square kilometers (km^2)	X	0.386	= square mile (mi^2)
meter (m)	X	3.281	= foot (ft)
kilometer (km)	X	0.621	= mile (mi)
millimeter (mm)	X	0.039	= inch

GEOLOGIC AND HYDROLOGIC CHARACTERIZATION AND EVALUATION OF THE BASIN AND RANGE PROVINCE RELATIVE TO HIGH-LEVEL RADIOACTIVE WASTE,

PART III

GEOLOGIC AND HYDROLOGIC EVALUATION

by

M.S. Bedinger, K.A. Sargent, and B.T. Brady

Summary

This report describes the first phase in evaluating the geology and hydrology of the Basin and Range Province for potential suitability of geohydrologic environments for isolation or high-level radioactive waste. The evaluation or the Province applies the guidelines, discussed in Part I (Bedinger, Sargent, and Reed, 1983) of this report to the geologic and hydrologic information compiled for the Province in Part II (Sargent and Bedinger, 1983).

The geologic and hydrologic factors considered in the Province evaluation include distribution of potential host rocks, tectonic conditions and data on ground-water hydrology. Potential host media considered include argillaceous rocks, tuff, basaltic rocks, granitic rocks, evaporites, and the unsaturated zone. The tectonic factors considered are Quaternary faults, late Cenozoic volcanics, seismic activity, heat flow, and late Cenozoic rates of vertical uplift. Hydrologic conditions considered include length of flow path from potential host rocks to discharge areas, interbasin and geothermal flow systems and thick unsaturated sections as potential host media.

The Basin and Range Province was divided into 12 subprovinces; each subprovince is evaluated separately and prospective areas for further study are identified. About one-half of the Province appears to have combinations of potential host rocks, tectonic conditions, and ground-water hydrology that merit consideration for further study.

The prospective areas for further study in each subprovince are summarized in a brief list of the potentially favorable factors and the issues of concern. Data compiled for the entire Province do not permit a complete evaluation of the favorability for high-level waste isolation. The evaluations here are intended to identify broad regions that contain potential geohydrologic environments containing multiple natural barriers to radionuclide migration.

Introduction

This report, the third of three parts, evaluates areas within the Basin and Range Province for their potential to contain geohydrologic environments suitable for isolation of high-level radioactive waste. Based on geologic and hydrologic factors, regions are identified that appear to warrant further investigation. Information used in evaluation includes distribution of potential host rocks, tectonic conditions, and groundwater hydrology. This and supplementary information on Pleistocene hydrologic features, are discussed in Part II (Sargent and Bedinger, 1983) of this report. References to reports and sources of information cited in the report on characterization of the geology and hydrology (Part II) are not repeated in this report (Part III). Evaluations follow the guidelines adopted by the Province Working Group described in Part I (Bedinger, Sargent, and Reed, 1983).

The objective of this phase of evaluation is not to identify all prospective environments in the Basin and Range Province, but to identify regions of several thousands to several tens of thousands of square kilometers that appear promising for further study. The generalized data compiled for the Province evaluation stage will not permit complete evaluation of the factors being considered. For example; host-rock distribution is known principally from outcrops. Detailed evaluation would need data on subsurface distribution, thickness, depth, and physical properties. Another example is ground-water travel time. Time of ground-water flow from a point in the aquifer to the discharge area is a function of flow length, hydraulic conductivity, effective porosity, and hydraulic gradient. Of these, the principal data compiled for Province characterization were hydraulic gradient and length of flow path.

Acknowledgments

The State members and alternates of the Province Working Group were the principal consultants and reviewers during the evaluation of geologic and hydrologic information and preparation of this report. In addition to the members of the Basin and Range Province Working Group and alternates, the following individuals are acknowledged for their assistance during various phases of preparation, compilation, and review of this report: Don R. Mabey of the Utah Geological and Mineral Survey; John Hawley and William Stone of the New Mexico Bureau of Mines and Mineral Resources; and Robert B. Scarborough of the Arizona Bureau of Geology and Mineral Technology. Acknowledgment is given to Isaac Winograd, Newell Trask, Robert Schneider and George Dinwiddie of the U.S. Geological Survey for consultation during the process of Province evaluation and helpful suggestions and critical review of the report.

Evaluation of Province subdivisions

The Basin and Range Province is herein divided into 12 subprovinces (fig. 1), that are convenient subdivisions for

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Figure 1 belongs near here.

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evaluating the geology and hydrology of the Province. Subprovinces are further subdivided into ground-water units, which in turn, are systematically numbered within each subprovince. The method used in defining ground-water units is described in Part II of this report (Sargent and Bedinger, 1983). The boundary of the Basin and Range Province, as used for this study, closely follows the physiographic province defined by Fenneman (1938). The boundary, as used here, follows the natural ground-water flow-unit boundaries that define most of the study area.

Trans-Pecos subprovince

The Trans-Pecos subprovince of Texas and New Mexico (fig. 2)

Figure 2 belongs near here.

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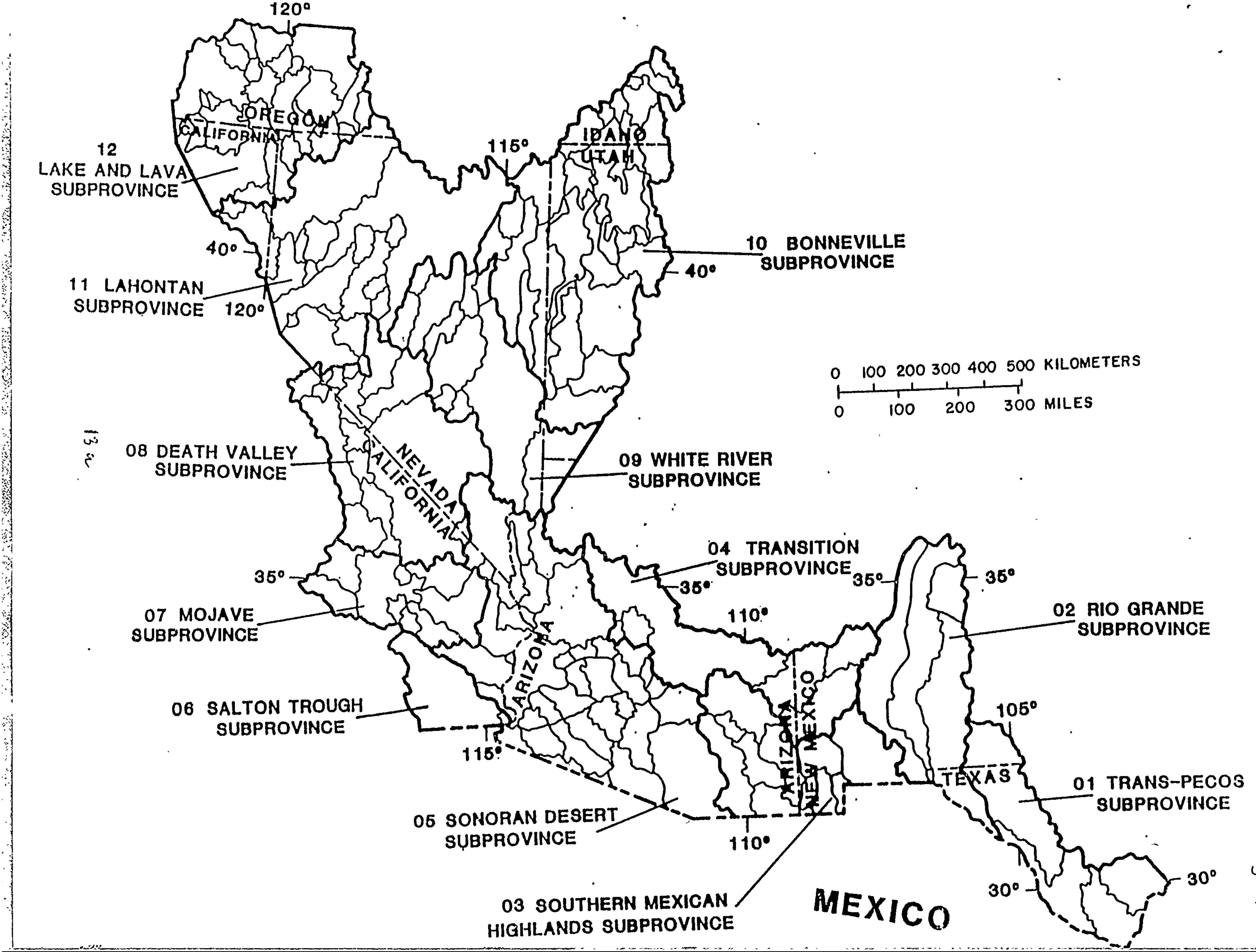
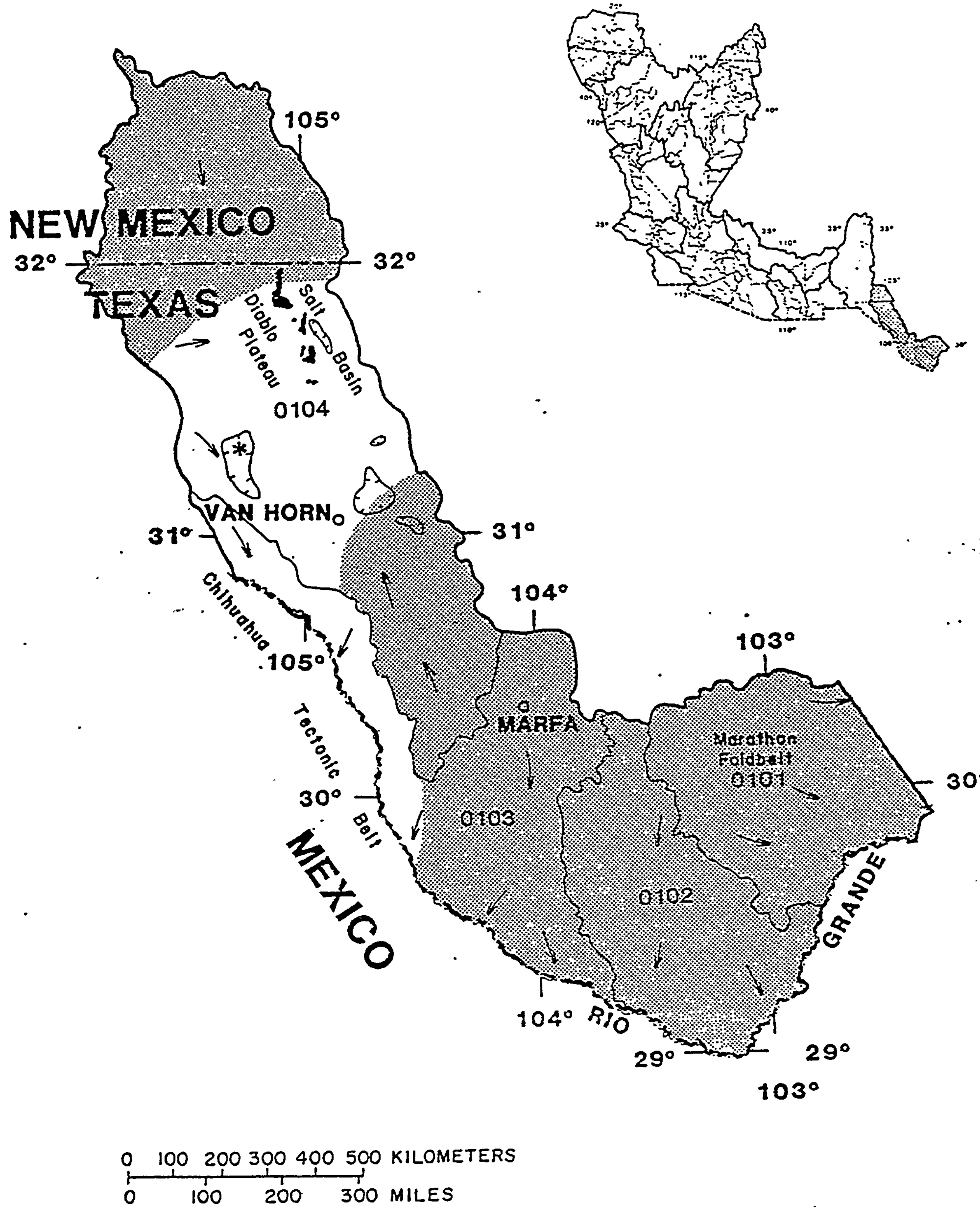
includes basins tributary to the Rio Grande, and a large closed basin of interior drainage. The bedrock includes Precambrian basement rocks, Paleozoic and Cretaceous sedimentary rocks, and Tertiary volcanic and intrusive rocks. Structurally, this subprovince is transitional between the near-horizontal Paleozoic rocks of the interior craton to the east, and the complex structure of the Basin and Range Province to the west.

