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GROUND-WATER HEAT PUMPS: AN EXAMINATION OF HYDROGEOLOGIC, ENVIRONMENTAL, LEGAL, AND ECONOMIC FACTORS AFFECTING THEIR USE

Appendix D. State Hydrogeologic Descriptions and Maps

By
Dana M. Armitage
Douglas J. Bacon
John T. Massey-Norton
James M. Miller

November 12, 1980

Work Performed Under Contract No. AC01-78CS20060

National Water Well Association
Worthington, Ohio

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

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APPENDIX D
STATE HYDROGEOLOGIC DESCRIPTIONS AND MAPS

This appendix contains hydrogeologic descriptions of the 48 conterminous United States along with maps depicting ground-water quality and temperatures in each state. These maps are measured in units of miles, which can be converted to kilometers with the equation

$$1.069 \times \text{number of miles} = \text{kilometers}$$

Likewise, temperatures are illustrated in degress Fahrenheit and can be converted to degrees Celsius with the equation

$$°C = 5/9\ (°F - 32)$$

ALABAMA

The Piedmont physiographic province, extending northeastward from east-central Alabama, is flanked on the west by the elongate mountains of the Valley and Ridge province. In the northwestern part of the state, relatively flat-lying strata of Mississippian and Pennsylvanian age crop out. The southwestern three-fifths of Alabama consist of a seaward-dipping wedge of Cretaceous and Cenezoic strata that reaches a maximum thickness of more than 20,000 feet (6,100 m) near Mobile. The average annual precipitation and runoff are 54 and 21 inches (137.2 and 53.3 cm), respectively.

The Piedmont is formed primarily of metamorphic rocks of low permeability that produce small yields of good quality water to wells. Maximum well yields generally do not exceed 50 gpm (3.2 l/s) in the Piedmont province. Well depths vary considerably and can range up to 400 feet (122 m). Dissolved solids are generally less than 150 mg/l, and chloride concentrations do not normally exceed 15 mg/l. Folded rocks in the Valley and Ridge province include some moderately productive limestone and dolomite aquifers. Maximum well yields in the Valley and Ridge province reach upwards of 500 gpm (31.6 l/s). Well depths generally range from 200 to 350 feet (61 to 106.8 m). Cavernous and shattered zones are scattered throughout these aquifers causing local differences in yields. Ground water is hard (generally less than 150 mg/l) and dissolved solid concentrations are generally less than 250 mg/l.

The Mississippian-age rocks that crop out in the northwest consist mainly of thick sandstone units and a basal zone of oolitic limestone and marl. Most of the overlying Pennsylvanian strata are included in the Pottsville Formation, and consist of interbedded shale, coal, and sandstone sequences. Sandstone forms the major aquifers in this area, which are moderately productive and provide water of low mineral content. However, high concentration of sodium and potassium (290 mg/l) and dissolved solids (525 mg/l) are present in Walker County. Sands and sandstone aquifers in the Warrior Basin in north-central Alabama have maximum well yields of 100 gpm (6.3 l/s). Higher yields, 2,000 gpm (126.2 l/s), are obtained from carbonate formations in the northern part of the state.

Coastal Plain sediments comprise the most productive aquifer system in the state. These aquifers, chiefly sandstones and conglomerates, contain artesian water that is generally of excellent quality. However, the water becomes increasingly saline downdip. The maximum depth to which fresh water extends usually exceeds 1,000 feet (305 m) and, in some places, is greater than 2,000 feet (610 m). Maximum well yields range from 500 gpm to 2,000 gpm (31.6 to 126.2 l/s) for these Coastal Plain sediments. Well depths vary considerably, depending on the attitude of the aquifer with respect to the well location. In general, well depths range from 150 to over 1,000 feet (45.8 to over 305 m). The Mobile Bay area has experienced some salt-water encroachment (chlorine in excess of 250 mg/l) due to heavy pumping. Areas of naturally occurring saline water include Green, western Hale, Lowndes, and Marengo Counties. In Marengo County, highly mineralized water has percolated upward along faults into a heavily utilized aquifer. In general, Alabama has an abundant supply of excellent quality ground water (chloride concentrations less than 15 mg/l, sulfate less than 20 mg/l, and dissolved solids concentrations less than 250 mg/l. Alabama's chief water-quality problem is local salt-water contamination from deep saline aquifers and encroachment along the Gulf of Mexico. Along the northeast edgo of the Coastal Plain, water usually has a high iron content.

The Alabama ground-water quality maps are based on data including more than 700 analyses, 500 of which are from domestic and municipal wells.

ARIZONA

Arizona lies predominantly in the Basin and Range physiographic province of the southwestern United States. The northeastern part of the state is part of the Colorado Plateau. In this state, annual precipitation averages only 14 inches (35.6 cm), ranging from about 4 inches 10.2 cm) in the Yuma area to more than 30 inches (76.2 cm) in some mountain ranges. Due to high rates of evaporation, transpiration, and infiltration, runoff averages only 0.7 inch (1.8 cm). Although very small, runoff is extremely important because it provides recharge to shallow aquifers which serve as important sources of irrigation water.

Large quantities of water are used in Arizona, mainly for irrigation. Most of the ground-water is obtained from alluvial basins in the southwestern three-fifths of the state. This region has the driest climate, the lowest runoff, 90 percent of the cultivated land, and 80 percent of the population. Hydrologically, the region is characterized by alluvial-fill aquifers that have large storage capacities. Unfortunately, ground-water recharge rates are very low and limited to infrequent floods and infiltration near the mountain fronts. Since most of the ground water used is withdrawn from storage, water levels have declined drastically in several basins.

Alluvial aquifers in the Basin and Range province may be either shallow or deep -- well yields range from a few gallons per minute to as much as 2,500 gpm (157.8 l/s). Well depths range from less than 100 feet (30.5 m) to over 400 feet (122 m). The surrounding mountains consist largely of igneous and metamorphic rocks, and ground water is obtained from fractures. Although usually capable of yielding less than 10 gpm (0.6 l/s), some wells in highly fractured areas provide as much as 100 gpm (6.3 l/s). Well depths vary considerably and may reach upward of 500 feet (152.5 m).

The Colorado Plateau is underlain by consolidated sedimentary rocks, generally alternating units of sandstone and shale. The strata have been eroded into a mesa and butte topography, but pinnacled ranges of volcanic rocks occur in the southern or Central Highlands regions. Most ground water is obtained from fine-grained sandstone and fractured rock.

The Coconino, Navajo, and Dakota Sandstones are the major aquifers. The Coconino in Navajo County yields 300 to 1,800 gpm (18.9 to 113.6 l/s), but the water is salty in many places. Water scarcity is a general condition throughout the Colorado Plateau. In some places, such as Coconino County and the Grand Canyon National Park, ground water lies at great depths and wells are more than 1,000 feet (305 m) deep.

In addition to low rainfall and declining ground-water levels, water quality problems also plague Arizona. Dissolved solids concentrations widely range throughout the state with locally high concentrations of sulfate, chloride, nitrate, hardness, and fluoride. In Graham County, some deep artesian valley-fill aquifers contain poor-quality water. In Maricopa County, particularly southeast of Phoenix and southwest of Florence, the salt content of ground-water is increasing due to irrigation return flows. In addition, water from deep aquifers is highly mineralized in places. To the northeast in Mohave County, water is scarce except along the Colorado River. Much of the ground water is salty in the Haulapai Valley north of Kingman.

In Coconino, Navajo, and Apache Counties (part of the Colorado Plateau), ground water quality is fair to good south of the Little Colorado and Zuni Rivers, but poor to the north. Also, springs that flow into the Little Colorado River just above its confluence with the Colorado River are saline. Ground-water is locally saline in the Pine and Payson areas of Gila County and along the Gila River. High concentrations of metals may be found in ground water due to mining and natural mineralization. For example, arsenic and lead are found in ground water in the Lukeville-Ajo area, and lead is present in areas south of Tucson. Excessive chromium levels are found in parts of Paradise Valley northeast of Phoenix.

The Arizona ground-water quality maps are based on data including more than 8,100 analyses, 5,300 of which are from domestic and municipal wells.

ARKANSAS

The northwestern half of Arkansas, which lies in the mature plains of the Ozark Plateau, grades southward into the folded strata of the Arkansas River Valley and the intensely folded sediments of the Ouachita Mountains. The southwestern half of the state is formed by the Mississippi alluvial plain and the gently-dipping Cretaceous sediments of the west Gulf Coastal Plain. Mean annual precipitation, increasing from 43 inches (109.2 cm) in the northwest to 56 inches (142.2 cm) in the southeast, averages 48 inches (121.9 cm) statewide. Runoff averages 17 inches (43.2 cm) but ranges from 10 to 24 inches (25.4 to 60.9 cm) a year.

In southwestern Arkansas, the Coastal Plain is underlain by southward-dipping Cretaceous and Tertiary strata. To the east lies the flat alluvial plain of Quaternary age deposited by the Mississippi River. In the Coastal Plain, the Sparta Sand of Eocene age is the most extensive and heavily-tapped aquifer in south-central and southwestern Arkansas. Well yields vary from 50 to 500 gpm (3.2 to 31.6 l/s) and well depths range from 100 to over 400 feet (30.5 to 122 m).

Ground-water quality in the Quaternary alluvium is variable but generally hard (180 mg/l). Cretaceous strata yield water of desirable quality (250 mg/l of dissolved solids) in the outcrop area, but mineralization increases southward in the downdip direction. Tertiary strata generally contain soft to moderately hard (120 to 180 mg/l) water of the sodium bicarbonate type.

In the Northern Highlands, Paleozoic rocks forming the Ozark Plateau provide water from soution-enlarged fractures of limestone and dolomite and from fractured cherts and sandstones. Although sandstone aquifers provide the most consistent well yields, the largest yields are obtained from limestone and dolomite.

In the Interior Highlands of northwestern Arkansas, several formations yield between 50 and 500 gpm (3.2 and 31.6 l/s). Flanking the Arkansas River valley on the north, the Boston Mountains consist of flat-lying and gently-folded shales and sandstones. South of the Arkansas River are the Ouachita Mountains, which are composed of fractured shale, chert, and sandstone. The Arkansas River Valley, a broad alluvial region underlain by shale and sandstone of

Pennsylvanian-age Atoka Formation, is the most productive aquifer of the area; wells tapping the alluvium may yield over 500 gpm (31.6 l/s). Water quality throughout much of the Interior Highlands is good (less than 500 mg/l of dissolved solids).

Quaternary alluvium and the Sparta, Cockfield, and Wilcox Formations are capable of yielding over 500 gpm (31.6 l/s) in the eastern Arkansas. Well depths generally range from 100 to 200 feet (30.5 to 61 m). This ground water from the alluvium commonly exceeds 240 mg/l of hardness.

Most of the state has problems caused by excessive hardness and locally high iron content. The hard water encountered in most of the Quaternary deposits can be overcome by drilling to the underlying Tertiary and, locally, Cretaceous strata. The largest area of hard water is the Mississippi Alluvial Plain.

The Arkansas ground-water quality maps are based on data from more than 1,000 chemical analyses, 650 of which are from domestic and municipal wells.

CALIFORNIA

Forming the western part of California are the Coastal Ranges, a series of parallel, echelon mountain chains that project successively farther northward into the Pacific. Along the California coast, alluvial sediments washed down from the surrounding mountains are frequently interspersed with layers of marine sediments. Lying to the east is the Cascade-Sierra Nevada chain. The Cascades are dominated by a series of volcanic peaks, while the Sierra Nevada Mountains consist of uplifted bedrock that slopes westward into California's Great Valley where it is covered by extensive alluvial deposits. In northern California, the Coastal Rnages and the Cascades are connected by the Klamath Mountains. The Great Valley, which separates the Coastal Ranges from the Sierra Nevada, is drained by the Sacramento and San Joaquin Rivers whose tributaries partly fill the valley with material eroded from the surrounding mountains. Southeastern California lies in the arid Basin and Range province, a region of fault-block mountains and alluvial basins.

California is the nation's largest user of ground water. Although ground-water storage capacity is vast, withdrawal exceeds recharge in some basins in the central and southern parts of the state, and water levels continue to decline. Mean annual precipitation exceeds 70 inches (177.8 cm) in parts of the Sierra Nevada, and decreases to less than 4 inches (10.2 cm) in the southeastern Mojave Desert. Mean annual runoff ranges from almost 0 to more than 60 inches (0 to 152.4 cm), averaging 8 inches (20.3 cm).

California's numerous alluvial basins are the major ground-water systems, although basalts in the northern part of the state are also productive. Maximum well yields reach over 5,000 gpm (315.5 l/s), but average 50 to 300 gpm (3.2 to 18.9 l/s). Well depths range from 100 to over 500 feet (30.5 to 152.5 m). Northern basins generally have surplus water, while many basins in the central and southern areas have water deficiencies due to low rainfall and heavy demands. Plentiful supplies are needed for irrigation in the central portion of the state, and municipal and industrial purposes require much water in the extensively developed south.

In the northern and east-central regions of California, the ground-water is usually of excellent quality (with dissolved solids generally less than 200 mg/l). Elsewhere, the dissolved solids concentration of ground water in most alluvial basins exceeds 500 mg/l. In some areas, the native quality may be highly mineralized, while man's activities have deteriorated the water quality in other areas.

In portions of the state, particularly parts of the San Joaquin Valley, the development of irrigation coupled with poor, natural drainage and saline and alkaline soils has led to salt accumulation in the soil and underlying ground water. In these locations, poor quality ground waters are highly mineralized, i.e., concentrations of chloride commonly exceed 200 mg/l, sulfates over 250 mg/l, hardness greater than 300 mg/l, and total dissolved solids more than 1,000 mg/l.

Salt-water encroachment in coastal ground-water basins, largely due to overpumping, is another major concern. The most serously affected regions are southern San Francisco Bay and portions of greater Los Angeles where considerable effort has been made to halt the inward movement of sea water. Parts of other areas, such as the Oxnard Plain of Ventura County (located between Los Angeles and Santa Barbara) and the Pajaro and Salinas Valleys (both of which border Monterey Bay), have been affected by sea water intrusion into the principal aquifers.

Nearly half of the state's ground-water storage is in the heavily-developed San Joaquin Valley. Although the basin contains several thousand feet of sediment, the water is commonly saline below a depth of 1,000 feet (305 m). This is rarely a problem, however, since most domestic wells are less than 300 feet dep (91.5 m).

California ground-water quality maps are based on more than 8,300 chemical analyses, 5,000 of which are from domestic and municipal wells.

COLORADO

Colorado can be divided into three distinct regions. The eastern third of the state, which is crossed by the South Platte and Arkansas Rivers, consists of almost featureless plains. To the immediate west are the high rugged ranges and valleys of the southern Rocky Mountains. The Colorado Plateau encompasses the southwestern part of the state, and the north is blanketed by the dry, elevated, and eroded plains and low mountains of the Wyoming Basin.

The annual statewide precipitation of 17 inches (43.2 cm) along the eastern boundary decreases westward toward the mountain areas where it increases to about 50 inches (127 cm). It ranges from approximately 8 to 123 inches (20.3 to 31.24 cm) west of the major mountain ranges. The San Luis Valley, which is surrounded by mountains, receives only about 6 inches (15.2 cm) yearly.

Most of Colorado's major ground-water supplies are east of the Front Range, stored in the sandy deposits of the High Plains. Wells are the only source of supply throughout much of this region. The Ogallala Formation is the principal aquifer along the eastern boundary of the High Plains, except near the South Platte and Arkansas Rivers where it has been removed by erosion. Irrigation wells tapping the Ogallala pump an average of 1,000 gpm (63.1 l/s). In the South Platte River basin alluvium, the major aquifer yeilds 400 to 2,000 gpm (25.2 to 126.2 l/s) to irrigation wells in the eastern part of the state.

The Arkansas River trends eastward across the southern third of Colorado and forms the northern boundary of the southern High Plains. The area is heavily irrigated. Wells in the alluvium along the river yield 100 to 3,000 gpm (6.3 to 189.3 l/s). Wells tapping alluvial deposits are generally less than 250 feet (76.3 m) deep.

Surrounding Denver is the Denver artesian basin, a series of fine to coarse-grained deposits interbedded with shale. The deepest aquifer, the Fox Hills Formation, underlies abut 5,000 square miles (12,950 square km). Well yields vary by aquifer and location, ranging from 1.0 to as much as 100 gpm (0.06 to 6.3 l/s).

In the sparsely inhabited mountains, ground-water supplies are obtained largely from fractures in crystalline

rocks. Well depths generally range from 200 to 500 feet (61 to 152.5 m); yields are low. Four large basins separating the mountain ranges (the North, Middle, and South Parks and the San Luis Valley) contain abundant ground-water supplies. Well yields generally do not exceed 100 gpm (6.3 l/s), but some wells in the San Luis Valley pump over 4,000 gpm (252.4 l/s).

Ground water in the sparsely settled Colorado Plateau is acquired largely from sandstone aquifers such as the Dakota, Entrada, and Wingate. Most of these aquifers yield less than 50 gpm (3.2 l/s).

Ground-water quality in Colorado varies widely. Dissolved solids concentrations generally range between 250 and 1,000 mg/l in the High Plains, while hardness, averaging 240 mg/l, varies between 60 and 1,000 mg/l. In South Platte Valley, the quality of ground water deteriorates downstream from an average concentraton of 100 to 300 mg/l of dissolved solids near Denver, to 1,200 mg/l at the state line. Similarly, concentrations of dissolved solids and hardness increase downstream in the Arkansas River Valley, from an average of 2,600 and 1,400 mg/l near La Junta to over 3,000 and 1,500 mg/l at the state line. In the Arkansas Valley artesian area, ground water from consolidated rocks is softer and less mineralized than that from the valley fill. In the Denver Basin, ground water of sodium bicarbonate type is usually of good quality and relatively soft.

Locally, ground water in the Colorado River alluvium is highly mineralized. Elsewhere in the Colorado Plateau, ground water is quite variable and is generally a sodium bicarbonate type.

In the crystalline rocks of the Rockies, ground water normally contains low concentrations of dissolved solids. Likewise, it is generally of good quality in the parks although more mineralized than in the mountains. Locally in the San Luis Valley, ground water is saline.

The Colorado ground-water quality maps are based on more than 5,700 analyses, 3,500 of which are from domestic and municipal wells.

CONNECTICUT

Connecticut is situated in the glaciated Appalachian province. The centrally-located Connecticut River Valley consists of Triassic-age redbeds (sandstone, shale) intruded by diabase dikes. Precambrian to Devonian-age metamorphic rocks (gneisses, schists) and a few igneous intrusions form the rolling hills on both sides of the Connecticut Valley.

Most of Connecticut is mantled by glacial till that is generally dense and of low permeability. Where sand and gravel deposits occur, commonly along streams, they form excellent ground-water reservoirs. Most of the state's ground-water resources occur in glacial material because dense crystalline bedrock contains water that is largely confined to fractures. Bedrock formations of late Triassic-age, however, yield 50 to 550 gpm (3.2 to 34.7 l/s) to large-capacity wells. Elsewhere in the state, large-capacity wells drilled in crystalling rock yield 5 to 50 gpm (0.3 to 3.2 l/s), reaching a maximum of 100 gpm (6.3 l/s) in favorable locations. Wells tapping some sand and gravel deposits yield more than 1,000 gpm (63.1 l/s). Wells tapping glacial outwash deposits are generally less than 200 feet (61 m) deep, while crystalline bedrock wells are generally not deeper than 400 feet (122 m).

In general, the ground-water quality in Connecticut is good to excellent. In a few areas such as the northern and north-central parts of the state, ground water may be unusually hard. Iron concentrations, which vary widely, pose serious problems in several places.

Calcium and magnesium and sodium and potassium concentrations are quite low (less than 50 and 25 mg/l, respectively) except in areas of carbonate bedrock or calcium-rich tills. The background concentraton of chloride and sulfate in Connecticut is less than 25 mg/l. Locally along the coast, areas of high chloride concentrations indicate salt-water intrusion. This may result from excessive ground-water withdrawals, low discharge of streams into embayments (which at low flow permits sea water to advance upstream), or contamination from unusually high tides and waves during storms. High concentratons of sulfate occur near larger cities, but the only areas approaching or exceeding 250 mg/l are near New Haven and New London.

High concentrations of dissolved solids occur in the Connecticut River Valley and in the eastern part of the state. The only wells exceeding 500 mg/l are near New Haven and New London.

The ground-water quality in Connecticut is generally excellent, although more mineralized water occurs locally in areas of dense population and industrialization. With an average annual precipitation of 47 inches (119.4 cm) and runoff of 22 inches (55.9 cm), ample ground-water recharge occurs.

The Connecticut ground-water qulity maps are based on more than 1,100 chemical analyses, 800 of which are from domestic and municipal wells.

DELAWARE

Almost all of Delaware lies in the nearly flat Coastal Plain that consists of Cretaceous-, Tertiary-, and Quaternary-age layers of sand, silt, and clay. These sediments dip southeastward and thicken to nearly 8,000 feet (2440 m) along the Atlantic coast. Wells tapping these Atlantic Coastal Plain sediments generally yield 100 to 600 gpm (6.3 to 37.9 l/s) to large-diameter wells. Well depths range from less than 100 feet (30.5 m) to several hundred feet. The northernmost part of Newcastle County is in the Piedmont province, where rolling hills consist of Precambrian and Paleozoic crystalline rocks. Maximum well yields in favorable locations range up to 50 gpm (31.6 l/s) from large-diameter wells. Well depths generally do not exceed 400 feet (122 m).

Most of the high-yield wells in Delaware tap Coastal Plain sediments of sand and gravel. Salt-water encroachment has occurred locally in shallow aquifers along the coast and adjacent to estuaries. Although variable, ground water tends to become brackish with increasing depth.

Water quality over much of the area is excellent. Dissolved solids are generally less than 175 mg/l and chloride rarely exceeds 10 mg/l. Along the coast, higher concentrations of chloride indicate salt-water encroachment and infiltration of salt-enriched rain. Water is generally soft; hard water is only found north of Milford and in the Piedmont near Wilmington.

Since the average annual precipitation exceeds 40 inches (101.6 cm), Delaware has ample water supplies and many potential pollutants are diluted. Only in northern New Castle County is it difficult to obtain adequate supplies. Much of the state's population is situated in this area, which is underlain largely by aquifers that provide only low well yields.

The Delaware ground-water quality maps are based on more than 250 analyses, 116 of which are from domestic and municipal wells.

FLORIDA

Florida has an abundant ground-water supply due to high precipitation (53 inches/134.6 cm) and low runoff (14 inches/35.6 cm). In addition, the ground-water reservoir strata is extensive and very permeable. The state, which lies in the Coastal Plain, is underlain by permeable limestone, dolomite, and sand. Most of the state has little relief, although a central highland trends through the axis of the peninsula and a few hills exist in the northern panhandle.

Most of the ground-water is derived from the Floridan Aquifer, an artesian aquifer consisting of Eocene-age limestone and dolomite that underlies the entire state and extends under the Coastal Plain of Alabama, Georgia, and South Carolina, covering 83,000 square miles (214,970 square km). It yields water of desirable quality except south of Lake Okeechobee and in coastal portions of northeast and east-central Florida. Minor aquifers include the Tampa Limestone and Hawthorn Formation of Miocene age. The Floridan Aquifer, which crops out in only a few places, is covered by thick clay and marl deposits of the Floridan Aquiclude, which includes thick beds of the Hawthorn Formation and several other detrital formations. Fortunately, however, many sinkholes breach the overlying material and allow surface water to infiltrate quickly. Typical well yields for a 6-inch (15.2 cm) diameter well are 800 gpm (50.5 l/s) for the Floridan Aquifer. The Biscayne Aquifer, situated in the southeastern tip, generally yields 1,200 gpm (75.7 l/s) to 6-inch (15.2 cm) diameter wells. Other aquifers, mainly surficial sediments, yield 300 gpm (18.9 l/s) to 6-inch (15.2 cm) diameter wells. Well depths vary considerably throughout the state and may reach over 1,000 feet (305 m) for the Floridan Aquifer.

The concentrations of calcium and magnesium are generally less than 50 mg/l, but concentrations over 100 mg/l are present in the extreme southwest. Sodium and potassium occur in relatively higher concentrations 25 to 1,000 mg/l) along the coast and at the southern tip. Sulfate is quite low (less than 25 mg/l) with higher concentrations in Taylor, Hillsborough, and Collier Counties. Although the state has an extensive coastline with great potential for salt-water intrusion, chloride concentrations are low with higher concentrations (greater than 250 mg/l) in Volusia, Dixie, and Levy Counties plus

small portions of the southern tip. Dissolved solids and hardness are present in higher concentration in the same areas.

The natural ground-water quality throughout most of Florida is good, but hard. Water obtained from sand and gravel aquifers in the western panhandle is generally softer than that from the Floridan Aquifer. Also, many areas along both the Atlantic and Gulf coasts are susceptible to salt-water encroachment. Among cities that have lost well fields to salt-water encroachment are Miami, Coral Gables, Fort Myers, Tampa, St. Petersburg, and New Port Richey. Ground water in the Everglades is generally of poor quality due to high concentrations of many chemical constituents. Areas that are heavily populated, overpumped, or overdrained generally have mineralized water.

Saline water is naturally present in much of the southeast. Local problems with storm water, industrial wastes, and septic-tank disposal are troublesome.

The Florida ground-water quality maps are based on more than 11,200 chemical analyses, 9,700 of which are from domestic and municipal wells.

GEORGIA

Georgia enjoys extremely abundant ground-water resources and overall excellent water quality. Very few water quality problems exist, although locally hard and residual saline waters have been encountered.

The southeastern three-fifths of the state forms the Coastal Plain, a low relief region of Cretaceous to Recent sediments that thickens and dips gently to the south-southeast. Four major extensive aquifers underlie this region. The largest and most developed is the principal artesian aquifer (the northward extension of the Floridan Aquifer), which underlies about 40 percent of the state in the southeast. These limestones are 500 feet (152.5 m) thick at the coast and decrease in thickness towards the northwest. Where present, these strate provide the major source of ground water. Well yields range from 100 to 4,000 gpm (6.3 to 252.4 l/s), and the maximum recorded yield is 11,000 gpm (694.1 l/s). Wells tapping this aquifer range from 300 to 800 feet (91.5 to 244 m) deep. The water is of good quality, except locally where it is hard and contains high concentrations of dissolved solids (up to 600 mg/l). Although the aquifer is highly developed near the coast and its water level has declined significantly, salt-water intrusion has occurred in only a few places.

Other aquifers in the Coastal Plain are sands of Cretaceous age, early Tertiary limestones, and sands which usually overlie the Cretaceous but are used only when the more productive Tuscaloosa Formation is too deep. Also present are the little-used Miocene and Pliocene sands and limestones that form a thin blanket along the coast. Well yields for the Paleocene and Eocene formations range from 50 to 900 gpm (3.2 to 56.8 l/s). Water quality from these sediments is generally good to excellent, although it becomes somewhat saline downdip.

The rest of the state lies in the Piedmont province, except for the Appalachian Plateau and Ridge Valley provinces in the northwestern corner and an extension of the Blue Ridge in the northeastern corner of the state. The Valley and Ridge consists of folded sedimentary rocks (sandstone, limestone, shale, and dolomite) and numerous springs; carbonate rocks are the major aquifers. Massive dolomite formations yield from 5 to 50 gpm (0.3 to 3.2 l/s) with maximum yields of 1,000 gpm (63.1 l/s). Limestone,

sandstone, mudstone, and chert generally yield 1.0 to 20 gpm (.06 to 1.3 l/s) with maximum yields from 50 to 300 gpm (3.2 to 18.9 l/s). Well depths range from 100 to 500 feet (30.5 to 152.5 m). Locally, the water is hard (120 mg/l) even though dissolved solids concentrations are low (150 mg/l). The carbonate aquifers yield water of excellent quality except for hardness. A similar situation exists in the Plateau although the rocks are only gently tilted.

The Piedmont and Blue Ridge consist of crystalline rocks, primarily gneiss, schist, granite, quartzite, slate, and marble, with ground water confined to fractured and weathered zones. Supplies larger than those sufficient for domestic needs are difficult to obtain without a careful analysis of the local geology. Typically, well yields are low and range from 1.0 to 25 gpm (0.06 to 1.6 l/s), and maximum well yields in favorable locations yield upward of 400 gpm (25.2 l/s). Water quality is generally excellent, although highly fractured or solutioned areas are susceptible to pollution from nearby sources.

Overall, the ground water in Georgia is excellent. Higher concentrations of calcium and magnesium (25 mg/l), sodium and potassium (25 mg/l), and sulfate (25 mg/l) occur northwest in the carbonate terrain of the Appalachian Plateau, locally near Atlanta, and in the southwestern corner of the state. Chloride follows a similar pattern, except for higher concentrations (as much as 100 mg/l) near the coast. Hardness and dissolved solids are higher near populated areas, in the Appalachian Plateau, and along the coast.

The Georgia ground-water quality maps are based on more than 550 analyses, 250 of which are from domestic and municipal wells.

IDAHO

Much of Idaho lies in the rugged northern Rocky Mountains, a region dominated by intrusive igneous rocks. Sweeping the western and southern margins of the mountains in a long arc are the lava fields and alluvial valleys of the Columbia Plateau drained by the Snake River. Extending into Idaho's southeast corner are the arid isolated ranges and desert plains of the Basin and Range province, which is bordered on the east by the complex mountains and intermontane basins of the middle Rocky Mountains. Mean annual precipitation ranges from more than 50 inches 127 cm) in the mountains along the Idaho-Montana border to less than 10 inches (25.4 cm) along the Snake River. Runoff averages 9 inches (22.9 cm).

In the northern Rocky Mountains, ground water is obtained from weathered rock or from fractures in the dense crystalline rock. Although highly variable, yields are generally only a few gallons per minute. In the valleys, however, coarse deposits of sand and gravel are common, and well yields may exceed 300 gpm (18.9 l/s) from wells less than 150 feet (45.8 m) deep. In the Columbia Plateau, basaltic lava flows and interbedded sedimentary strata (the Snake River Group) serve as important aquifers that generally yield 500 to 5,000 gpm (31.6 to 315.5 l/s) for irrigation. Older basaltic lava flows and volcanic and sedimentary rocks yield 50 to 500 gpm (3.2 to 31.6 l/s). Deposits of alluvial sand and gravel, including glacial outwash, generally yield moderate to large supplies of ground water. Well depths vary considerably throughout the region and can range up to 1,000 feet (305 m).

Overall, ground-water quality in Idaho is good, particularly in the upland areas. Locally high concentrations of dissolved solids and sodium are present, and the water is generally hard. In the Moscow and Salmon River basins, the ground water is hard but contains less than 300 mg/l of dissolved solids. In the Twin Falls area, the water is exceptionally hard; near Salmon Falls, high concentrations of chloride, sulfate, and sodium are present. Along the Snake River, floodplain ground water has a low dissolved solids content but chloride concentrations are variable. In the Great Basin region of Oneida County, ground-water quality is poor or fair because evaporite deposits yield waters containing large concentrations of dissolved solids, sulfate, and chloride.

Relatively high concentrations of calcium and magnesium occur only in the southeastern and south-central parts of Idaho where evaporite and carbonate deposits are present. Sodium and potassium concentrations are greater along an east-west belt that trends across the southern part of the state, correlating well with the basaltic aquifers.

The Idaho ground-water quality maps are based on more than 1,400 analyses, 850 of which are from domestic and municipal wells.

ILLINOIS

The flat to gently rolling plains of Illinois are part of the Central Lowland and were glaciated except in the northwestern corner, the southern tip, and in a narrow strip along the Mississippi River south of Monroe County. Glacial drift mantles most of the gently dipping underlying Paleozoic strata, although it is thin in places. Annual precipitation averages 37 inches (93.9 cm), ranging from 32 inches (81.3 cm) in the north to 46 inches (116.8 cm) in the south. Runoff, averaging 10 inches (25.4 cm), ranges from 7 to 16 inches (17.8 to 40.6 cm).

Unconsolidated sand and gravel deposits are the primary sources of ground water in all but the northern quarter of Illinois. The most productive of these aquifers occur along major watercourses like the Mississippi, Illinois, and Wabash Rivers and their tributaries, and in ancient bedrock valleys covered by glacial drift. Industrial and municipal wells generally yield 100 to 500 gpm (6.3 to 31.6 l/s); well depths are generally less than 200 feet (61 m). Glacial drift also serves as an important source of water. However, the underlying Paleozoic dolomites and sandstones serve as the chief source of ground-water supply in the northern third of the state. Large-capacity wells tapping these shallow aquifers generally yield 100 to 500 gpm (6.3 to 31.6 l/s). Well depths generally range from 50 to 300 feet (15.3 to 91.5 m).

From adjacent states, Paleozoic rocks dip gently into the Illinois basin. These rocks range in age from Cambrian to Pennsylvanian, and the major aquifers are sandstone, limestone, and dolomite. Well yields as high as 1,500 gpm (94.6 l/s) are obtained from Cambrian sandstone aquifers in the northern part of the state, but yields from other bedrock aquifers are far less.

Ground-water quality in Illinois is fair to good, although water is very hard throughout much of the state. Hardness commonly exceeds 300 mg/l in water from glacial deposits, and 200 mg/l in ground water from bedrock aquifers. Dissolved solids exceed 500 mg/l over wide areas, particularly in bedrock aquifers in the southern and western two-thirds of the state. Concentrations of chloride and sulfate are also locally excessive (more than 250 mg/l). In sand and gravel deposits, chloride concentrations are generally less than 10 mg/l but water from bedrock aquifers

in much of western and southern Illinois may contain higher concentrations. These waters generally occur at depths of about 250 feet (76.3 m) in the south and 350 feet (106.8 m) in the west.

INDIANA

Indiana with its flat to gently rolling terrain has been extensively glaciated except in the south-central part. The underlying bedrock of Paleozoic age (Ordovician to Pennsylvanian) gently dips because of the Kankakee-Cincinnati arch that extends southeast-northwest, separating the Illinois basin on the southwest from the Michigan basin on the northeast. The bedrock strata consists of limestone, shale, sandstone, and coal.

Glacial drift dates back to Wisconsinan, Illinoian, Kansan, and possibly older ages. Where present, the Illinoian and older drift is generally a poor aquifer. Where it is overlain by younger glacial deposits, the greater thickness (over 100 feet/30.5 m) and permeability form a productive aquifer. Along major streams, deposits of alluvium (many glacially derived) are important aquifers capable of yielding 100 to over 500 gpm (6.3 to 31.2 l/s). Yields from sand and gravel deposits in the drift are good, especially where it is thick, but the ground water is hard (generally more than 200 mg/l) and dissolved solids locally exceed 500 mg/l. Wells tapping glacial and alluvial deposits generally range from 50 to 250 feet (15.3 to 76.3 m) deep.

Silurian and Devonian limestone and dolomite aquifers in the central, north-central, and northwestern parts of the state are important bedrock sources that may yield more than 500 gpm (31.6 l/s) to wells. Elsewhere, well yields from bedrock aquifers are generally less than 10 gpm (0.6 l/s). Maximum bedrock yields in the southern portion of the state reach over 40 gpm (2.5 l/s). Bedrock well depths vary considerably and commonly range from 100 to 400 feet (30.5 to 122 m). Water quality is fair to good depending on the aquifer.

Overall ground-water quality in Indiana is good, although high hardness is noted in northeastern Indiana and objectionable concentrations of sodium bicarbonate are locally present in southwestern Indiana. Higher concentrations also occur in isolated areas in the southern part of the state. Indiana has ample average annual precipitation and runoff varies from 4 to 13 inches (10.2 to 33 cm).

IOWA

Iowa lies entirely in the Central Lowland, and glacial till covers the underlying Paleozoic or Cretaceous bedrock throughout most of the state. Mean annual precipitation averages 31 inches (78.7 cm), ranging from 35 inches (88.9 cm) in the southeast to 25 inches (63.5 cm) in the northwest. Runoff averages 5 inches (12.7 cm), varying from about 2 inches (5.1 cm) in the northwest to 8 inches (20.3 cm) along the eastern border.

The Paleozoic rocks dip gently southwestward from structurally higher areas to the north and east into a broad south-opening syncline. Cretaceous rocks cover these strata in the northwest and include the artesian Dakota Sandstone Aquifer. The Mesozoic and Paleozoic rocks are mantled by glacial drift that averages about 200 feet (61 m) thick over much of the state except along the northeastern edge.

Ground-water supplies are obtained from thick Paleozoic strata (Cambrian to Pennsylvanian) in the eastern half of Iowa, and all except Pennsylvanian-age rocks (10 to 20 gpm/0.6 to 1.3 l/s) provide substantial yields (300 to 3,000 gpm/18.9 to 189.3 l/s) of good quality water. Noteworthy aquifers include the Dresbach Group (Cambrian), Jordan Sandstone (Cambrian), Prairie du Chien Group and St. Peter Sandstone (Ordovician), and Silurian to Mississippian-age carbonate rocks (50 to 4,000 gpm/3.2 to 252.4 l/s). Well depths range from less than 100 feet (30.5 m) to several hundred feet. Water from carbonate rocks is commonly of poor quality and limited quantity. Dissolved solids increase from less than 500 mg/l in the northeast to more than 1,500 mg/l in the southwest. Hardness and sulfate generally increase with dissolved solids.

Southwestern Iowa is underlain primarily by Pennsylvanian rocks (sandstone and shale) that contain somewhat highly mineralized water and provide only limited yields (less than 10 gpm/0.6 l/s). Here, the best and most abundant ground-water supplies are obtained from thin outwash deposits along major streams.

Northwestern Iowa is underlain by Cretaceous rocks, including the Dakota Sandstone, and is mantled by thick deposits of glacial drift. The Dakota Sandstone contains rather highly mineralized water in which dissolved solids commonly exceed 1,000 mg/l; in Osceola, O'Brien, Buena Vista, and Ida Counties, it is greater than 2,500 mg/l.

Other Iowa aquifers include those along watercourses and in buried valleys. Extensive streamside aquifers along the Mississippi and Missouri Rivers yield 1,000 to 2,000 gpm (63.1 to 126.2 l/s). In certain adjacent reaches of the Wapsipinicon, Cedar, Iowa, Skunk, Des Moines, Raccoon, Floyd, Little Sioux, and Nishnabotna Rivers, yields commonly exceed 200 gpm (12.6 l/s). Segments of these aquifers, particularly in western Iowa, contain 500 to 1,000 mg/l of dissolved solids. Wells tapping the glacial drift that occurs extensively throughout the state typically yield 5 to 20 gpm (0.3 to 1.3 l/s). Well depths are generally less than 200 feet (61 m).

Ground-water quality in Iowa is poor in many places, especially in the south-central, southwestern, and western regions where very hard, mineralized, sulfate-rich water is present in the glacial drift, alluvium, and bedrock sources.

The Iowa ground-water quality maps are based on more than 850 chemical analyses, 450 of which are from domestic and municipal wells.

KANSAS

Kansas is a plains state with large amounts of ground-water storage in the semiarid western part and lesser quantities of storage in alluvial, glacial, and underlying confined aquifers in the eastern part. The eastern third of Kansas is in the Central Lowlands province while the western two-thirds is in the Great Plains province, the westernmost part of which is called the High Plains.

The average annual precipitation in Kansas is 27 inches (68.6 cm). The east receives approximately 40 inches (101.6 cm) and the west approximately 16 inches (40.6 cm). Annual runoff decreases from 10 inches (25.4 cm) at the Missouri-Kansas border to 0.1 inch (0.3 cm) at the Colorado-Kansas border.

The major aquifers in the west occur in unconsolidated sands and gravels of Tertiary-Pleistocene age. These aquifers yield abundant supplies of generally good quality water with localized hardness. The confined Cretaceous sandstone aquifers are also used extensively where the overlying unconsolidated sediments are absent or nonwater-bearing. Water from the sandstone aquifers is generally of poorer quality due to higher concentrations of sodium and fluoride. The quality varies from highly mineralized in the north-central and northwestern portion of Kansas to irrigation quality in the southwest. These Cretaceous rocks overlie Paleozoic rocks in the western half of Kansas and are mantled by unconsolidated Tertiary and Pleistocene sediments, as much as 700 feet (213.5 m) thick, in southwest Kansas. This thick section of unconsolidated sediments furnishes a major portion of ground-water supplies in the western half of the state.

Alluvium of Pleistocene age overlies the Tertiary sediments and extends into south-central Kansas where it provides an excellent source of good quality water. The unconsolidated material lies on mineralized Permian "redbed" formations. This causes water-quality deterioration in the lower portion of the unconsolidated aquifer because of upward leakage of mineralized water. In general, wells tapping a variety of formations in western and south-central Kansas are capable of yielding 100 to 500 gpm (6.3 to 31.6 l/s).

In eastern Kansas, ground water is obtained from alluvial deposits associated with major river floodplains, glacial outwash in the northeast, and confined Paleozoic sandstones, limestones, and dolomites. Kansas is underlain by Paleozoic rocks that form a series of shallow structural basins and anticlines superimposed on a regionally westward-dipping monocline. The Paleozoic rocks include aquifers containing characteristically poor quality water, limited storage, or both. Well yields are characteristically less than 100 gpm (6.3 l/s).

The best Paleozoic aquifers are the dolomitic sandstones and limestones in the southeastern corner of the state which supply a reasonably good quantity and quality of ground water to several communities. Well depths range from 150 to over 500 feet (45.8 to 152.5 m) in some locations. Some Permian rocks in east-central Kansas produce moderate quantities of water. However, each Permian aquifer has extreme lateral quality and quantity variations. Pleistocene glacial outwash serves as an aquifer in the northeastern part of Kansas and varies widely in quality, having high sulfate concentrations. The underlying Paleozoic rocks yield insignificant amounts of usable water.

Future aquifer development in the western, southwestern, northwestern, and south-central parts of Kansas is hindered by the rate of natural recharge to the aquifers. Locally, well depths vary considerably. Wells tapping unconsolidated sand and gravel deposits range from less than 100 to 300 feet (30.5 to 91.5 m) deep. Wells tapping the Dakota Aquifer may vary from 150 to over 500 feet (45.8 to 152.5 m) deep. Because large ground-water supplies are located in the semiarid west, withdrawals by wells penetrating these aquifers exceed natural recharge, resulting in a gradual water-level decline which has become locally critical. Widespread irrigation and increased water-using activities have accelerated this decline.

It is not possible to arrive at an overall classification of ground-water availability and quality in Kansas. High and low mineralization levels within the same aquifer occur both laterally and vertically. Localized increases in dissolved solids, hardness, sulfate, and chloride have resulted from both natural mineral intrusion from underlying formations in contact with the aquifer, and from man-induced pollution such as past oil-field brine disposal practices.

The Kansas ground-water maps are based on more than 250 analyses, 150 of which are from domestic and municipal wells.

KENTUCKY

Kentucky lies in the Central Lowland and Appalachian Plateau, which is further divided into the Mississippian Plateau, Blue Grass, Western Coal Field and Eastern Coal Field regions, the Ohio River alluvium, and the Mississippi Embayment (Jackson Purchase region). Annual precipitation averages about 45 inches (114.3 cm), but nearly half runs off or is temporarily stored in the alluvial deposits along the Ohio and Mississippi Rivers. Ground-water supplies are generally small to moderate from the Paleozoic aquifers, and small to large from unconsolidated aquifers.

Although not usually considered a separate physiographic region, the alluvial terraces and bottomlands along the Ohio River in Kentucky are a distinct geologic unit and are treated separately here because they are the area of greatest present and potential ground-water development. Large to very large supplies of ground water are available from sand and gravel varying in thickness up to 200 feet (61 m). Single wells in these alluvial aquifers yield as much as 1,500 gpm (94.7 l/s). Water is generally hard, but dissolved solids concentrations are usually less than 250 mg/l and chloride less than 10 mg/l.

The Jackson Purchase region includes the eight westernmost counties. Here, the most important aquifer consists of thick beds of sand and gravel of Cretaceous and Eocene age. Moderate to very large (500 to 1,000 gpm/31.6 to 63.1 l/s) supplies of ground water are available from these unconsolidated sediments from wells less than 200 feet (61 m) deep. The water is generally hard, but dissolved solids concentrations are usually less than 250 mg/l and chloride less than 10 mg/l.

The roughly cresent-shaped Mississippian Plateau forms western, southern, and central Kentucky and encircles the Western Coal Field region on the west and the Blue Grass region on the east. Aquifers consist of sandstone and limestone, but the cavern systems tend to drain rapidly during dry weather. Locally, in the southern part of the Plateau, the water becomes increasingly saline at depths as little as 50 to 75 feet (15.3 or 22.9 m) and is highly variable in chemical quality. Generally, ground water quality in this region is poor. The northern and western parts of the region contain ground water of more desirable quality: chloride is typically less than 50 mg/l, calcium

and magnesium are less than 100 mg/l, and dissolved solids are less than 500 mg/l. Well yields in the western portion of this region range from 1.0 to 200 gpm (0.06 to 12.6 l/s). Well yields are considerably lower in the eastern portion of the Mississippian Plateau and generally range from 0.1 to 10 gpm (0.006 to 0.631 l/s). Well depths range from 100 (30.5 m) to several hundred feet.

In the Blue Grass region in north-central Kentucky, ground water is hard to very hard (240 to 500 mg/l). Low-flow samples from the Kentucky and Licking Rivers contain less than 100 mg/l of hardness. About one-eighth of the wells examined in this region reportedly yield water containing excessive concentrations of sodium and chloride. Well yields in the Outer Blue Grass province range from 0.1 to 10 gpm (0.006 to 0.631 l/s). Well yields in the Inner Blue Grass province range from 5 to 500 gpm (0.3 to 31.6 l/s).

The Western Coal Field region yields adequate water supplies from sandstone and limestone aquifers. Well yields range from 1 to 200 gpm (0.06 to 12.62 l/s) but generally average less than 20 gpm (1.3 l/s). A major problem is drainage of ground water from coal mines, which contaminates streams with large concentrations of dissolved solids, hardness, sulfate, and iron. Throughout this region, dissolved solids range from 250 to 500 mg/l. Water is generally very hard (240 to 500 mg/l) and exceeds 500 mg/l in Union and McLean Counties. Chloride concentrations are less than 50 mg/l, but sulfate generally exceeds 100 mg/l.

The Eastern Coal Field region is similar to the Western Coal Field in ground-water availability, use, and quality. Water from low-yielding wells is softer, generally less than 200 mg/l hardness, and chloride is commonly less than 25 mg/l except in Menifee, Breathitt, Magoffin, and Wolfe Counties. For the most part, the water is of good quality where uncontaminated by coal-mine drainage or oil-field brine. Well yields are extremely variable, and range from 1 to 200 gpm (0.06 to 12.62 l/s) for sandstone and limestone aquifers and 0.1 to 10 gpm (.006 to .631 l/s) for dense limestone, shale, and siltstone aquifers.

The Kentucky ground-water quality maps are based on more than 4,550 chemical analyses, 4,000 of which are from domestic and municipal wells.

LOUISIANA

Louisiana lies entirely within the Coastal Plain and is a water-rich state with large supplies of ground water. Mean annual precipitation is 55 inches (139.7 cm), and runoff ranges from 15 inches (38.1 cm) in the west to more than 20 inches (50.8 cm) in the southeast. About two-thirds of all ground water pumped in the state is from Quaternary deposits.

In northwestern Louisiana, fresh water is obtained from the Wilcox Aquifer, a lignitic sand, sandy siltstone, and clay sequence forming a deltaic deposit that thickens rapidly southward. The water is generally of good quality, but contamination has occurred locally due to the movement of poor quality water toward heavily pumped centers and the movement of salt water along confining beds of clay. Yields are relatively low due to fine-grained sediments. Chloride content typically ranges from 25 to 50 mg/l and dissolved solids vary from 250 to 500 mg/l.

The Claiborne Group of Eocene age, which is tapped in northern Louisiana, contains two important fresh-water aquifers: the Sparta and Cockfield. These aquifers are capable of yielding several hundred gallons per minute. The Sparta Sand contains massive beds of sand near the base, although the clay content increases in the upper part of the formation. The water is soft (less than 60 mg/l hardness) and has less than 25 mg/l of chloride. The Cockfield Formation consists of layers of lignitic sand, silt, and clay. Fresh water is present in this aquifer in Sabine, Vernon, and Natchitoches Parishes northeastward to East Carroll Parish. The water increases in hardness northeastward, eventually exceeding 200 mg/l. Chloride, while generally less than 25 mg/l, locally may exceed 100 mg/l, depending on well depth. The Cockfield and Sparta Aquifers are, in some places, high in iron. As the water migrates downdip, it is naturally softened, resulting in an increase in sodium bicarbonate content. Well depths range from 300 to over 800 feet (91.5 to 244 m).

Water occurs in sediments of Miocene age in a broad east-west trending belt that extends across the south-central part of Louisiana into an area east of the Mississippi River and north of Lake Pontchartrain. This water is of good quality with dissolved solids less than 250 mg/l. However, in Concordia Parish, water is more highly

mineralized (dissolved solids around 450 mg/l) and highly colored. Water is soft (less than 60 mg/l) except for Catahoula Parish where hardness exceeds 200 mg/l. Well water in some areas of Rapides and Avoyelles Parishes contains high concentrations of fluoride. Well yields and well depths vary considerably. Well depths range from 100 to over 1,000 feet (30.5 to 305.0 m) in some localities.

Pliocene-age deposits generally contain fresh water in a broad east-west trend in central-south Louisiana, but they are interrupted by salt water in St. Landry Parish. The saltwater zone extends northward, parallel to the axis of the Mississippi trough, and includes Avoyelles, Catahoula, and Concordia Parishes. Elsewhere, the Pliocene aquifers contain water of excellent quality (less than 500 mg/l of dissolved solids).

Quaternary deposits cover the entire southern half of the state as well as most main river valleys in the north. The valley deposits, composed of sand and gravel near the base, generally contain hard water (exceeding 180 mg/l) and high concentrations of iron. In southern Louisiana, these deposits thicken gradually as they dip toward the Gulf. These deposits are capable of yielding several hundred gallons per minute from wells ranging from 50 to 300 feet (15.3 to 91.5 m) deep. Ground-water quality is variable in the southwest. Excessive pumping has caused concern about salt-water migration from the coastal areas during dry season. Salt-water intrusion is, thus far, limited to an area along the Vermilion River in Vermilion Parish.

The Louisiana ground water-quality maps are based on more than 5,000 chemical analyses, 4,500 of which are from domestic and municipal wells.

MAINE

Maine lies in the glaciated part of the Appalachians and exhibits considerable relief. Bedrock consists predominantly of Paleozoic rocks and minor amounts of Precambrian and Mesozoic rocks, mostly crystalline, that generally provide only low yields to wells. Glacial till mantles the region, while marine clay blankets an area along the coast and partly fills the major river valleys. Stratified sand and gravel deposits occur predominantly in the coastal region and supply moderate amounts of water to wells, generally less than 50 gpm (3.2 l/s). Well depths are generally less than 200 feet (61 m).

Intrusive and related rocks (mostly granite and pegmatites) occur in many areas in the southern half of the state. Most pegmatites have extremely low yields, often less than 10 gpm (0.6 l/s). Metamorphic rocks range from very high grade in the south to low grade in the north where slate and limestone are found. The limestone of eastern Aroostook County is a better than average bedrock aquifer. Ribbon limestones found in the south-central part of the state and small segments of marble in the central coastal area are locally good aquifers. The limestones tend to produce harder water than that found in the other crystalline rocks. Glacial sand and gravel deposits commonly produce ground water containing excessive concentrations of iron and manganese.

In general, crystalline rock in Maine is a suitable aquifer for domestic needs with 85 percent of the drilled wells yielding at least 2.0 gpm (0.1 l/s). However, 70 percent yield less than 10 gpm (0.6 l/s). Of the 162 municipal water systems in the state, 52 percent use all or some ground water. Considering the large number of rural homes, it appears that about 75 percent of Maine's population depend in part on ground-water supplies.

Highly fractured zones occur throughout the crystalline bedrock in the state where higher than average well yields occur. The most productive fractured zone is generally encountered at depths of 200 to 300 feet (61 to 91.5 m). Fracture zones yielding 10 gpm (0.6 l/s) or more (maximum of 800 gpm/50.5 l/s) occur in the coastal region.

Many domestic wells tap glacial till and provide barely adequate supplies. Only in the southern fifth of the state

are permeable sand and gravel deposits widespread and screened wells relatively common. Similar aquifers also are found adjacent to the St. John River along the northern border of the state. Maximum recorded well yields are about 2,000 gpm (126.2 l/s) for permeable glacial outwash deposits of sand and coarse gravels.

Overall, ground water in Maine is of excellent quality. Most of the bedrock and glacial cover are only slightly soluble. Thus, ground water has a relatively low mineral content which increases slightly (up to 275 mg/l of dissolved solids) in areas of carbonate bedrock. Excessive iron and manganese are a problem for many individual homes and some municipalities.

The Maine ground-water quality maps are based on more than 250 analyses, 100 of which are from domestic and municipal wells.

MARYLAND

More than half of Maryland is underlain by the nearly flat coastal plain consisting of Cretaceous, Tertiary, and Quaternary-age sands, silts, and clays. These sediments dip southeastward and thicken to over 8,000 feet (2440 m) along the Atlantic coast. The rolling hills of the Piedmont province consist of Precambrian and Paleozoic crystalline rocks. To the west, the Blue Ridge, Valley and Ridge, and the Appalachian Plateaus consist of Precambrian to Mesozoic rocks. Stretching southward through west-central Maryland is a fault-block basin filled with Triassic-age redbeds that have been intruded by diabase dikes. This entire Appalachian region is characterized by a series of ridges and valleys consisting of metamorphic and sedimentary rocks.

Most of the high-yield wells in Maryland tap coastal plain sediments of sand and gravel. Domestic wells are capable of yielding 50 gpm (3.2 l/s) from depths less than 250 feet (76.3 m). Salt-water encroachment has occurred locally in shallow aquifers along the coast and estuaries, and ground water often becomes brackish with increasing depth. In the Piedmont and Appalachian provinces, wells usually produce less than 10 gpm (0.6 l/s), although maximum yields of 580 gpm (36.6 l/s) have been obtained in carbonate-rock areas. Well depths vary from 100 to 350 feet (30.5 to 106.8 m).

Water quality over much of the area is excellent. Dissolved solids are generally less than 175 mg/l and chloride rarely exceeds 10 mg/l. Locally and along the coasts, higher concentrations indicate salt-water encroachment and infiltration of salt-enriched rain. Water is generally soft, except in certain parts of the Piedmont and in carbonate areas in the Appalachian highlands.

Since the average annual precipitation exceeds 40 inches (101.6 cm), Maryland generally has ample water supply and many potential pollutants are diluted. Locally, however, considerable difficulty is encountered in obtaining even small supplies.

The Maryland ground-water quality maps are based on more than 2,000 chemical analyses, 1,560 of which are from domestic and municipal wells.

MASSACHUSETTS

Massachusetts consists of four physiographic provinces: the western mountainous Berkshires, the central Piedmont Upland, the Triassic Lowland, and the Coastal Plain. Precipitation ranges from 35 inches (88.9 cm) along the coast to about 55 inches (139.7 cm) in the west. Most aquifers are consolidated crystalline and sedimentary rocks, but glacial till and sand and gravel deposits are also sources of water. The most extensive bedrock aquifer is a Precambrian-Carboniferous crystalline complex in western and central Massachusetts. Wells tapping this aquifer range between 100 and 200 feet (30.5 to 61 m) deep and produce an average of 10 gpm (0.6 l/s). The majority of these wells are unlikely to produce more than 5 or 6 gpm (0.3 or 0.4 l/s) on a sustained pumping basis. Some wells, originally tested at 50 or 60 gpm (3.2 to 3.8 l/s) with no obvious drop in water level after the first few hours, dropped off to only 5 to 10 gpm (0.3 to 0.6 l/s) with sustained pumping during the low-rainfall summer months. Locally, a few wells yield as much as 200 gpm (12.6 l/s).

In western Massachusetts, carbonate rocks are the principal aquifers. Yields average about 10 gpm (0.6 l/s) but may be much greater in areas where weathering has enlarged the openings. In the Narragansett and Boston basins (the southeastern and northeastern part of the state), carboniferous sandstones, shales, and conglomerates, which underwent some metamorphism, overlie the crystalline rocks and are major aquifers. Yields are comparable to those in crystalline terrain. Triassic rocks, primarily sedimentary, occur in the central part of the state and form the Connecticut River Valley where yields average 41 gpm (2.6 l/s). Wells completed in gneiss, quartzite, and schist generally report yields of 6 gpm (0.4 l/s) or less, and well depths range from 100 to 300 feet (30.5 to 91.5 m); wells located in limestone and sandstone generally yield more than 15 gpm (0.9 l/s) at comparable depths. One industrial well in Pittsfield is reported to produce 1,400 gpm (88.3 l/s) from a fault involving limestone, schist, and quartzite. Flowing wells are also present in this area of the state.

All of the region has been glaciated, and till mantles much of the state. Well yields in the till are extremely low (1.0 to 2.0 gpm/0.06 to 0.12 l/s), and many go dry during periods of low rainfall. The best aquifers, sand and gravel, are also glacial in origin. These deposits are most

extensive in the southeast and Cape Cod area. However, localized sand and gravel aquifers occur throughout the state. A majority of public water systems in the state utilize these unconsolidated deposits as water supply sources.

Overall, ground water is of excellent quality in Massachusetts. It is generally soft, except in the western part of the state where carbonate aquifers yield moderately hard to hard water. Only four of the public water supplies in the state are reported to have sulfate concentrations over 100 mg/l. All of these are in the northeast and are not representative of nearby wells in the same area or in adjacent communities. Approximately 30 percent of the wells in the northeast have sulfate concentrations ranging from 25 to 40 mg/l. Similar sulfate concentrations may be encountered in certain areas of the Triassic Lowlands and along the Rhode Island border. In the northeast, both surficial and bedrock aquifers yield harder water (60 to 120 mg/l). The most prevalent ground-water quality problem in the state, as well as in much of New England, is concentrations of iron and manganese.

Concentrations of calcium and magnesium and sodium and potassium are greater in the western carbonate belt than in the northeast where crystalline and sedimentary rocks are tapped. Some bedrock wells contain high concentrations of chloride in the northeast and Boston area. Locally high chloride concentrations have been reported in bedrock wells along the coast. Some of the chloride problem along the coast may be due to salt-water intrusion, while inland chloride problems are related to road salting. Only one public water supply (Provincetown) has a well in which chlorides approach 250 mg/l. The pumping rate of this well is controlled so that the chloride concentration is kept within permissible limits. Overall, Massachusetts has good to excellent water with few areas having major problems.

The Massachusetts ground-water quality maps are based on more than 1,350 analyses, 650 of which are from domestic and municipal wells.

MICHIGAN

Michigan has an abundant supply of water which is evident by its large number of lakes. Annual precipitation averages 32 inches (81.3 cm), ranging from 26 to 36 inches (66 to 91.4). Runoff varies from 10 to 15 inches (25.4 to 38.1 cm), averaging 12 inches (30.5 cm).

The entire state has been glaciated several times. In the Upper Peninsula, the glacial drift is relatively thin and is entirely absent in places. Glacial materials averaging 300 feet (91.5 m) thick cover the entire Lower Peninsula, exceeding 1,000 feet (305 m) in some areas. Glaciers also deposited extensive amounts of sand and gravel in places. Along the edges of the state are glacial lake deposits consisting of clay, silt, and fine sand.

Bedrock structure in Michigan is controlled by an uplift called the southern Superior Upland (Upper Peninsula) and a bowl-shaped depression called the Michigan Basin. The Superior Upland is formed by sedimentary and crystalline rocks of Precambrian and early Paleozoic age, while the Michigan Basin is filled with Ordovician and younger Paleozoic sediments.

In the northwestern part of the Upper Peninsula, most aquifers provide 10 gpm (0.6 l/s) or less to 6-inch (15.2 cm) diameter wells. However, the water contains less than 250 mg/l of dissolved solids. Elsewhere, the Upper Peninsula is underlain by southeastward-dipping Paleozoic strata mantled by glacial drift. In these areas, both bedrock and drift deposits provide adequate yields that typically range from 10 to 500 gpm (0.6 to 31.6 l/s) to 6- or 8-inch (15.2 to 20.3 cm) diameter wells. Well depths are generally less than 250 feet (76.3 m). The water is hard (as much as 250 mg/l) with locally high concentrations of calcium and sulfate.

The Lower Penisula consists of thick deposits of Paleozoic sediments (sandstone, shale, and limestone) overlain by glacial drift. Both bedrock and drift aquifers are utilized for water supplies, and wells in these deposits usually provide between 10 to over 100 gpm (0.6 to 6.3 l/s) to 6-inch (15.2 cm) or larger diameter wells. Well depths range from less than 100 to about 400 feet (30.5 to 122 m). However, many glacial lake deposits are only moderately productive and yield less than 10 gpm (0.6 l/s).

Throughout most of the Lower Peninsula, ground water contains more than 200 mg/l of both dissolved solids and hardness. South of a line trending northeast through Saginaw Bay, ground water is more highly mineralized. In some areas, dissolved solids exceed 400 mg/l, hardness is greater than 300 mg/l, and sulfate and chloride concentrations are locally excessive.

The Michigan ground-water quality maps are based on 3,700 analyses, 1,200 of which are from domestic and municipal wells.

MINNESOTA

Minnesota's mean annual precipitation ranges from 19 inches (48.3 cm) in the northwest to 32 inches (81.3 cm) in the southeast, with a state average of 25 inches (63.5 cm). Mean annual runoff, averaging 4 inches (10.2 cm), varies from 1.0 inch (2.5 cm) along the Red River Valley in the northwest, to about 12 inches (30.5 cm) in the northeast adjacent to Lake Superior.

Most of the state lies in the Central Lowland except for the northeastern corner which forms part of the Superior Upland. Geologically, Minnesota can be divided into four regions. To the northeast of Lake Superior, Precambrian volcanics, intrusives, and metasedimentary rocks are mantled by a thin layer of glacial drift. Similar rocks extend into the central part of the state and are overlain by glacial deposits in the north and east, by lake deposits in the west, and by outwash and terrace deposits in the south. The southeastern part of Minnesota contains the state's major aquifers, which consist of Cambrian, Ordovician, and Devonian carbonates and sandstones covered by glacial drift. The western half of the state is made up largely of bands of Precambrian metamorphic and intrusive rocks, with Ordovician and Jurassic carbonates in the northwest and some Cretaceous sandstones in the south.

Ground-water supplies are adequate in the central and southern parts of the state. Sand and gravel deposits are capable of yielding several hundred gallons per minute to shallow wells generally less than 200 feet (61 m) deep. In the northeast, ground-water supplies are limited due to the thin cover of drift over the crystalline bedrock. The western section has extremely variable ground-water supplies, with patchy sandstones and sands forming the major producing zones. In general, aquifers located in the central and southern portion of the state are capable of yielding at least 50 gpm (3.2 l/s). Bedrock wells generally do not exceed 500 feet (152.5 m) deep.

Ground-water quality in southeastern Minnesota is good (less than 350 mg/l of dissolved solids), although hard to very hard (120 to nearly 500 mg/l) in carbonate areas. The east-central area has very hard water (as much as 250 mg/l), but is low in dissolved solids (less than 300 mg/l). The northeast has the best overall water (less than 150 mg/l of dissolved solids), although it is commonly moderately hard

(less than 120 mg/l). The most variable ground-water quality occurs in western Minnesota where very poor water (more than 1,000 mg/l of dissolved solids and 500 mg/l of sulfate) is derived from glacial lacustrine deposits.

In general, ground-water quality in Minnesota is good but usually hard. Water is relatively scarce in the western part of the state. Some problems related to iron mining, excessive pumping, and septic-tank effluent are present.

The Minnesota ground-water quality maps are based on more than 2,900 chemical analyses, 1,400 of which are from domestic and municipal wells.

MISSISSIPPI

Mississippi benefits from very large ground-water supplies of low mineral content which are used by most municipalities. Precipitation averages 54 inches (137.2 cm) a year and ranges from 46 to 65 inches (116.8 to 165.1 cm), runoff averages 21 inches (53.3 cm) and varies from 15 to 30 inches (38.1 to 76.2 cm) a year.

With the exception of the northeast corner, the state lies in the Coastal Plain physiographic province where Cretaceous and Tertiary strata dip generally southwestward, increasing in thickness from the outcrop in the northeast to thousands of feet in the south and southwest. The geologic setting provides a nearly continuous series of confined aquifers that underlie the entire state. In many parts of the state, the fresh water portion of the aquifers overlap and a number of separate aquifers are available for exploitation. These strata are overlain in places by alluvium, loess, and terrace sand and gravel of Quaternary age that are as much as 300 feet thick (91.5 m); this alluvium is productive in the Mississippi River Floodplain.

Aquifers of the Coastal Plain are high-yielding, with most capable of 2,000 gpm (126.2 l/s). Well depths range from 100 to 500 feet (30.5 to 152.5 m) throughout the state, depending on the attitude of the aquifer with respect to the well site. With the exception of the Cretaceous-age Selma Group and the Tertiary-age Porters Creek Clay and Yazoo Clay, all strata include water-bearing sand, gravel, and limestone. Cretaceous aquifers include parts of the Tuscaloosa Group, McShan and Eutaw Formations, Coffee Sand, and Ripley Formation. Tertiary aquifers are found in the Wilcox Group, Claiborne Group, Jackson Group, Miocene Series, and Citronelle Formation. The northeast corner of Mississippi is underlain by Mississippian and Devonian limestone and sandstone which yields 100 to 200 gpm (6.3 to 12.6 l/s) in places, reaching a maximum of 800 gpm (50.5 l/s) in favorable locations. Well depths generally range from 150 to 450 feet (45.8 to 137.3 m).

In general, ground-water quality in Mississippi is good. Within each aquifer, water quality varies downdip from the outcrop. As a rule, ground water close to the outcrop is low in dissolved solids but may be hard and acidic. There is a progressive increase in dissolved solids downdip, but the water becomes soft and alkaline and is

dominated by sodium and bicarbonate. Also, water becomes saline further downdip and water obtained from Quaternary sands is usually hard (120 mg/l). Water availability is a problem in a belt of tight sediments between the Cretaceous deposits and the north-central region. Some naturally occurring saline waters are present and salt-water encroachment along the coast is a potential problem.

The Mississippi ground-water quality maps are based on more than 4,200 chemical analyses, 2,800 of which are from domestic and municipal wells.

MISSOURI

The northern half of Missouri lies in the dissected till plains of the Central Lowland, with the southern part of the state in the Ozark Plateau. Precipitation, ranging from 30 inches (76.2 cm) in the northwest to more than 50 inches (127 cm) in the southeast, averages about 40 inches (101.6 cm) per year. Runoff varies between 3 and 20 inches (7.6 and 50.8 cm), averaging 11 inches (27.9 cm).

The glacial boundary which roughly bisects the state generally follows the trend of the Missouri River. Most of Missouri is underlain by Paleozoic rocks that dip steeply off the Precambrian-centered Ozark uplift. Paleozoic rocks become younger (Cambrian to Pennsylvanian) away from the uplift.

Relatively large amounts of ground water are available throughout most parts of the state. In the glaciated northern part, glacial drift (which is thin on the uplands and locally as much as 400 feet/122 m thick) and outwash deposits in buried valleys (many of which are coincident with modern valleys) serve as water supply sources, as does alluvium in present valleys. These deposits are capable of yielding upwards of 1,000 gpm (63.1 l/s) to wells less than 200 feet (61 m) deep. In the underlying Pennsylvanian-age bedrock (primarily shale, sandstone, and limestone), water is generally of poor quality (locally exceeding 250 mg/l of dissolved solids) and low yield (5 to 30 gpm/0.3 to 1.9 l/s).

In northeastern Missouri, a thin cover of glacial till covers Pennsylvanian and Mississippian strata. This is the least productive ground-water area in the state due to low well yields and an abundance of highly mineralized and hard water.

In southeastern Missouri, the Mississippi Embayment and alluvial valleys contain excellent aquifers. In the Mississippi Embayment (the most productive area in the state), Cretaceous and Tertiary sedimentary rocks (sandstone, shale, and limestone) up to 2,000 feet (610 m) thick commonly yield as much as 500 gpm (31.6 l/s). Water from Cretaceous deposits is very soft, less than 60 mg/l, while that from Tertiary strata is generally hard, about 180 mg/l. Thick permeable deposits of Quaternary alluvium along the Mississippi River and its tributaries provide as much as

4,000 gpm (252.4 l/s), although the water is hard. Well depths vary from slightly less than 100 feet (30.5 m) to over 450 feet (137.3 m).

The Ozark Highlands are underlain largely by Paleozoic rocks, and well yields from Precambrian and Pennsylvanian rocks are low. However, the remaining Paleozoic rocks, consisting primarily of carbonates, produce large quantities of water from solution-enlarged fractures. Some of the largest springs in the United States such as Big Springs and Mammoth Springs have their sources in these Cambrian and Ordovician rocks.

Wells tapping the Roubidoux Formation yield 15 gpm (0.9 l/s), the Gasconade Formation, 20 gpm (1.3 l/s), the Gunter, 40 gpm (2.5 l/s), and the Potosi Formation, 250 gpm (15.8 l/s). Well depths range throughout the state from 250 to over 1,000 feet (76.3 to 305 m).

Local ground-water problems in Missouri include low yields and highly mineralized water, especially in the northern and western parts of the state. Many bedrock aquifers contain saline water even at shallow depths. In addition, highly mineralized water is found near some mining districts, and the cavernous carbonate areas are easily and quickly polluted by inadequate waste disposal.

The Missouri ground-water quality maps are based on more than 4,600 chemical analyses, 2,600 of which are from domestic and municipal wells.

MONTANA

The eastern three-fourths of Montana lies in the Great Plains, a vast region of dissected, nearly flat-lying, fine-grained Mesozoic and Cenozoic rocks. Interrupting these prairies locally are relatively small ranges, such as the Big Snowy, Judith, Little Rocky, and Bearpaw Mountains, where older rocks are exposed. This vast region is drained by the Yellowstone and Missouri Rivers and their tributaries. The western part of Montana is composed of the northern and middle Rocky Mountains, a region of rugged ranges that trend north-south and are separated by elongate valleys. Many of these ranges are cored by crystalline Precambrian rocks and surrounded by upturned Paleozoic and Mesozoic sediments. In Montana's southwestern corner, many of the intermontane basins contain widespread Tertiary deposits, including lake deposits and alluvium.

Throughout most of the Great Plains, average annual precipitation is less than 15 inches (38.1 cm) but exceeds 50 inches (127 cm) in the high mountains. The state average is 15 inches (38.1 cm). Similarly, runoff ranges within wide extremes from less than 1.0 inch (2.5 cm) in most of the eastern two-thirds of the state, to more than 20 inches (50.8 cm) in the mountains in the extreme west.

A large share of Montana's population is in the Great Plains, a region of great water use. Glacial drift is present north of the Missouri River. Water is obtained from sand and gravel lenses in the till, but the largest yields (some more than 1,000 gpm/63.1 l/s) come from numerous buried valleys that contain outwash from wells less than 200 feet (61 m) deep. Elsewhere, wells yield large quantities of ground water by tapping coarse alluvium along water-courses. Where these sources are lacking, sedimentary rocks are the major aquifers. These include the Fort Union Formation (sandstone and coal) in the east and southeast, and sandy units in the Fox Hills, Hell Creek, Kootenai, and Judith River Formations. Well depths range from 150 to over 300 feet (45.8 to 91.5 m) in some portions of the state. Yields from sandy deposits are generally only a few gallons per minute, although more can be obtained by deepening wells to tap several water-bearing zones.

Large yields (more than 1,000 gpm/63.1 l/s) have also been obtained from coarse-grained aquifers in structural and intermontane basins such as Deer Lodge, Bitterroot,

Kalispell, Clark Fork, Big Hole, and Townsend Valleys. In the mountains, well yields from fractures in crystalline rocks are generally only a few gallons per minute from wells up to several hundred feet deep.

There are many places in Montana where water is scarce and wells as deep as 2,000 feet (610 m) are required. In general, ground water in the mountains is good to excellent in quality, but varies from good to locally extremely poor in the east. The quality of water from bedrock aquifers is extremely variable and, in many parts of east and central Montana, ground water may be highly mineralized and very hard. The best quality water is found near recharge areas, but the mineral content appreciably increases within short distances downgrade. Excessive dissolved solids are common in water from both the Hell Creek and Fort Union Formations. If sufficient recharge occurs, ground water is generally good to fair in quality when obtained from alluvial aquifers.

In several parts of the Missouri and Yellowstone basins, ground water is hard and contains large concentrations of dissolved solids; much of it can only be used for livestock. Likewise, dissolved solids exceed 3,000 mg/l in the White Sulphur Springs area. Other problems include waterlogging from irrigation and disputes over water use in the east where vast coal reserves are present.

The Montana ground-water quality maps are based on over 950 well water analyses, 425 of which are from domestic and municipal wells.

NEBRASKA

Nebraska is favored with ample ground-water supplies that are distributed widely. These supplies are extensively developed where cropland is irrigated. Current pumpage averages 6 to 7 million acre-feet (approximately 7.8 x 10^9 cu. meters) per year. Annual precipitation averages 22 inches (55.9 cm), ranging from 14 inches (35.6 cm) in the west to 35 inches (88.9 cm) in the southeast. Runoff averages 2 inches (5.1 cm) but varies from 0.25 to 5.0 inches (0.6 to 12.7 cm).

The eastern fifth of the state, the Drift Hills region, has been glaciated. Here, the glacial deposits generally rest on the Cretaceous or Paleozoic rocks, although significant thicknesses of stream alluvium are present in parts of preglacial, interglacial, and postglacial valleys. Much of the remainder of the state is in the High Plains province which is mostly underlain by rocks of Tertiary age, but is mantled in large part by dune sand, loess, and fluvial deposits of Quaternary age. Where the Quaternary sediments and Tertiary rocks have been removed by erosion, rocks of Cretaceous age are exposed. Such areas occur in the extreme northwest part of the state, the Ponca Creek drainage basin, the lower part of the Niobrara River basin in northeastern Nebraska, and along the valley of the Republican River in southern Nebraska.

In the Drift Hills region, small supplies of ground water generally can be obtained from the glacial deposits. In some places, moderately large supplies (200 gpm/12.6 l/s) can be obtained either from surficial or buried valley-fill sediments, or from Cretaceous or Paleozoic rocks. Where the High Plains are underlain by thick Quaternary sediments or Tertiary rocks, moderately large to large supplies of ground water are generally available. The more important aquifers are fluvial sandy gravel deposits of Pleistocene age, the Ogallala Formation of Pliocene age, and the Arikaree Group of Miocene age. Wells tapping valley-fill alluvial deposits yield a maximum of 4,000 gpm (252.4 l/s); other alluvial deposits in the state range from 10 to 2,000 gpm (0.6 to 126.2 l/s). Dune sand aquifers generally yield 50 to 2,000 gpm (3.2 to 126.2 l/s). Similar well yields are obtained from the Arikaree Group. Wells tapping the Ogallala are generally less than 200 feet (61 m) deep.

The water table is shallow throughout much of the broad fertile valley of the Platte River, which flows generally eastward across the High Plains. The Loup River, an important tributary of the Platte, heads in the Sand Hills region of north-central Nebraska and derives a large part of its flow from ground-water seepage. In parts of northeastern, northwestern, and southern Nebraska, ground-water supplies are scarce where the thick Pierre Shale of Cretaceous age is only thinly mantled or exposed. In such areas, small water supplies can be obtained locally from Quaternary valley-fill sediments, and larger supplies generally can be obtained from the underlying Cretaceous or Paleozoic rocks. The Dakota Sandstone is the most important aquifer among the rocks of Cretaceous age with well yields of 10 to 4,000 gpm (0.6 to 252.4 l/s).

Ground water in Nebraska is mostly of good to moderately good quality. Water in the Sand Hills region is soft, but water is hard to very hard elsewhere in the state. The better quality ground water is in the highly permeable fluvial deposits of Tertiary age, and in the Ogallala Formation and Arikaree Group of Tertiary age. Water in the glacial drift and Cretaceous and Paleozoic aquifers is generally high in dissolved solids.

Large withdrawals for irrigation have lowered the water table several feet in a few areas, particularly in the upper Big Blue River basin. In two other upland areas--one in Gosper, Phelps, and Kearney Counties, the other in Sherman and Howard Counties--the water table has been mounded by excess recharge from river water used for irrigation. Waterlogging has occurred locally in these areas.

Increasing agricultural and urban demands for water create local problems with water supply and deteriorating water quality. Overall, however, the state still has large amounts of good quality ground water available from depths of less than 400 feet (122 m).

The Nebraska ground-water quality maps are based on more than 2,900 analyses, 1,750 of which are from domestic and municipal wells.

NEVADA

Nevada lies almost entirely within the Basin and Range provinces, a vast, dry region characterized by eroded fault-block mountains and alluvial basins. Throughout most of the state, the drainage is internal and streams flow into large closed depressions to form playas or saline lakes such as Humboldt and Carson Sinks. Resting in the rain shadow of the Sierra Nevada and Cascade Ranges, Nevada is the driest state in the nation. Precipitation averages 9 inches (22.9 cm) per year, ranging from less than 5 inches (12.7 cm) in a belt extending from Winnemucca southeastward to Las Vegas, to more than 15 inches (38.1 cm) in the mountains around Ely and Carson City. Runoff averages only 0.6 inches (1.5 cm), varying from less than 0.25 (0.64 cm) to slightly more than 1.0 inch (2.5 cm). Most of the water is lost by evaporation and transpiration.

The major aquifers in Nevada are Tertiary and Pleistocene coarse-grained deposits in the alluvial basins. Bedrock includes various Paleozoic, Mesozoic, and Cenozoic sedimentary and igneous rocks. Yields from wells obtaining water from fractures in consolidated deposits are variable, but generally average only a few gallons per minute. Yields from unconsolidated deposits commonly exceed 500 gpm (31.6 l/s), but fine-grained strata in many basins reduce the yield significantly. Wells tapping cavernous limestones or permeable volcanic rocks can yield 10 to 50 gpm (0.6 to 3.2 l/s) in local areas. Well depths range from 50 feet (15.3 m) to several hundred feet throughout the state.

Available data, although sparse, indicate that ground-water quality in Nevada varies widely. The quality may be poor over broad areas where high concentrations of sulfate are often present. The least mineralized water is found near the valley margins and in mountains where principal recharge occurs. The poorest quality is generally encountered in ground-water discharge areas in the central part of many basins. High levels of arsenic and fluoride are found in many private wells and certain community water systems. Many local areas of highly mineralized water are too small to be shown on the maps. Regionally, the least mineralized water is found in northeastern Nevada in the Snake River basin (Columbia Plateau), in areas where Cenozoic volcanic and sedimentary strata are present, and in the central part of the state.

Overpumping has occurred in the Las Vegas and Pahrump Valleys. Excessive withdrawals from many other heavily populated valleys also may strain the local ground-water systems in the future.

The Nevada ground-water quality maps are based on more than 250 chemical analyses, 100 of which are from domestic and municipal wells.

NEW HAMPSHIRE

New Hampshire, the most rugged New England state, has few serious water problems. Receiving 43 inches (109.2 cm) of precipitation each year and generous runoff, the state is largely rural with forests covering 85 percent of the land. About half of the annual precipitation results in runoff, which is greater than any other state. This factor alone indicates why few critical water problems develop.

The entire state has been glaciated, and till mantles most of the bedrock. Glacial deposits form the major aquifers; stratified drift, especially in the lowlands, is moderately productive and supplies the best source of ground water. Extensive outwash deposits occur in the southeast, but sand and gravel lenses within the till are also important aquifers. Wells tapping glacial deposits are generally less than 200 feet deep (61 m).

New Hampshire lies in the glaciated Appalachians province and is subdivided into the Seaboard Lowland, New England Upland, and White Mountains. Bedrock in over two-thirds of the state consists of sedimentary rocks of Ordovician to Devonian age, many of which are metamorphosed. Elsewhere, the state is underlain by intrusive rocks of Paleozoic age. Yields from wells drilled into bedrock are generally less than 10 gpm (0.6 l/s). The water is stored largely in fractures, which decrease in number with increasing depth. In general, most bedrock wells do not yield appreciable amounts of water at depths greater than 300 feet (91.5 m). Overall, ground-water quality in New Hampshire is excellent, and surface waters are usually only slightly less mineralized than ground water. Dissolved solids concentrations are less than 200 mg/l, and the water is generally soft (less than 60 mg/l) with the hardest in the state found in the Connecticut River Valley and along the coast (rarely more than 180 mg/l). Calcium and magnesium, sodium and potassium, and sulfate rarely exceed 50 mg/l. Chloride is locally high (up to 250 mg/l) near the coast. Some streams have been polluted, especially by paper-mill wastes, but this is being carefully scrutinized. Fluoride concentrations have been reported as being unusually high near Lake Winnipesaukee.

The New Hampshire ground-water quality maps are based on more than 250 analyses, 150 of which are from domestic and municipal wells.

NEW JERSEY

New Jersey is a heavily populated and growing state that has plentiful average annual precipitation and runoff, 47 and 20 inches (119.4 and 50.8 cm) respectively, which tend to minimize water problems.

The geology of New Jersey can be divided by a line that extends northeastward from Trenton to Carteret. To the south, the Coastal Plain consists of Quaternary to Cretaceous-age sediments (sand, clay, and marl) forming a wedge that dips and thickens southeastward. To the north, the Appalachian Piedmont, Reading Prong, and Valley and Ridge provinces consist of older, folded, and faulted sedimentary, metamorphic, and igneous rocks. Well yields in the Reading Prong range from 0 to 40 gpm (0. to 2.5 l/s) from consolidated rocks. Yields up to 500 gpm (31.6 l/s) are obtained from consolidated rocks in the Piedmont province. Bedrock well depths generally range from 100 to 400 feet (30.5 to 122 m). Glacial till and outwash lie as far south as a line extending from Perth Amboy to Phillipsburg.

Most ground-water resources in New Jersey are obtained from Coastal Plain deposits, but surface water accounts for almost 90 percent of the supply to public water systems in the north. In the Appalachian region, yields from bedrock aquifers range from 0 to 150 gpm (0 to 9.5 l/s); the highest yields occur in limestone areas. Coastal Plain deposits yield large quantities of ground water, especially in the interior, but salt-water encroachment is a potential problem along the coast. In some of the glaciated areas, sand and gravel deposits in buried valleys are excellent aquifers. Coastal Plain sediments or stratified drift generally yield several hundred to a few thousand gallons per minute to large-diameter municipal or industrial wells. Domestic well depths are generally less than 200 feet (61 m).

Ground-water quality is good to excellent. Calcium and magnesium are usually quite low, but higher concentrations (25 mg/l) occur in the northern part of the state. Two areas of higher concentration are associated with the Raritan and overlying Magothy Formation. Sodium, potassium, and chloride concentrations are low (less than 25 mg/l), particularly in the interior. Dissolved solids and hardness concentrations have a similar distribution since they are well-correlated with the geology. High concentrations (100

to 200 mg/l) are present in the glaciated northern part of the state and along the Delaware River. Other high concentrations are present along the coast and in the northwest where ground water is obtained from limestone aquifers.

The New Jersey ground-water quality maps are based on more than 1,500 analyses, 1,100 of which are from domestic and municipal wells.

NEW MEXICO

The Paleozoic, Mesozoic, and Quaternary strata in the eastern third of New Mexico (which lies in the Great Plains) are drained in the north by the Canadian River and other Mississippi River tributaries, and in the south by the Pecos River, which drains into the Rio Grande. In the north-central area are the southern Rockies, which are characterized by various complex mountains and intermontane basins. The northwestern part of New Mexico is in the Colorado Plateau, an arid structural basin drained by the San Juan River. The Zuni Mountains, volcanic necks, and lava flows dominate the plateau in the south. The rest of the state, consisting of mountain ranges and alluvial valleys, forms part of the Basin and Range province and is drained by the Rio Grande River.

Precipitation is less than 8 inches (20.3 cm) per year along parts of the Rio Grande, but more than 20 inches (50.8 cm) in the higher parts of the southern Rockies. Statewide, precipitation averages 15 inches (38.1 cm). Similarly, runoff is small but variable, ranging from less than 0.1 inch (0.3 cm) in the dry areas to as much as 20 inches (50.8 cm) in the Sangre de Cristo Mountains.

Major aquifers in New Mexico form a complex sequence of alluvial deposits in the Basin and Range province and along the Rio Grande. Limestone formations and alluvium are major aquifers along the Pecos River Valley and Piedmont. Ground water is obtained from the Ogallala Formation of Pliocene age and from alluvium in eastern New Mexico. In northern Lea County, the Ogallala yields 200 to 1,800 gpm (12.6 to 113.6 l/s) to wells less than 300 feet (91.5 m) deep. Most of this water is used for irrigation.

Generally, water is of good quality but is locally hard and contains excessive concentrations of fluoride. Ground-water supplies are scarce in the Canadian and Cimarron River basins where shale and sandstone of Cretaceous and Cenozoic age are primarily present. However, these formations in the northern High Plains in New Mexico, together with the Ogallala, yield sufficient amounts of water for irrigation. Ground-water supplies are widespread, but yields are generally low along the upper reaches of the Pecos River basin. Farther downstream, water in alluvium and limestone provides adequate supplies for extensive irrigation.

Water is scarce or deep along the upper reaches of the Rio Grande basin, but yields as high as 1,000 gpm (63.1 l/s) have been obtained from streamside deposits. Throughout the basin, well yields range widely from only a few gallons per minute to more than 3,000 gpm (189.3 l/s).

In central and south-central New Mexico, ground water is obtained from various aquifers such as valley-fill, sandstone, and limestone. Yields vary widely but irrigation wells commonly yield 200 to 2,000 gpm (12.6 to 126.2 l/s). Well depths also vary considerably and may exceed 400 feet (122 m) in some locations. Extensive alluvial deposits occur in the southwestern part of the state, and many have been tapped for irrigation supplies since the turn of the century. The Gila River and its tributaries drain the western part of New Mexico of volcanic mountains and plateaus associated with the Mogollon Rim. Yields are small in the upland but ground water is extensively developed along the Gila where alluvium and volcanic rocks yield as much as 2,500 gpm (157.8 l/s) to large-capacity wells. Well depths generally range from 200 to 800 feet (61 to 244 m).

Palezoic, Mesozoic, and Cenozoic rocks underlie the Colorado Plateau in the northwest quarter of the state. Most of the rocks have low permeability and relatively high dissolved solids content.

Ground-water quality in New Mexico is only fair at best, with poor quality water throughout much of the state. In the southern High Plains, ground water is normally very hard with high concentrations of calcium, magnesium, sulfate, and chloride. In the populated Pecos River Valley, ground water is relatively poor with high concentrations of chloride, sulfate, hardness, and dissolved solids. Over much of the Basin and Range province, moderate yields of good to fair quality water are obtained, although some contain high concentrations of sulfate and fluoride. The Colorado Plateau is underlain primarily by sandstone and shale of low permeability, and it has poor quality water that is excessively high in sulfate. Overall, the best water is from igneous rocks in the Rocky Mountains. In the northeast, low yields of poor quality water are present in the Canadian and Cimarron River basins. Some of the most developed ground-water supplies are in the southeast where heavy pumping has substantially lowered the water levels of the Ogallala and Quaternary deposits, which contain generally good water.

The New Mexico ground-water quality maps are based on more than 1,500 chemical analyses, 750 of which are from domestic and municipal wells.

NEW YORK

Several distinct ground-water regions exist in New York. These regions are defined by the rocks that are present, which exert a strong influence on both the quality and quantity of ground water available. Much of the state is mantled by glacial deposits. Long Island, hydrologically similar to the Atlantic Coastal Plain, is composed of Pleistocene glacial deposits that are underlain by unconsolidated sand and gravel of Cretaceous age. Well yields exceeding 1,000 gpm (63.1 l/s) are common. Most domestic wells tap surficial Pleistocene deposits and generally are less than 200 feet (61 m) deep. Properly constructed domestic wells are capable of yielding 15 gpm (0.9 l/s) or more.

The southern part of the state consists of (1) nearly flat-lying shales and sandstones that form the Appalachian Plateau, (2) the deeply dissected sandstones of the Catskills, and (3) the folded and metamorphosed rocks of the lower Hudson Valley. Wells in these strata normally yield less than 10 gpm (0.6 l/s); well depths generally do not exceed 350 feet (106.8 m). A belt of limestone and dolomite of Silurian and Devonian age extends from Buffalo eastward across the central part of New York to Albany; wells in these rocks generally produce 15 to 20 gpm (0.9 to 1.3 l/s) from depths of 100 to 300 feet (30.5 to 91.5 m). The Precambrian granite and gneisses that make up the Adirondack Mountains produce the smallest yields of any region in the state. Water occurs primarily in fractures, and well yields seldom exceed 2.0 or 3.0 gpm (0.12 to 0.18 l/s). Most wells generally do not exceed 400 feet (122 m) deep.

The most productive aquifers, other than those of Long Island, are the sand and gravel deposits scattered throughout the state. These occur as valley fills in the Appalachian Plateau, Hudson Valley, and northern Adirondacks. Well yields in many places are as much as several hundred gallons per minute. Well depths vary considerably and range from less than 100 to 250 feet (30.5 to 76.3 m).

The least mineralized ground water occurs in the crystalline rocks of the Adirondacks, the sandstones of the Catskills and headwaters of the Delaware basin, and the sand and gravel deposits of eastern Long Island. The concentrations of all constituents are very low (less than

25 mg/l), and the water is soft (less than 60 mg/l). The most highly mineralized ground water occurs in carbonate and shale aquifers in western New York between Buffalo and Syracuse and in a small area near Albany. In certain formations in western New York, excessively mineralized ground water is present.

With average annual precipitation of 39 inches (99.1 cm) and runoff of 22 inches (55.9 cm), ample ground-water recharge occurs. The state has very large resources of good-quality water; wise development of supplies for urban areas will require careful planning.

The New York ground-water quality maps are based on over 4,100 chemical analyses, 1,300 of which are from domestic and municipal wells.

NORTH CAROLINA

North Carolina has large ground-water resources which must keep pace with growing water demands. Approximately half the state lies in the Coastal Plain, with the western edge formed by the Blue Ridge and the remainder fabricated by the Piedmont. Annual precipitation, ranging from 40 to 78 inches (101.6 to 198.1 cm), averages 49 inches (124.5 cm). Runoff varies from 10 to 55 inches (25.4 to 139.7 cm), averaging 16 inches (40.6 cm).