Figure 1.--Map of the Basin and Range Province as defined for this study showing extent and names of subprovinces.



120°
OREGON
CALIFORNIA
12
LAKE AND LAVA
SUBPROVINCE
IDAHO
UTAH
115°
10 BONNEVILLE
SUBPROVINCE
40°
40°
11 LAHONTAN
SUBPROVINCE
120°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES
08 DEATH VALLEY
SUBPROVINCE
NEVADA
CALIFORNIA
09 WHITE RIVER
SUBPROVINCE
04 TRANSITION
SUBPROVINCE
35°
35°
35°
35°
07 MOJAVE
SUBPROVINCE
110°
02 RIO GRANDE
SUBPROVINCE
ARIZONA
06 SALTON TROUGH
SUBPROVINCE
NEW MEXICO
ARIZONA
105°
115°
TEXAS
01 TRANS-PECOS
SUBPROVINCE
05 SONORAN DESERT
SUBPROVINCE
110°
30°
30°
03 SOUTHERN MEXICAN
HIGHLANDS SUBPROVINCE
MEXICO

Figure 2.--The Trans-Pecos subprovince, New Mexico and Texas, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas or significant ground-water withdrawal by wells, or in unit 0104, a natural depression in the water table (noted by *).



105°
NEW MEXICO
32°
32°
TEXAS
Diablo Plateau
Salt Basin
0104
VAN HORN
31°
31°
104°
Chihuahua
105°
103°
Tectonic
MARFA
Marathon Foldbelt
0101
30°
30°
Belt
0103
MEXICO
0102
GRANDE
104°
RIO
29°
29°
103°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

14a

Granite and syenite occur both as deep-seated masses and laccoliths. The deep-seated masses may be potential host rocks in the saturated and unsaturated zones. Near-surface bodies, such as laccoliths, may be potential host rocks in the unsaturated zone. Shale beds of Permian, Upper Cretaceous, and lower Tertiary age crop out in the subprovince. Argillaceous rocks as thick as 460 meters (1,500 feet) occur in units 0101 and 0102. Ash-flow tuff beds are thin, generally less than 20 meters (65 feet); however, within caldera collapse zones, thicknesses as great as 800 meters (2,600 feet) have been reported in unit 0103. Individual basalt flows generally are less than 15 meters (50 feet) thick, but locally, aggregate thicknesses of basalt flows may be about 150 meters (500 feet). Evaporites occur as interbeds of the Yeso Formation of Permian age in the northern part of unit 0104, and as bolson deposits of Tertiary and Quaternary age in the Salt Basin (unit 0104).

Much of the subprovince appears to be relatively stable as evidenced by little seismic activity and heat flow, slow rate of vertical movement (1 to 2 meters or 3 to 6 feet per 10,000 years), absence of Quaternary volcanic rocks, and few mapped Quaternary faults; however, data are limited for the subprovince. Reilinger, Brown, and Powers (1980) present releveling data that indicate tectonic uplift in the Diablo Plateau east of El Paso (unit 0104).

Long flow paths from potential host rocks near and at the boundaries of basins to natural discharge areas or ground-water withdrawal areas may be indicative of long flow times. Ground water is withdrawn for irrigation in many basin-fill areas. Locally, ground-water use is limited because of saline water (dissolved-solids concentrations greater than 1,000 milligrams per liter) in basin fill.

Interbasin ground-water flow from unit 0104 is inferred to occur both eastward into the Pecos River basin, and westward into the narrow sections of unit 0103 bordering the Rio Grande. These interbasin flows are inferred by Gates and others (1980), on the basis of water-budget data, and the presence of a water-table depression on the west side of unit 0104. This depression is not due to pumping and is presumed to indicate downward flow from the water-table aquifer to deeper aquifers.

The unsaturated zone is greater than 150 meters (500 feet) thick in parts of the subprovince. Large areas with a thick unsaturated zone underlie the northern part of unit 0104, and occur under the topographically higher parts of units 0101, 0102, and 0103.

The statements in the following table pertain to units 0101 and 0102, part of unit 0103, and parts of unit 0104 (shaded in figure 2), which appear to merit consideration for further study:

Potentially favorable factors	Issues of concern
* Potential host media include saturated and unsaturated intrusive plutonic granite and syenite. Locally, tuff and basalt may be potential host rocks in the unsaturated zone. * Available mapping and data indicate regionally little heat flow, vertical movement, and seismicity; few Quaternary faults, absence of Quaternary volcanic activity. * Little tectonic activity and studies showing slow rates of vertical uplift would appear to indicate slow denudation rates. * Long flow paths from ground-water divides to natural discharge areas and areas of large ground-water withdrawal. * Small ground-water yields would be expected from igneous intrusive rocks.	* Problems in differentiating shallow laccolithic intrusive bodies from plutonic masses. * Areas of Quaternary faulting, recent uplift and seismicity have been identified and need to be studied further to determine the extent of tectonic activity. * Natural flow paths may be shortened by ground-water withdrawal. * Complicated geology in the Marathon fold belt (unit 0101) and the Chihuahua tectonic belt (unit 0103) present problems in defining the geohydrologic framework of the subprovince.

In the central part of unit 0104, and in that part of unit 0103 bordered on the west by the Rio Grande and on the east by unit 0104, ground-water flow paths are relatively short, and ground-water withdrawal is locally large. Ground-water flow is not well-defined where interbasin flow is inferred to occur from unit 0104. These areas are considered to be less favorable for further study.

Rio Grande subprovince

The Rio Grande subprovince of New Mexico and Texas (fig. 3)

Figure 3 belongs near here.

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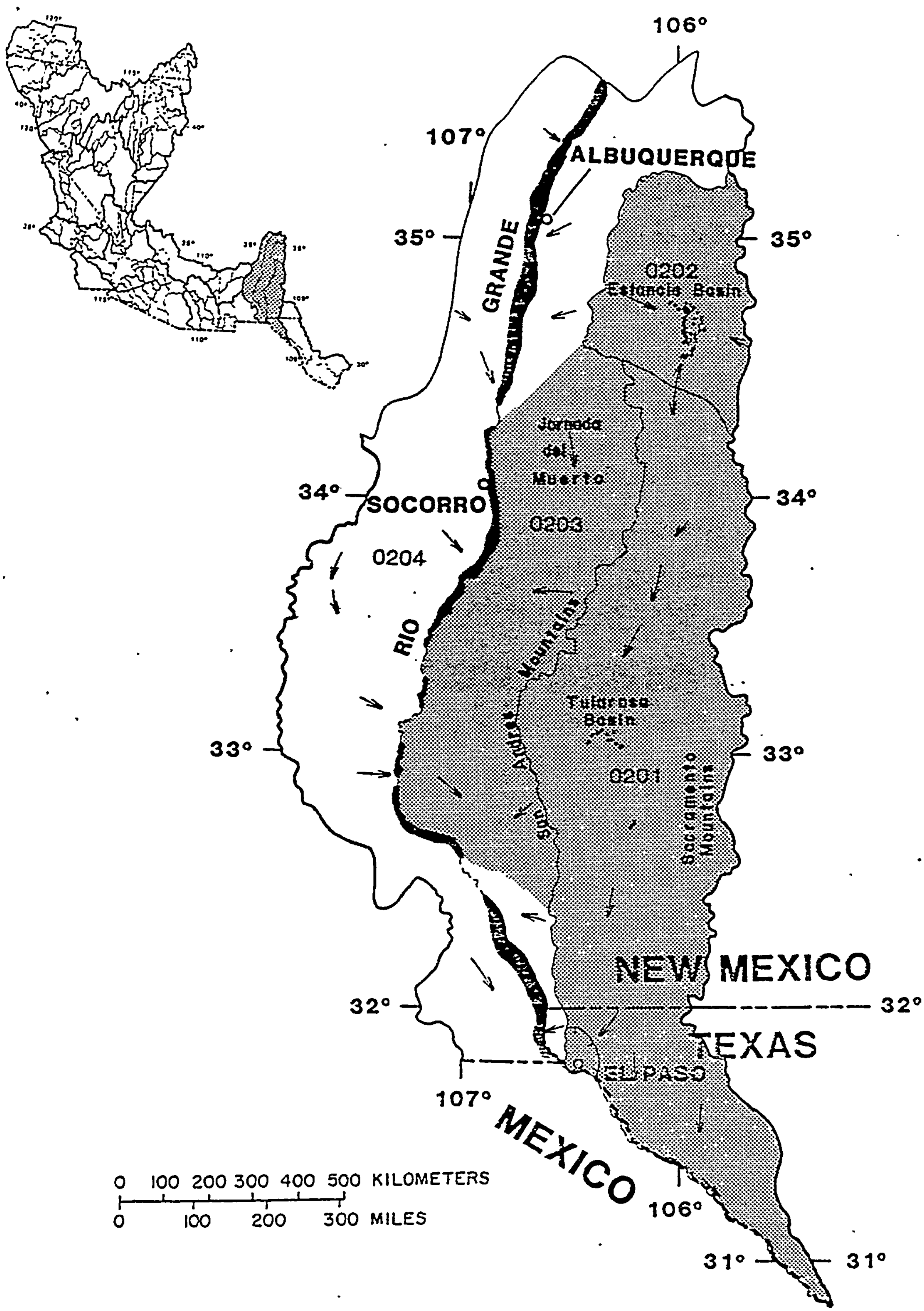
follows the structural trough that extends from Mexico into Colorado. The subprovince includes the broad alluvial valley of the Rio Grande, and its adjacent uplands, composed largely of Paleozoic sedimentary and Cenozoic intrusive and extrusive rocks. The subprovince includes, east of the Rio Grande, three structural basins--the Jornada del Muerto in the central part of unit 0203, the Estancia basin in unit 0202, and the Tularosa basin in unit 0201. The Jornada del Muerto is a broad, elongate synclinal basin of Paleozoic and Mesozoic sedimentary rocks overlain by deposits of Tertiary and Quaternary age. The Estancia basin is a topographically closed synclinal basin, bordered on the east and west by Precambrian crystalline rocks overlain by sedimentary rocks of Paleozoic age and basin fill of Quaternary and probable Tertiary age. South of the Estancia basin is the Tularosa basin, an elongated graben bounded by Paleozoic rocks of the San Andres Mountains on the west and the Sacramento Mountains on the east. The basin fill is of late Tertiary and Quaternary age. The Tularosa basin extends southward to the Rio Grande at the Texas-Mexico border. Surface drainage in the central part of the basin is closed; ground-water discharge is by evapotranspiration in the central part of the basin, seepage to the Rio Grande, and withdrawal by wells in the vicinity of El Paso. Surface drainage of units 0203 and 0204, bordering the Rio Grande, is to that river.

Figure 3.--The Rio Grande subprovince, New Mexico and Texas, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Area outlined by solid hachured line is area of significant ground-water withdrawal by wells.


106°
107°
ALBUQUERQUE
35°
35°
GRANDE
0202
Estancia Basin
Jornada
del
Muerto
34°
34°
SOCORRO
0203
0204
RIO
Mountains
Andres
San
Tularosa
Basin
33°
33°
0201
Sacramento
Mountains
NEW MEXICO
32°
32°
TEXAS
EL PASO
107°
MEXICO
106°
31°
31°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

20 a

Precambrian and Tertiary granitic rocks and structurally complex Precambrian metamorphic rocks crop out in the mountains along the common border of units 0201 and 0203. Tertiary granitic rocks crop out in unit 0201, and Precambrian granitic rocks crop out in unit 0202 and in the northern part of unit 0203. Scattered Precambrian and Tertiary granitic rocks crop out west of the Rio Grande in unit 0204.

Shale of Paleozoic and Mesozoic age crop out in the subprovince. Argillaceous rocks with some interbedded coarser clastic units are as thick as 550 meters (1,800 feet). Broad facies changes are common in the shale units. Thin-bedded marine evaporites occur in the rocks of Permian age in all units. Saline ground water is found in association with these evaporites.

Laharic breccia ranging in thickness from 600 to 1,070 meters (2,000 to 3,500 feet) occurs in units 0203 and 0204, and may be a potential host rock with confining and sorptive barriers to flow of water and radionuclides. Ash-flow tuff of Oligocene age is believed to be as thick as 900 meters (3,000 feet) in units 0203 and 0204, where it is associated with calderas. Basaltic rocks, as much as 240 meters (800 feet) thick are sparsely distributed in unit 0204.

Tectonic activity in the Rio Grande subprovince presumably is related to the Rio Grande rift. The principal evidence of this tectonic activity is the significant density of Quaternary faults and seismic epicenters in the northern parts of 0203 and 0204; the significant heat flow (as great as 2.5 heat-flow units) in the southern part of units 0203 and 0204; and occurrence of basalt of late Cenozoic age in the central parts of unit 0203 and the southern parts of units 0203 and 0204. Reiter, Shearer, and Edwards (1978) consider geothermal anomalies along the Rio Grande rift evidence of underlying magma bodies. Reilinger and Oliver (1976), and Reilinger and others (1980) have ascribed the crustal doming observed in the Socorro area to activity of an underlying magma body. Rates of uplift are slow (1 to 2 meters or 3 to 6 feet per 10,000 years) in most of the subprovince. East of the Rio Grande, a narrow zone of Quaternary faults parallels the western boundary of unit 0201. Several Quaternary basalt vents occur in the northern one-half of unit 0201. Thermal springs and wells in the Rio Grande valley (units 0201, 0203, and 0204) are evidence of discharge at the surface and to basin fill from hydrothermal convection systems related to the significant heat flow in the Rio Grande rift.

Ground-water quality is variable and in much of the subprovince the water is saline. West of the river (unit 0204), the ground water generally contains less than 500 mg/L (milligrams per liter) of dissolved solids; east of the river in unit 0203, the ground water generally contains 500 to 1,000 mg/L of dissolved solids. In the central part of unit 0203, the Jornada del Muerto, the dissolved-solids concentrations commonly range from 2,000 to 5,000 mg/L. In units 0201 and 0202, the dissolved-solids concentrations generally range from 500 to 5,000 mg/L and are as much as 25,000 mg/L in unit 0201. The large dissolved-solids concentrations of the water in much of the Rio Grande subprovince are derived from solution of marine evaporites in the Paleozoic and Mesozoic bedrock. Saline ground water in many parts of the subprovince has limited large ground-water withdrawals. Ground-water withdrawal is greatest from basin fill near El Paso and from alluvium and basin fill in the irrigated parts of the Rio Grande Valley.

Ground-water flow paths from potential host rocks near ground-water divides to natural discharge areas in units 0201 and 0203 are relatively long and flow times are possibly very long. Unsaturated zones are thick (greater than 150 meters or 500 feet) in many areas throughout the subprovince. Granitic rocks occur in the thick unsaturated sections in parts of unit 0201.

Pleistocene Lake Otero occupied the playa of unit 0201. If pluvial conditions recur, a significant change in the ground-water flow regime in unit (0201) may be an increase in height of the ground-water divide south of the Lake Otero playa and a greater percentage of ground-water flow from the northern part of the unit discharged to the playa.

Potential host rocks are granite, tuff, and laharic breccia in the saturated zone. These rocks also may have thick sections in the unsaturated zone. Areas containing potential host rocks with little tectonic activity, saline ground water, and long flow paths from potential host media to natural discharge areas are prospective units for further study. Unit 0204 and the northern and southern parts of unit 0203 are less suited for further study because of fewer occurrences of potential host rocks, significant heat flow, and greater tectonic activity.

The statements in the following table summarize the favorable conditions and the issues of concern for units 0201 and 0202, and the central two-thirds of unit 0203 (shaded areas in figure 3):

Potentially favorable factors	Issues of concern
* Potential host rocks are in saturated and unsaturated zones. * Tectonic activity generally is low as characterized by little seismicity and heat flow, slow uplift rates, little late Cenozoic volcanic activity and few Quaternary faults. * Ground water commonly is saline in basin fill and sedimentary rocks; potential igneous host rocks have little permeability, consequently, there is minimal inducement for water-supply development. * Long natural flow paths from potential host rocks to natural discharge areas indicate potentially long travel times.	* Potential hazard due to volcanic activity needs to be considered. * Quaternary faults, which are mapped locally, need to be studied and hazards assessed. * Ground water generally is saline, but may be used for some purposes.

Ground-water unit 0204 and the northern and southern parts of unit 0203 are considered to have less potential for further study because of the relatively significant seismic activity and heat flow, density of Quaternary faulting, local rapid rate of uplift in 0204, and generally shorter flow paths from ground-water divides to areas of natural discharge.

Southern Mexican Highlands subprovince

The Southern Mexican Highlands subprovince of Arizona and New Mexico (fig. 4) consists of well-defined northwest-trending

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Figure 4 belongs near here.

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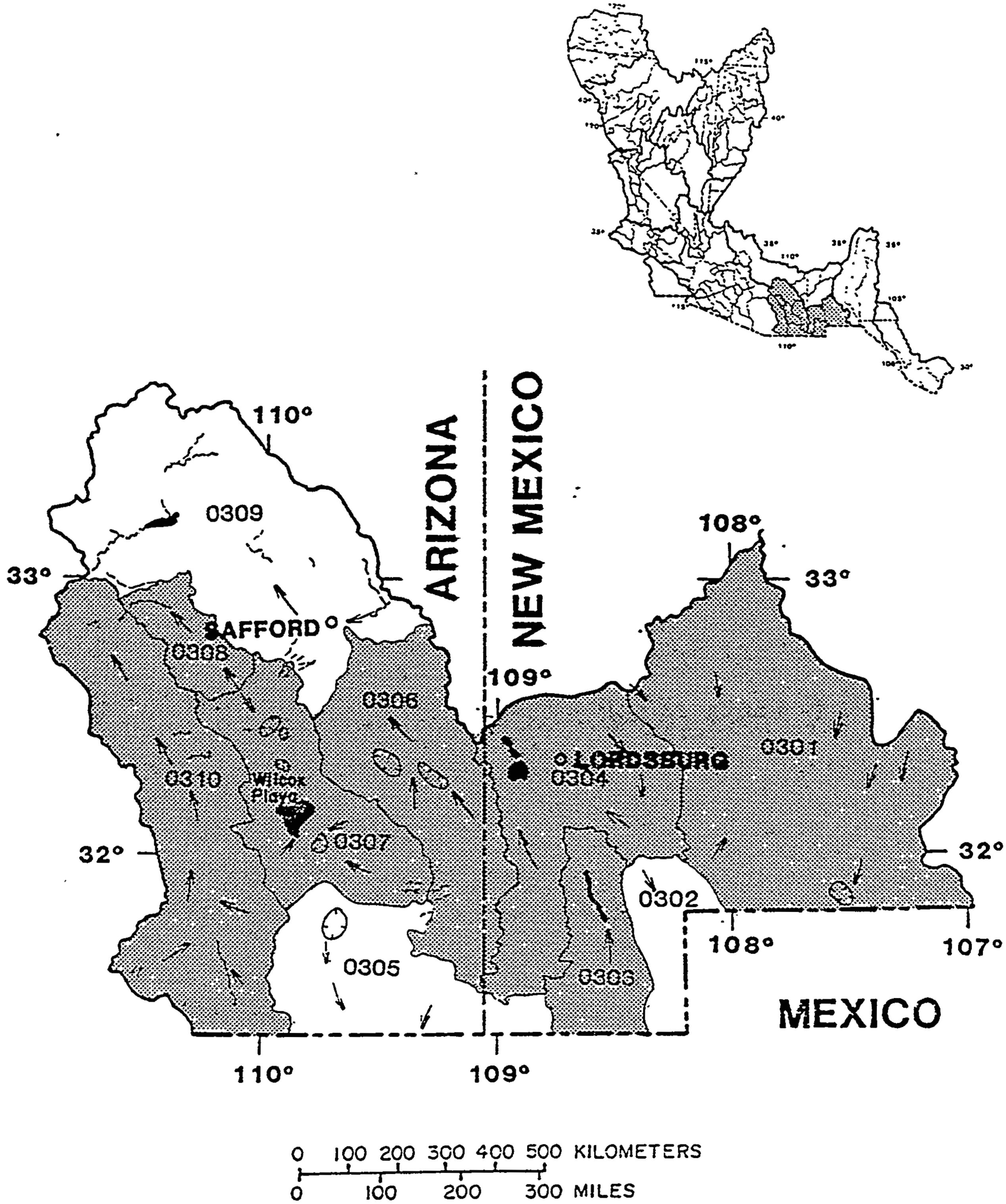
mountain ranges separated by wide valleys. The mountain ranges consist of Precambrian and Paleozoic rocks intruded by Mesozoic and Tertiary granitic stocks and plugs, that are partly overlain by marine and nonmarine sedimentary rocks of Cretaceous age, volcanic rocks of Tertiary age, and extensive basin-fill deposits of late Cenozoic age. Several of the topographically-closed basins in southeast Arizona and southwest New Mexico extend into Mexico.

Figure 4.--The Southern Mexican Highlands subprovince, Arizona and New Mexico, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas of significant ground-water withdrawal by wells.


110°
0309
ARIZONA
NEW MEXICO
108°
33°
33°
SAFFORD
0308
109°
0306
LORDSBURG
0301
0310
Wilcox Playa
0304
0307
32°
32°
0302
0305
108°
107°
0303
MEXICO
110°
109°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

Granite and other intrusive crystalline masses or Precambrian and Tertiary age occur throughout much of the subprovince. Basaltic rocks are common locally, but generally are less than 50 meters (150 feet) thick. Tuff is widespread, but only locally is of sufficient thickness to be considered a possible host rock. Tuff, which is 100 meters (330 feet) or more thick and that may warrant further study, is common in and near the calderas in units 0301, 0302, 0303, 0304, 0305, 0306, and 0307. Laharic mudflow breccia, commonly 150 to 300 meters (500 to 1,000 feet) thick, in units 0304 and 0306 may have potential for study as a host rock. Locally, shale occurs in thicknesses or 150 meters (500 feet) or more. Further study of shale would be needed to determine it it could be considered a potential host rock. Extensive anhydrite, gypsum, and possible salt deposits have been penetrated by drill holes near Safford (units 0306 and 0309), but the extent of the deposits are incompletely known from drilling data at this time (Peirce, 1981).