The Coastal Plain is underlain by an eastward-thickening wedge of Cretaceous and Tertiary sand, clay, and limestone that exceeds 10,000 feet (3,050 m) thick at Cape Hatteras. The sands and limestones are productive aquifers widely used throughout the Coastal Plain. These formations commonly yield 50 to 1,000 gpm (3.2 to 63.1 l/s) to wells ranging from 150 feet (45.8 m) to several hundred feet deep. Water availability is a local problem in parts of the Piedmont and Blue Ridge. The Piedmont consists of belts of fractured metamorphic and igneous rocks of Precambrian to Palezoic age that provide moderate yields to wells. Wells tapping slates and sandstones generally average less than 20 gpm (1.3 l/s). Well depths rarely exceed 300 to 500 feet (91.5 to 152.5 m).

A similar situation exists in the Blue Ridge. In the central part of North Carolina, Triassic-age sedimentary rocks fill fault-block basins, and only small well yields are possible. Along streams, alluvial deposits form important aquifers. Well depths are generally less than 150 feet (45.8 m).

The state has few serious ground-water quality problems. In the Coastal Plain, the water is of generally good quality (dissolved solids vary from 100 to 250 mg/l) and is usually soft (30 to 120 mg/l). Some danger of salt-water encroachment is present near the coast where overpumping occurs. The Piedmont area is fairly productive and the ground water is generally soft (less than 60 mg/l), although it may be locally hard (180 mg/l) and more highly mineralized (dissolved solids up to 500 mg/l). The Triassic basins, consisting of redbeds and intrusives, yield hard (120 to 180 mg/l) and mineralized (dissolved solids 250 to 500 mg/l) water.

The North Carolina ground-water quality maps are based on more than 3,300 analyses, 2,350 of which are from domestic and municipal wells.

NORTH DAKOTA

Lying in both the Great Plains and Central Lowlands, North Dakota is a nearly flat, semiarid region where ground-water resources are small compared to potential demand. Water supplies are not evenly distributed and are only locally abundant. Precipitation averages 17 inches (43.2 cm), ranging from less than 15 inches (38.1 cm) in the west to about 22 inches (55.9 cm) in the southeast. Annual runoff, the lowest of all the states, is less than a 0.5 inch (1.3 cm).

Except for the southwestern quarter of the state, North Dakota is mantled by glacial deposits. The underlying strata consist largely of Cretaceous- and Tertiary-age shale and fine-grained sandstones that dip gently westward into the Williston Basin. Along the eastern border, Paleozoic and Precambrian rocks underlie the drift. Bedrock and glacial till aquifers are fine-grained and not highly permeable, but surficial and buried outwash along several streams and rivers (as well as outwash plains and delta deposits) serve as important, locally high-yielding aquifers.

Two groups of bedrock aquifers are tapped in the state. In the eastern half, the Dakota Sandstone of Cretaceous age is part of the famous "Dakota artesian basin." These sandy strata are not highly permeable and do not supply large yields to wells despite the fact that they are widespread and many of them flow. A second group of bedrock aquifers is generally used in the western half of North Dakota. These aquifers consist of fine sand, shale, and lignite in the Fox Hills and Hell Creek Formations of Cretaceous age, and the Fort Union Group of Paleocene age. Yields are generally small, averaging only a few gallons per minute. Well depths range from 100 feet (30.5 m) to several hundred feet.

Glacial deposits provide most of the ground water used in North Dakota. Sand and gravel lenses within the till yield a few gallons per minute. Extensive outwash plains and deltas, such as those in Kidder and Richland Counties, provide as much as 500 gpm (31.6 l/s) to wells. The most prolific aquifers are coarse deposits found along waterways

such as the Missouri River (2,000 gpm/126.2 l/s), along former glacial streams (as much as 1,000 gpm/63.1 l/s), and in several buried river valleys such as the New Rockford Channel that extends from Griggs County, across Foster and Wells Counties, and northwestward into Ward County. Municipal wells in a buried channel at Minot yield more than 3,000 gpm (189.3 l/s). The majority of wells tapping glacial deposits are less than 200 feet deep (61 m).

In North Dakota, ground water containing less than 500 mg/l of dissolved solids is generally limited to surficial deposits of sand and gravel. Although usually hard to very hard (120 to 240 mg/l), chloride concentrations are commonly less than 30 mg/l and sulfate in many aquifers averages about 160 mg/l.

Buried sandy deposits usually contain water in which dissolved solids range between 700 and 1,500 mg/l, and dissolved solids exceed 1,500 mg/l in parts of Williams, Divide, Burleigh, Wells, Grand Forks, Traill, and Cass Counties. The higher concentrations are accompanied by increased hardness (as much as 1,820 mg/l), sulfate (in excess of 1,500 mg/l), and chloride (maximum of 1,930 mg/l).

The chemical quality of ground water obtained from bedrock aquifers ranges widely. In the eastern half of the state, ground water is generally very hard and may contain large concentrations of chloride and sulfate. A well tapping the Cretaceous Pierre Shale in Barnes County contains 3,930 mg/l of dissolved solids. Hardness, sulfate, and chloride concentrations are 300 mg/l, 56 mg/l, and 1,980 mg/l, respectively. In Grand Forks County, a well in the Dakota Sandstone yields water with nearly 14,000 mg/l of dissolved solids, 2,387 mg/l of hardness, 5,644 mg/l of chloride, and 627 mg/l of sulfate. In western North Dakota, ground water from the Fort Union Group is generally sodium-rich and relatively soft, although quite mineralized. A Fort Union well in Divide County contained 1,640 mg/l of dissolved solids but relatively low concentrations of hardness (72 mg/l). Lignite seams locally serve as aquifers; the quality of the water is similar to other supplies obtained from the Fort Union Group, but water is usually brown or black due to organic acids or very finely-divided coal.

The North Dakota ground-water quality maps are based on more than 9,900 chemical analyses, 5,500 of which are from domestic and municipal wells.

OHIO

Mississippian and Pennsylvanian-age bedrock in the eastern half of Ohio consists largely of alternating layers of sandstone and shale with minor amounts of coal and limestone. The southwest corner contains relatively thin, alternating layers of shale and limestone of Ordovician age, while much of the western half of the state is underlain by Silurian limestone. The southeastern third of Ohio was not glaciated, and the topography is characterized by rolling hills, modified in places by strip mining. Elsewhere, glacial deposits mantle the surface, which is nearly flat except where streams have cut into the glacial till or the underlying bedrock. Several of the major river valleys, including the Mad, Great Miami, Scioto, Hocking, Tuscarawas, and Muskingum, contain extensive deposits of sand and gravel that provide large quantities of water to wells. These deposits are similar to those adjacent to the Ohio River.

Wells tapping limestone in the western part of the state or the sand and gravel in the major river valleys produce more than 500 gpm (31.6 l/s) and generally average from 10 to 100 gpm (0.6 to 6.3 l/s). Wells tapping sand and gravel deposits are generally less than 150 feet (45.8 m) deep; bedrock wells generally range from 100 to 300 feet (30.5 to 91.5 m) deep. A 10-mile (16.1 km) wide belt extending northward from Columbus to Lake Erie and along the shoreline into Pennsylvania contains an abundance of Devonian shale. Wells in these deposits generally produce less than 5 gpm (0.3 l/s). Elsewhere, yields from glacial till and sandstone range from 5 to 100 gpm (0.3 to 6.3 l/s).

Wells in the glacial till or limestone in northwestern Ohio commonly contain more than 500 mg/l of dissolved solids, and concentrations approach 2,000 mg/l locally. In a few areas in the southeast and northeast parts of the state, dissolved solids exceed 500 mg/l.

Except in a few relatively small areas, the hardness of ground water in Ohio exceeds 120 mg/l. In the western half of the state, hardness is generally greater than 300 mg/l and reaches more than 1,000 mg/l in some areas.

Although extremely variable, calcium and magnesium in Ohio ground water range from about 30 mg/l in the east to nearly 300 mg/l in the west. Sodium and potassium also increase from east to west, ranging from less than 10 to

more than 170 mg/l. Throughout most of Ohio, chloride concentrations are less than 25 mg/l but locally approach 200 mg/l, particularly in areas of existing or former oil and gas fields. In general, the concentration of sulfate in ground water is less than 250 mg/l, but concentrations exceeding 100 mg/l are prevalent in eastern coal-mining regions and in the northwest where sulfate locally surpasses 500 mg/l.

Since Ohio has an average annual rainfall of 38 inches (96.5 cm), sufficient water supplies for domestic uses can generally be obtained from either surface or underground sources.

The Ohio ground-water quality maps are based on over 500 chemical analyses, 200 of which are from domestic and municipal wells.

OKLAHOMA

Oklahoma consists primarily of plains with portions of the Ozark Plateau in the northeast and the Ouachita Mountains in the southeast. The Arbuckle Mountain uplift region is found in the south-central part of Oklahoma, and the Wichita Mountain uplift occurs in the southwestern sector. The state is situated in the unglaciated Central Lowlands, the High Plains in the panhandle area, and a part of the dissected western Coastal Plain along the southeastern border. Annual precipitation averages 32 inches (81.3 cm), but ranges from 16 inches (40.6 cm) in the west to over 50 inches (127 cm) in the southeast.

Most of the state is underlain by Paleozoic rocks which, where undisturbed, dip gently to the west. Beneath the High Plains, these rocks underlie flat-lying Triassic to Cretaceous-age strata that are capped by the Tertiary Ogallala Formation. Quaternary alluvium deposits are found along the major streams. The Paleozoic rocks are folded and faulted in the Ozark, Ouachita, Arbuckle, and Wichita uplifts, and Precambrian rocks are exposed in the Ozark and Arbuckle areas.

Cretaceous rocks of the Coastal Plain onlap Precambrian and Paleozoic rocks in the Arbuckle and Ouachita Mountains. The western half of Oklahoma is underlain by Permian redbeds, which are characterized by extensive evaporite deposits.

Nearly one-half of Oklahoma's ground-water resources occur in the western part of the state. Major ground-water basins include the Arbuckle Group, Dog Creek Shale, Blaine Gypsum, Rush Springs Sandstone, Elk City Sandstone, Ogallala Formation, and alluvium and terrace deposits. Maximum recorded well yields reach upwards of 2,000 gpm (126.2 l/s) and generally average 300 gpm (18.9 l/s). Central Oklahoma contains about one-third of the state's ground-water resources, which occur in six major ground-water basins: the Arbuckle Group, Simpson Group, Vamoosa Formation, Oscar Formation, Gadner-Wellington Formation, and alluvium and terrace deposits. Wells commonly yield 200 gpm (12.6 l/s). Eastern Oklahoma contains one-fourth of the state's ground-water resources with the major ground-water basins being the Roubidoux, Antlers Sand, and alluvium and terrace deposits. Wells generally yield 100 gpm (6.3 l/s). Depth to water averages 100 to 250 feet (30.5 to 76.3 m) and may locally exceed 500 feet (152.5 m).

Water quality, which is geographically quite variable, also varies both vertically and horizontally within individual aquifers. The western part of the state generally has poorer quality water due to the evaporite deposits and drier climate, but generally the quality of water in Oklahoma aquifers is good. The most developed aquifers, such as the Ogallala, Tillman Terrace, and Rush Springs Sandstone, contain water that is suitable for municipal, industrial, and agricultural (irrigation) uses. Some terrace and alluvial deposits contain rather highly mineralized water and tend to reflect surface-water quality. In general, ground water becomes increasingly mineralized with depth and distance from recharge area. The Dog Creek Shale and Blain Gypsum deposits are high in sulfate (more than 250 mg/l), but the water is suitable for irrigation.

Ground water supplies about 60 percent of the total water needs in Oklahoma and over 80 percent of the irrigation requirement; thus, it is a resource of major importance. Ground-water problems in the state result from excessive pumping of some aquifers and brine pollution from abandoned and improperly plugged oil and gas wells.

The Oklahoma ground-water quality maps are based on more than 500 analyses, 250 of which are from domestic and municipal wells.

OREGON

Oregon contains a wide range of climates and ground-water conditions. The western third of the state is occupied by the Coastal Ranges, the Cascades, and the Klamath Mountains on the south. Most of these areas receive at least 50 inches (127 cm) of precipitation per year and some more than 100 inches (254 cm). The Cascades are composed of permeable volcanic rocks which generally yield the most water in the state, while the other mountain regions are less permeable, leading to higher amounts of runoff. In the southwestern part of the state, alluvium and sedimentary rocks provide relatively low but adequate yields to domestic wells. Well depths are extremely variable and can range up to several hundred feet.

In the coastal belt, marine sediments are only slightly permeable and wells generally yield less than 5 gpm (0.3 l/s). Dune sands and terrace deposits provide moderate supplies of ground water with yields ranging from 0 to 50 gpm (0 to 3.2 l/s). Well depths commonly range from 50 to 250 feet (15.3 to 76.3 m). Between the Coastal Range and Cascade Range lies the Willamete River Valley, an elongate valley where most of the state's population reside. Throughout most of the valley, wells provide high yields from alluvial deposits.

The eastern two-thirds of the state is in the Columbia Plateau and Basin and Range physiographic provinces. The Plateau consists of several thousand feet of Tertiary volcanics and alluvium that generally form a nearly level surface except for the deep canyons of the major rivers. The region is drained in the west by the Deschutes and John Day Rivers, in the north by the Columbia River, and in the east by the Snake River. Large supplies of ground water are obtained from the permeable lava flows and interbedded sediments. Large-diameter irrigation wells several hundred feet deep commonly yield over 1,000 gpm (63.1 l/s). Well depths vary considerably and may range up to 1,000 feet (305 m).

The Basin and Range province, an area of block-faulted mountains of volcanic rocks and associated alluvial fills, is situated in south-central Oregon. Precipitation in these areas ranges from 8 to 16 inches (20.3 to 40.6 cm), except in the Wallowa Mountains in the northeast where it averages 30 to 40 inches (76.2 to 101.6 cm). Runoff is only about

1.0 inch (2.5 cm). The major aquifers are alluvial deposits along major streams and the Columbia River Group basalt. The southeast, the driest part of the state, is underlain by moderately permeable volcanic and alluvial aquifers. The area has undergone only limited ground-water assessment and development.

There are few regional ground-water quality problems of natural origin in Oregon. Locally high concentrations of hardness (180 mg/l) and dissolved solids (600 mg/l) are present in parts of Clackamas, Douglas, Polk, Washington, and Yamhill Counties. Most of the state's population is centered in the Willamette Valley where ground water from basaltic aquifers is usually only moderately mineralized (100 to 200 mg/l of dissolved solids) and moderately hard (60 to 180 mg/l). In some playa lake areas in eastern Oregon, high concentrations of sodium bicarbonate and sodium chloride water is present.

The Oregon ground-water quality maps are based on more than 750 chemical analyses, 350 of which are from domestic and municipal wells.

PENNSYLVANIA

Pennsylvania has large supplies of ground water along with the economic base needed to develop these supplies. Annual precipitation averages 42 inches (106.7 cm), varying from 38 to 48 inches (96.5 to 121.9 cm), while runoff averages 20 inches (50.8 cm), ranging from less than 15 inches (38.1 cm) in the north-central part of the state to more than 30 inches (76.2 cm) in the northeast.

Most of Pennsylvania consists of mountains and rolling hills largely comprised of Paleozoic sedimentary and metasedimentary rocks. The state is divided into (1) the nearly flat-lying sedimentary rocks of the Appalachian Plateau in the west, (2) a longitudinal belt of valleys and mountains forming the Valley and Ridge province and the complicated structure of the crystalline rocks of the Blue Ridge which trend northeastward through the central portion of the state, and (3) the rolling topography of the Piedmont in the east. In the northwestern part of the Piedmont is a down-faulted basin filled with Triassic conglomerate, sandstone, and shale intruded by diabase. In a small area in the southeastern corner of the state, Cretaceous strata of the Coastal Plain are mantled by Quaternary deposits. Glacial drift occurs in the northeastern and northwestern parts of Pennsylvania, but it is very thin except in a few lowlands. More important are permeable deposits of sand and gravel that lie in many valleys south of the glacial limit.

Because Pennsylvania is geologically complex, the ground-water hydrology is equally complex and variable. Well yields in the Appalachian Plateau province range from 10 to 3,000 gpm (0.6 to 189.3 l/s), and well depths range from 100 to over 400 feet (30.5 to 122 m). Well yields in the Valley and Ridge province tend to be low, ranging from 5 to 300 gpm (0.3 to 18.9 l/s). Wells tapping Triassic formations generally yield 5 to 25 gpm (0.3 to 1.6 l/s), reaching a maximum of several hundred gallons per minute. Cretaceous-age sediments of the Atlantic Coastal Plain are capable of yielding several hundred gallons per minute to shallow (50 to 150 feet/15.3 to 45.8 m) large-capacity wells. Crystalline bedrock of the Piedmont province in southeast Pennsylvania typically yields 2 to 15 gpm (0.1 to 0.9 l/s) to domestic wells. Well depths generally do not exceed 300 to 400 feet (91.5 to 122 m). Aquifers in the Coastal Plain consist of Cretaceous sands and Quaternary alluvium. The water is of good to excellent quality (100 to

150 mg/l of dissolved solids) and is usually soft (less than 100 mg/l). Crystalline rock aquifers in the Piedmont generally contain soft water, but water is hard in the calcium-rich rocks (120 to 240 mg/l).

Mountainous areas, including the Blue Ridge and Valley and Ridge provinces, consist of alternating layers of sandstone, shale, and limestone. In the Appalachian Plateau in western Pennsylvania, nearly flat-lying Devonian to Permian sandstone, shale, limestone, and coal beds yield rather highly mineralized water (250 to 750 mg/l of dissolved solids, 120 to 300 mg/l of hardness, and variable amounts of chloride and sulfate). Glacial drift aquifers are important only where they are composed largely of sand and gravel. These deposits generally produce good water (200 mg/l of dissolved solids), although it is moderately hard (180 mg/l).

Ground-water quality in Pennsylvania is good to excellent throughout most of the state, but water is more highly mineralized in a region stretching from the Valley and Ridge province through the Appalachian Plateau. Some problems result from coal mining and the extensive urbanization near Pittsburgh, Philadelphia, and other areas.

The Pennsylvania ground-water quality maps are based on more than 3,800 analyses, 2,300 of which are from domestic and municipal wells.

RHODE ISLAND

With the exception of Block Island, the entire state of Rhode Island is situated in the glaciated Appalachians. The southeast corner and the western half of the state consist of igneous and metamorphic bedrock varying in age from Precambrian to post-Pennsylvanian. Domestic wells from these crystalline rocks have low yields (less than 12 gpm/0.8 l/s). Well depths generally range from 50 to 250 feet (15.3 to 76.3 m). A sequence of late Paleozoic, metamorphosed, sedimentary rocks underlie Narragansett Bay and separate the igneous and metamorphic bedrock. These rocks are slightly better aquifers and yield an average of 31 gpm (1.9 l/s) to wells similar in depth.

The state is mantled by glacial deposits, mainly till in the northern uplands and outwash in the central and southern lowlands. The till is a poor aquifer and yields only 1.0 to 2.0 gpm (0.06 to 0.12 l/s). The outwash is the principal aquifer when it is composed of sorted and stratified coarse sand and gravel and located adjacent to major streams. Yields of 2,000 gpm (126.2 l/s) have been reported and 300 gpm (18.9 l/s) are common. Well depths are less than 200 feet (61 m) and commonly less than 100 feet (30.5 m). To the south on Block Island, most wells tap glacial deposits or consolidated Cretaceous sediments and yield about 12 gpm (0.8 l/s).

The natural chemical quality of ground water in Rhode Island is excellent. No well examined exceeded 500 mg/l of dissolved solids. The water varies from soft to moderately hard, rarely exceeding 120 mg/l of hardness and commonly in the 30 mg/l range. In some wells tapping bedrock or glacial outwash, high concentrations of iron and manganese are present.

The only potential natural ground-water quality problem in Rhode Island is contamination by salt-water intrusion or salt spray blown inland. Along the coast, higher concentration of sodium and chloride have been noted. On Block Island, chloride ranges from 14 to 248 mg/l; however, the median concentration is 34 mg/l.

Ground-water quality problems are entirely localized. For example, overdevelopment in the Potowomut-Wickford area could result in salt-water encroachment. Other areas where salt-water problems have been reported are in metropolitan

Providence and Barrington in Bristol County. These problems are also related to overdevelopment.

The Rhode Island ground-water quality maps are based on more than 250 chemical analyses, 100 of which are from domestic and municipal wells.

SOUTH CAROLINA

South Carolina has a substantial ground-water supply that is largely underdeveloped. Precipitation is abundant, averaging 46 inches (116.8 cm) per year, while runoff ranges from 10 to 30 inches (25.4 to 76.2 cm), averaging 15 inches (38.1 cm) per year.

The southeastern two-thirds of the state is underlain by Coastal Plain sediments that thin northwestward until they reach the Piedmont and Blue Ridge where crystalline rocks crop out. In the extreme northwestern part of the state (the Blue Ridge) a thick residuum overlies older fractured crystalline and sedimentary rocks. Along the major streams, alluvium forms productive aquifers. The Piedmont is a complexly-folded belt of metamorphic rocks intruded by igneous bodies. Wells tapping alluvial deposits along major streams are generally less than 200 feet deep (61 m) and are capable of yielding several hundred gallons per minute. Elsewhere in the Blue Ridge and Piedmont, well depths can range up to several hundred feet.

Although deeply buried by Coastal Plain sediment, several downfaulted basins filled by Triassic-age sedimentary rocks and igneous dikes are present. However, they are too deep to be readily exploited for domestic water supplies. The crystalline rocks are deeply weathered and fractured and ground-water quality is good throughout the region, although water is locally hard and many domestic wells are capable of only small yields, generally less than 10 gpm (0.6 l/s).

The Coastal Plain is composed of semiconsolidated to consolidated sedimentary rocks of Cretaceous to Quaternary age that thicken southeastward from their outcrop at the Fall Line to more than 6,000 feet (1,830 m) seaward. In these deposits, the principal aquifers are the Tuscaloosa, Black Creek, Santee, Pee Dee, and McBean Formations. These aquifers are capable of producing upwards of 1,000 gpm (63.1 l/s) to large-capacity wells. Well depths vary throughout the Coastal Plain and commonly range from 200 to over 800 feet (61 to 244 m). The Santee Limestone is a correlative aquifer to that located southward in Georgia and Florida. Most of the water present in the Coastal Plain aquifers is of good to excellent quality (dissolved solids range from 50 to 250 mg/l), but it is hard (as much as 180 mg/l) where derived from limestones.

The overall ground-water quality is excellent, with higher concentrations of various ions along the coast. Elsewhere, calcium and magnesium and sodium and potassium are less than 25 mg/l. Sulfate data are not available for much of the state, but a few analyses indicate that concentrations are typically less than 10 mg/l. In most places, chloride is less than 10 mg/l, but locally may exceed 100 mg/l. Dissolved solids and hardness appear in low concentrations, generally less than 100 mg/l and 60 mg/l, respectively.

At one time, the most densely populated areas of South Carolina were in the Piedmont. However, there has recently been a population shift to the Coastal Plain where water supplies are more abundant. The state has an enormous ground-water supply available to support growth, but surface water is used to a large extent by communities in the Piedmont. Local water quality problems include pulp-and-paper mill wastes, salt-water encroachment, and overpumping.

The South Carolina ground-water quality maps are based on more than 950 analyses, 500 of which are from domestic and municipal wells.

SOUTH DAKOTA

South Dakota lies in the northern Great Plains, a vast expanse of prairie interrupted by upturned rocks surrounding the Precambrian core of the Black Hills. East of the Missouri River, glacial deposits mantle the surface and the rich soils and adequate rainfall permit extensive dry-land farming. The unglaciated region west of the Missouri is characterized by ranch lands. In this sparsely populated area, Cretaceous and Tertiary shale is the predominant rock type. Surrounding the Black Hills is a series of largely Paleozoic and Mesozoic strata that dip steeply away from the central uplift.

South Dakota's precipitation is slightly more than 25 inches (63.5 cm) per year in the southeastern corner, but gradually decreases to less than 15 inches (38.1 cm) in the northwest. Precipitation exceeds 20 inches (50.8 cm) near the Black Hills. Runoff is less than 1.0 inch (2.5 cm) except in the Black Hills and in a narrow strip along the eastern border of the state.

East of the Missouri River, ground-water supplies are obtained predominantly from alluvium along the major streams, sand and gravel lenses in the till, surficial outwash, or the Dakota Sandstone. Most domestic wells produce only a few gallons per minute, but some irrigation wells yield over 1,000 gpm (63.1 l/s). The major source of water in eastern South Dakota is the Dakota Sandstone which is tapped by thousands of flowing and pumped wells, particularly in the James River basin. Well depths vary from 300 feet (91.5 m) in the southeast to 1,400 feet (427 m) near the Missouri River in central South Dakota.

Water supplies are scarce in many parts of western South Dakota, especially in the west-central part and in a wide belt surrounding the Black Hills where shale crops out. Well yields in these areas may be only a few gallons per day. In some places, wells over 1,000 feet (305 m) deep derive water from Cretaceous sandstones despite the fact that this water is saline or at least highly mineralized. To the northwest and southwest, aquifers are tapped in the Fox Hills, Hell Creek, and Fort Union Formations, and in the White River Group, Arikaree Sandstone, and Ogallala Formation. Well yields tend to average 10 gpm (0.6 l/s), reaching maximum yields of 2,000 gpm (126.2 l/s).

In the Black Hills, ground water comes from fractures in crystalline rocks, fractures and solution openings in Paleozoic limestones, and some Paleozoic and Mesozoic sandstones. Yields range widely (20 to 300 gpm/1.3 to 18.9 l/s) and some wells flow. The Madison Group underlies the northwestern portion of South Dakota; maximum recorded well yields are 2,000 gpm (126.2 l/s) to wells over 4,000 feet (1220 m) deep.

In many areas in South Dakota, water from bedrock aquifers is highly mineralized. Water from the Dakota Sandstone generally exceeds 1,000 mg/l of dissolved solids and is greater than 3,000 mg/l in many places. Locally, water contains excessive concentrations of dissolved solids, iron, and sulfate. The quality from limestone aquifers ranges widely, being best in recharge areas near the Black Hills and rapidly deteriorating down-gradient.

The least mineralized water is stored in permeable streamside or surficial deposits of sand and gravel which are readily recharged by precipitation. On the other hand, water in many sand and gravel deposits, at least locally, contains more than 3,000 mg/l of dissolved solids.

South Dakota has several ground-water problems, i.e., low or inadequate well yields, poor quality in many places, and local overdevelopment. Many communities are forced to use saline water. These problems are compounded by scanty rainfall, erratic streamflow, and droughts.

The accompanying maps of South Dakota are based on over 2,400 analyses, 1,400 of which represent individual domestic and municipal wells.

TENNESSEE

Tennessee has substantial ground-water supplies which have not been extensively developed, although ground water is used by most rural residents. The availability of ground water varies widely. Except in carbonate rocks, well yields are generally low in the Appalachian region and quite high throughout the Coastal Plain in the Mississippi Embayment. Mean annual precipitation and runoff are 50 and 20 inches (127 and 50.8 cm), respectively.

Eastern Tennessee lies in the Blue Ridge, an area of Precambrian and Cambrian crystalline rocks. Ground water occurs mainly in fractures and solution cavities and is of good quality, although hard. Well depths generally do not exceed 350 feet (106.8 m). Westward in the Valley and Ridge province (which is known locally as the Great Valley), the lowlands are underlain by carbonate rocks and the ridges are capped by resistant sandstone and shale. Here, most ground-water supplies are derived from Cambrian and Ordovician carbonates. Well yields generally average 14 gpm (0.9 l/s) to wells 150 to 350 feet (45.8 to 106.8 m) deep. The water is of good quality, although locally very hard (240 mg/l), and dissolved solids concentrations are as high as 500 mg/l.

Farther west lies the Appalachian Plateau, which is formed by Pennsylvanian sandstone and shale except southward in the Sequatchie Valley where carbonate rocks are exposed. In this region, most ground water is obtained from fractured sandstone. Dissolved solids exceed 200 mg/l, and the water is commonly characterized by a low pH value. Still farther west is the Interior Low Plateau, a Mississippian limestone area of karst and rugged hills developed on resistant cherts that is drained by the Duck, Cumberland, and Tennessee Rivers. Well yields range from 11 to 16 gpm (0.7 to 1.0 l/s). The Nashville Basin occurs in the northeastern part of the region. Ground water contains less than 500 mg/l of dissolved solids, although it is commonly very hard (240 mg/l). Much water is obtained from solution openings in limestone. The western edge of Tennessee consists of Coastal Plain sediments, an area of westward-dipping Cretaceous and Tertiary sand and gravel and Quaternary alluvium. This is the most important ground-water region in the state; domestic wells generally yield 15 gpm (0.9 l/s) while large municipal wells yield upwards of 1,000 gpm (63.1 l/s). Well depths are quite

variable and can extend over 700 feet (213.5 m) when deeper aquifers are tapped. The water commonly contains only 200 mg/l of dissolved solids.

In general, Tennessee is fortunate in having ample supplies of good quality ground water. Local areas of poor ground-water quality and quantity are present, and many streams are sediment-choked from farmland erosion.

The Tennessee ground-water quality maps are based on more than 1,200 chemical analyses, 1,000 of which are from domestic and municipal wells.

TEXAS

Texas, the largest of the conterminous United States, is favored with a large but unevenly distributed supply of ground water. More than half the state has aquifers capable of moderate to large yields. Areas that have limited ground-water supplies are the southwest, much of central Texas, and belts of fine-grained sediments in the Coastal Plain. Average annual precipitation ranges from 8 inches (20.3 cm) in the west to 60 inches (152.4 cm) in the east, with a mean of 27 inches (68.6 cm) for the state. Annual runoff averages 4 inches (10.2 cm), varying from less than 0.25 inch (0.6 cm) to over 15 inches (38.1 cm).

In the Marathon region, the Paleozoic basement was exposed following Cretaceous and Tertiary intrusions. Paleozoic rocks, primarily Pennsylvanian and Permian, are also exposed in north-central Texas. The Mesozoic record includes minor outcrops of Triassic and Jurassic strata in the north-central part of the state. Cretaceous rocks deposited over most of Texas are exposed in a northeast to southwest trend from the Red River to the Rio Grande. In the High Plains, the Pliocene Ogallala Formation lies unconformably on Permian through Cretaceous strata. Quaternary sediments include alluvial deposits along all the major rivers, valley-fill (bolson) deposits along the Rio Grande and in intermontane basins in the southwest, and Coastal Plain deposits along the Gulf Coast.

The aquifers of Texas have been divided into five geographic regions: the Coastal area; the High Plains; central, north-central, and northeast Texas; southwest Texas; and west Texas. The Coastal area is composed of Cenozoic clastic sediments. Two major aquifers, the Miocene Coastal sandstones and Eocene Carrizo-Wilcox sandstones, supply water to the Coastal region. Well yields range from 10 to 4,530 gpm (0.6 to 285.8 l/s) and average 1,291 gpm (81.5 l/s) from the Coastal Plain aquifer. Wells tapping the Carrizo-Wilcox sandstones yield 20 to 2,800 gpm (1.3 to 176.7 l/s) and average 490 gpm (30.9 l/s). Well depths range considerably and vary from 150 feet to 1,500 feet (45.8 to 457.5 m). The Coastal sandstones contain water of very poor quality and dissolved solids exceed 1,000 mg/l in most places. South of Refugio County, chloride concentrations exceed 250 mg/l; the high mineralization is caused by salt-water encroachment. Overpumping around

Houston has caused considerable subsidence throughout Harris County. In the Carrizo-Wilcox aquifer, which extends from the Rio Grande northeastward across the entire state, ground-water quality improves greatly.

The Pliocene Ogallala Formation is the principal aquifer of the High Plains. It extends from Ector County to the two northeastern rows of counties in the panhandle. Sandstone, conglomerate, and siltstone interfinger in this aquifer with the coarsest material near the bottom. An extensive layer of caliche, the so-called "caprock," covers most of the Ogallala. Well yields range from 190 to 1,620 gpm (11.9 to 102.2 l/s) and average 500 gpm (31.6 l/s). Well depths range from 150 feet (45.8 m) in the southern part of the Ogallala to 400 feet (122 m) in the north. In the southern High Plains, ground-water quality deteriorates because of upward leakage of more highly mineralized water from the underlying Cretaceous rocks.

In north-central Texas, the Cretaceous Trinity Sandstone, interbedded with layers of shale and thin beds of limestone, is the principal aquifer. Wells penetrating the Trinity aquifer yield 10 to 1,440 gpm (0.6 to 90.9 l/s) and generally average 322 gpm (20.3 l/s). Well depths vary from less than 200 feet (61 m) in the western portion of the aquifer to several hundred feet in the east where it dips to the east-southeast. The quality of water is generally good; sulfates and chlorides are low, dissolved solids concentrations are 500 to 750 mg/l, and the water is soft east of Clay County.

The relatively undeveloped Ellenberger and San Saba aquifer, which consists of cavernous limestones and dolomites, underlies central Texas. The Woodbine Formation, underlying most of northeastern Texas, is a Cretaceous wedge of sandstone and sandy-shale thinning to the southeast. Excluding Red River County, some of the best water in the state is found in this area because high precipitation allows ample ground-water recharge.

In the southwest, the major aquifers are Cretaceous limestones. The water north of the Nueces River can be of good quality; however, some contamination of these aquifers by oil field brines has caused the water quality to be variable.

In west Texas, Quaternary alluvial deposits are the main aquifers, producing water of variable quality since low precipitation limits the availability of fresh water. Well yields also vary and range from 60 to 2,500 gpm (3.8 to 157.8 l/s). Well depths commonly range from 200 to 800 feet (61 to 244 m). Where fresh water is available in the El Paso region, it is overlain, underlain, or adjoined by saline water-bearing aquifers which are potential sources of contamination. Along the Rio Grande and in the intermontane basins, ground-water recharge occurs principally by runoff from the mountains to the west and southwest. Water in some of the bolson valley-fill deposits is saline. Overall, Texas has a large supply of ground water of fair to good quality.

The Texas ground-water quality maps are based on more than 8,500 analyses, 3,000 of which are from domestic and municipal wells.

UTAH

The western part of Utah, extending southwestward from Logan to St. George, is in the Great Basin section of the dry Basin and Range province. This is a region of fault-block mountains surrounding alluvial plains and interior drainage. East of a line through Logan and Payson lie the mountains of the middle Rockies province - the Wasatch and Uintas. The remainder of Utah is in the Colorado Plateau province, a semiarid to arid region filled with canyonlands and gorges of the Colorado, Green, and San Juan Rivers and their tributaries. Most of Utah's population is located in a broad belt that trends south and southwestward across the state from Logan through Ogden, Salt Lake City, Provo, Cedar City, and St. George. Normal annual precipitation in the state ranges from 5 to 60 inches (12.7 to 152.4 cm) and averages about 12 inches (30.5 cm). Mean annual runoff varies from less than 1 to 40 inches (2.5 to 101.6 cm), averaging about 2 inches (5.1 cm).

Precambrian metamorphic rocks crop out in the Uinta and Wasatch Mountains; Cambrian sedimentary rocks are exposed in both the Great Basin and the Wasatch Mountains. Late Paleozoic rocks crop out through wide areas in the Wasatch and Uinta Mountains, the Great Basin, and the canyonlands. Mesozoic sedimentary rocks are exposed in the canyonlands and the high plateaus, capped locally by Tertiary volcanics. Tertiary and quaternary sediments occur throughout much of the state; where these alluvial and lacustrine deposits are confined to valleys, they contain Utah's principal aquifers.

The alluvial aquifers that occur over much of the Basin and Range province and in several valleys to the east are major sources of water, and many are heavily pumped. Yields of individual wells that tap these aquifers range from barely adequate to several thousand gallons per minute. Well depths also range considerably and may extend to 1,000 feet (305 m) to reach artesian aquifers. Bedrock aquifers are less extensive and largely undeveloped. Bedrock wells generally yield less than 50 gpm (3.2 l/s); well depths range up to several hundred feet. Paleozoic and Mesozoic strata adjacent to the Uinta Mountains and in the high plateaus contain locally good aquifers. In many areas, however, the annual rate of ground-water recharge is very low. To the southeast in Wayne, Garfield, Kane, and San Juan Counties lie several important aquifers in the Dakota and Navajo Sandstones. Although some of the aquifers are

deep (1,000 feet/305 m or more), good quality water is available and may be under considerable head in some instances.

Overall, ground-water quality in Utah is fair to good. However, little is known of ground-water quantity and quality in many places. The most mineralized water is found in desert areas where the population is sparse. Wells in the Great Basin, which is underlain by thick deposits of alluvium, usually yield moderate supplies in which the dissolved solids content is less than 1,000 mg/l. Nearer the Great Salt Lake, ground water locally contains as much as 3,000 mg/l of dissolved solids, and sodium concentrations exceed 500 mg/l. High fluoride concentrations have also been reported from some areas in the Great Basin.

Ground water has not been extensively developed in the Colorado Plateau. In many places it is deep and locally difficult to obtain. Ground-water quality in the lower and upper Colorado River basins is good except in parts of Uinta, Duchesne, Emery, and Grand Counties where it contains dissolved solids over 2,000 mg/l.

In some areas, heavy pumping has caused progressive water-level declines. In other regions, such as mountainous areas, ground water is yielded slowly except in stream alluvium.

The Utah ground-water quality maps are based on more than 3,600 chemical analyses, 2,100 of which are from domestic and municipal wells. Ground-water quality data is inadequate for large parts of Utah, especially in the Great Basin and mountainous regions.

VERMONT

Vermont can be divided into six physiographic provinces. Because of the mineral characteristics of the rock formations and the influence of unique topographic configurations, each of these provinces affects the quality and quantity of the state's ground-water resources.

The Vermont Lowland, which includes Lake Champlain, occupies the northwestern portion of the state between the Green Mountains on the east and the Adirondack Mountains on the west. This lowland is underlain by Cambrian and Ordovician limestones, dolomites, marbles, shales, and quartzites. A mantle of glacial drift and marine clays covers much of the bedrock.

Ground water, which is neither abundant nor easily located in the lowland, tends to be excessively hard (carbonate rocks) and locally sulfurous (pyritiferous shales). A well 800 feet (244 m) deep penetrated brackish water in the southern portion of this province.

The Taconic Mountains rise in southwestern Vermont and extend westward into New York. Bedrock in the Taconics is predominantly composed of Cambrian slates and phyllites with subordinate Ordovician slates and carbonates. Glacial drift and alluvial deposits mantle the surface.

Drilled bedrock wells are usually highly successful for domestic water supplies due to the fractured bedrock and dissolved carbonate zones; these zones generally yield 6 gpm (0.4 l/s) for domestic wells 150 to 400 feet (45.8 to 122 m) deep. Buried sands and gravels in major drainage arteries form highly productive aquifers with yields ranging from 50 to 1,500 gpm (3.2 to 94.7 l/s) to wells 20 to 100 feet (6.1 to 30.5 m) deep. Ground water tends to be hard but is otherwise of good quality in the Taconic Mountain province.

The Vermont Valley, a narrow, north-south continuation of the Vermont Lowland, lies between the Taconic Mountains in the west and the Green Mountains to the east, extending into Massachusetts. The Valley is underlain by limestone, dolomite, marble, and quartzite of Cambro-Ordovician age. Bedrock wells in this province are likely to encounter fractures filled with weathered gouge or ocher having high concentrations of iron. The chemical quality of ground water is noticeably affected, and turbidity problems are common.

The Green Mountain province, the dominant physical feature of Vermont, is part of the northern extension of the Appalachian Mountain system and forms a continuous high "spine" for 160 miles (257.5 km) through the center of the state. Precambrian gneiss and metasediments and early to mid-Paleozoic metasediments and metavolcanics are the dominant rock types comprising the Green Mountains. Glacial till forms a discontinuous, thin veneer throughout the higher elevations and on mountain flanks. Fluvioglacial deposits are located in and adjacent to present drainage valleys.

Generally, bedrock wells provide ample potable water for domestic supplies, but the bacteriological and chemical quality of this water may be impaired by local conditions. Drilled bedrock wells capable of producing 300 to 500 gpm (18.9 to 31.6 l/s) exist in the Green Mountain province, and over 1,000 gpm (63.1 l/s) is locally obtained from sand and gravel deposits along streams and in buried valleys. Springs still serve as an important supply for both domestic users and small municipalities.

Lithologically, the Vermont Piedmont is a distinct province. East of the Green Mountains to the New Hampshire border, lithologies of the Waits River and Gile Mountain Formations predominate; impure marbles are interbedded with phyllite and schist. The crystalline limestones weather to a high degree of porosity and constitute Vermont's best and most dependable bedrock and aquifers.

High-producing sand and gravel wells partially or entirely supply municipalities along the Connecticut River valley. Wells less than 200 feet (61 m) deep are capable of yielding several hundred gallons per minute. Ground water in both bedrock and unconsolidated aquifers tends to be quite hard, and iron-manganese problems are common. Sulfide mineralization locally degrades ground-water quality, particularly in the Orange County copper district.

The Northeastern Highlands province is an extension of the White Mountains of New Hampshire into northeastern Vermont, where granitic plutons have intruded bedrock formations to form a mountainous province, most of which is wilderness. Ground-water characteristics are similar to the Vermont Piedmont. However, this province is noted for its particularly poor surface drainage characteristics. It is suspected that the many wetlands, swamps, and lakes serve as

recharge sources to the bedrock aquifers, and thus have a significant influence on the quantity and chemical quality of the ground water.

The Vermont ground-water quality maps are based on more than 250 analyses, 100 of which are from domestic and municipal wells.

VIRGINIA

Virginia contains parts of the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Cumberland Plateau physiographic provinces, which form generally northeastward-trending belts. Annual precipitation and runoff average 43 and 15 inches (109.2 and 38.1 cm), respectively. Coastal Plain sediments generally yield moderate to large supplies of ground water. Maximum well yields range up to 1,000 gpm (63.1 l/s), and well depths range from 100 to over 500 feet (30.5 to 152.5 m). The water is highly mineralized in York County and in the city of Suffolk where dissolved solids exceed 500 mg/l. Along Chesapeake Bay and the eastern shore, dissolved solids typically range from 250 to 500 mg/l but decrease to less than 250 mg/l westward. The western boundary of a high chloride zone extends from the upper part of James City County southeastward along the James River to Suffolk. The high chloride content, which increases eastward along the peninsula, is from aquifers not completely flushed of original sea water.

Water from the Coastal Plain comes from a number of aquifers, the quality of which differs substantially. For example, hard (more than 120 mg/l) bicarbonate water with a dissolved solids content of approximately 200 mg/l is present in several deep wells in Hanover County; however, water from shallow wells in terrace deposits has a total hardness less than 50 mg/l.

In the Piedmont, aquifers provide only low to moderate yields. Locally, well yields range up to 400 gpm (25.2 l/s) in favorable areas; well depths range from 50 to over 350 feet (15.3 to 106.8 m). Generally, the water is of excellent quality and dissolved solids are less than 250 mg/l, but there are locally excessive iron concentrations. Hardness varies from 9 mg/l in Patrick County to 194 mg/l in Fauquier County, and the composition of the aquifers, which consist largely of metamorphic rocks, also differs.

The Blue Ridge Mountains are not a productive ground-water source. Well yields tend to be less than 10 gpm (0.6 l) and well depths vary considerably. Although available data is sparse, the water appears to be of good quality except in Loudoun County where dissolved solids range from 22 mg/l (crystalline rock) to 1,600 mg/l (Triassic sediment), sulfate from 8 to 2,500 mg/l, and chloride from 4 to 136 mg/l.

Principal aquifers in the Valley and Ridge province are limestone and dolomite which locally are capable of high yields. The water is generally hard (more than 200 mg/l), and dissolved solids range between 250 and 500 mg/l.

In the Cumberland Plateau, ground water occurs along fractures, coal seams, and sandstone, and well yields are low. Near coal mines, water tends to be acidic and high in iron as a result of the oxidation of sulfide compounds. Elsewhere, water contains less than 500 mg/l of dissolved solids.

The Virginia ground-water quality maps are based on more than 1,250 analyses, 600 of which are from domestic and municipal wells.

WASHINGTON

The western half of Washington consists of the rugged mountains of the Pacific Coastal Ranges, the adjacent Puget Sound-Willamette Valley depressions, and the bordering Cascade Range. In north-central Washington, the northern Cascade Mountains join with the northern Rocky Mountains to form a rugged highland. Surrounded on three sides by mountains, the southeastern part of the state lies in the extensive arid lava fields of the Columbia Plateau. The Cascade and Olympic (Coastal) Ranges cause the moisture-laden winds from the Pacific to rise and cool, bringing heavy precipitation and runoff to the west and desert conditions to the Columbia Plateau. Mean annual precipitation, ranging from 200 inches (508 cm) in the west to less than 5 inches (12.7 cm) in some arid sections, averages about 40 inches (101.6 cm). Annual runoff, averaging 20 inches (50.8 cm), varies from 0.5 inch (1.3 cm) to over 80 inches (203.2 cm). Thus, although large amounts of water are available in Washington, uneven distribution poses serious problems.

The Coastal Ranges form a mountainous region underlain by fine-grained sedimentary rocks that provide only low yield to wells (less than 25 gpm/1.6 l/s). The most productive aquifers, unconsolidated sand and gravel that lie along the coast and major streams, may yield more than 2,000 gpm (125.2 l/s). Well depths range from less than 100 feet (30.5 m) to several hundred feet. Ground water is used extensively in Clallam, Pacific, and Grays Harbor Counties for irrigation.

Over two-thirds of the state's population is located in the Puget Sound lowland, an area underlain by as much as 2,000 feet (610 m) of glacial and alluvial deposits, including thick sand and gravel aquifers that can yield several thousand gallons of water per minute to wells.

Two-fifths of the state lies in the arid Columbia Plateau, which is composed of a thick sequence of basaltic lava flows that form an important aquifer. Much of the Plateau is thinly mantled by loess, till, and lacustrine deposits. Alluvial and glacial sand and gravel deposits are present along the major streams. Some areas, such as parts of the Yakima River basin, are underlain by volcanic rocks of low permeability that yield very little water to wells. The Columbia Basin Irrigation Project (east of the Columbia

River) has been irrigated by surface water, and waterlogging is a common problem because ground-water levels have risen as much as 250 feet (76.3 m). In other areas, irrigation by well water has resulted in substantial water level declines. Accordingly, well depths vary considerably and range from 100 to 1,000 feet (30.5 to 305 m) in various localities.

The northern Rocky Mountain region consists primarily of intrusive igneous rocks; ground water can only be obtained from fractures and yields are low. Principal aquifers are sand and gravel deposits along major streams and in intermontane valleys. Wells tapping sand and gravel deposits range from 50 to 150 feet (15.3 to 45.8 m) deep.

Ground water in Washington is good to excellent, and the least mineralized water is found in areas of high precipitation and recharge. East of the Cascades, good quality water is generally present although it is locally highly mineralized. Most unconsolidated aquifers yield water with less than 250 mg/l of dissolved solids and less than 120 mg/l of hardness. The quality of ground water in the Columbia Plateau is variable. Irrigation has increased the dissolved solids content (more than 500 mg/l) and hardness (over 180 mg/l) in Pleistocene sediments that overlie the basaltic bedrock. The basalt itself generally yields water with less than 300 mg/l of dissolved solids and about 20 mg/l of sulfate, except in the upper zone of the aquifer at the Columbia Basin Irrigation Project where sulfate may exceed 200 mg/l.

Along the coast, saline water is encountered at shallow depths and represents connate or relict sea water. Locally, iron concentrations are troublesome and bedrock of Tertiary age yields water high in dissolved solids (greater than 400 mg/l).

The Washington ground-water quality maps are based on more than 800 chemical analyses, 650 of which are from domestic and municipal wells.

WEST VIRGINIA

The rolling hills and mountains of West Virginia consist of the Appalachian Plateau in the west and the Valley and Ridge province in the east. The state is underlain largely by Cambrian to Permian sedimentary strata with a very small area of Cambrian metamorphic rocks in the eastern panhandle. The rocks are nearly horizontal in the Plateau, while they are strongly folded in the Valley and Ridge. Almost all of the state is deeply dissected by streams.

Ground-water usage in West Virginia is small (about three percent of the total water usage), but it is very important because it supplies over 75 percent of the public water-supply systems and almost all of the state's rural residents. The most productive aquifer is the coarse alluvium along the Ohio River Valley. Wells less than 150 feet (45.8 m) deep commonly yield several hundred gallons per minute. This water is usually hard (greater than 180 mg/l) and high in dissolved solids (greater than 500 mg/l).

Cambro-Ordovician and Mississippian carbonate rocks form the major aquifers in the Valley and Ridge and are capable of yielding over 150 gpm (9.5 l/s) to small-diameter drilled wells. Wells tapping the Allegheny series of the Pennsylvania System and formations in the Valley and Ridge province typically yield 15 to 50 gpm (0.9 to 3.2 l/s) to small-diameter wells. Most wells in the Valley and Ridge province yield less than 15 gpm (9.5 l/s). High yields of good quality are obtained from many springs that issue from these carbonate rocks, but yields vary considerably in both quantity and quality due to the nature of fracture permeability. Most of the aquifers in the Plateau are interbedded sandstones, limestones, and fractured shales; domestic well yields are less than 15 gpm (0.9 l/s) and the water usually contains relatively high concentrations of dissolved solids and hardness. Small-diameter drilled wells tapping Mississippian and early to mid-Pennsylvanian formations in central West Virginia generally average 50 to 150 gpm (3.2 to 9.5 l/s). Well depths commonly range from 100 to 400 feet (30.5 to 122 m). In many places, saline water lies at shallow depths and upward leakage has contaminated otherwise fresh-water aquifers.

Overall, ground-water quality in West Virginia is good to fair. Throughout the Appalachian Plateau, the major

concern is with inadequate supplies. Many domestic wells in this area are marginal from both quantity and quality standpoints. In some cases, it has been necessary to drill several wells to provide adequate supplies for a single household. Highly mineralized water occurs in areas of coal extraction and preparation. Pollution of ground water in the eastern carbonate aquifers caused by surface sources (such as sewage and runoff from farmyards and roads) is becoming a problem. At present, water supplies seem to be adequate throughout most of West Virginia. Projected future development of some areas, however, will require supplemental supplies. The average annual precipitation and runoff are 45 and 19 inches (114.3 and 48.3 cm), respectively.

The West Virginia ground-water quality maps are based on over 600 chemical analyses, 430 of which are from domestic and municipal wells.

WISCONSIN

Wisconsin consists of the glaciated Superior Upland in the north, the west-central driftless region, and the lake and till plains section of the Central Lowland.

Most of the northern half of the state is composed of Precambrian igneous, metamorphic, and some sedimentary rocks that generally yield less than 10 gpm (0.6 l/s). The southern margin of the Upland consists of Paleozoic deposits of sandstone, carbonate, and some shale that dip southward and underlie the remainder of Wisconsin. Wells penetrating formations near the upland generally yield 10 to 100 gpm (0.6 to 6.3 l/s). Farther south, well yields increase and can exceed 500 gpm (31.6 l/s) for large-capacity wells. However, most domestic wells generally tap permeable glacial deposits which mantle the bedrock; domestic well depths range from 50 to 250 feet (15.3 to 76.3 m). Except for the "driftless" area, most of the state is covered by glacial drift, largely till. Sand and gravel deposits occur along most of the streams, and a large sand plain occupies central Wisconsin. Well yields commonly range from 10 to 100 gpm (0.6 to 6.3 l/s), and depths usually do not exceed 100 to 200 feet (30.5 to 61 m).

The Mississippi River Valley and its major tributaries contain thick masses of alluvium including a large percentage of sand and gravel. These deposits, averaging 200 feet (61 m) thick, are excellent aquifers and are underlain in many places by Cambrian sandstone, which is also a good aquifer. The centrally-located sand plain is an area of outwash that occupies several thousand square miles. This region has considerable ground-water potential because the deposits are very permeable.

In northern Wisconsin, glacial drift mantles the Precambrian rocks which are not productive aquifers. However, lenses of sand and gravel within the till (as well as outwash and buried valley deposits) comprise good aquifers throughout much of this region. Shallow domestic wells are capable of yielding 15 gpm (0.9 l/s) or more. On the other hand, the drift is thin and not productive in the south-central part of this area, primarily in Marathon County.

The western "driftless area" includes several Paleozoic formations that act as a single hydrologic unit. The

aquifer, consisting of carbonates and sandstones, is moderately productive. Similar Paleozoic rocks mantled by drift underlie the heavily-populated eastern part of Wisconsin. Here, sandstone and dolomite aquifers supply water as does the overlying glacial till.

Ground water in extensive sand and gravel deposits that cover crystalline rocks in northern and central Wisconsin generally contains less than 100 mg/l of dissolved solids. Where thin glacial deposits cover dolomitic sandstone and dolomite, dissolved solids usually range between 100 and 250 mg/l. Regions characterized by thick deposits of glacial drift typically provide ground water that contains more than 250 mg/l of dissolved solids. In deep bedrock aquifers, such as sandstone in central and western Wisconsin, ground water generally contains less than 250 mg/l of dissolved solids; but in the southern, eastern, and western areas, dissolved solids often range between 250 and 500 mg/l. Near the state's borders, ground water moves very slowly in deeply buried sandstone and shale deposits, and dissolved solids generally exceed 400 mg/l. These waters also contain large amounts of sulfate, chloride, calcium, and magnesium.

The Wisconsin ground-water quality maps are based on more than 4,100 chemical analyses, 2,400 of which are from domestic and municipal wells.

WYOMING

East of the Laramie Range and the Bighorn Mountains are the dissected prairies of the Great Plains, a region of nearly flat-lying, predominantly Cenozoic, sediments. These are interrupted in the northeast corner of Wyoming by upturned Mesozoic and Paleozoic strata that flank the Precambrian core of the Black Hills. Mesozoic, Paleozoic, and Precambrian rocks also crop out in the Bighorn, Laramie, Medicine Bow, and Wind River mountain ranges to the west and the Absaroka Range in the northwest. All of these ranges form part of the middle and southern Rocky Mountains. Igneous and metamorphic rocks composing these ranges typically yield less than 25 gpm (1.6 l/s). Lying within these ranges are arid to semiarid intermontane basins which are generally mantled by predominately fine-grained Paleocene and Eocene sediments. Capping the surface in the northwest corner of Wyoming are extensive deposits of Pliocene volcanic rocks.

Precipitation ranges from more than 24 inches (60.9 cm) in the mountains to less than 10 inches (25.4 cm) in desert basins. Mean annual precipitation is 14 inches (35.6 cm). The greatest annual runoff, more than 20 inches (50.8 cm), occurs in western Wyoming near the Tetons, but the rest of the state averages less than 1.0 inch (2.5 cm).

Alluvial aquifers along the major rivers (the Snake, Green, Platte, Bighorn, Powder, and Belle Fourche Rivers) are shallow and relatively inexpensive to develop. Yields greater than 500 gpm (31.6 l/s) have been obtained from wells tapping these alluvial deposits. Tertiary sandstones are present over extensive areas in the state but provide low yields in many localities. Early to late Cretaceous and early Tertiary formations generally yield 5 to 10 gpm (0.3 to 0.6 l/s). Yields over 100 gpm (6.3 l/s) can be developed from deep wells in most areas. Where the Tertiary sequences contain coarse-grained arkosic sequences, very high yields (500 to 1,000 gpm/31.6 to 63.1 l/s) may be developed except in the southwestern portion of the state where yields are usually less than 50 gpm (3.2 l/s). Some Paleozoic rocks are excellent aquifers with substantial well yields.

Ground-water quality in Wyoming varies widely. Streamside aquifers yield moderate to very hard water (over 200 mg/l). Sandstones of Cretaceous age generally yield softer water than Tertiary or Paleozoic rocks. Available

data indicate that the median concentration of dissolved solids in unconsolidated aquifers and sandstones shallower than 1,000 feet (305 m) is about 500 mg/l. In deeper aquifers, the median value exceeds 2,000 mg/l. On the other hand, Wyoming has a great deal of undeveloped and unassessed ground-water potential. Each basin is unique, making it difficult to apply generalizations to ground-water quality.

In the Green River basin, ground water generally becomes more mineralized with depth; below 2,000 feet (610 m), dissolved solids commonly exceed 1,000 mg/l. In the northern part of the basin, dissolved solids are usually less than 400 mg/l, while in the south they range from 500 to 3,500 mg/l. Locally, concentrations of iron, sulfate, and fluoride are excessive.

The dissolved solids concentration in ground water in the alluvial deposits of the Bighorn River basin varies from 250 to 4,000 mg/l, but generally is about 1,000 mg/l. The quality of ground water in some floodplain and terrace deposits has been affected by irrigation returns and, in some areas, is so highly mineralized that it is unsuitable for either domestic or irrigation use. In Sheridan County, sulfate concentrations exceed 250 mg/l in water from two-thirds of the wells and springs sampled.

In northeastern Wyoming, ground-water quality varies considerably according to aquifer, depth, and proximity to recharge area. Well depths range from 30 to over 1,000 feet (9.2 to 305 m), but most domestic wells are less than 350 feet (106.8 m) deep.

Water in alluvial aquifers is generally very hard and moderately mineralized with excessive amounts of iron. In Crook County, dissolved solids average less than 1,000 mg/l, chloride less than 25 mg/l, and sulfate less than 250 mg/l. Along the southeastern margin of the basin, high-yield wells extending to depths over 2,000 feet (610 m) produce very good quality water.

In the Platte River Basin, ground-water quality in alluvial and terrace deposits is generally fair to good. The chloride content is less than 25 mg/l in Laramie County, and does not exceed 50 mg/l in the entire basin. However, water in certain aquifers is of poor quality.

In pre-Tertiary sediments, dissolved solids range from 200 to 100,000 mg/l. The ground-water quality is best near the recharge areas but deteriorates toward the interior of deep sedimentary basins.

Wyoming has serious water problems of quantity and quality because large amounts are needed for irrigation, and much water is highly mineralized. However, ground water is largely undeveloped and unexplored and may be useful in solving the state's water problems.

The Wyoming ground-water quality maps are based on more than 3,100 analyses, 1,500 of which are from domestic and municipal wells.

GLOSSARY

ACES (Annual Cycle Energy System)

A heating/cooling system for which the design concept involves the extraction of heat from a storage tank using a heat-only heat pump during the heating season. The device makes ice over the duration of the season and uses that ice for summer cooling.

ACIDITY

A condition of water usually caused by the presence of uncombined carbon dioxide, mineral acids, and salts of strong acids and weak bases such as iron and aluminum salts from mine waters or industrial wastes.

ACOP (Annual Coefficient of Performance)

A dimensionless number reflecting the efficiency of a heating/cooling system on an annual basis. It is the ratio of the annual heating and cooling requirement to the energy used by a system to satisfy that requirement for a specific structure.

AQUIFER

An underground formation or group of formations containing sufficient saturated permeable material to yield significant quantities of water to wells and springs.

ARTIFICIAL RECHARGE

The addition of water to the ground-water reservoir by activities of man such as irrigation or induced infiltration from streams, wells, or spreading basins.

ASHRAE

American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BEDROCK

A general term describing the rock, usually consolidated, that underlies soil or other unconsolidated, superficial material.

BTU (British Thermal Unit)

The heat required to raise the temperature of one pound of water one degree fahrenheit; a unit of energy equal to 0.293 watt-hour, or 252.0 calories.

COEFFICIENT OF PERMEABILITY

See HYDRAULIC CONDUCTIVITY.

CONE OF DEPRESSION

The conical lowering of the water table surface which develops around a pumping well, the periphery of which delimits the ground water moving toward the well.

CONSOLIDATED FORMATION

Any of the various kinds (sedimentary, igneous, or metamorphic) of solid rock with a minimum of void space occupied by air, water, or gaseous or liquid material.

COP (Coefficient of Performance)

A measure of efficiency of space-conditioning system. For heating operation:

$$(COP)_H = \frac{\text{Rate of heat energy delivery}}{\text{Rate of energy input to the equipment}}$$

For cooling operation:

$$(COP)_C = \frac{\text{Rate of heat energy removal}}{\text{Rate of energy input to the equipment}}$$

CORROSION

The material degradation of a surface (usually metallic) by mechanical, electrical, and/or chemical means.

DEGREE DAYS

A term used as a descriptor of climate, based on temperature difference from a reference temperature, and the period of time for which that temperature exists. For example, using 65°F (18.3°C) as a reference temperature, there are 20 heating degree days in a day for which the average temperature is 45°F (7.2°C). Similarly, there are 20 degree days in a 20 day period for which the average daily temperature is 64°F.

DESUPERHEATER

A domestic hot-water generating device offered as optional equipment by most ground-water heat pump manufacturers. The device uses a water-to-refrigerant heat exchanger located between the discharge side of the compressor and the heat rejection heat exchanger in the circuit. A portion of the superheat of the refrigerant is used to heat domestic water which is stored in a hot water tank that contains a back-up electric element to generate hot water when the heat pump is not operating.

DISCHARGE

The rate of flow at a given time expressed as volume per unit of time.

EFFECTIVE POROSITY

The portion of pore space in saturated, permeable material in which movement of water takes place.

GEOTHERMAL GRADIENT

The rate of temperature increase in the earth with depth. The gradient varies with location and depends on regional heat flow and the thermal conductivity of the rock. The average value in the earth's crust is approximately 25 C°/km.

GROUND-WATER MINING

The process, deliberate or inadvertent, of extracting ground-water from a source at a rate in excess of replenishment so that the ground-water level declines persistently, posing supply exhaustion or a decline of pumping levels to uneconomic depths.

HARDNESS

A property of water causing formation of an insoluble residue resulting in a scale formation in vessels where water has been allowed to evaporate. It is primarily due to the presence of calcium and magnesium ions but is produced by ions of other alkali metals, ions of other metals (e.g., iron), and hydrogen ions.

HVAC (Heating, Ventilating, and Air Conditioning)

Term used to describe the equipment or services of the entire industry of manufacturers, suppliers, consultants, engineers, etc., related to heating and cooling.

HYDRAULIC CONDUCTIVITY

The volume of water at the existing kinematic viscosity that will move in unit time under unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT

The change in static head per unit of distance in a given direction.

HYDROLOGIC CYCLE

A constant circulation of water from the sea, through the atmosphere, to the land, and eventually to the atmosphere by way of evaporation from the sea and land surfaces.

HYDROSTATIC PRESSURE

The pressure exerted by water at any given point in a body of water at rest. The hydrostatic pressure of ground-water is generally due to the weight of water at higher levels in the zone of saturation.

INCRUSTATION

A deposit of mineral scale which accumulates on wetted surfaces, such as well screens, water pipes, and heat exchangers.

INFILTRATION

The movement of water or solutions into rock through its interstices or fractures or into soil from another area.

LITHOLOGY

The description of rocks, especially sedimentary clastics, on the basis of such characteristics as color, structure, mineralogic composition, and grain size.

NPDES (National Pollution Discharge Elimination System)

A Federal program created as part of the Clean Water Act of 1977. The NPDES permit program is designed to control all discharge of pollutants into U. S. waterways.

PERCOLATION

Water movement through the interstices of a substance, as through soils.

PERMEABILITY

The capacity of water-bearing material to transmit water, measured by the quantity of water passing through a unit cross section in a unit time under 100 percent hydraulic gradient.

PIEZOMETRIC SURFACE

The level to which water from a confined aquifer will rise under its own pressure in a borehole. See POTENTIOMETRIC SURFACE.

POROSITY

The ratio of void volume to total volume of soil in rock, generally expressed in percentages.

POTENTIOMETRIC SURFACE

A surface representing the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells.

PP (Simple payback period of incremental costs)

Used in this report to represent the time in years required for payback of incremental costs resulting from installing a ground-water heat pump rather than a less expensive conventional heating/cooling system. It is calculated by dividing the difference in installed costs by the difference in first-year fuel and operation and maintenance costs of the conventional system and the ground-water heat pump system.

PRECIPITATION

(1) The total measurable supply of water received directly from clouds, as rain, snow, or hail, usually expressed as depth in a day, month, or a year and designated as daily, monthly, or annual precipitation. (2) The formation of a solid scale material from solution on water pipes and heat exchangers.

RECHARGE

The processes involved in the absorption and addition of water to the zone of saturation. This does not include water reaching the belt of soil water or the intermediate belt.

SAFE YIELD

The rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal is no longer economically feasible.

SPECIFIC YIELD

The ratio of water volume a given mass of saturated rock or soil will yield by gravity to the volume of that mass.

SPF (Seasonal Performance Factor)

A term describing the performance of equipment including all cycling losses during the heating or cooling mode of operation. A ratio of total heat energy moved to the total energy used by the device.

STATIC WATER LEVEL

The water level in a non-pumping well outside the area of influence of any pumping well. This level registers one point on the water table in a water-table well or one point on the pressure surface in a confined-water well.

STORAGE COEFFICIENT

The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

SUBSIDENCE

A local mass movement that principally involves the gradual downward settling or sinking of the solid earth's surface with little or no horizontal motion.

TRANSMISSIVITY

The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

UIC (Underground Injection Control)

A federal program developed under the authority of the Safe Drinking Act of 1974 and directed by the U.S. E.P.A. to prevent ground-water contamination by subsurface injection of pollutants.

UNCONSOLIDATED FORMATION

A sediment consisting of loosely arranged or unstratified particles which are not cemented together and occur either at the surface or at various depths beneath the surface.

WATER TABLE

The upper surface of a zone of saturation in soil or in permeable strata or beds. It is defined by the levels at which water stands in wells that sufficiently penetrate the water body enough to hold standing water.

Alabama

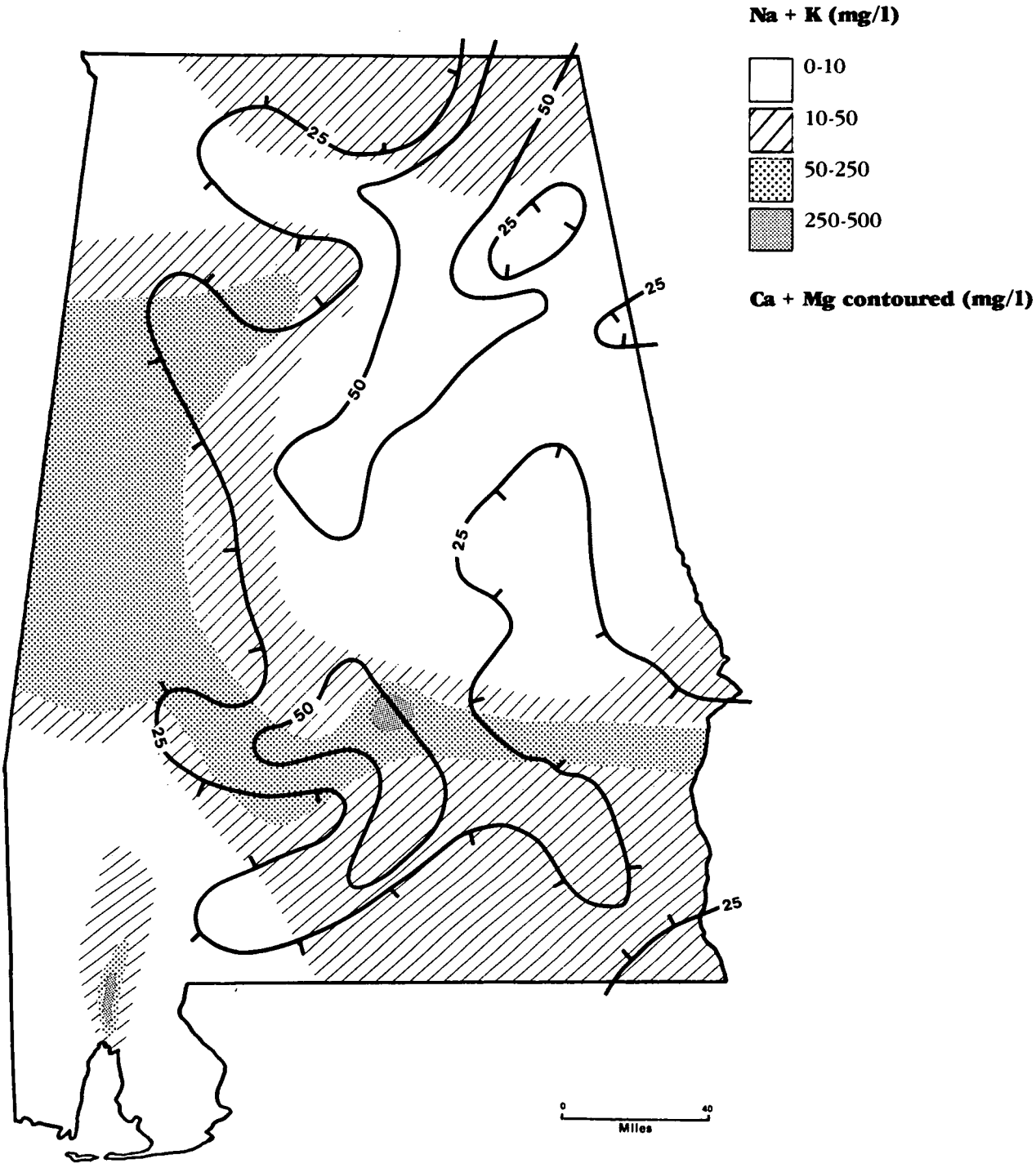


Plate 1

Alabama

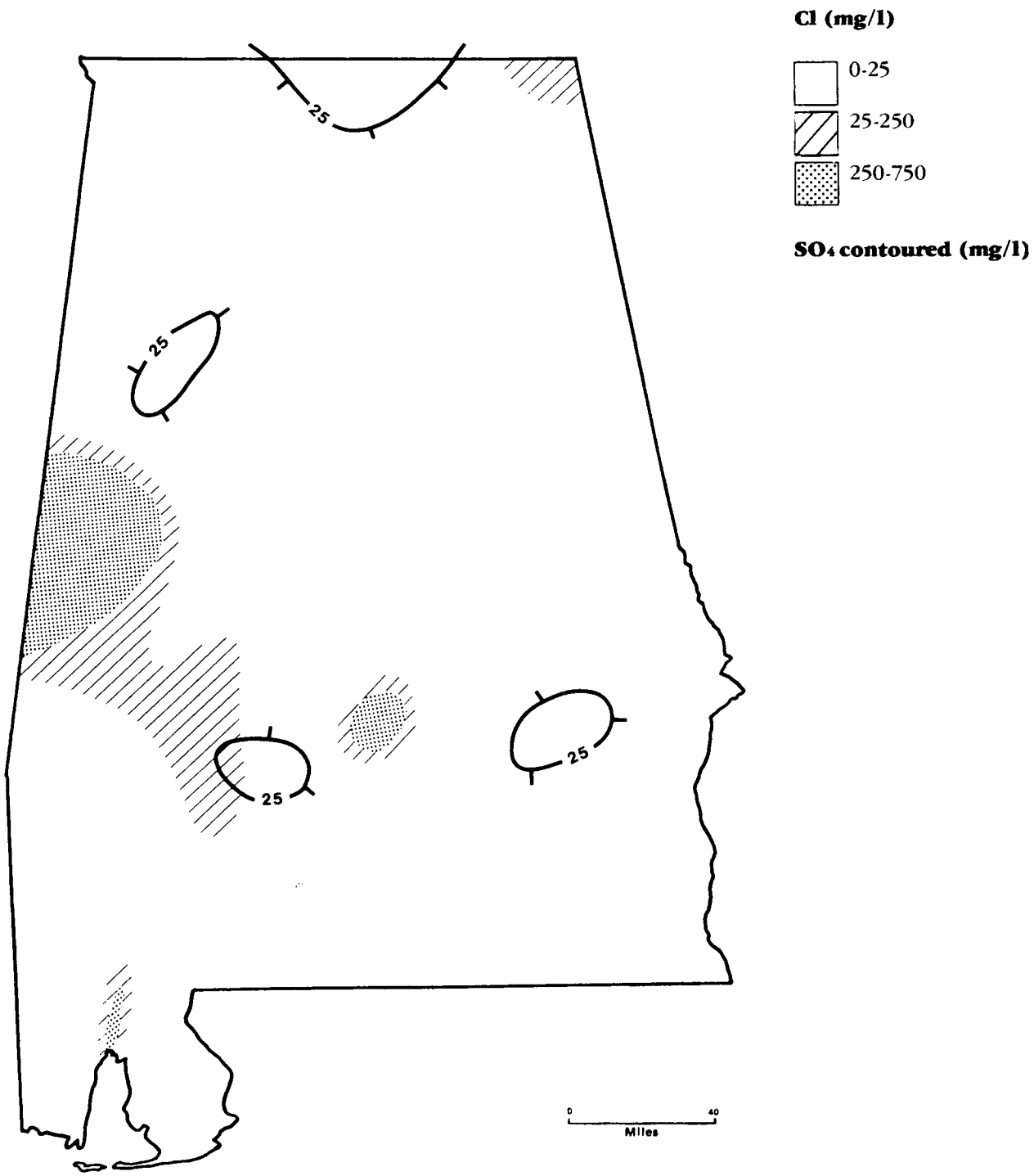


Plate 2

Alabama

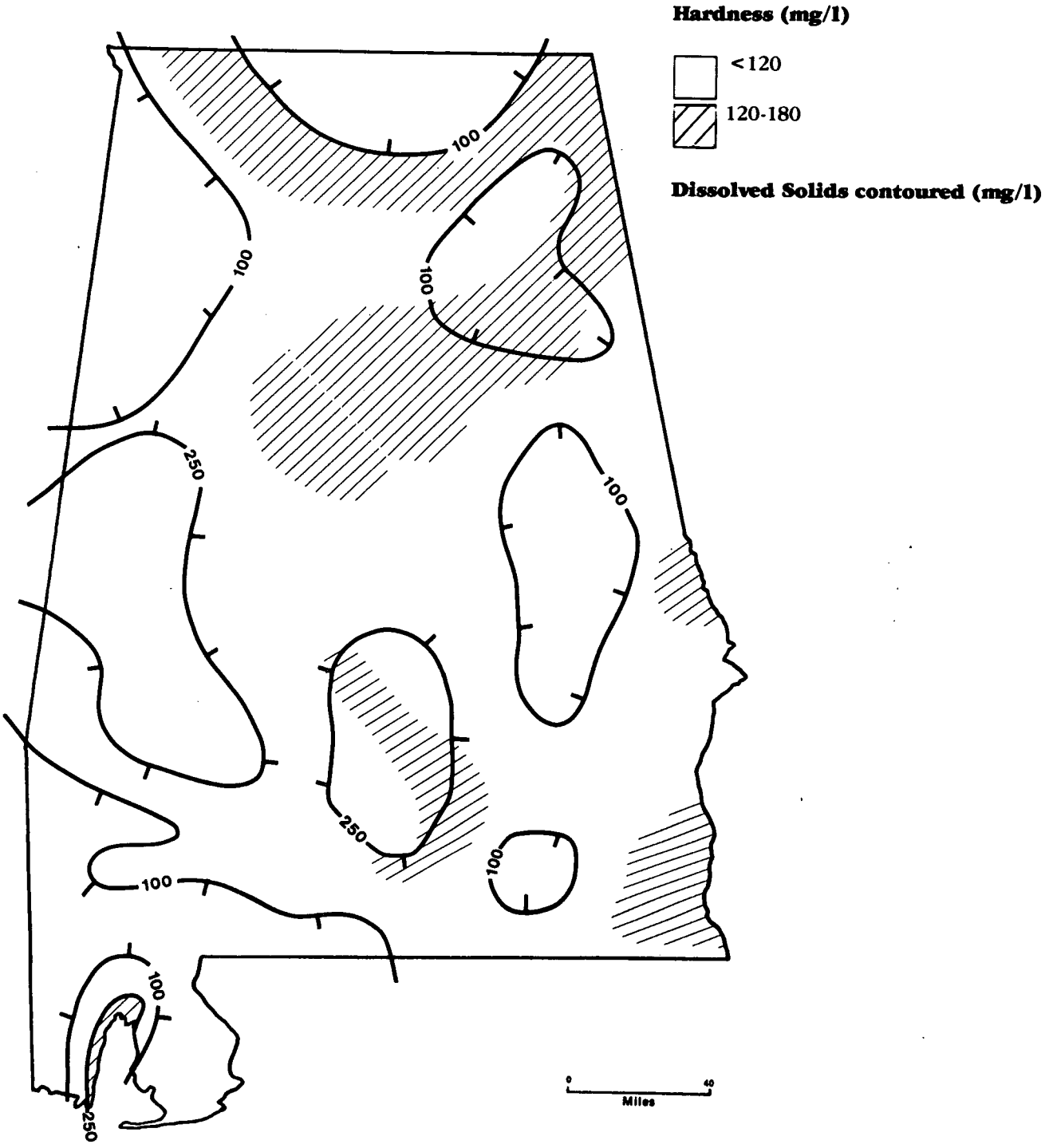
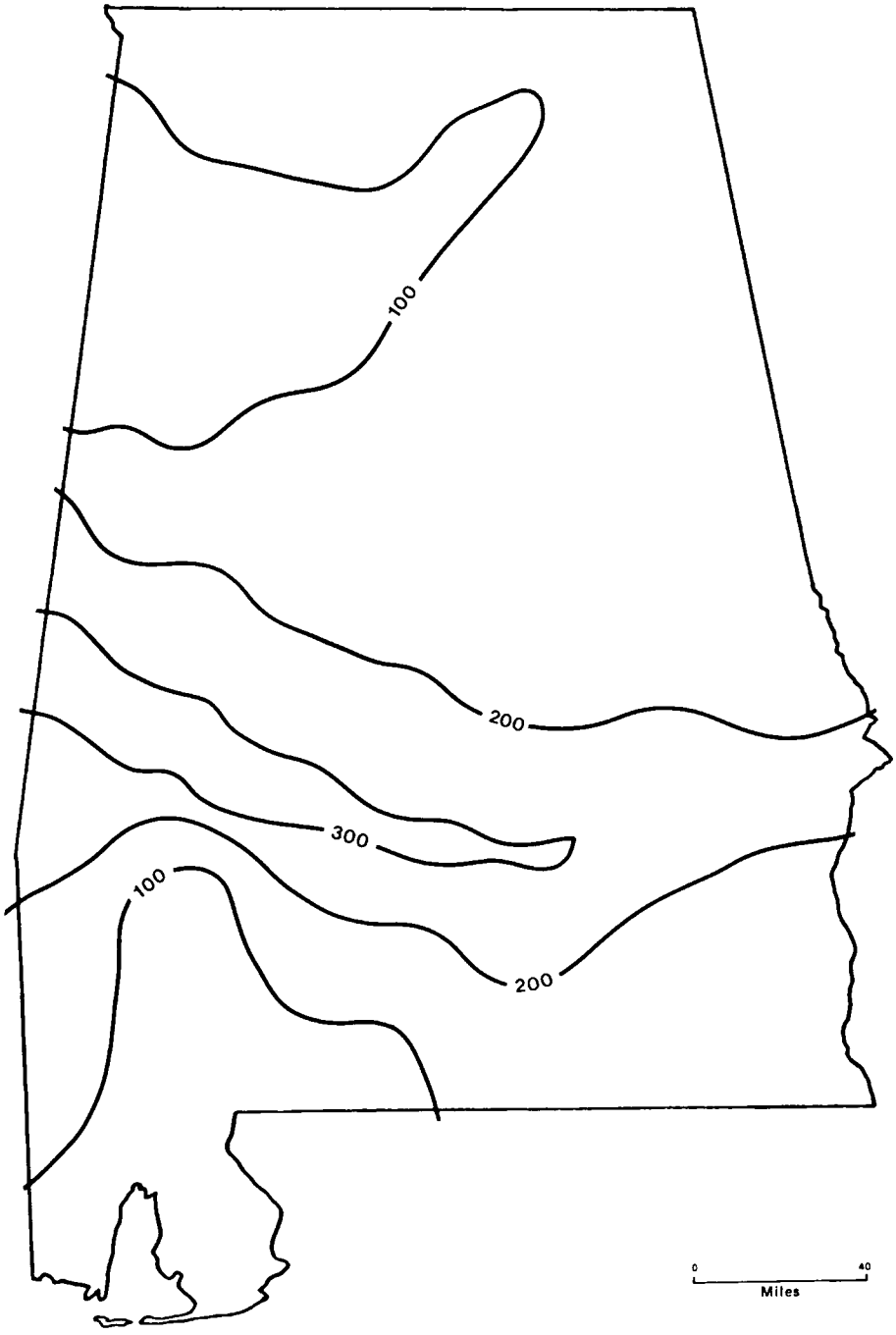


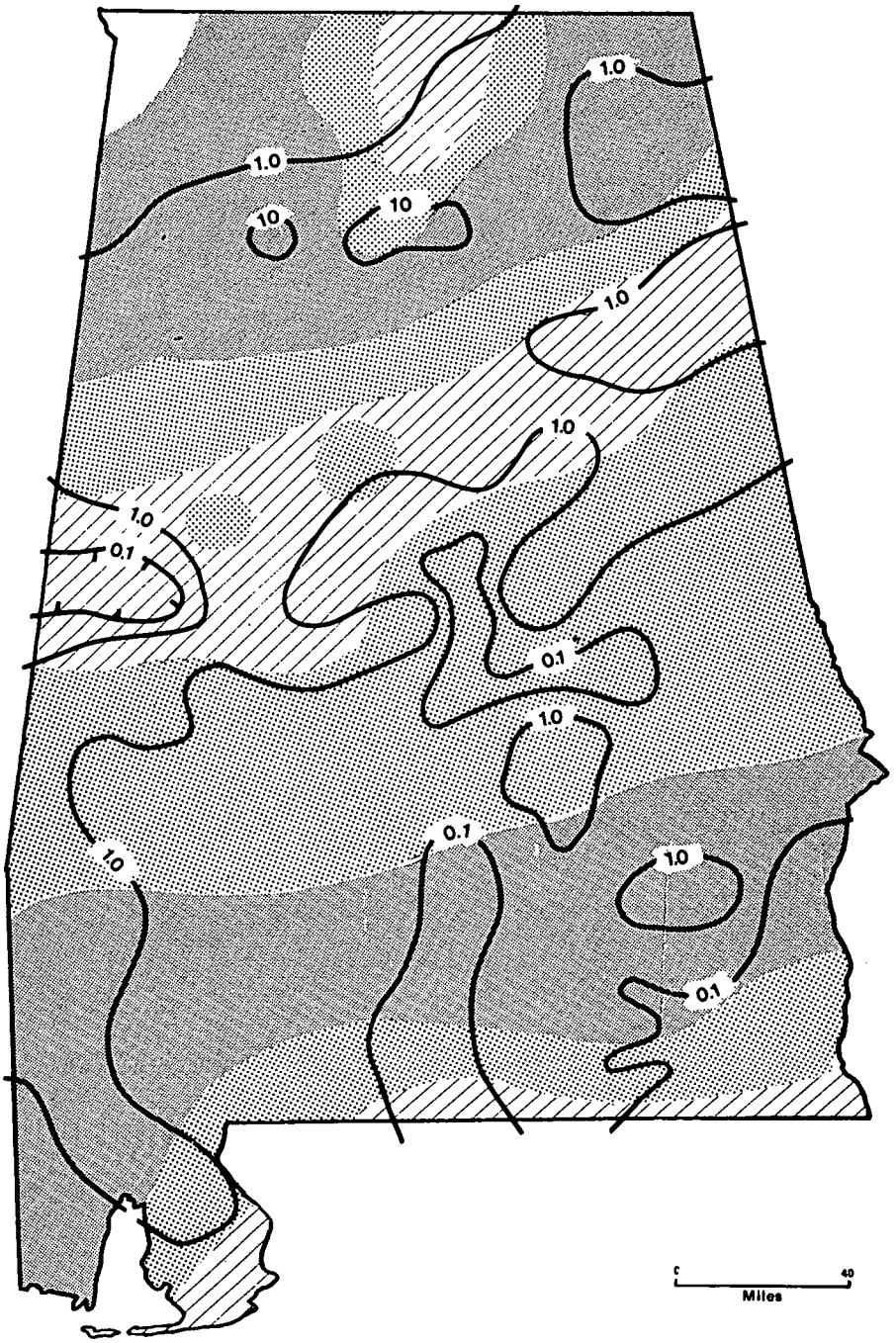
Plate 3

Alabama

HCO_3 contoured (mg/l)



Alabama

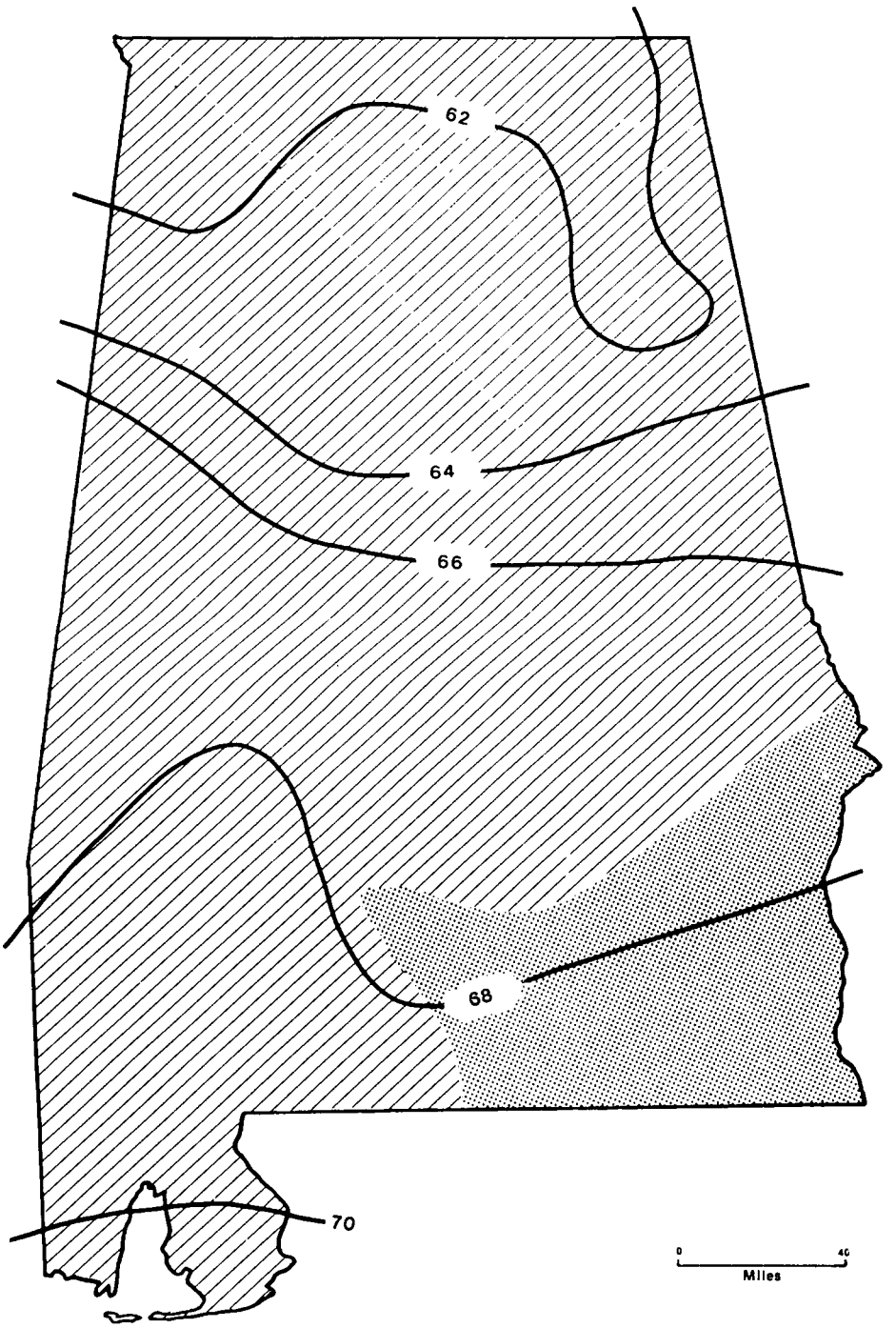


Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Alabama



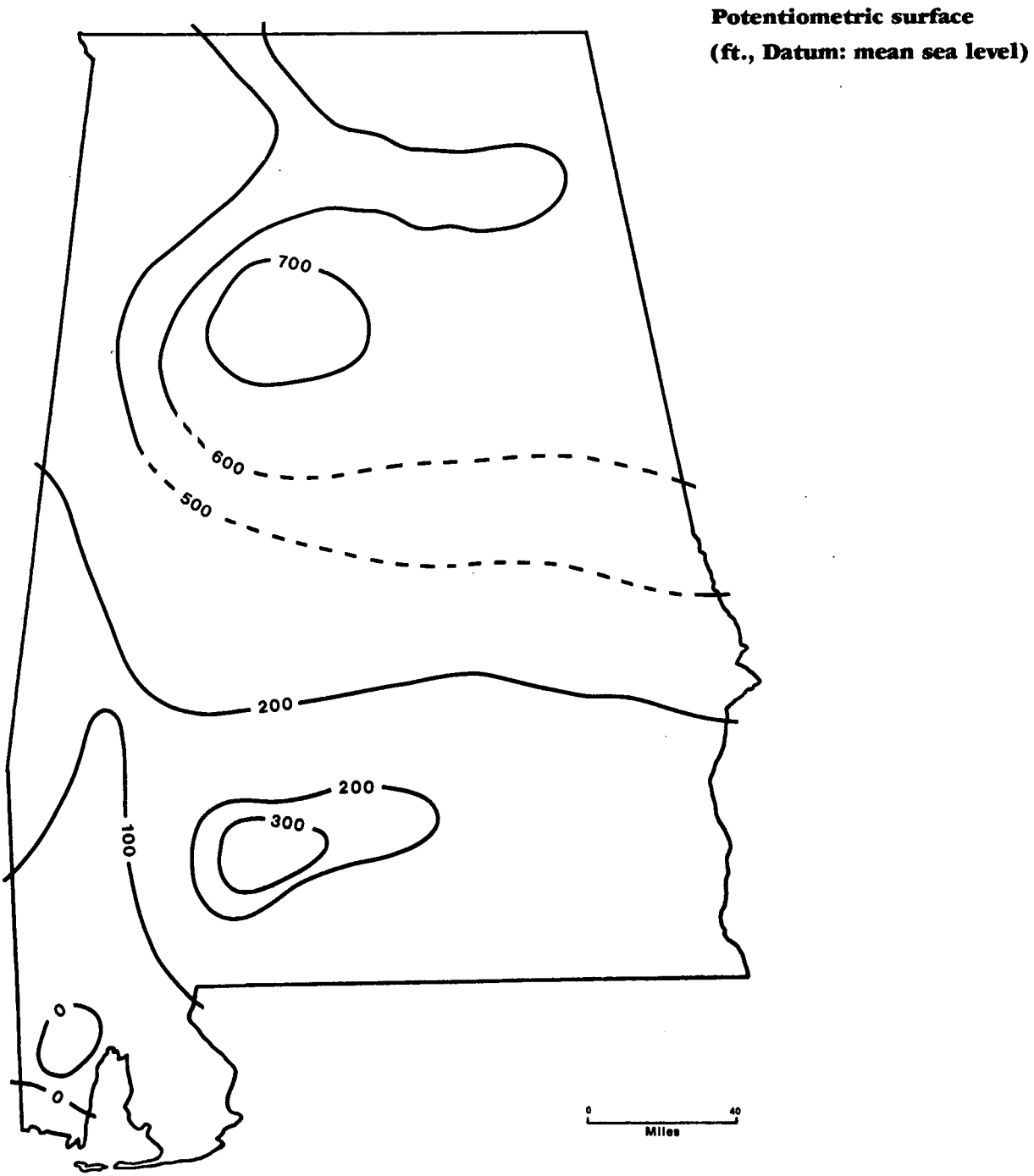
pH

6.1 - 8.0

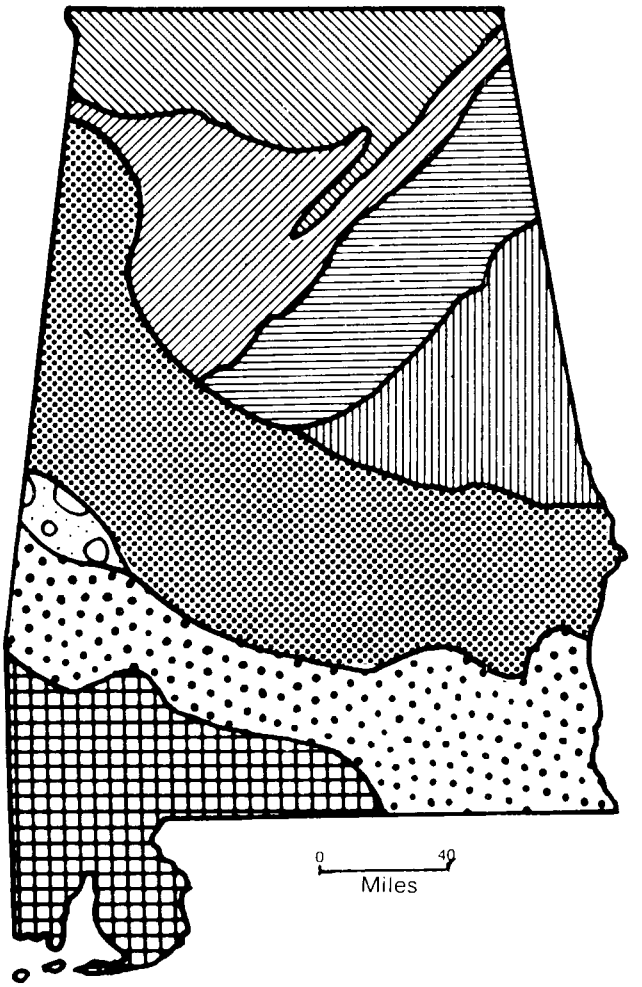
8.1 - 10

Temperature contoured (°F)

Alabama


Potentiometric surface
(ft., Datum: mean sea level)
700
600
500
200
200
300
100
0
0
0
40
Miles

Alabama



Sand and gravel
50 gpm

Sand and sandstone
100 gpm

Sand
1,500 gpm

Limestone, chert, and sandstone
2,000 gpm

Sand and limestone
500 gpm

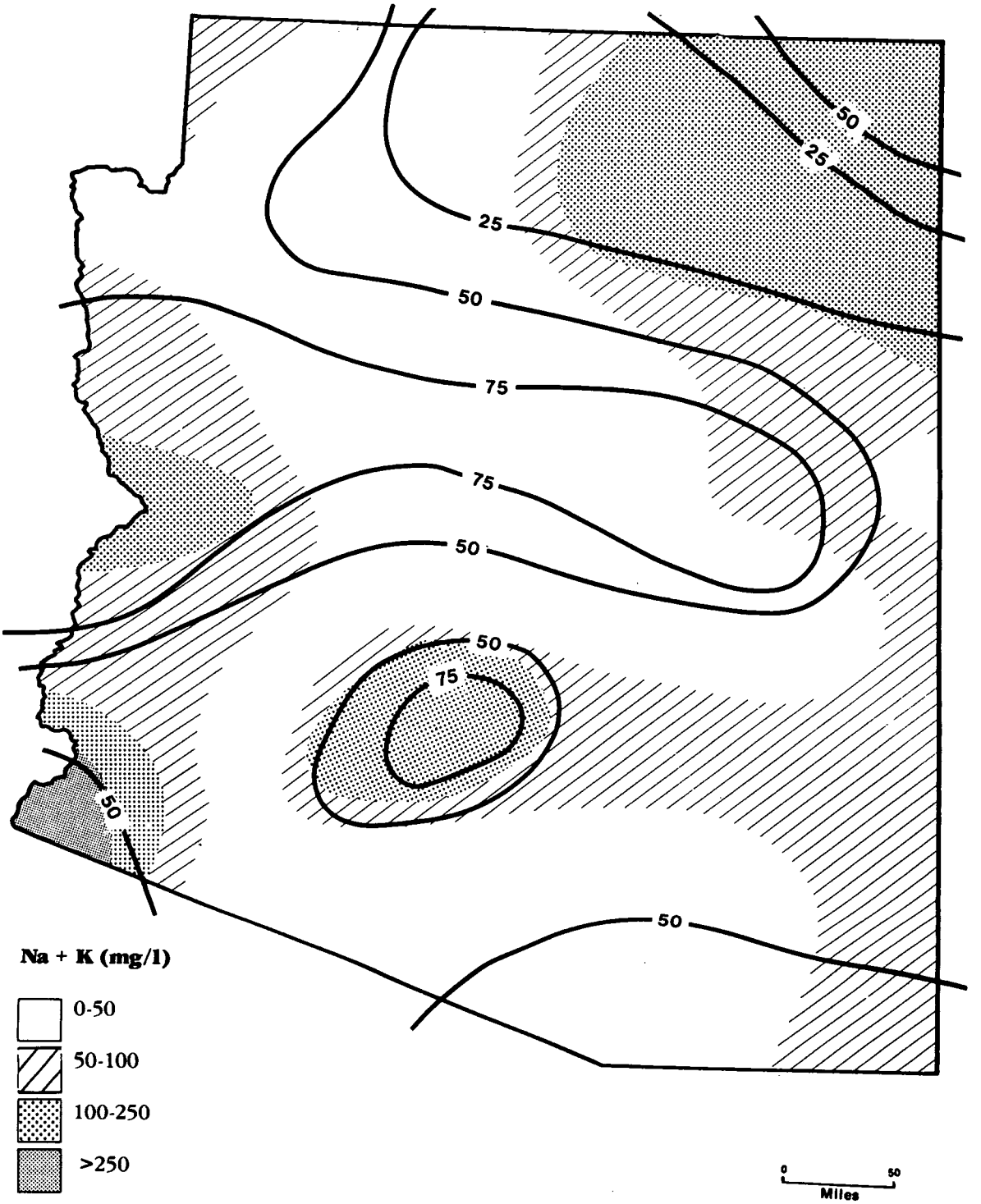
Limestone and sandstone
500 gpm

Sand and gravel
2,000 gpm

Metamorphic rocks and saprolite
50 gpm

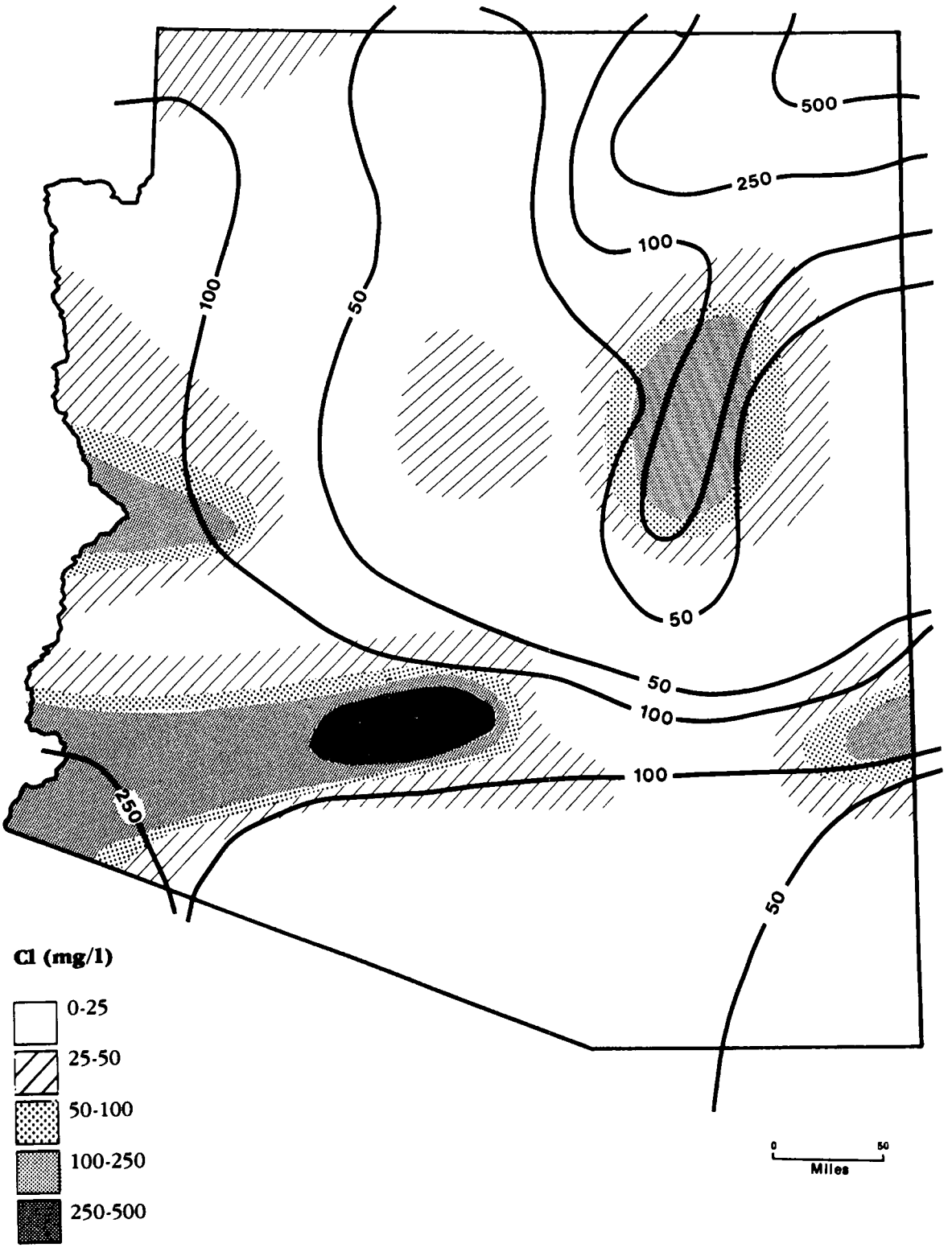
TYPE AND MAXIMUM YIELD OF AQUIFERS

Arizona



Ca + Mg contoured (mg/l)

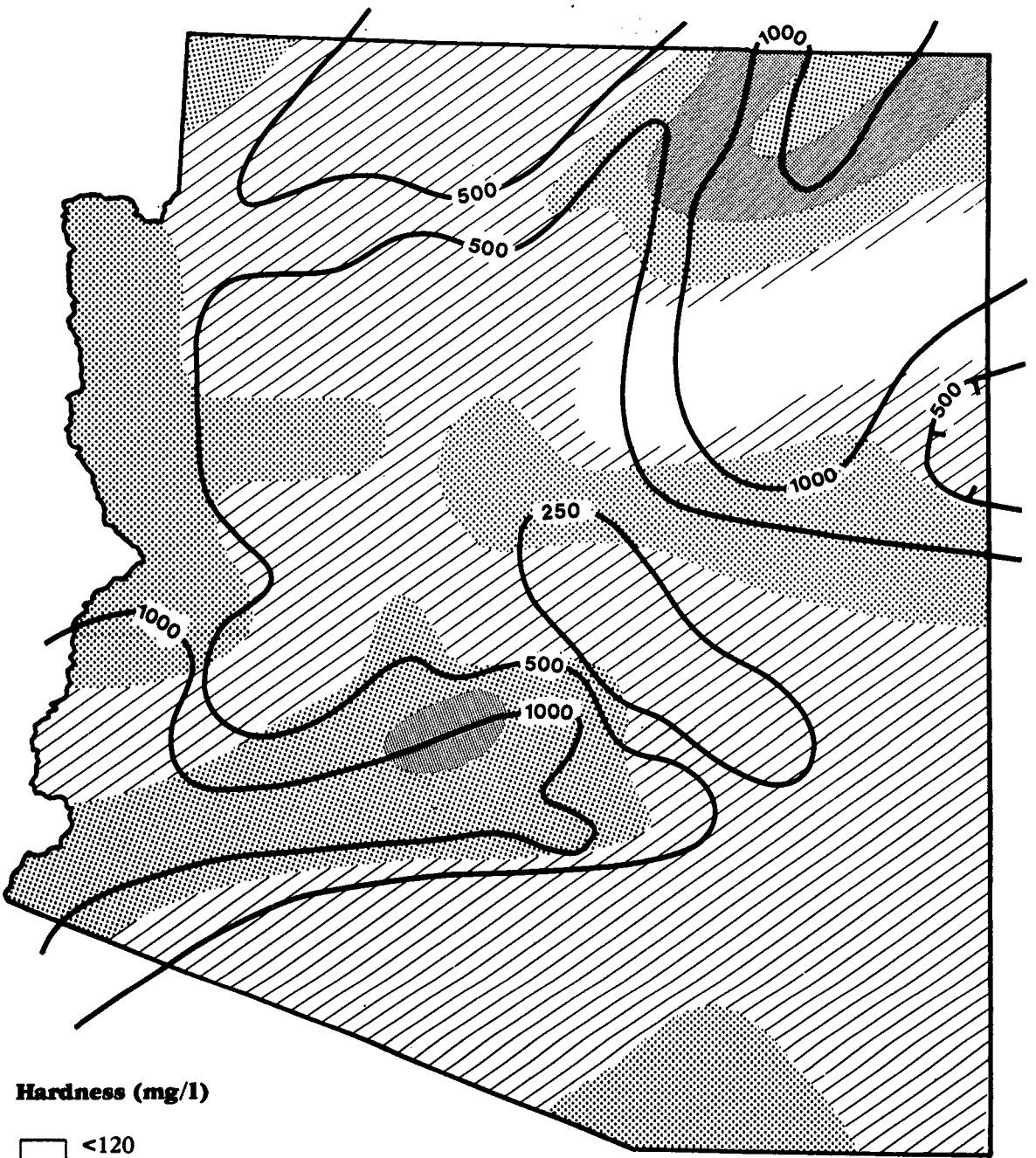
Arizona



SO_4 contoured (mg/l)

Plate 10

Arizona



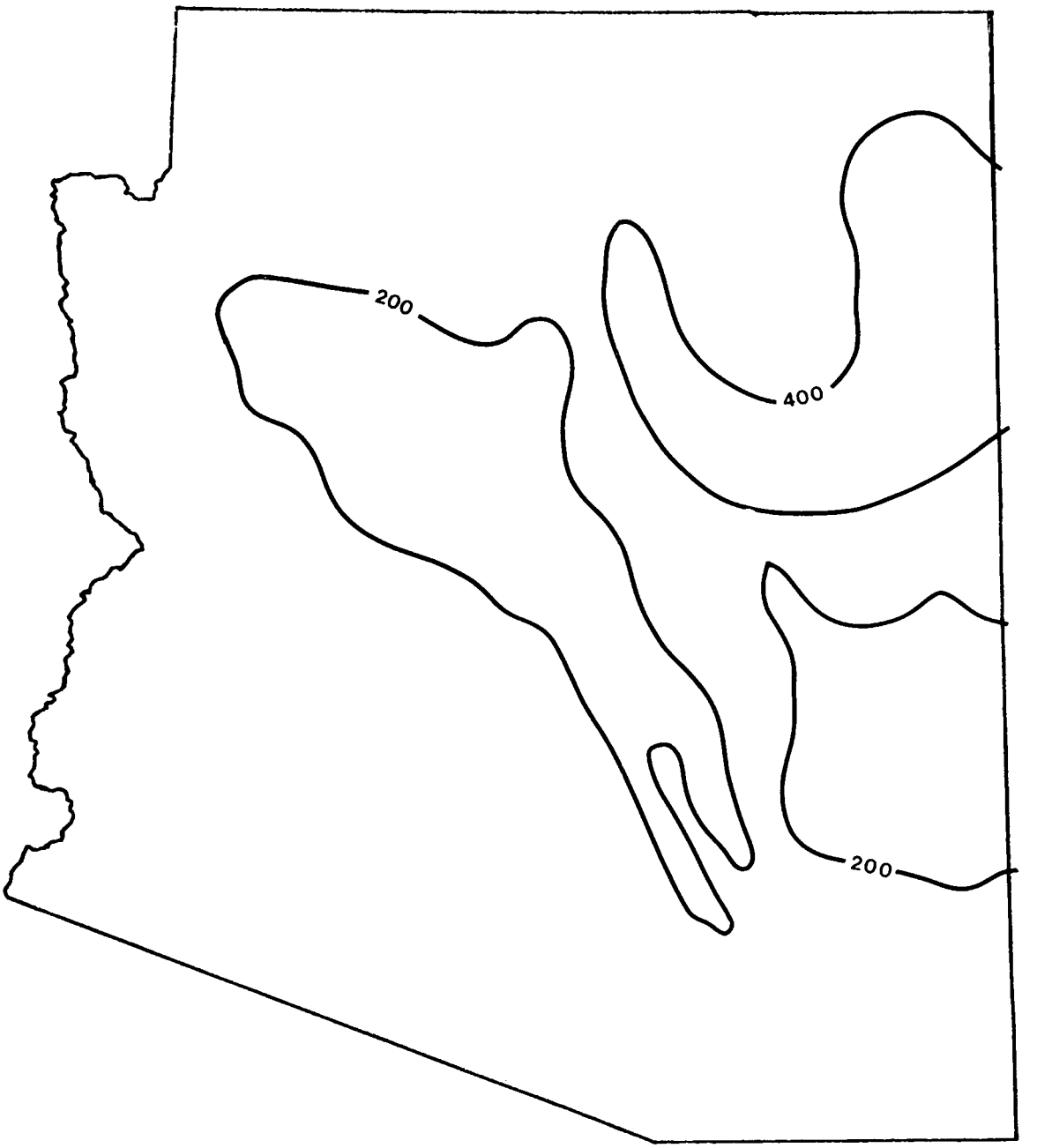
Hardness (mg/l)

- <120
- 120-240
- 240-500
- 500-1000

0 50
Miles

Dissolved Solids contoured (mg/l)

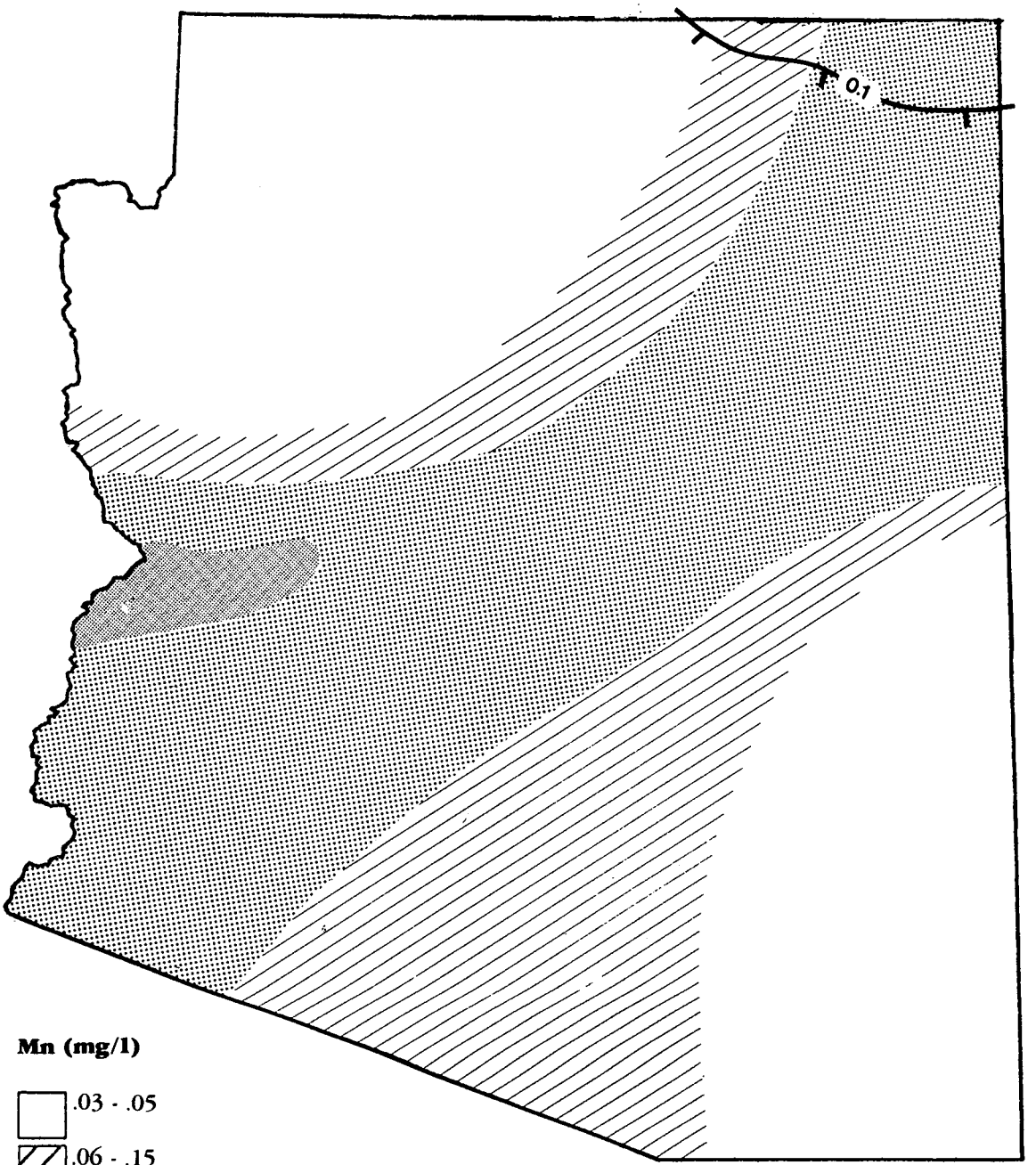
Arizona



HCO_3 contoured (mg/l)

0 50
Miles

Arizona



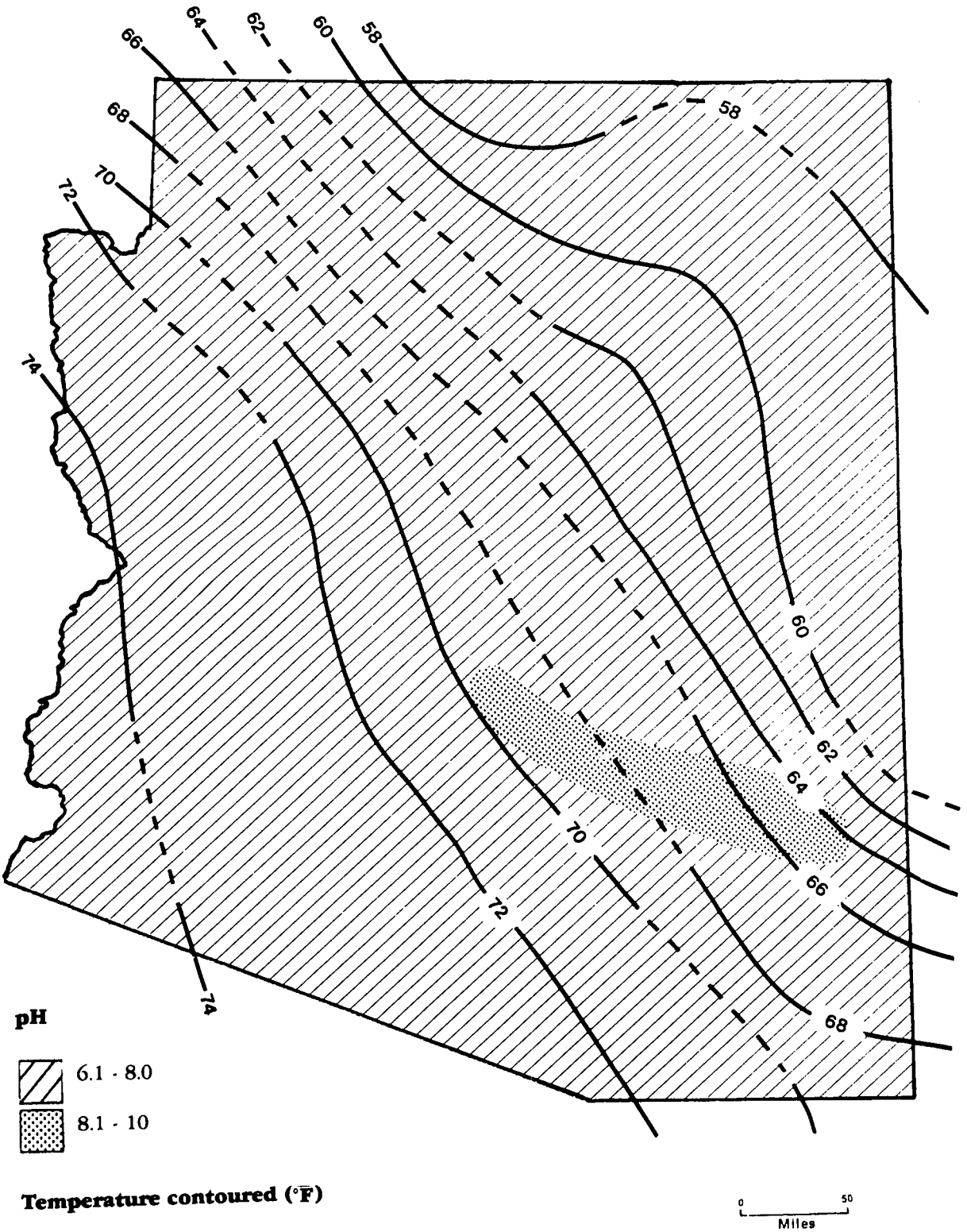
Mn (mg/l)

- .03 - .05
- .06 - .15
- .15 - 1.0
- Greater than 10

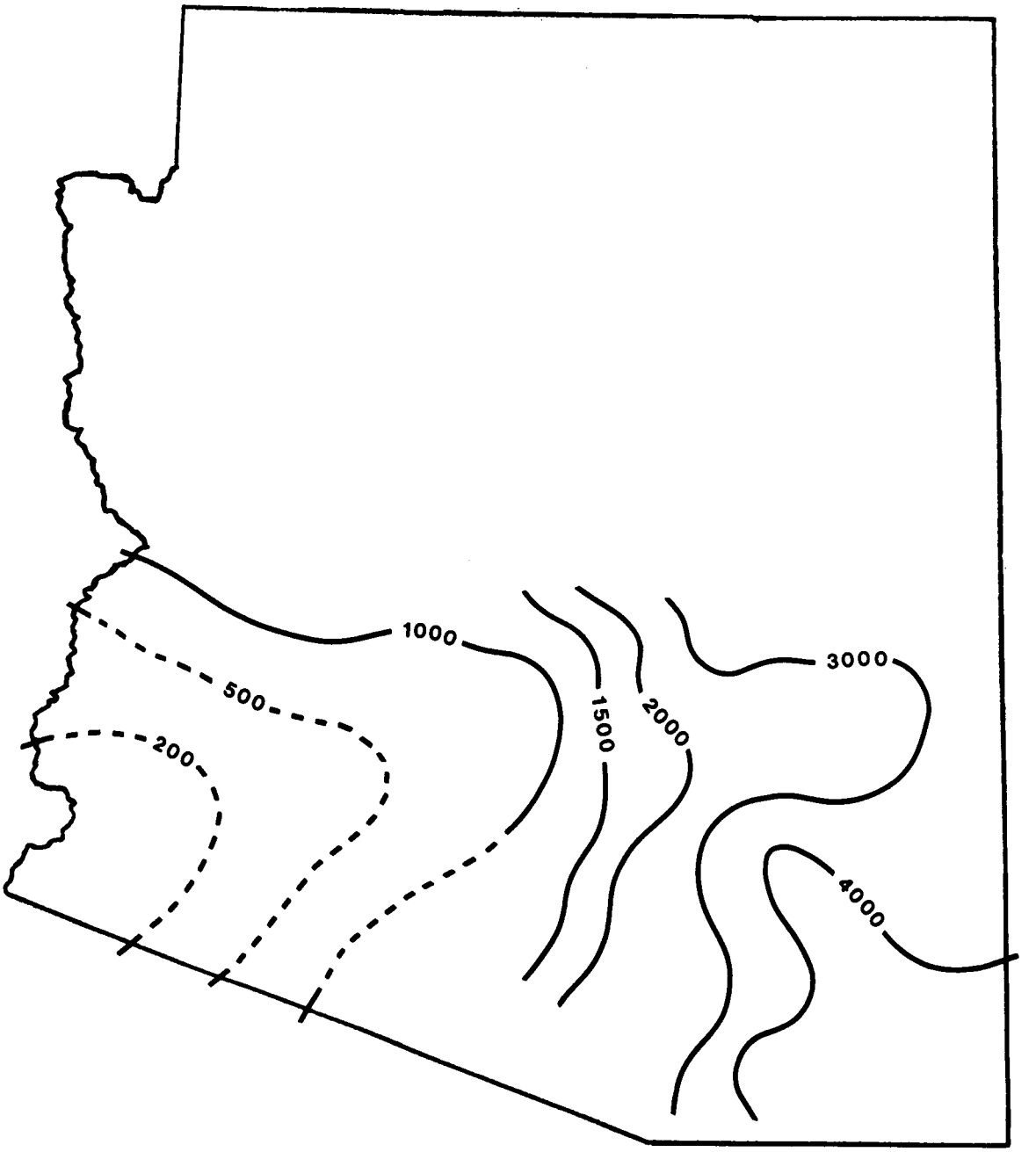
0 50
Miles

Fe contoured (mg/l)

Arizona


58
60
62
64
66
68
70
72
74
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles

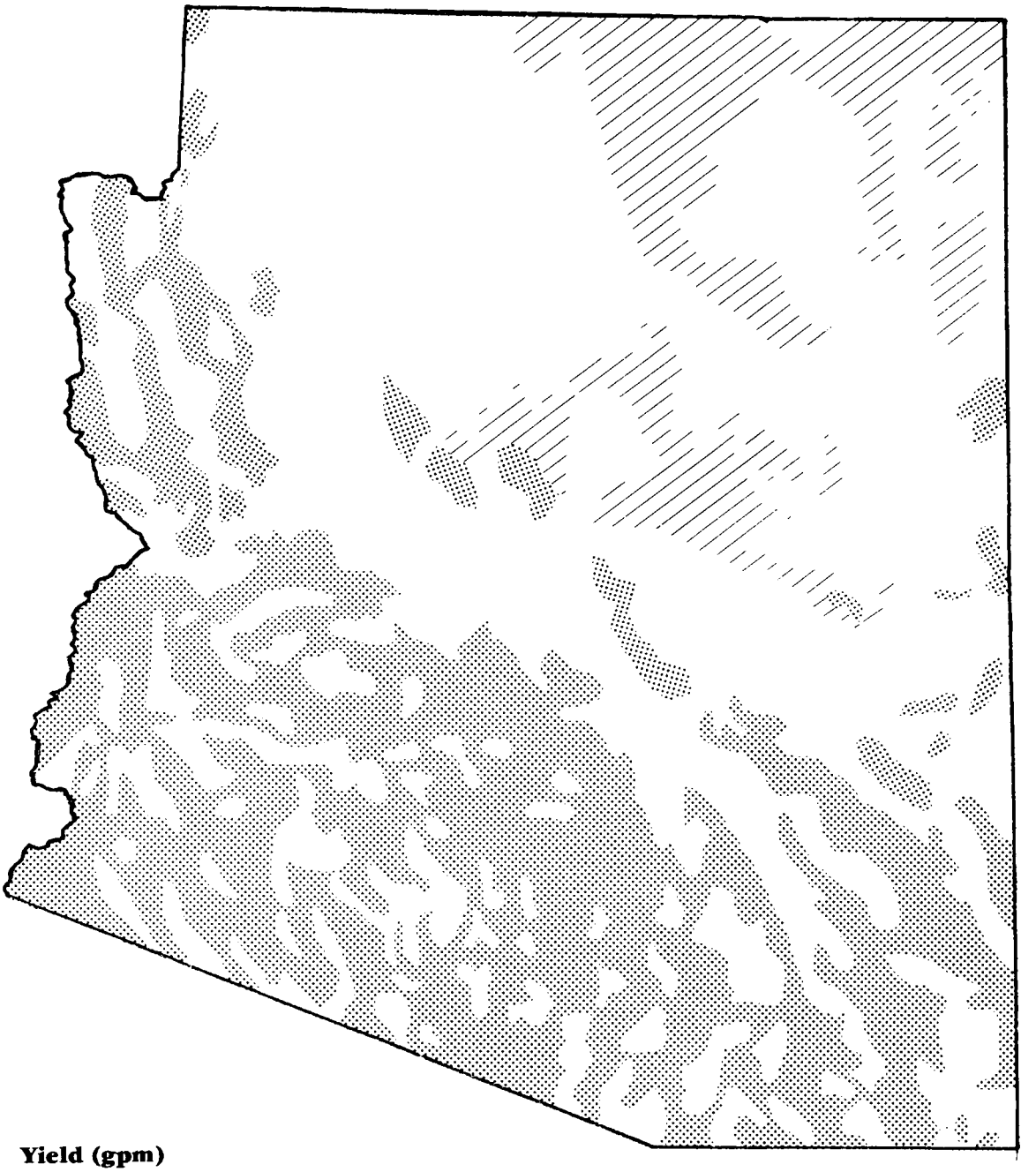
Arizona



Potentiometric surface
(ft., Datum: mean sea level)

0 50
Miles

Arizona



Yield (gpm)

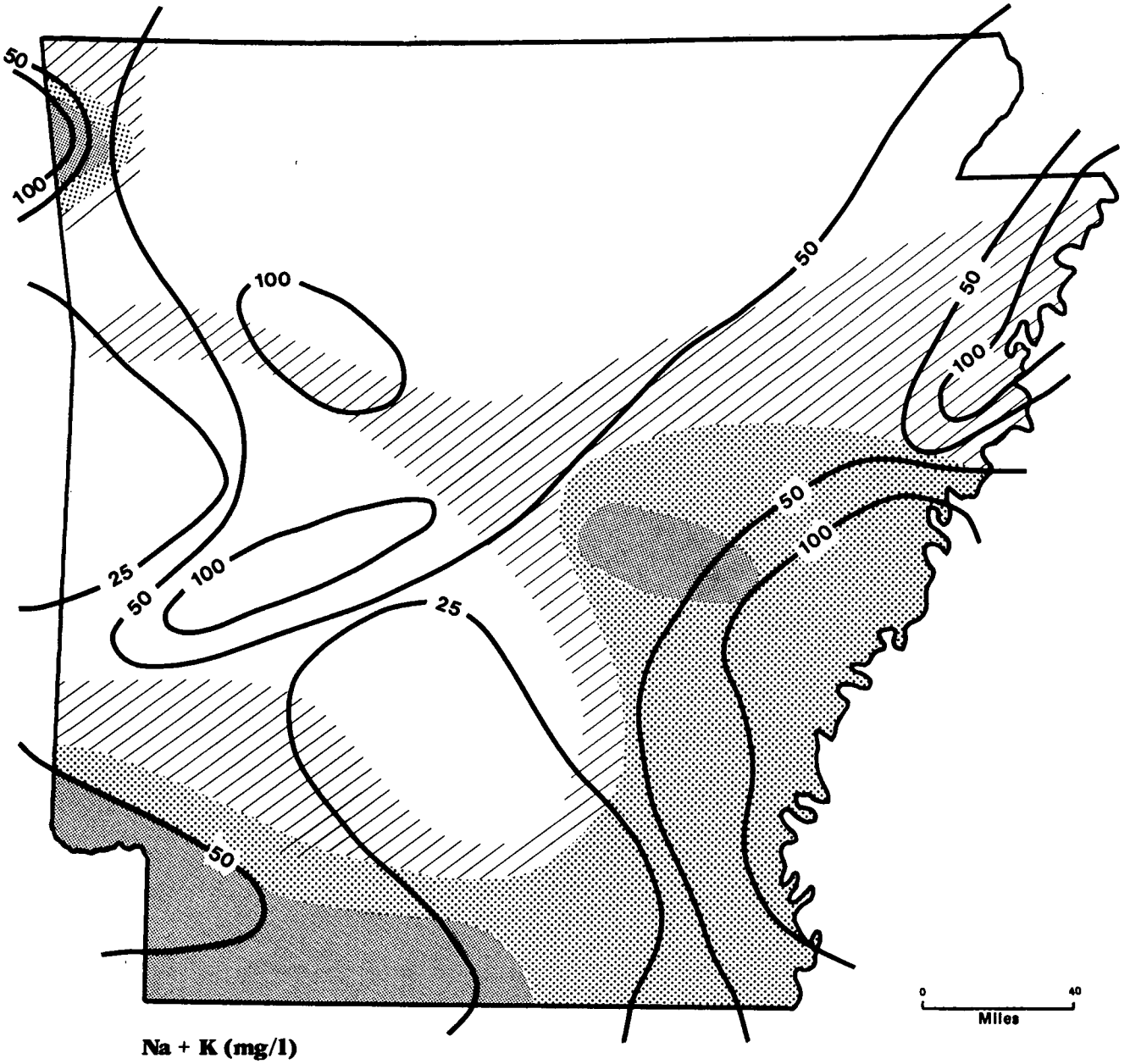
Undifferentiated, volcanic and metamorphics, Paleozoic and Mesozoic bedrock, 0-25 gpm

Coconino, Dakota and Navajo sandstones 10-500 gpm

Alluvium 0-2500 gpm

0 50
Miles

Arkansas

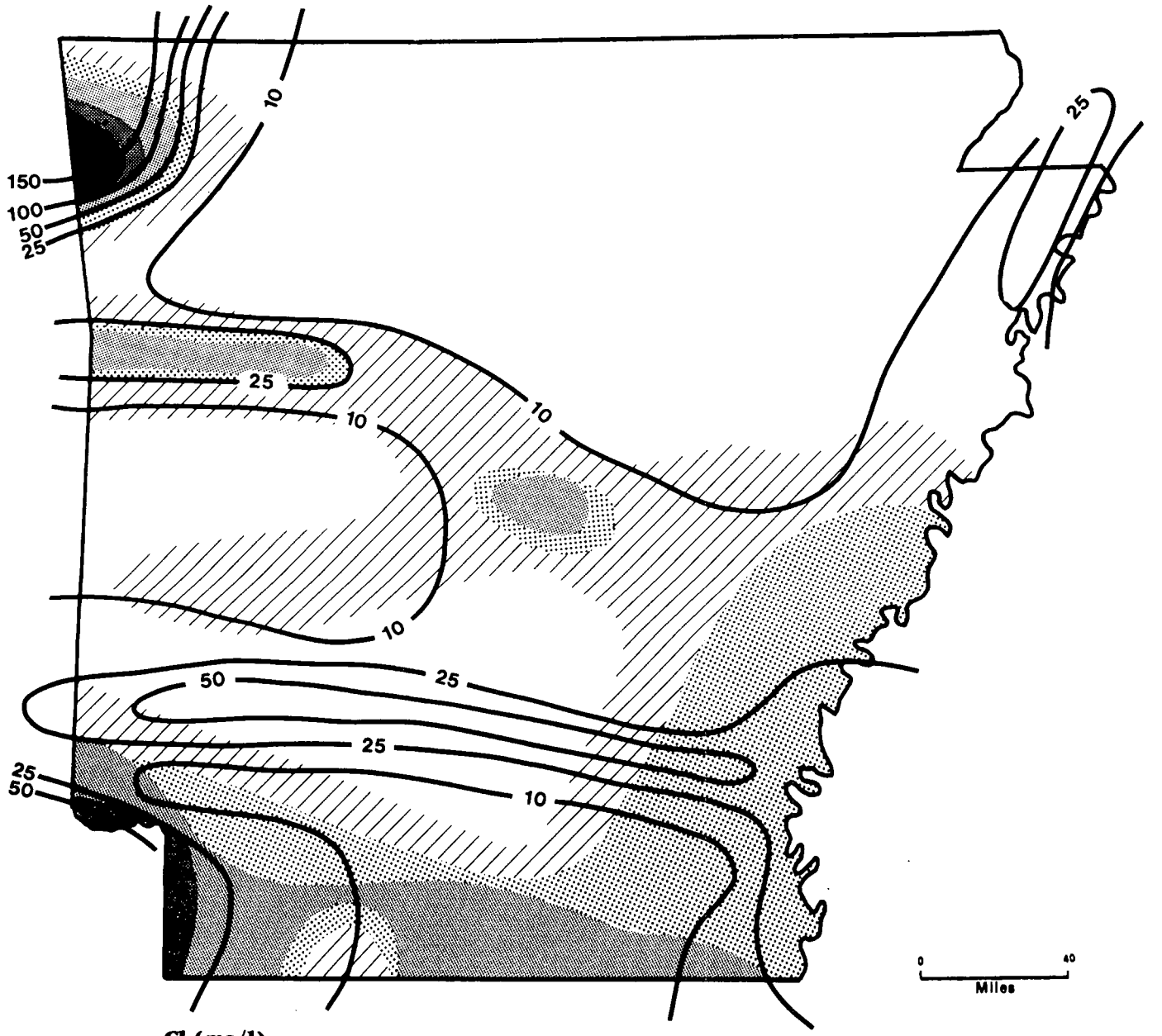


Na + K (mg/l)

- 0-10
- 10-25
- 25-50
- 50-250

Ca + Mg contoured (mg/l)

Arkansas



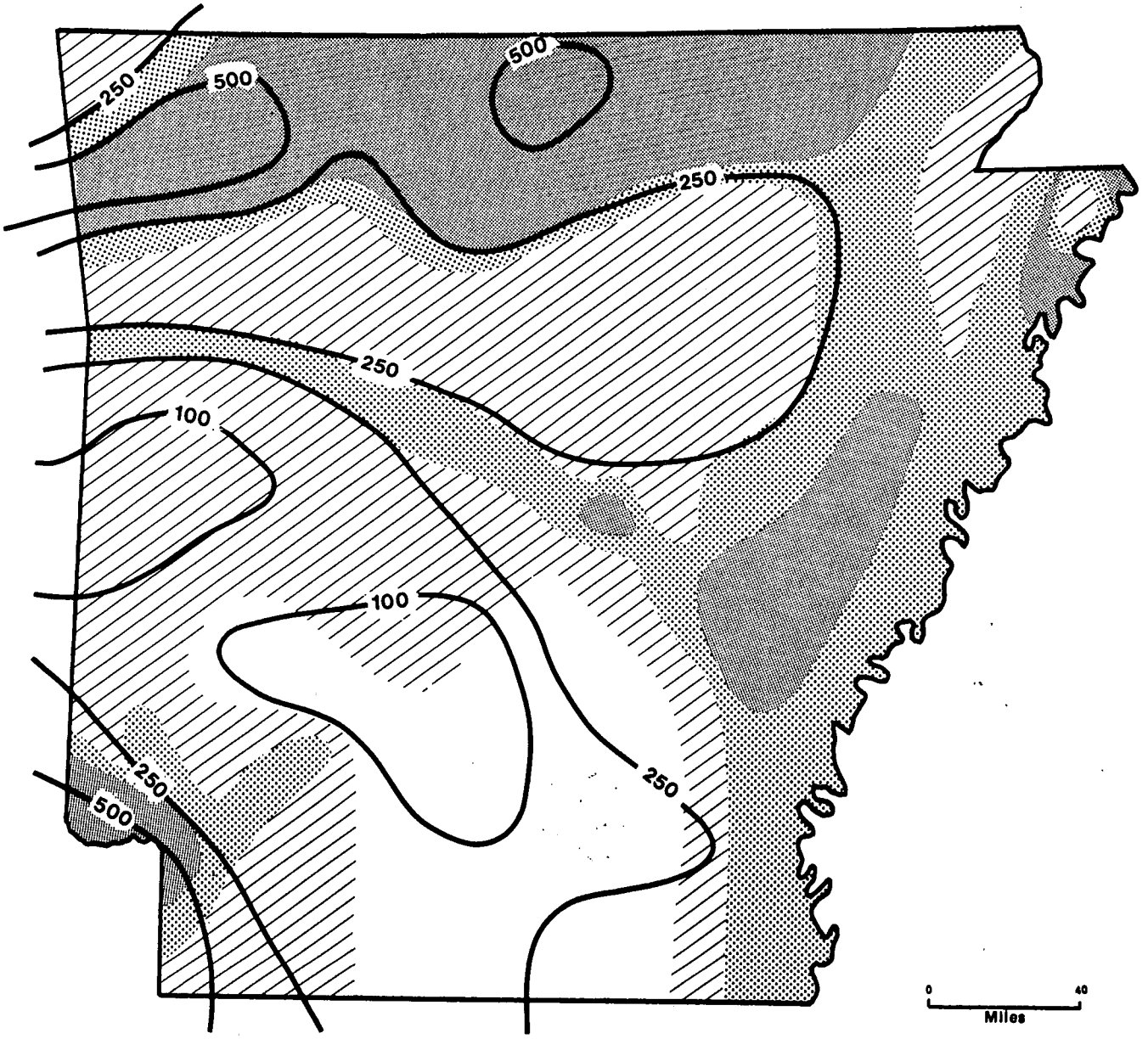
Cl (mg/l)

- 0-10
- 10-25
- 25-50
- 50-100
- 100-250
- 250-500

SO_4 contoured (mg/l)

Plate 18

Arkansas

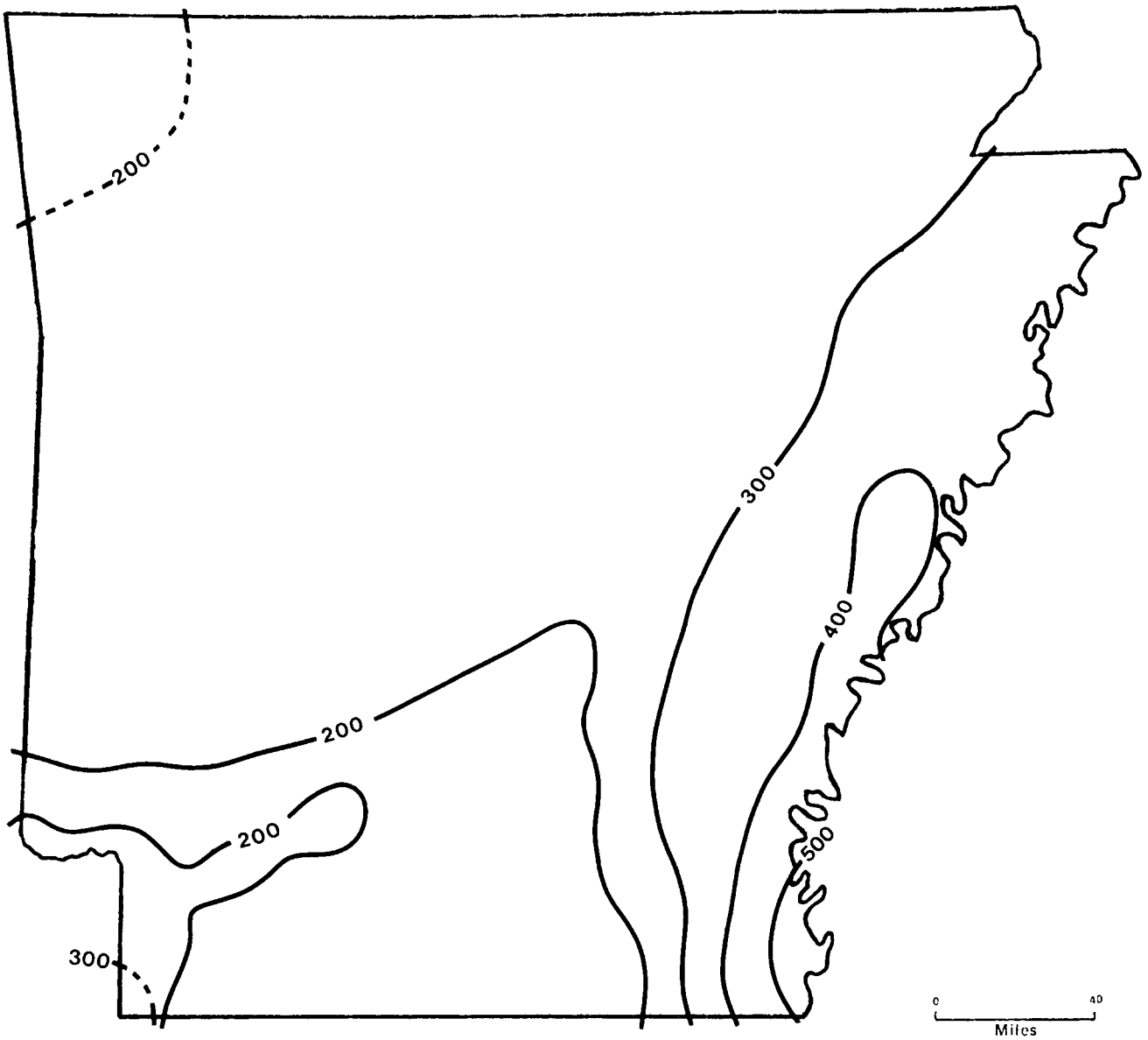


Hardness (mg/l)

- 0-60
- 60-180
- 180-240
- >240

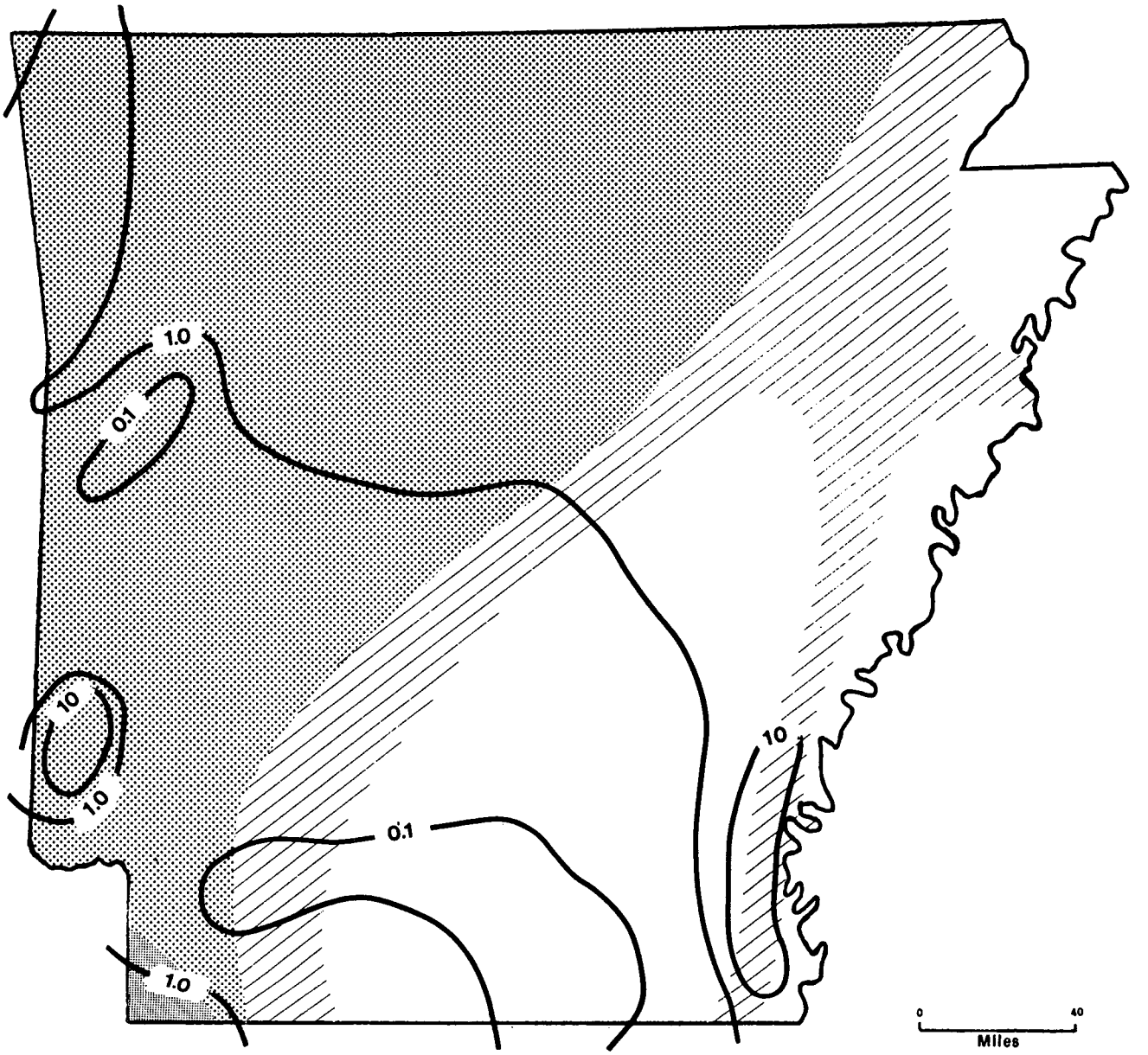
Dissolved Solids contoured (mg/l)

Arkansas



HCO_3 contoured (mg/l)

Arkansas

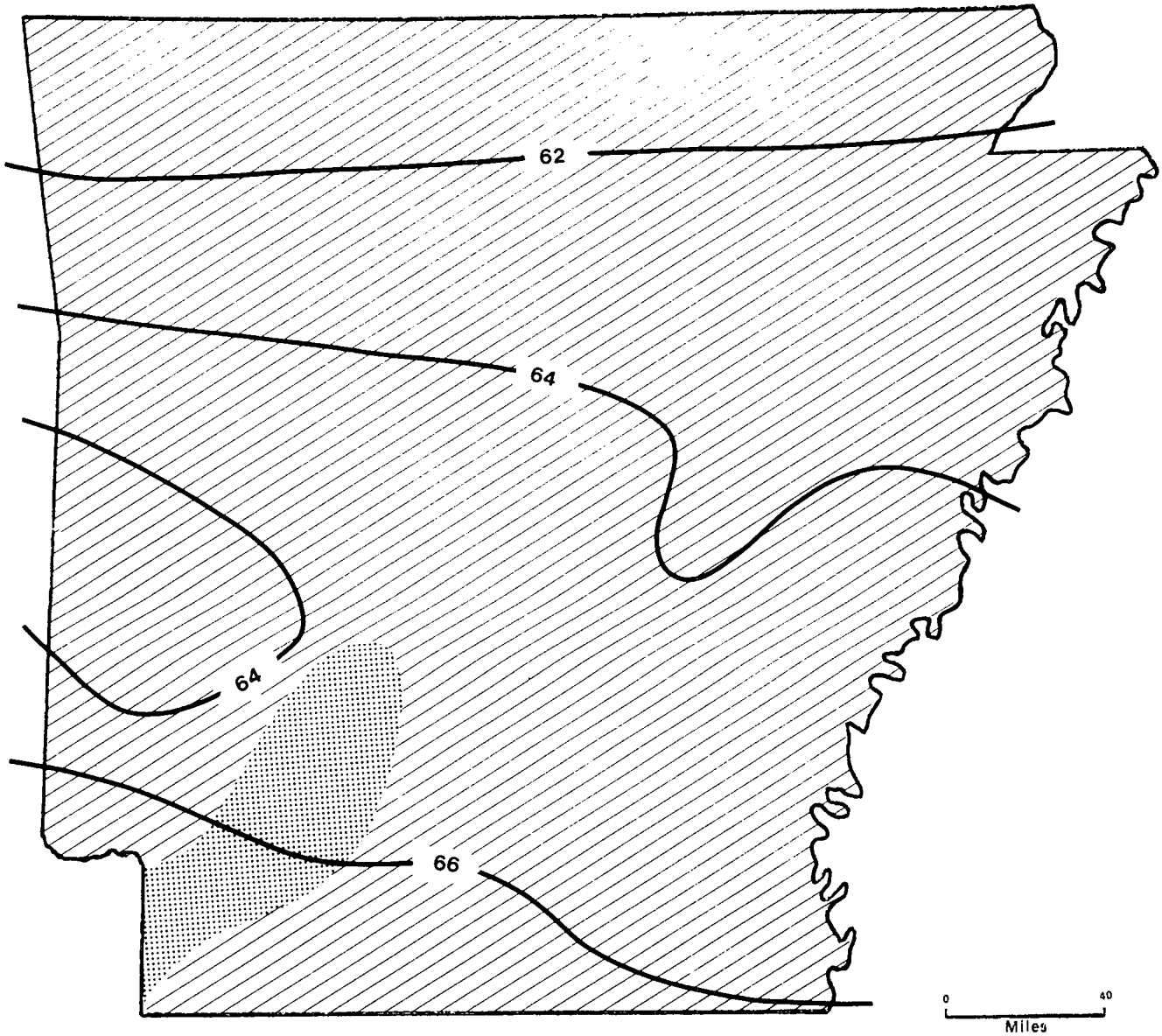


Mn (mg/l)

- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Arkansas



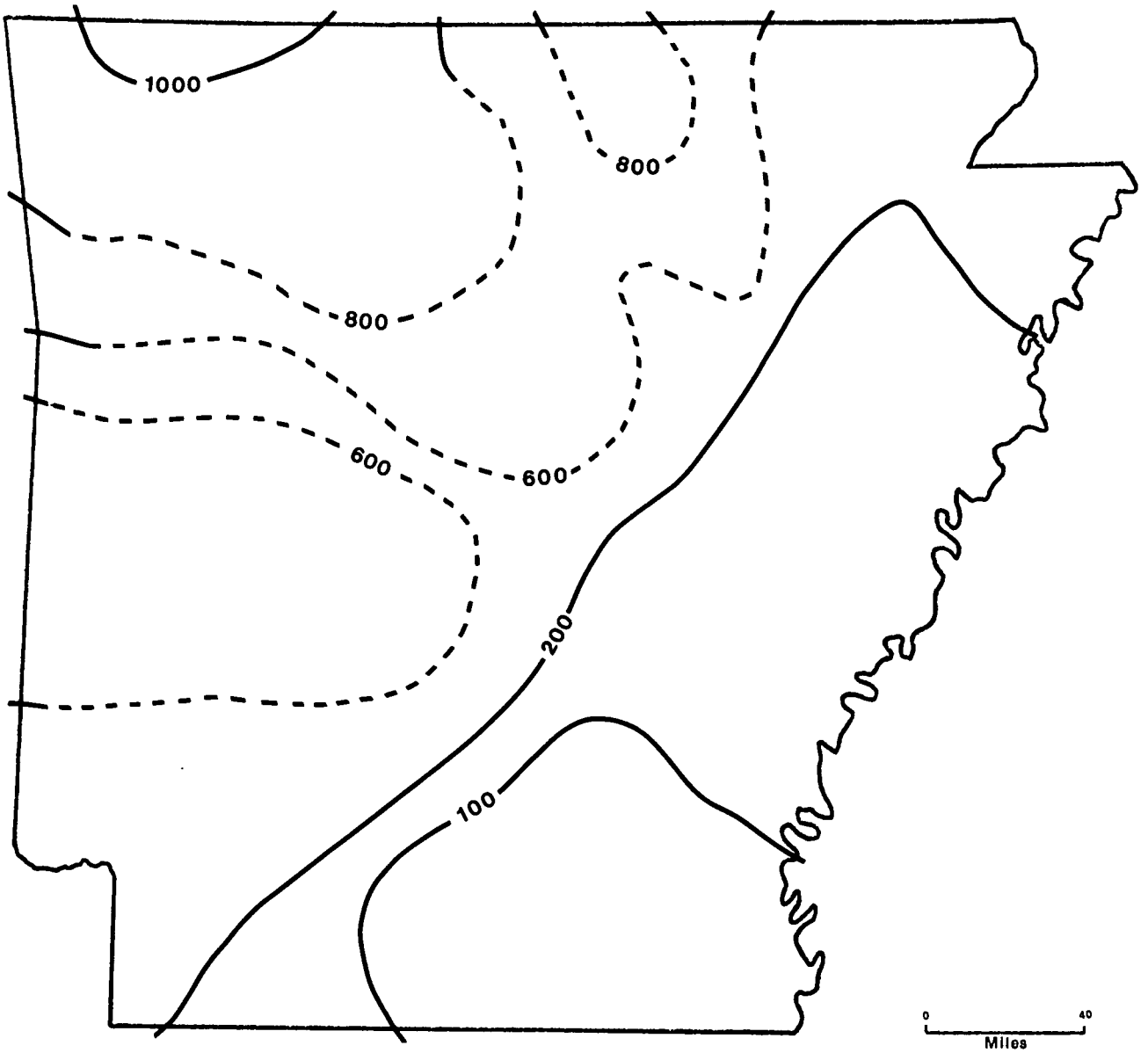
pH

6.1 - 8.0

8.1 - 10

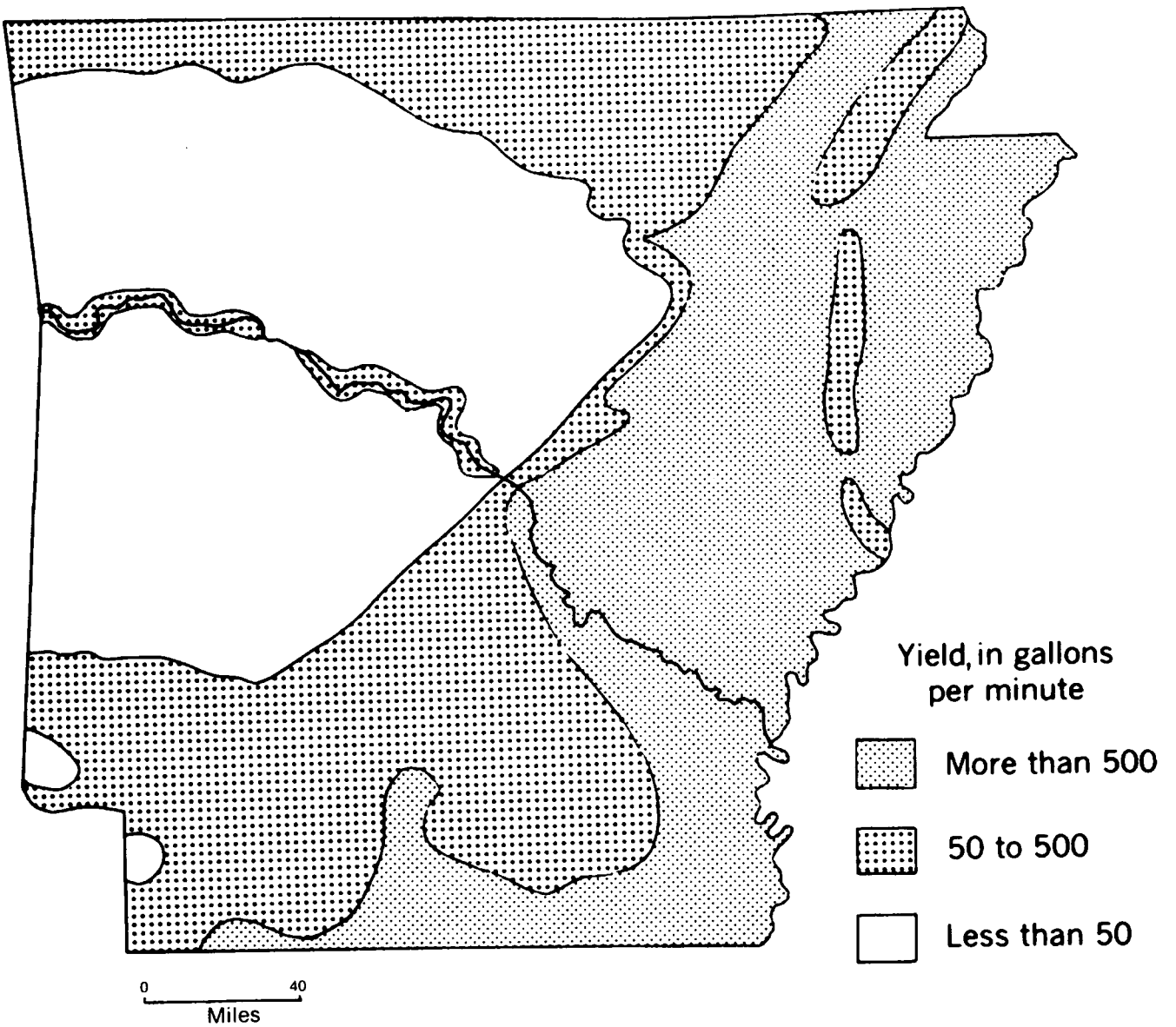
Temperature contoured (°F)

Arkansas



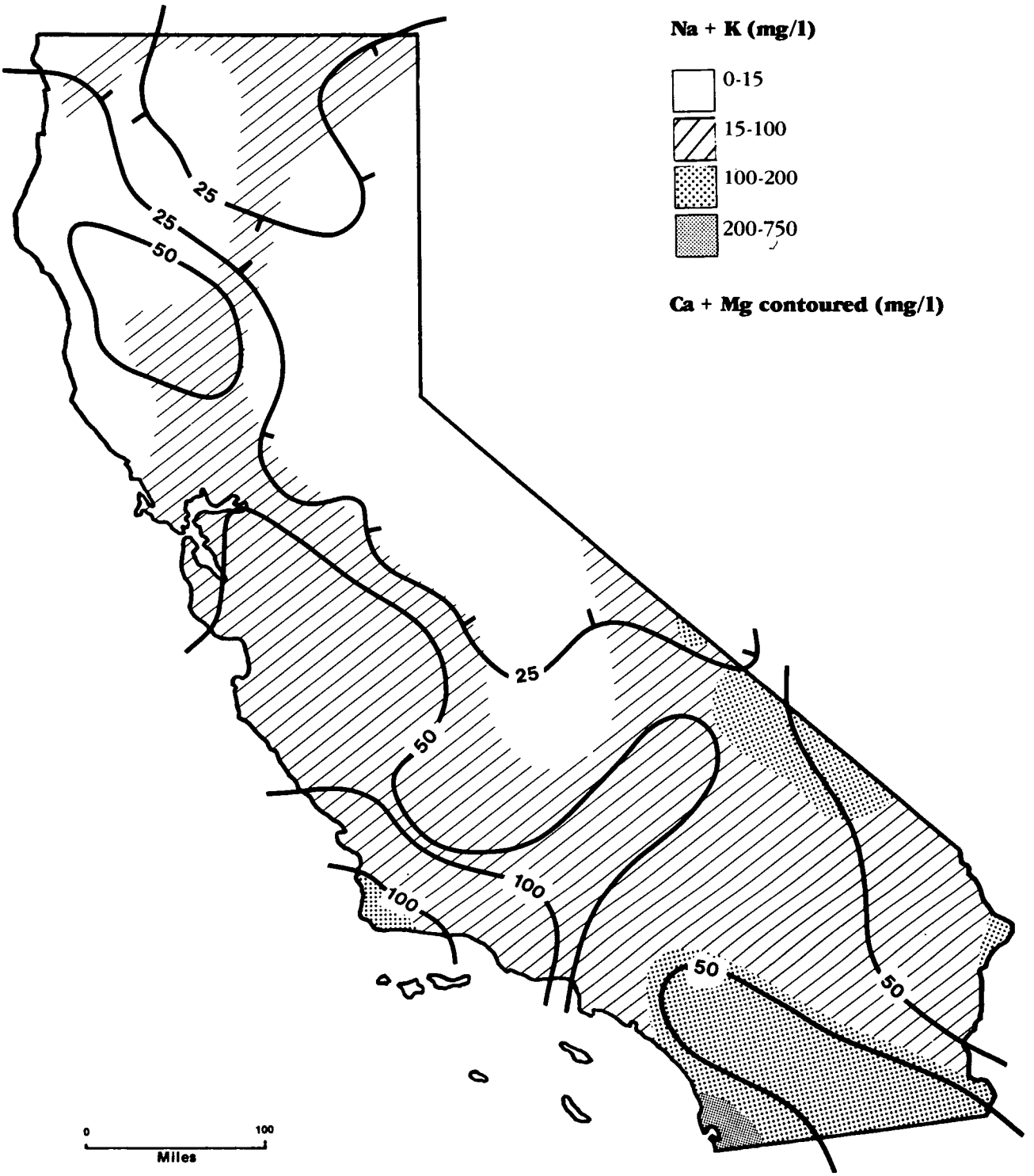
Potentiometric surface
(ft., Datum: mean sea level)

Arkansas

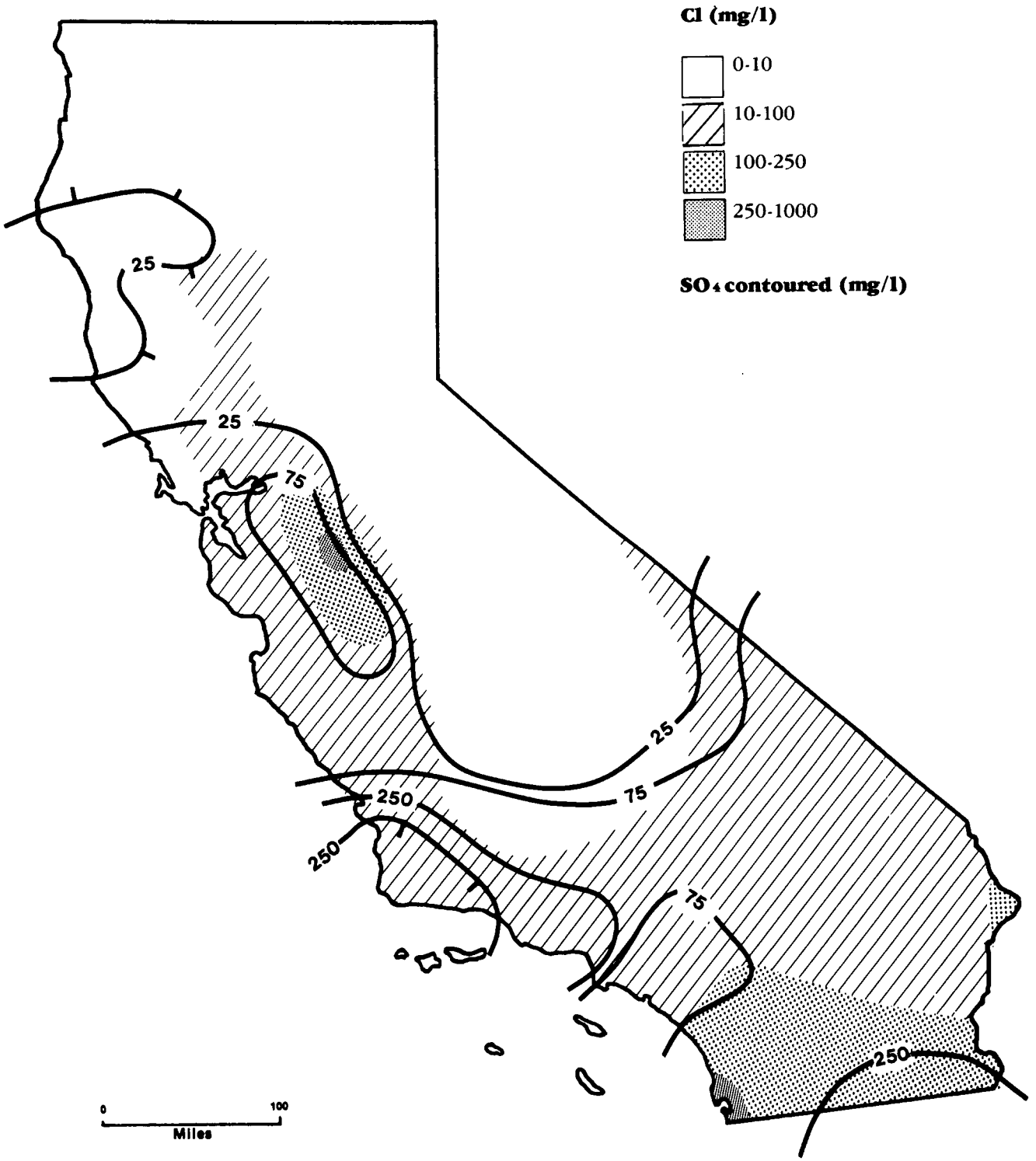


APPROXIMATE YIELDS TO BE EXPECTED FROM WELLS

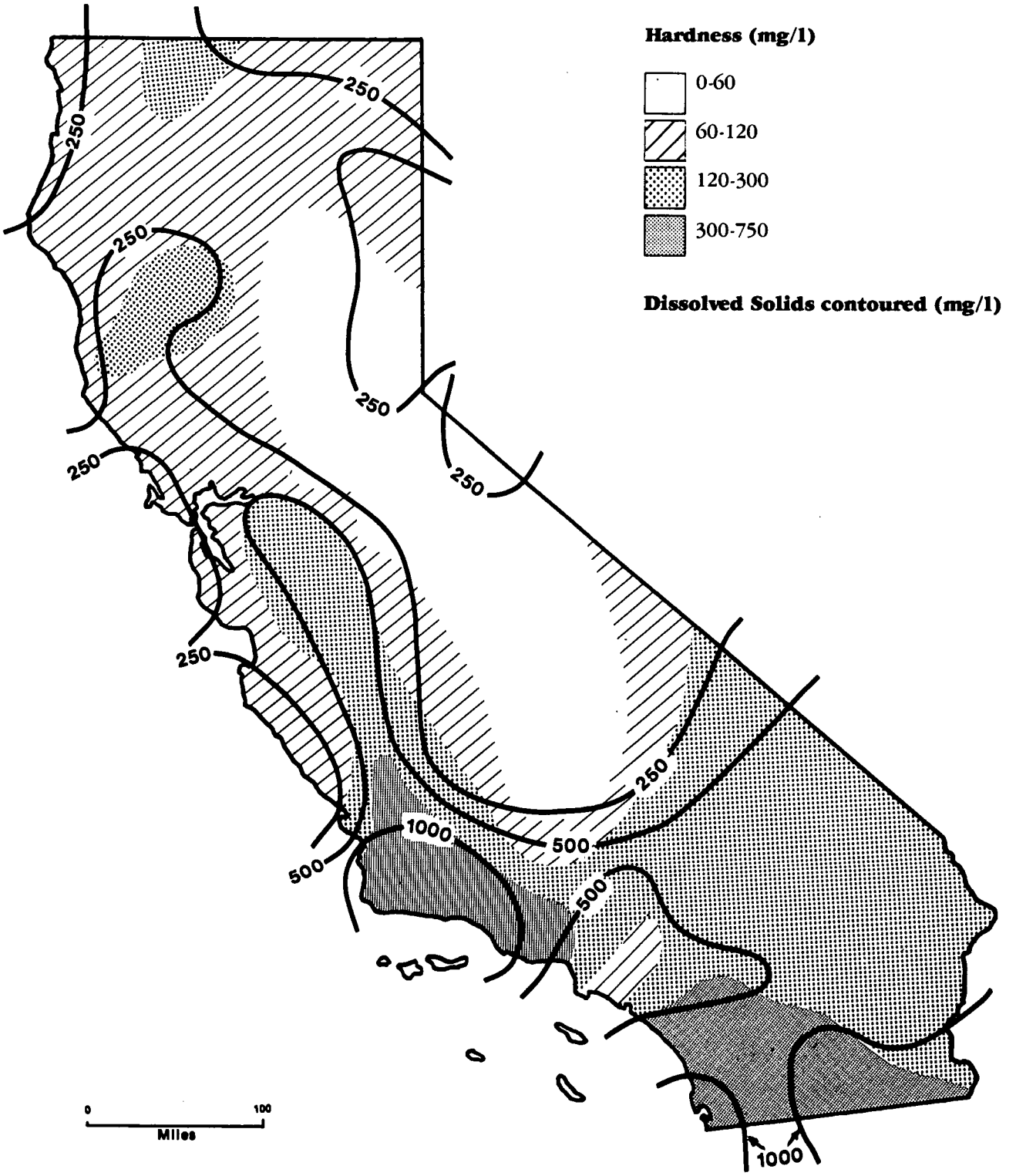
California


Na + K (mg/l)
0-15
15-100
100-200
200-750
Ca + Mg contoured (mg/l)
25
25
50
25
50
100
100
50
50
0
100
Miles

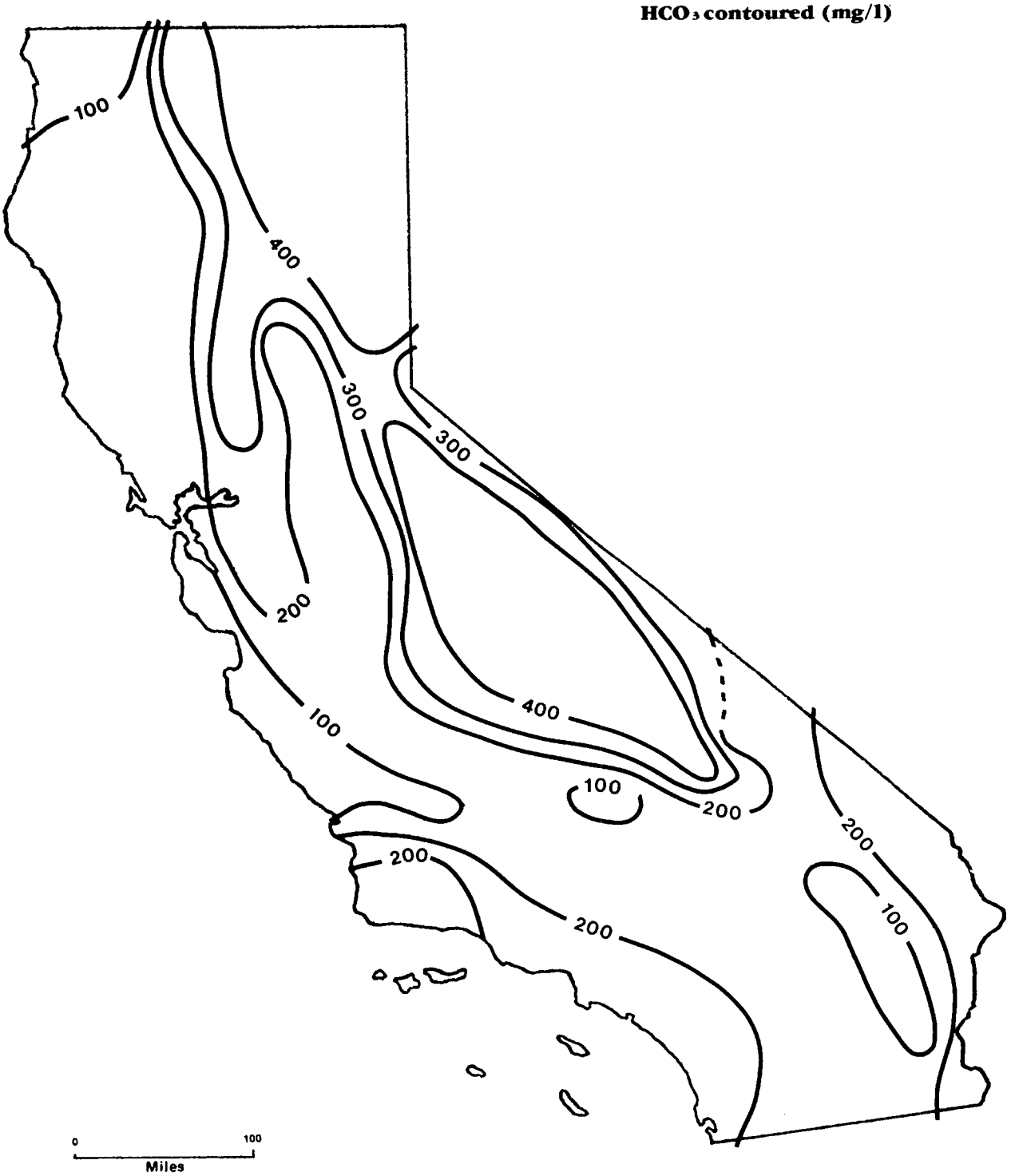
California


Cl (mg/l)
0-10
10-100
100-250
250-1000
SO4 contoured (mg/l)
25
25
75
25
75
250
250
75
250
0
100
Miles

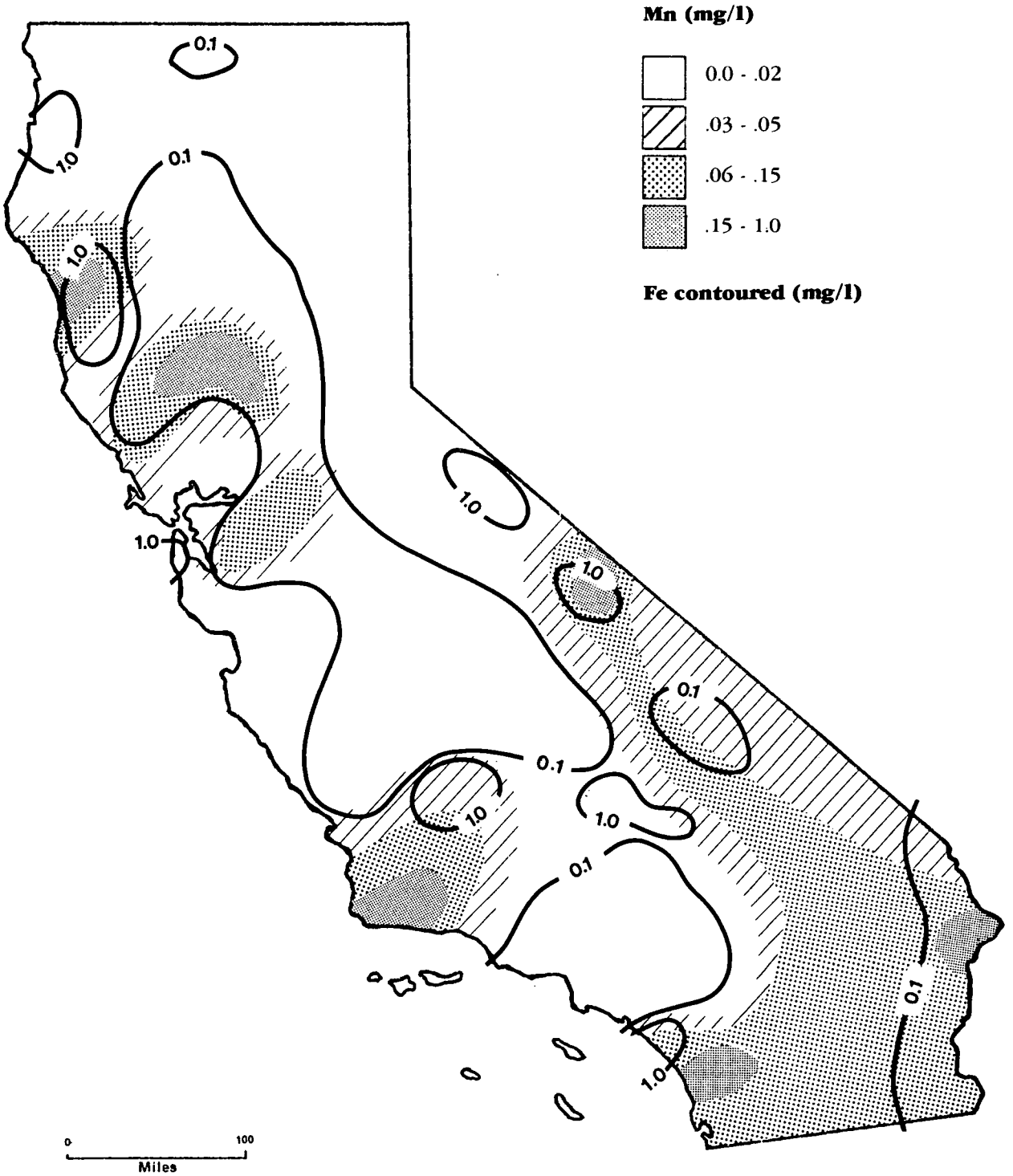
California


Hardness (mg/1)
0-60
60-120
120-300
300-750
Dissolved Solids contoured (mg/1)
250
250
250
250
250
250
250
250
500
500
500
1000
1000
0
100
Miles

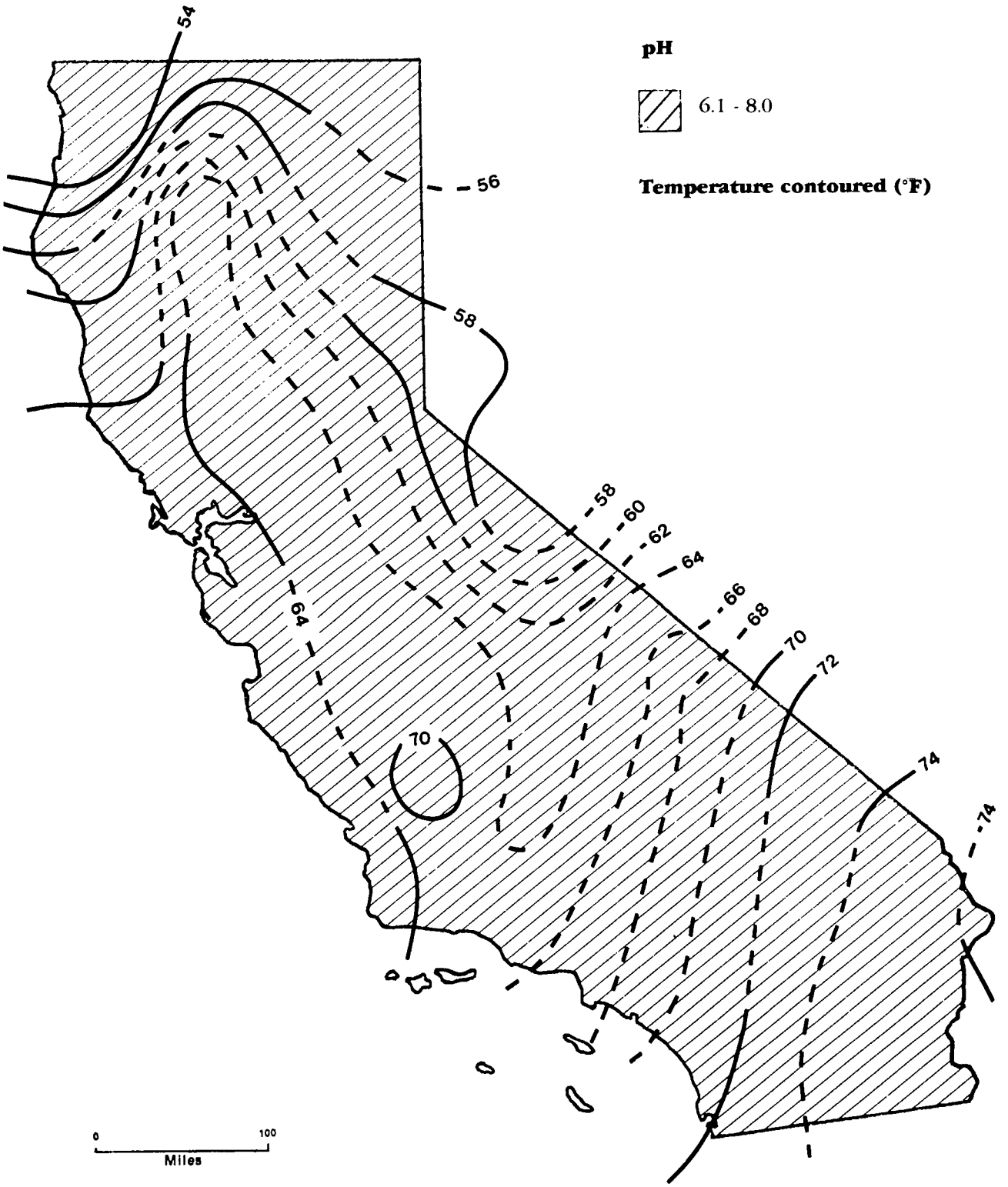
California


HCO₃ contoured (mg/l)
100
400
300
300
200
100
400
100
200
200
200
200
100
0
100
Miles