Heat flow generally is less than 2.5 HFU (heat-flow units) except in parts of units 0301, 0302, and 0303. However, local high-temperature [90^{o} to 150^{o}C (Celsius)] hydrothermal-convection systems are indicated by springs in units 0304 and 0306. Seismicity and vertical uplift are low. Quaternary faults are sparse but widely distributed in the subprovince. Volcanic rocks of late Cenozoic age, generally of minor areal extent, have been mapped in units 0301, 0302, 0304, 0305 and 0309. Tectonic conditions differ within the subprovince and tectonism generally is more intense in the New Mexico part of the subprovince. Long flow paths in most of the units indicate the possibility of long travel times, however, the potential for shortening of flow paths by development of water supplies from ground water near potential repository host media and the effect of recurrence of pluvial conditions need to be considered. Wilcox Playa (unit 0307) contained a lake and Lake Animas occupied the playa in unit 0304 in Pleistocene time. Ground water generally is fresh except in the playa areas. The unsaturated zone has a thickness of 150 meters (500 feet) or greater principally on and near topographic divides in the Arizona part of the subprovince, whereas few occurrences of the unsaturated zone as great as 150 meters (500 feet) are known to occur in the New Mexico part of the subprovince.

Units 0301, 0303, 0304, 0306, 0307, 0308, and 0310 (shaded areas in figure 4) are considered the best prospects for further study. Factors affecting their suitability are summarized in the following table:

Potentially favorable factors	Issues of concern
* Potential host rocks include intrusive igneous rocks, laharic breccia, basalt, and tuff. * Tectonic activity is low. * Unsaturated zone probably is of sufficient thickness and extent to be considered for further study in the Arizona part of the subprovince. * Potential travel times may be long based on the long flow paths from potential host rocks to natural-discharge areas.	* Hazard from Quaternary faulting and igneous activity must be assessed; may be restrictive locally. * Long, natural flow paths would be shorted by withdrawal of ground water downgradient. * Recurrence of lakes during pluvial climate would shorten flow paths.

Units 0302, 0305, and 0309 (fig. 4) generally have shorter flow paths from potential host rocks to natural-discharge and withdrawal areas. In addition, units 0301, 0302, and 0305 extend across the United States-Mexico International border, and some ground-water flow in these units probably moves from the United States into Mexico.

Transition subprovince

The Transition subprovince of Arizona and New Mexico (fig. 5),

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Figure 5 belongs near here.

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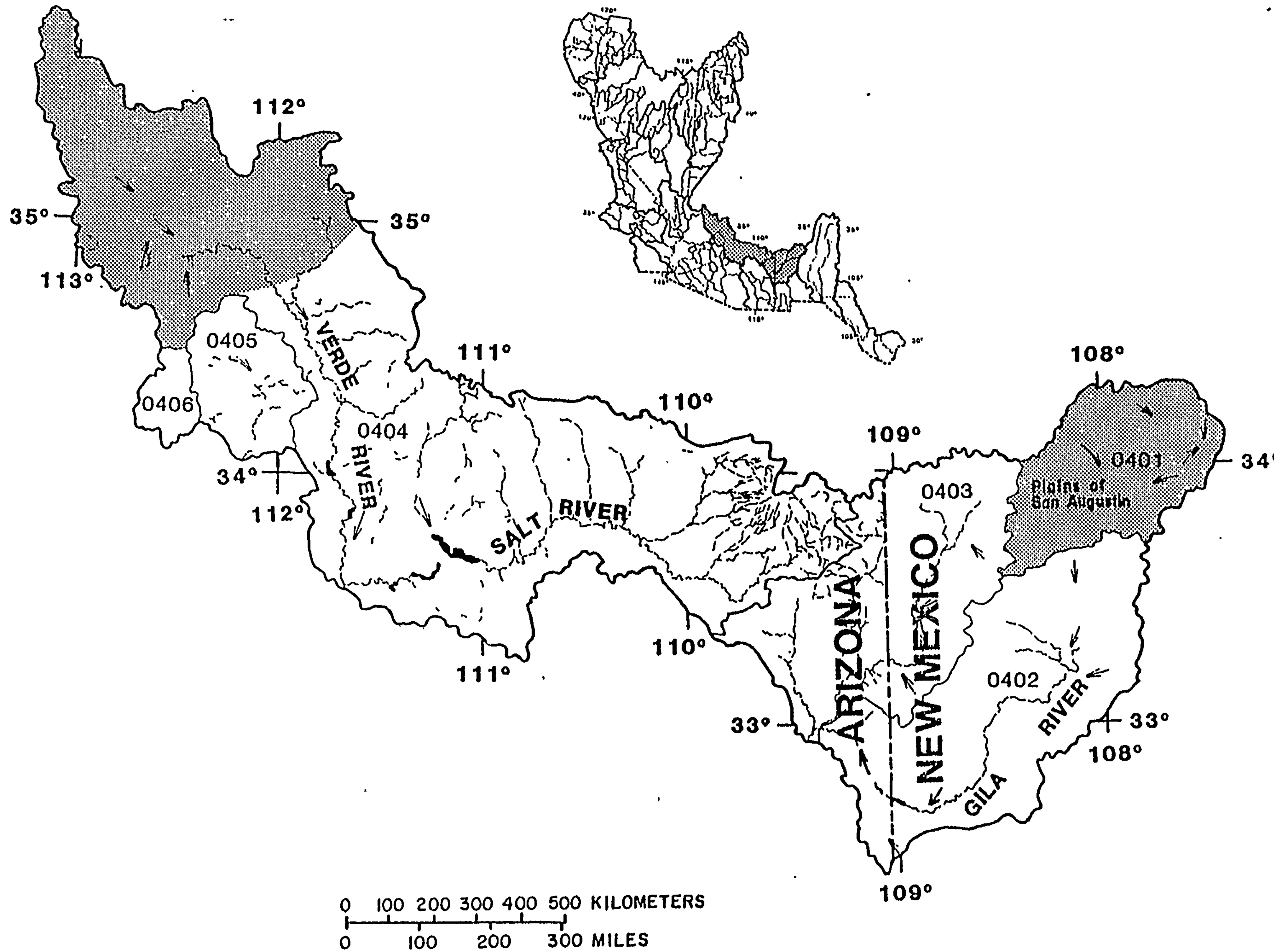
extending 800 kilometers (500 miles) from near the Colorado River in Arizona to the Rio Grande trough in New Mexico, is a geological and topographical zone of transition between the higher Colorado Plateau to the north, and the lower basin and range structure to the south. In New Mexico, the Transition subprovince consists of a block-faulted lava plateau. In Arizona, the subprovince consists of a high southward-facing dissected escarpment of Precambrian crystalline rocks, Paleozoic and Mesozoic sedimentary rocks, and Tertiary lavas. Drainage in most of the Transition subprovince is well developed, and streams drain to the Gila River, except for one closed basin, the Plains of San Augustin (unit 0401) in New Mexico.

Potential host rocks include granite, basalt, and tuff. Granitic rocks of primarily Precambrian age crop out in the central part of unit 0404 and in the southern part of unit 0402. Basalt and tuff outcrops are widespread throughout the subprovince. Tuff associated with calderas in the central and eastern part of the region (units 0401, 0402, 0403, and 0404) is as thick as 600 meters (2,000 feet). Extensive outcrops of Precambrian shale, probably less than 60 meters (200 feet) thick occur in unit 0404.

Figure 5.--The Transition subprovince, Arizona and New Mexico, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge.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0401
Plains of
San Augustin
0403
0402
ARIZONA
NEW MEXICO
GILA
RIVER
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

Tectonic activity, though locally intense, generally is low. Quaternary faults have been mapped in units 0401, 0402, and 0404. Seismicity generally is moderate with maximum magnitude of a few earthquakes as large as 5 and 6. Heat flow is less than 2.5 HFU, except in unit 0402. Local ground-water convection of heat flow is evidenced by hot springs in unit 0402 and 0403. Vertical uplift is less than 2 meters (6 feet) per 10,000 years. Late Cenozoic volcanic activity is evidenced by lava flows and cinder cones in the northern parts of units 0401 and 0403, and in unit 0404 adjacent to the Colorado Plateau.

This subprovince generally is higher in elevation than adjacent parts of the Basin and Range Province, and receives greater precipitation. This results in greater recharge, integrated surface-drainage networks, and many streams that receive ground-water discharge. Two basins are closed: units 0401 and 0406. Ground water in the Plains of San Augustin (unit 0401) may discharge in part within the basin by evapotranspiration. Large springs in unit 0403 and in the Rio Grande basin (unit 0204 in the Rio Grande subprovince) are believed to represent interbasin flow from unit 0401 (John McLean and Robert Meyers, U.S. Geological Survey, oral commun., 1983).

Ground-water quality generally is fresh and contains less than 500 mg/L of dissolved solids. Areas with saline ground water occur in the Verde River valley (western part of unit 0404), Gila River basin (unit 0402) and Salt River basin (eastern part of unit 0404). The unsaturated zone is believed to be 150 meters (500 feet) thick or greater in broad areas throughout the subprovince. During the Pleistocene Epoch, a lake occupying the playa of the Plains of San Augustin (unit 0401) had an areal extent of more than 1,000 square kilometers (400 square miles) and a water level more than 60 meters (200 feet) higher than the shallowest water level in the playa today.

The northwestern part of unit 0404 and all of unit 0401 (shaded in fig. 5) appears promising for further study, as summarized in the table below:

Potentially favorable factors	Issues of concern
* Potential host rocks include unsaturated basalt and tuff; saturated and unsaturated granitic rocks.	* Ground water generally is fresh.
* Flow paths from potential host rocks to natural-discharge areas are long.	* Interbasin flow of ground water from unit 0401 to units 0403 and 0204 (Rio Grande subprovince) is not well known.
* Quaternary faulting and seismic activity generally are low.	* Hazard from volcanic activity needs to be assessed based on further study of upper Cenozoic volcanic rocks.
	* Hazards from seismic activity and faulting needs to be studied further.

The unshaded part of the Transition subprovince (fig. 5) is considered to be less favorable for further study, because of generally short flow paths from potential host rocks to discharge areas, the prevalence of fresh ground water, and locally, areas affected by late Cenozoic volcanic activity.

Sonoran Desert subprovince

The Sonoran Desert subprovince of Arizona, California, and Nevada (fig. 6) includes basins in California, Nevada, and

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Figure 6 belongs near here.

Arizona, many of which have surface drainage to the Colorado River. Many ground-water flow units in central Arizona terminate in depressions created by ground-water withdrawal. The mountain ranges are faulted blocks of Precambrian intrusive and metamorphic rocks, Mesozoic and Tertiary granitic intrusions and volcanic rocks. Basin fill, as thick as 3,000 meters (10,000 feet) and perhaps averaging 900 meters (3,000 feet) thick, ranges in age from middle Tertiary to Quaternary.

Figure 6.--The Sonoran Desert subprovince, Arizona, California, and Nevada, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas of significant ground-water withdrawal by wells.

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Potential host rocks include granitic intrusive rocks and some metamorphic rocks in both tne saturated and unsaturated zones. Granitic and other silicic to intermediate intrusive rocks of Precambrian, Mesozoic, and Tertiary age are widespread in tne subprovince. The Gunnery Range batholith ot southwest Arizona, a particulary large body of quartz monzonite underlying about 40,000 square kilometers (15,000 square miles) of units 0507 and 0523, has potential as a host media in the saturated and unsaturated zones. Basalt, tuff, basin fill, and possibly other rocks are potential host rocks in the unsaturated zone. Basalt crops out in sections 100 meters (300 feet) or more thick in units 0531, 0534, and 0537 in California, and in the part of unit 0536 in California. Basalt occurrences in Arizona and Nevada are generally less than 60 meters (200 feet) thick. Tuff greater than 90 meters (300 feet) thick occurs in California and Nevada in units 0531, 0532 and 0536. Occurrences of tuff in Arizona in units 0503, 0508, 0515, 0516, 0517 and 0524 generally are less than 100 meters (330 feet) thick, but locally may be as much as 600 meters (2,000 feet) thick.