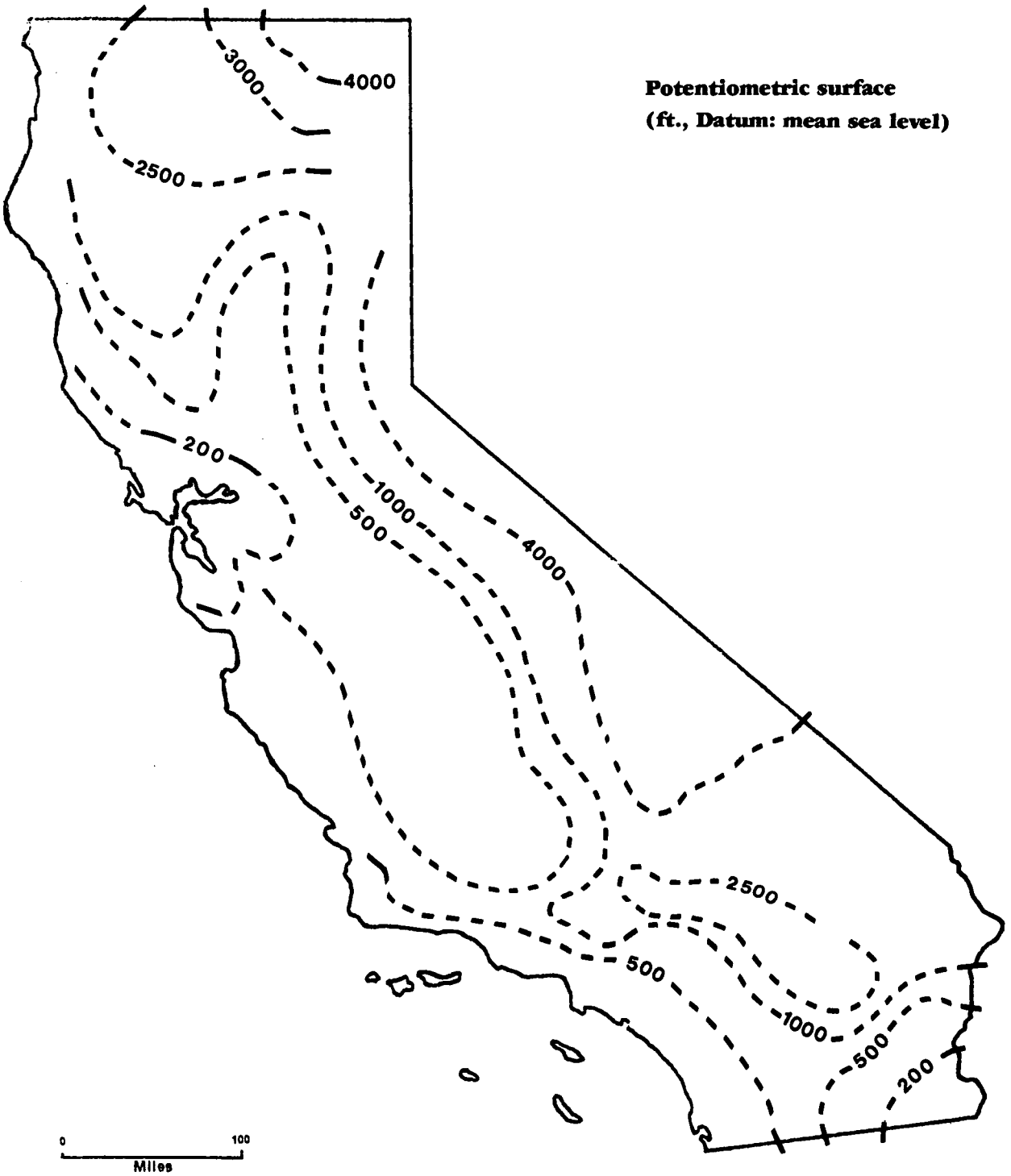
California



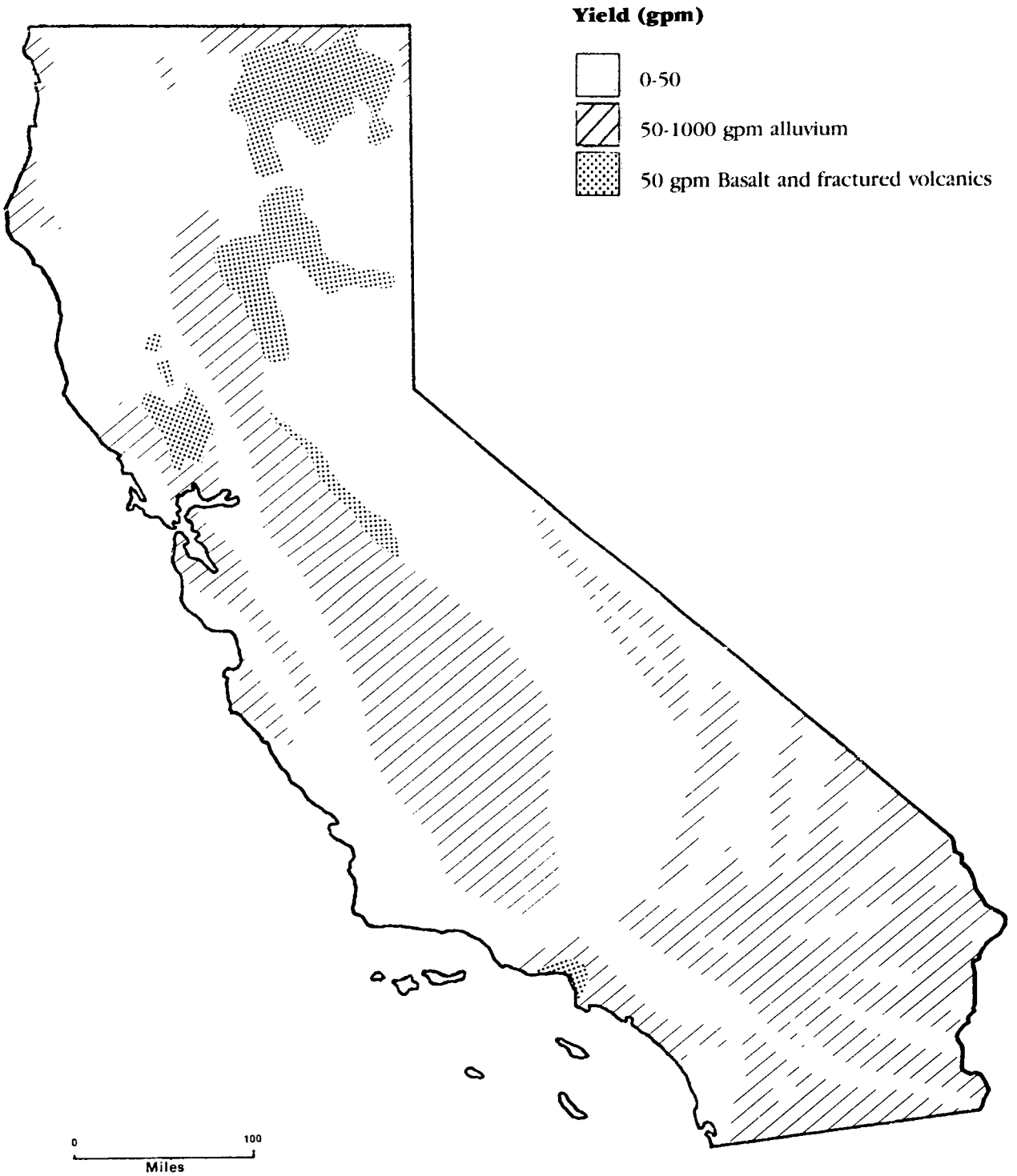
California


pH
6.1 - 8.0
Temperature contoured (°F)
54
56
58
58
60
62
64
66
68
70
72
74
74
64
70
0
100
Miles

California


Potentiometric surface
(ft., Datum: mean sea level)
3000
4000
2500
200
1000
500
4000
2500
500
1000
500
200
0
100
Miles

California


Yield (gpm)
0-50
50-1000 gpm alluvium
50 gpm Basalt and fractured volcanics
0
100
Miles

Colorado

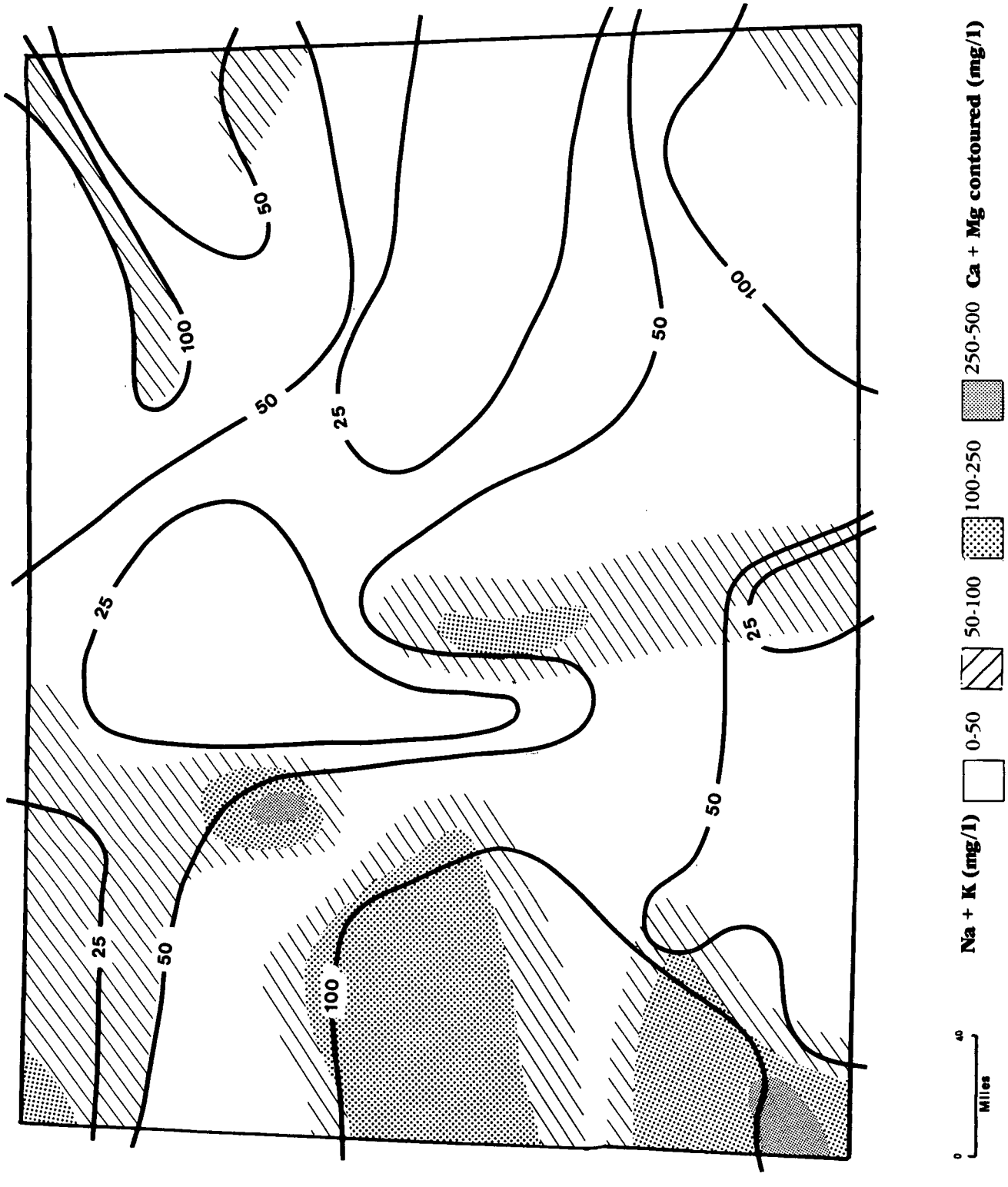


Plate 33

Colorado

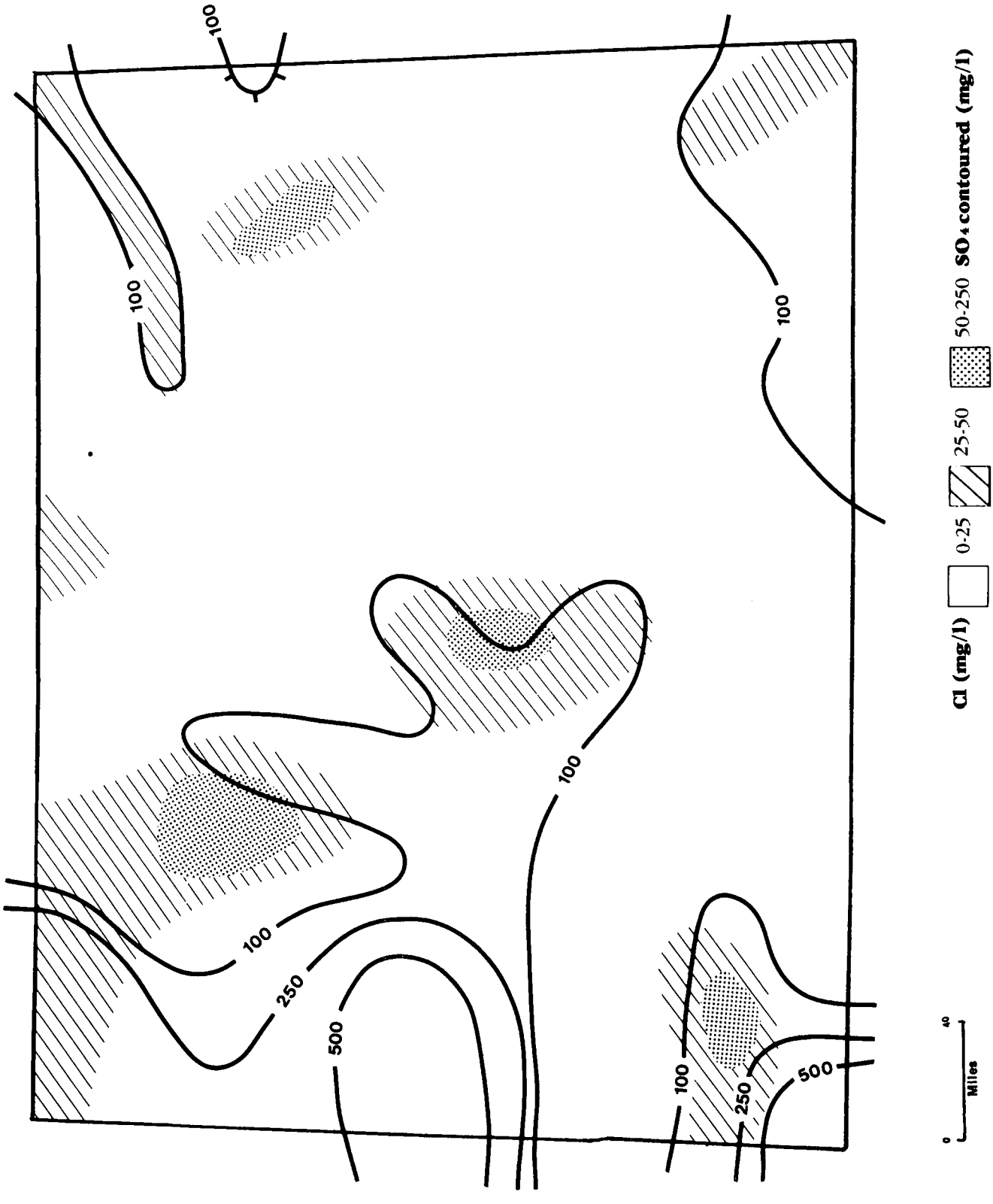
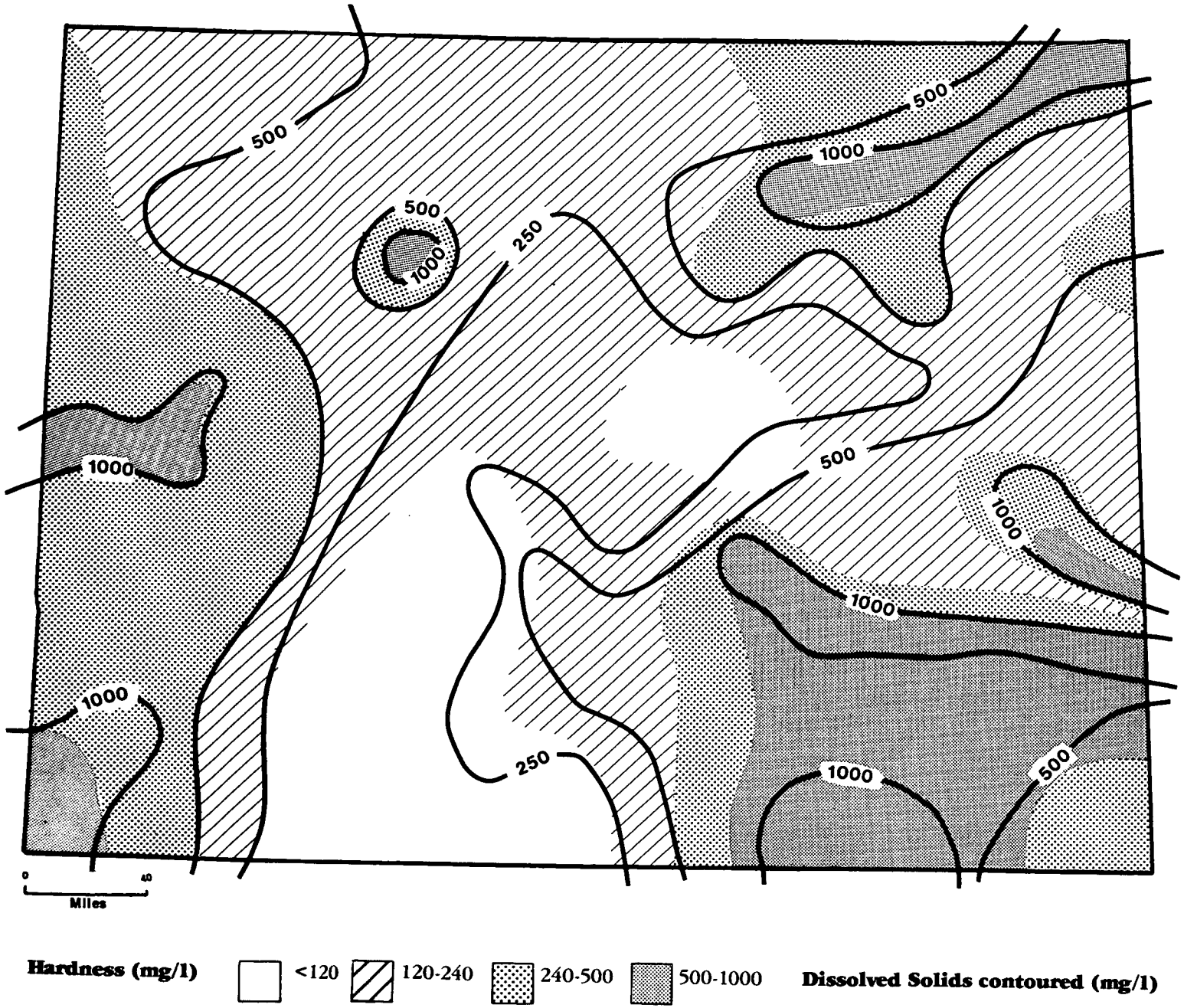
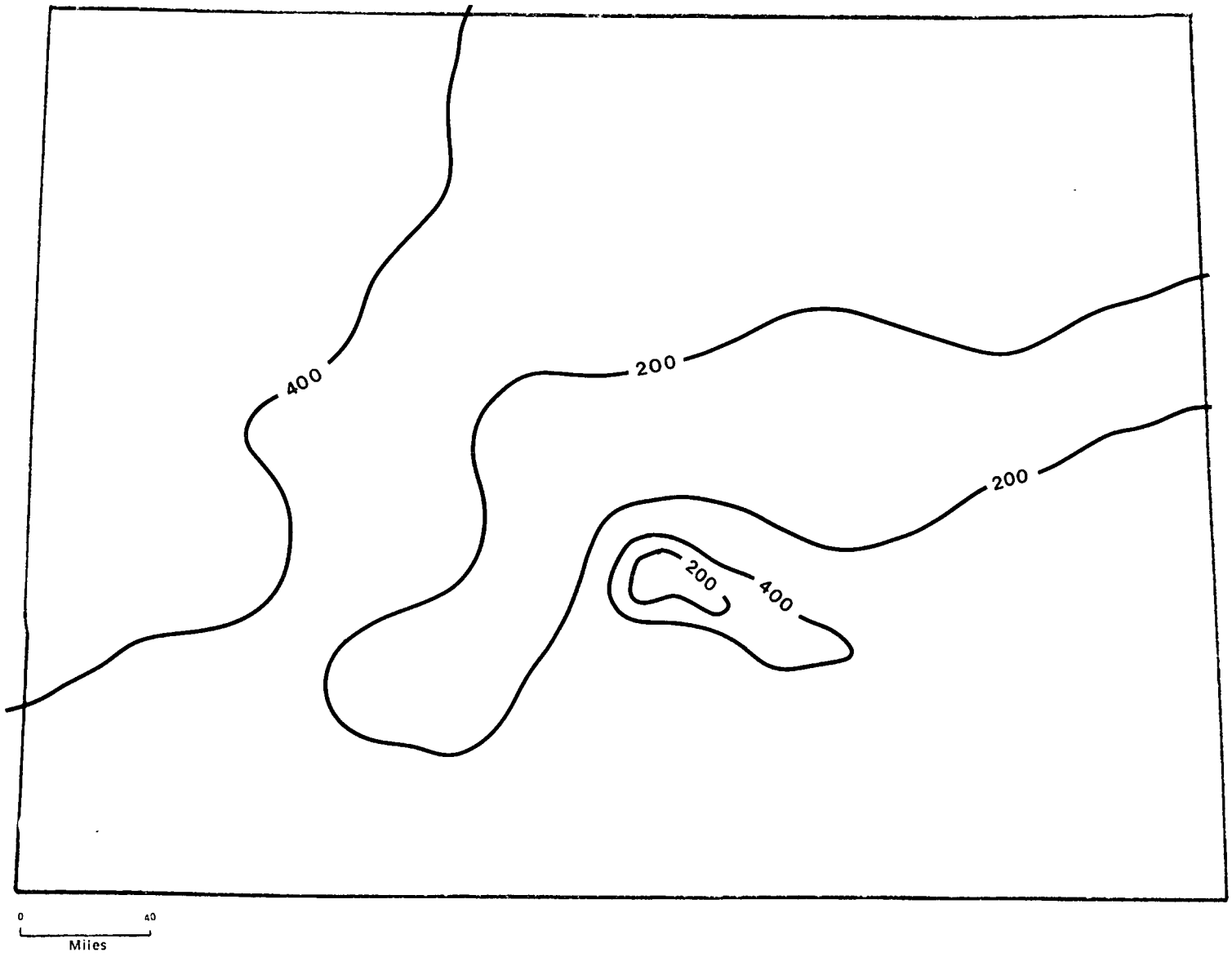


Plate 34

Colorado

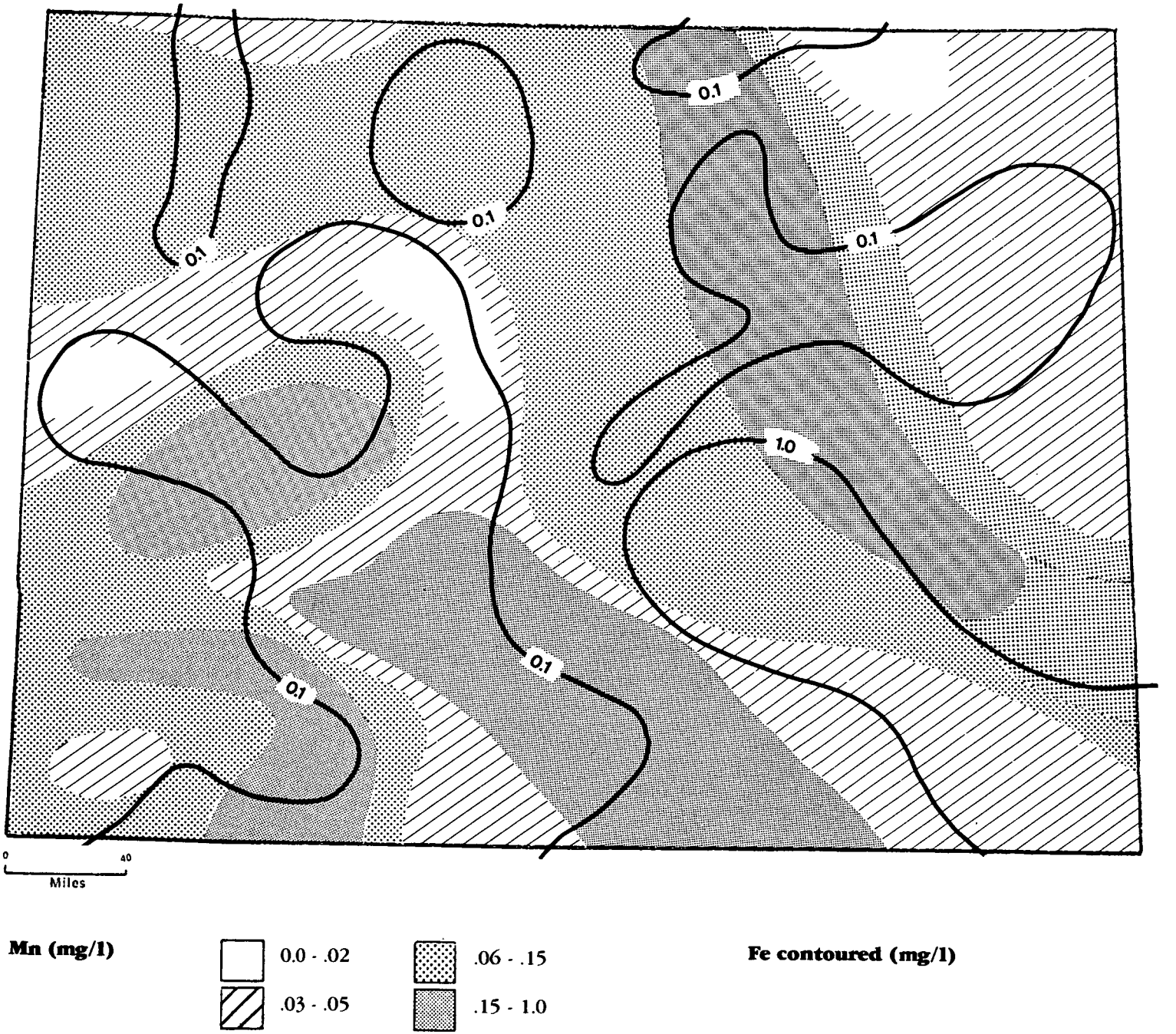

500
500
1000
500
1000
250
1000
500
1000
1000
1000
250
1000
500
0
40
Miles
Hardness (mg/l)
<120
120-240
240-500
500-1000
Dissolved Solids contoured (mg/l)

Colorado

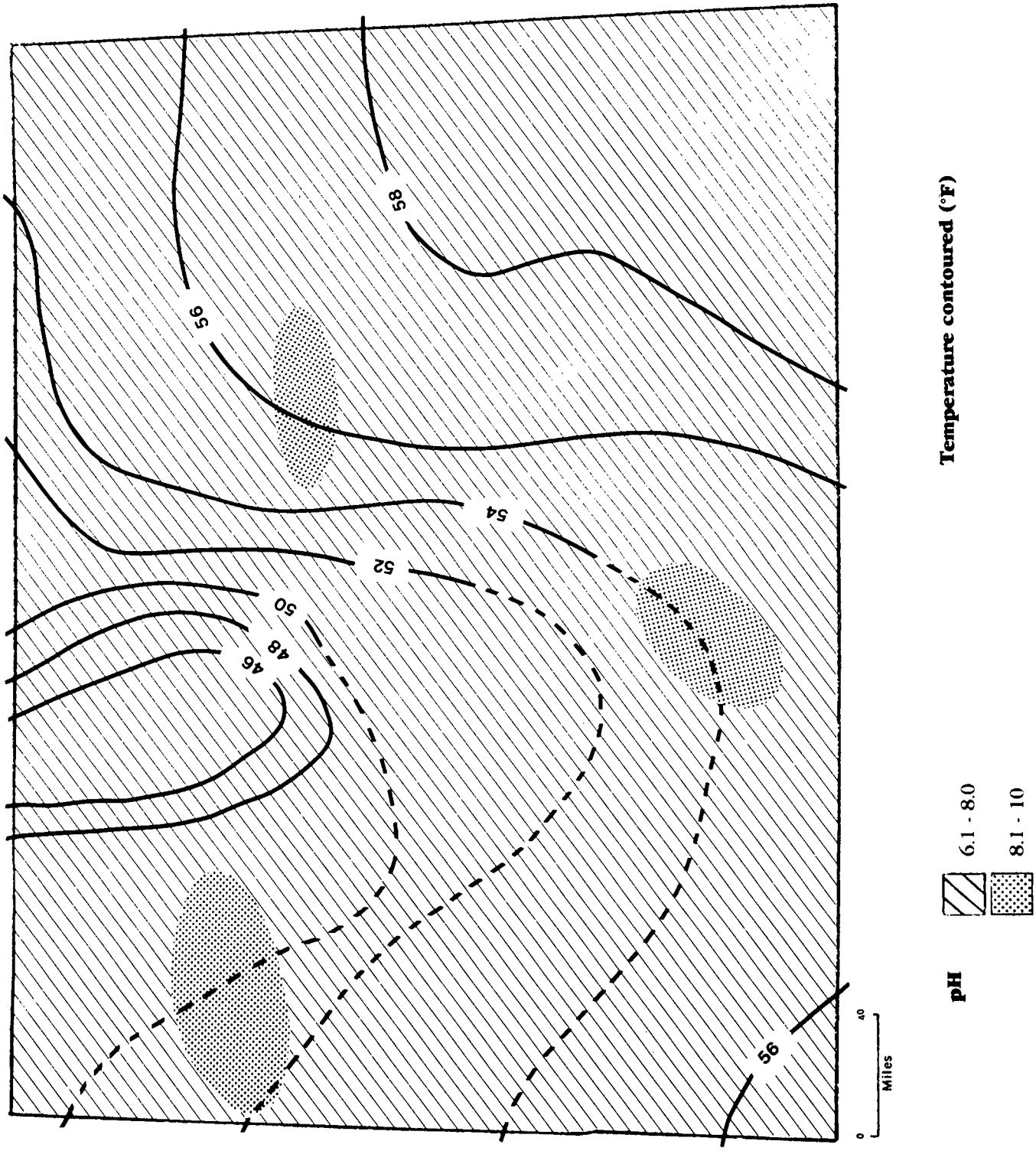


HCO_3 contoured (mg/l)

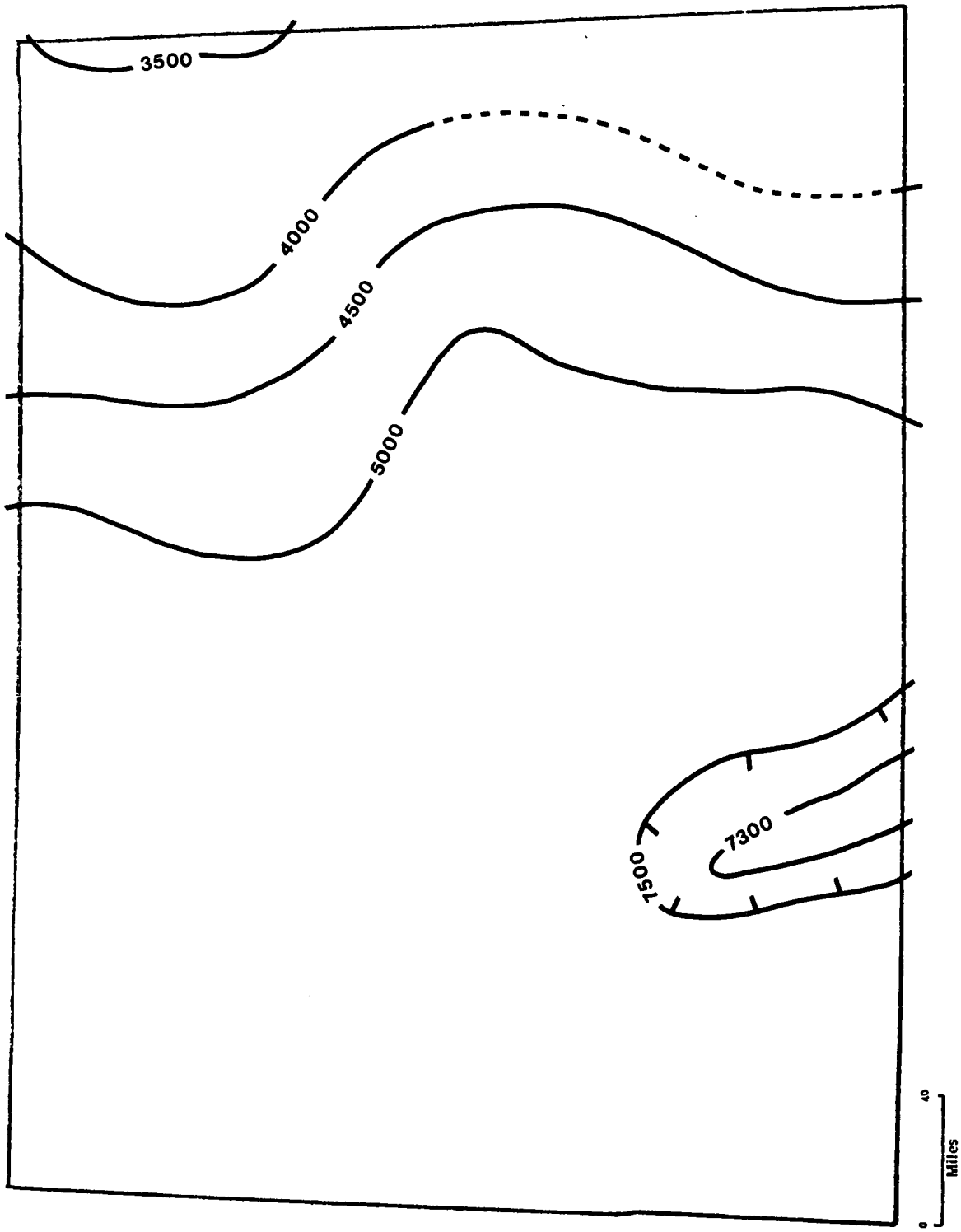
Colorado


0.1
0.1
0.1
0.1
0.1
0.1
1.0
0
40
Miles
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)

Colorado

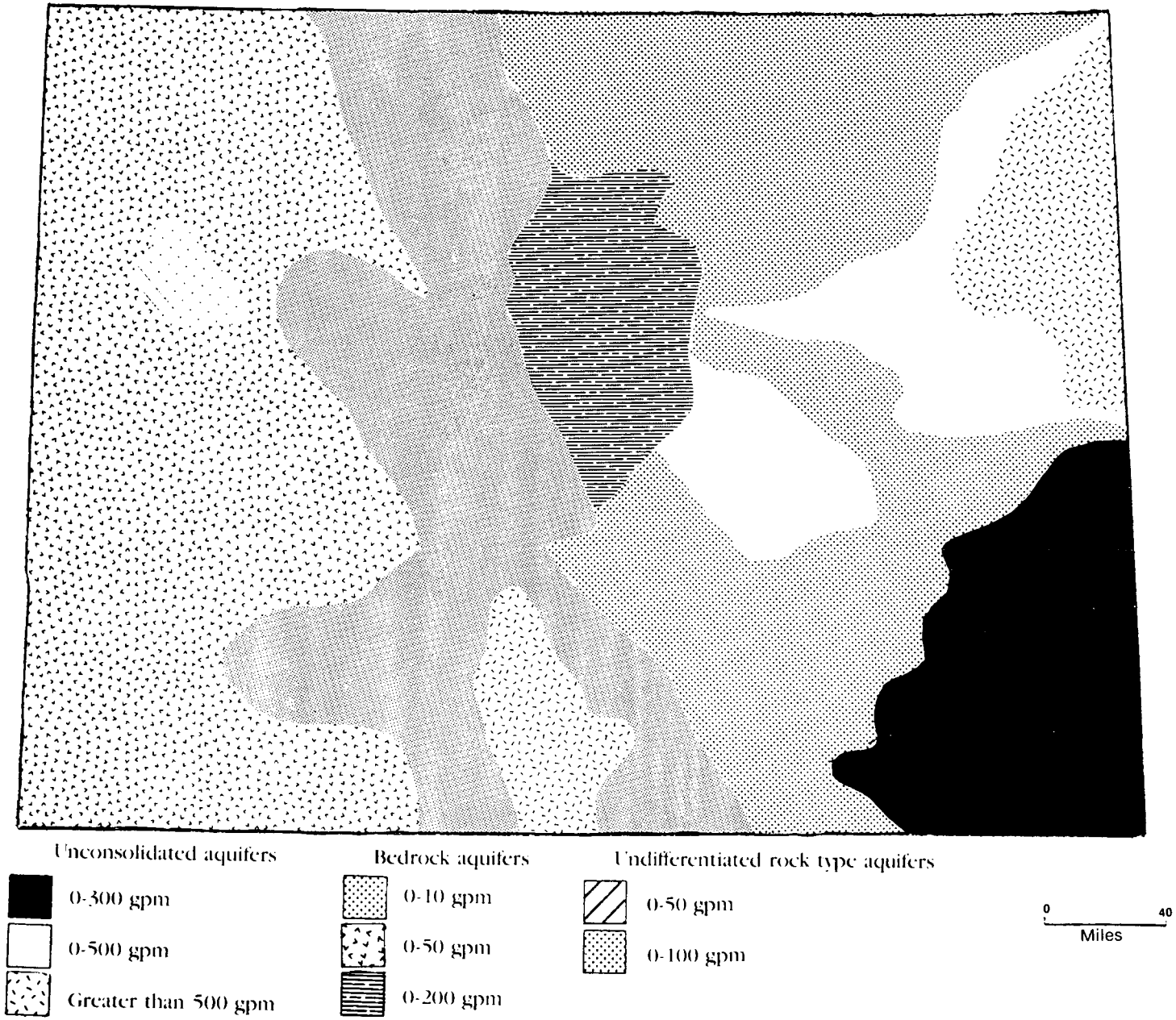

46
48
50
52
54
56
58
56
0
40
Miles
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)

Colorado



Potentiometric surface (ft., Datum: mean sea level)

Colorado


Unconsolidated aquifers
0-300 gpm
0-500 gpm
Greater than 500 gpm
Bedrock aquifers
0-10 gpm
0-50 gpm
0-200 gpm
Undifferentiated rock type aquifers
0-50 gpm
0-100 gpm
0
40
Miles

Connecticut

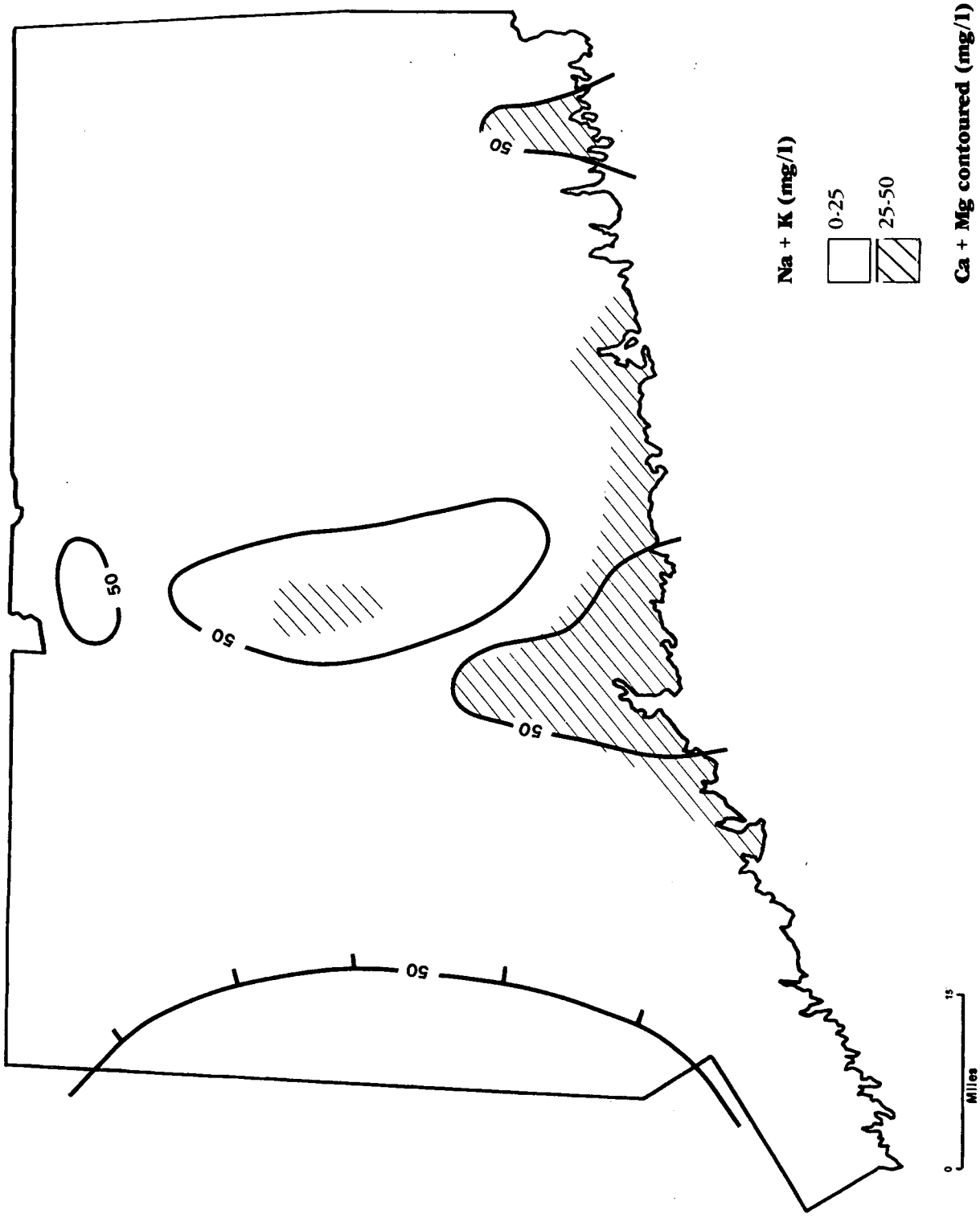


Plate 41

Connecticut

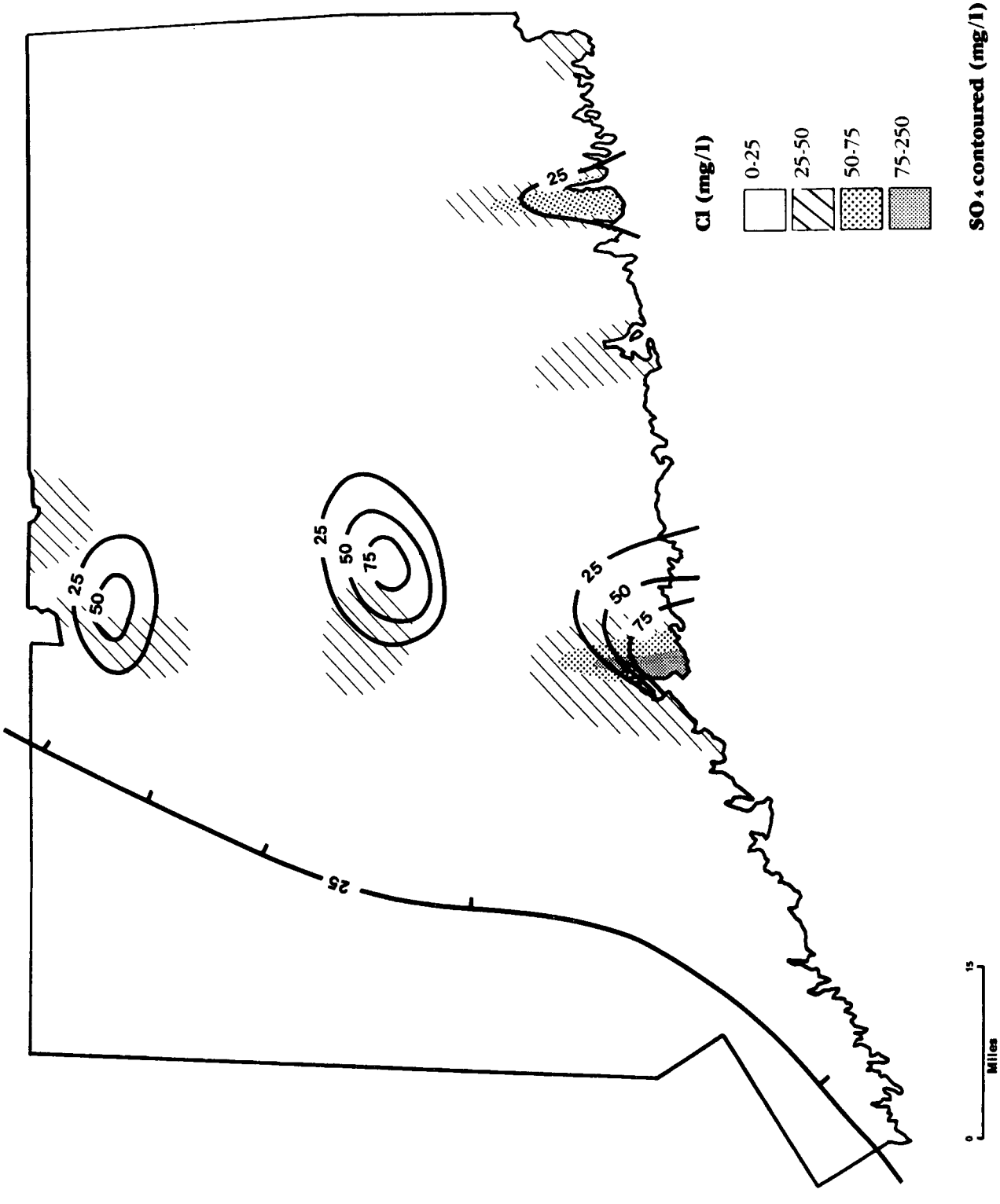
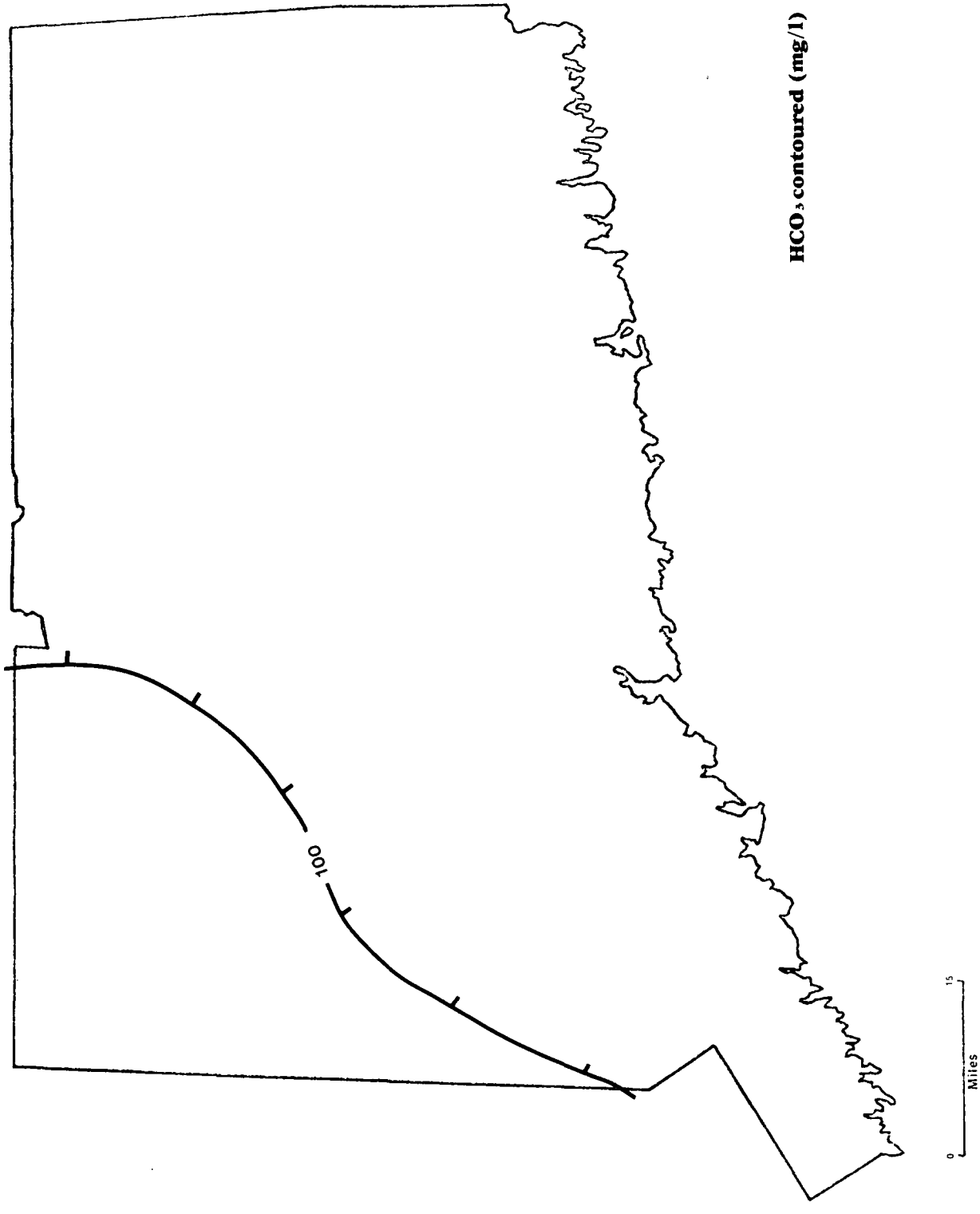
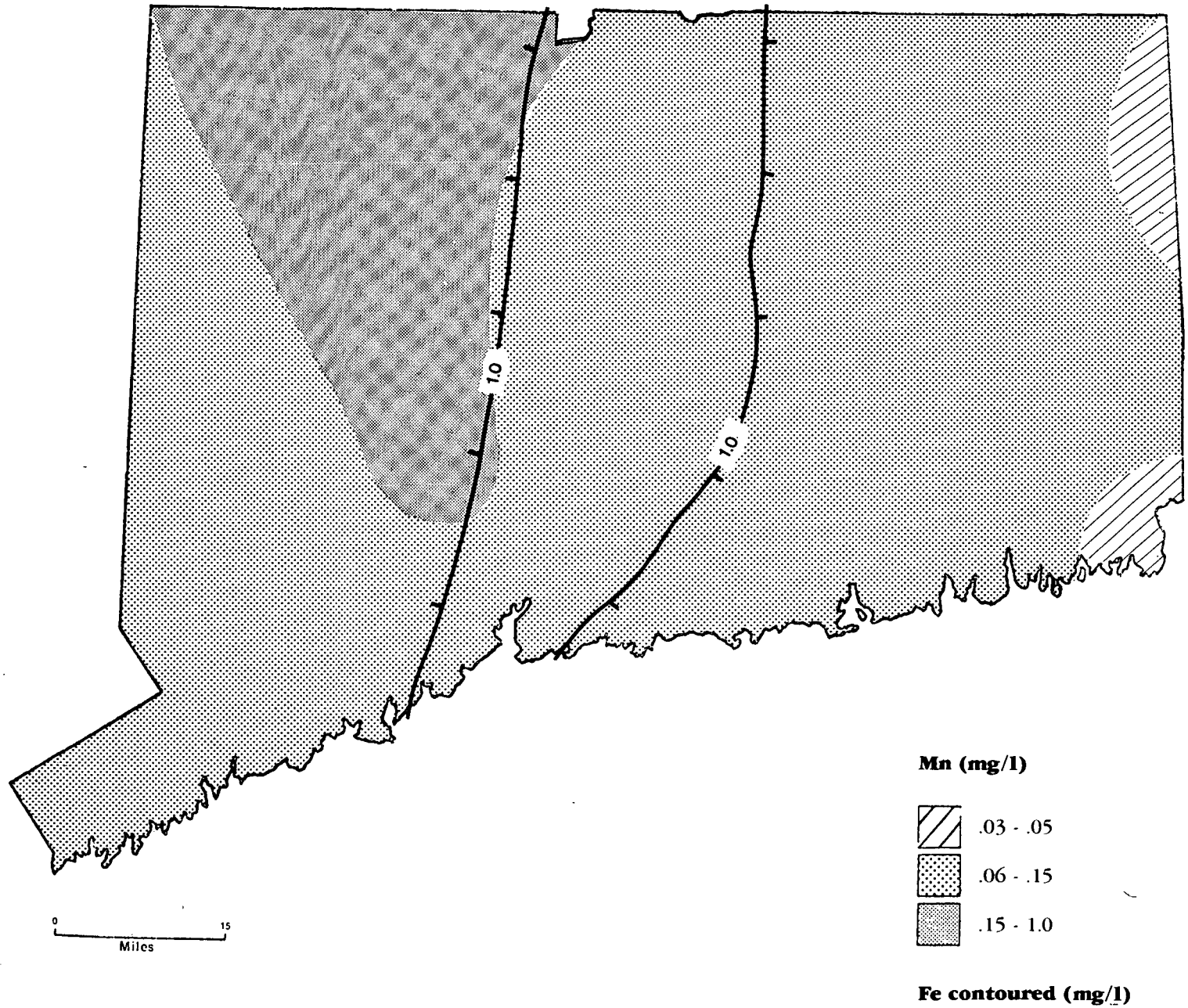


Plate 42

Connecticut



Connecticut



Connecticut

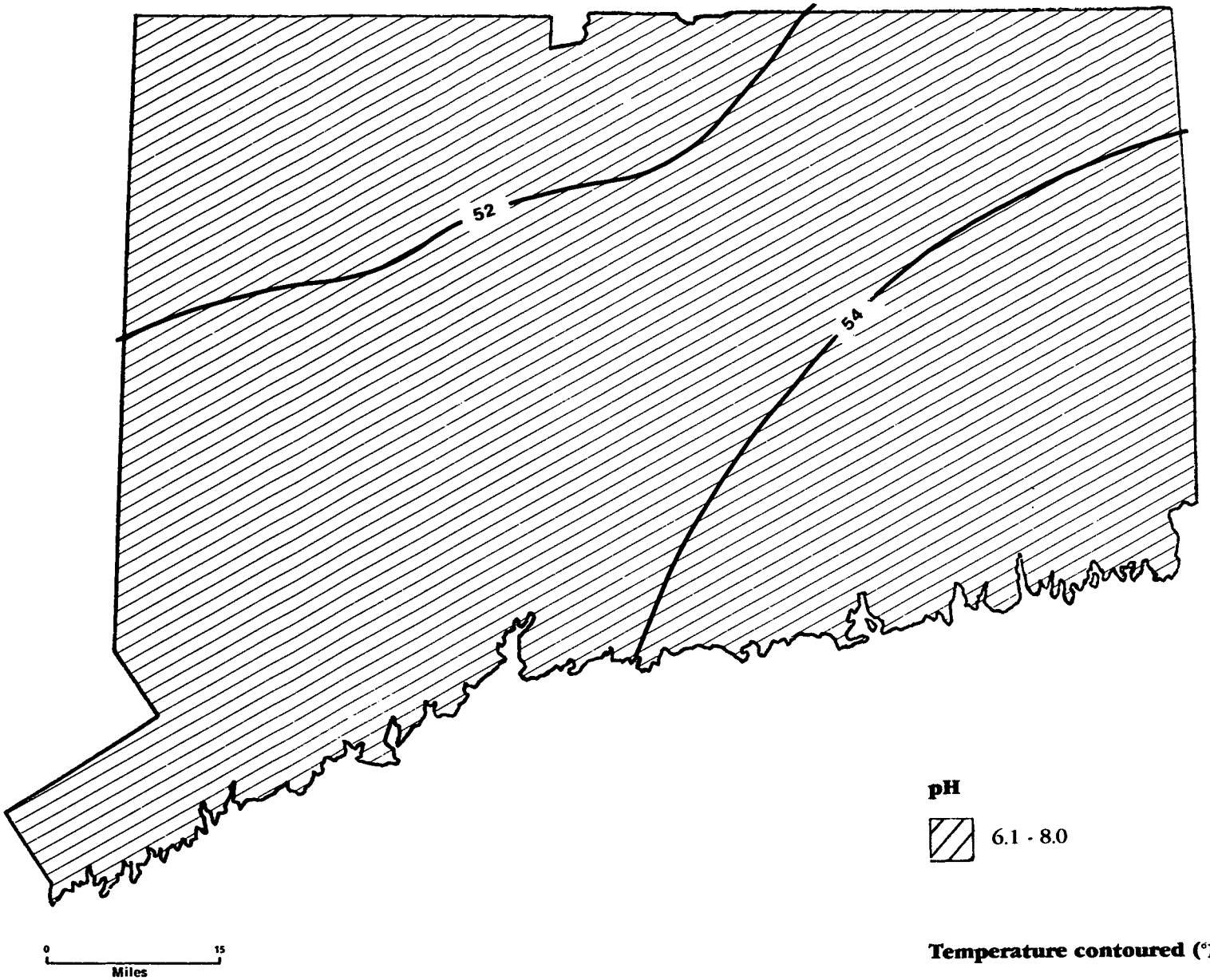
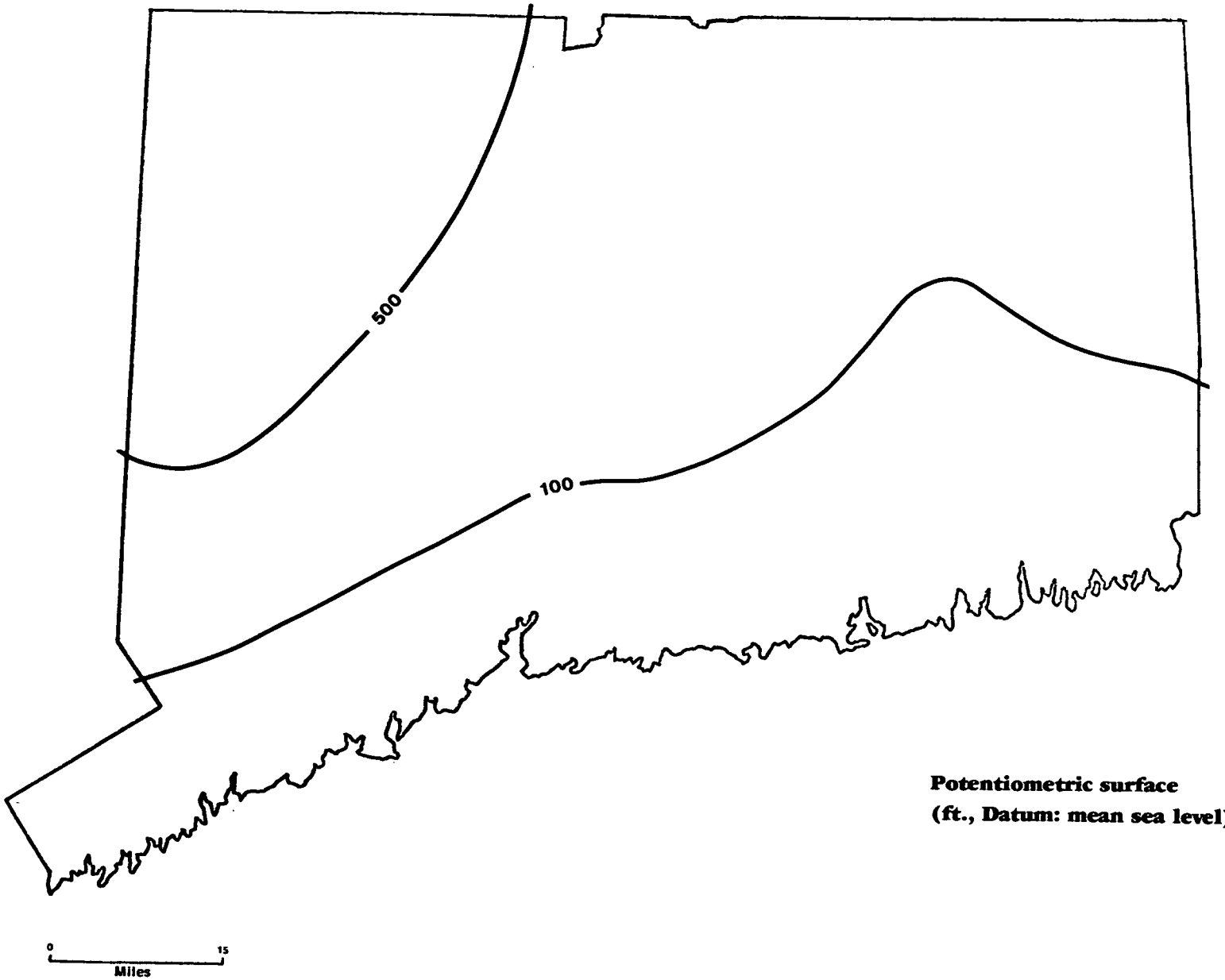


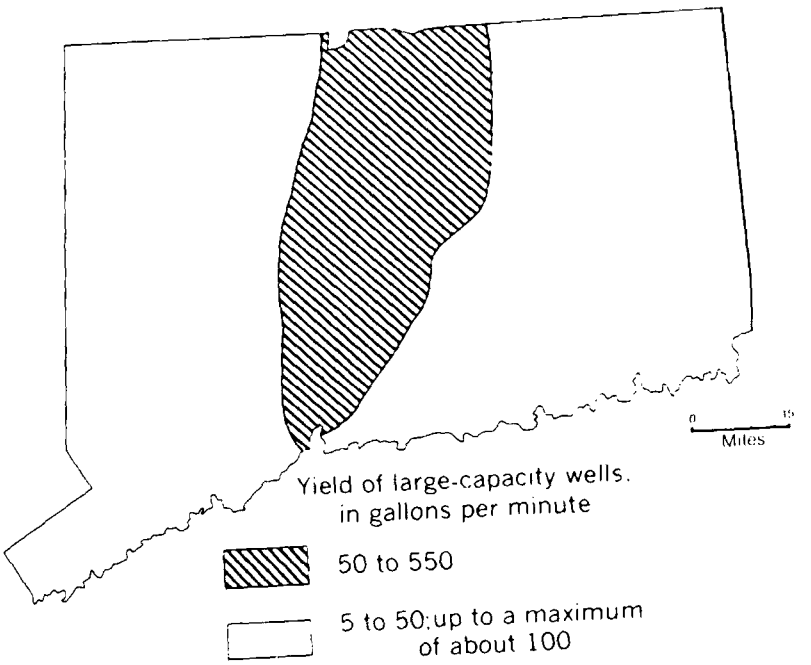
Plate 46

Connecticut

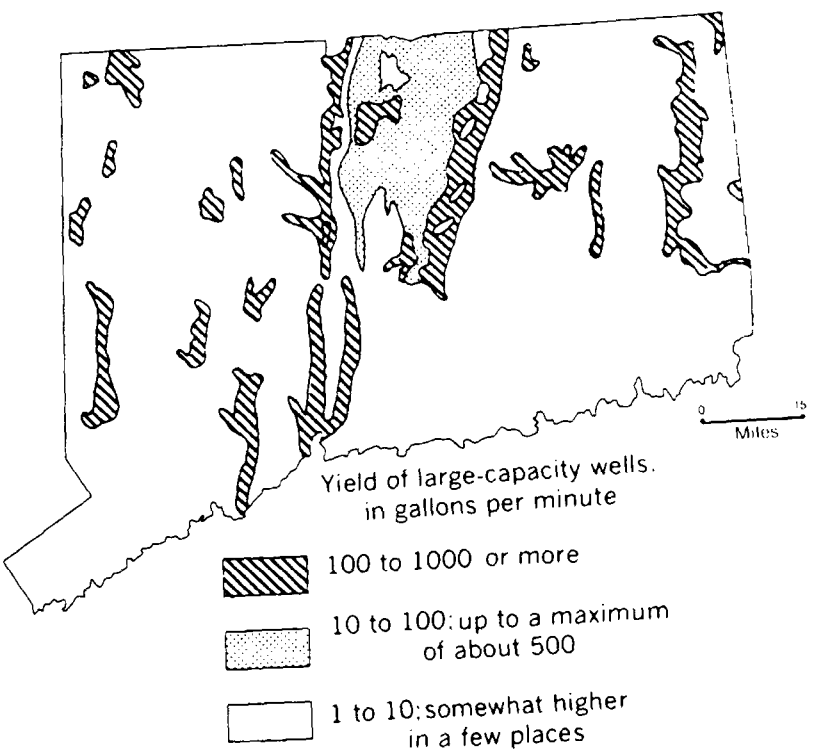


Potentiometric surface
(ft., Datum: mean sea level)

Connecticut



AVAILABILITY OF GROUND WATER FROM BEDROCK



AVAILABILITY OF GROUND WATER FROM UNCONSOLIDATED DEPOSITS

Delaware

Na + K (mg/l)

- 0-10
- 10-25
- 25-250

Ca + Mg contoured (mg/l)

0 15
Miles

Delaware

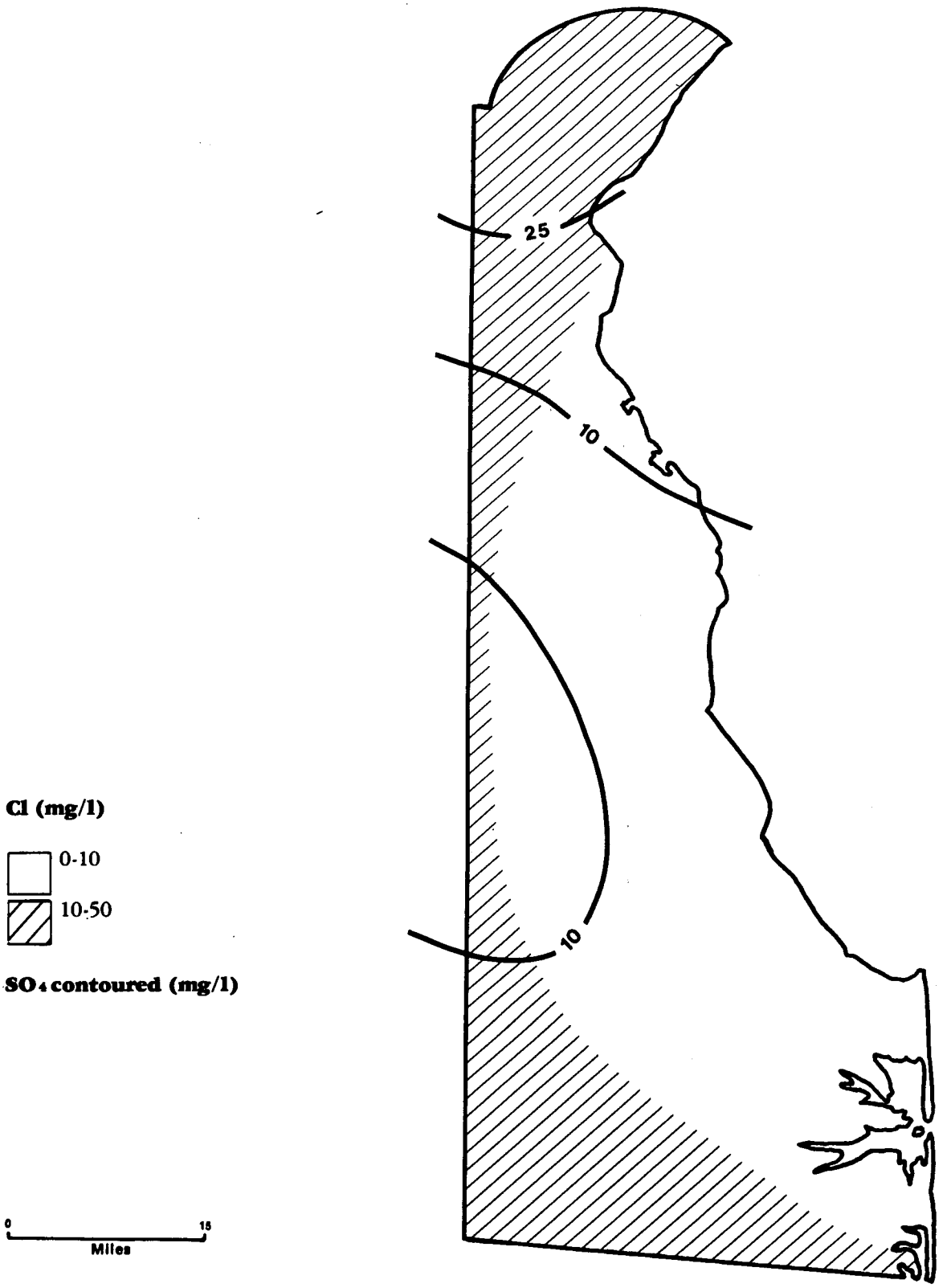


Plate 50

Delaware

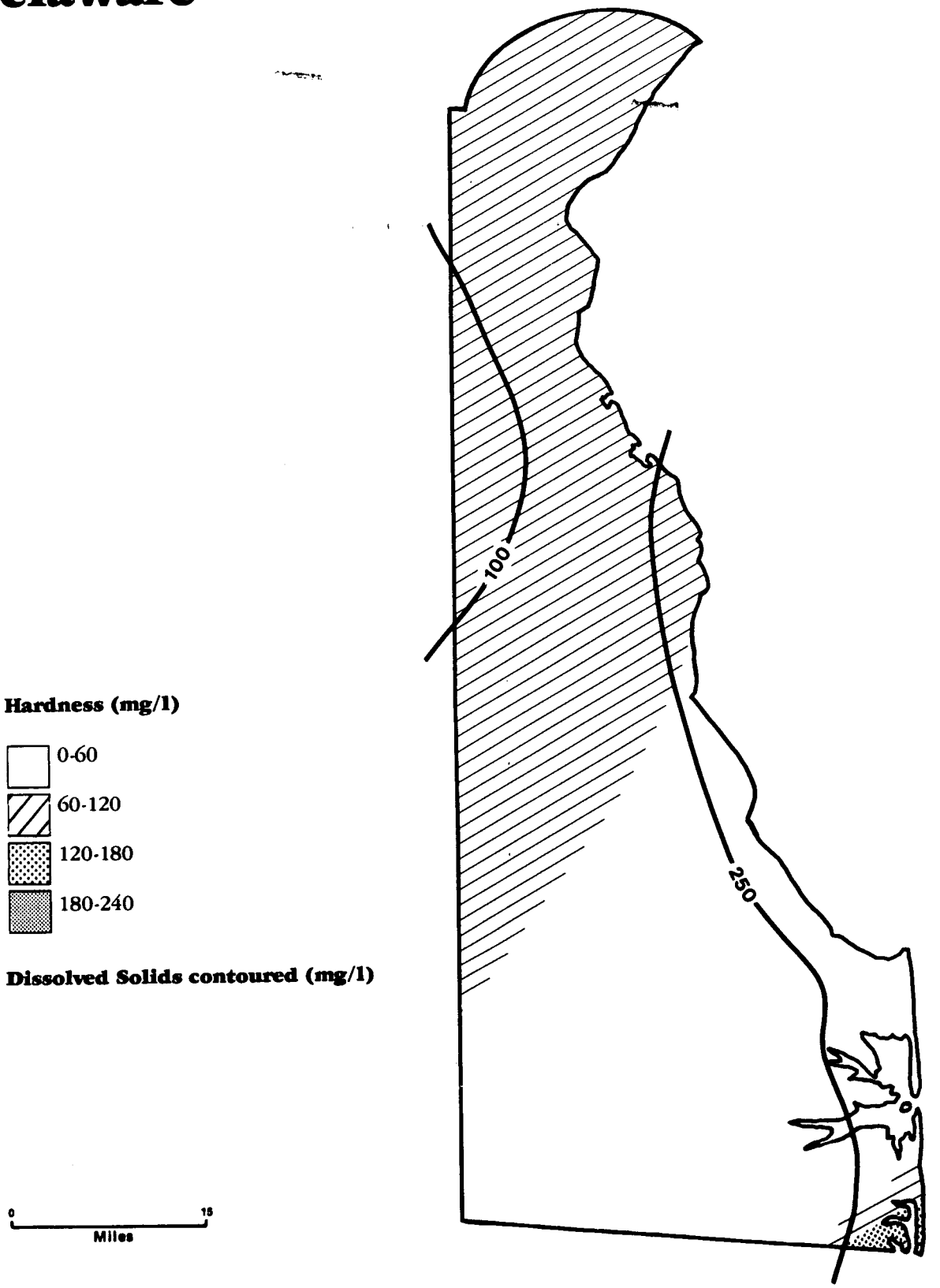
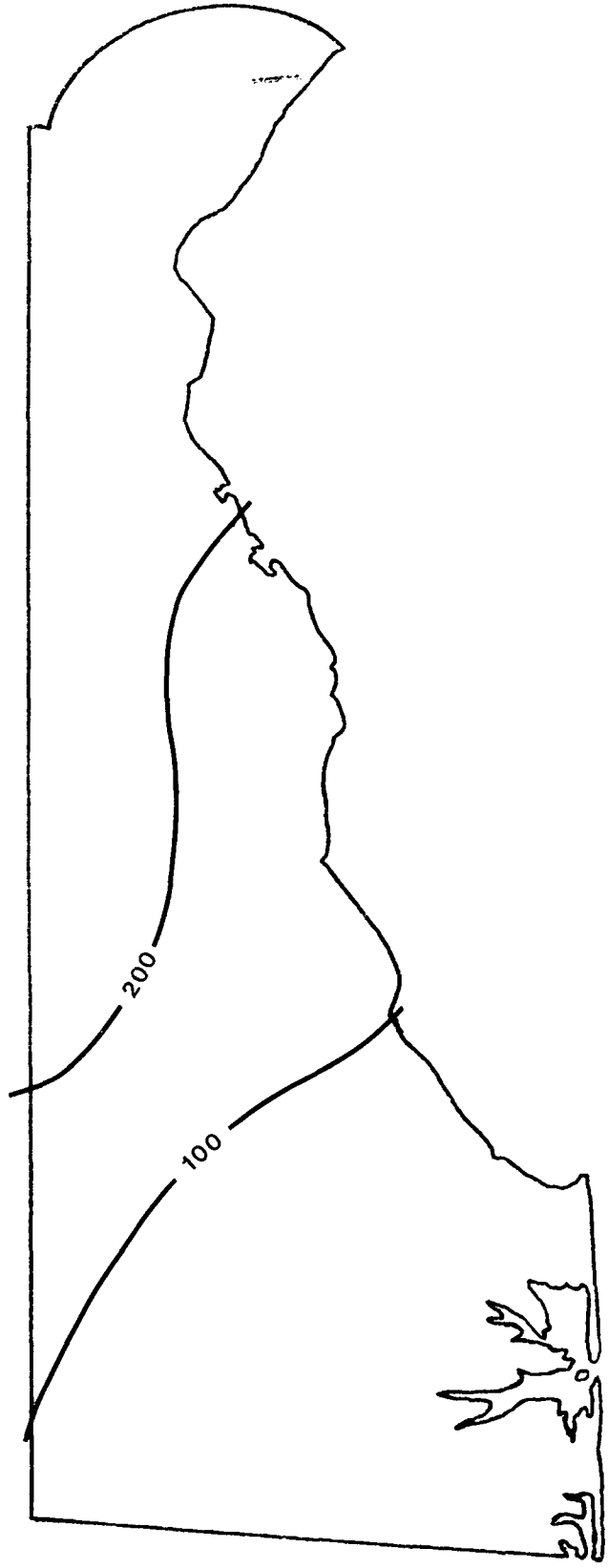


Plate 51

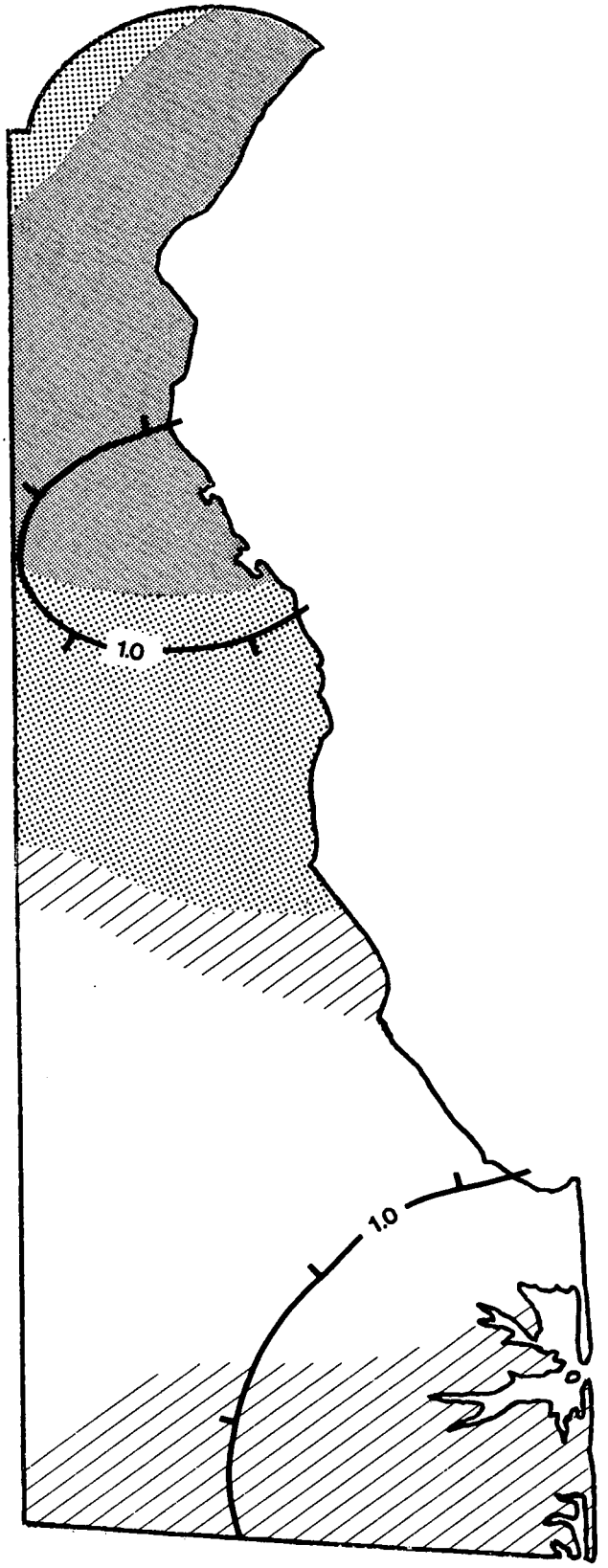
Delaware

HCO_3 contoured (mg/l)



0 15
Miles

Delaware



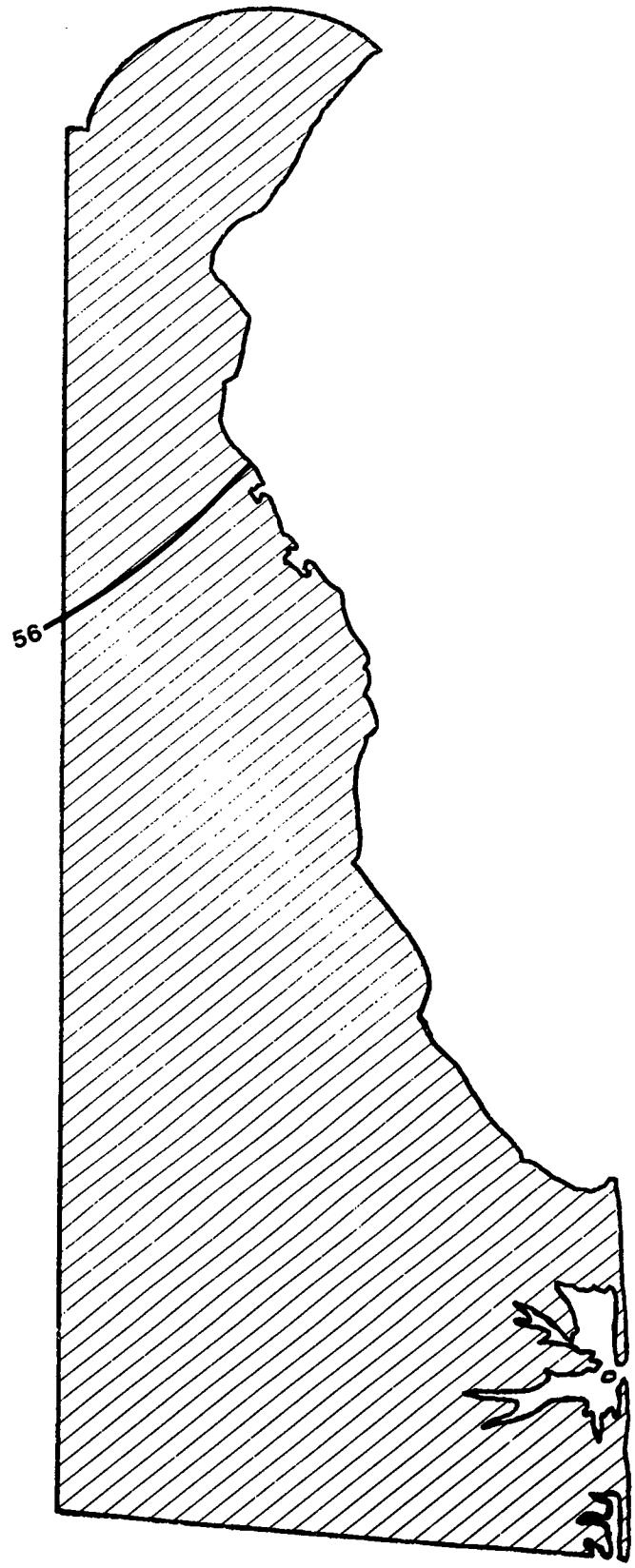
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

0 15
Miles

Delaware



pH

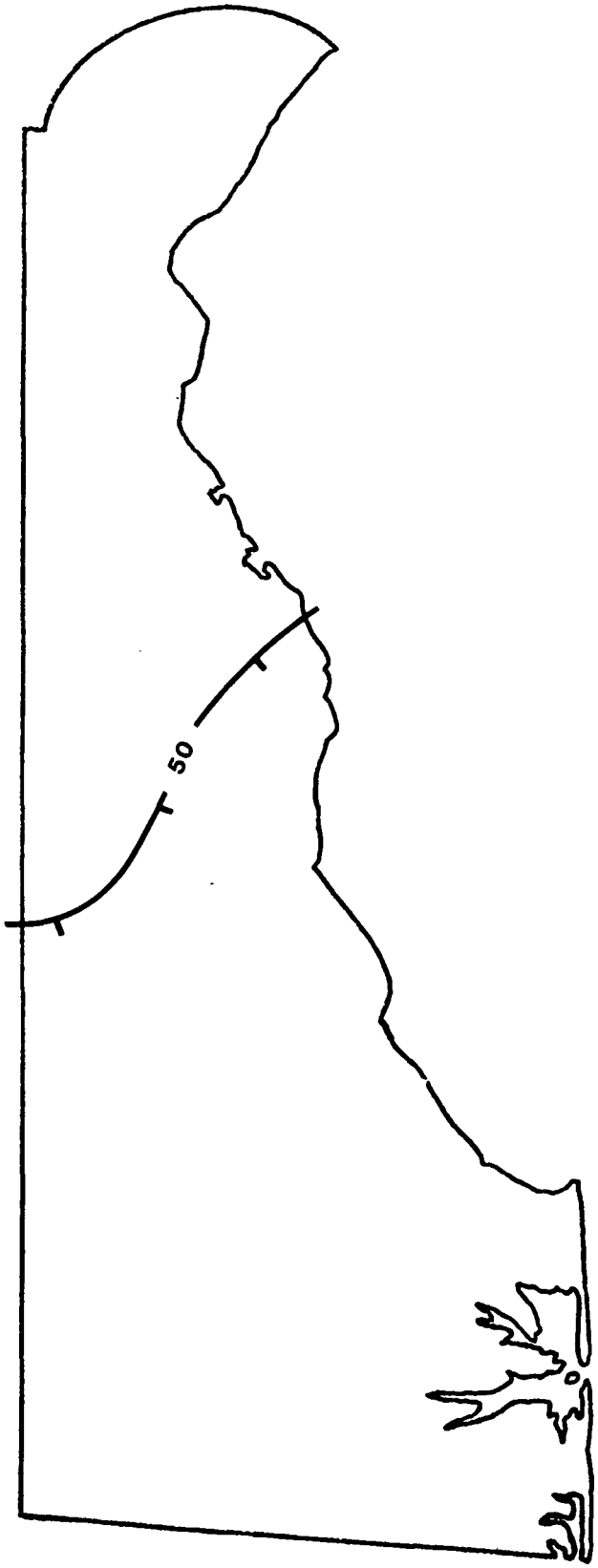
6.1 - 8.0

Temperature contoured (°F)

0 15
Miles

Delaware

Potentiometric surface
(ft., Datum: mean sea level)

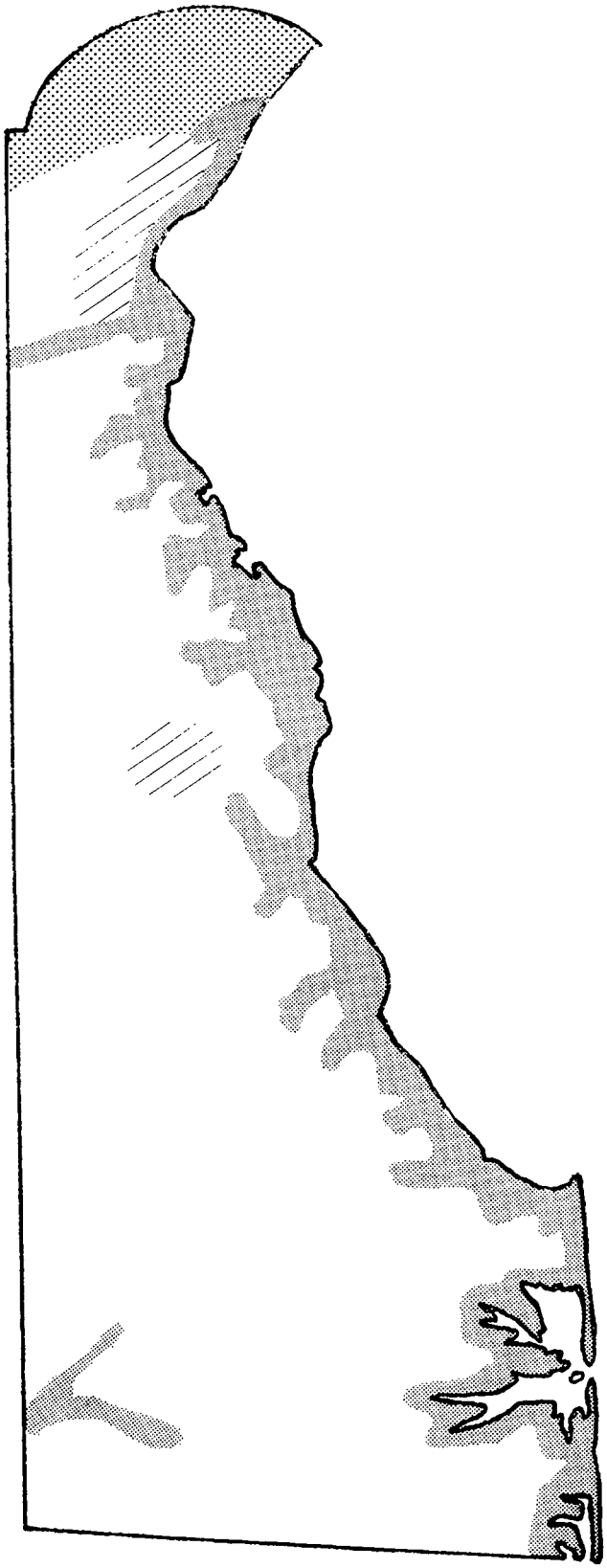


0 15
Miles

Delaware

Yield (gpm)

- 50-500 gpm, adequate or abundant water
- 50-500 gpm, present withdrawals approaching or exceeding recharge
- Less than 10 gpm, meager ground water in crystalline rocks
- 50-500 gpm, possible salt water encroachment



0 15
Miles

Florida

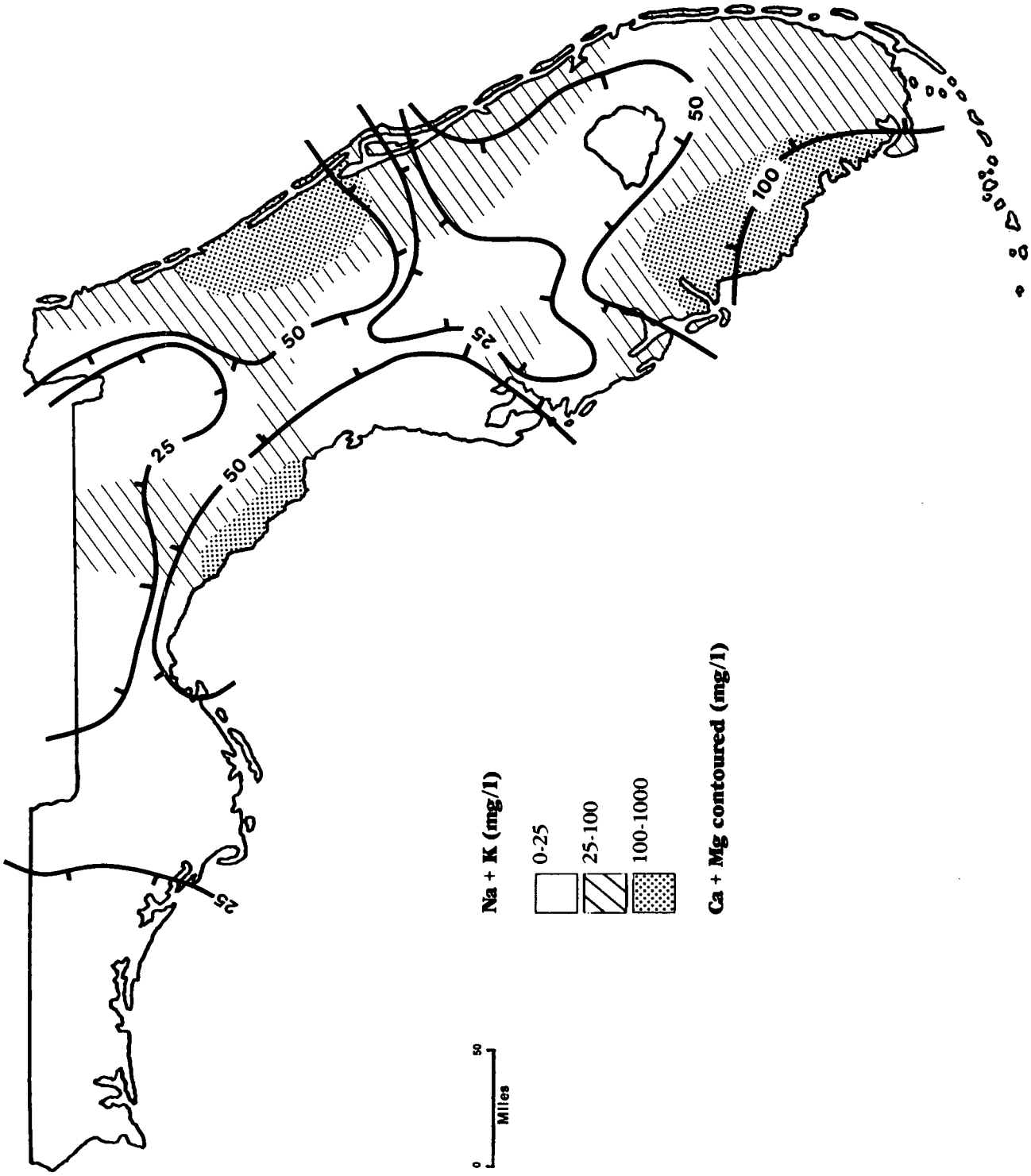


Plate 57

Florida

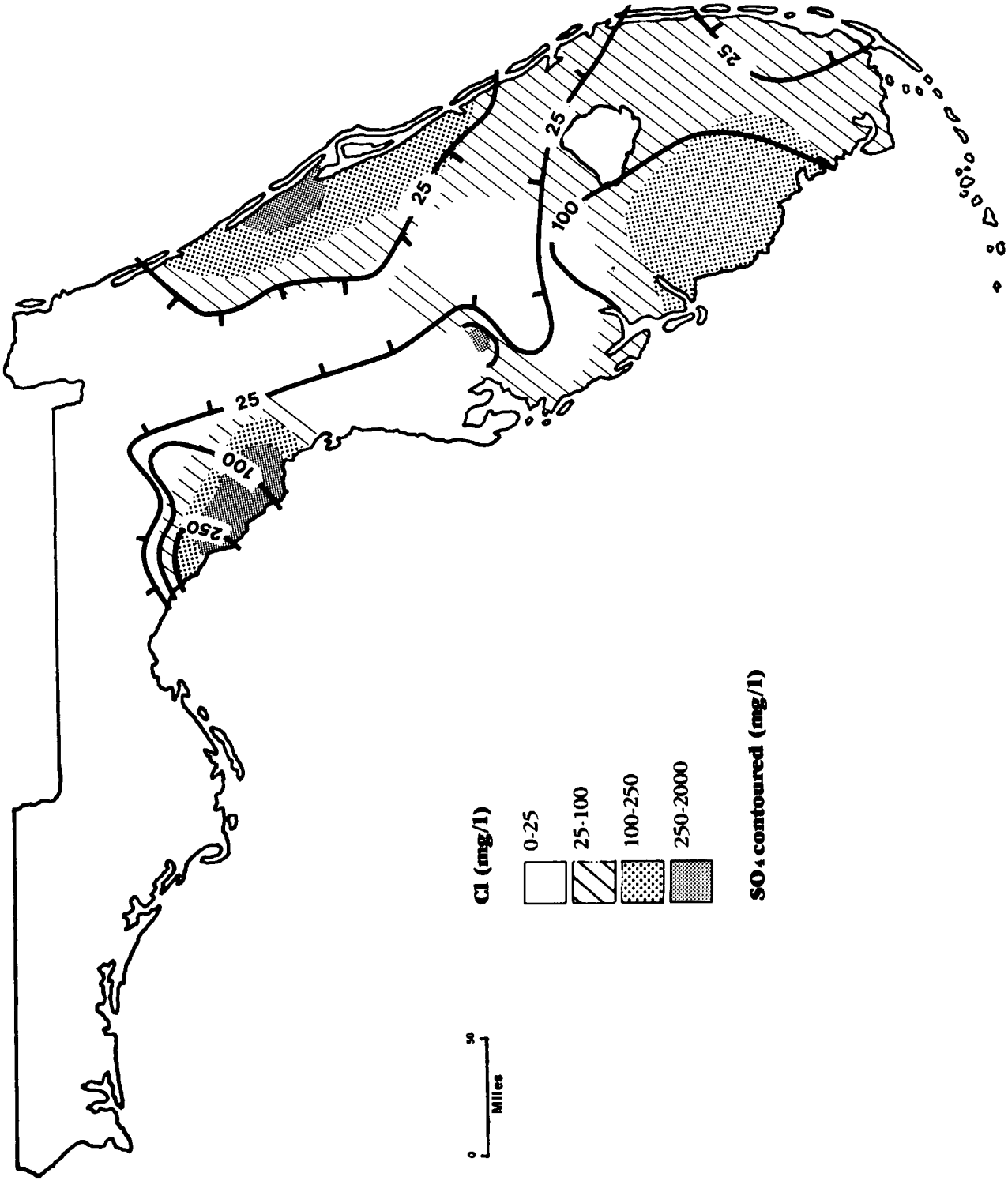


Plate 58

Florida

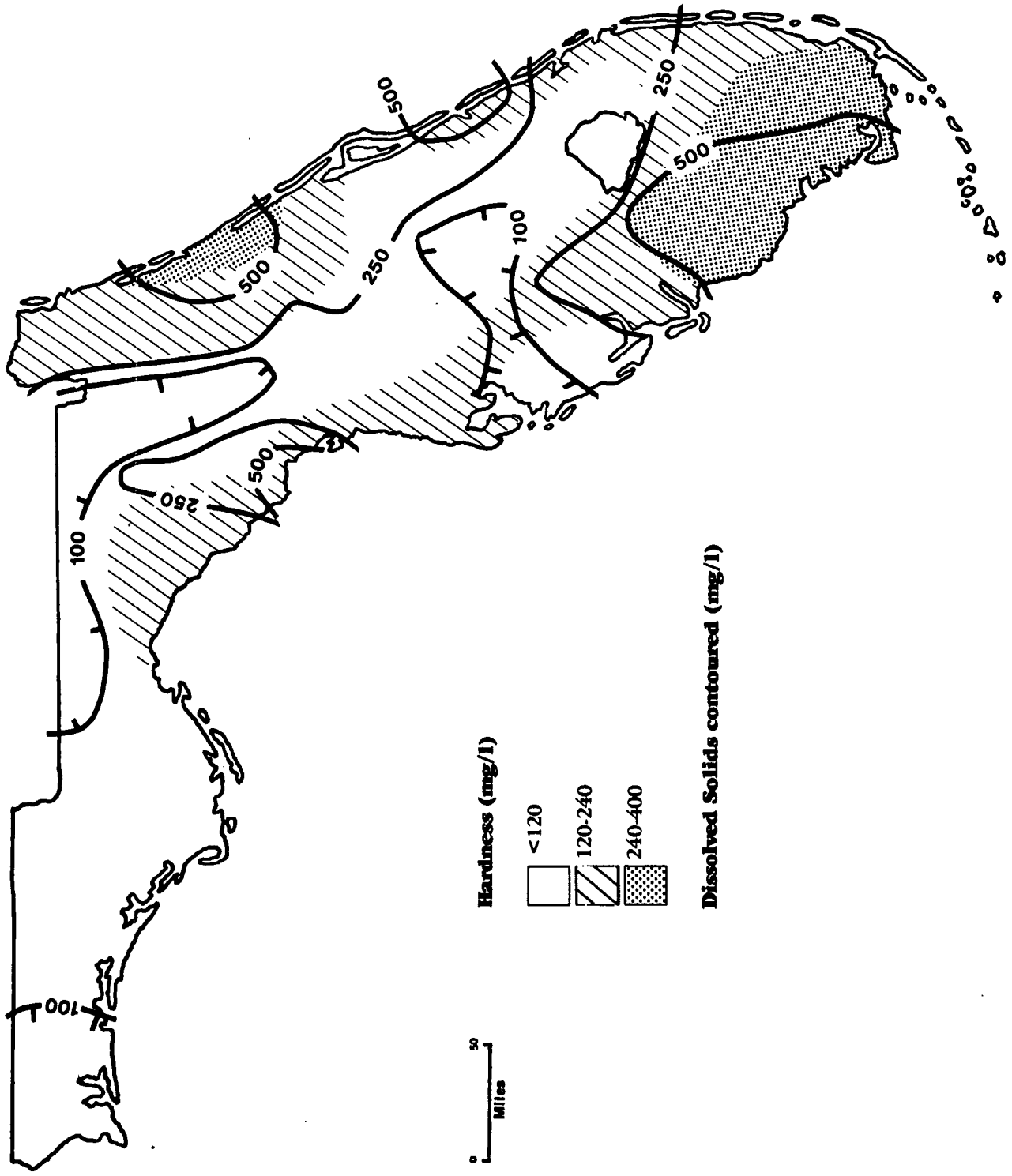
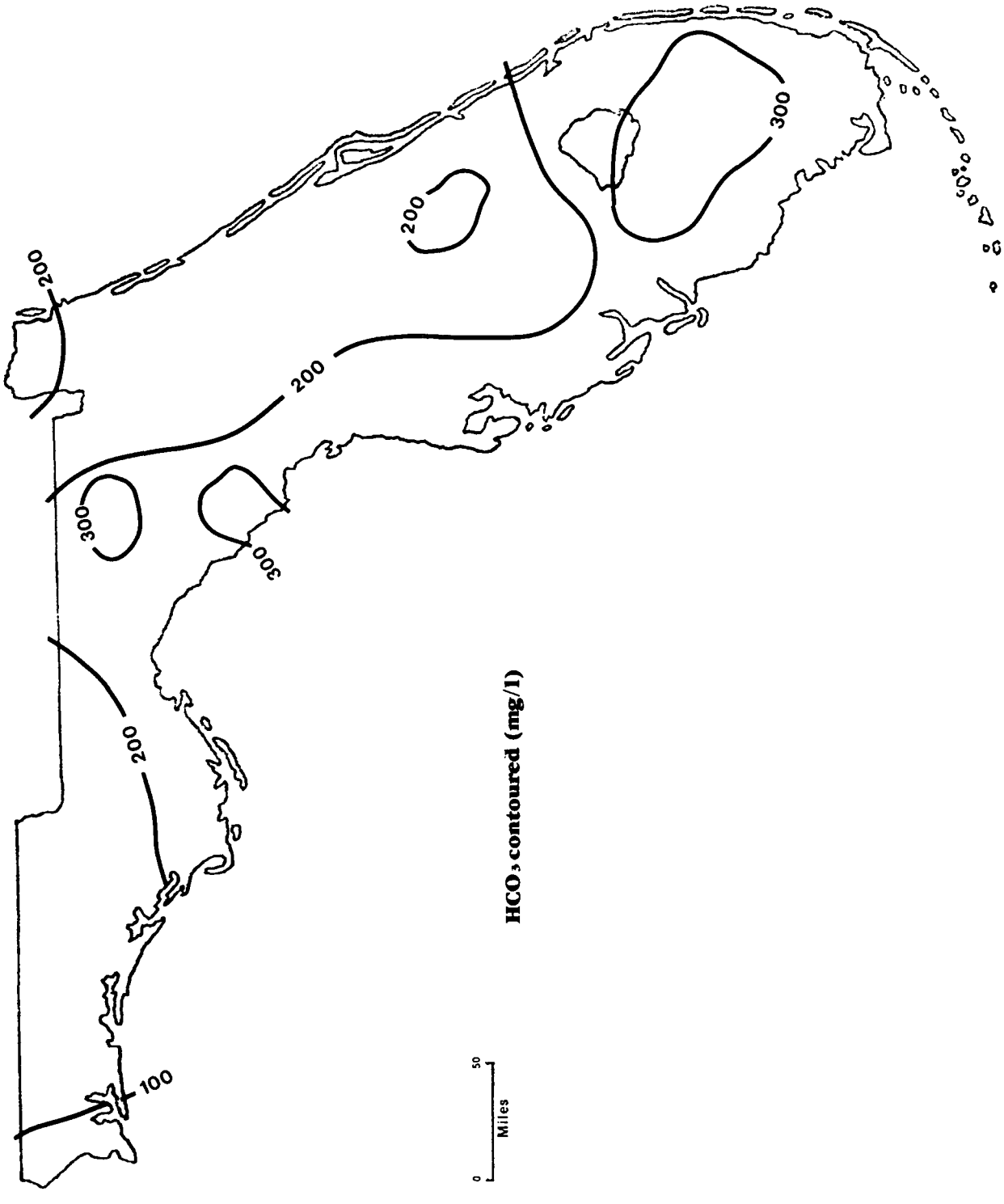


Plate 59

Florida



Florida

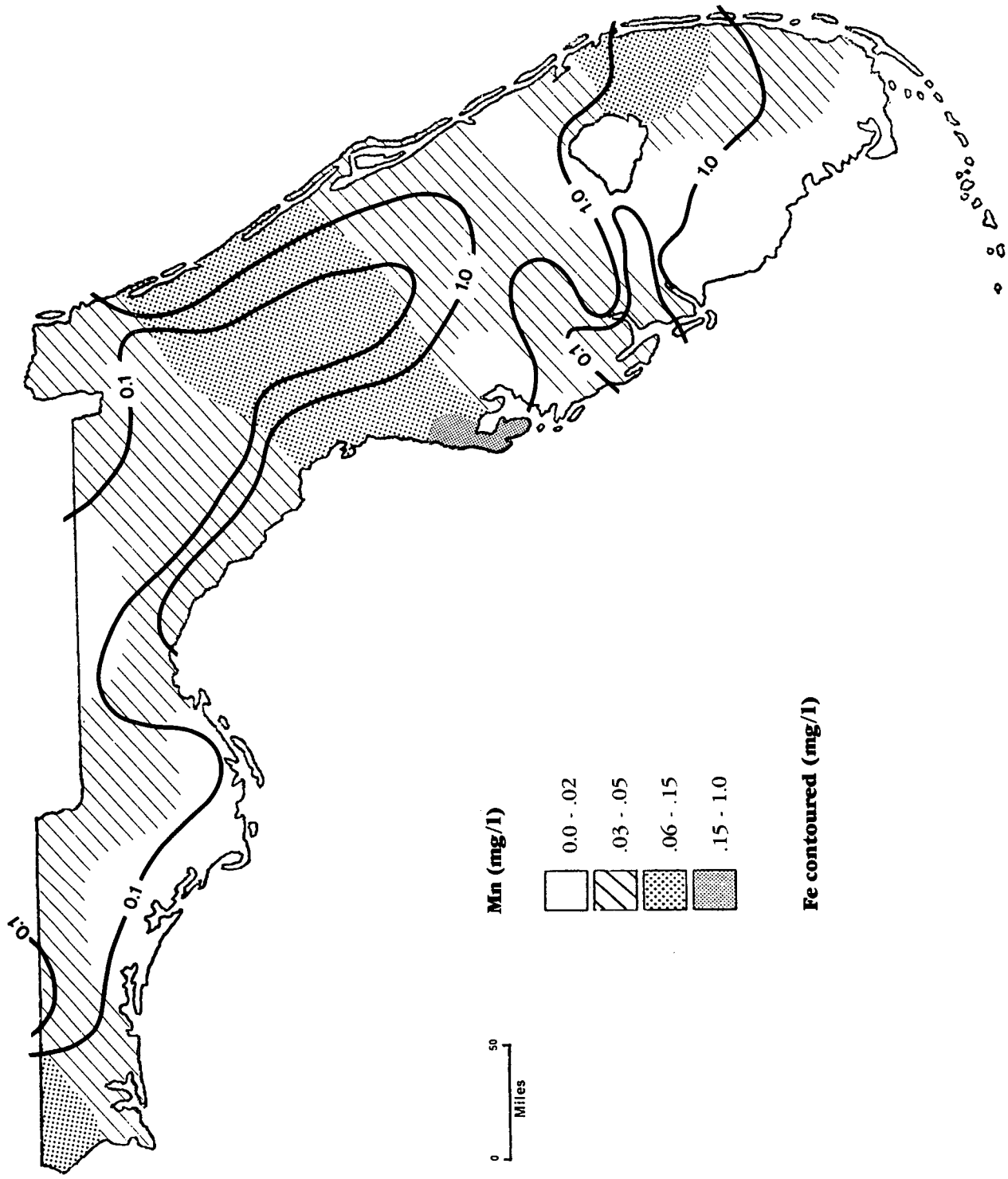
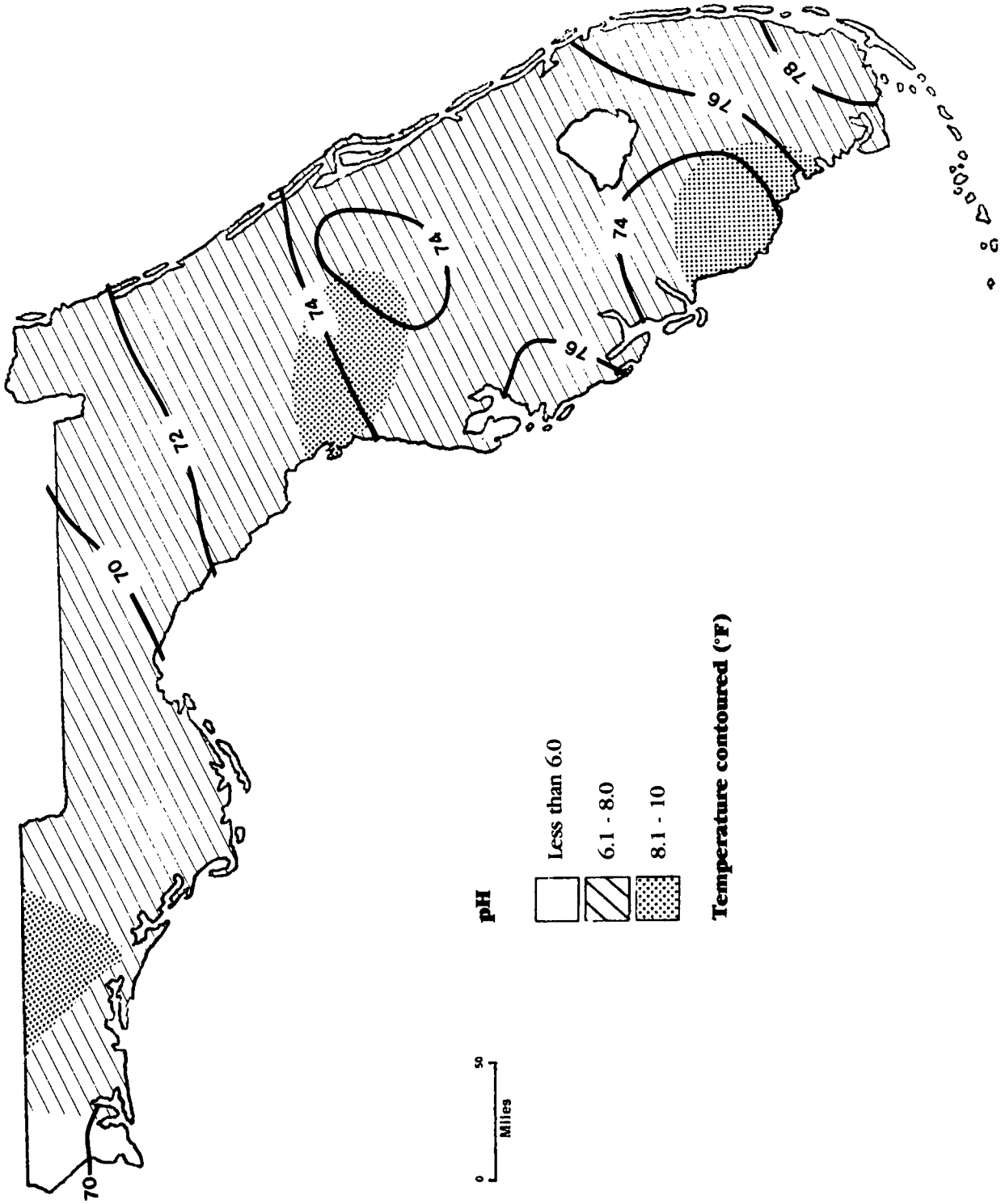
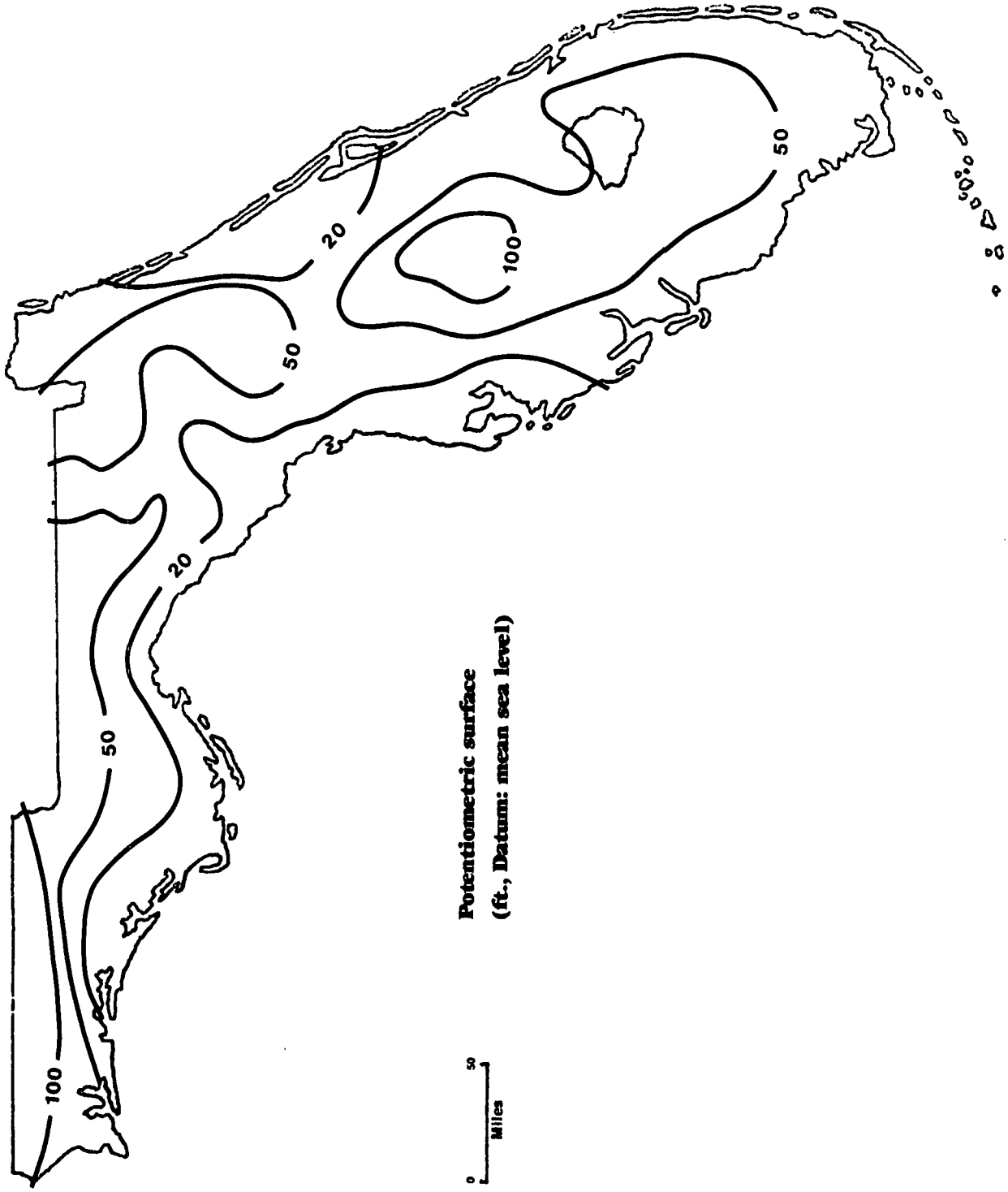


Plate 61

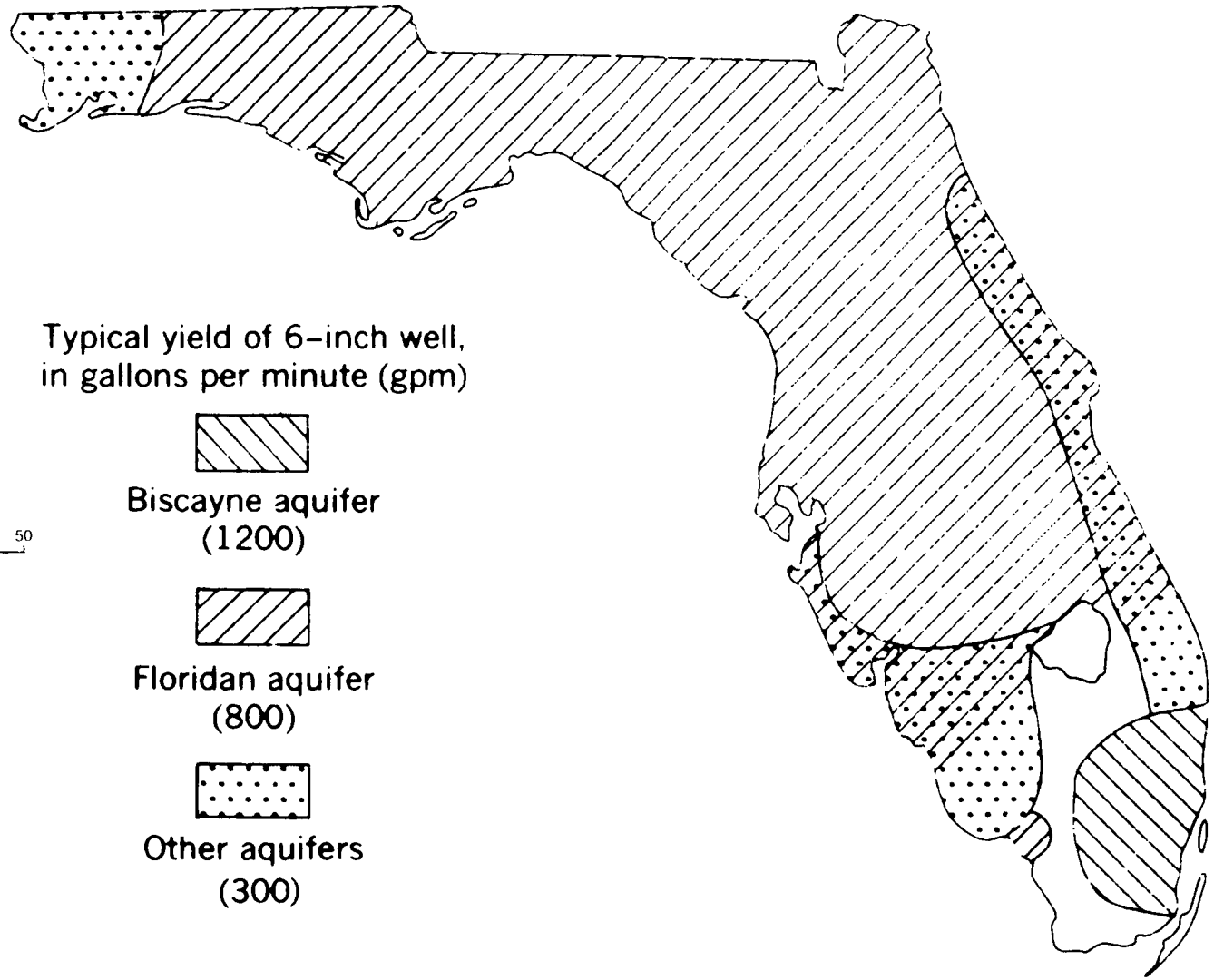
Florida


70
70
72
74
74
74
76
76
78
0
50
Miles
pH
Less than 6.0
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)

Florida


100
50
20
20
50
100
50
Potentiometric surface
(ft., Datum: mean sea level)
0
50
Miles

Florida



PRINCIPAL SOURCES OF GROUND WATER

Georgia

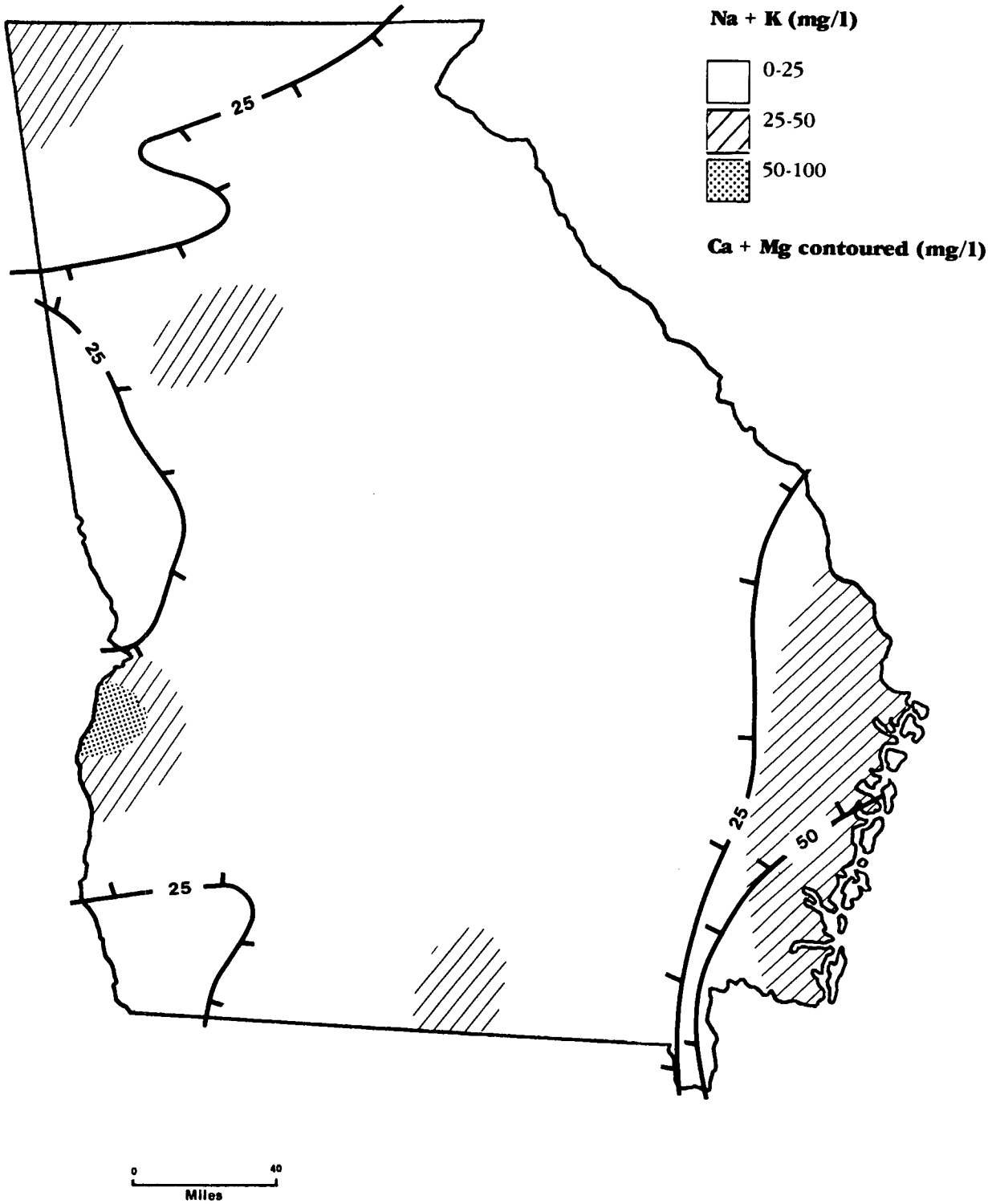


Plate 65

Georgia

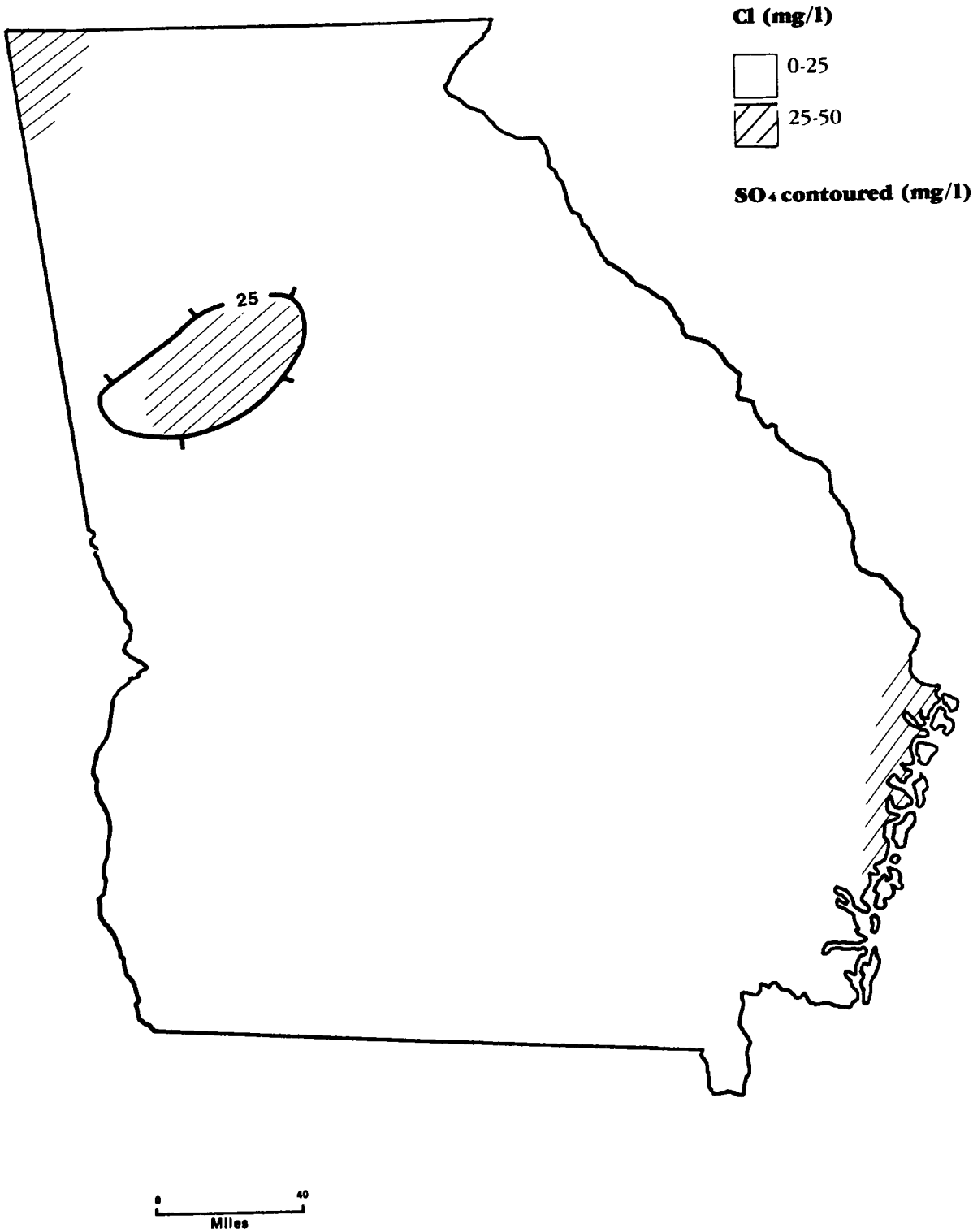


Plate 66

Georgia

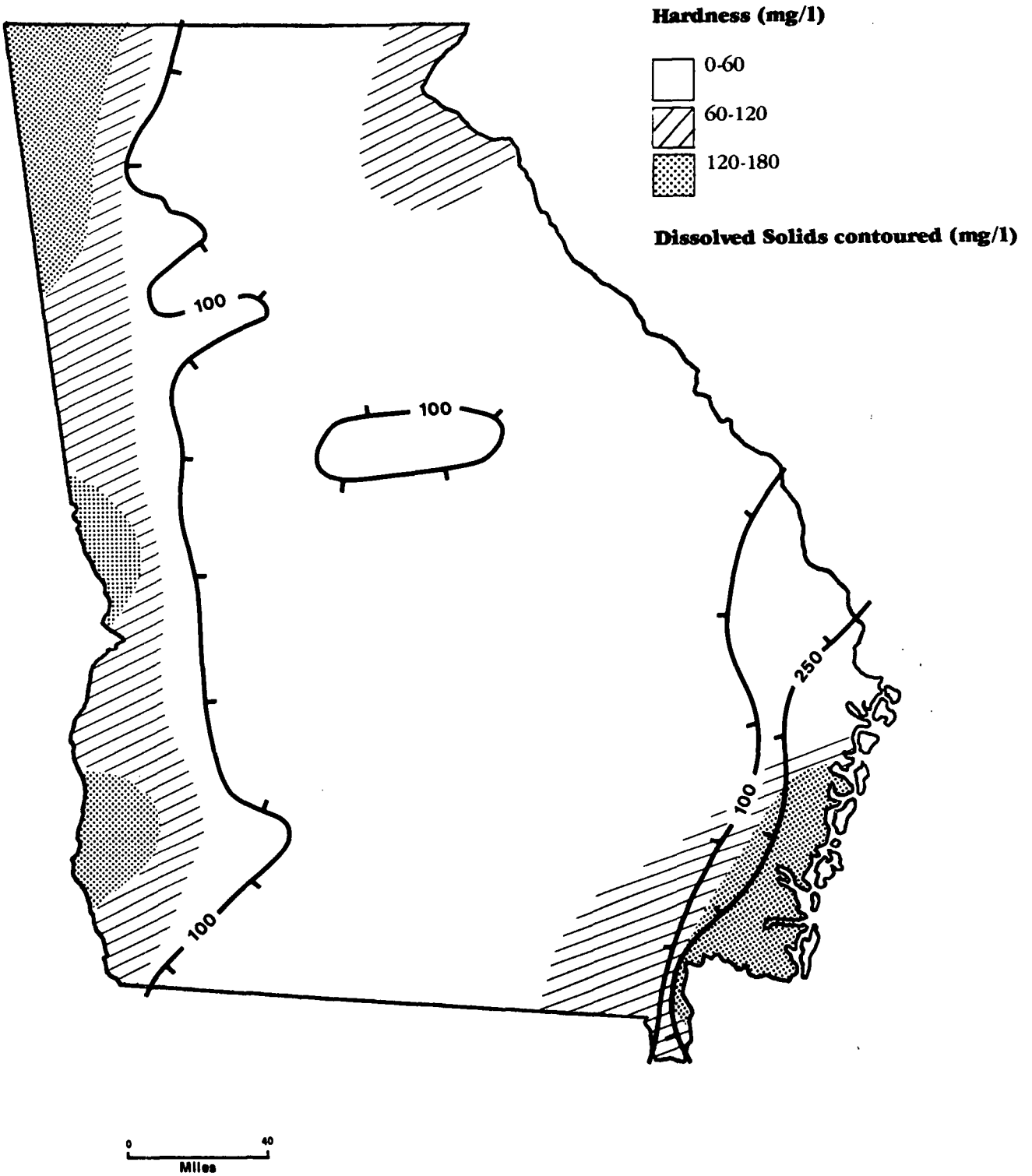
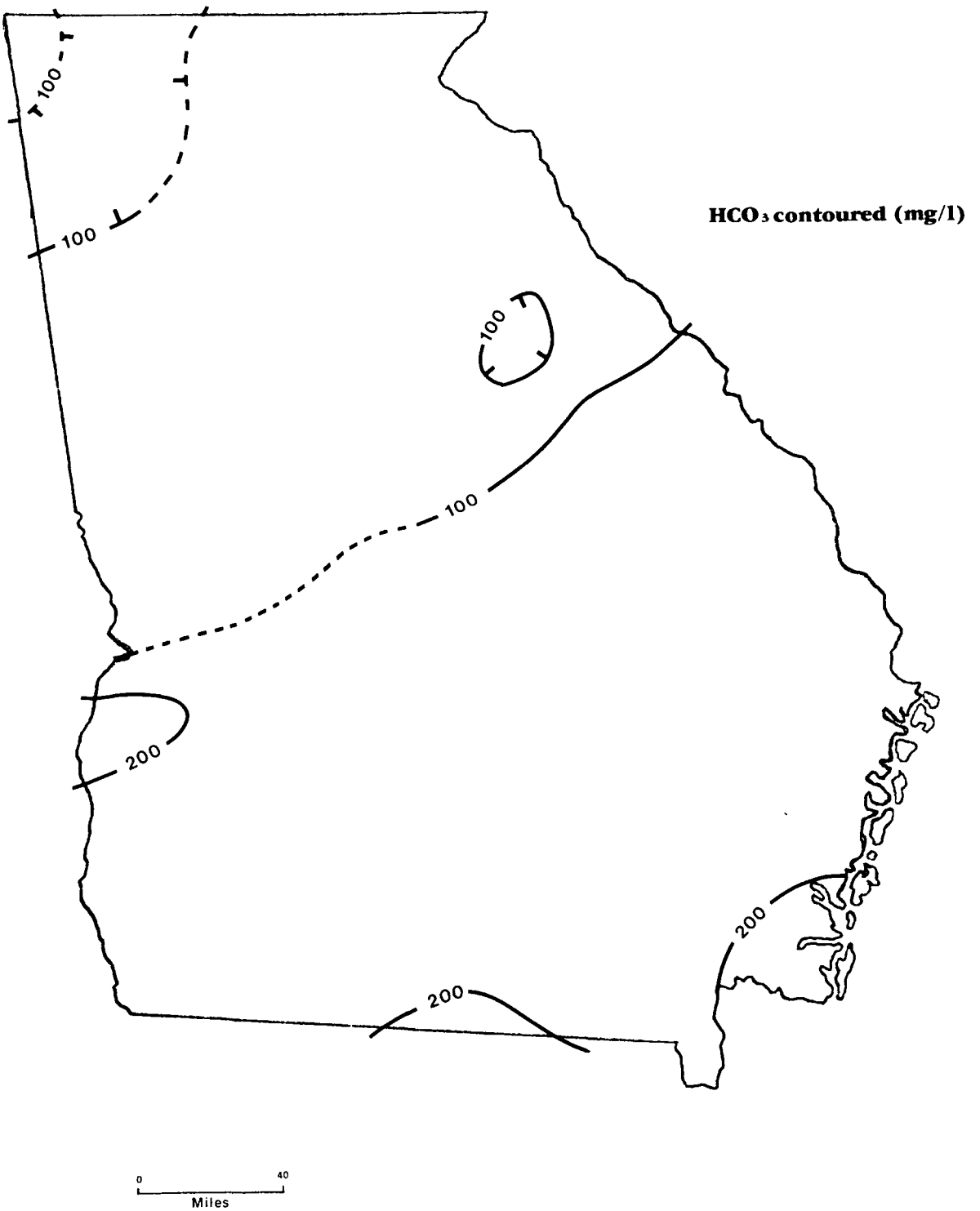


Plate 67

Georgia



Georgia

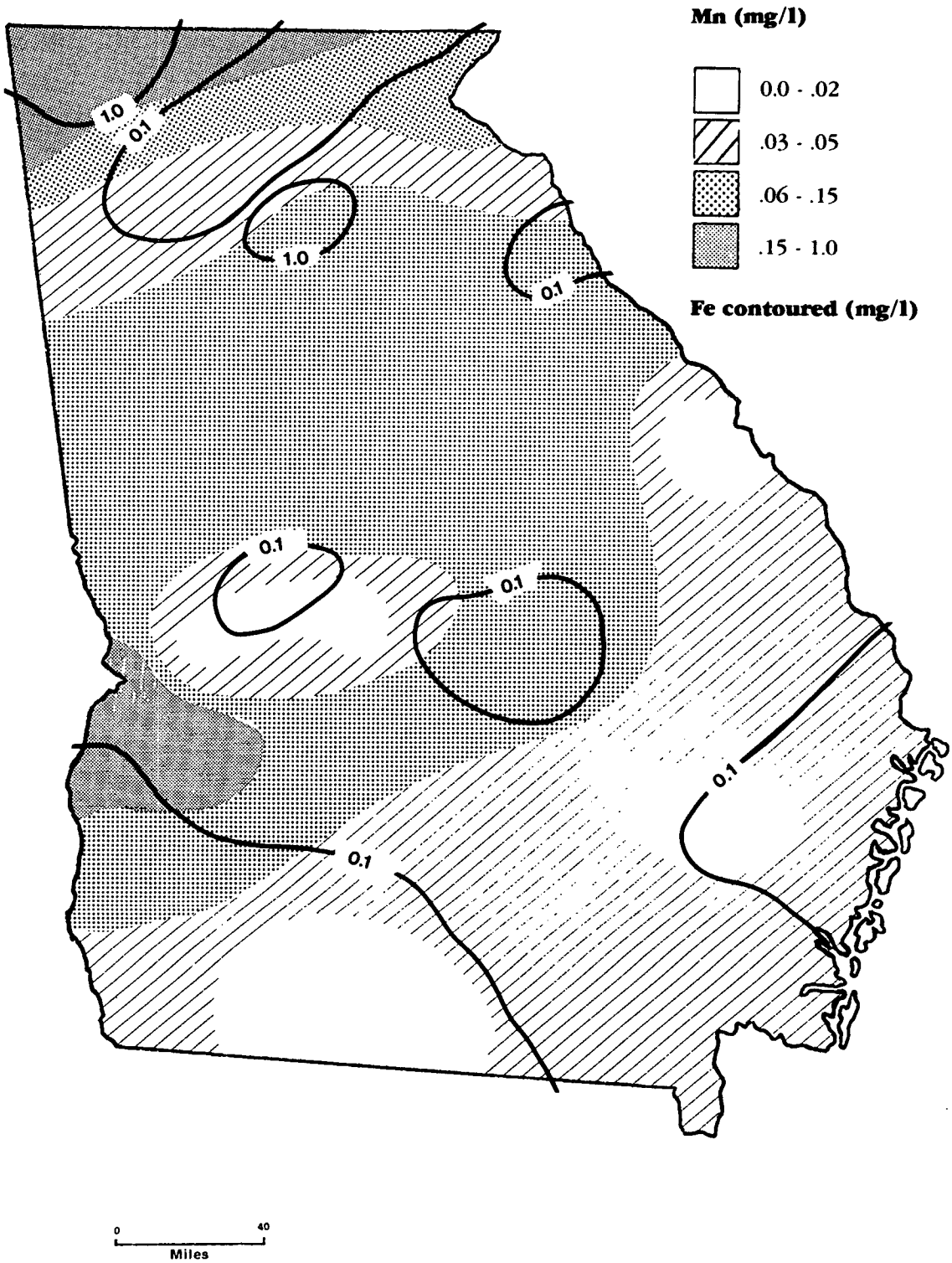
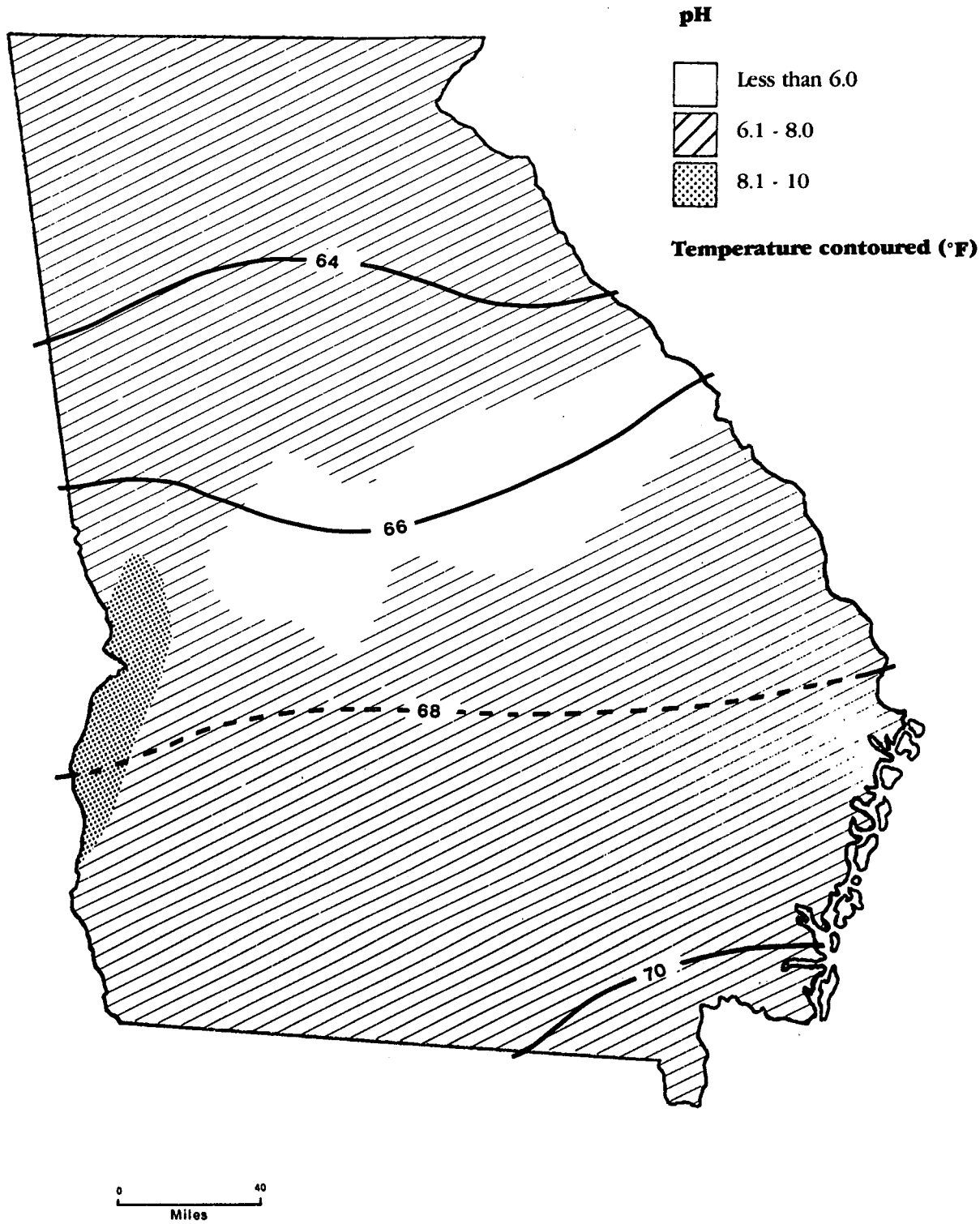
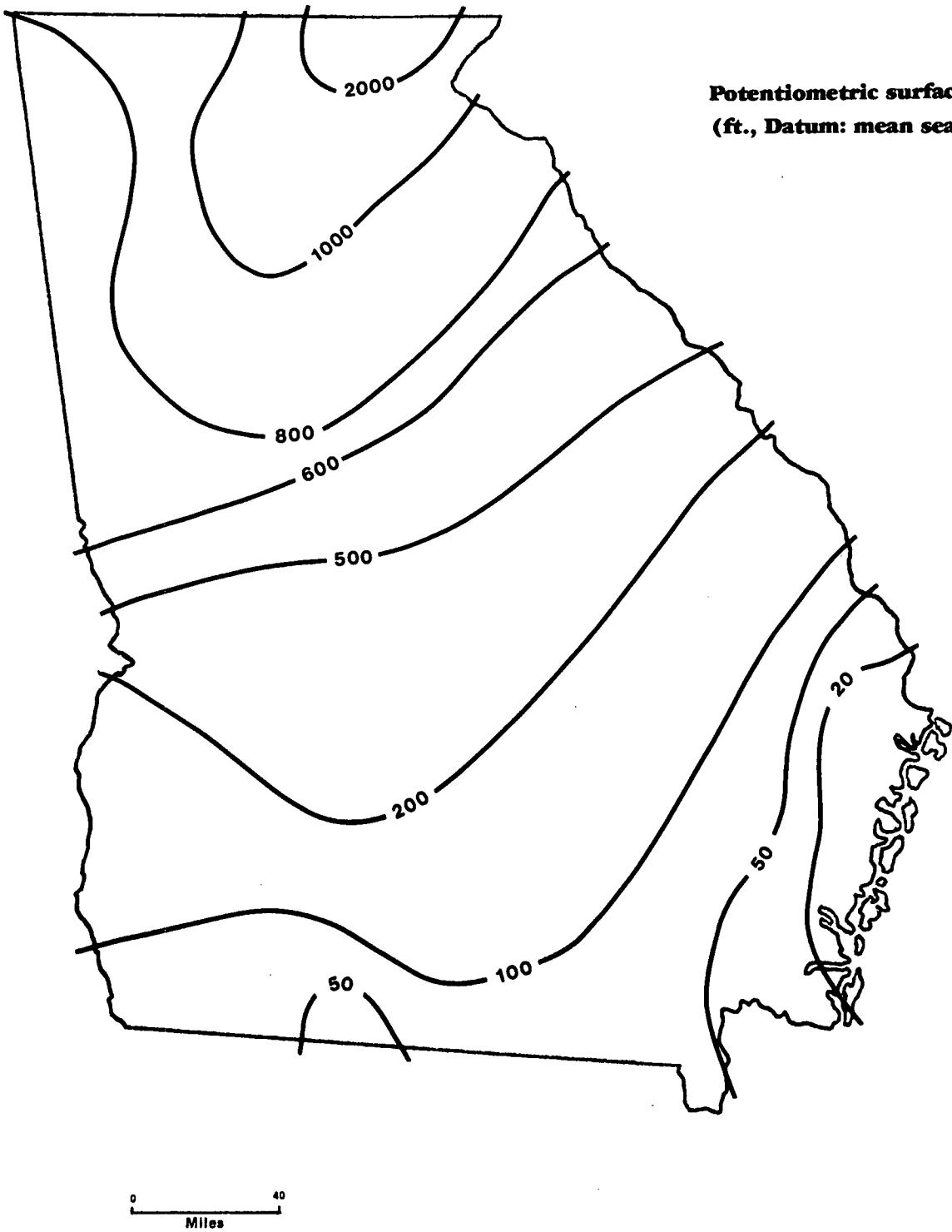


Plate 69

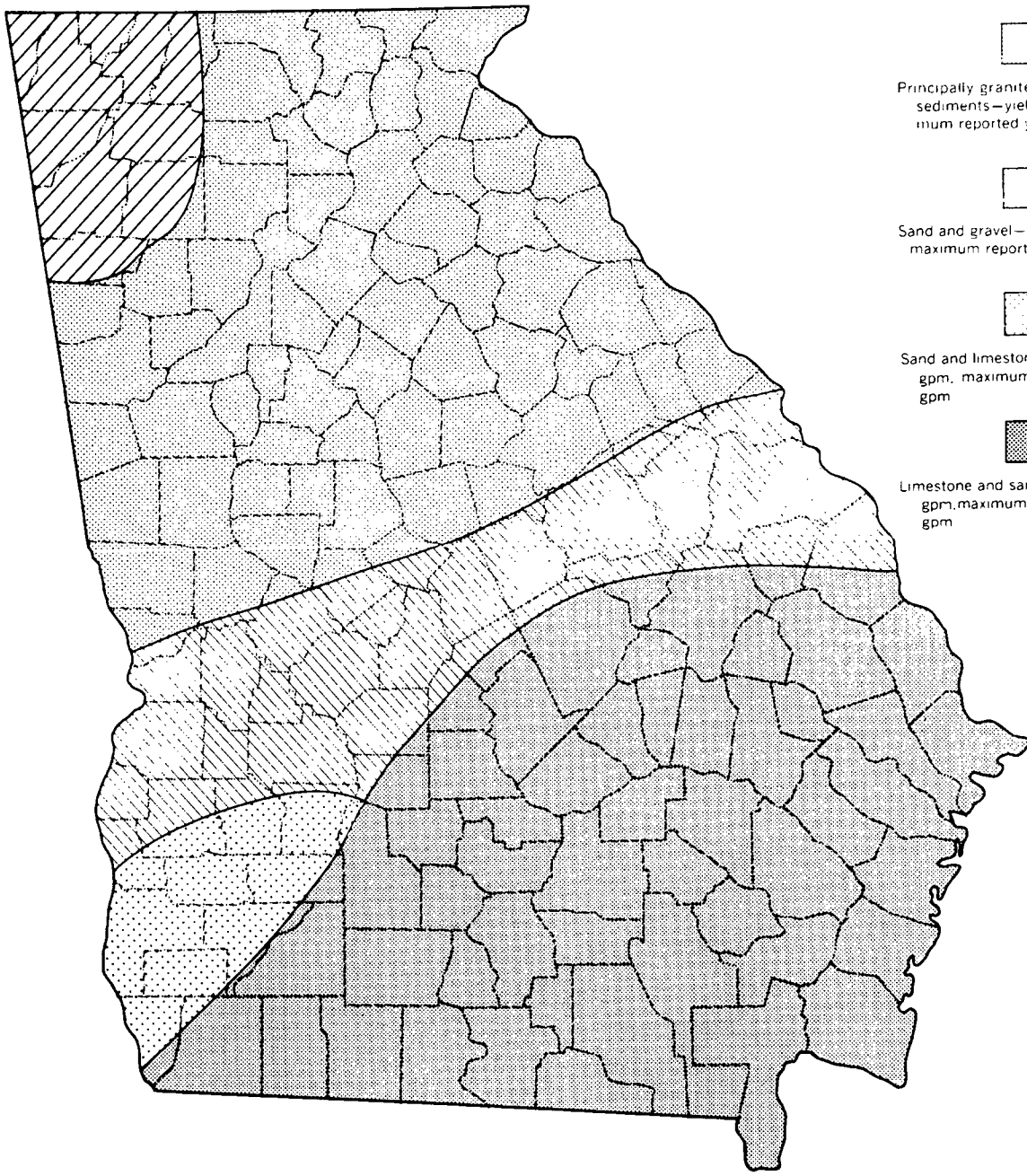
Georgia


pH
Less than 6.0
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
64
66
68
70
0
40
Miles

Georgia


Potentiometric surface
(ft., Datum: mean sea level)
2000
1000
800
600
500
200
100
50
50
20
0
40
Miles

Georgia



AQUIFERS AND WELL YIELDS

Massive dolomite—yields 5-50 gpm, maximum reported yield 1000 gpm
Limestone, sandstone, mudstone, chert—yields 1-20 gpm, maximum reported yield 50-300 gpm

Principally granite, gneiss, and metasediments—yields 1-25 gpm, maximum reported yield 400 gpm

Sand and gravel—yields 50-1200 gpm, maximum reported yield 1800 gpm

Sand and limestone — yields 250-600 gpm, maximum reported yield 1400 gpm

Limestone and sand—yields 1000-5000 gpm, maximum reported yield 11,000 gpm

0 40
Miles

Idaho

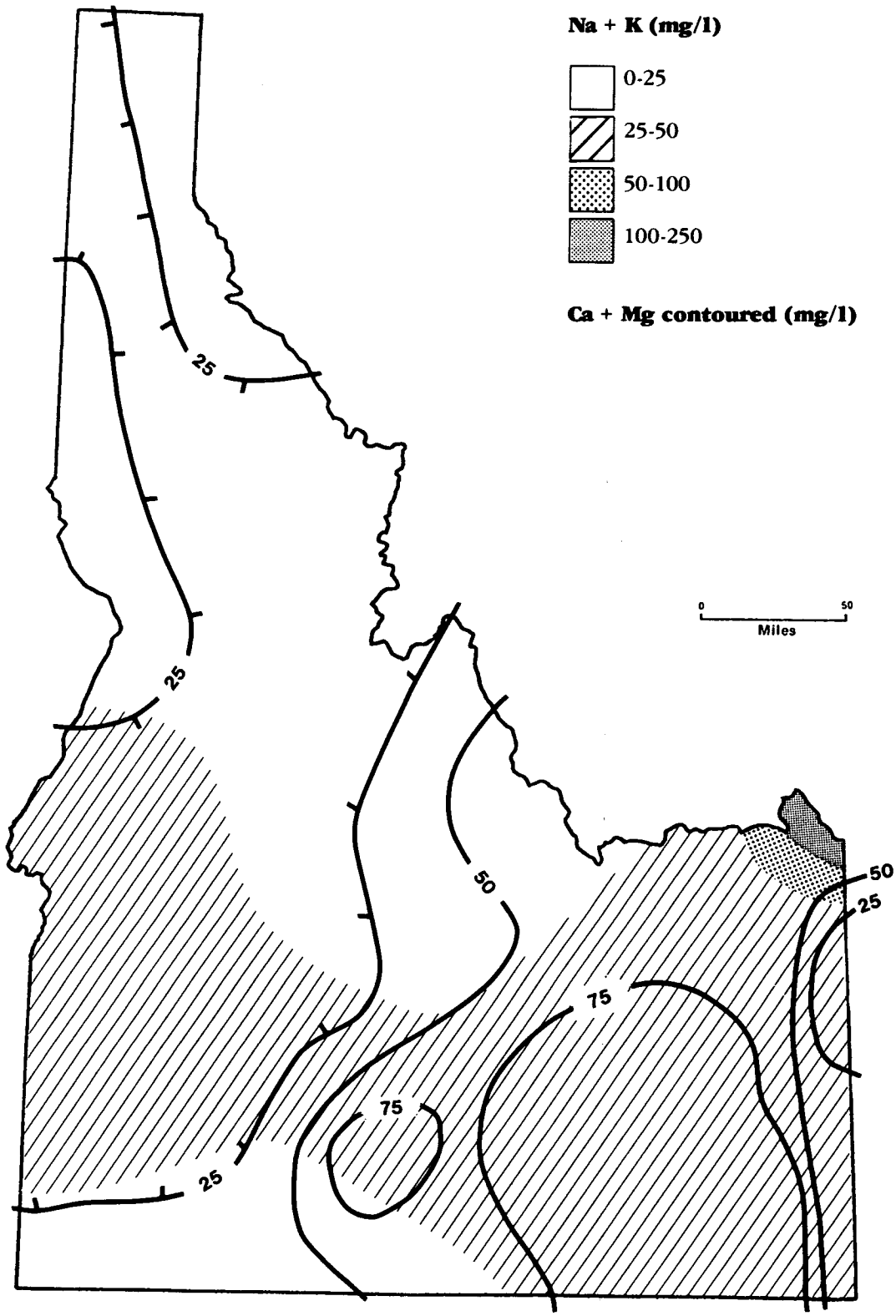


Plate 73

Idaho

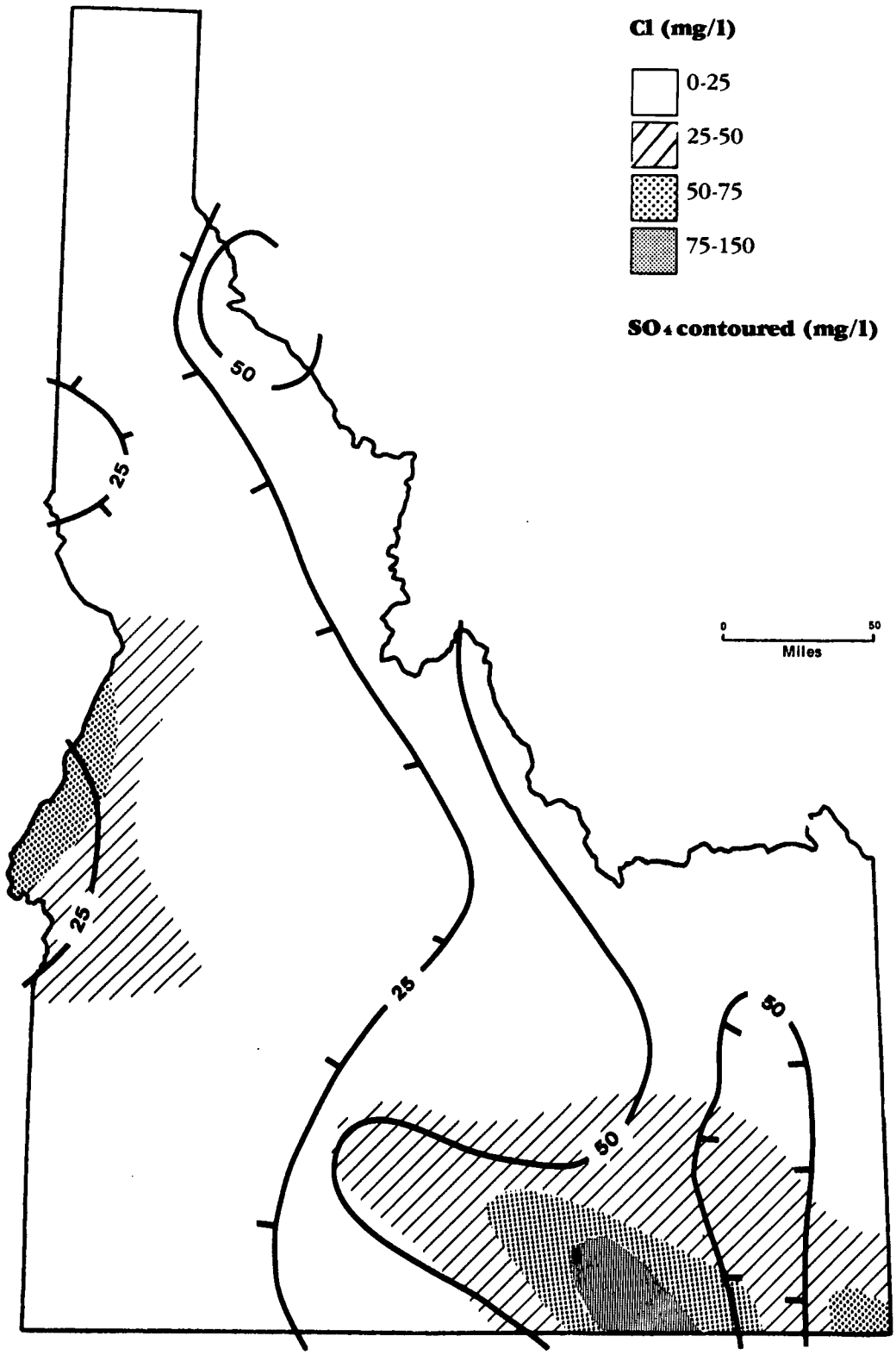


Plate 74

Idaho

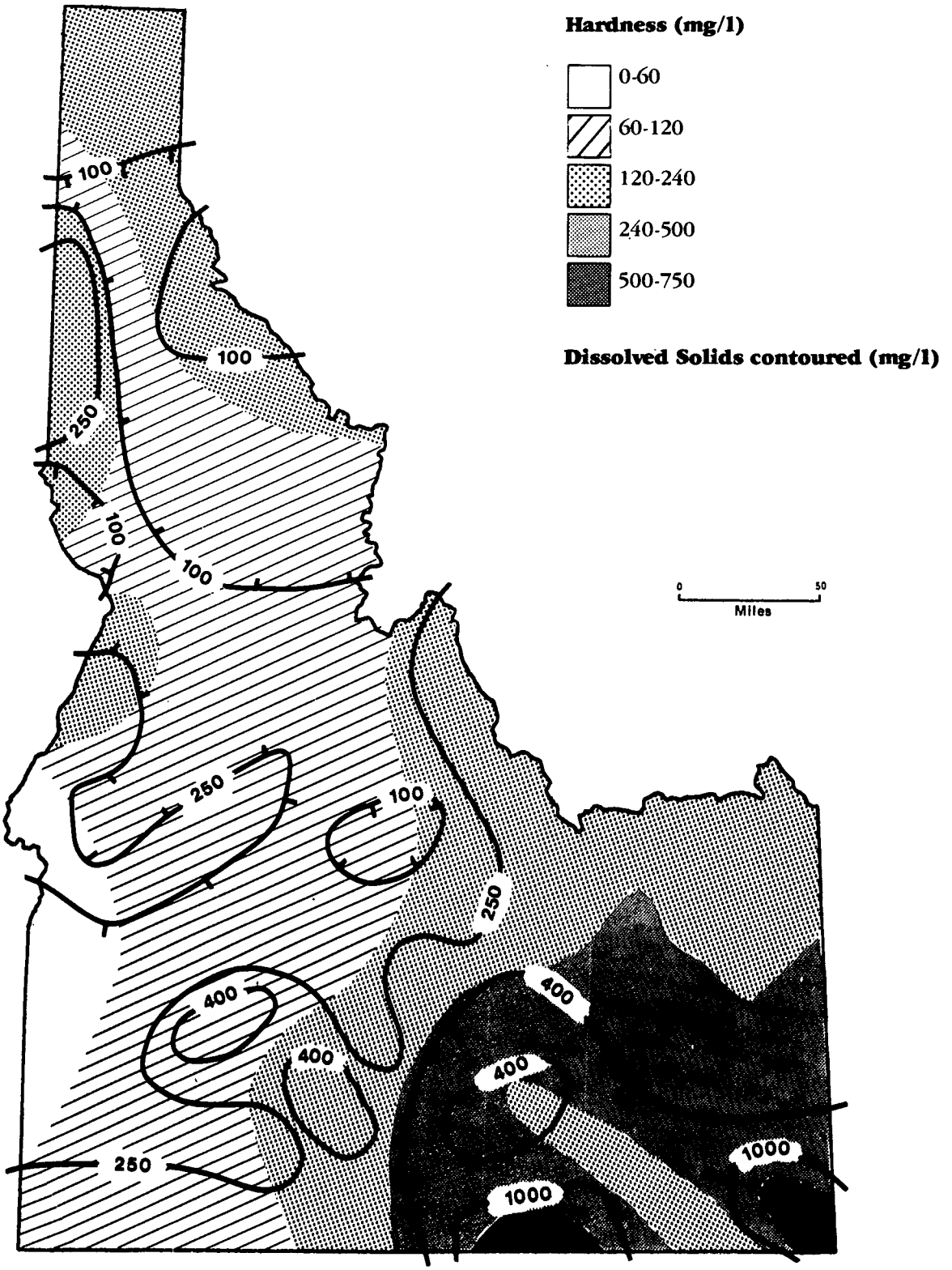
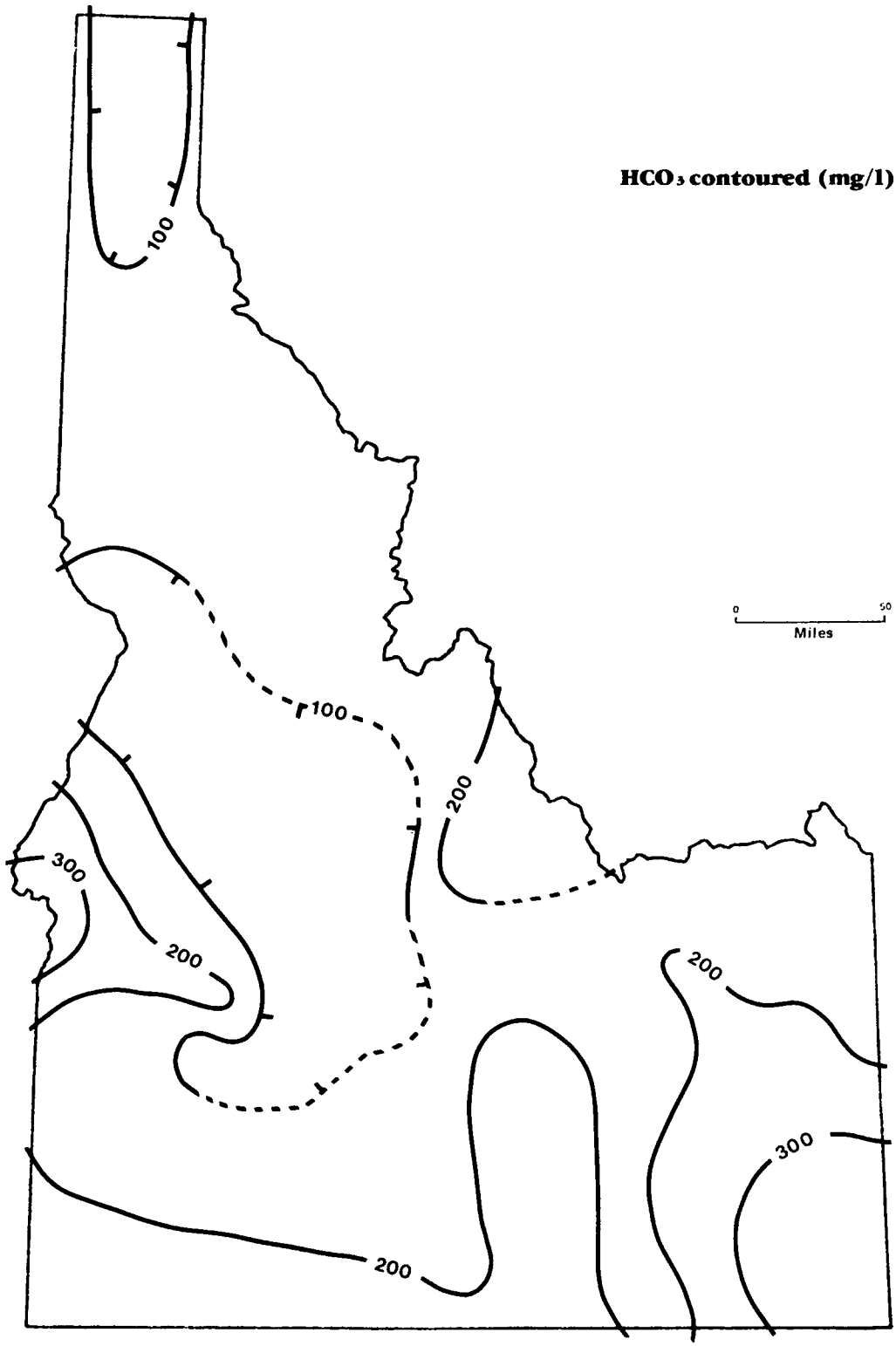
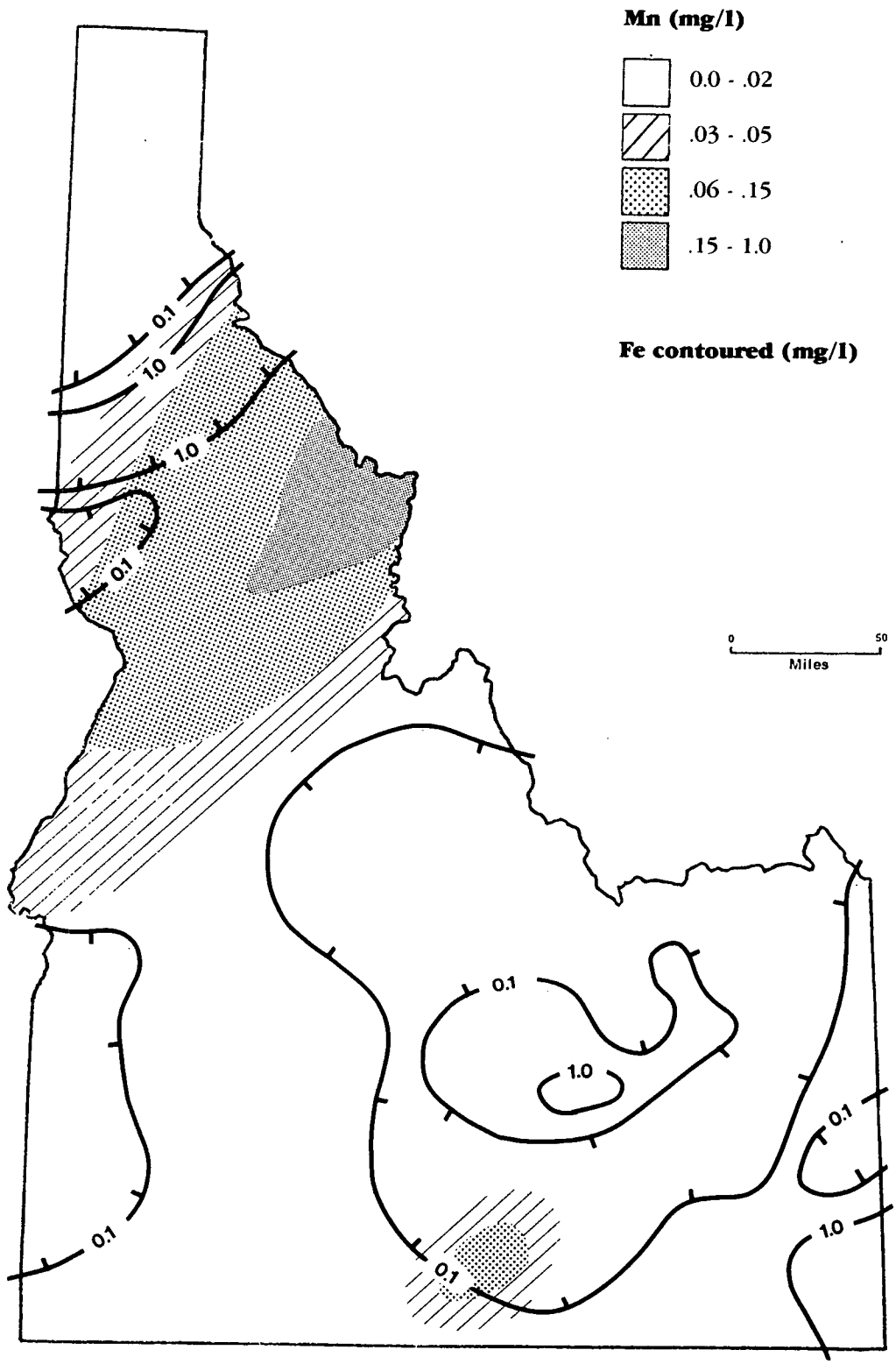


Plate 75

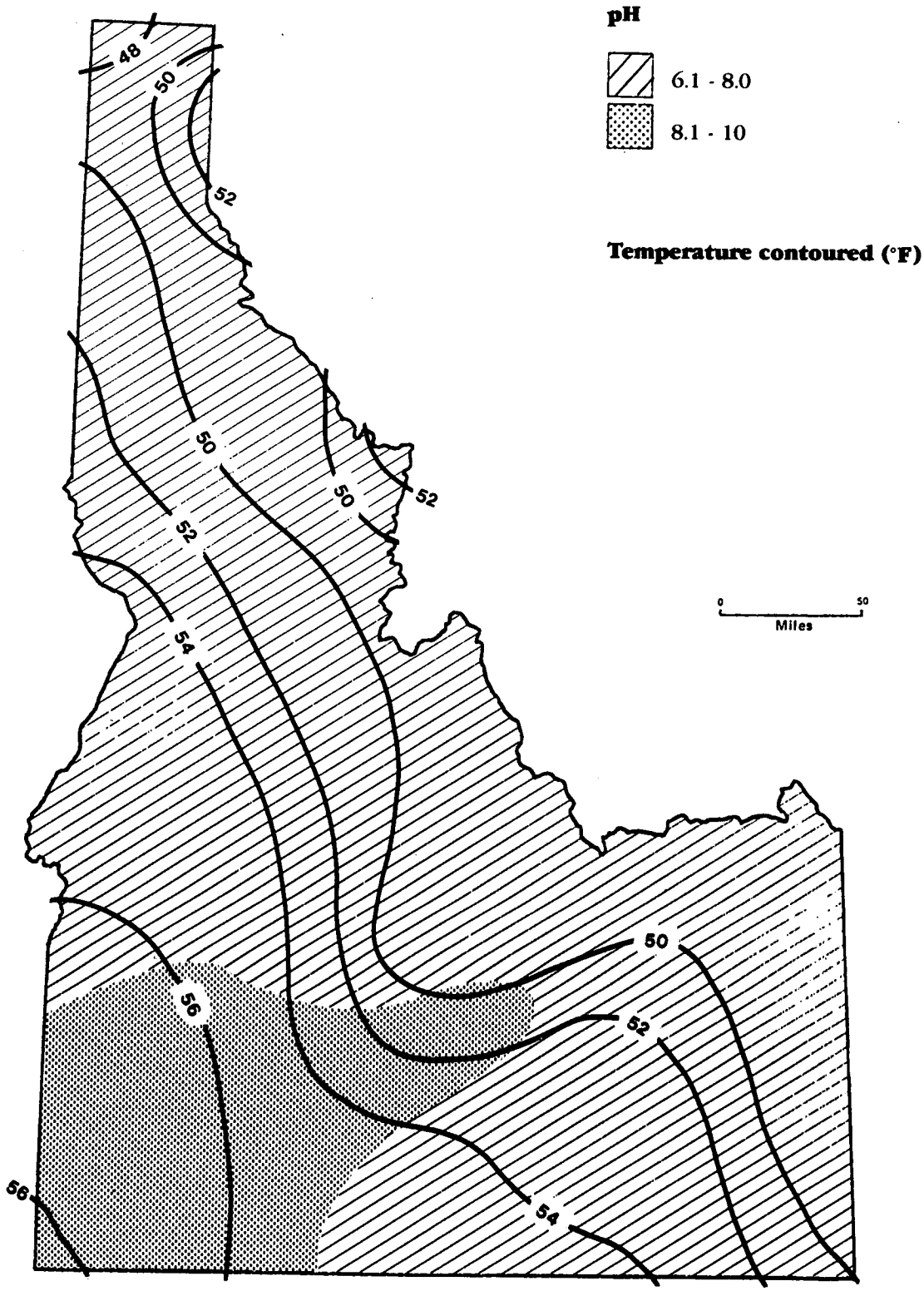
Idaho



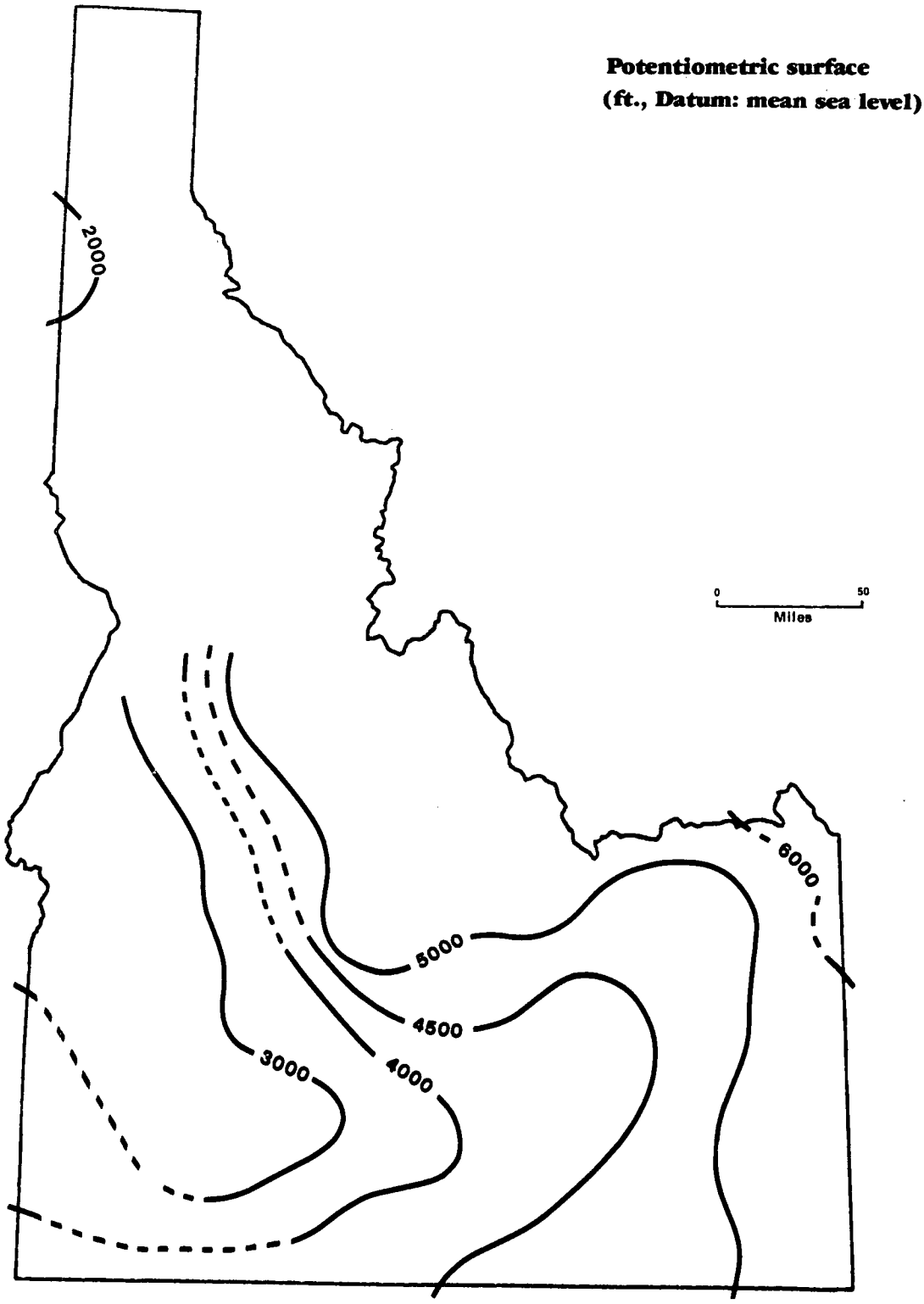
Idaho


Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
50
Miles
0.1
1.0
1.0
0.1
0.1
1.0
0.1
0.1
0.1
1.0

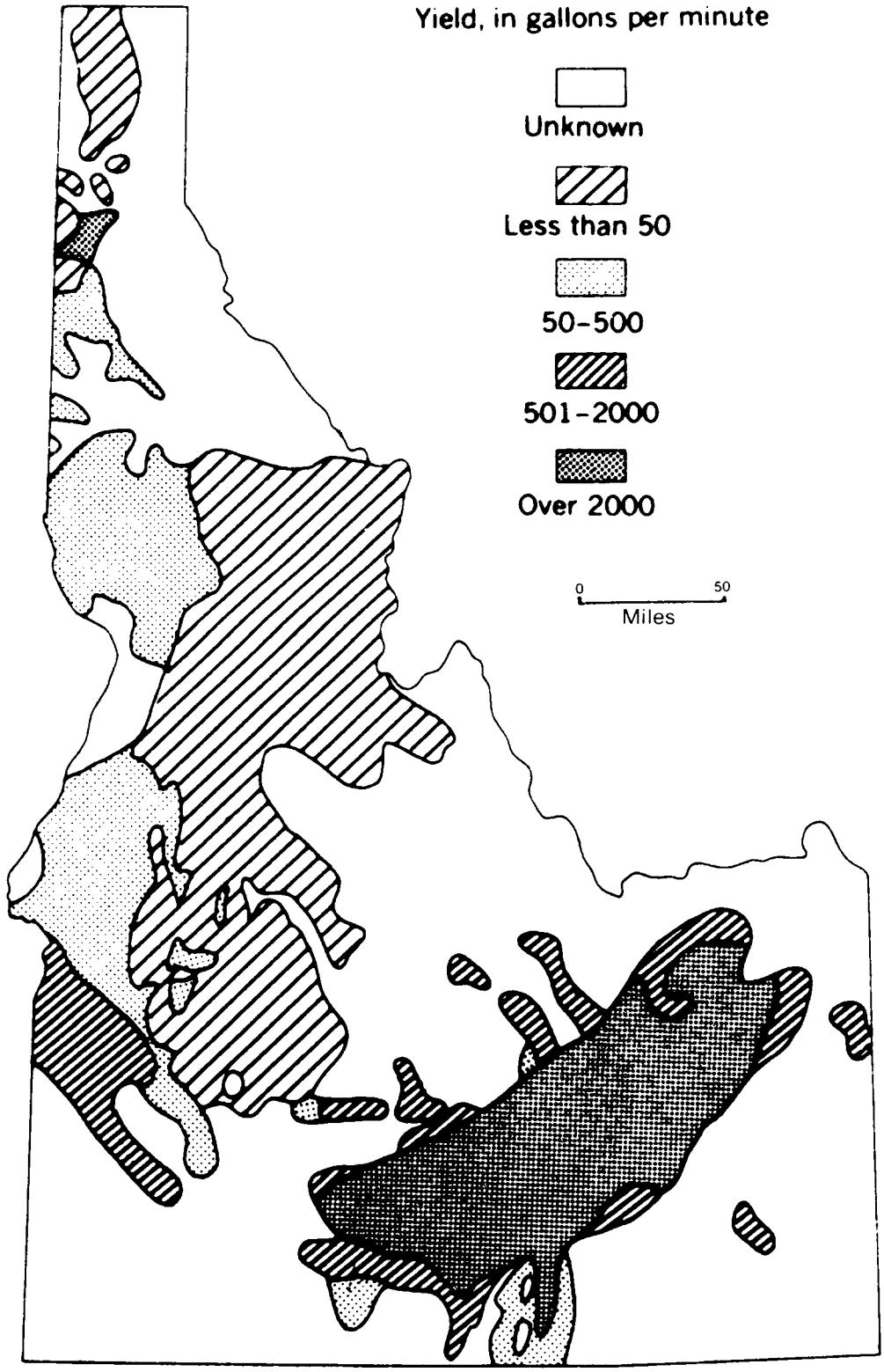
Idaho


pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles
48
50
52
50
52
50
52
54
56
56
50
52
54

Idaho


Potentiometric surface
(ft., Datum: mean sea level)
2000
3000
4000
4500
5000
6000
0
50
Miles