Shale occurs in large outcrops, as great as 80 square kilometers (30 square miles), in stratigraphic sections as tnick as 140 meters (460 feet) in the southeastern part of the subprovince in Arizona in unit 0501. The shale, mostly Cretaceous in age, has undergone considerable tectonic deformation. Shale, mostly of Cambrian age, occurs as small scattered outcrops in California and Nevada.

Thick evaporite deposits, mostly halite, occur in fault-block basins at Detrital Valley (unit 0530), Red Lake basin (unit 0528), and the Luke salt body (unit 0512) west of Phoenix. About 1,800 meters (5,900 feet) of anhydrite occur in the Picacho basin (units 0501 and 0502). Additionally, significant salt deposits may be present in the Higley basin (Peirce, 1981) southeast of Phoenix (units 0505 and 0512).

The region generally is low in seismicity, has few mapped Quaternary faults, and has a few late Cenozoic volcanic centers. Three poorly defined fault zones trend northward in Arizona. A cluster of faults occurs in unit 0536 (near Lake Mead) in Nevada and a concentration of faults is mapped in the western one-half of unit 0532 in California. There has been little recorded seismic activity in the subprovince; however, there are areas of many small earthquakes (such as the western part of unit 0532) and a few epicenters of magnitude 5 and 6. Volcanic vents of late Cenozoic age are mapped in units 0532, 0534 and 0535 in California, and units 0506, 0509, 0517, 0518, 0519 and 0524 in Arizona. Heat flow is between 1.5 and 2.5 HFU throughout the subprovince, and there are relatively few thermal springs in the subprovince. Vertical uplift is slight to moderate throughout most of the subprovince, although moderately rapid rates of uplift have been mapped in unit 0531 and the western part of unit 0532 in California.

Long natural flow paths exist from the ground-water divides to natural-discharge areas in many units. Concentrations of dissolved solids in ground water generally are less than 500 mg/L, but locally are greater in discharging playas. Withdrawal of water is large in many ground-water units particulary in Arizona; withdrawal is nonexistent or negligible in some units in California and western Arizona. The unsaturated zone in many areas is greater than 150 meters (500 feet) thick. The thick unsaturated sections include both basin fill and bedrock. The surface drainage, except for Red Lake basin in unit 0528, is integrated and there is no evidence of pluvial lakes in the subprovince during the Pleistocene Epoch.

The subprovince includes some of the more arid parts of the Basin and Range Province. Annual precipitation is as little as 10 centimeters (4 inches) or less and annual pan evaporation is as great as 356 centimeters (140 inches).

Units that appear to have favorable combinations of potential host rocks, tectonic stability, and long flow paths for further study include units 0501, 0503, 0504, 0507, 0508, 0509, 0515, 0516, 0524, 0525, 0527, 0528, and 0530 in Arizona; units 0531, 0532 (part), 0534, and 0535 in California, and unit 0536 in California and Nevada. These areas are shaded in figure 6. Potentially favorable factors and issues of concern are summarized in the following table:

Potentially favorable factors	Issues of concern
* Potential host media in the unsaturated or the saturated zones or both include granitic rocks, metamorphic rocks, tuff, basalt, and basin fill.	* Large ground-water with-drawals in some units result in shorter flow paths from ground-water divides to discharge areas.
* Long ground-water flow paths from potential host rocks in low permeability media indicate potential for long travel times to natural-discharge areas.	* Ground-water in most of the area is fresh.
	* Locally, hazards of seismic conditions, faulting, and volcanism need to be assessed.
* Tectonic activity is low as indicated by few seismic epi-centers, and slow to moderate vertical uplift.	* Parts of western Arizona and California contain complex bedrock geology that is not well known.
* No evidence of Pleistocene lakes in the subprovince.	
* Crystalline igneous and meta-morphic rocks yield small quantities of water to wells.	
* Precipitation is greatly exceeded by potential evapotranspiration.	

Units 0501, 0503, 0506, and 0523 are, in part, tributary to and extend across the International border with Mexico. Ground-water units 0526, 0529, 0537, and units in central Arizona provide relatively short flow paths and limited outcrops of potential host rocks.

Salton Trough subprovince

The Salton Trough subprovince (fig. 7) of southern California

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Figure 7 belongs near here.

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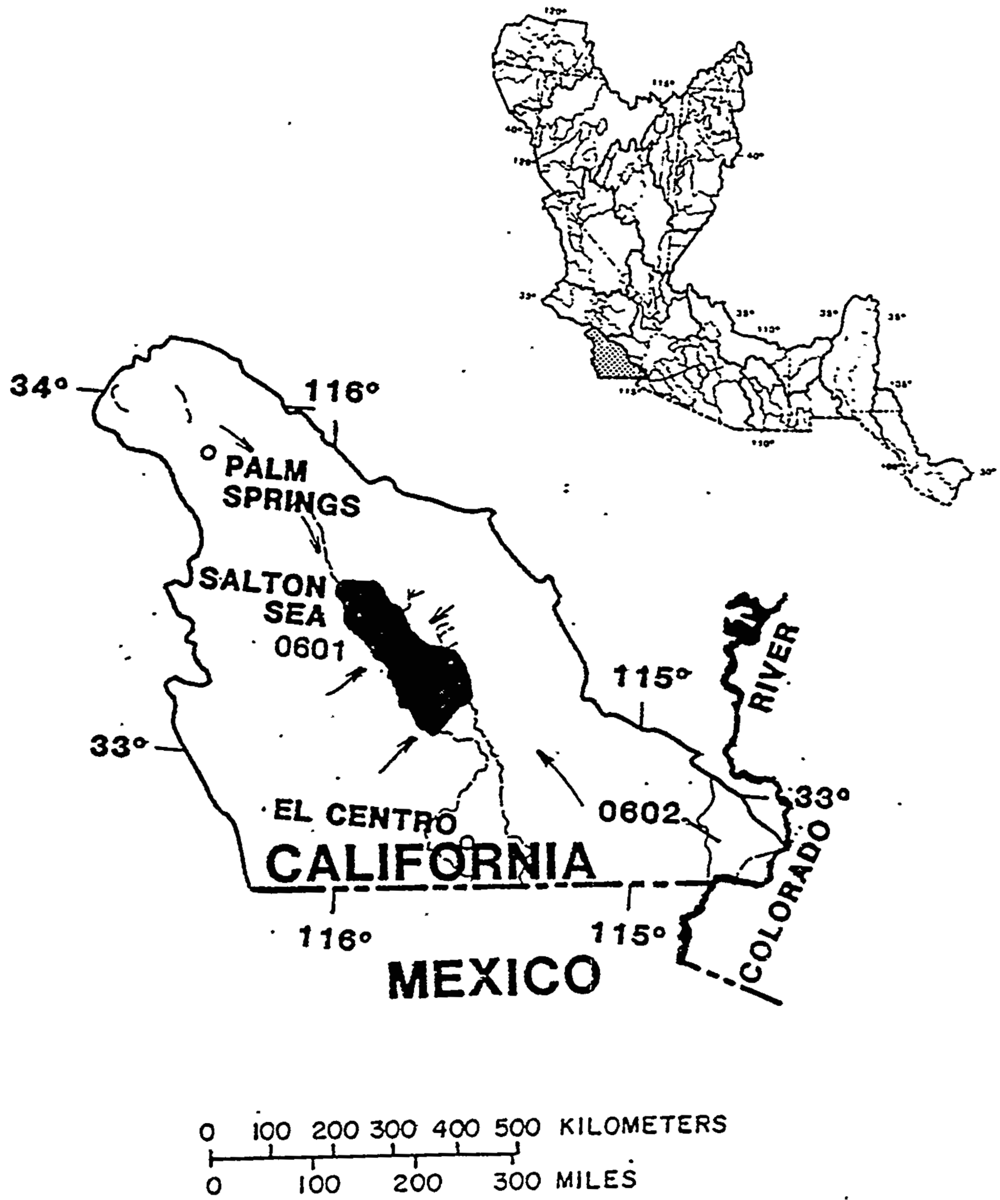
is a large desert trough with a broad alluvial slope and delta plain. The trough is a northward extension of the basin in which lies the Gulf of California. The Salton Trough is bounded by mountain ranges on the northeast and on the southwest. The structural trough is open to the southeast where it is occupied by the Gulf of California.

Granitic rocks are widespread in the ranges of the subprovince and are the primary potential host rocks. Small outcrops of basalt and tuff occur in the subprovince.

Tectonically the subprovince is very active as evidenced by the numerous Quaternary faults, density of earthquake epicenters, Quaternary rhyolite occurrences, rapid rates of vertical movement, and significant heat flow.

Figure 7.--The Salton Trough subprovince, California. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are steams that receive ground-water discharge.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0 100 200 300 400 500 KILOMETERS
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Relatively long flow paths from granitic intrusive rocks possibly provide long travel time to natural-discharge areas and areas of ground-water withdrawal in the basin fill. Thermal convective flow is substantiated by geothermal wells and springs in the subprovince. The water in much of the basin fill is saline. The thickness of the unsaturated zone may exceed 150 meters (500 feet) in the topographically higher parts of the mountain ranges. The trough was occupied by a large lake in the late Pleistocene with a maximum surface level 116 meters (380 feet) higher than at present.

Flow paths from potential host rocks to the natural discharge areas may provide long flow times; however, due to the degree of tectonic activity, the subprovince as a whole generally is less favorable for study than most other subprovinces. The following table summarizes the conditions in this subprovince:

Potentially favorable factors	Issues of concern
* Potential host media primarily are granitic intrusive rocks in saturated and unsaturated zone.	* Subprovince is tectonically active.
* Flow paths may provide long flow times from potential host rocks to discharge areas.	* Convective geothermal flow system in the subprovince is not defined.
	* The Salton Sea during the the late Pleistocene was much larger; the water level was 116 meters (380 feet) higher than the present lake. During pluvial conditions, shorter flow paths from ground-water divides to natural discharge areas and less thickness and extent of the unsaturated zone may be inferred.

Mojave subprovince

The Mojave subprovince of California (fig. 8) includes the

Figure 8 belongs near here.