Idaho



RANGE IN YIELDS OF WELLS

Illinois

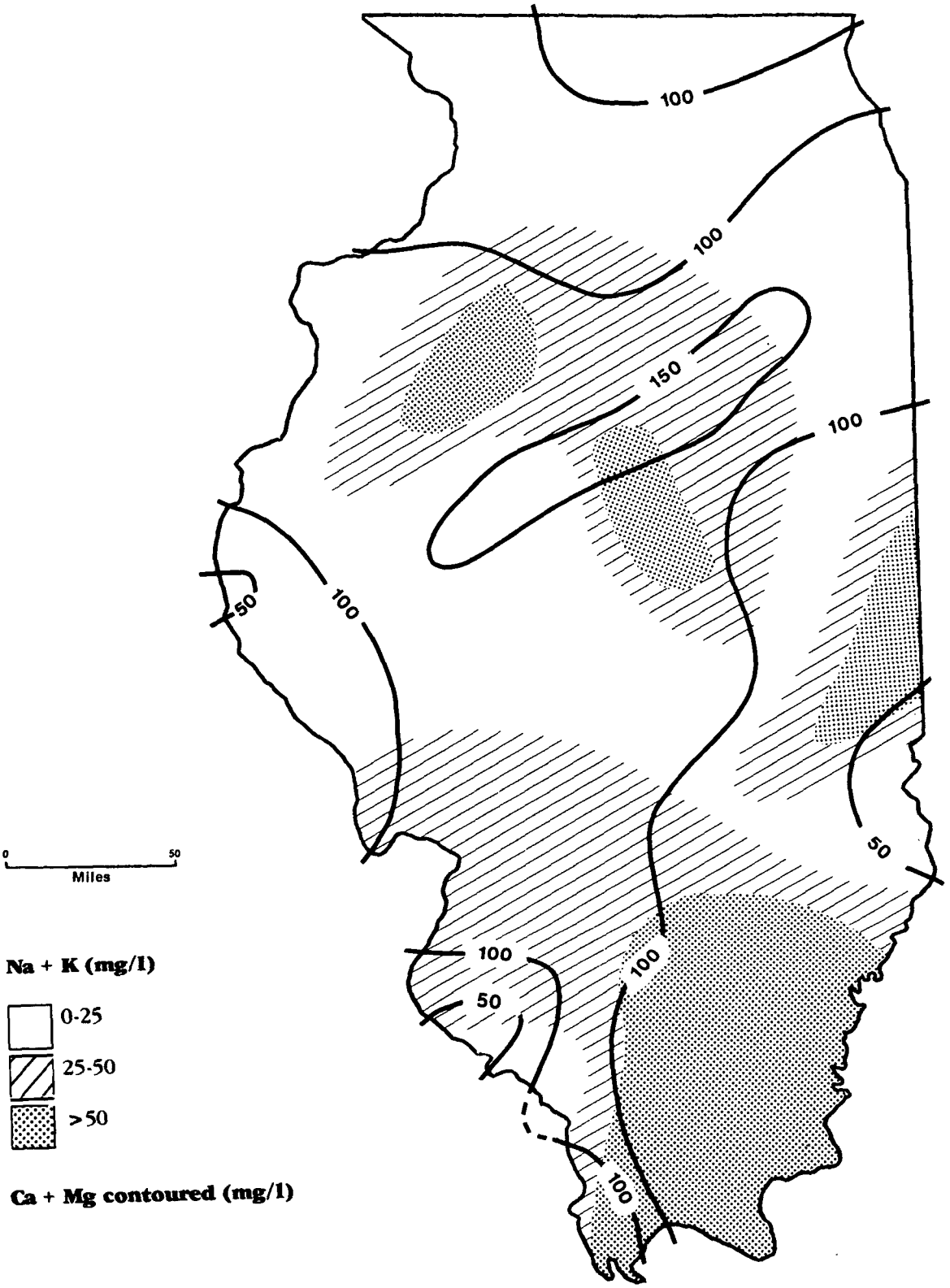


Plate 81

Illinois

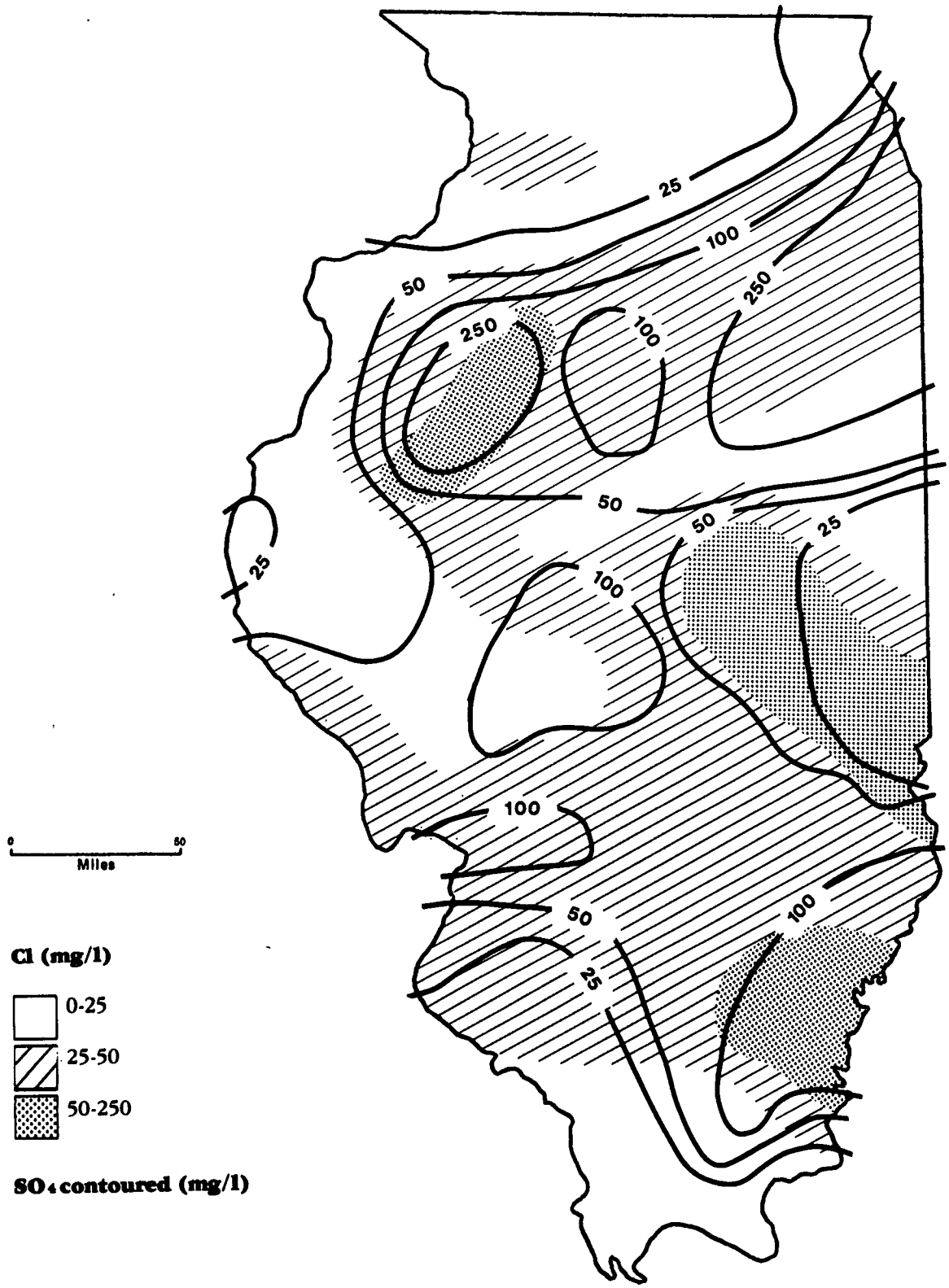
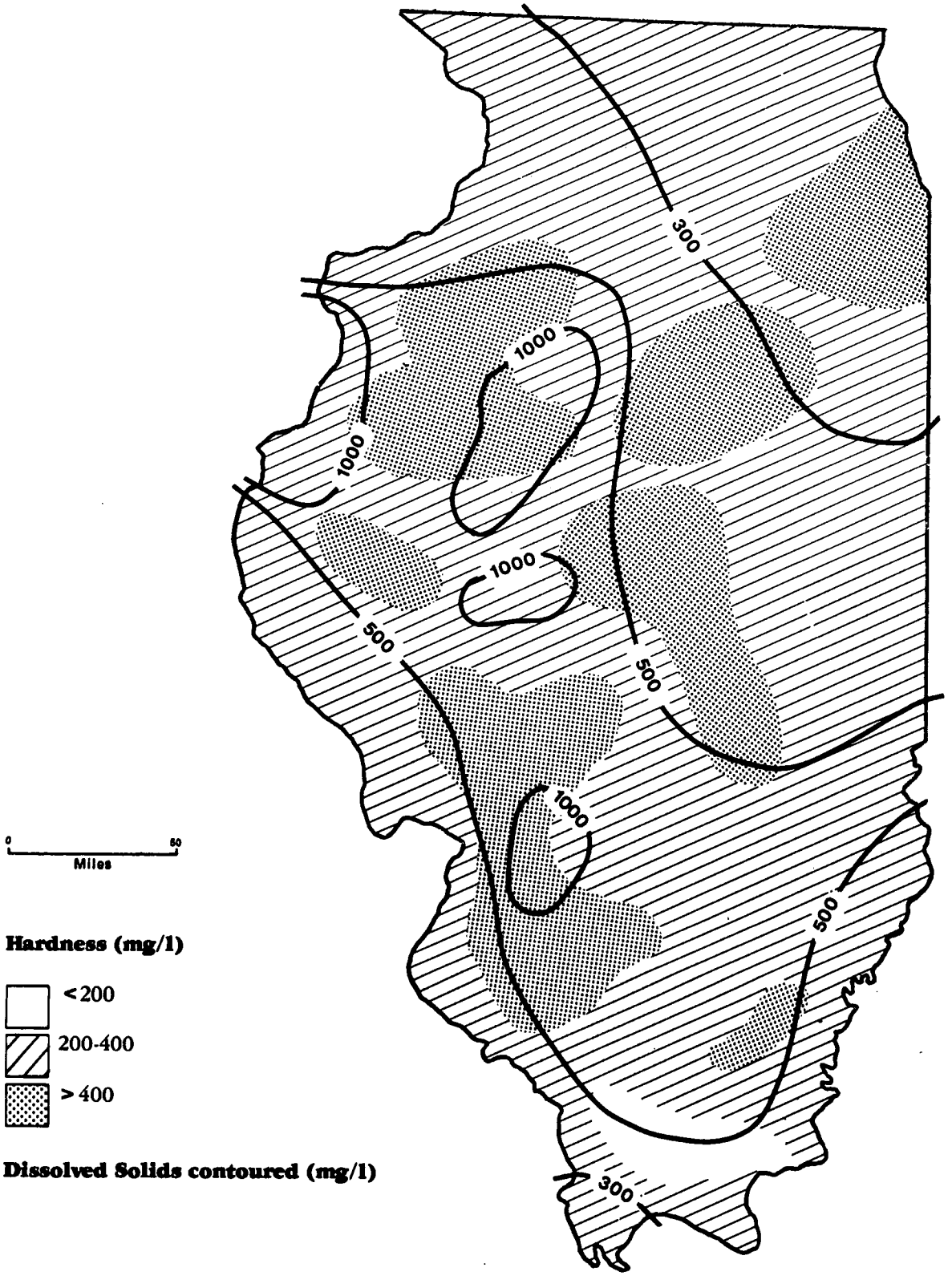
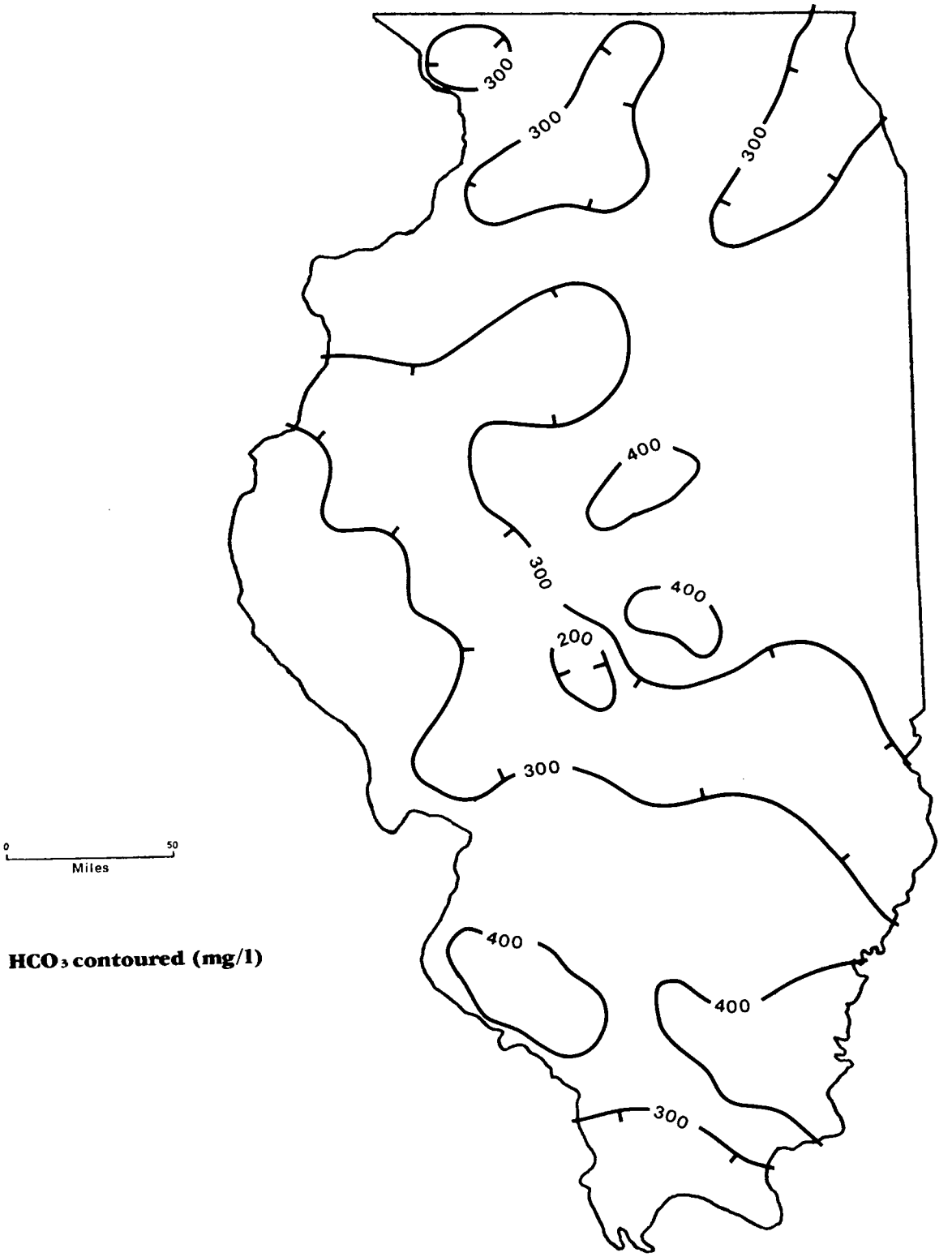


Plate 82

Illinois

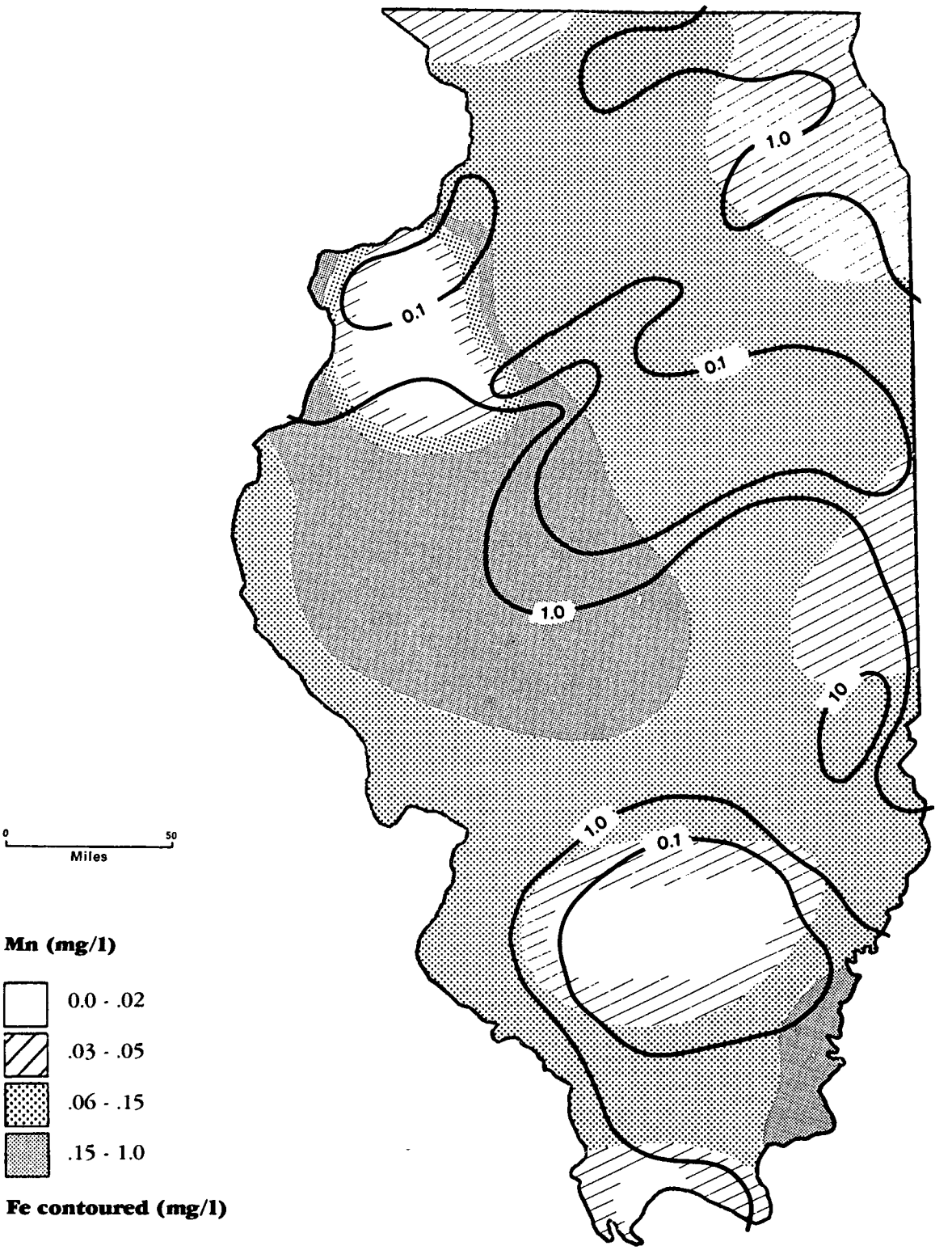

300
1000
1000
1000
500
500
1000
500
300
0
50
Miles
Hardness (mg/l)
<200
200-400
>400
Dissolved Solids contoured (mg/l)

Illinois

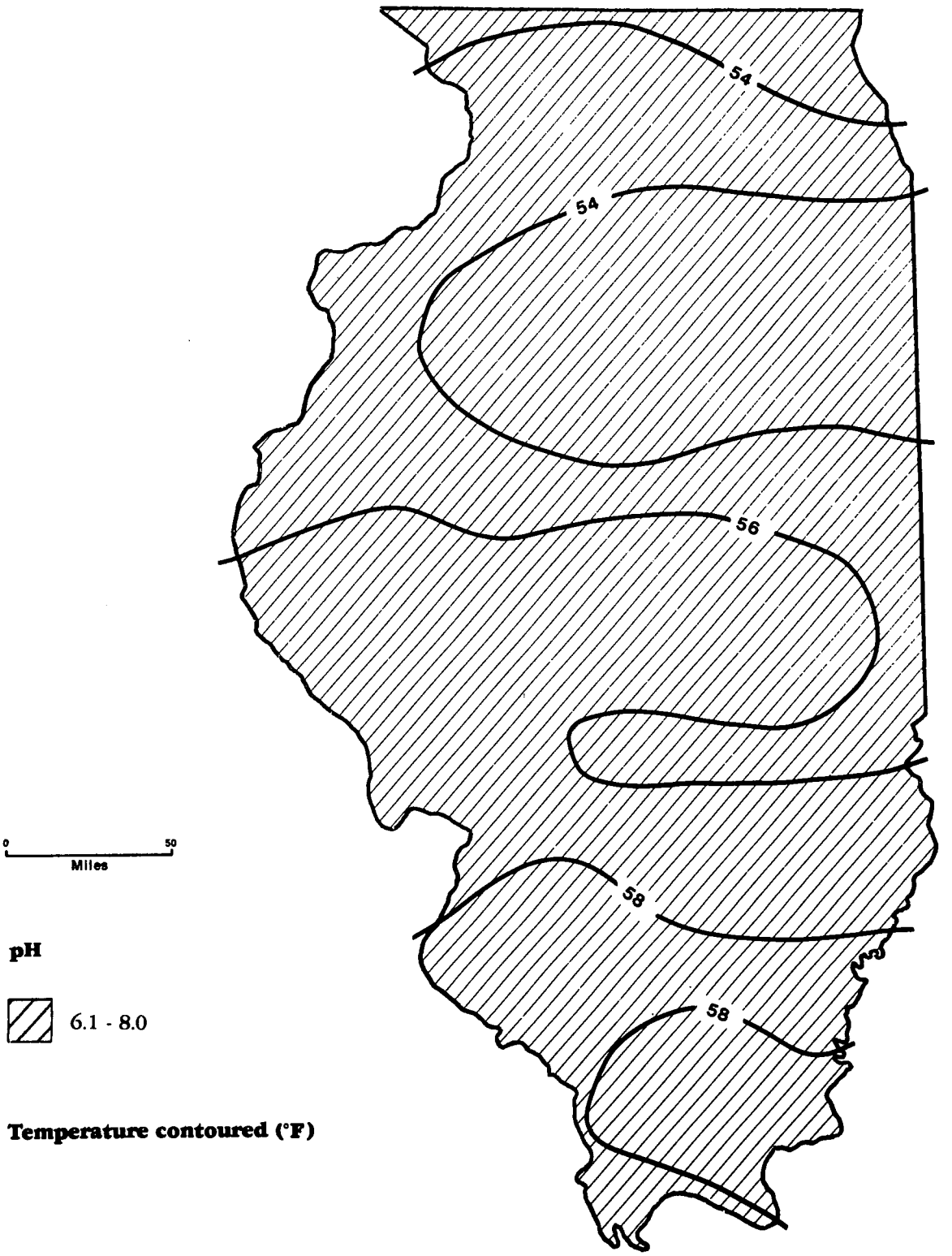


HCO_3 contoured (mg/1)

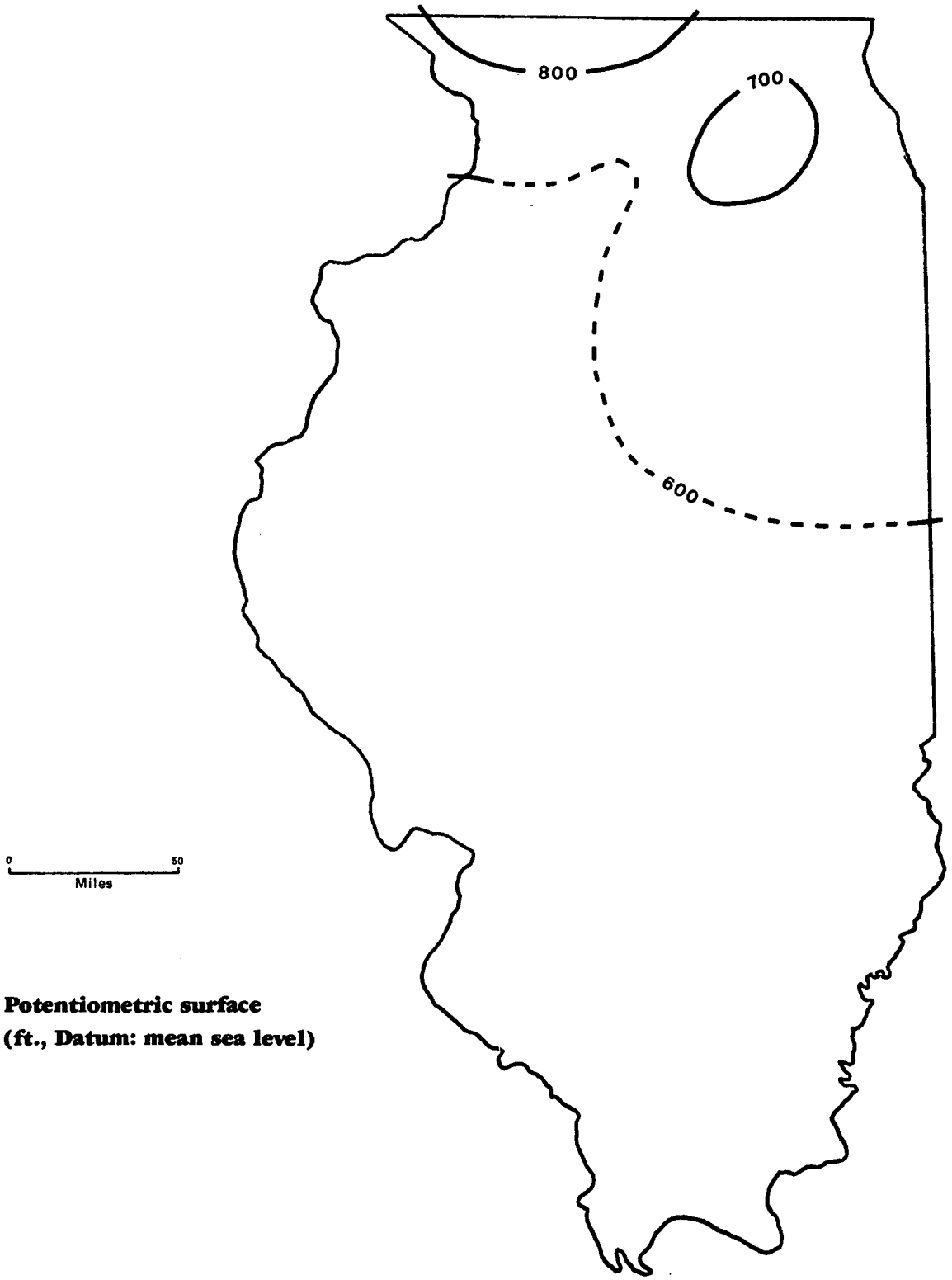
Illinois


1.0
0.1
0.1
1.0
10
1.0
0.1
0
50
Miles
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)

Illinois



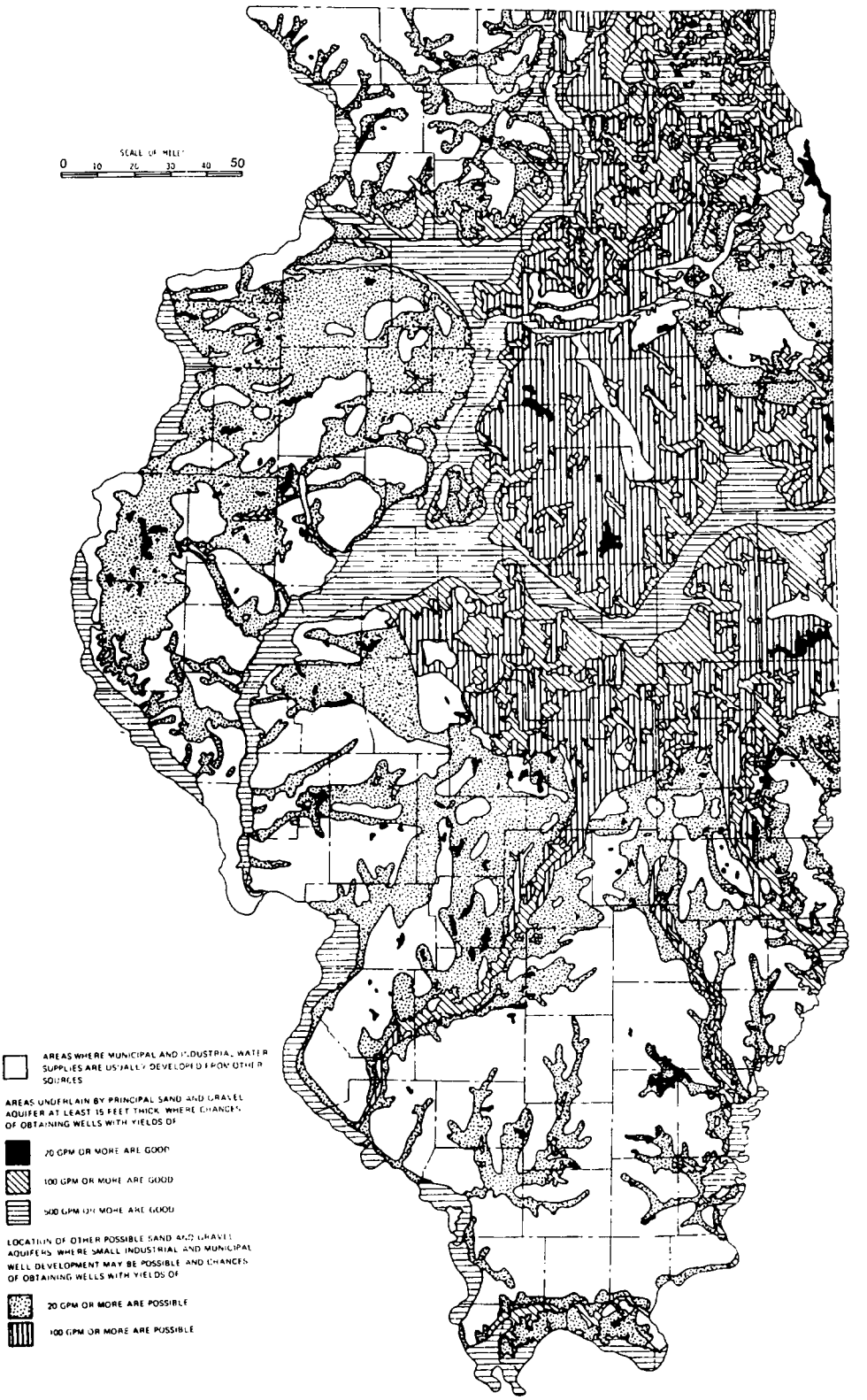
Illinois



Potentiometric surface
(ft., Datum: mean sea level)

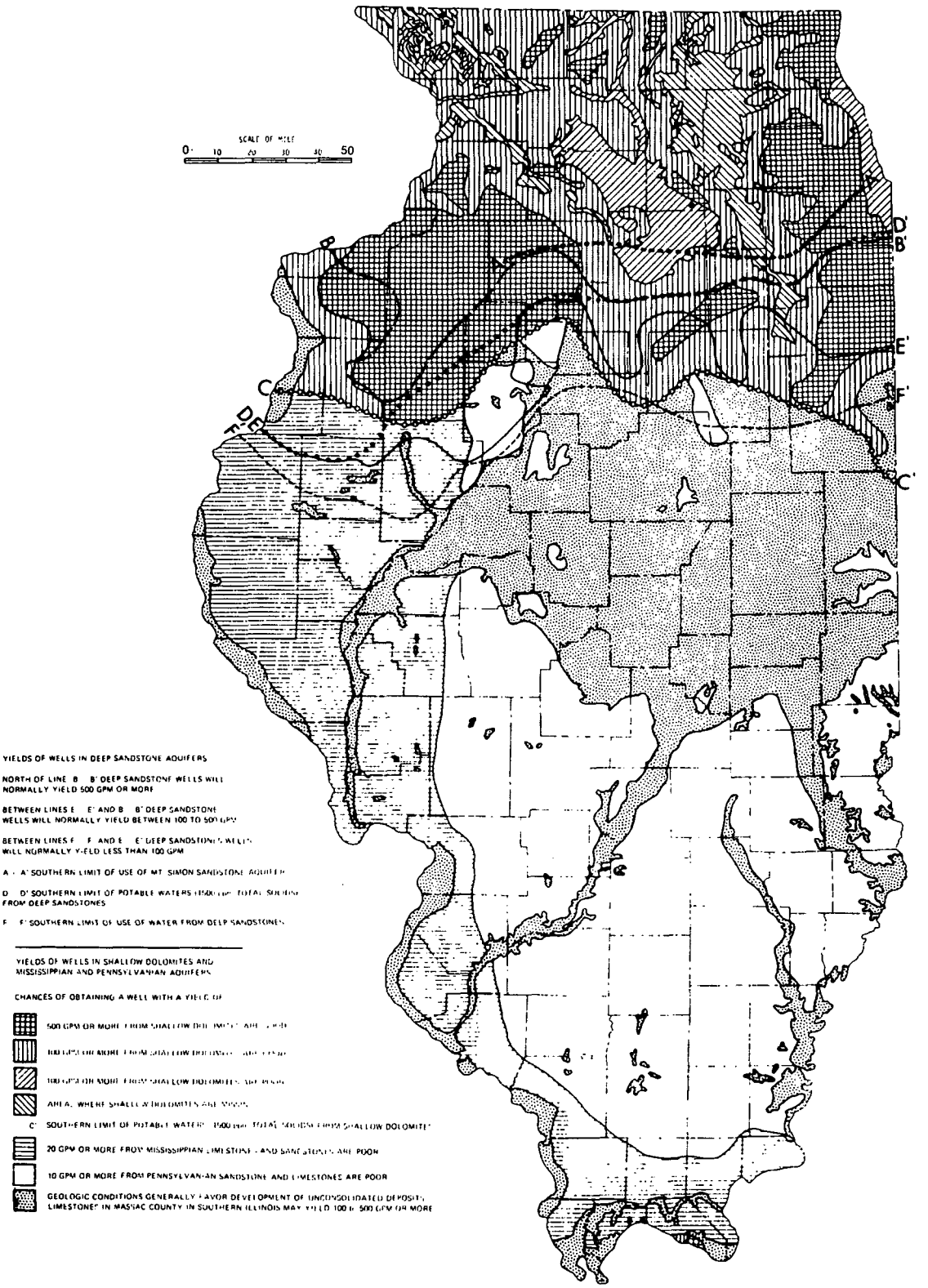
Illinois

ESTIMATED YIELDS OF WELLS IN SAND AND GRAVEL AQUIFERS



Illinois

ESTIMATED YIELDS OF WELLS IN BEDROCK AQUIFERS



Indiana

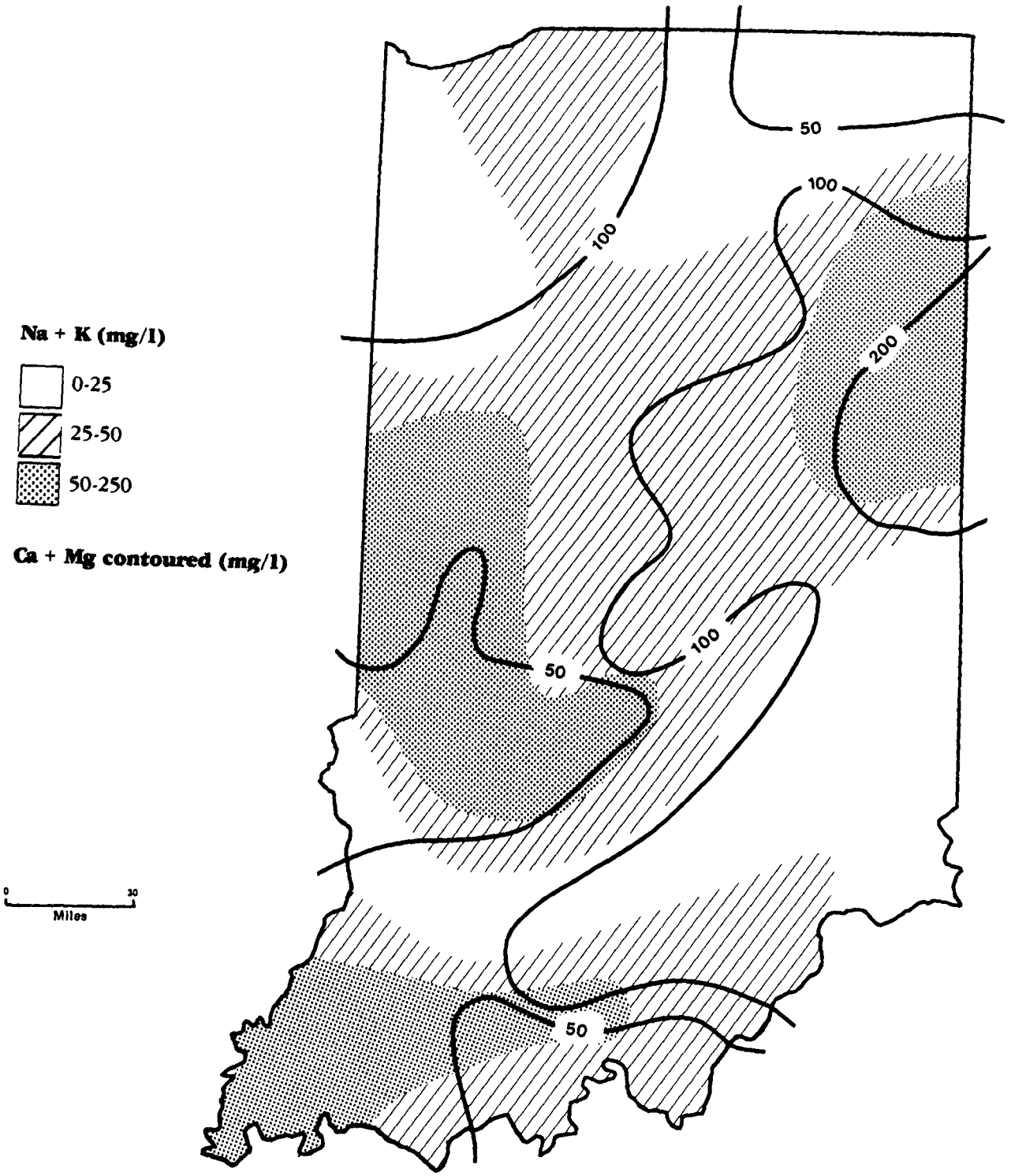


Plate 90

Indiana

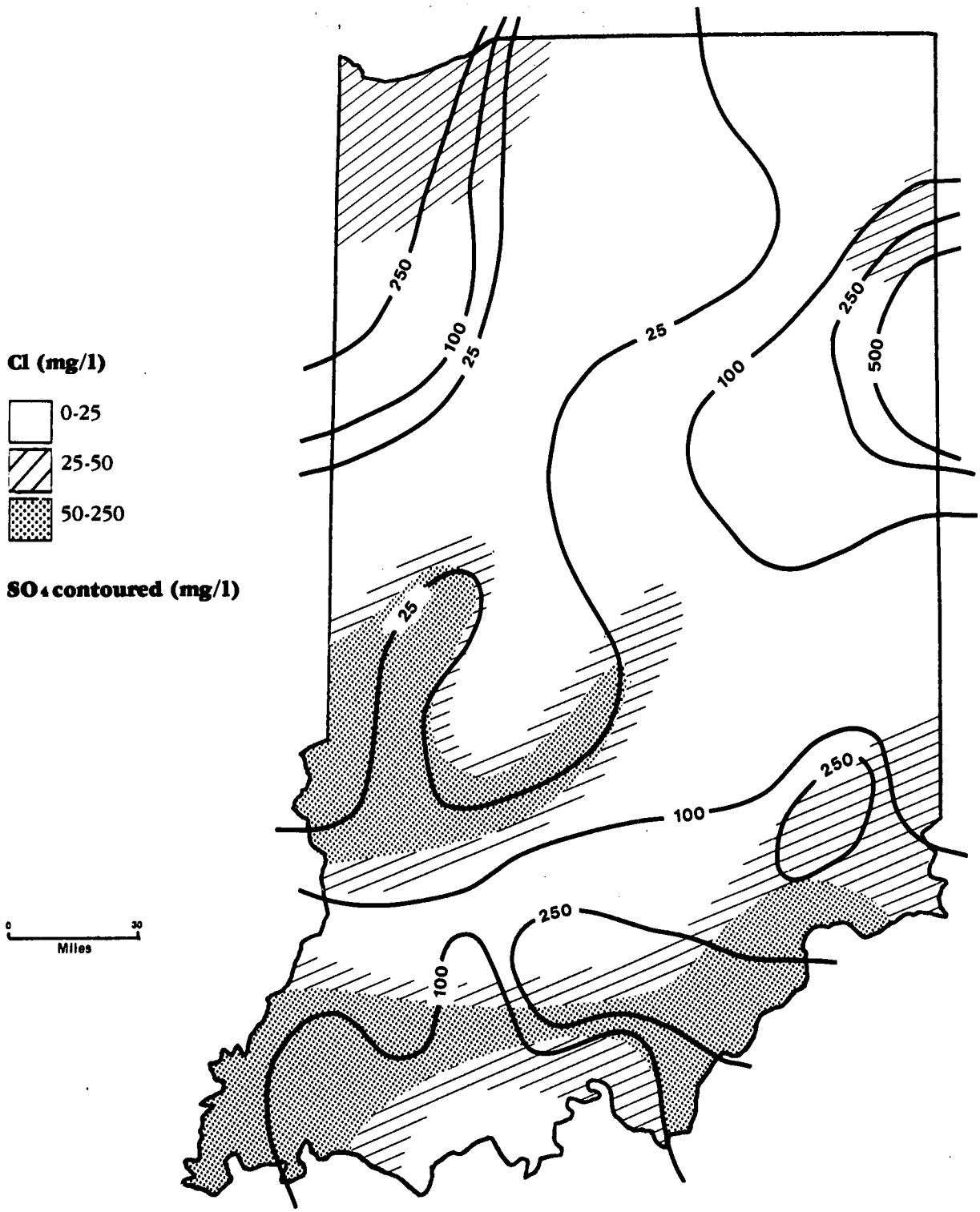
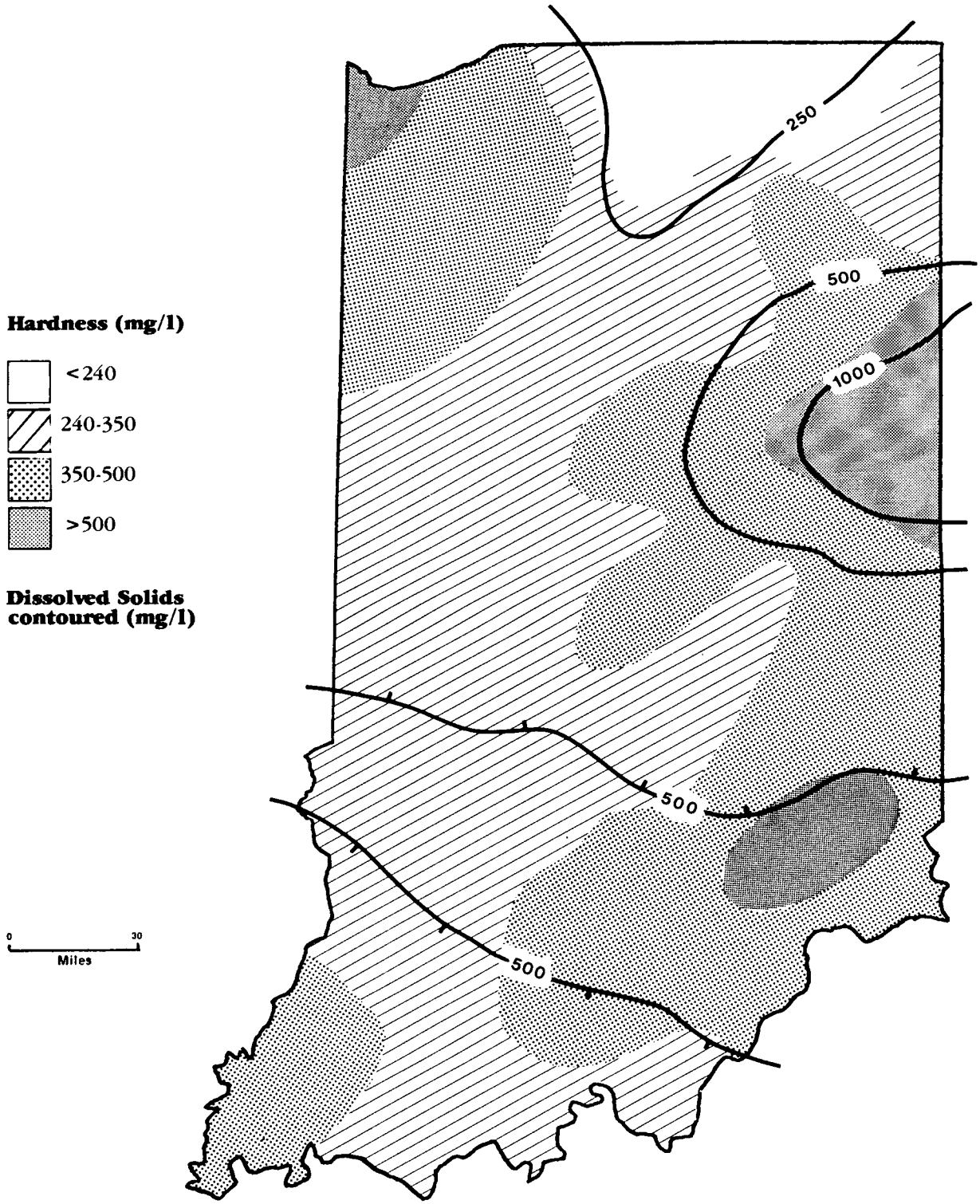


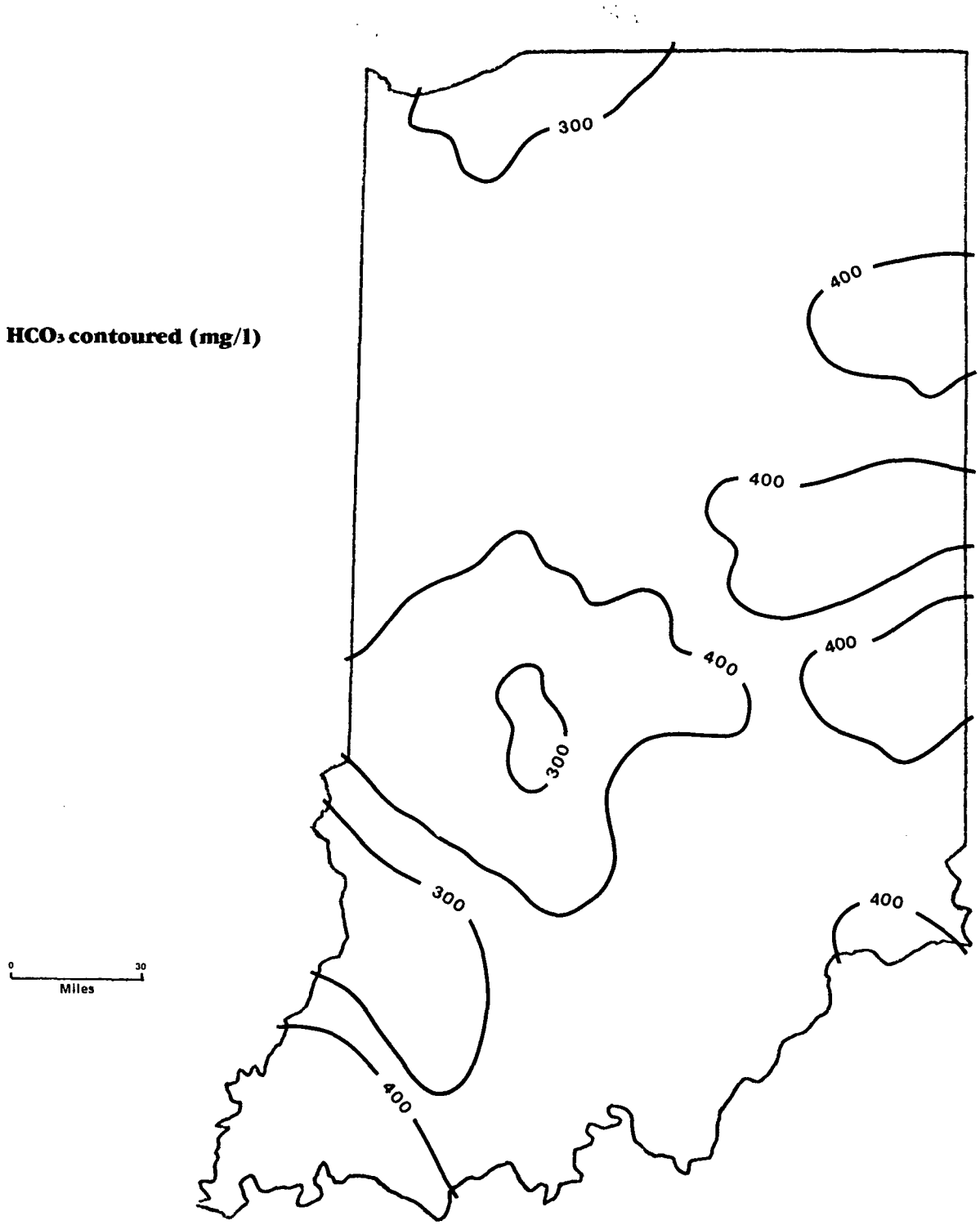
Plate 91

Indiana

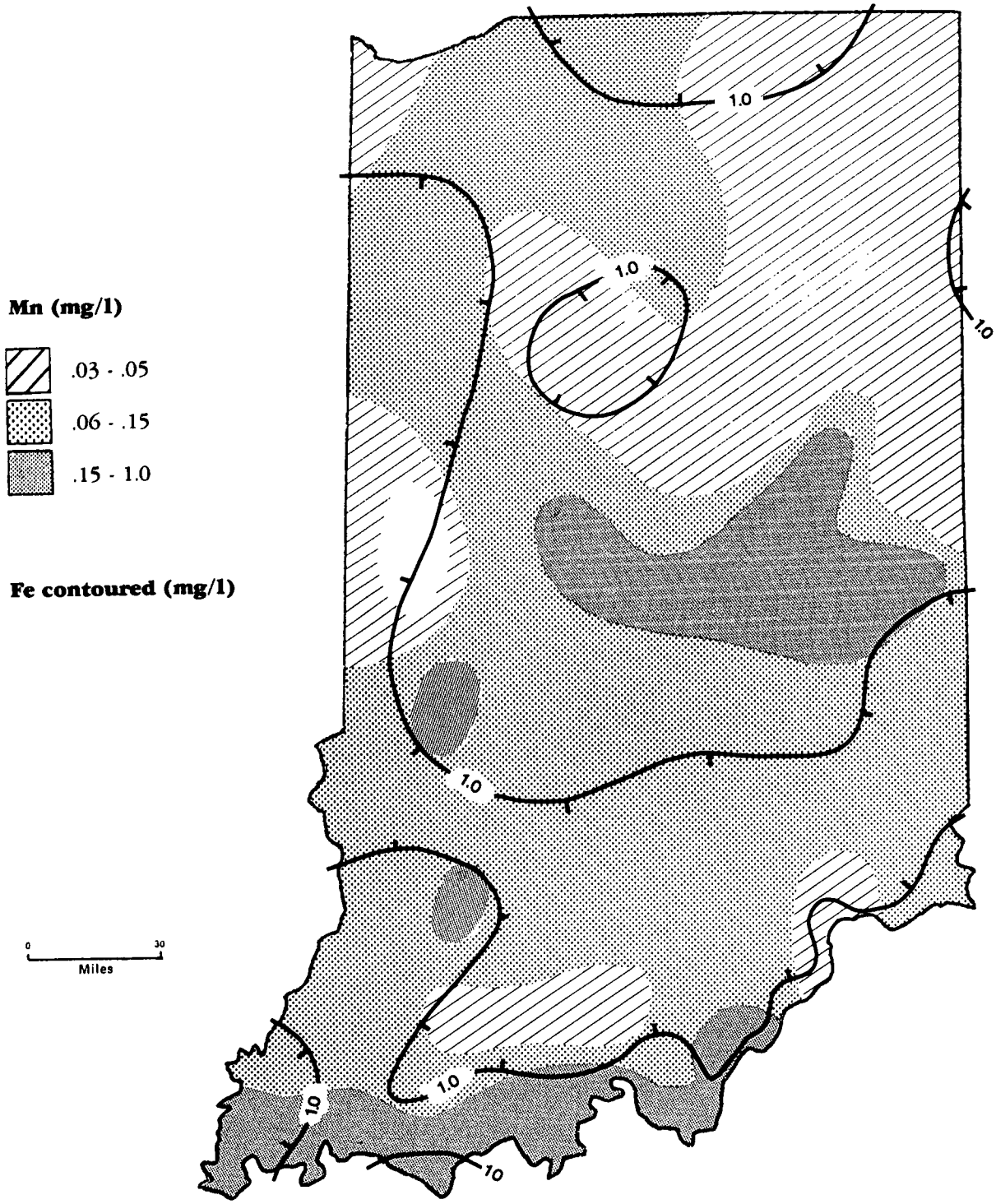

Hardness (mg/l)
<240
240-350
350-500
>500
Dissolved Solids contoured (mg/l)
250
500
1000
500
500
0
30
Miles

Indiana

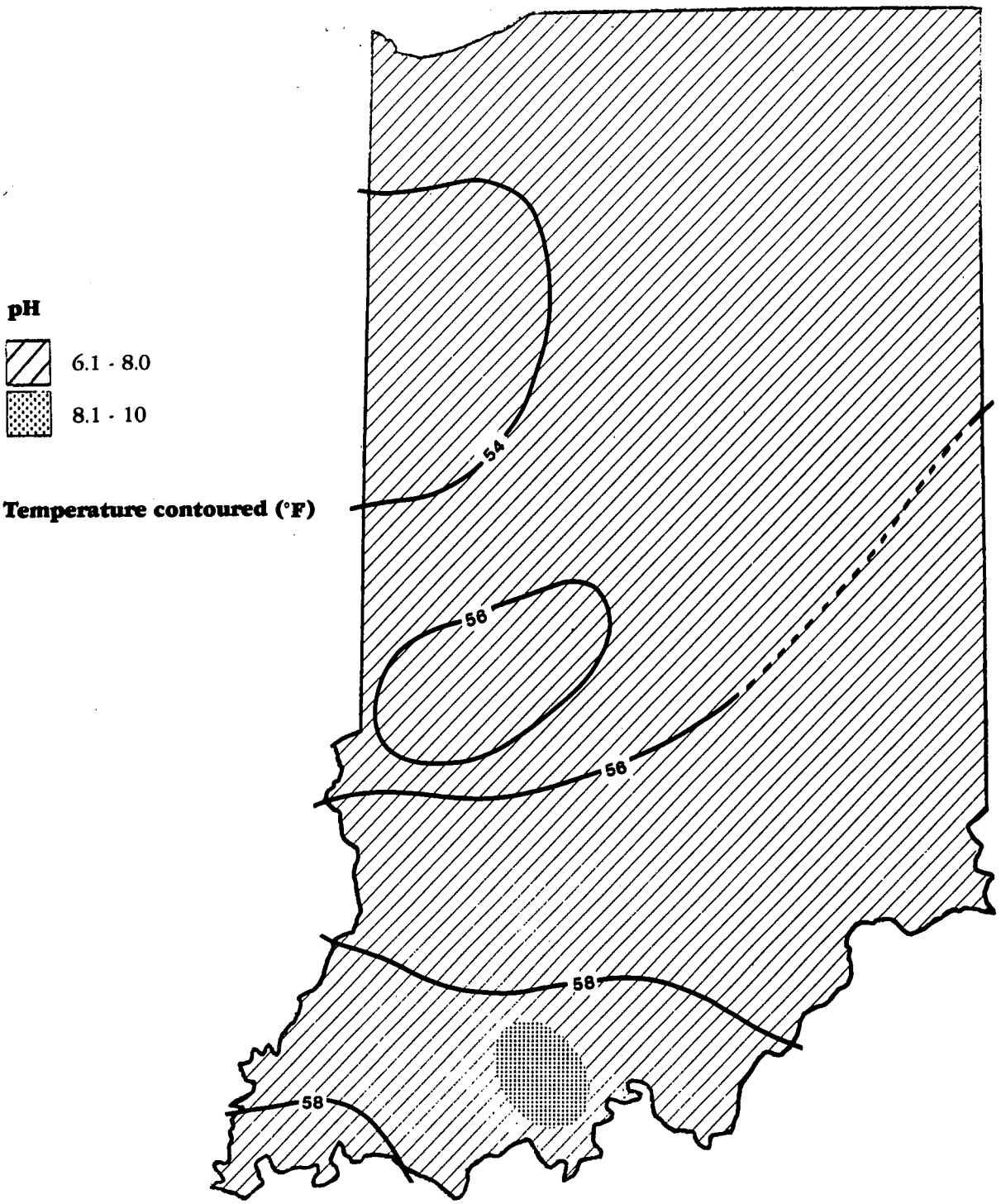
HCO_3 contoured (mg/l)



Indiana

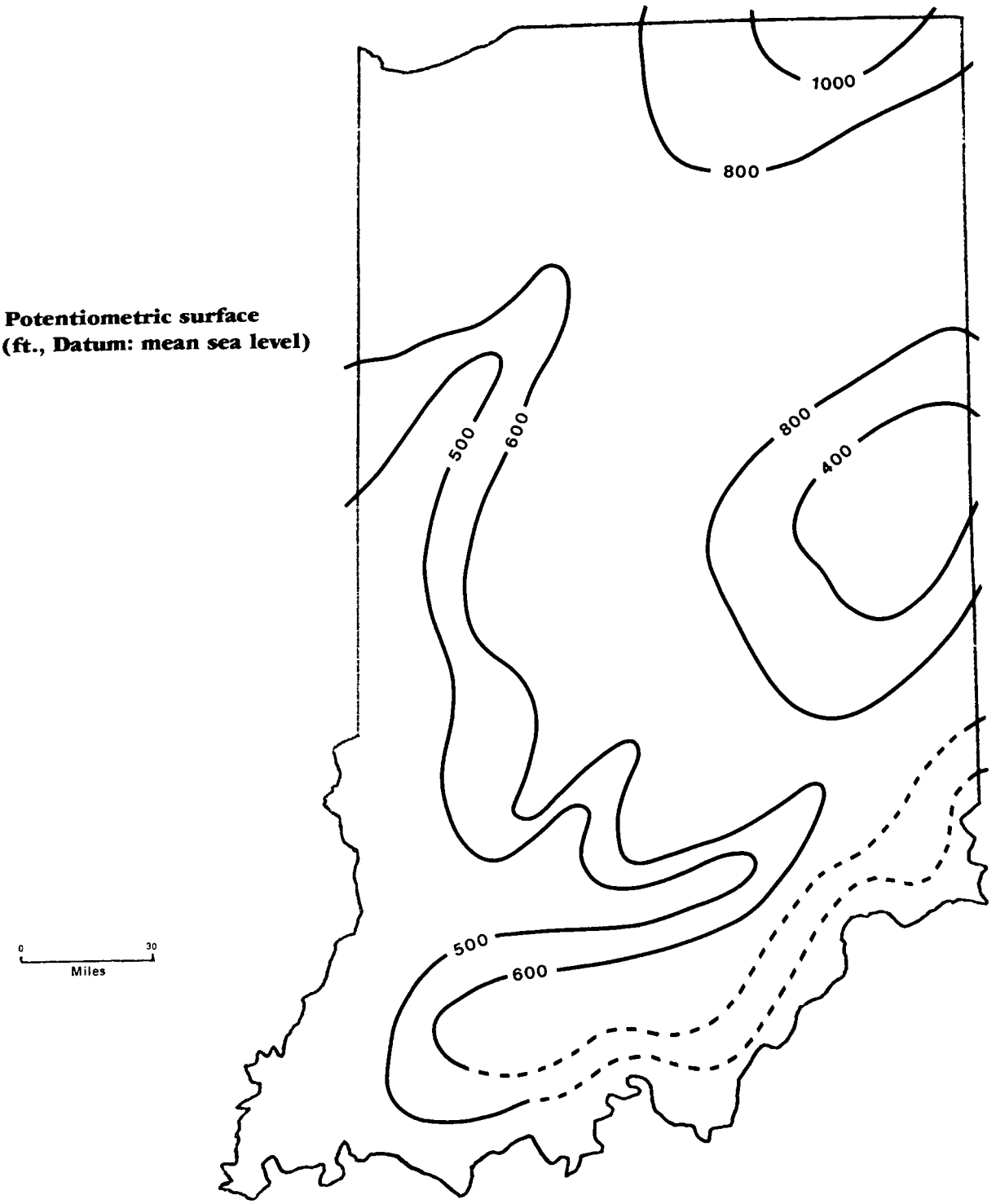

Mn (mg/l)
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
30
Miles
1.0
1.0
1.0
1.0
1.0
1.0
1.0

Indiana



Indiana

Potentiometric surface
(ft., Datum: mean sea level)



Indiana

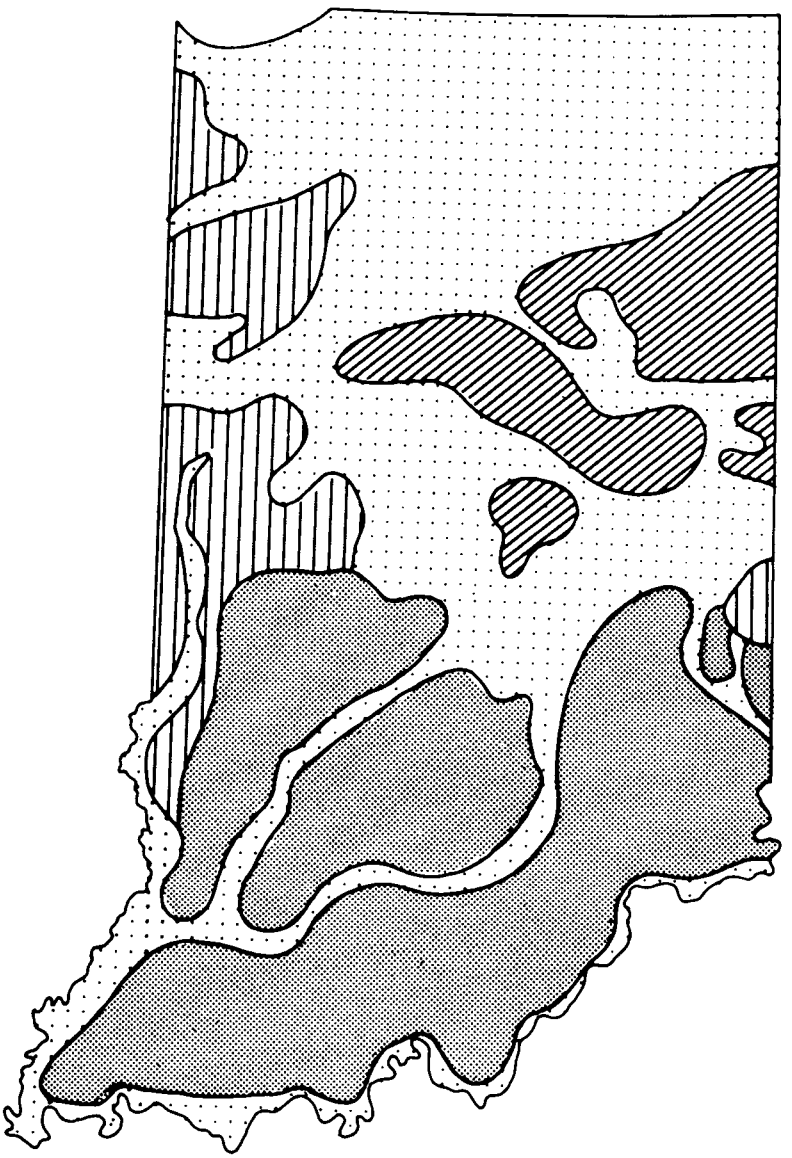
AVAILABILITY OF FRESH GROUND WATER

Production chiefly from sand or gravel. Generally yields range from about 100 to over 500 gpm Water generally contains from about 200 to about 800 mg/L dissolved solids

Production from either bedrock or sand or gravel. Generally yields range from about 100 to 500 gpm. Water generally contains from about 200 to about 800 mg/L dissolved solids

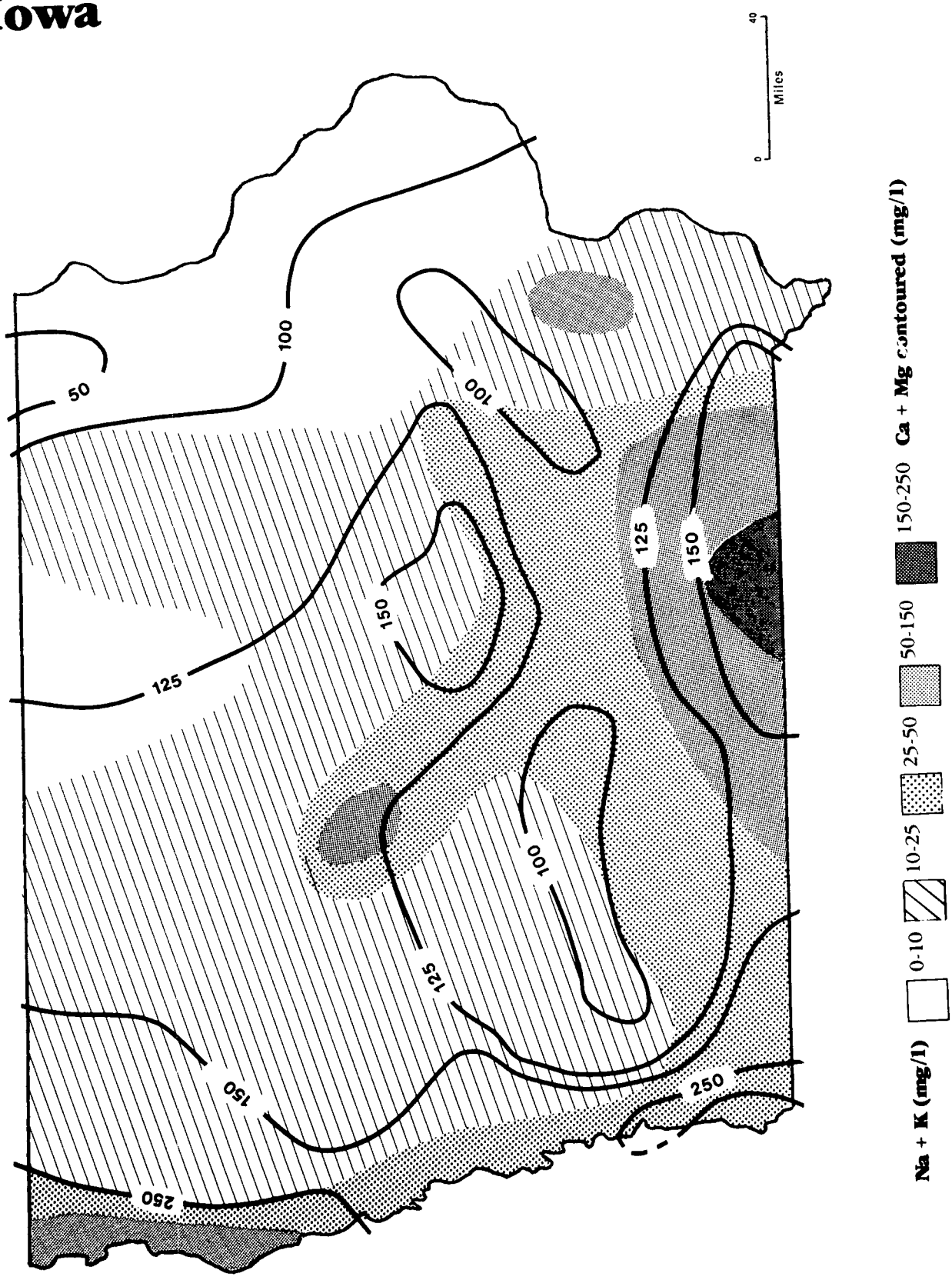
Production chiefly from bedrock. Generally yields range from about 100 to 500 gpm. Water generally contains from about 250 to about 800 mg/L dissolved solids

Production chiefly from bedrock. Generally yields range from less than 10 to about 40 gpm. Water generally contains from about 300 to about 1,000 mg/L dissolved solids



0 30
Miles

Iowa


0
40
Miles
50
100
125
150
250
Na + K (mg/l)
0-10
10-25
25-50
50-150
150-250
Ca + Mg contoured (mg/l)

Iowa

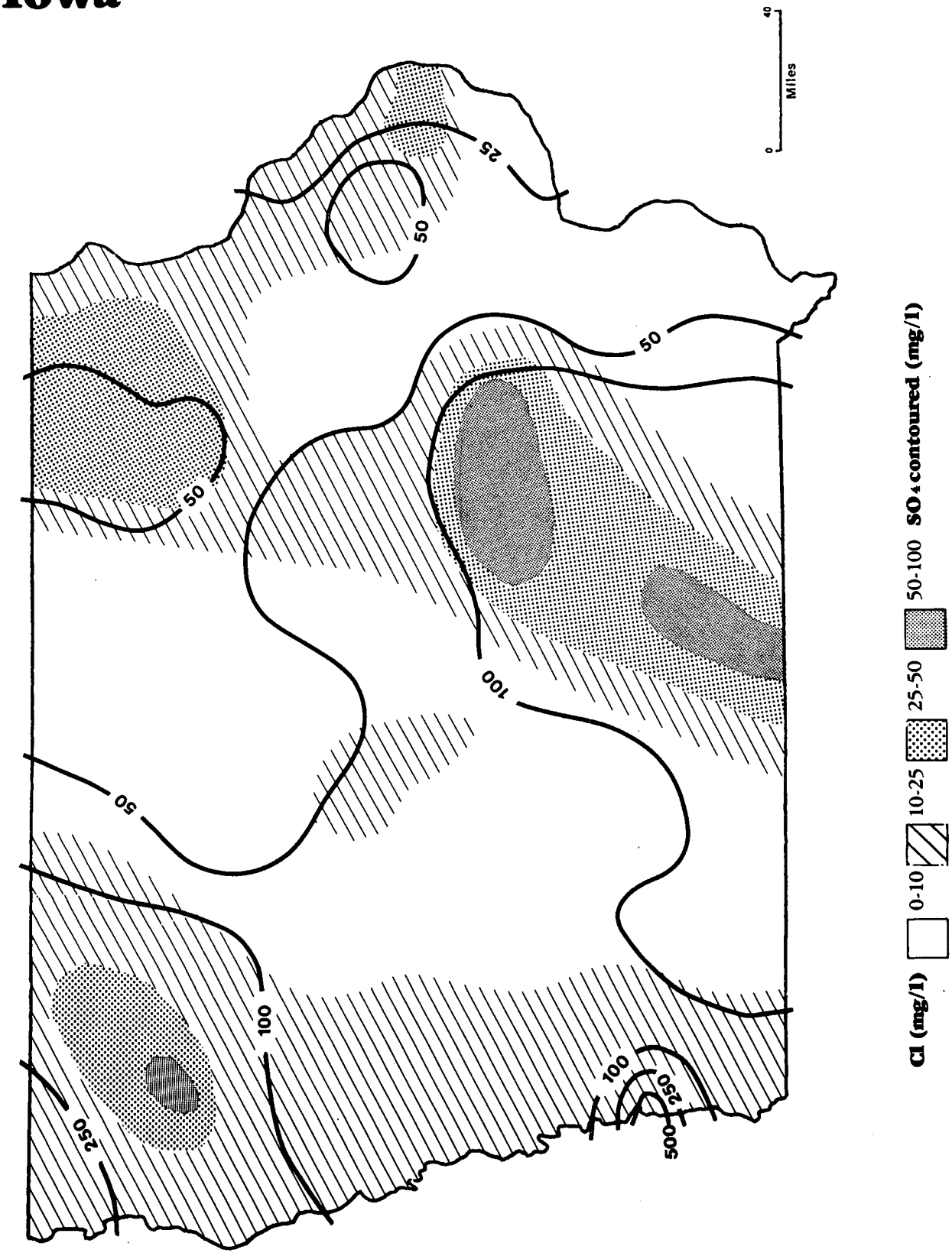


Plate 99

Iowa

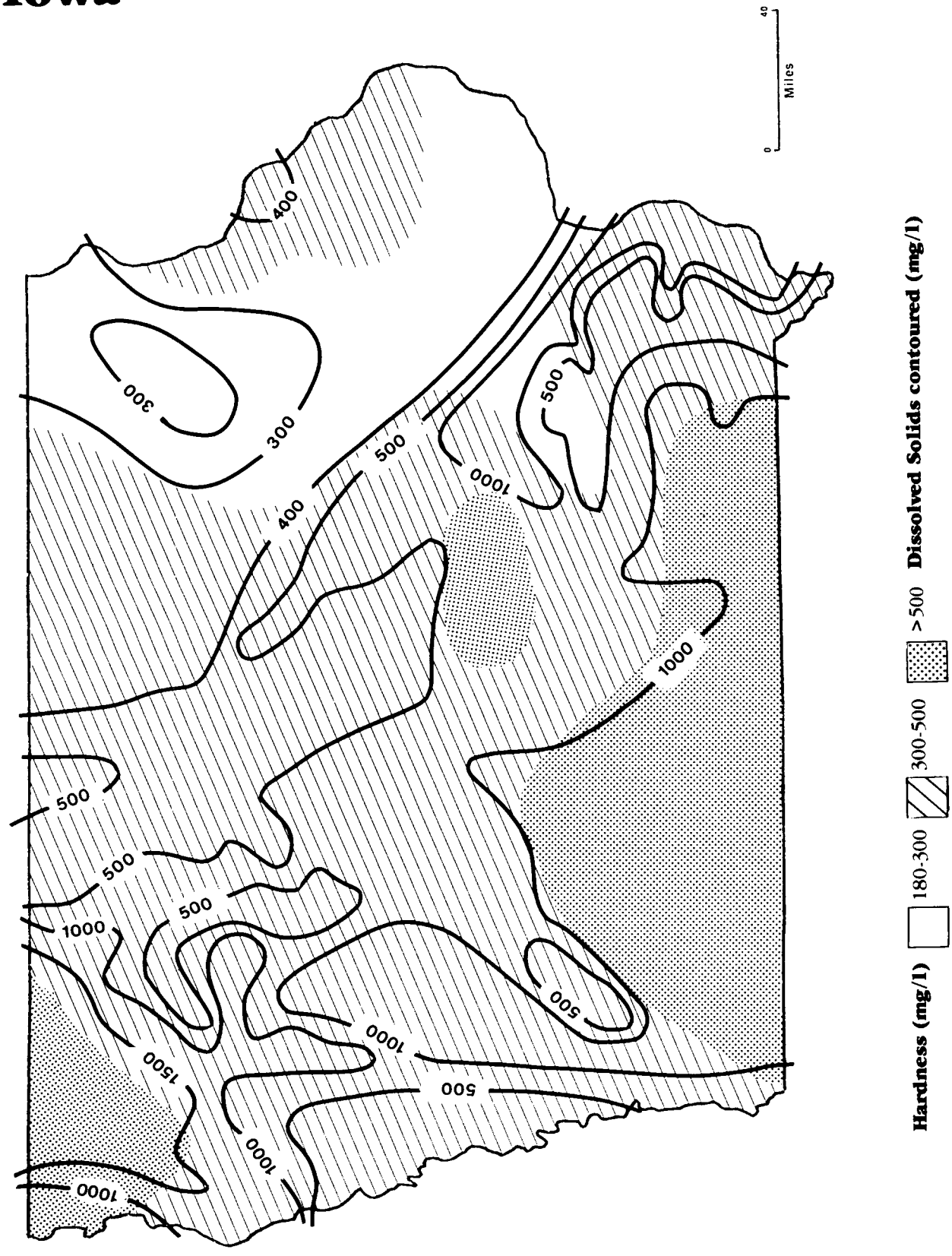
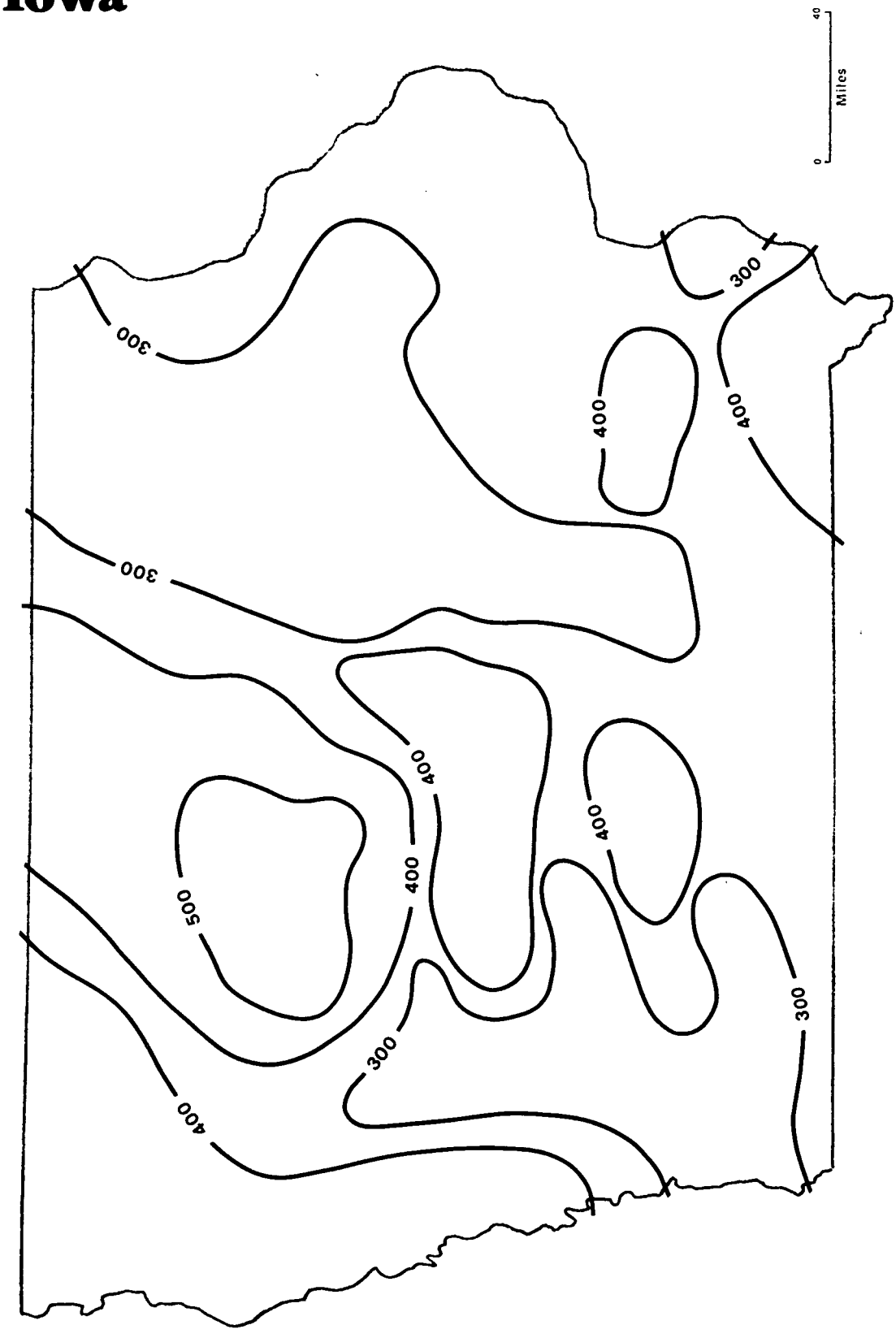


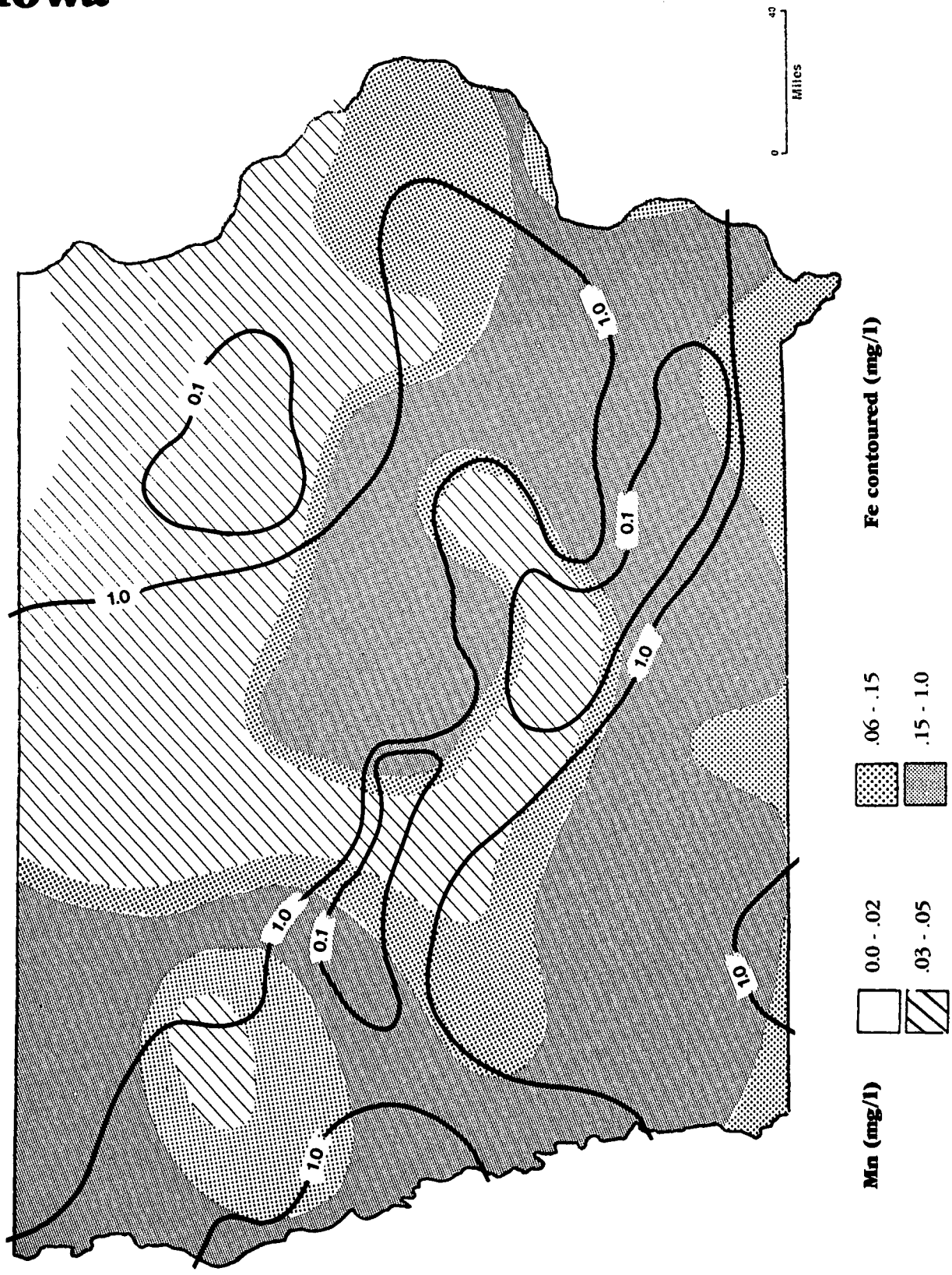
Plate 100

Iowa

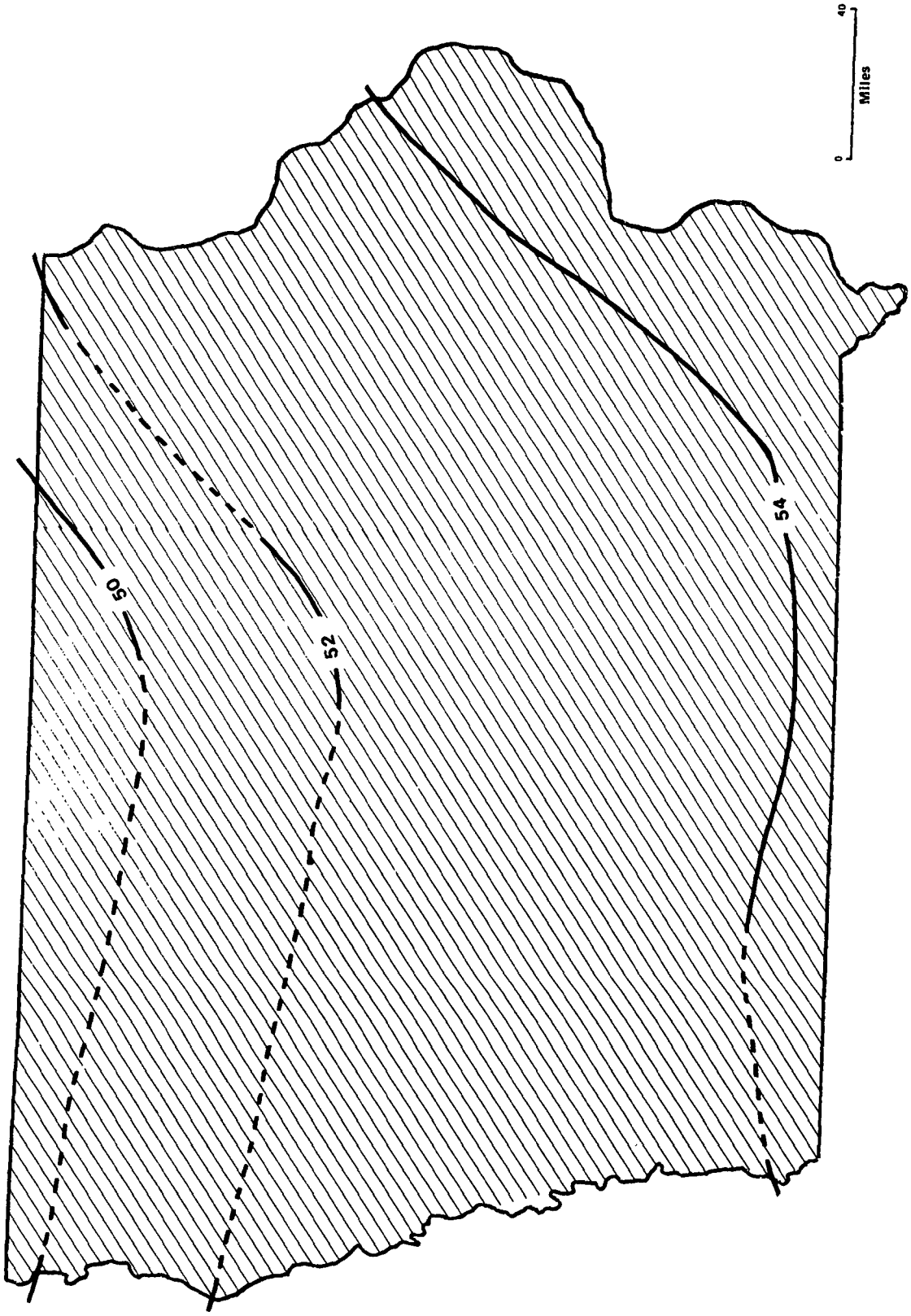


HCO_3 contoured (mg/l)

Iowa


0
40
Miles
1.0
0.1
0.1
1.0
1.0
0.1
1.0
1.0
Fe contoured (mg/l)
.06 - .15
.15 - 1.0
Mn (mg/l)
0.0 - .02
.03 - .05

Iowa

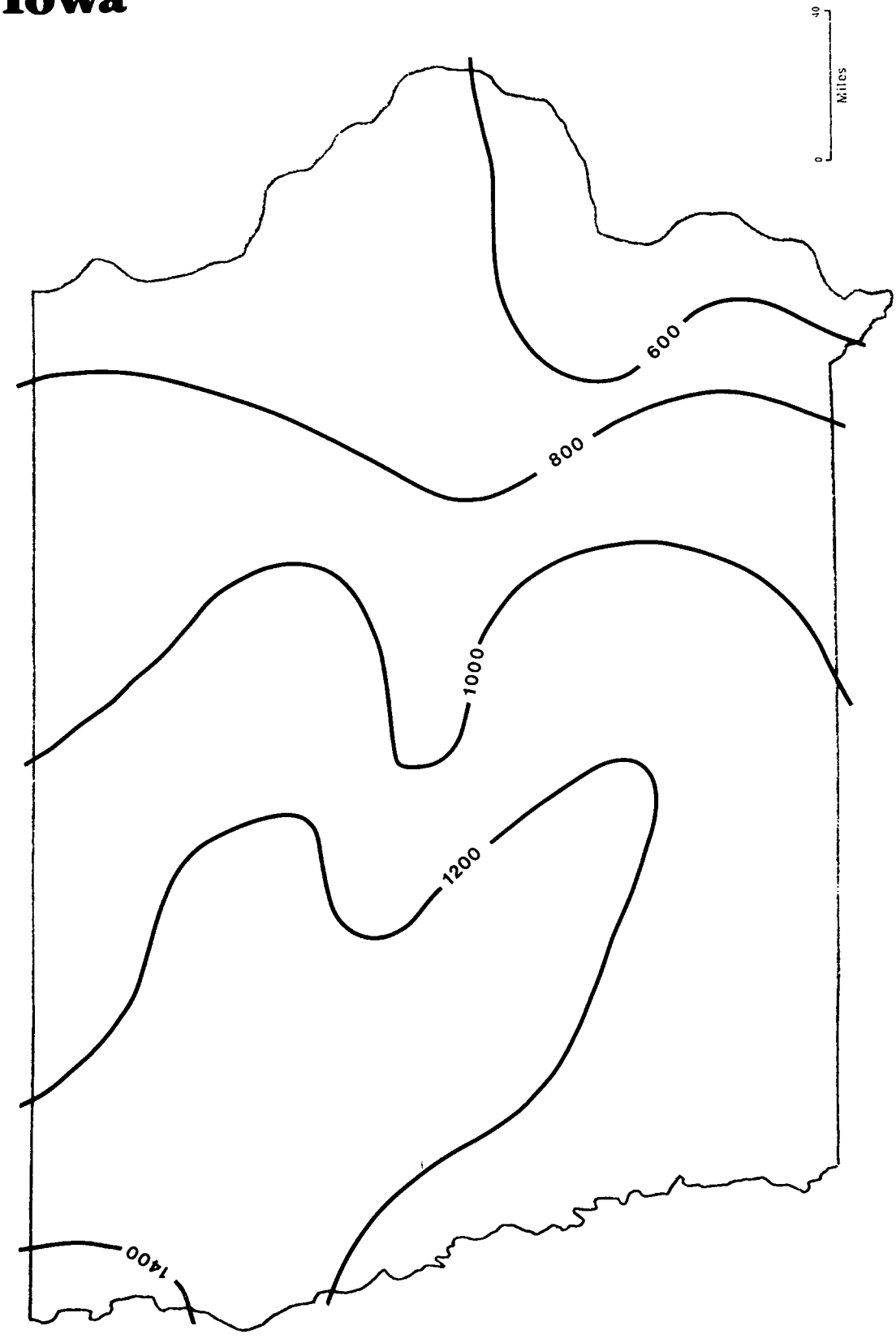


Temperature contoured (°F)

pH 6.1 - 8.0

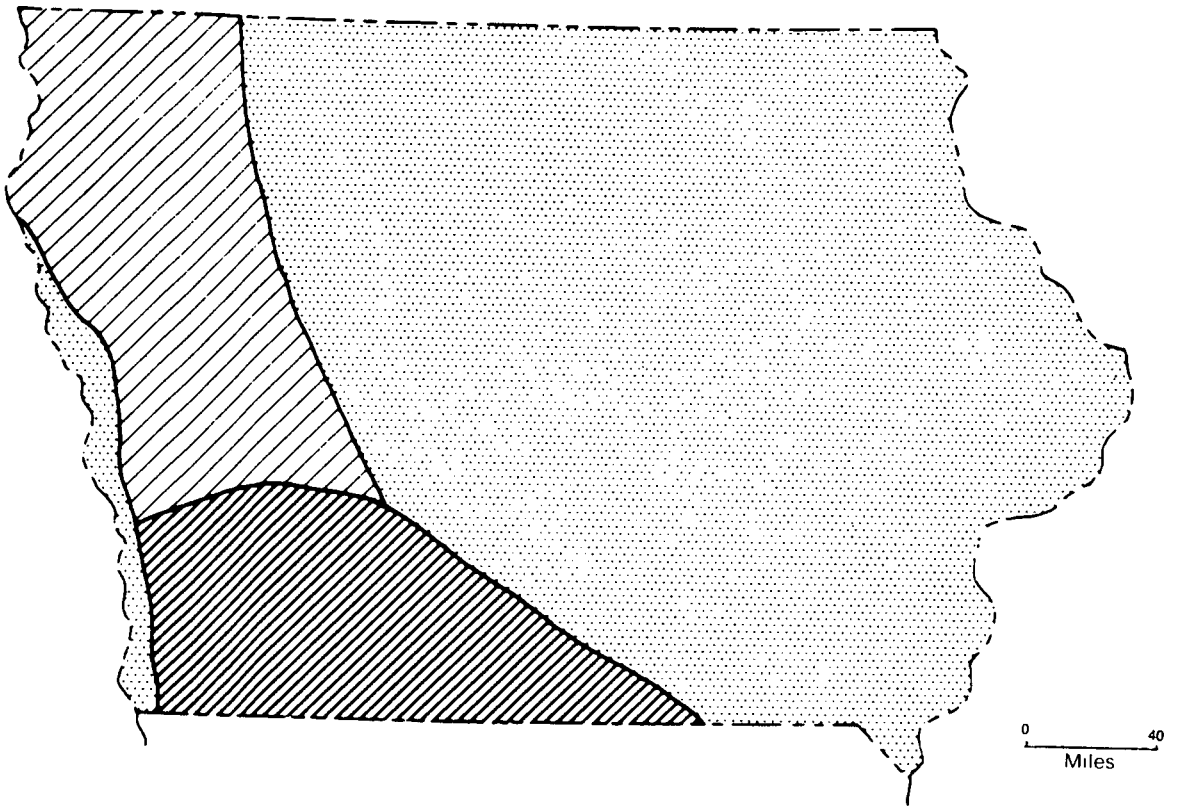
Plate 103

Iowa



Potentiometric surface (ft., Datum: mean sea level)