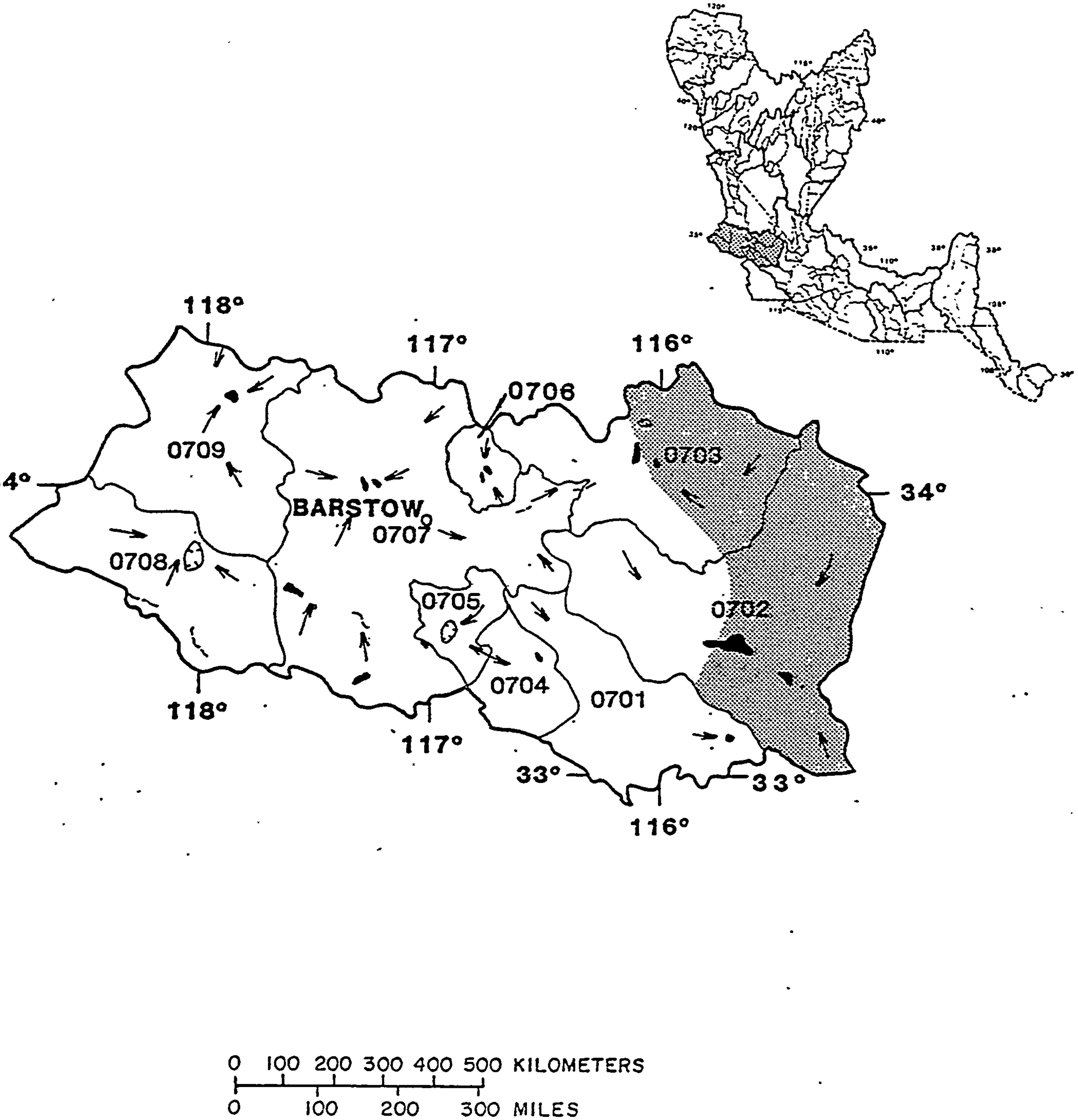
Mojave River basin (in units 0703 and 0707) and associated closed basins. The mountain ranges are mostly metamorphic rocks and granitic intrusions related to the Sierra Nevada batholith (west of the Basin and Range Province). The mountain ranges are irregular in outline and trend eastward, although major block-faulting trends northwestward.

The primary potential host rock is Mesozoic granite. Basalt and shallow intrusives are of limited extent, but may be potential host rocks in the unsaturated zone.

Tectonically this subprovince, located between the San Andreas fault (near southern boundary of the subprovince) and the Garlock fault (extends from westernmost part of unit 0707 through unit 0709 into the Death Valley subprovince), is characterized by widespread, numerous Quaternary faults and seismic epicenters. Vertical movement is moderately great in the west to moderately low in the east. Heat flow in the subprovince generally is 1.5 to 2.5 HFU. Quaternary faults and seismic epicenters are common in the western three-quarters of the subprovince, but only a few such features occur in the eastern one-quarter. Late Cenozoic volcanic activity is relatively common throughout.

Figure 8.--The Mojave subprovince, California, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge; areas outlined by solid hachured lines are areas of withdrawal by wells.

Fig. C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45 a

Flow paths from ground-water divides to natural-discharge points and areas of withdrawal are long in many units, and indicate potentially long travel times. Ground-water withdrawal is large in many units. The water quality, generally suitable for most uses except in playa areas, does not preclude further development in many units. Several of the playas were occupied by lakes or marshes in the late Pleistocene. Discharge of ground water is mostly internal to playas or to the Mojave River. Interbasin flow possibly occurs from unit 0703 into the Death Valley subprovince (Richard Moyle, U.S. Geological Survey, oral commun., 1982). Areas of unsaturated zone thicker than 150 meters (500 feet) are widespread; the largest areas being present in the eastern part of the subprovince.

The potential for further study of environments for storage of high-level radioactive waste is sharply contrasted between the eastern parts of units 0702 and 0703, and the central and western part of the subprovince. The eastern parts of 0702 and 0703 appear to have potential for further study because of generally low tectonic activity, common occurrence of granitic rocks, large areas of thick unsaturated zone, long flow paths, and minor ground-water withdrawal.

Factors which have impact on the geohydrologic suitability for repository siting in the eastern parts of units 0702 and 0703 (shaded in figure 8), are summarized in the table below:

Potentially favorable factors	Issues or concern
* Potential host rocks include granitic intrusive rocks in the saturated and unsaturated zones, and basalt, shallow intrusives, and basin fill in the unsaturated zone.	* Hazards of tectonic activity needs to be assessed locally, especially volcanism.
* Quaternary faults and seismic epicenters are few; rates of vertical movement are moderate.	* Ground water is fresh, except in playa areas, and further development may occur.
* Long flow paths from potential host media to natural-discharge areas provide prospectively long flow times through crystalline bedrock and fine-grained phases of the basin fill.	

Death Valley subprovince

The Death Valley subprovince of California and Nevada (fig. 9)

Figure 9 belongs near here.

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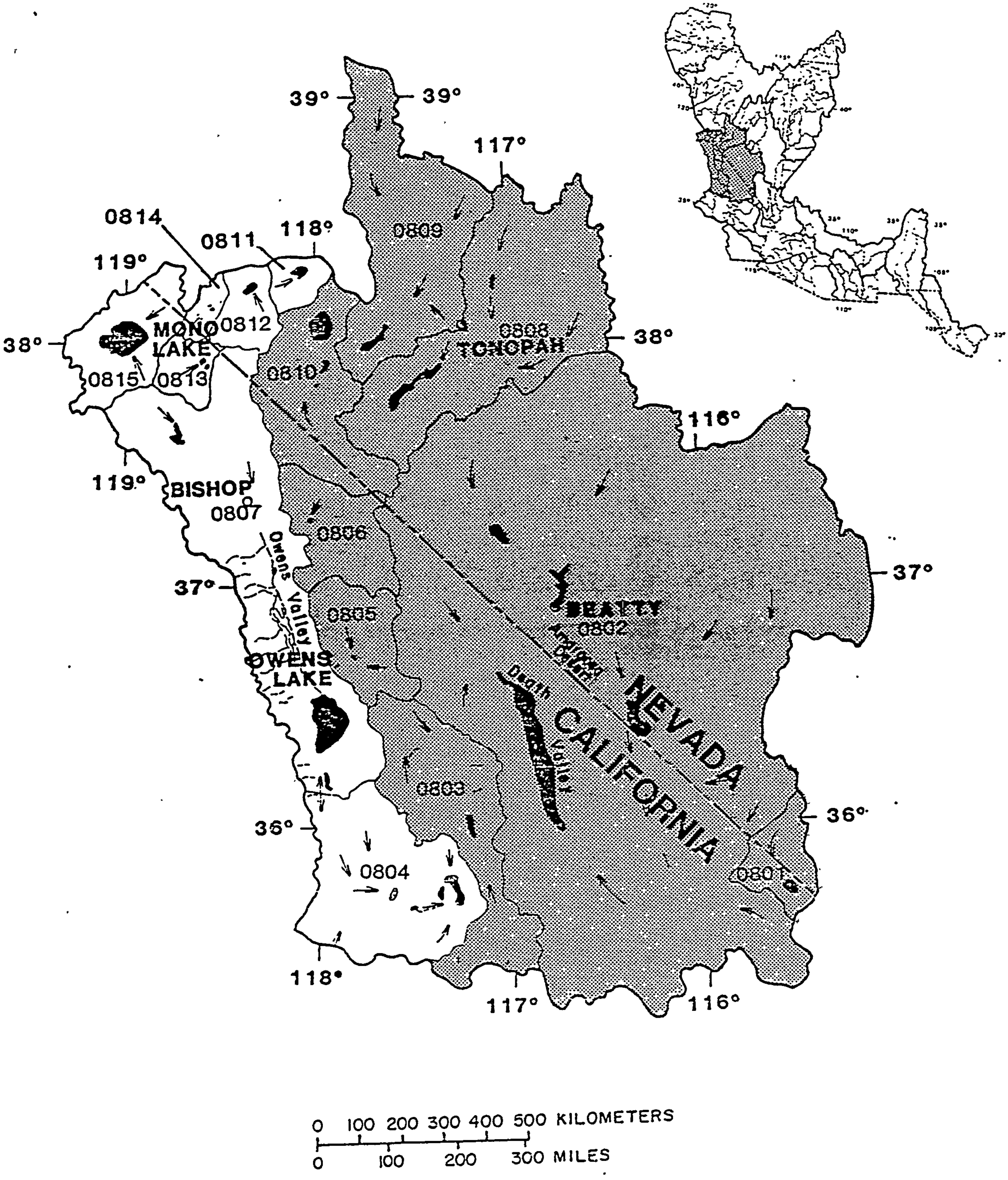
includes the large ground-water flow system that discharges in the Amargosa Desert, Death Valley, Owens Valley, and several smaller closed basins in California and Nevada. The mountain ranges are folded and faulted Precambrian and Paleozoic sedimentary rocks with some masses of deformed Mesozoic sedimentary rocks, and granitic intrusions, locally overlain by Tertiary and Quaternary volcanic rocks.

Deep-seated granitic rocks, mostly of Mesozoic age with some of Tertiary and Precambrian age, are widespread. These rocks occur both above and below the water table within the depth considered for repositories. Basalt is common, particularly in California, and may be a prospective host rock in the unsaturated zone. Thick sequences of ash-flow tuff occur in and near calderas in the Nevada part of the subprovince. Shale and argillite of Precambrian and Paleozoic age crop out in the California part of the subprovince; middle Paleozoic shale occurs in the Nevada part of the subprovince. Thicknesses of undisturbed shale may be as great as 900 meters (3,000 feet); however, in most occurrences, the shale is structurally deformed, and may thin abruptly by faulting or folding.

Figure 9.--The Death Valley subprovince, California and Nevada, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas of significant ground-water withdrawal by wells.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Tectonically the subprovince is dichotomous. The western part, including units 0804, 0807, 0811, 0812, 0813, 0814, and 0815, has numerous Quaternary faults and late Cenozoic volcanic activity, high heat flow, rapid rate of vertical uplift, and many seismic epicenters. In May 1982, the U.S. Geological Survey issued a "Notice of Potential Volcanic Hazard" for the Mammoth Lake area (in units 0807 and 0815). The potential volcanic hazards in the Mammoth Lake area are described by Miller and others, (1982). In contrast, the eastern part of the subprovince is relatively inactive tectonically. Exceptions in the eastern part of the subprovince include Quaternary faults in units 0802, 0803, and 0804. Quaternary faults generally are sparsely mapped in each unit with greater concentrations locally. Aside from the numerous man-made earthquakes at the Nevada Test Site and the seismically active area in unit 0809, the seismic activity in the eastern part of the subprovince is low. Volcanic activity of late Cenozoic age in the eastern part of the subprovince is limited to small occurrences in the central part of unit 0802. Heat flow in the eastern part of the subprovince generally is between 1.5 and 2.5 HFU and less than 1.5 HFU in the northern part of unit 0802 and 0808. Lachenbruch and Sass (1977) and Sass and Lachenbruch (1982) attribute the heat flow of less than 1.5 HFU to convective flow of heat from the area by ground water. The area is underlain, in part, by a regional aquifer in carbonate rocks. A major discharge area for the carbonate aquifer system is in the Amargosa Desert in the southwest part of unit 0802 in Nevada, where thermal water discharges from many springs or is pumped from wells.