Iowa



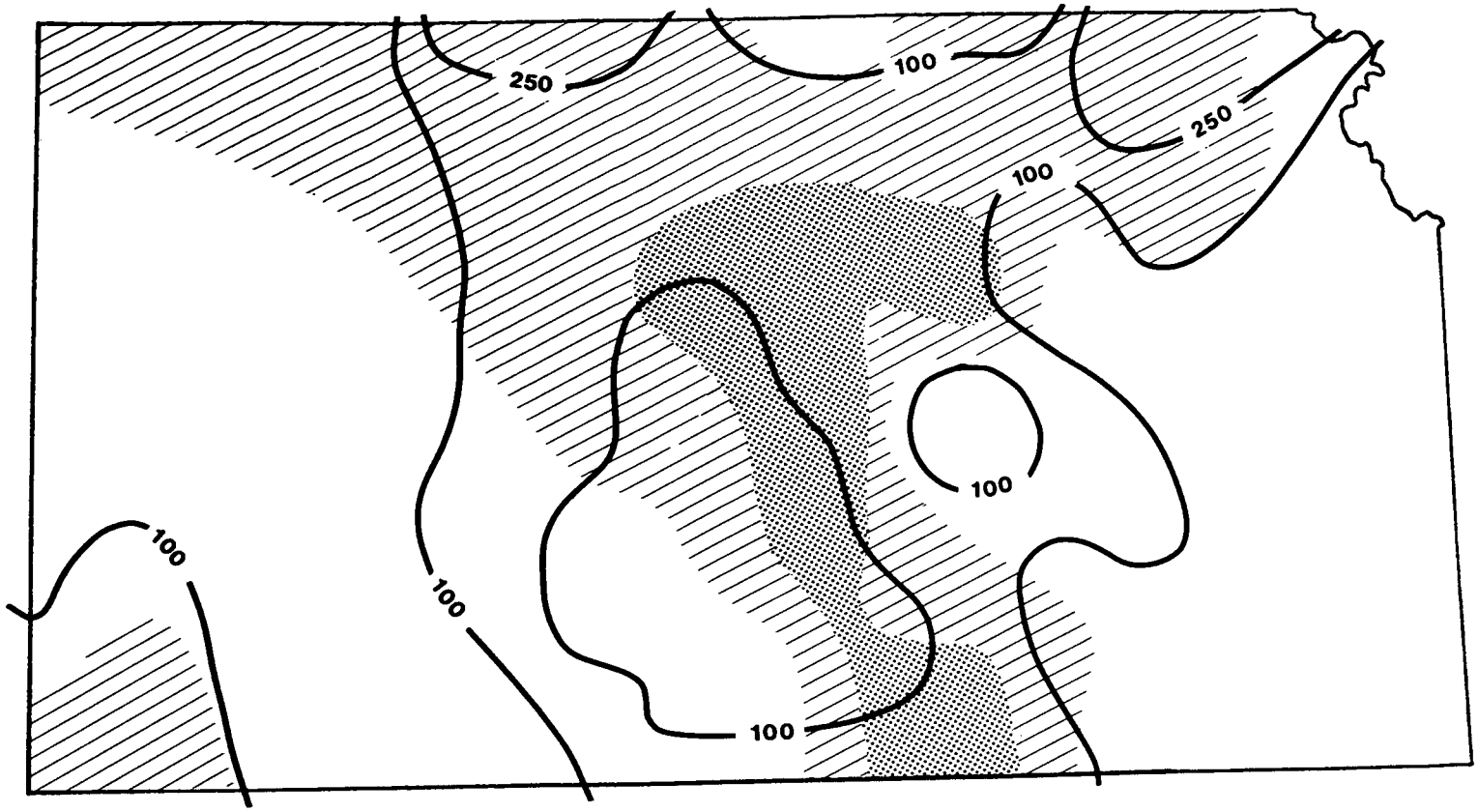
Large quantities generally available

Modest quantities; large quantities available locally

Small quantities only, except in alluvial fill

AVAILABILITY OF GROUND WATER

Kansas

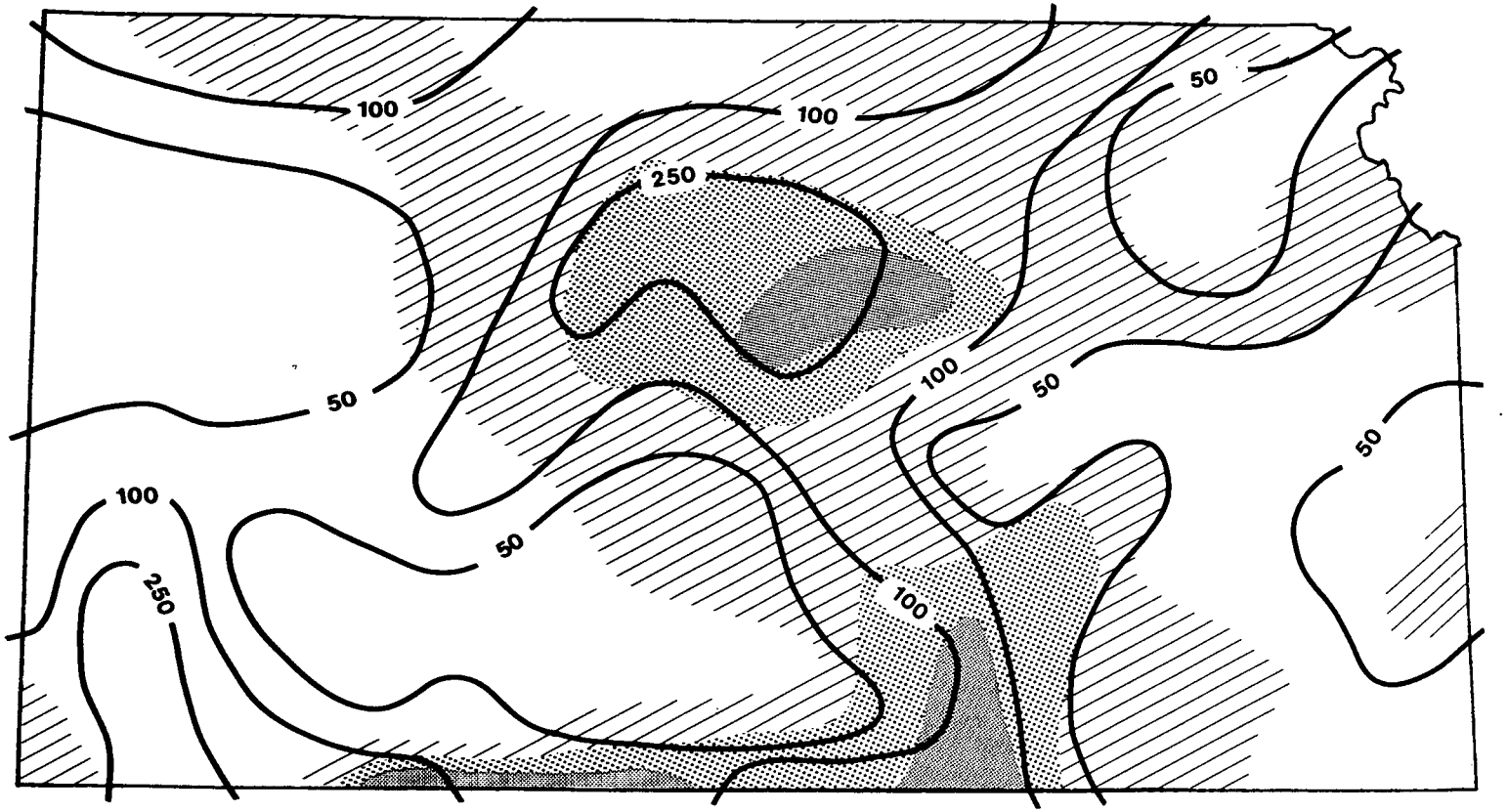


Na + K (mg/l)

- 0-50
- 50-100
- 100-250

Ca + Mg contoured (mg/l)

Kansas

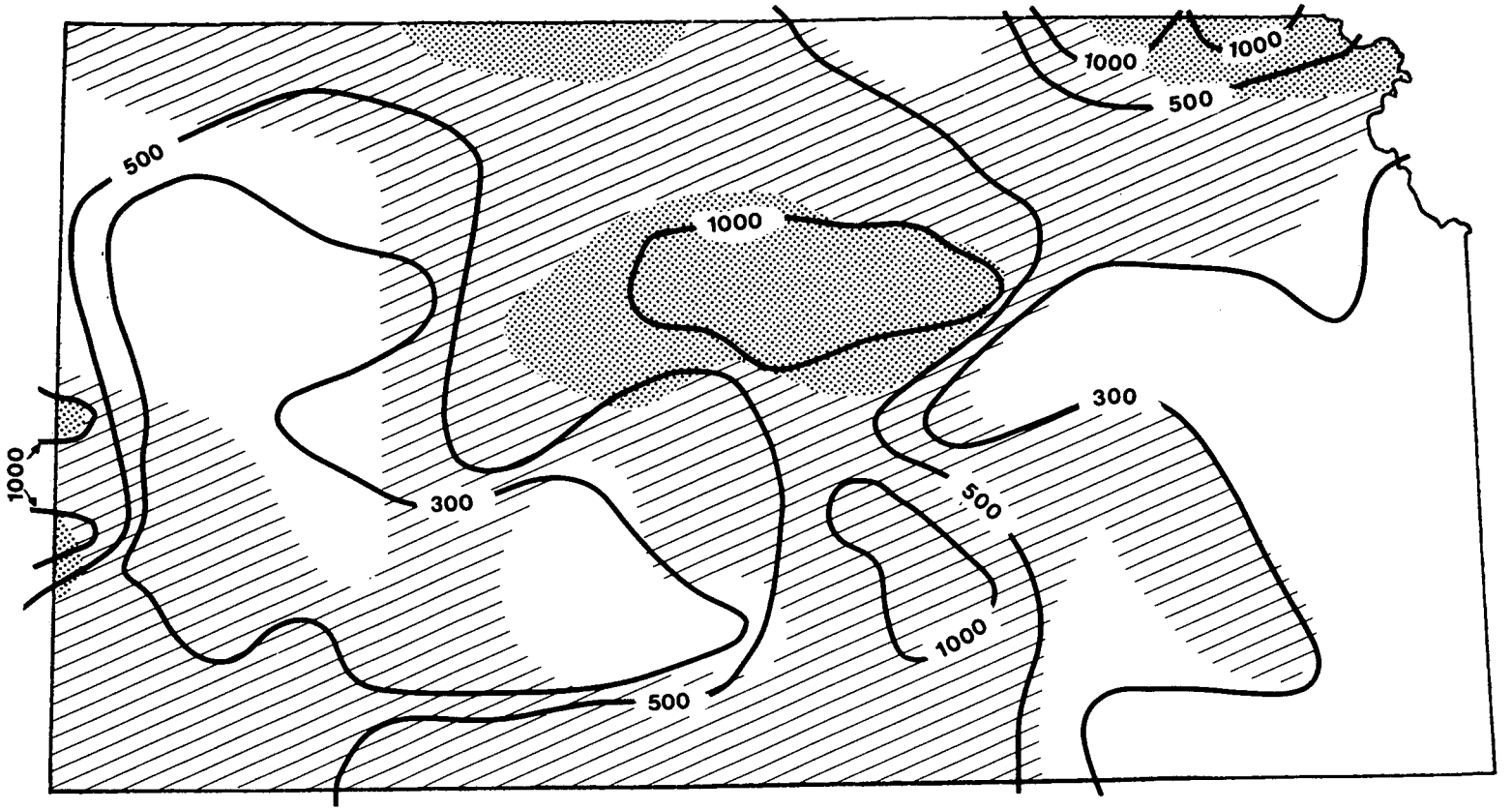


Cl (mg/l)

- 0-25
- 25-100
- 100-250
- 250-500

SO_4 contoured (mg/l)

Kansas



0 50
Miles

Hardness (mg/l)

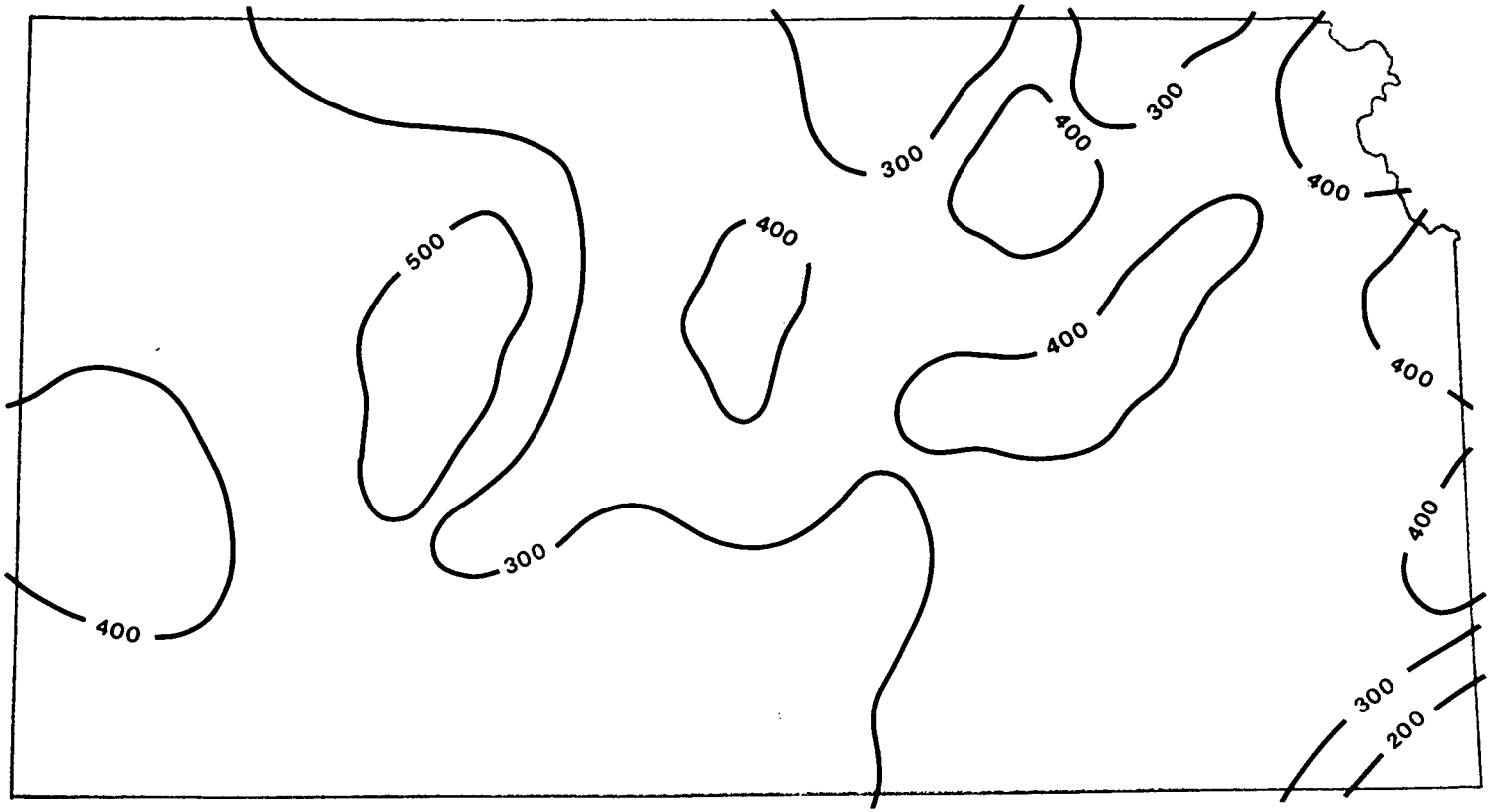
120-240

240-400

400-750

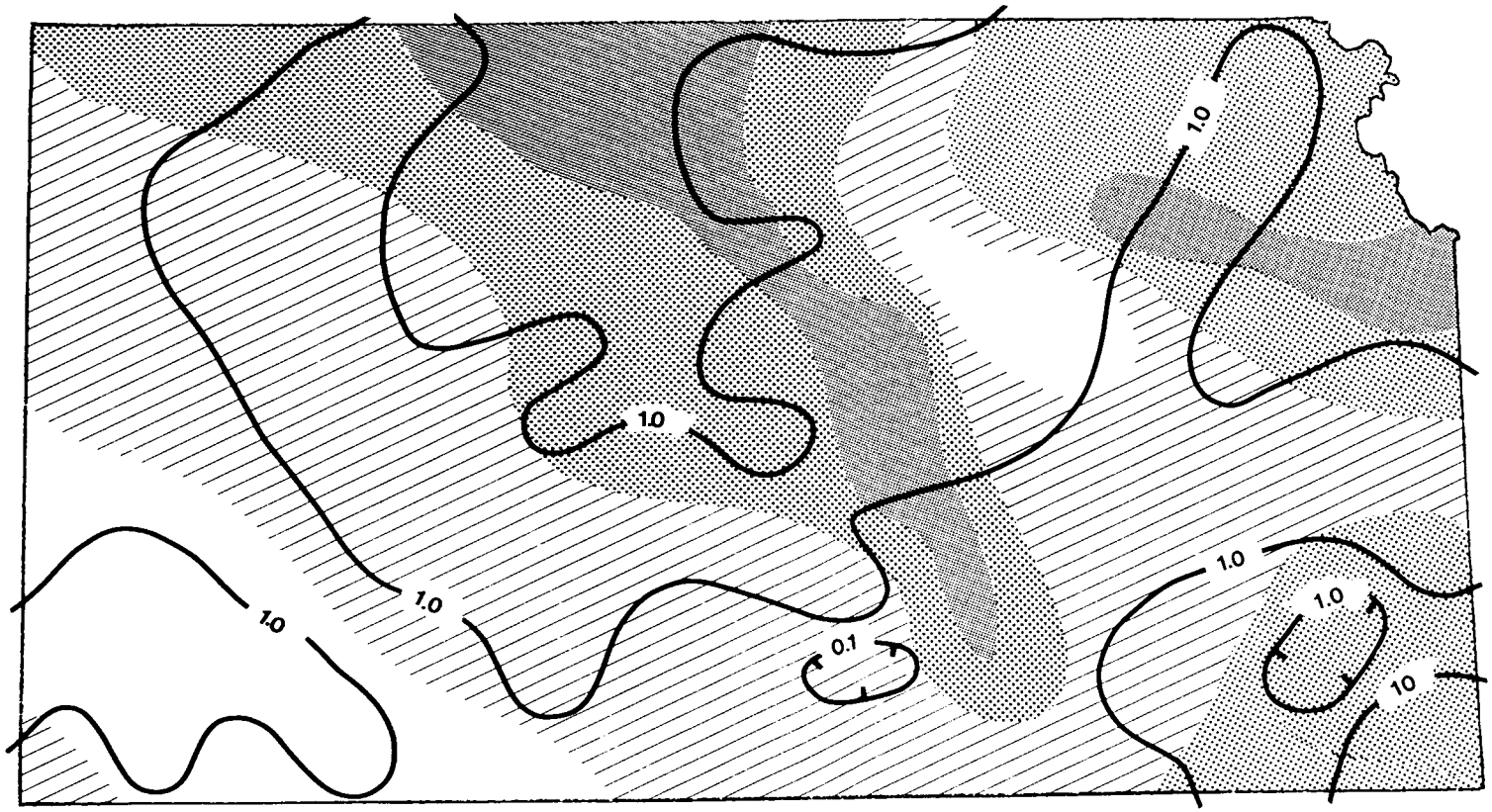
Dissolved Solids contoured (mg/l)

Kansas



HCO_3 contoured (mg/l)

Kansas



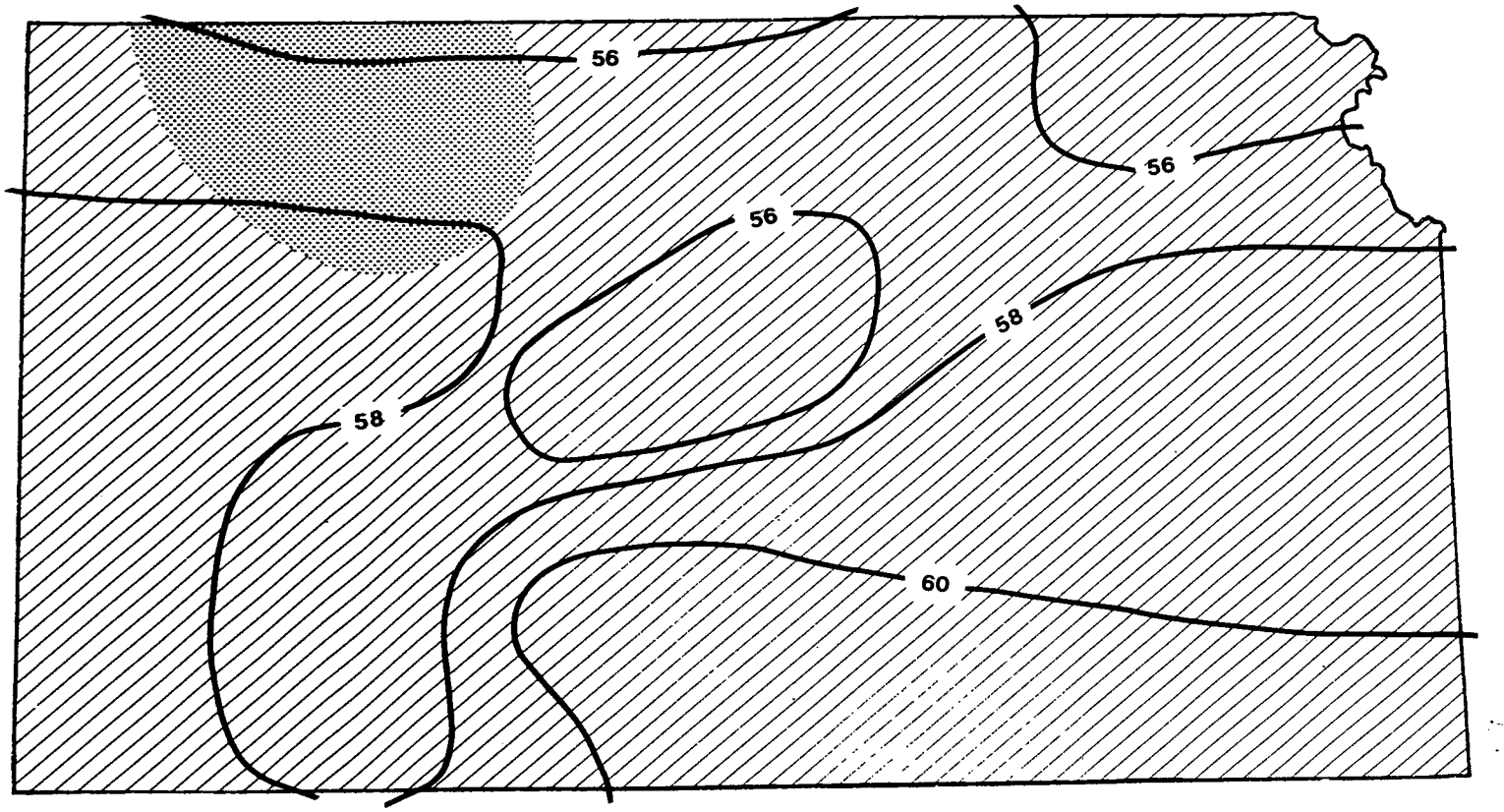
0 50
Miles

Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Kansas



0 50
Miles

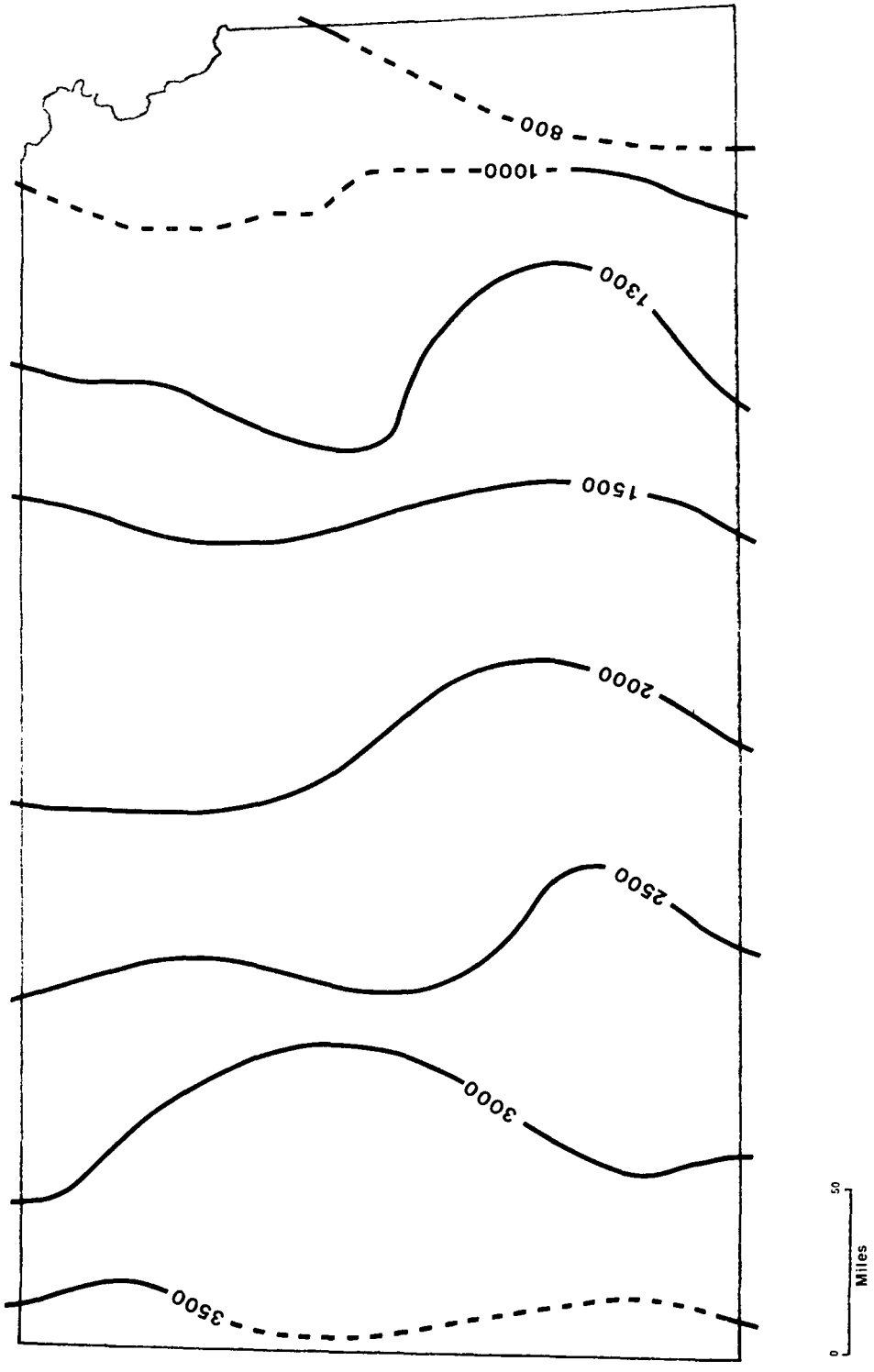
pH

6.1 - 8.0

8.1 - 10

Temperature contoured (°F)

Kansas



Potentiometric surface (ft., Datum: mean sea level)

Kansas

0 50
Miles

Yield (gpm)

- Less than 50 gpm
- 50-500 gpm
- Greater than 500 gpm

Kentucky

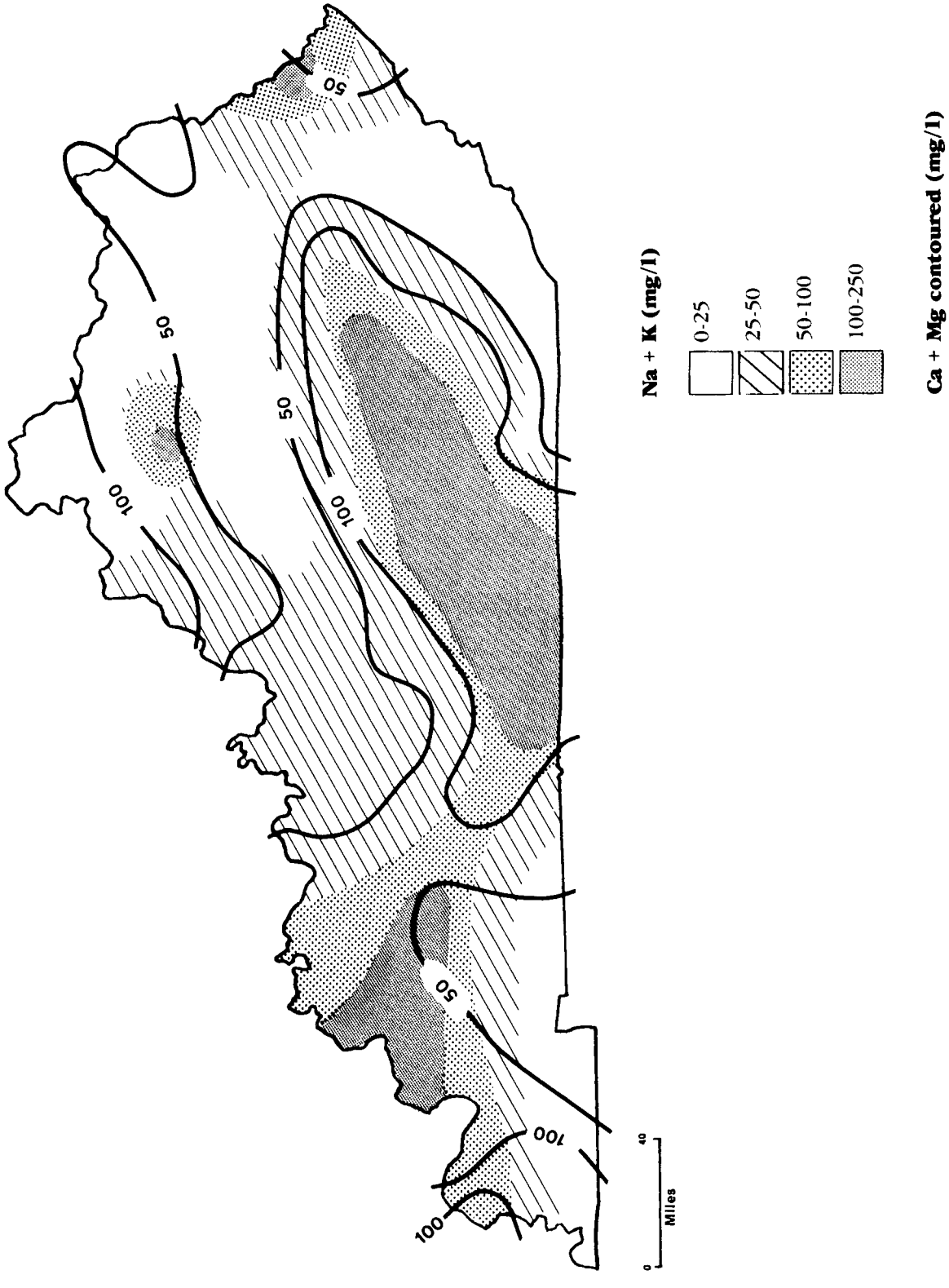


Plate 114

Kentucky

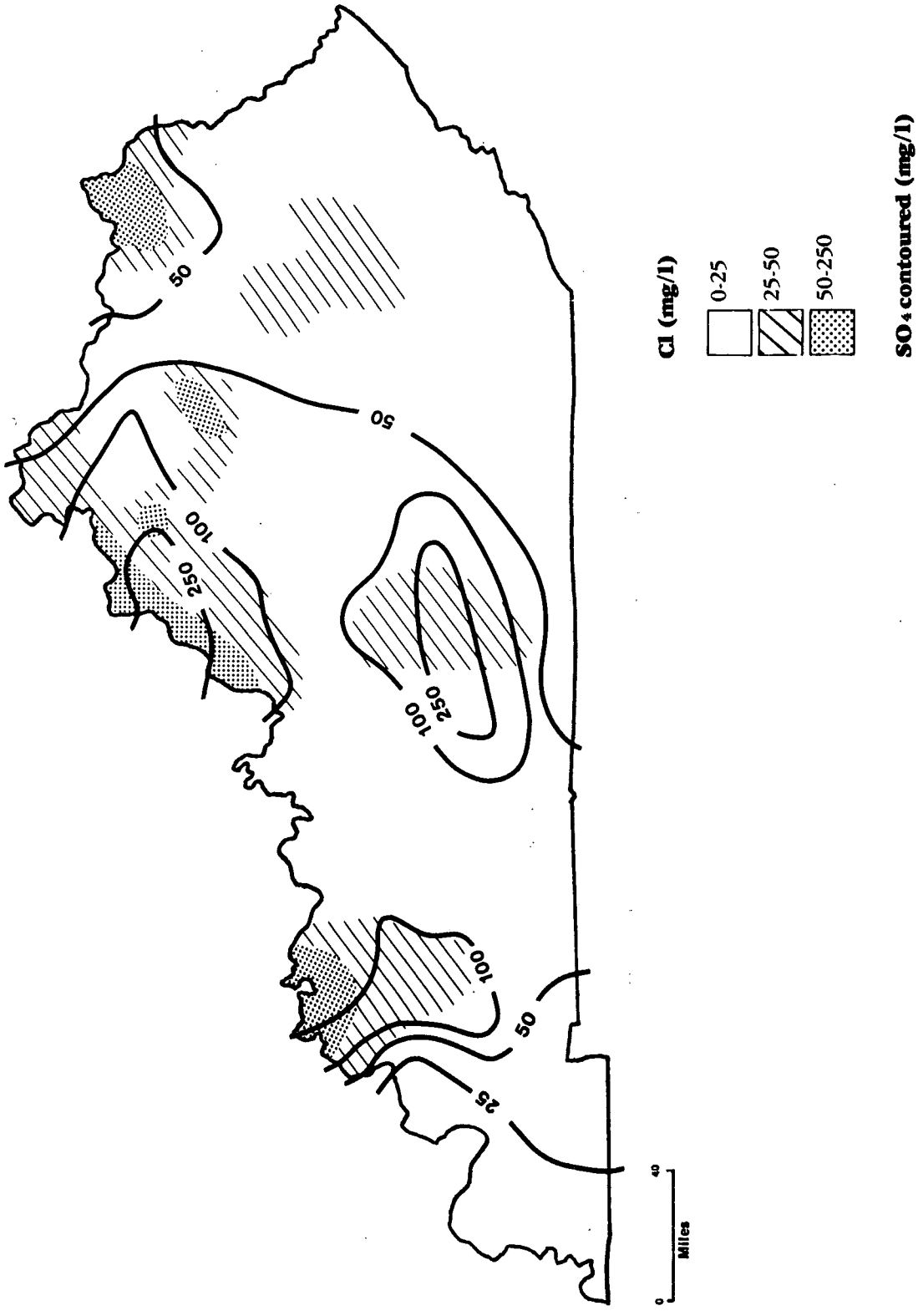
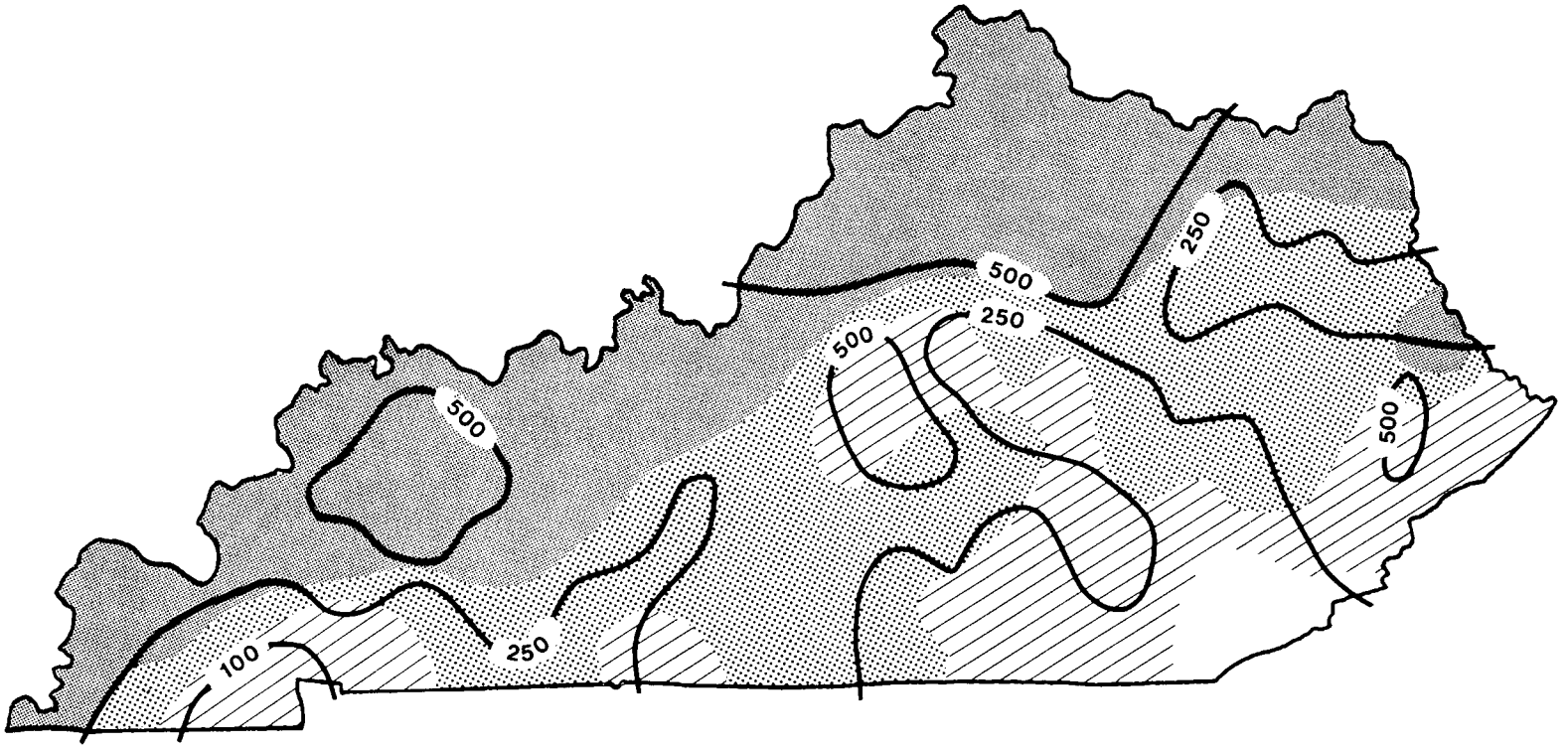


Plate 115

Kentucky



0 40
Miles

Hardness (mg/l)

- <120
- 120-180
- 180-240
- 240-500
- >500

Dissolved Solids contoured (mg/l)

Kentucky

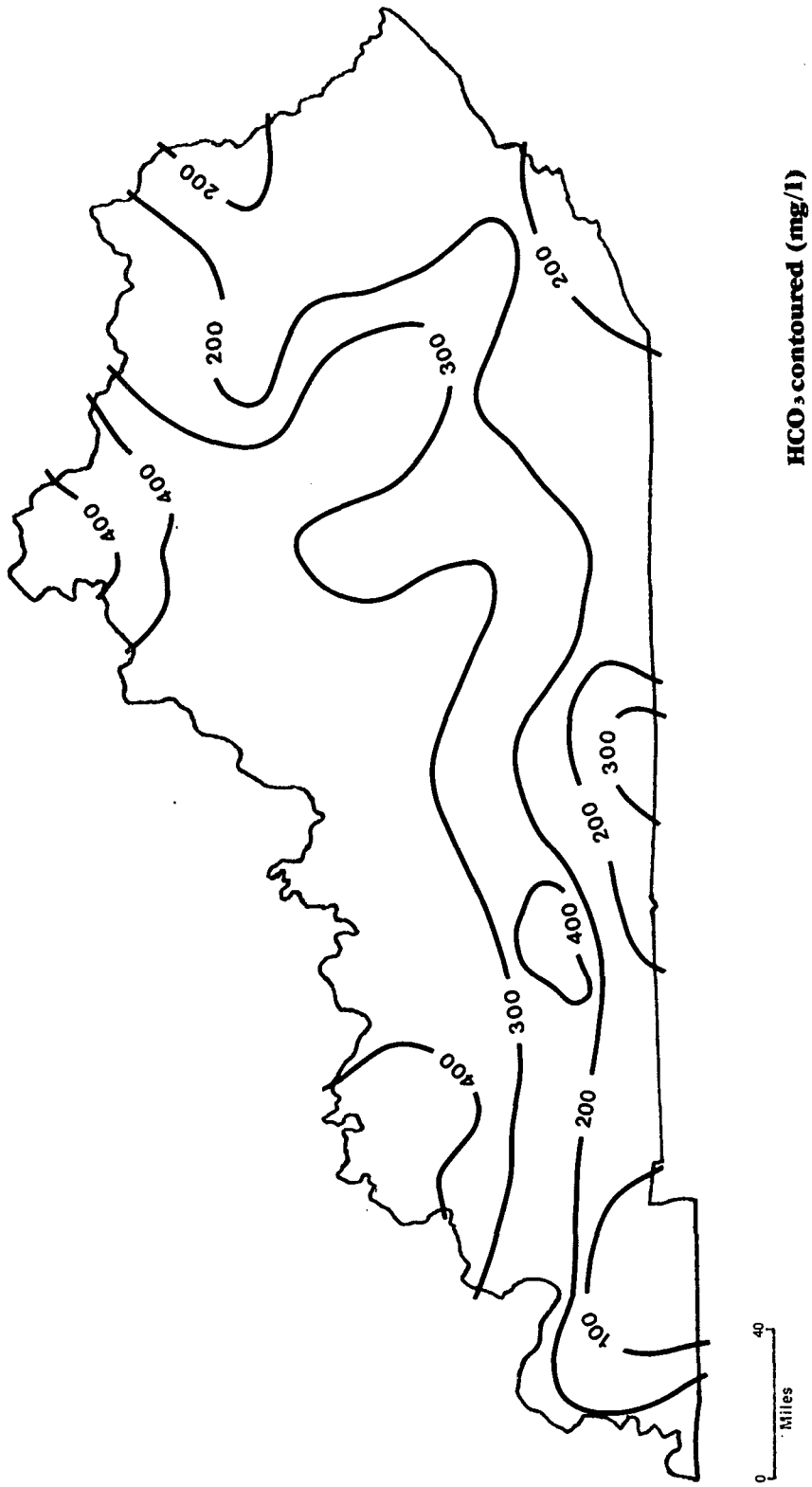
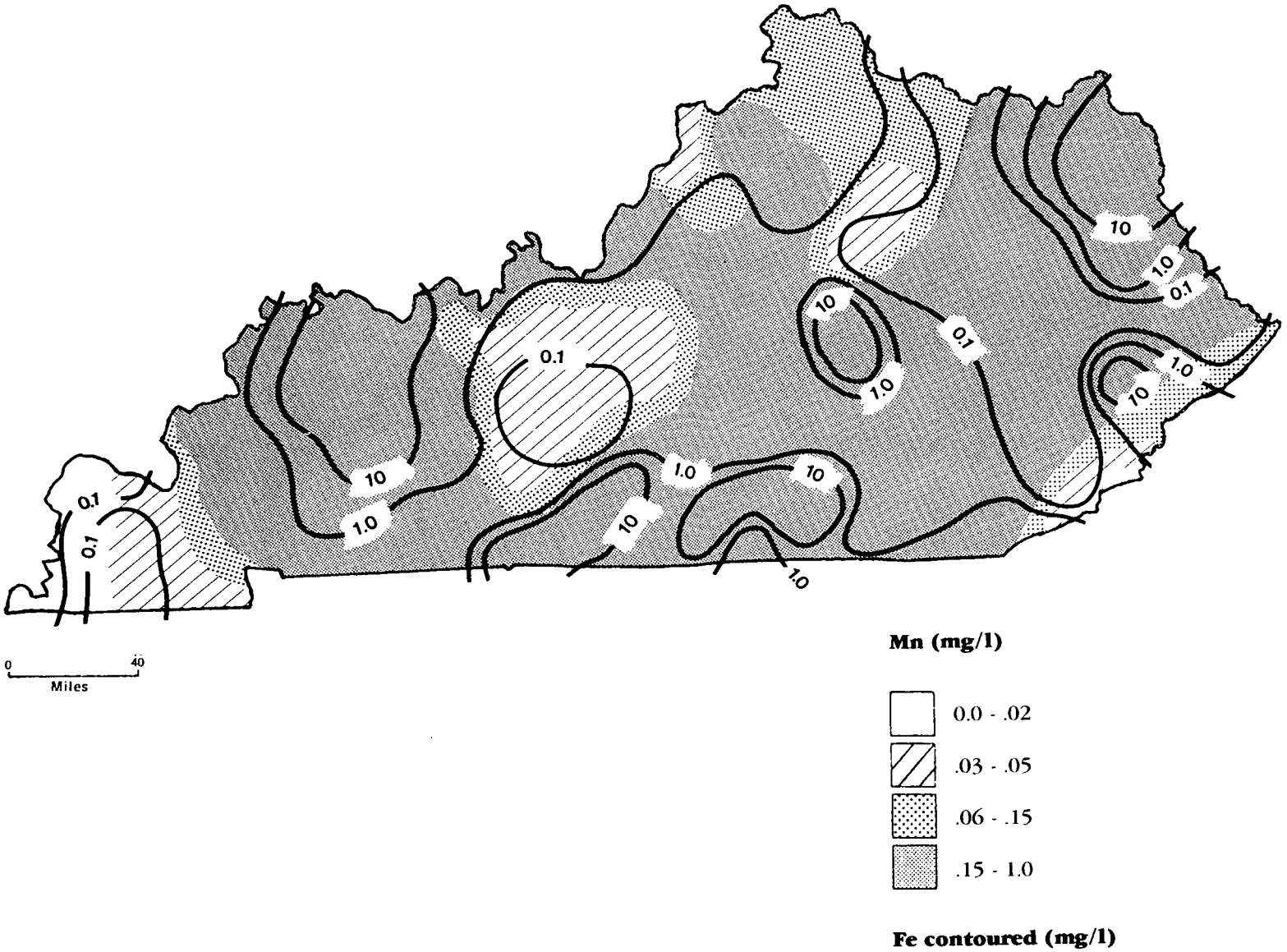
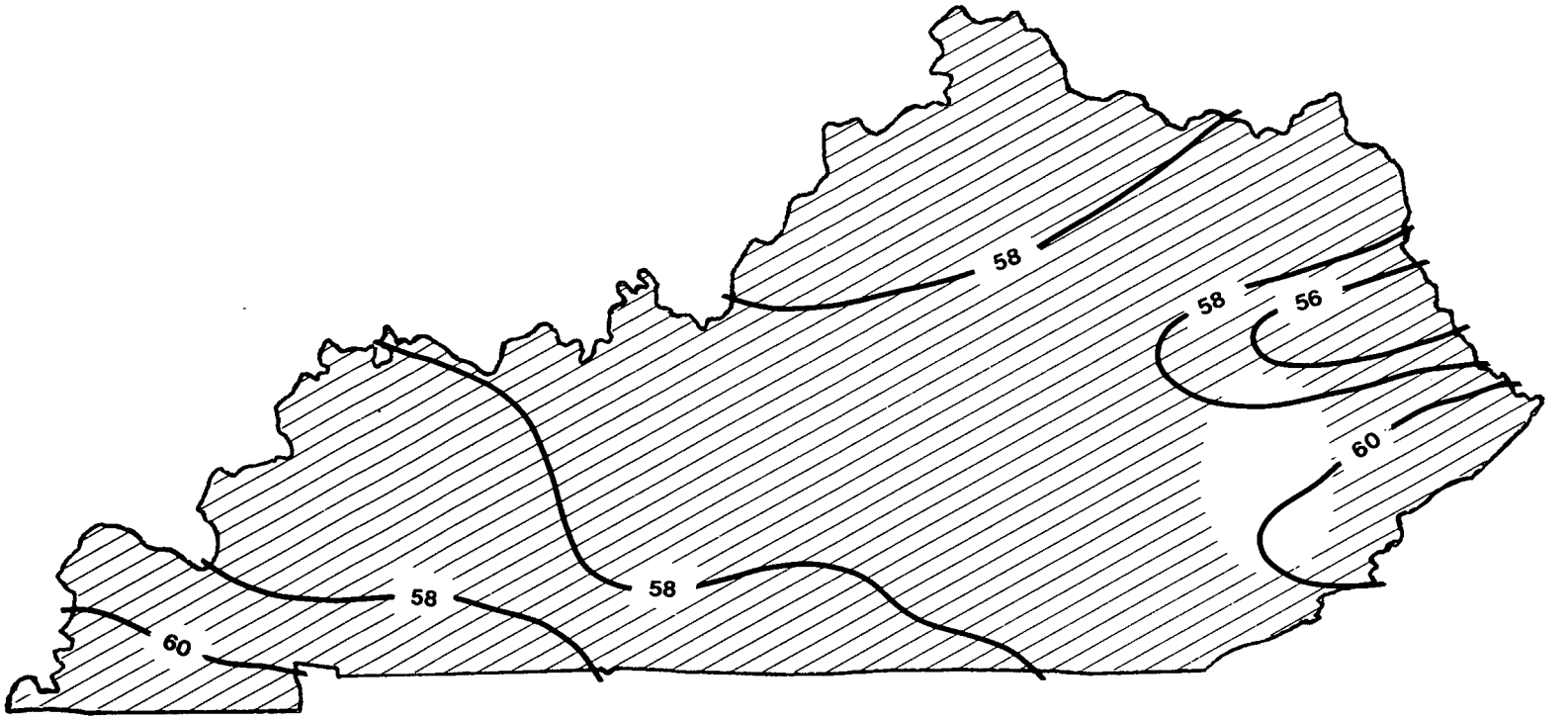


Plate 117

Kentucky


0.1
10
1.0
0.1
10
1.0
0.1
1.0
10
10
1.0
10
1.0
10
1.0
0.1
0.1
0 40
Miles
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)

Kentucky



0 40
Miles

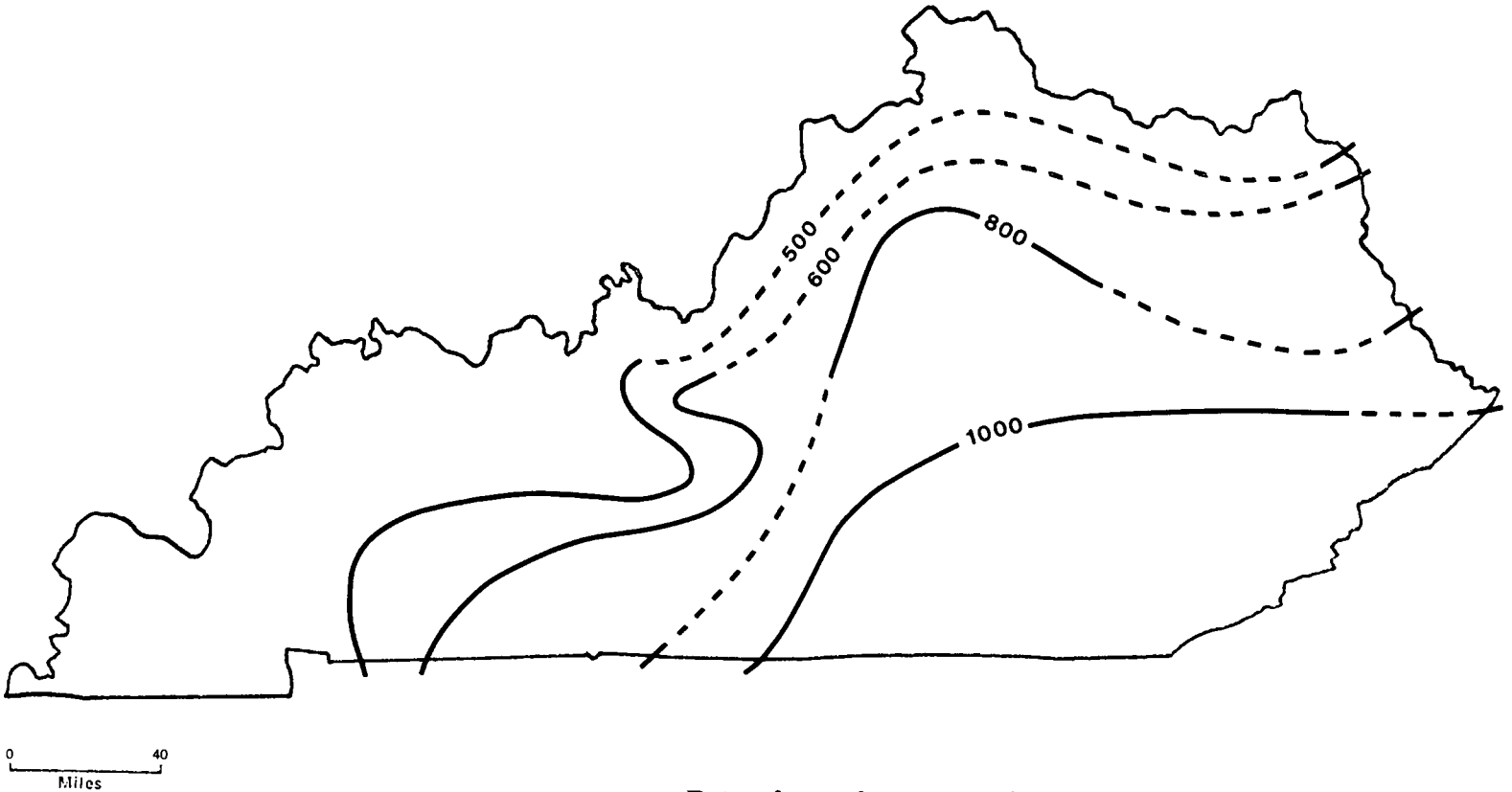
pH

Less than 6.0

6.1 - 8.0

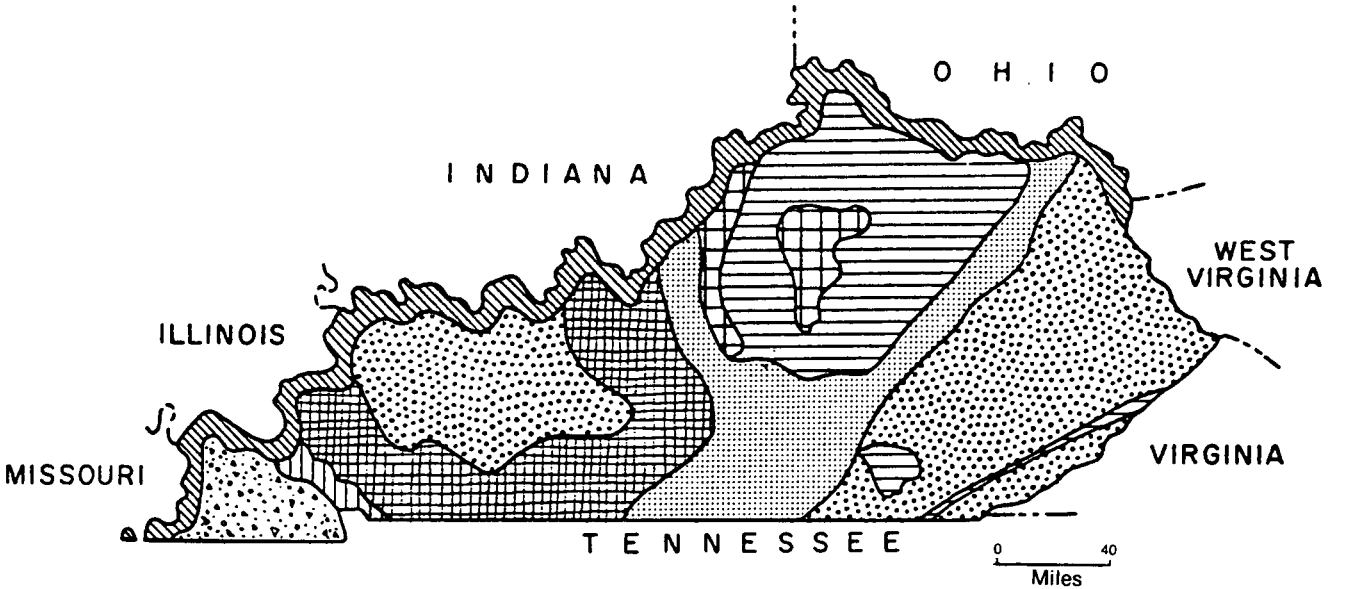
Temperature contoured (°F)

Kentucky



Potentiometric surface (ft., Datum: mean sea level)

Kentucky



RANGE OF YIELDS IN GALLONS PER MINUTE (GPM)

200-1500 gpm

Sand and gravel

Sand beneath surface formation

5-300 gpm

Sand

Limestone and sandstone

1-200 gpm

Sandstone and siltstone

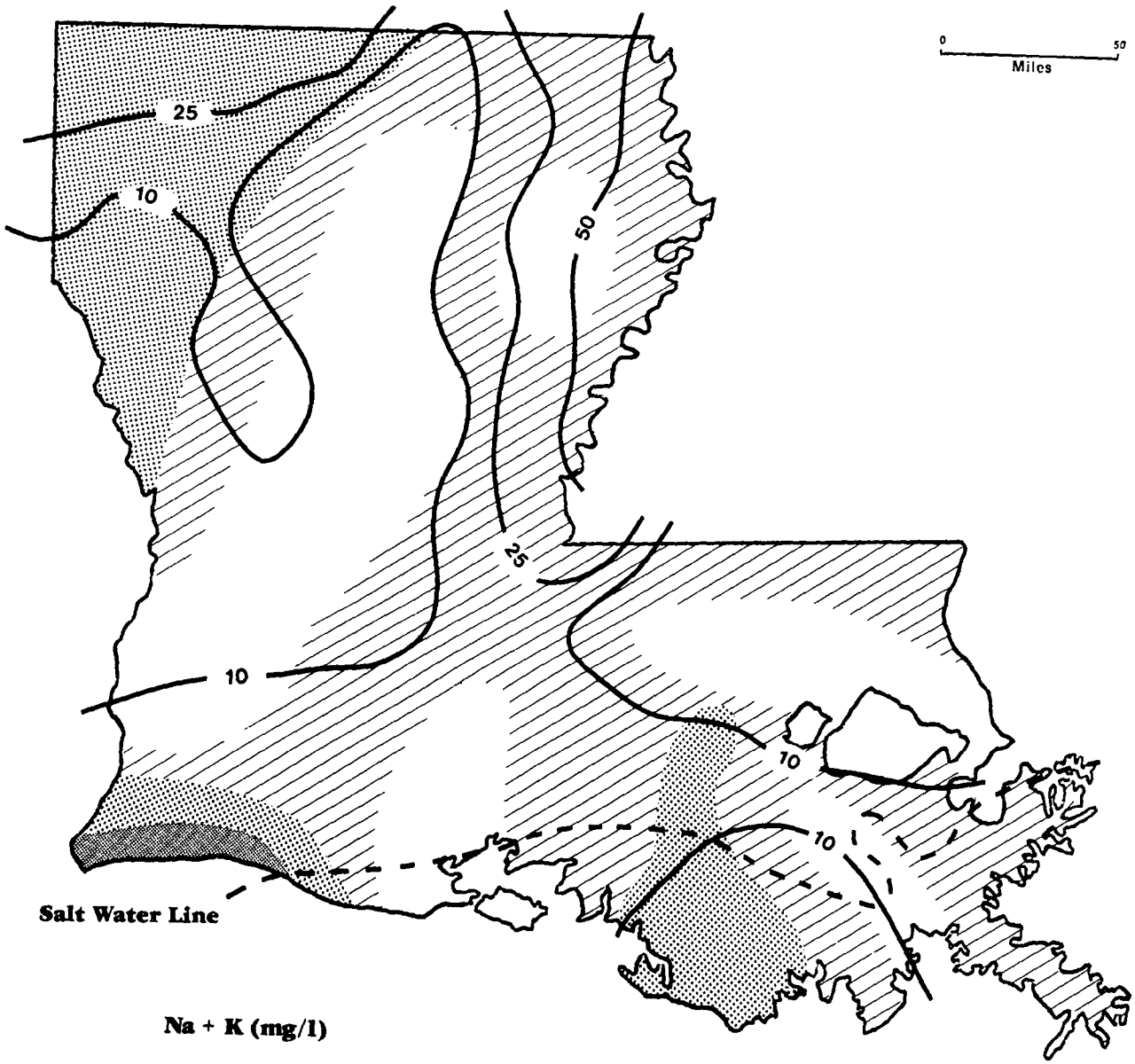
Limestone

0.1-10 gpm

Limestone and shale

Siltstone

Louisiana

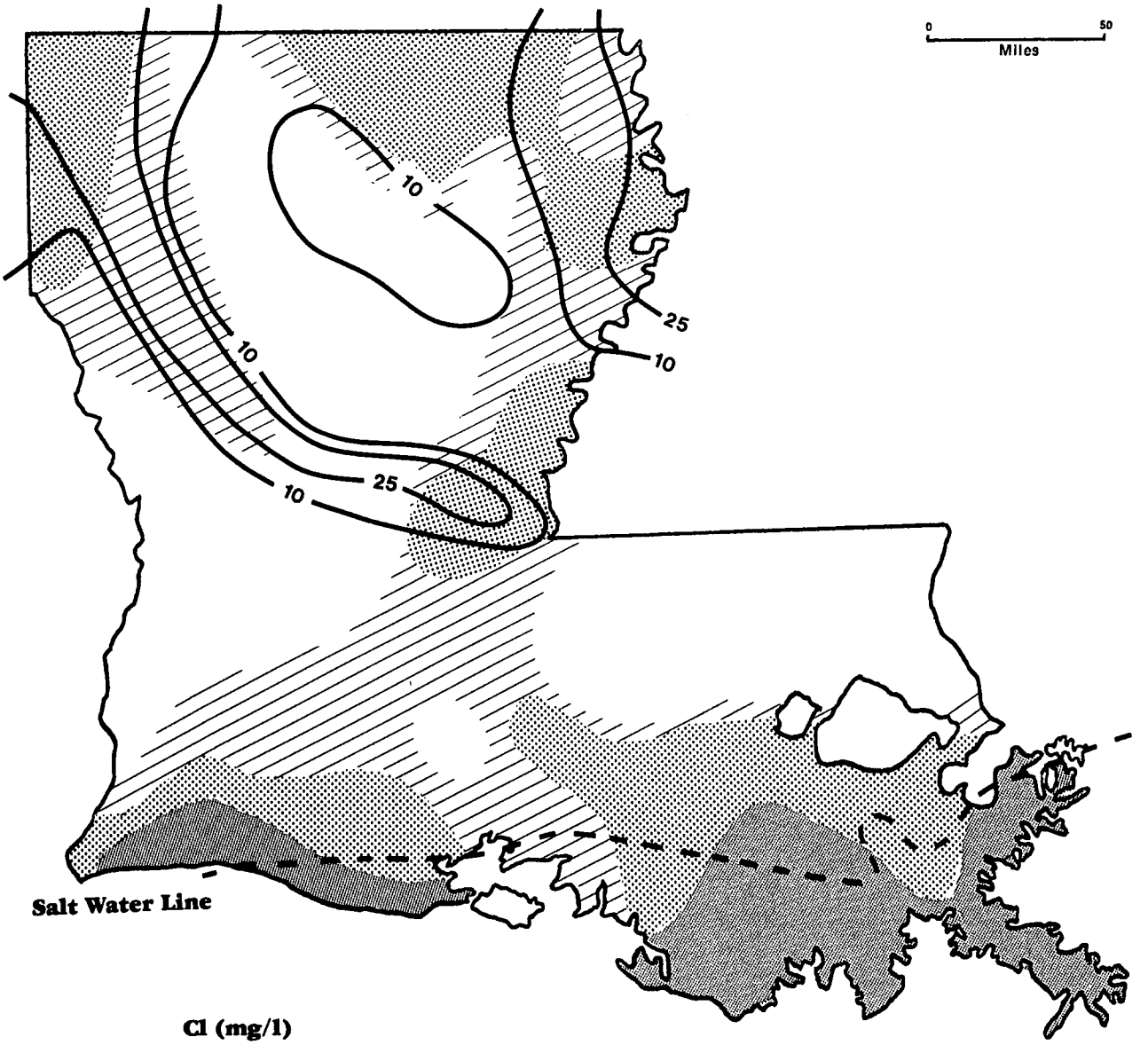


Na + K (mg/l)

- 0-25
- 25-50
- 50-250
- 250-500

Ca + Mg contoured (mg/l)

Louisiana

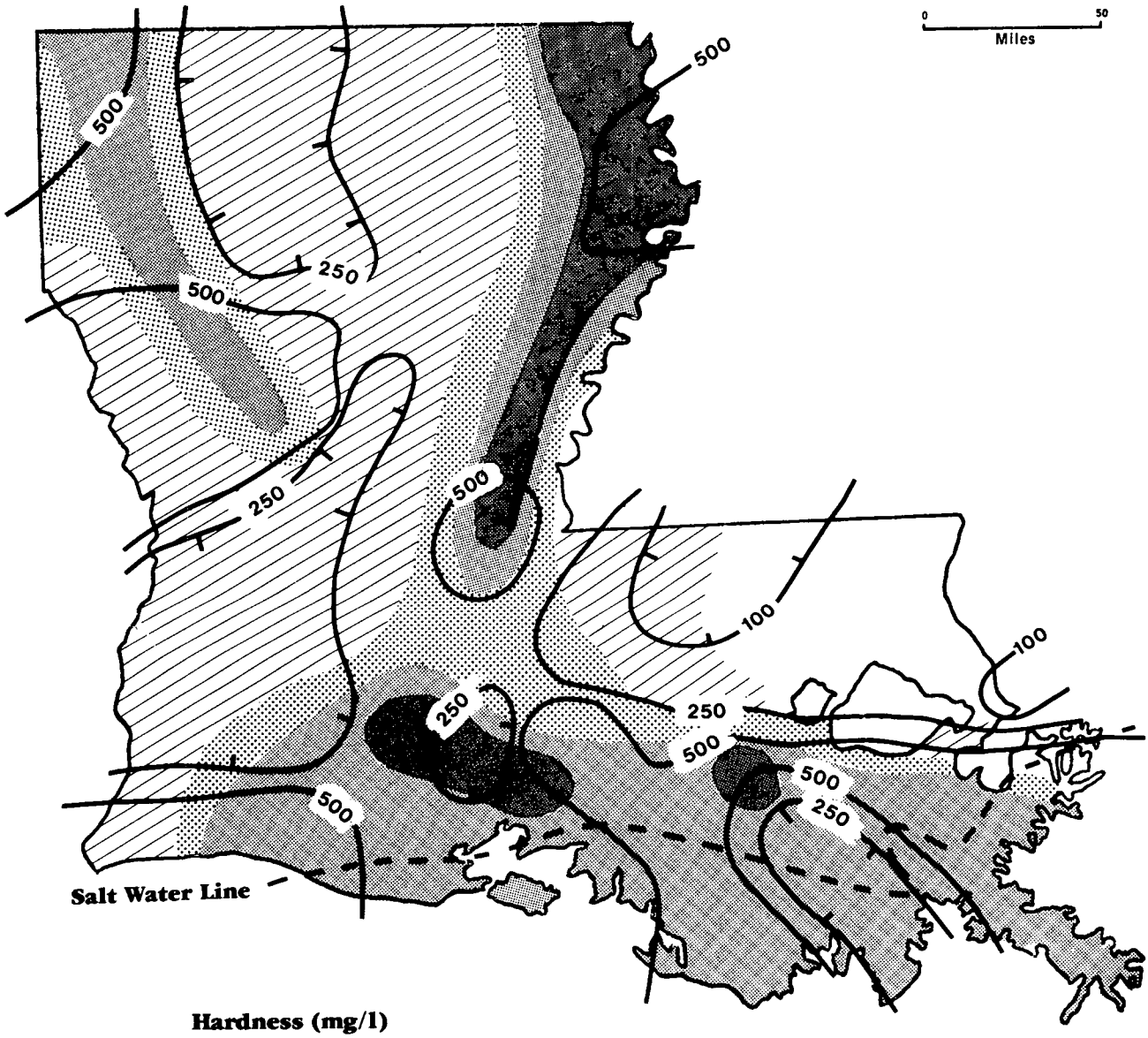


Cl (mg/l)

- 0-25
- 25-50
- 50-250
- 250-500

SO_4 contoured (mg/l)

Louisiana

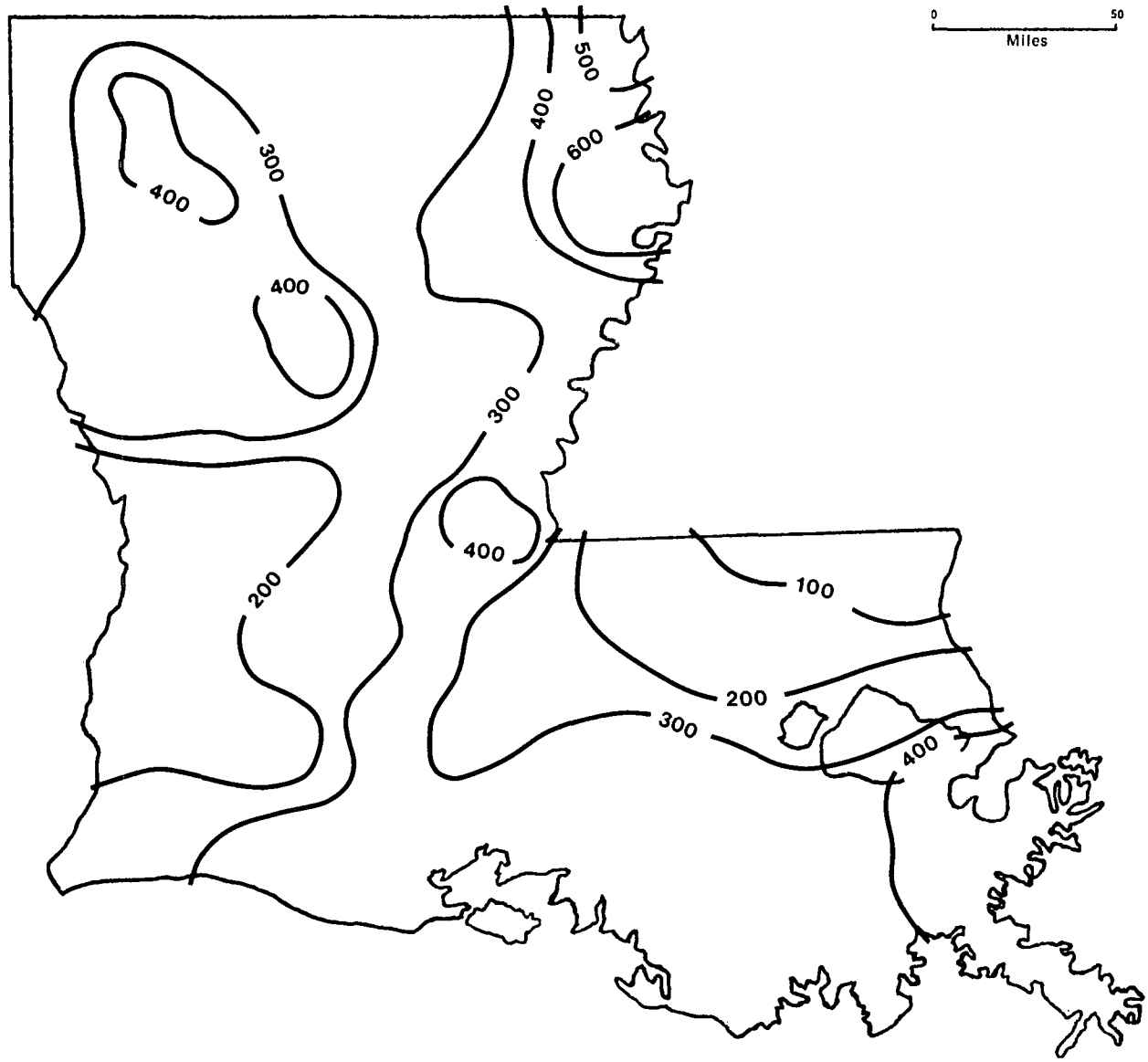


Hardness (mg/l)

- 0-30
- 30-60
- 60-120
- 120-180
- 180-240

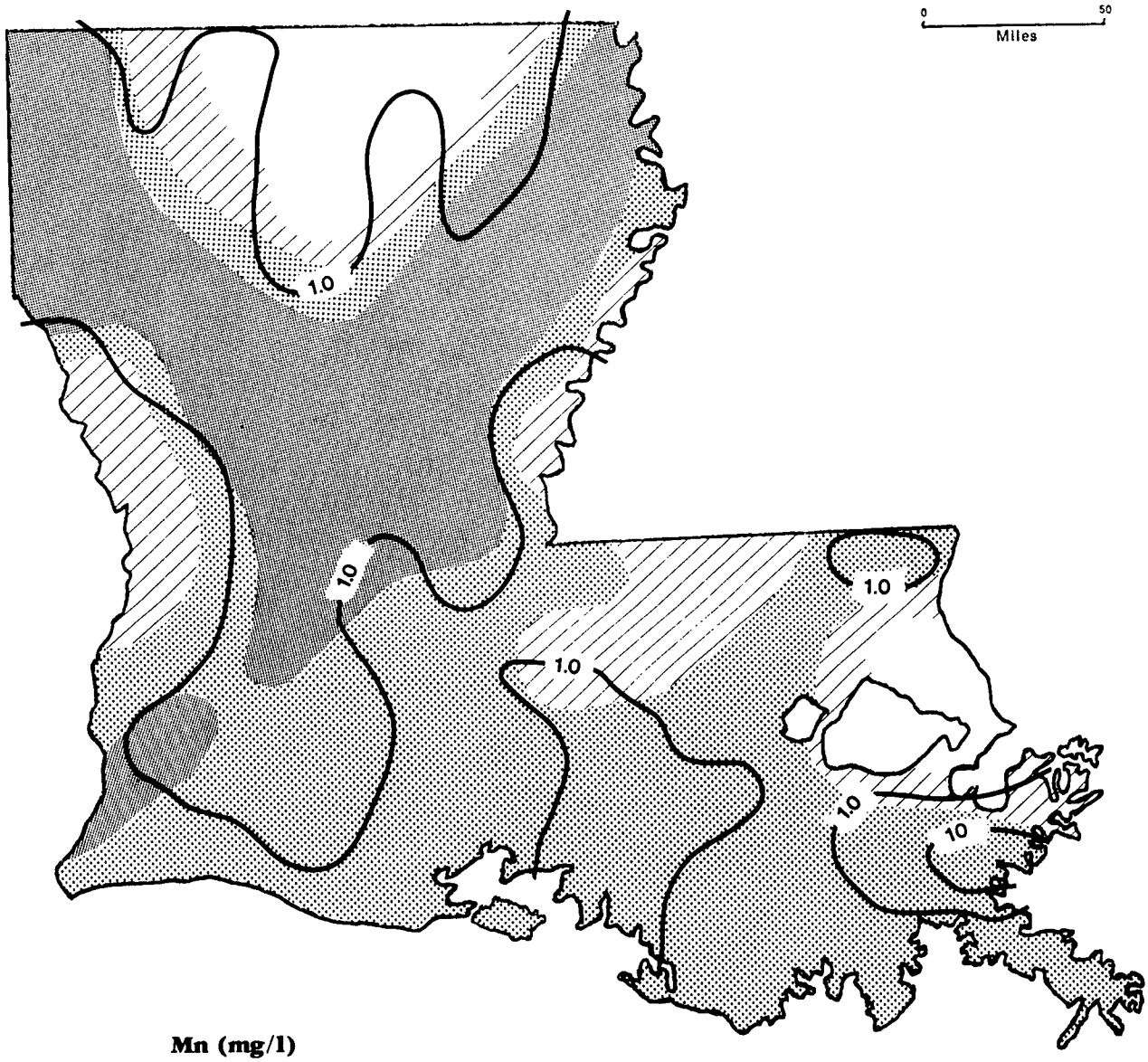
Dissolved Solids contoured (mg/l)

Louisiana



HCO_3 contoured (mg/l)

Louisiana

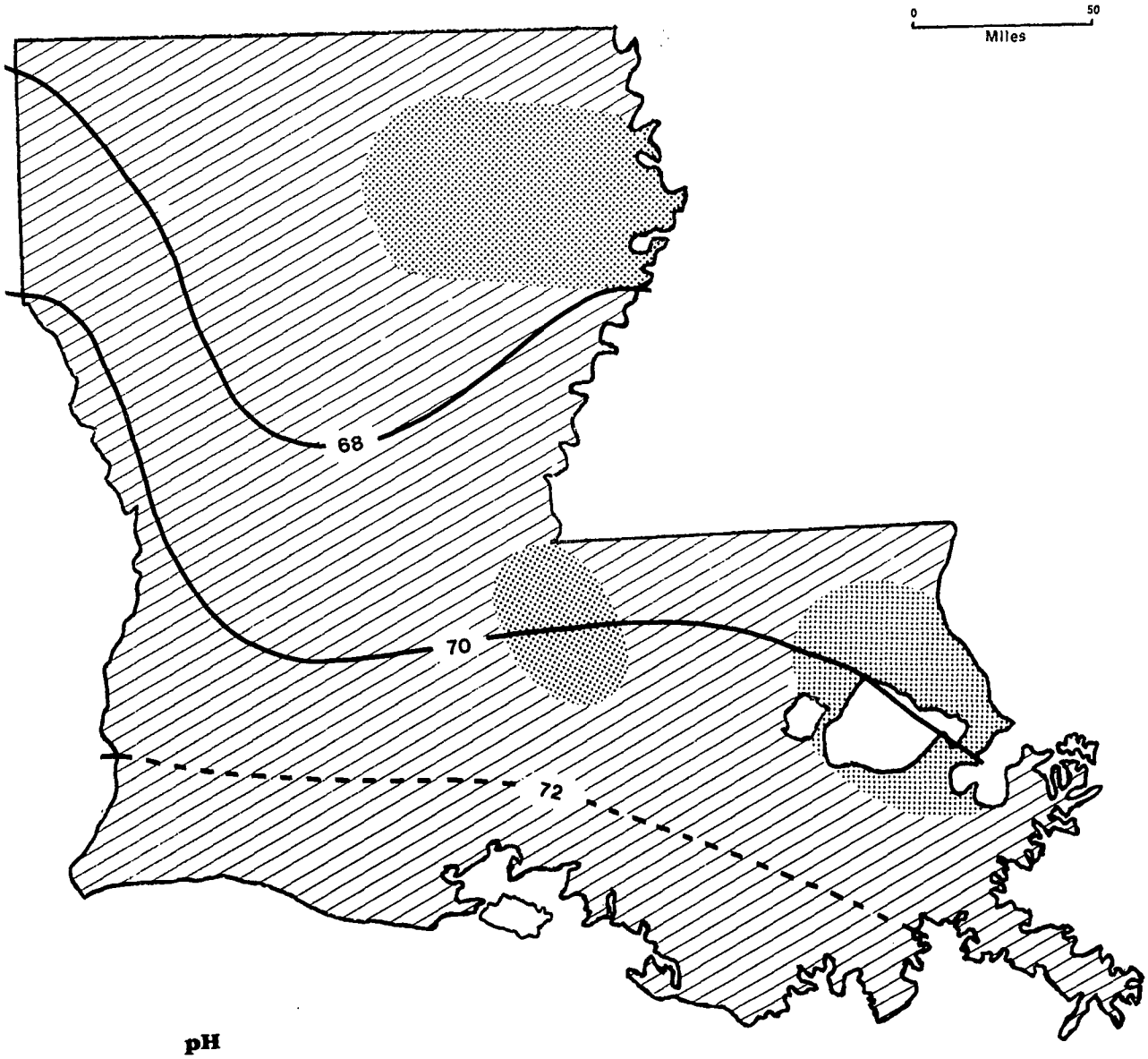


Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Louisiana



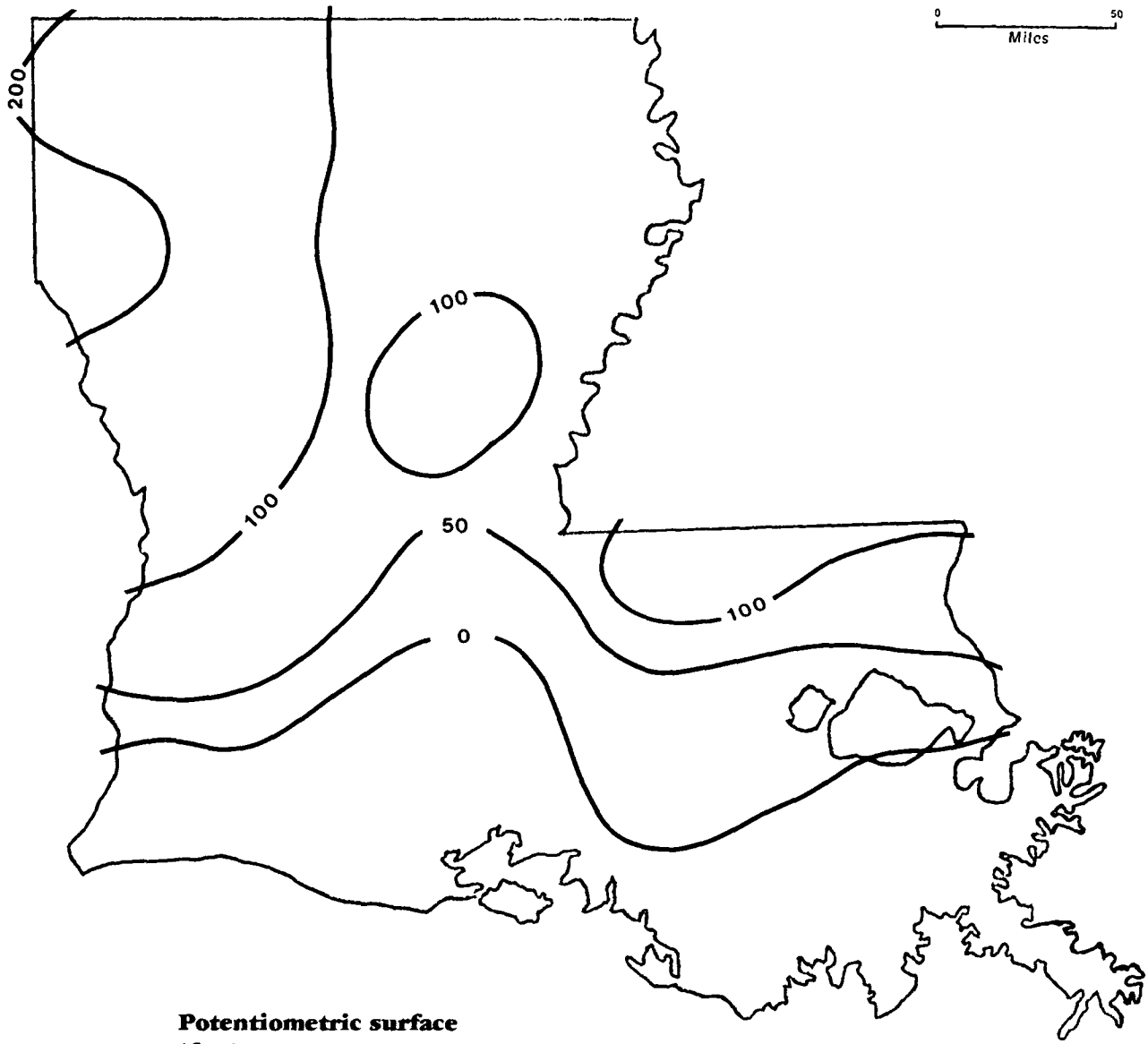
pH

6.1 - 8.0

8.1 - 10

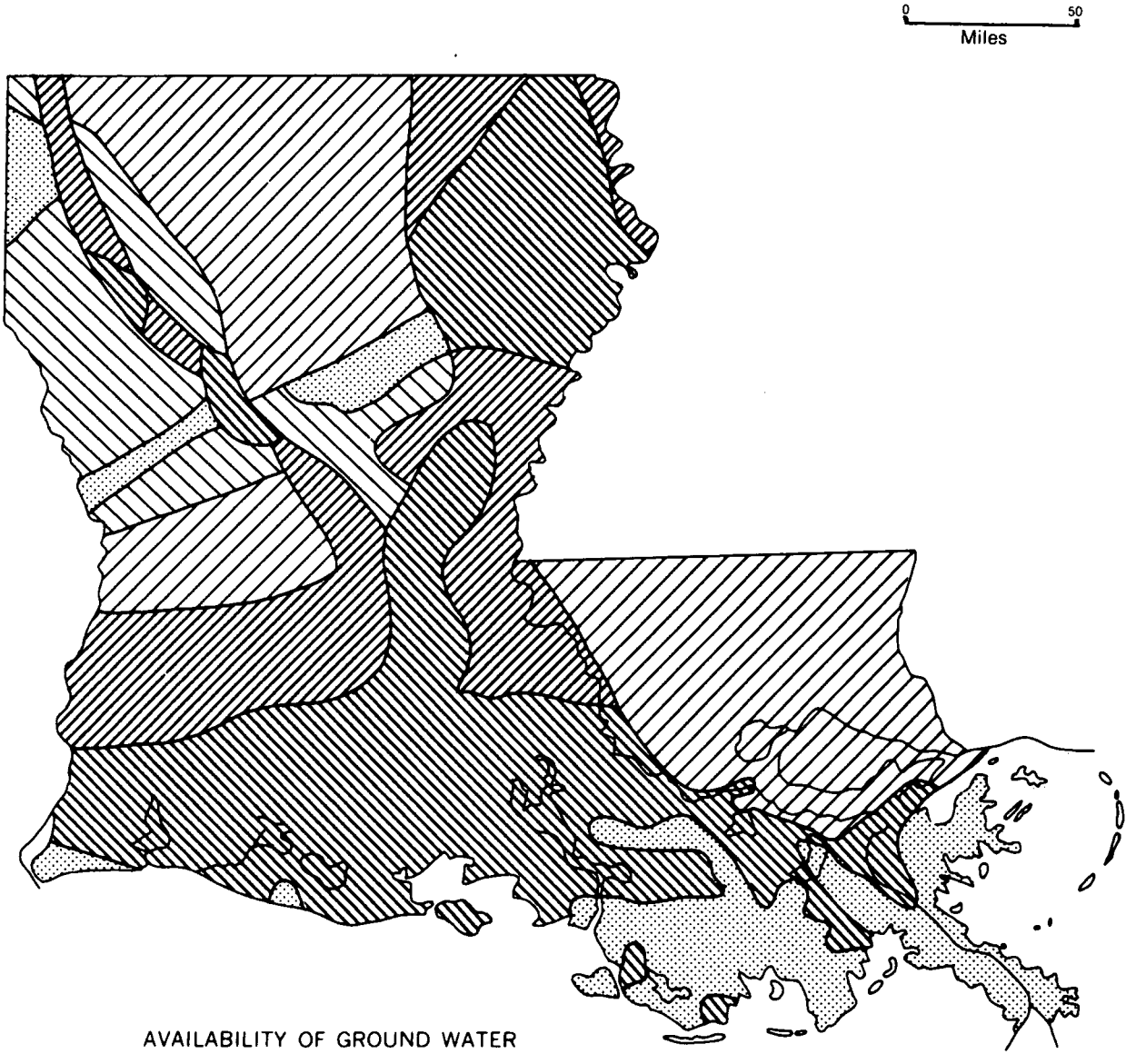
Temperature contoured (°F)

Louisiana



Potentiometric surface
(ft., Datum: mean sea level)

Louisiana



AVAILABILITY OF GROUND WATER

- Moderate to large supplies of soft water
- Small to moderate supplies of soft water
- Moderate to large supplies of hard water
- Moderate to large supplies of hard water and small to large supplies of soft water
- Little or no potable water