Long ground-water flow paths indicate the possibility of long flow times in units 0802 through 0810. Ground water generally is fresh in upland areas and saline in playa areas. Water use is large in units 0804 and 0807, indicating human access to parts of the flow systems before the flow reaches natural-discharge areas.

Parts of the subprovince receives as little as 10 centimeters (4 inches) of precipitation which is greatly exceeded by potential evapotranspiration. In this arid climate, thick sections of unsaturated zone are widely distributed and a potential environment for radioactive-waste disposal in the subprovince. The largest area and greatest known thickness of the unsaturated zone in the Basin and Range Province occurs in and near the Nevada Test Site in unit 0802. Several basins in the subprovince were occupied by lakes during the late Pleistocene. The effect of large changes in water level during pluvial conditions must be considered in studying sites in the unsaturated zone.

Several of the units, 0804, 0807, 0811, 0812, 0813, 0814, and 0815, in the western part of the subprovince appear to be less favorable for study because of greater tectonic activity. The areas for which further information would be useful in evaluating geohydrologic environments include units 0801, 0802, 0803, 0805, 0806, 0808, 0809, and 0810 (shaded areas in figure 9). The potentially favorable factors and issues of concern for these units are summarized in the table below:

Potentially favorable factors	Issues of concern
* Potential host media in both the saturated and unsaturated zones include tuff, basalt, granitic rocks, and basin fill.	* Tectonic hazards need to be assessed locally.
* Little tectonic activity in much of the northern part in Nevada and the southeastern part in California.	* Effect of changes in water level and length of flow paths during pluvial conditions need to be evaluated.
* Ground-water flow paths are long from ground-water divides to natural discharge areas.	
* Dilution of wastes may be effected along some flow paths by large flow in underlying carbonate aquifer.	
* Precipitation is greatly exceeded by potential evapotranspiration.	

White River subprovince

The White River subprovince of Arizona, Nevada and Utah (fig. 10)

Figure 10 belongs near here.

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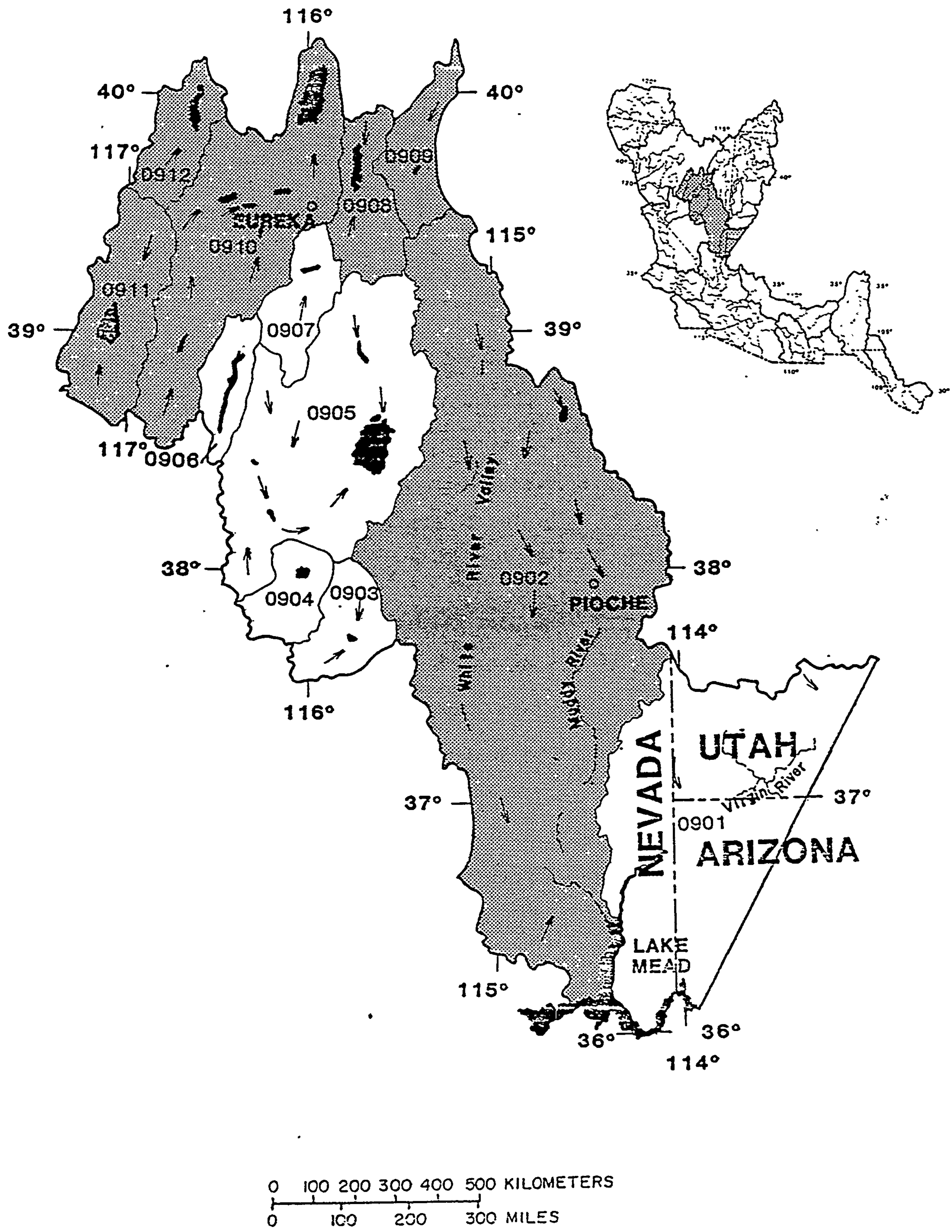
includes the White River and Muddy River basins as well as part of the Virgin River basin, all of which are tributary to the Colorado River (Lake Mead), and several topographically closed basins in central Nevada. The mountain ranges, many of which are more than 2,400 meters (7,900 feet) above sea level, are north-trending ridges of complexly deformed Paleozoic rocks, consisting, in large part, of limestone and dolomite. Younger tuff and lava occur in the southern and western parts of the subprovince, and lie with angular discordance on the Paleozoic rocks.

Granite and tuff are the most promising host rocks for further study. Thick sections of ash-flow tuff are common, especially in and near calderas. In many areas, tuff occurs where the depth to water is 150 meters (500 feet) or greater. Granitic rocks occur in widespread, but sparse, outcrops in both the saturated and unsaturated zones. Shale of Paleozoic age is widespread, but most outcrops show structural complexities, and are doubtful prospects as relatively uniform, and minable host rock.

Quaternary faults and seismic activity are common in the region, but neither is intense, except locally. Heat flow generally is less than 2.5 HFU. Quaternary volcanic centers occur in several units (0901 and 0905). The rate of vertical uplift is moderately rapid.

Figure 10.--The White River subprovince, Arizona, Nevada, and Utah, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge.

Fig 7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Bonneville subprovince

The Bonneville subprovince of Idaho, Nevada, and Utah (fig. 11)

Figure 11 belongs near here.

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includes mostly closed drainage basins, as well as several basins tributary to the Snake River northwest of the subprovince in Idaho. Large closed basins include the Bonneville Salt Flat, Great Salt Lake, and the Sevier Desert. Smaller closed basins are included in the western and southern parts of the subprovince.

The mountain ranges are complexly folded and faulted Paleozoic rocks that were divided into north-trending structural blocks by Tertiary and Quaternary faulting. In the southern part of the subprovince, volcanic rocks form large parts of some mountain ranges. In the northern part, volcanic rocks are young, and occur mostly in the basins.

Potential host rocks include principally granitic rocks and ash-flow tuff. Basalt exceeding 100 meters (330 feet) in aggregate thickness has been mapped in one area in unit 1003. Granite of Tertiary age is exposed in unit 1012 in Idaho; in units 1002, 1003, 1005B, 1005D, 1005E, and 1010D in Utah; and in units 1005B, 1006 and 1007 in Nevada.

Figure 11.--The Bonneville subprovince, Idaho, Nevada, and Utah, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas of significant ground-water withdrawal by wells.

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Thin tuff, generally less than 60 meters (200 feet) thick, occurs in the Idaho part of the subprovince. However, tuff as thick as 900 meters (3,000 feet) occur in the southern part of the subprovince in units 1001, 1002, and 1003, and 1005B. Undifferentiated volcanic rocks, including basalt flows and ash-fall tuff, occur in unit 1005A. Laharic breccia greater than 600 meters (2,000 feet) thick has been reported in unit 1017 in Idaho.

Argillaceous rocks occur widely in stratigraphic sequences 300 to 1,800 meters (1,000 to 6,000 feet) thick as shale, slate, and schist, but most are structurally deformed. A thick 1,500-meter (5,000-foot) section of evaporites was penetrated in two wells in unit 1005 at an initial depth of about 750 meters (2,500 feet).

Tectonically, the zone bordering the eastern edge of the subprovince, along the Wasatch Range, and parts of Idaho are active. Hydrothermal convection systems discharging hot water (greater than 90°C) occur mostly in the subprovince near the Wasatch Range and in the Raft River area (unit 1012). In the central and western part of the subprovince, deep hydrothermal systems are indicated by warm (20° to 90°C) geothermal-spring discharges. Upper Cenozoic volcanic rocks occur in units 1002, 1005A, 1012, 1016, and 1017. The western part of the subprovince is relatively inactive tectonically; Quaternary faults and earthquake epicenters are sparse. Vertical uplift associated with isostatic rebound following the decline in water level of Pleistocene Lake Bonneville has been documented (Crittenden, 1963).

The Bonneville subprovince contains some large ground-water flow systems discharging to large saline lakes and playas. Flow units in the western part of the subprovince generally contain the long flow paths with potentially long flow times and potential host rocks. Pleistocene Lake Bonneville extended over a large part of the subprovince at an elevation about 270 meters (890 feet) higher than the present Great Salt Lake. Many of the basin-fill areas are irrigated with ground water. Ground water is fresh outside the major natural discharge areas.

Much of the subprovince has unfavorable prospects for further study because of the probable lack of potential host rocks and significant tectonic activity. Units 1003, 1005A (part), 1005B (part), 1005E (part), 1006, 1007, 1008, and 1009 (shaded in fig. 11) are prospective areas for further study. The potentially favorable factors and issues of concern in these units are summarized in the following table:

Potentially favorable factors	Issues of concern
* Potential host media includes the saturated and unsaturated zones in tuff, granitic rocks and basalt.	* Tectonic hazards are locally of concern and need to be addressed in further studies.
* Tectonic activity is low, except locally.	* Interbasin flow is inferred to occur in carbonate rocks at depth; definition of deep flow and travel times from potential host rocks to discharge areas need to be defined.
* Ground-water flow paths from potential host media to natural discharge areas are long.	* Development of additional water supplies may shorten flow paths to accessible environment.
* Dilution of wastes may be effected by larger regional flow systems at depth.	* Effect of recurrence of pluvial conditions on ground-water travel time and extent of unsaturated zone needs to be further studied.

Other units in the Bonneville subprovince are characterized by generally greater tectonic activity, locally high heat flow, absence of prospective host media, and relatively short flow paths to the accessible environment. A large part of the subprovince may be inundated by lakes during a recurrence of pluvial climate.

It should be noted, that although ground-water flow paths are upward and flow paths are relatively short in the large ground-water discharge areas--Bonneville Salt Flat in unit 1005, Great Salt Lake basin in unit 1010, and much of the Sevier Desert in unit 1005A--the rate of ground-water movement at depths of 300 to 900 meters (1,000 to 3,000 feet) is probably very slow. The velocity at such depths is slow because of the small average flux density (a relatively slow discharge rate throughout a very large area), and the permeability of the fine-grained and evaporitic basin-fill sediments is low. Also, the fine-grained basin-fill sediments have a significant potential retardation rate for radionuclides. These generalizations are true to some degree for all discharging playa areas. In general, we have not considered playa discharging areas as favorable environments for waste isolation, one reason being the fact that longer travel times exist upgradient from the playas.

Lahontan subprovince

The Lahontan subprovince of California, Nevada, and Oregon (fig. 12) encompasses the major interior drainage basins of

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northern and western Nevada, including the Humboldt, Truckee, and Walker Rivers, and several large discharging playas - Black Rock Desert, Smoke Creek Desert, Pyramid Lake, Dixie Valley, Walker Lake, and Carson Sink. The area of Pleistocene Lake Lahonton, as well as several small closed basins are within this subprovince. The mountain ranges are fault blocks of complexly folded and faulted Triassic and Jurassic sedimentary rocks overlain by Tertiary volcanic rocks.

Potential host rocks in the subprovince include granitic rocks, basalt and ash-flow tuff. Granitic rocks are widespread, with most appearing to be extensions of the Sierra Nevada intrusion. Basalt and andesite are widespread, but individual flows commonly are less than 15 meters (50 feet) thick. Ash-flow tuff is not uniformly distributed, but occurs in thicknesses greater than 90 meters (300 feet) in units 1106, 1107, 1108, 1112, and 1117.

Shales and other argillaceous rocks occur in the easternmost part of the subprovince in stratigraphic sections as thick as 1,800 meters (5,900 feet). Virtually all these units have been folded and thrust-faulted.

Figure 12.--The Lahontan subprovince, California, Nevada, and Oregon, showing prospective areas (shaded) for further study. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge.

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Quaternary faulting and seismicity generally are great, particularly in the western part of the subprovince. Upper Cenozoic volcanic rocks have been mapped in units 1112 and 1119; volcanic rocks of possible Quaternary age occur in units 1117 and 1118. Heat flow is greater than 2.5 HFU, in the northern part of the subprovince, from the eastern margin of unit 1112 to the western border of the subprovince. Hydrothermal convection systems with temperatures greater than 90°C are indicated by the many, widespread thermal springs in the subprovince. Rates of uplift are moderately rapid and may be related in part to isostatic rebound of late Pleistocene Lake Lahontan. Pleistocene Lake Lahontan, with a surface elevation about 270 meters (890 feet) above the present basin floor, covered an area of 22,000 square kilometers (8,500 square miles).

Flow paths as long as 60 kilometers (37 miles) may provide long travel times from ground-water divides to natural-discharge areas in bedrock of low permeability.

The northern parts of units 1112 and 1117 (shaded in fig. 12) may be prospective areas for further study, as summarized below:

Potentially favorable factors	Issues of concern
* Potential host media exists in saturated and unsaturated zones. * Tectonic activity generally is low * Long flow paths from ground-water divides to natural-discharge areas may provide long travel times.	* Heat flow is greater than 2.5 HFU in part of the area, indicating possible tectonic instability. * Ground water is fresh in most of the area. * Extent and thickness of the unsaturated zone would be decreased by recurrence of pluvial cycle.

The other ground-water units and the southern parts of units 1112 and 1117 of the Lahontan subprovince are considered less favorable for further study because of tectonic activity, including Quaternary faulting, areas of late Cenozoic volcanism, historic earthquake activity and high heat flow. Parts of the area are characterized by short ground-water flow paths and evidence indicating widespread inundation during pluvial climates.

Lake and Lava subprovince

The Lake and Lava subprovince of California, Nevada, and Oregon (fig. 13) is a young, block-faulted lava plateau with

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Figure 13 belongs near here.

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perennial lakes and numerous volcanic centers. Tertiary and Quaternary lava flows principally are basaltic and andesitic in composition and are intercalated with some ash-flow tuff. Prominent scarps, as high as 750 meters (2,500 feet), mark the block-faulted basins, many of which have perennial lakes. Exterior drainage from part of the region is by the Klamath and Pit Rivers; other basins in the region are drained internally to saline perennial lakes, or ephemeral playa lakes having mud-salt flats.

Potential host rocks primarily include basalt and small outcrops of ash-flow tuff. Granitic rocks are limited to a few relatively small outcrops. Unsaturated sections thicker than 150 meters (500 feet) are limited in extent.

Upper Cenozoic volcanic rocks are widespread west of 121° West longitude. Seismic activity and faulting are locally intense. Heat flow is greater than average for the subprovince ranging from 1.5 to more than 2.5 HFU. Hydrothermal convection systems are indicated by the widespread occurrence of spring discharge with temperatures greater than 90°C. Rates of vertical uplift are 4 to 6 meters (13 to 20 feet) per 10,000 years.

Figure 13.--The Lake and Lava subprovince, California, Nevada, and Oregon. Ground-water units are numbered; the first two digits refer to the subprovince; the second two digits are unique for each ground-water unit within the subprovince. Arrows indicate the general direction of ground-water flow at the water table; black areas are natural discharge areas; dashed lines are streams that receive ground-water discharge. Areas outlined by solid hachured lines are areas of significant ground-water withdrawal by wells.

121°
120°
119°
122°
1226
1218
1212
1214
HARNEY LAKE
1217
CRATER LAKE
1225
43°
1216
1224
1215
1213
1211
1210
UPPER KLAMATH LAKE
1223
1222
1209
LAKEVIEW
KLAMATH FALLS
OREGON
GOOSE LAKE
1207
DENIO
42°
1219
1205
1206
1208
KLAMATH RIVER
1221
1220
NEVADA
CALIFORNIA
1204
119°
ALTURAS
1203
PIT RIVER
1201
41°
1202
121°
120°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

Flow systems are in volcanic rocks and basin fill. Volcanic rocks, primarily basalt and basaltic andesite commonly are aquifers, and are inhomogeneous and difficult to delineate. Flow lengths from divides to natural discharge areas commonly are less than 24 kilometers (15 miles). Flow times in largely permeable basaltic rocks are probably not long. Ground water generally is fresh, dissolved-solids concentrations generally are less than 500 mg/L, except near playa lakes. The closed basins were occupied by pluvial lakes during the Pleistocene Epoch.

The region contains limited areas favorable for further study because of the general lack of rocks for isolation of waste, commonly short ground-water flow paths, and tectonic activity in part of the subprovince. It is concluded that the subprovince is a relatively unfavorable prospect for further study, as summarized in the following table:

Potentially favorable factors	Issues of concern
* Host media, though limited in extent, occur in both the saturated and unsaturated zones.	* Granitic rocks are of very limited extent.
* Tectonic activity is low in eastern part of subprovince.	* Unsaturated zone is of limited extent.
* A few long flow paths exist from prospective host rocks to natural discharge areas.	* Tectonic activity very great locally, including extensive late Cenozoic volcanism in the western part of the subprovince.
	* Aquifers in basalt are difficult to define; flow times possibly are short.

Conclusions

The preceding sections evaluate the subprovinces of the Basin and Range Province with the objective of identifying large areas that appear to be prospective for further study. It is repeated from Part I of this report (Bedinger, Sargent, and Reed, 1983) that evaluation cannot be made on the basis of individual factors alone. The ultimate evaluation of an environment needs to recognize the interrelationships of all factors and the effect of each in providing multiple barriers in an integrated system. The evaluations here identify geohydrologic environments in large areas that may contain potential repository sites and multiple barriers to radionuclide migration. A summary of the areas believed to be prospective for further study is shown in figure 14. In the next phase of this study, selected areas will be

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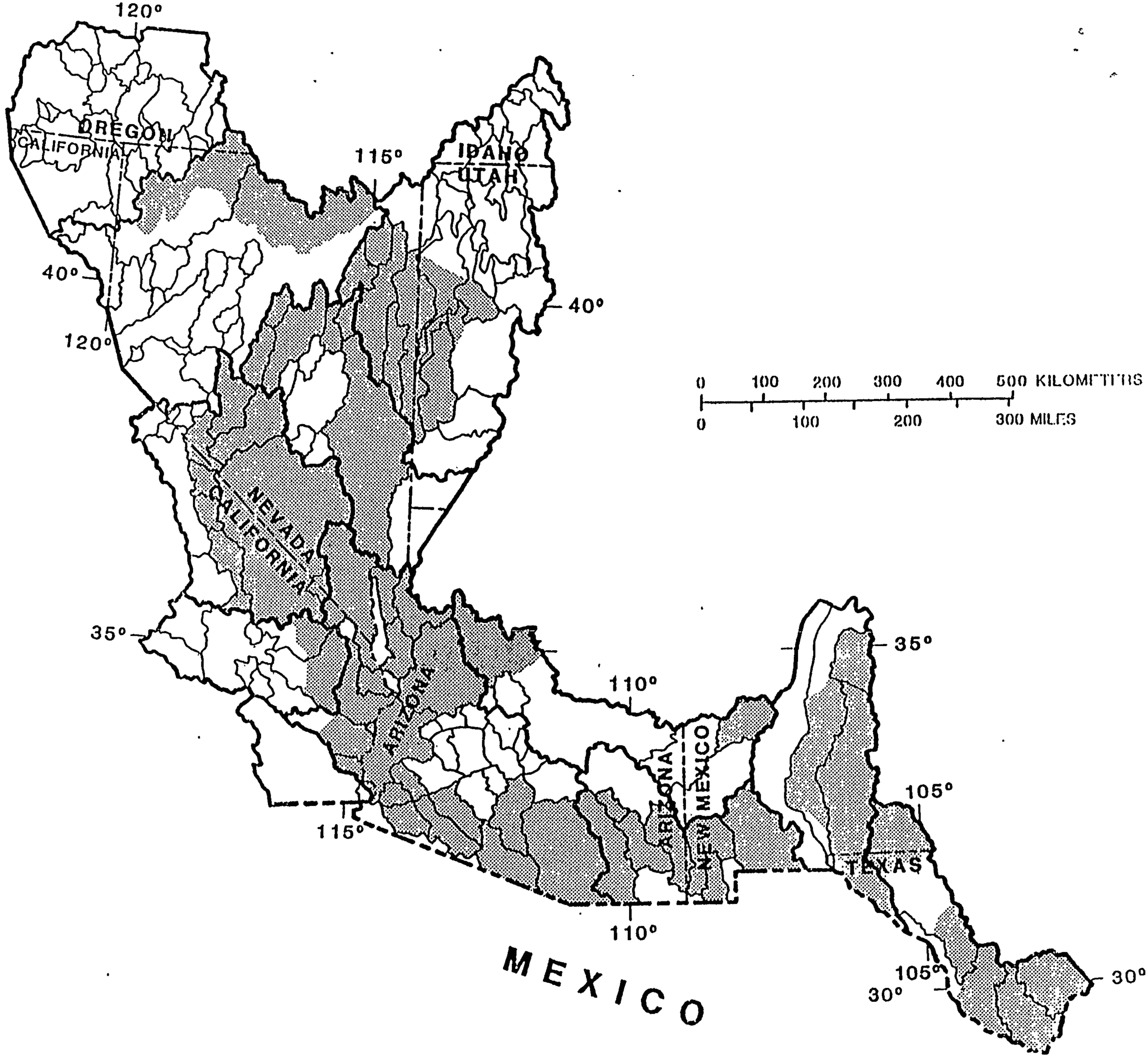
examined further.

Figure 14.--Prospective areas (shaded) for further study.



OREGON
CALIFORNIA
IDAHO
UTAH
NEVADA
CALIFORNIA
ARIZONA
ARIZONA
NEW MEXICO
TEXAS
MEXICO
120°
115°
110°
105°
40°
35°
30°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES

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