Maine

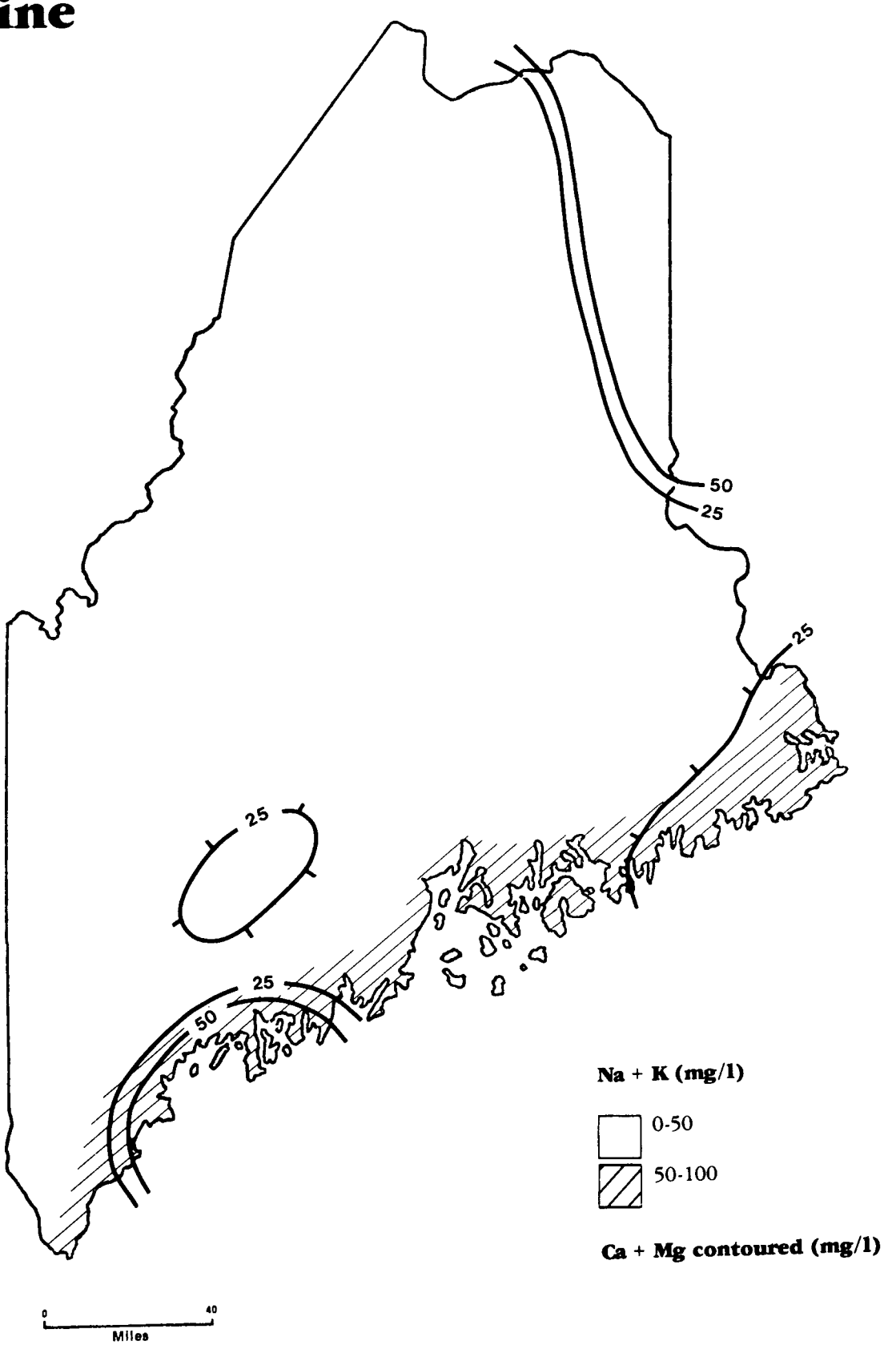


Plate 130

Maine

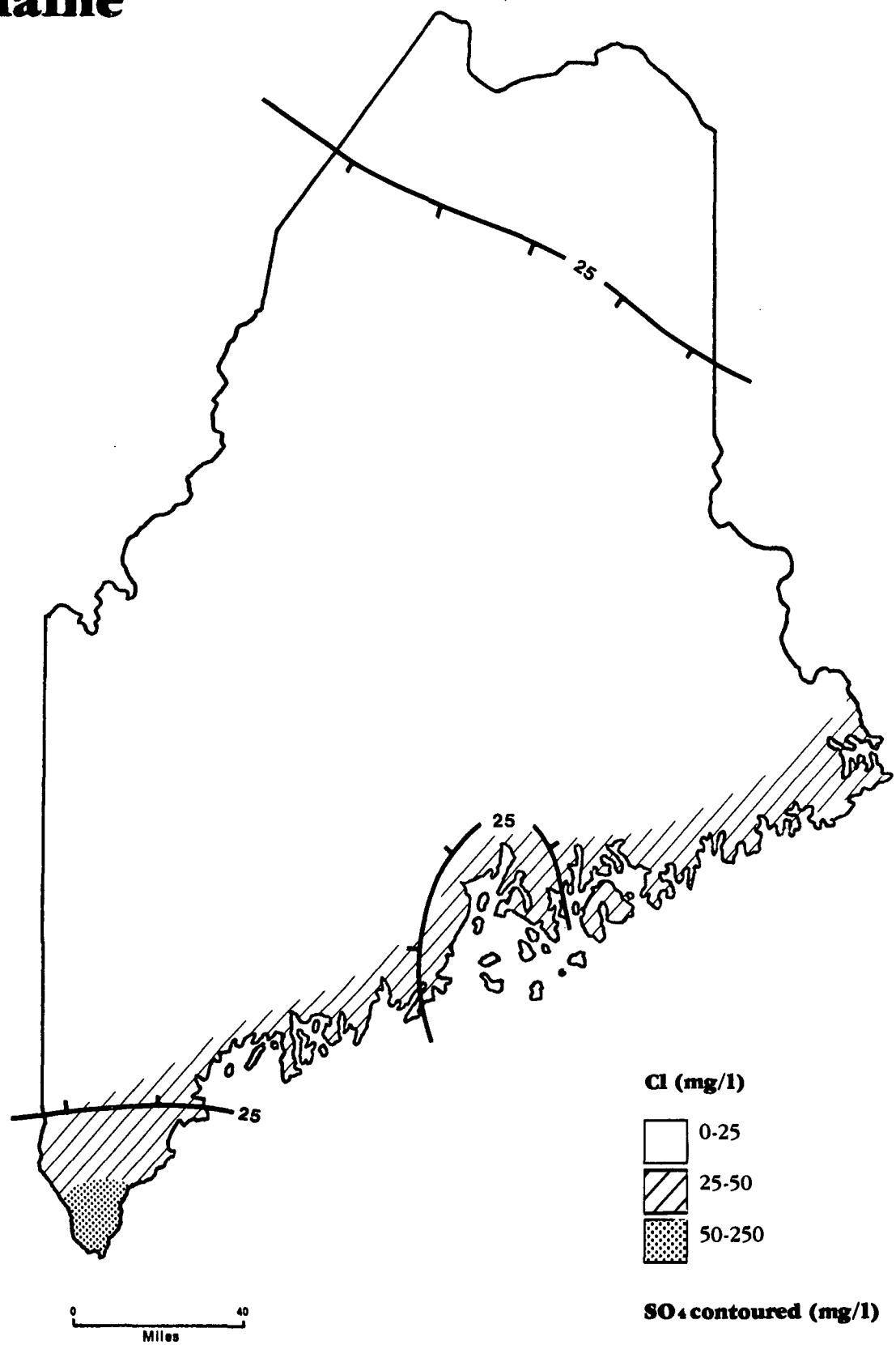
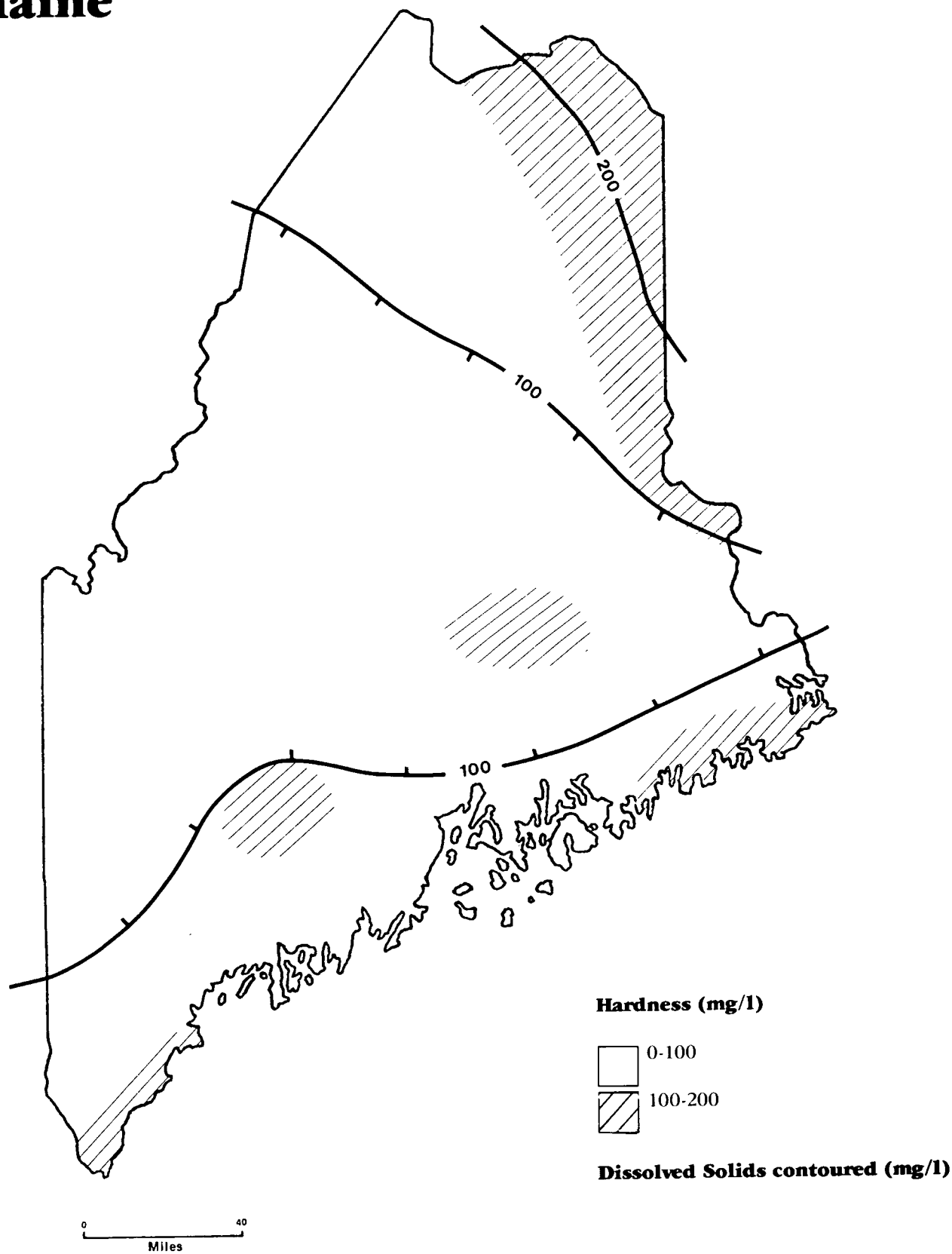
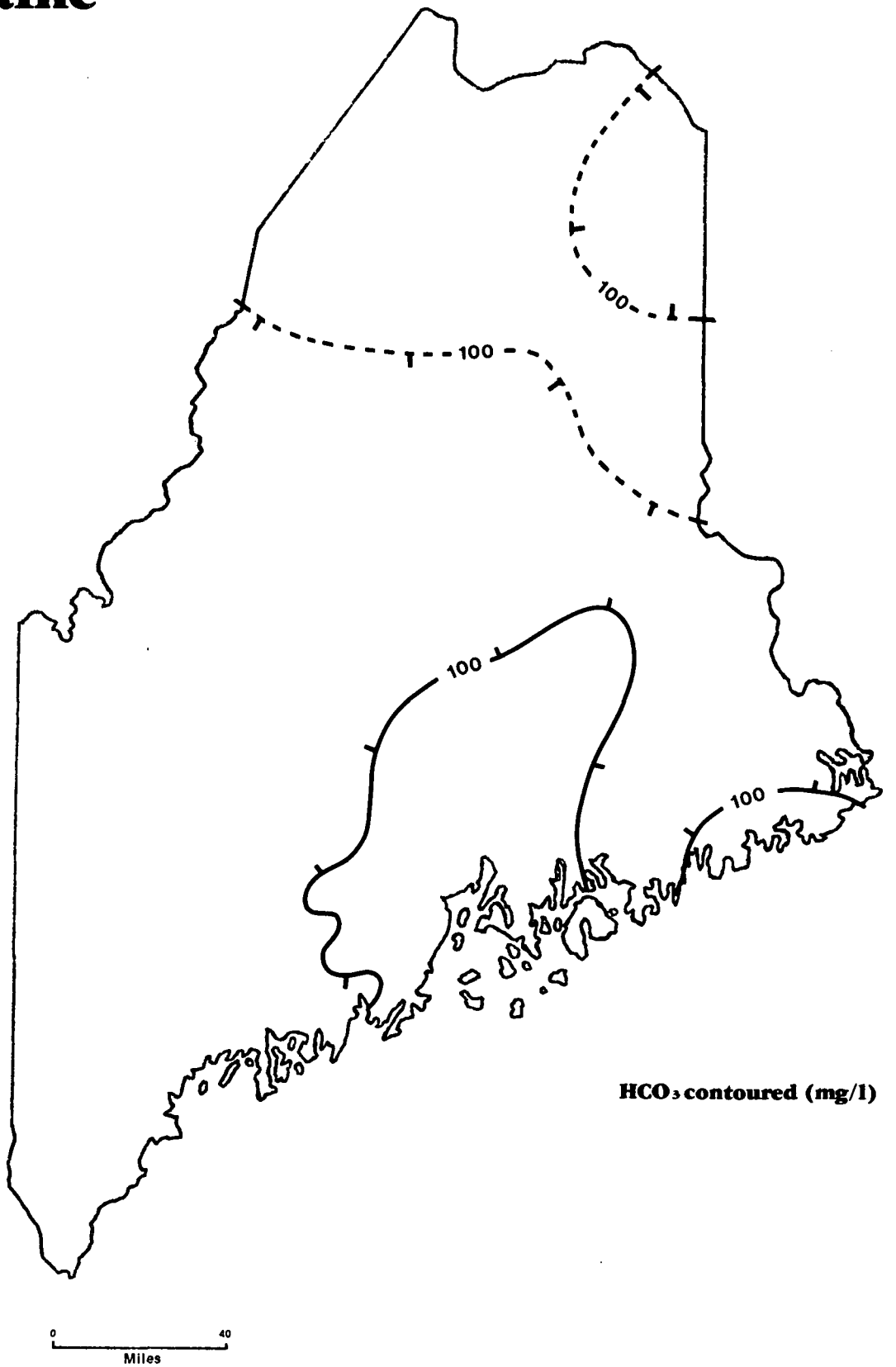


Plate 131

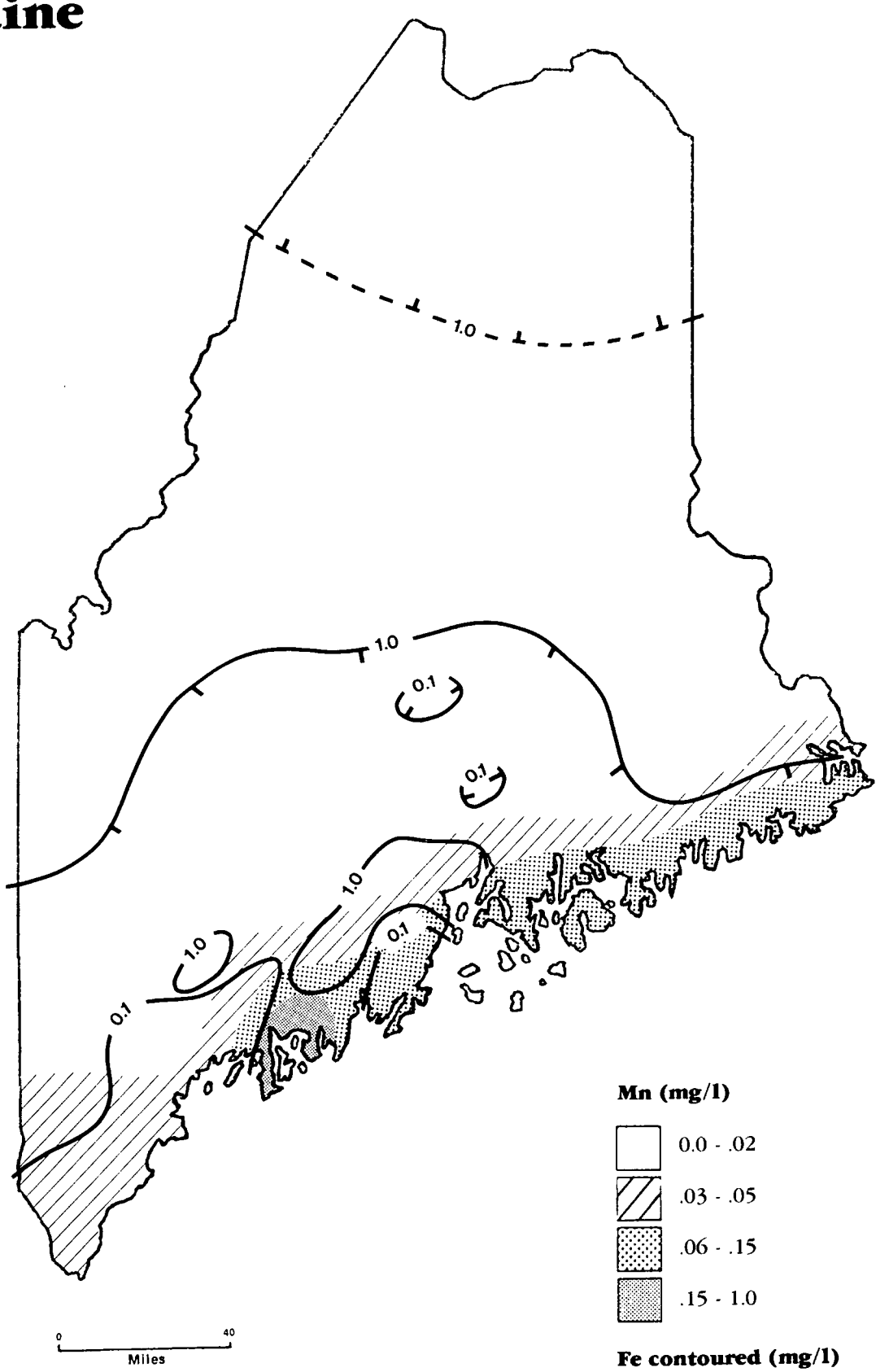
Maine


200
100
100
Hardness (mg/l)
0-100
100-200
Dissolved Solids contoured (mg/l)
0
40
Miles

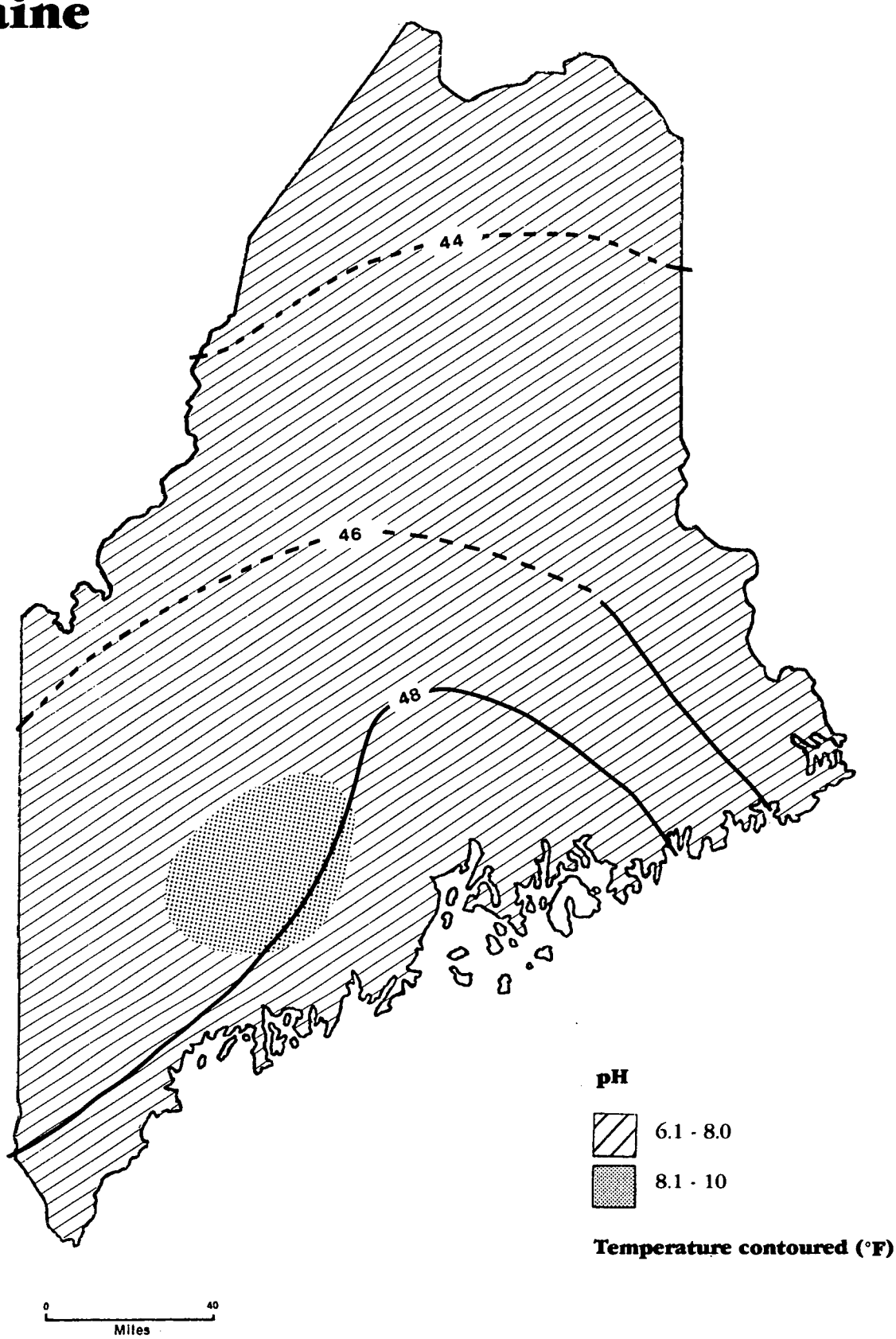
Maine



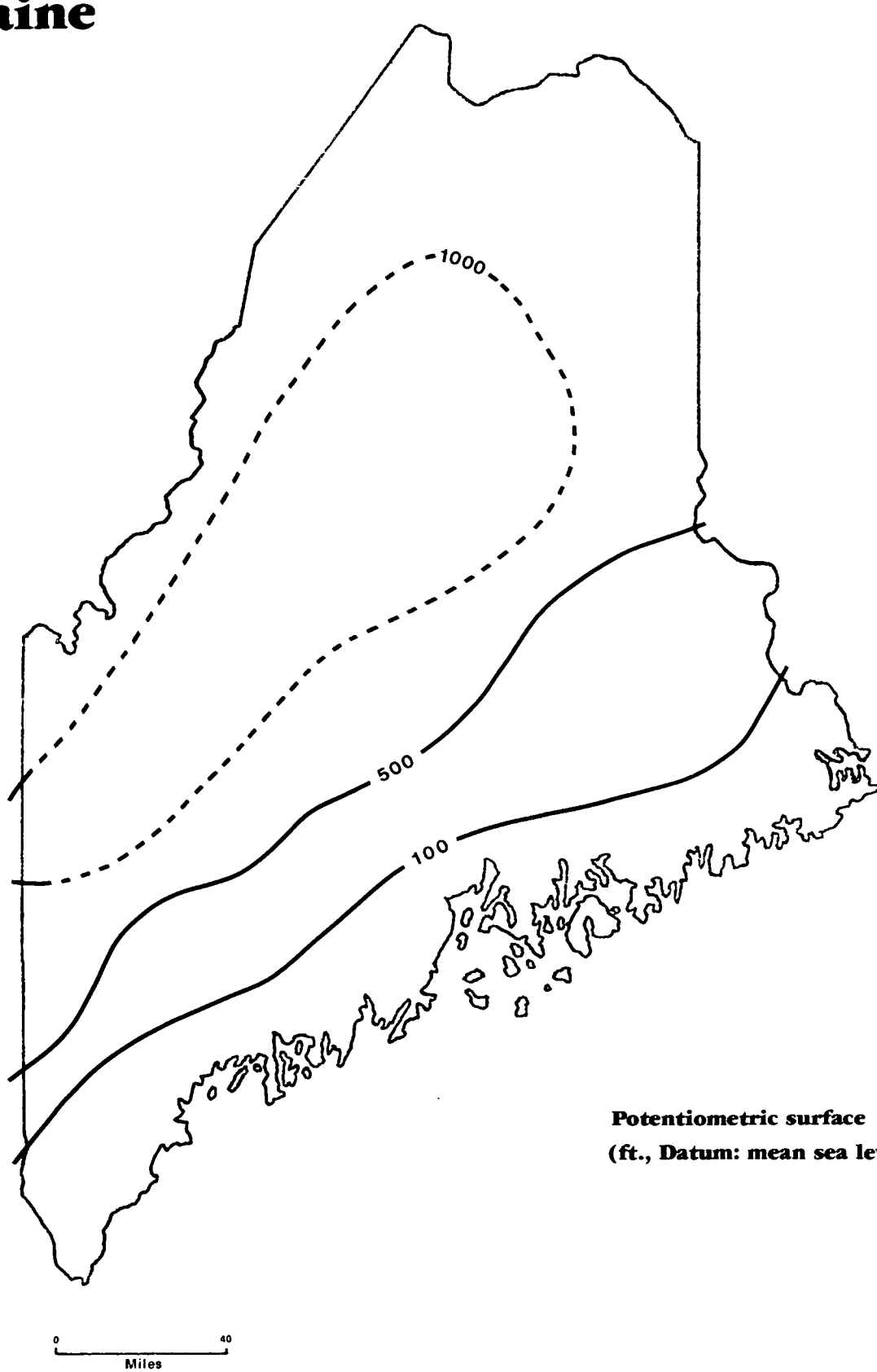
Maine


1.0
1.0
0.1
0.1
1.0
1.0
0.1
0.1
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
40
Miles

Maine

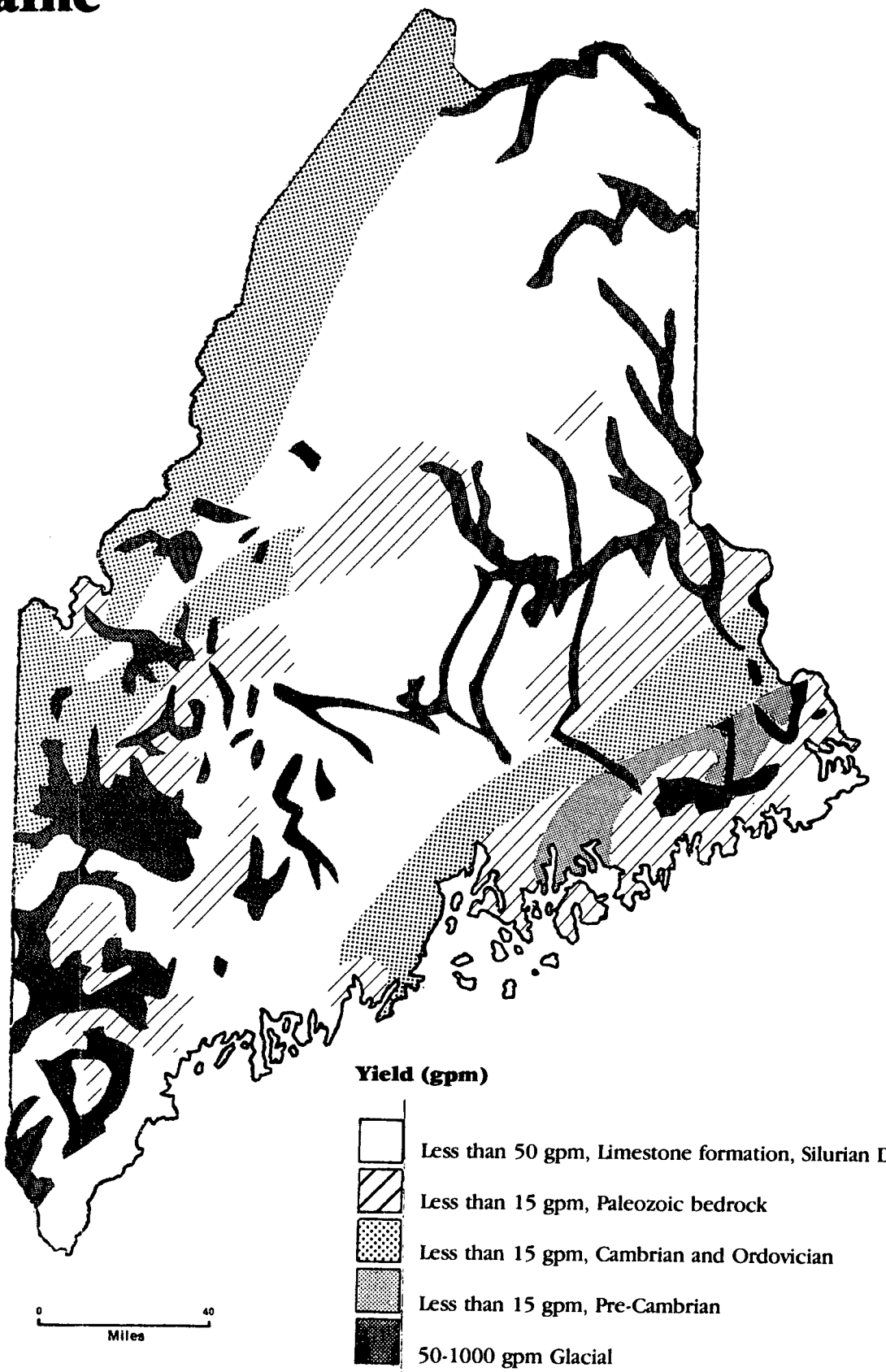


Maine



Potentiometric surface
(ft., Datum: mean sea level)

Maine


Yield (gpm)
Less than 50 gpm, Limestone formation, Silurian Devonian
Less than 15 gpm, Paleozoic bedrock
Less than 15 gpm, Cambrian and Ordovician
Less than 15 gpm, Pre-Cambrian
50-1000 gpm Glacial
0
40
Miles

Maryland

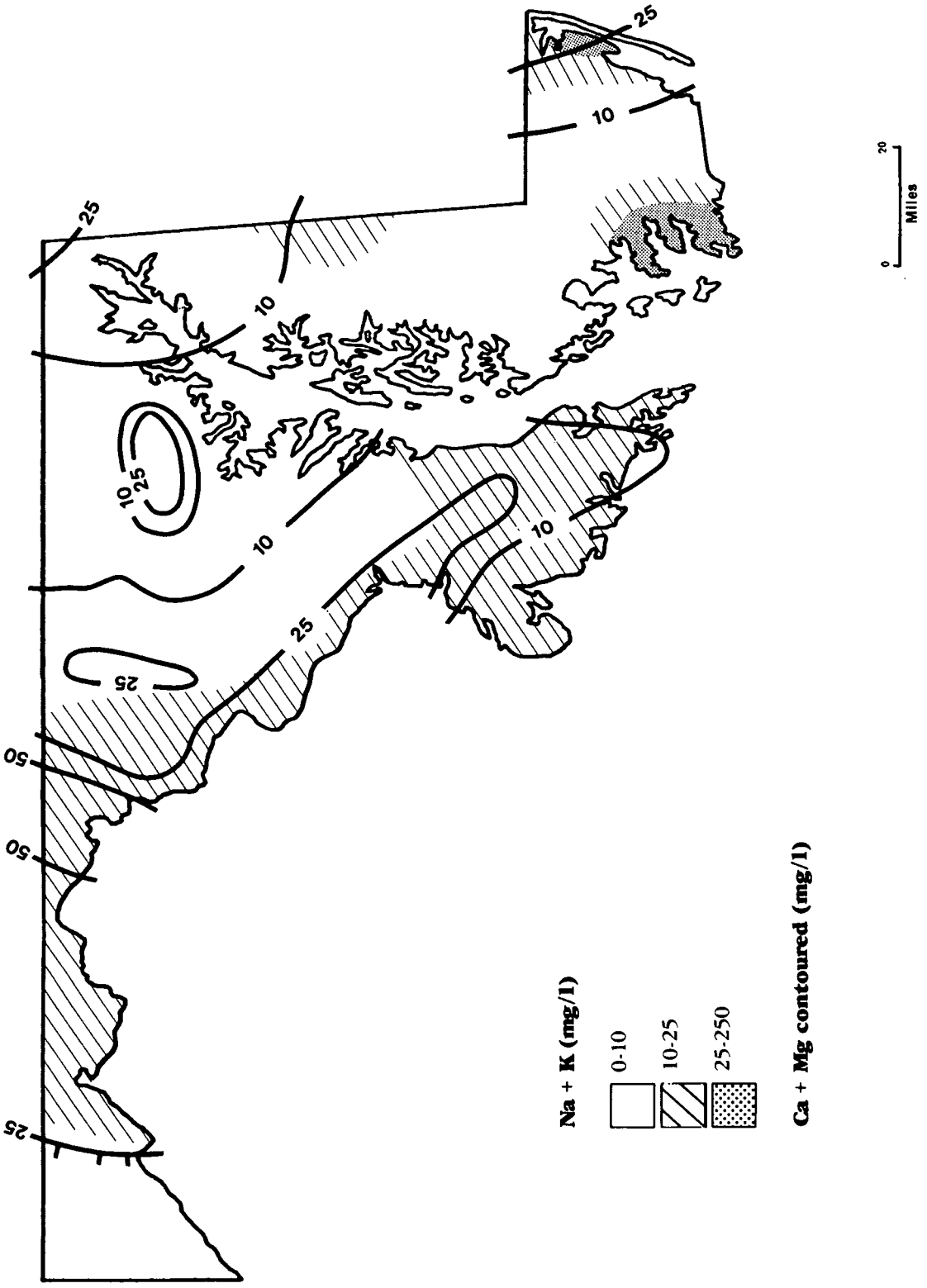


Plate 138

Maryland

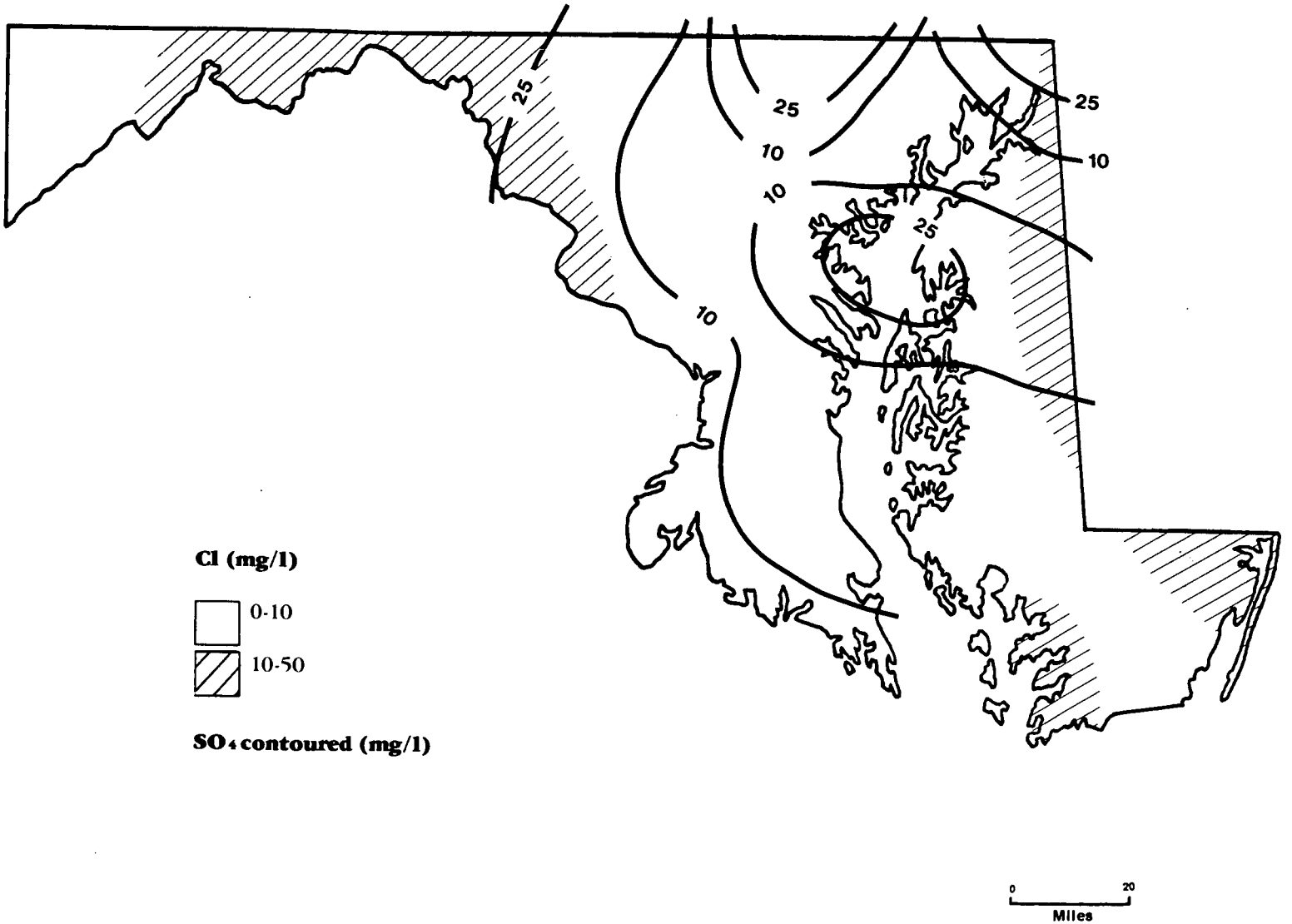
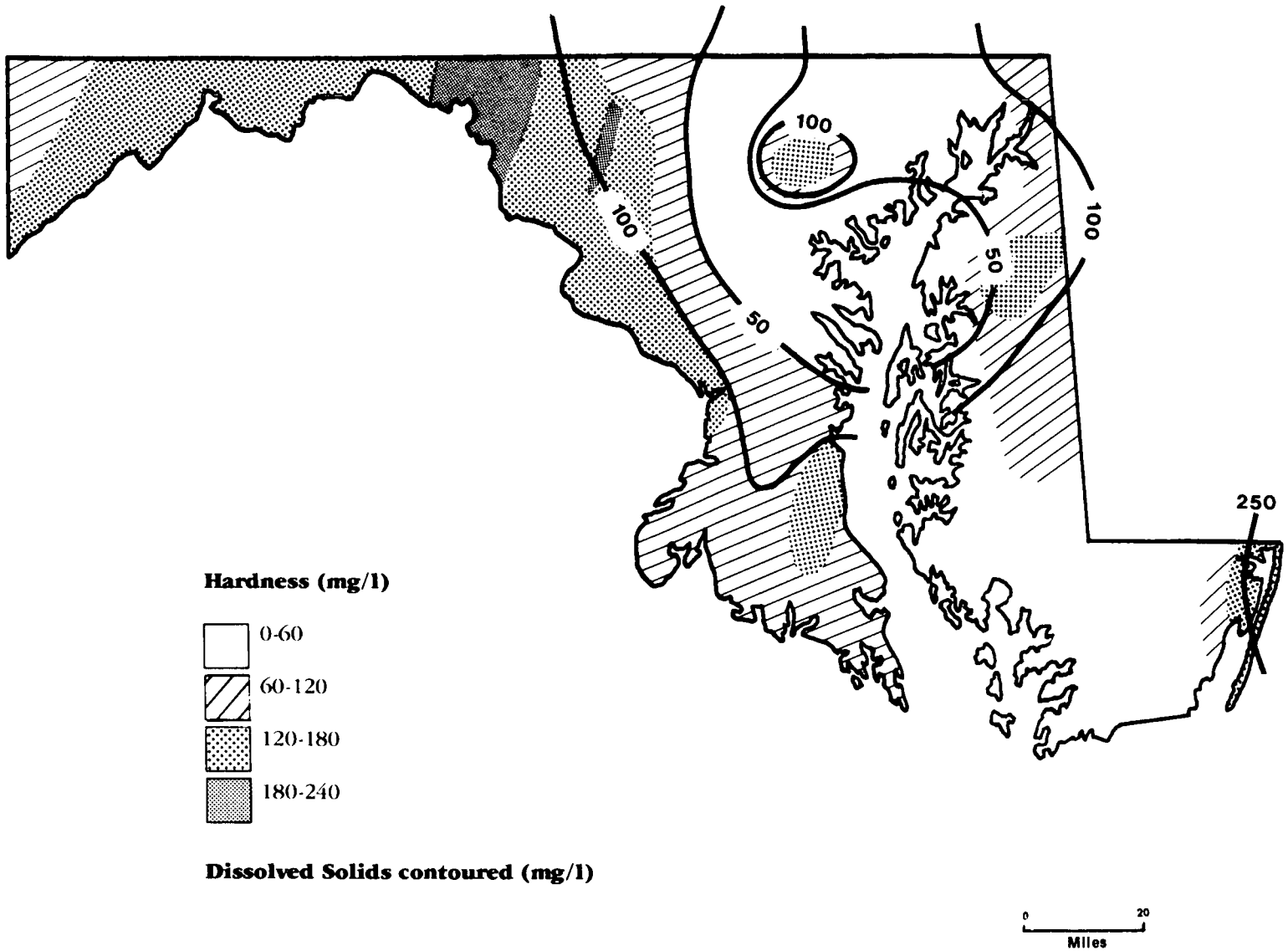
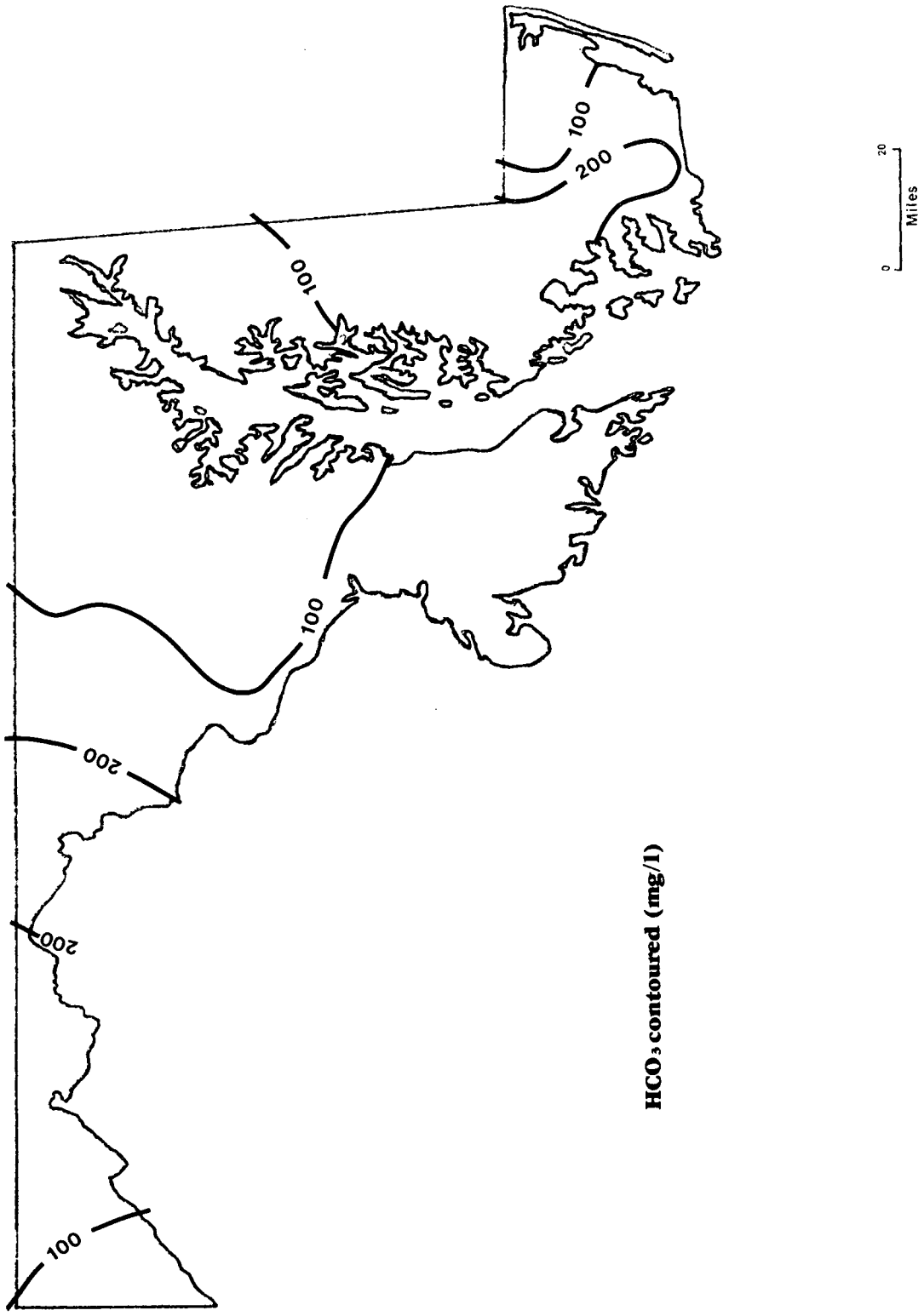


Plate 139

Maryland

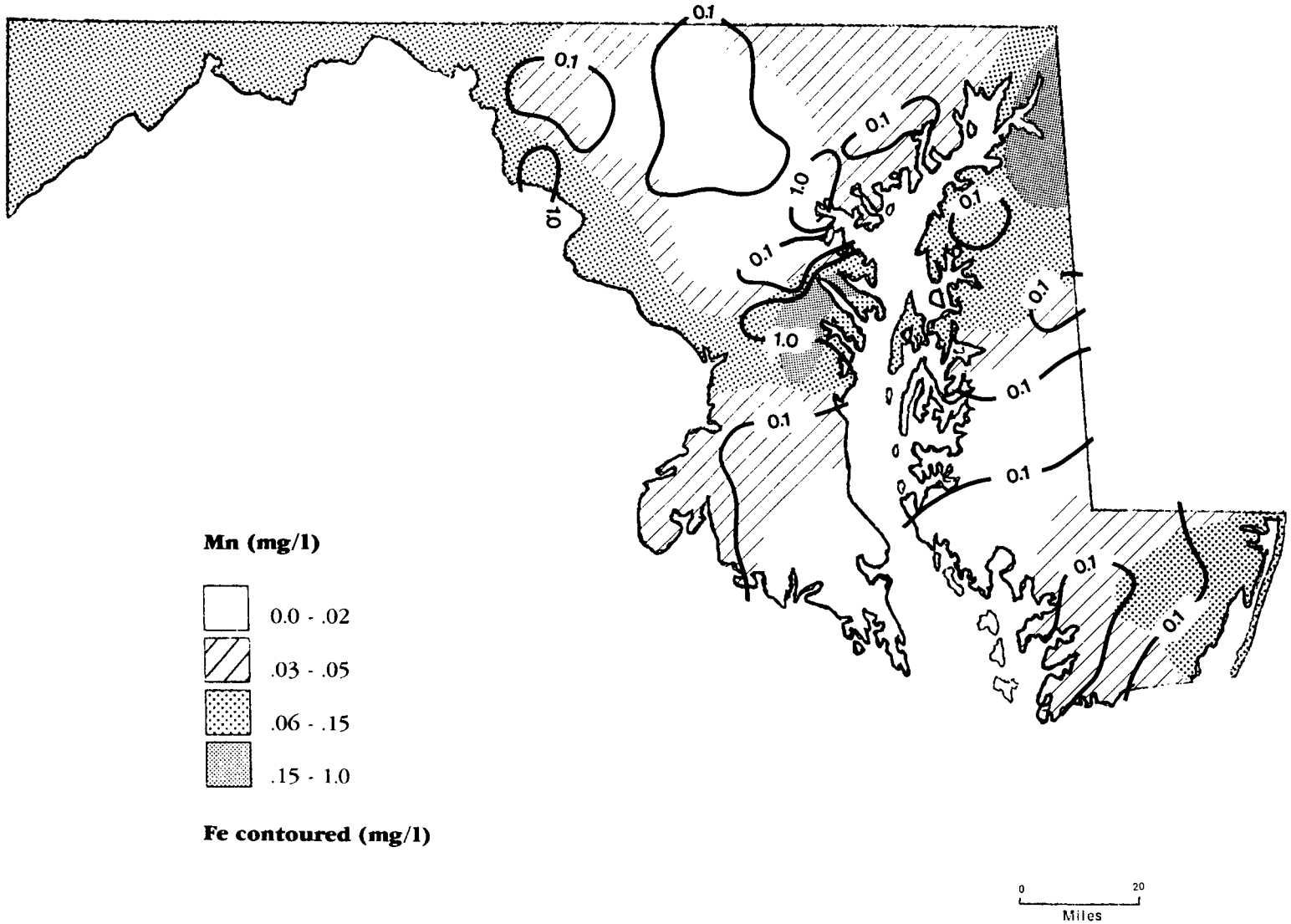

100
100
50
50
100
250
Hardness (mg/l)
0-60
60-120
120-180
180-240
Dissolved Solids contoured (mg/l)
0
20
Miles

Maryland

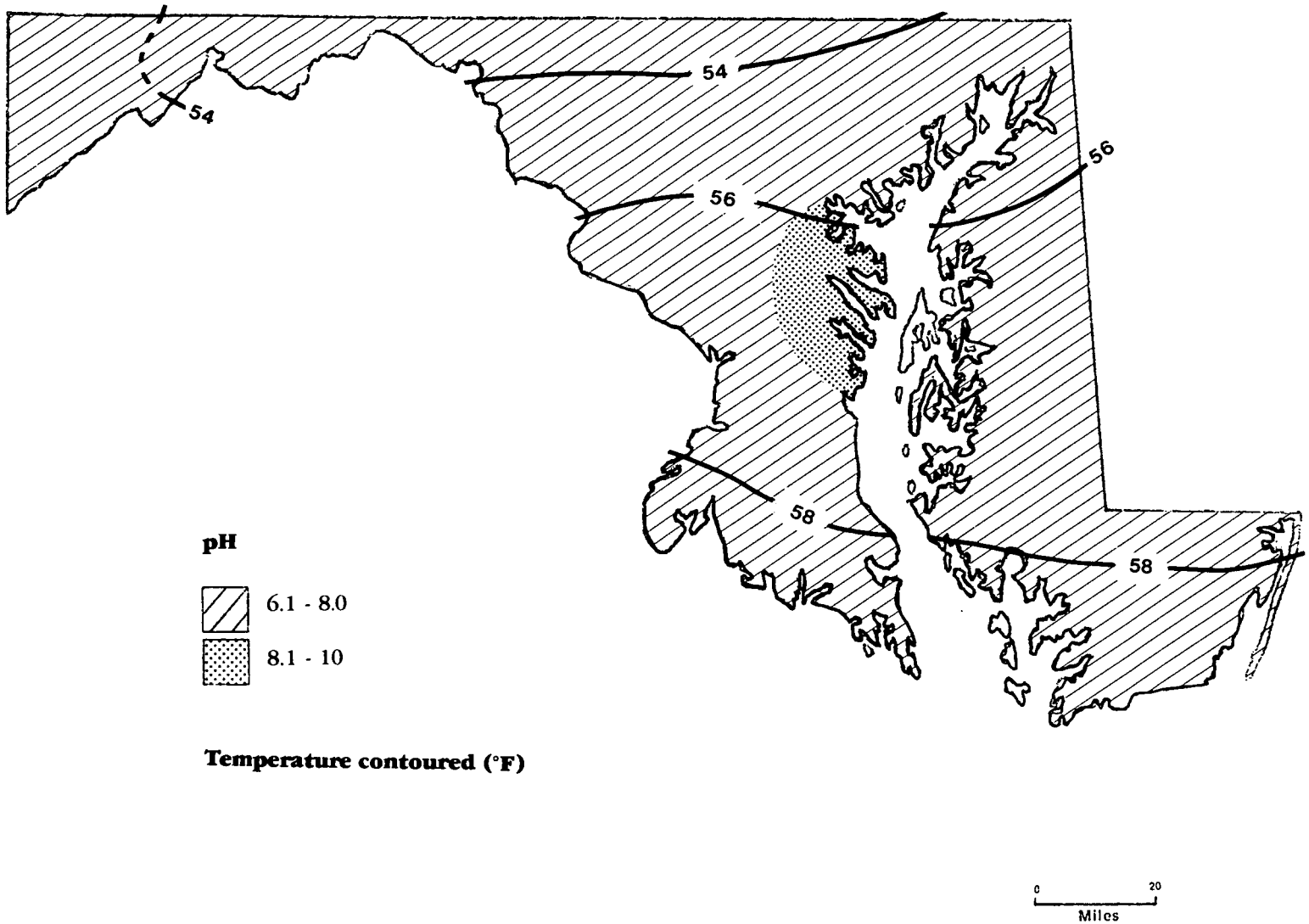


HCO_3 contoured (mg/l)

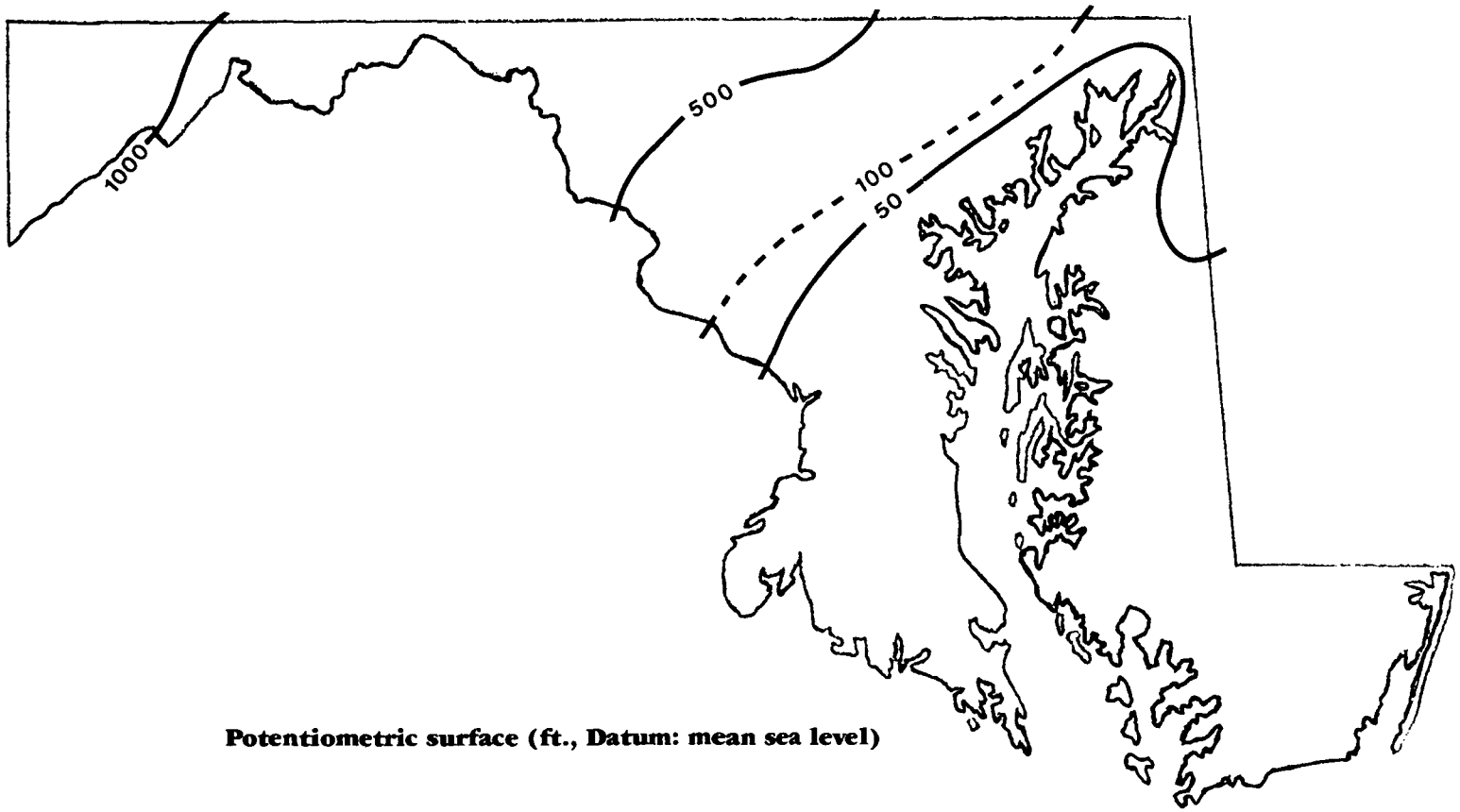
Maryland


0.1
0.1
1.0
0.1
1.0
0.1
0.1
1.0
0.1
0.1
0.1
0.1
0.1
0.1
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
20
Miles

Maryland


54
54
56
56
58
58
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
20
Miles

Maryland



Potentiometric surface (ft., Datum: mean sea level)

0 20
Miles

Maryland

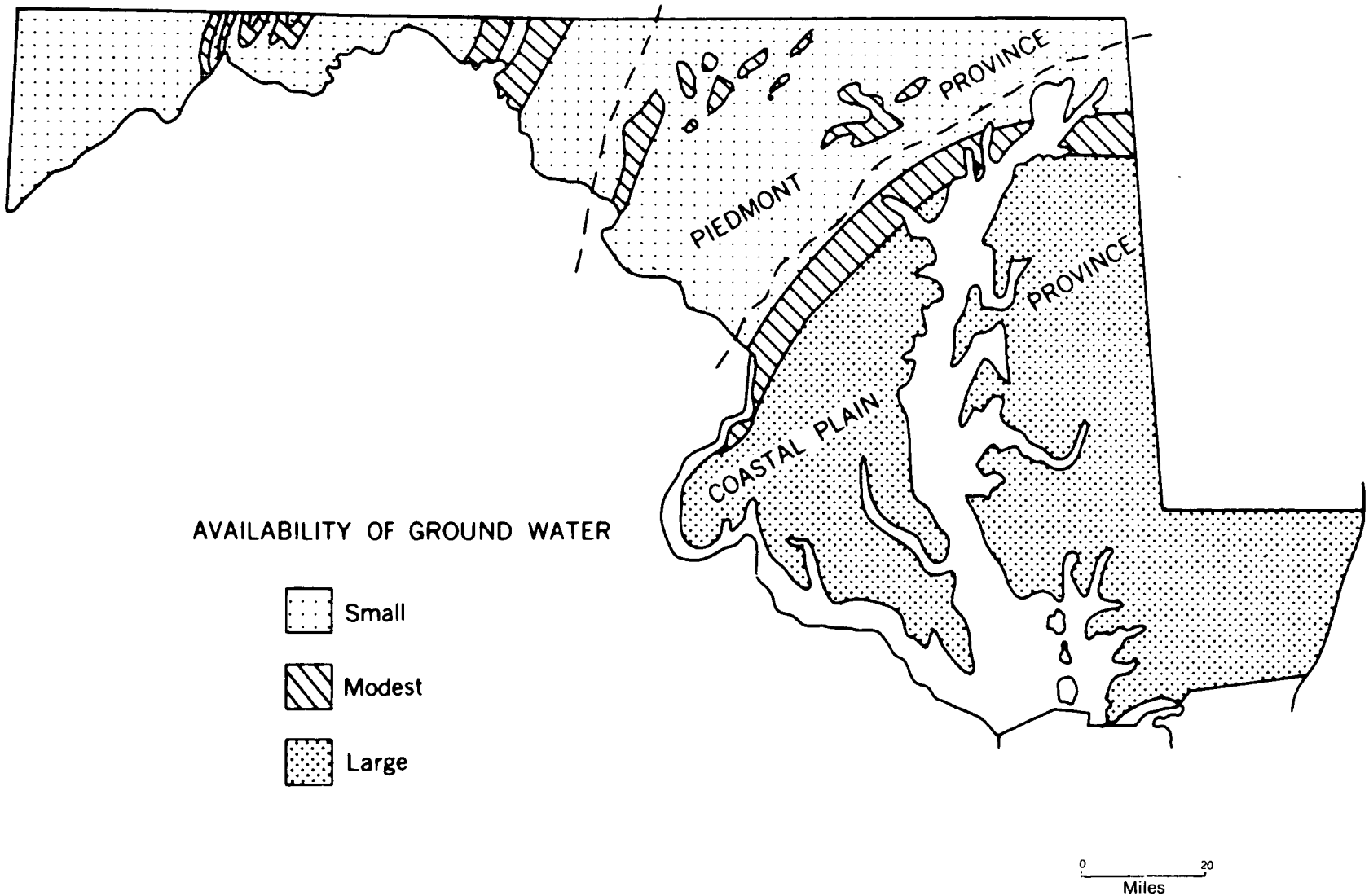
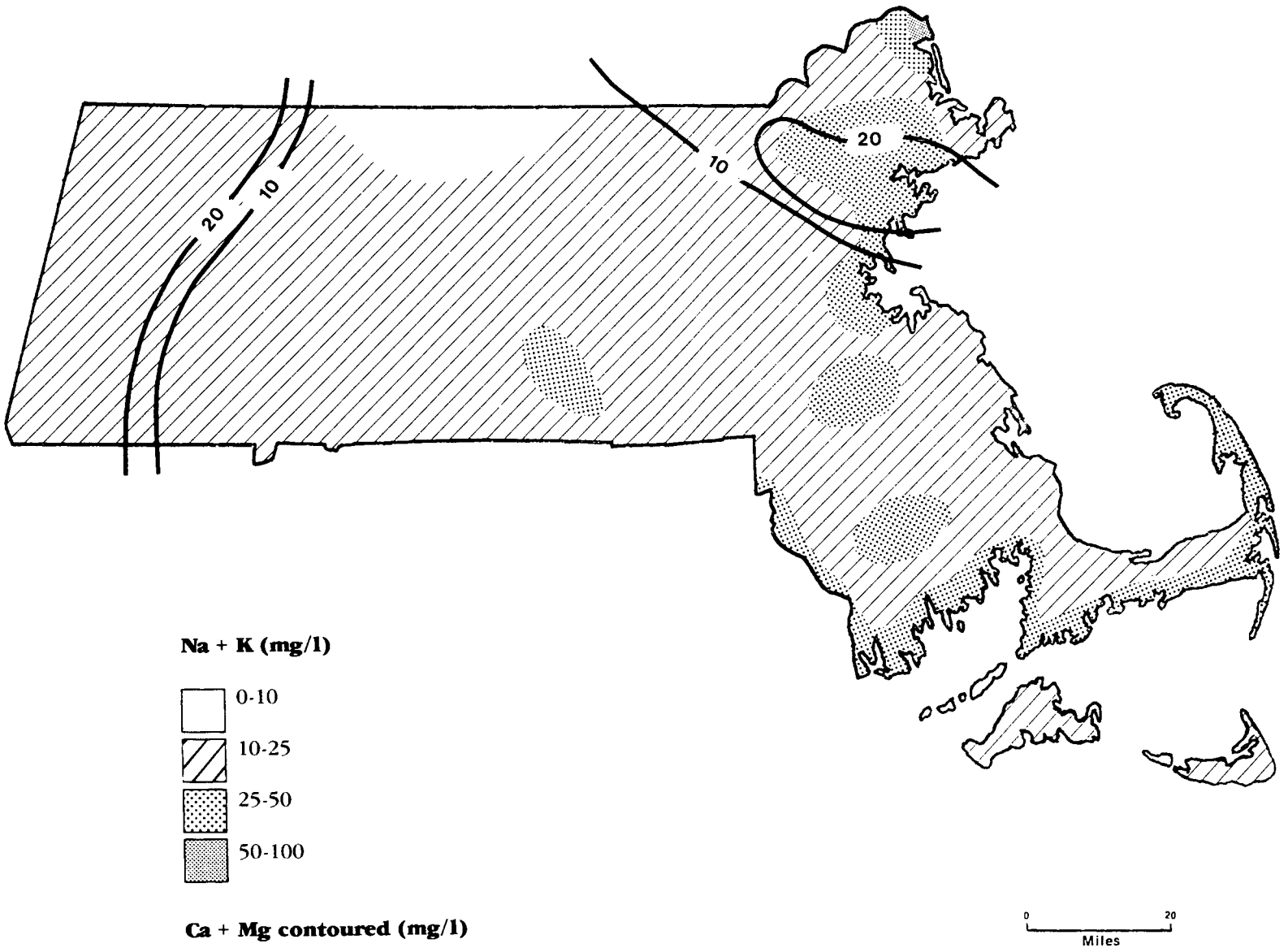


Plate 145

Massachusetts



Massachusetts

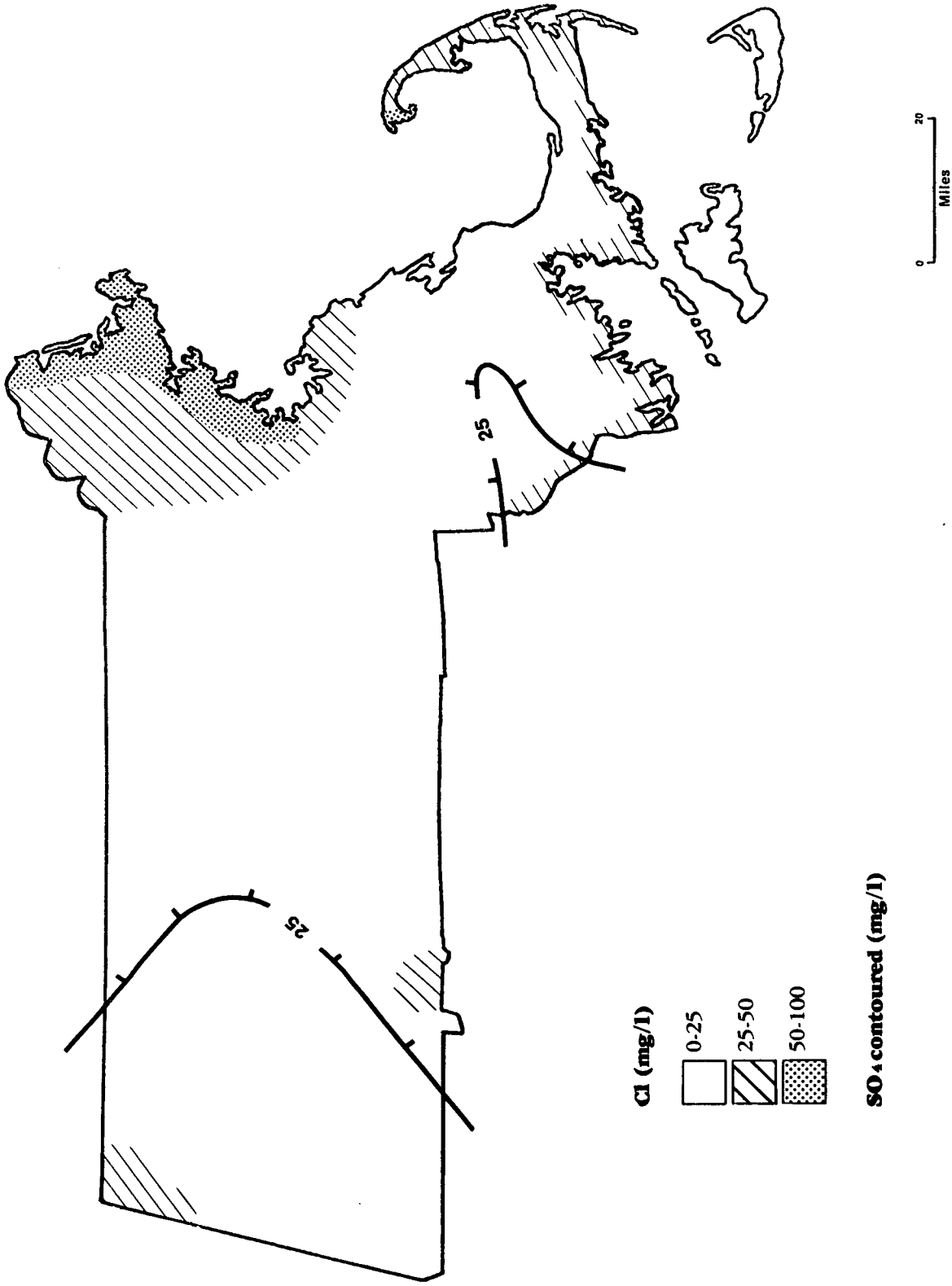


Plate 147

Massachusetts

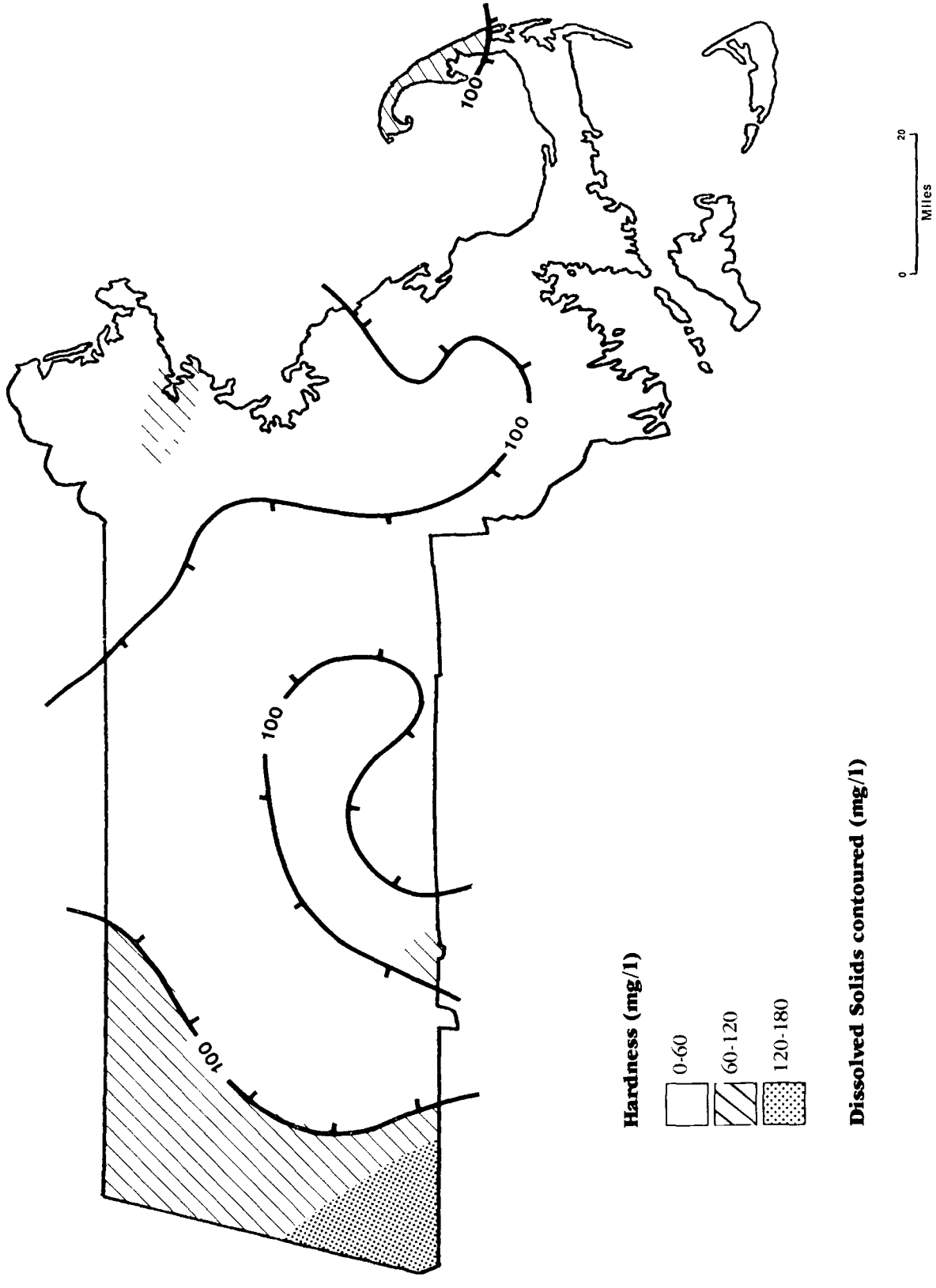


Plate 148

Massachusetts

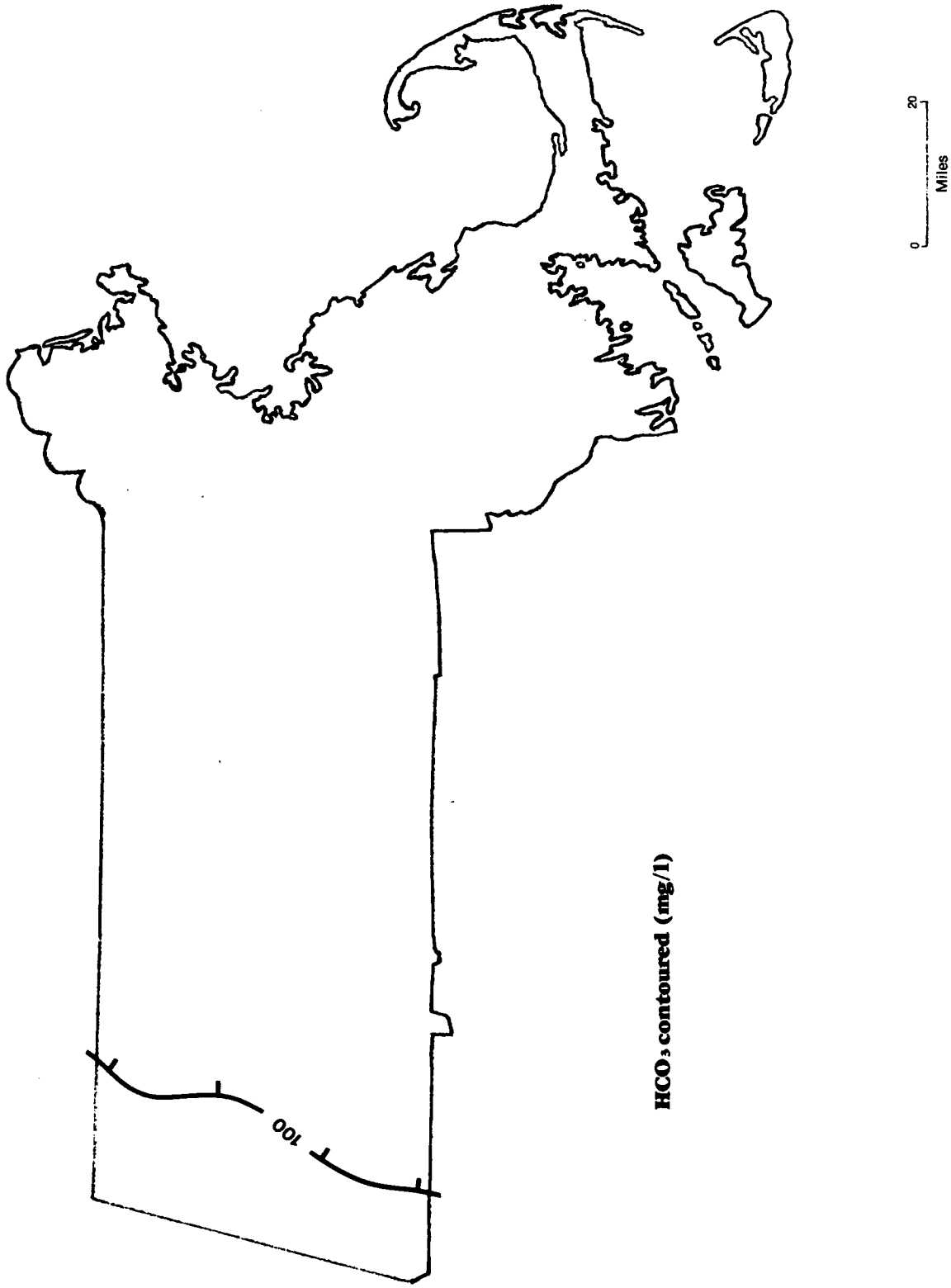
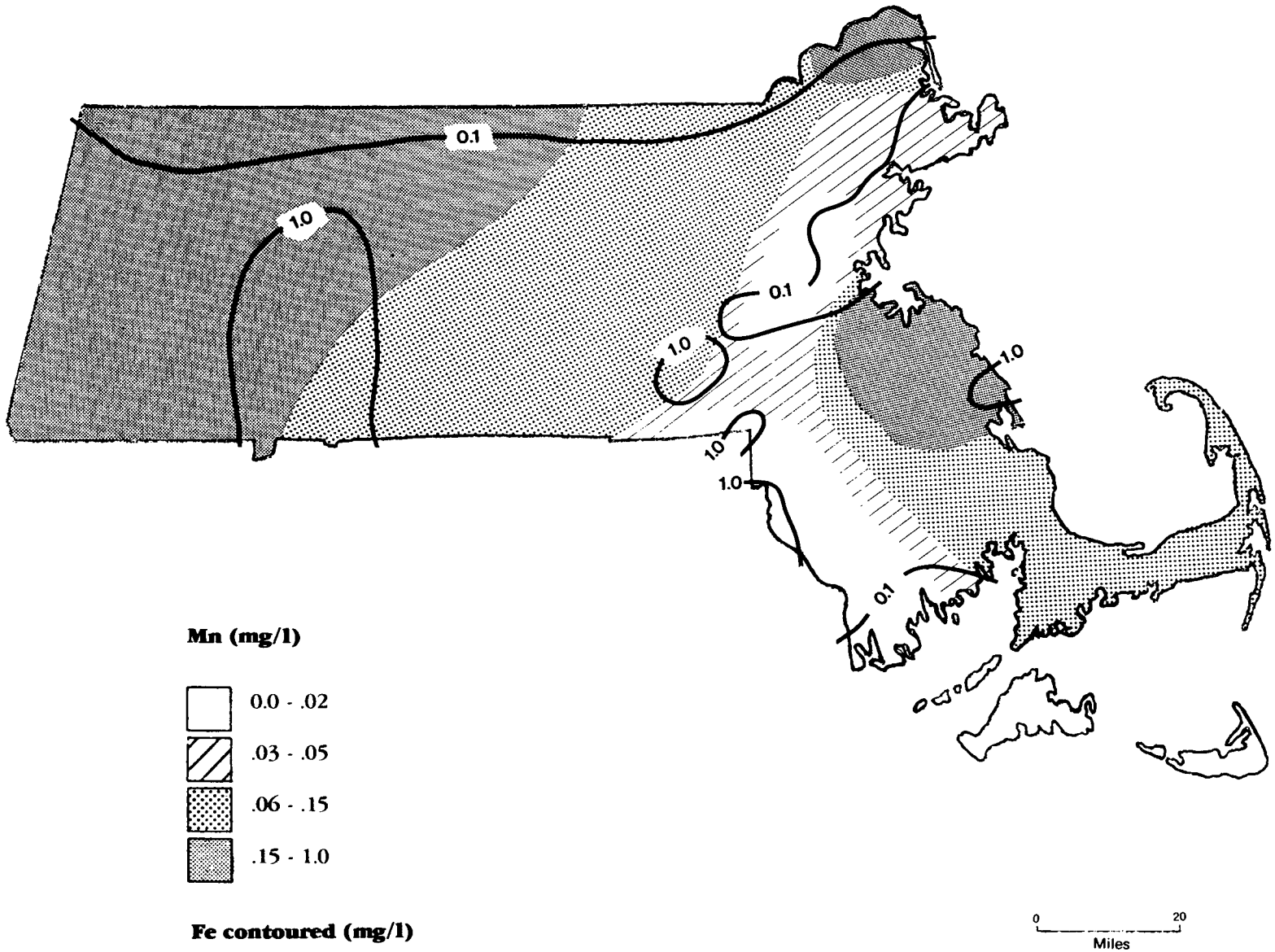
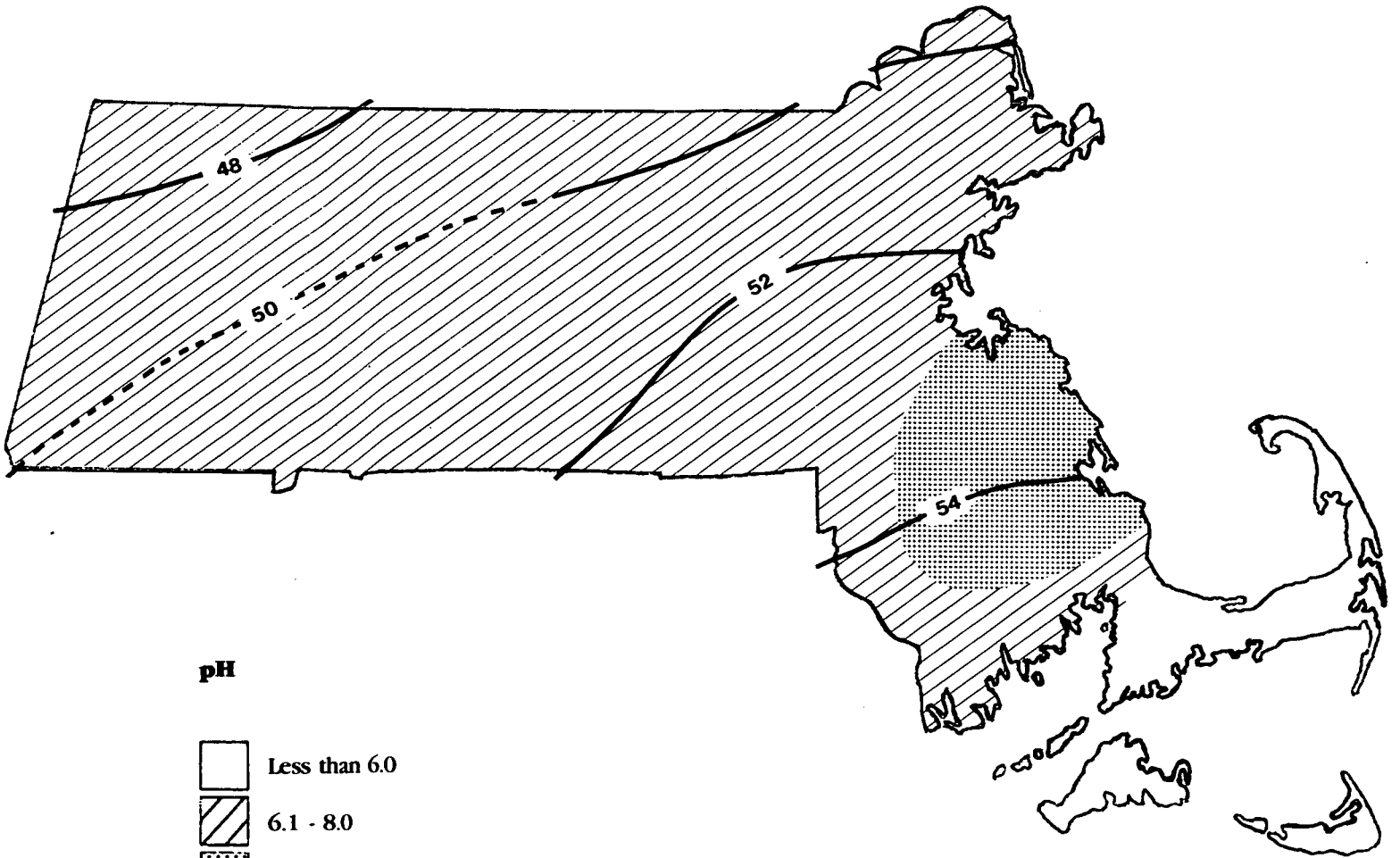


Plate 149

Massachusetts



Massachusetts



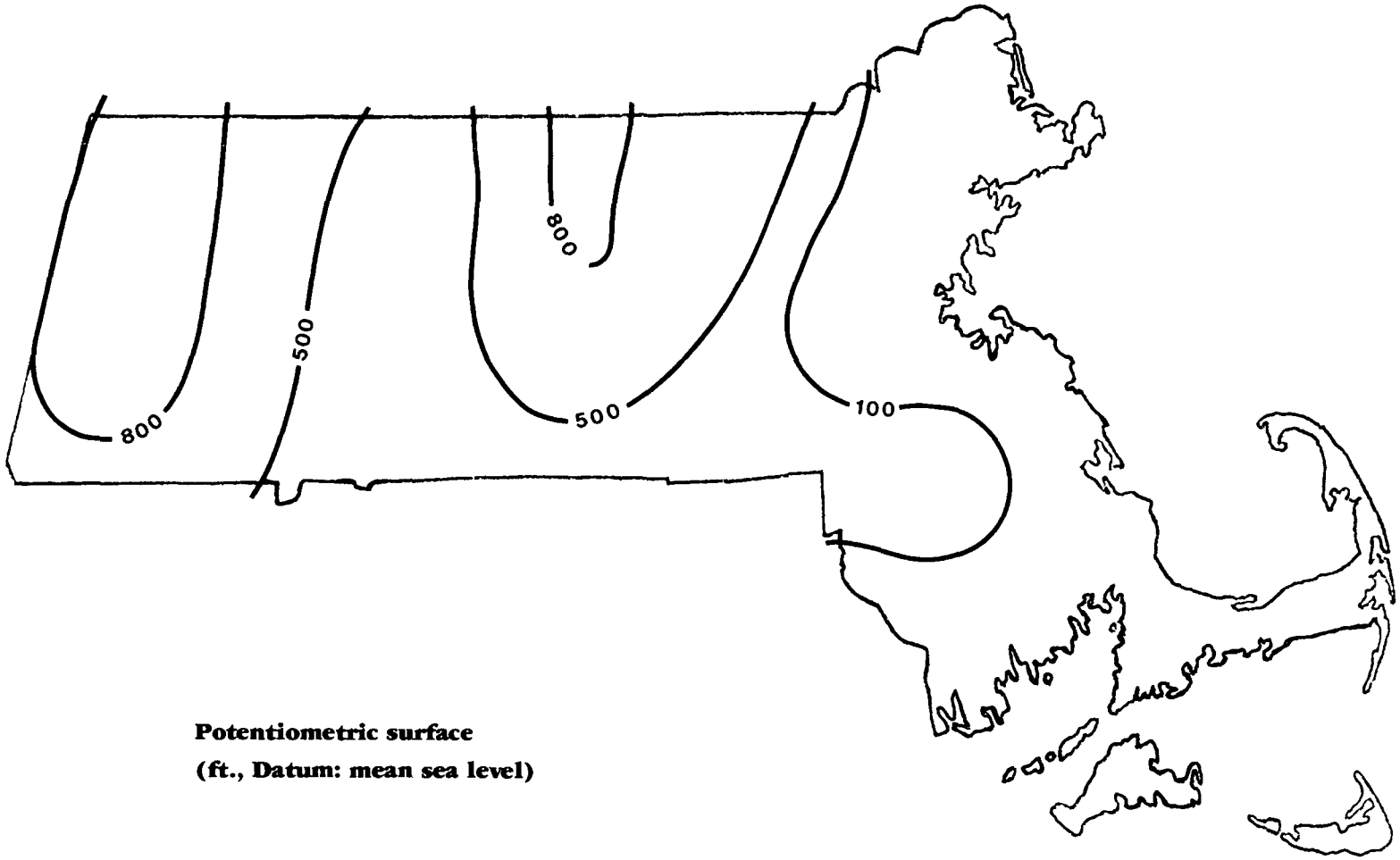
pH

- Less than 6.0
- 6.1 - 8.0
- 8.1 - 10

Temperature contoured (°F)

0 20
Miles

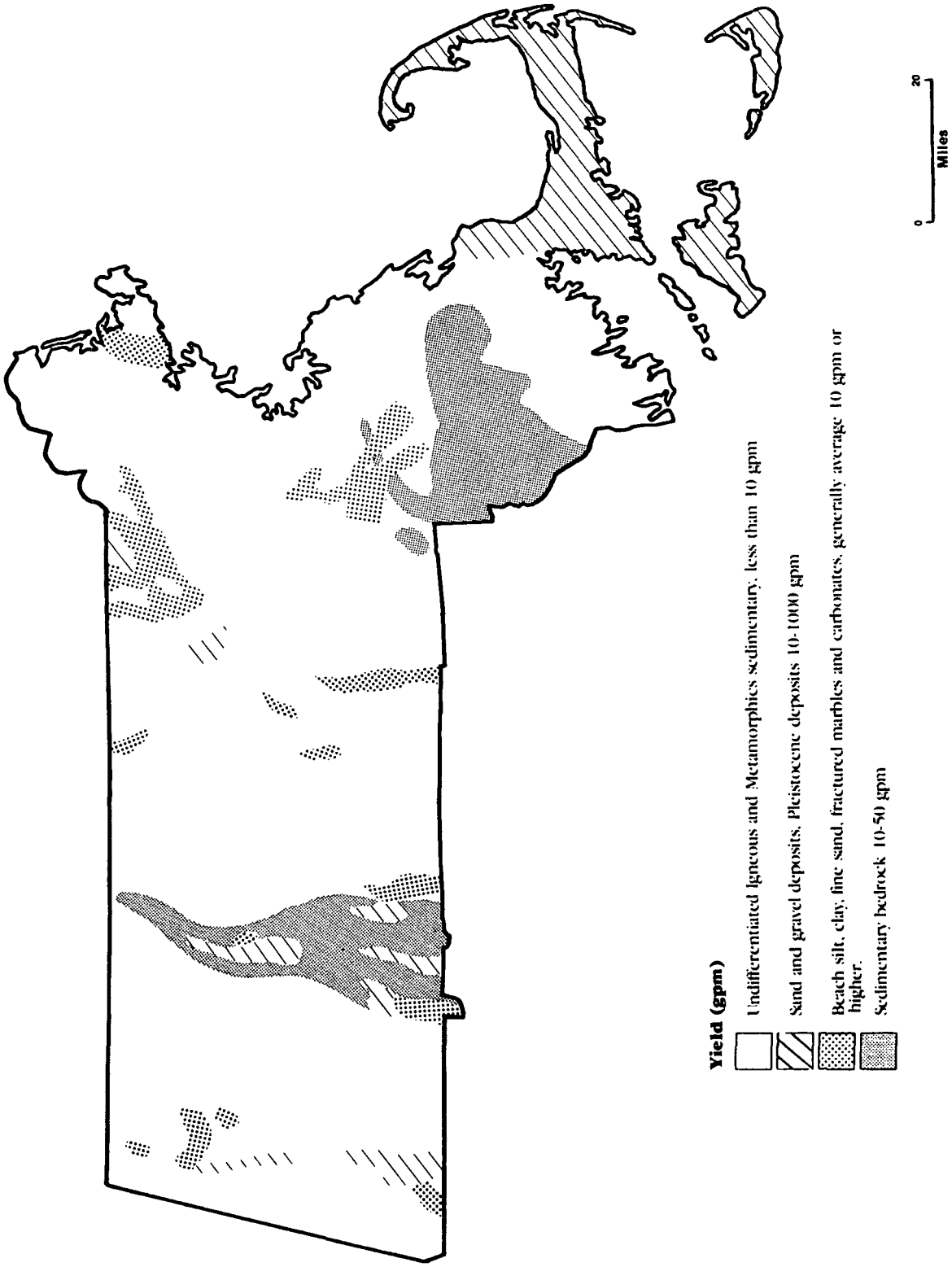
Massachusetts



Potentiometric surface
(ft., Datum: mean sea level)

0 20
Miles

Massachusetts



Michigan

50
50
100
50
100
Na + K (mg/l)
0-15
15-25
25-50
Ca + Mg contoured (mg/l)
0
60
Miles

Michigan

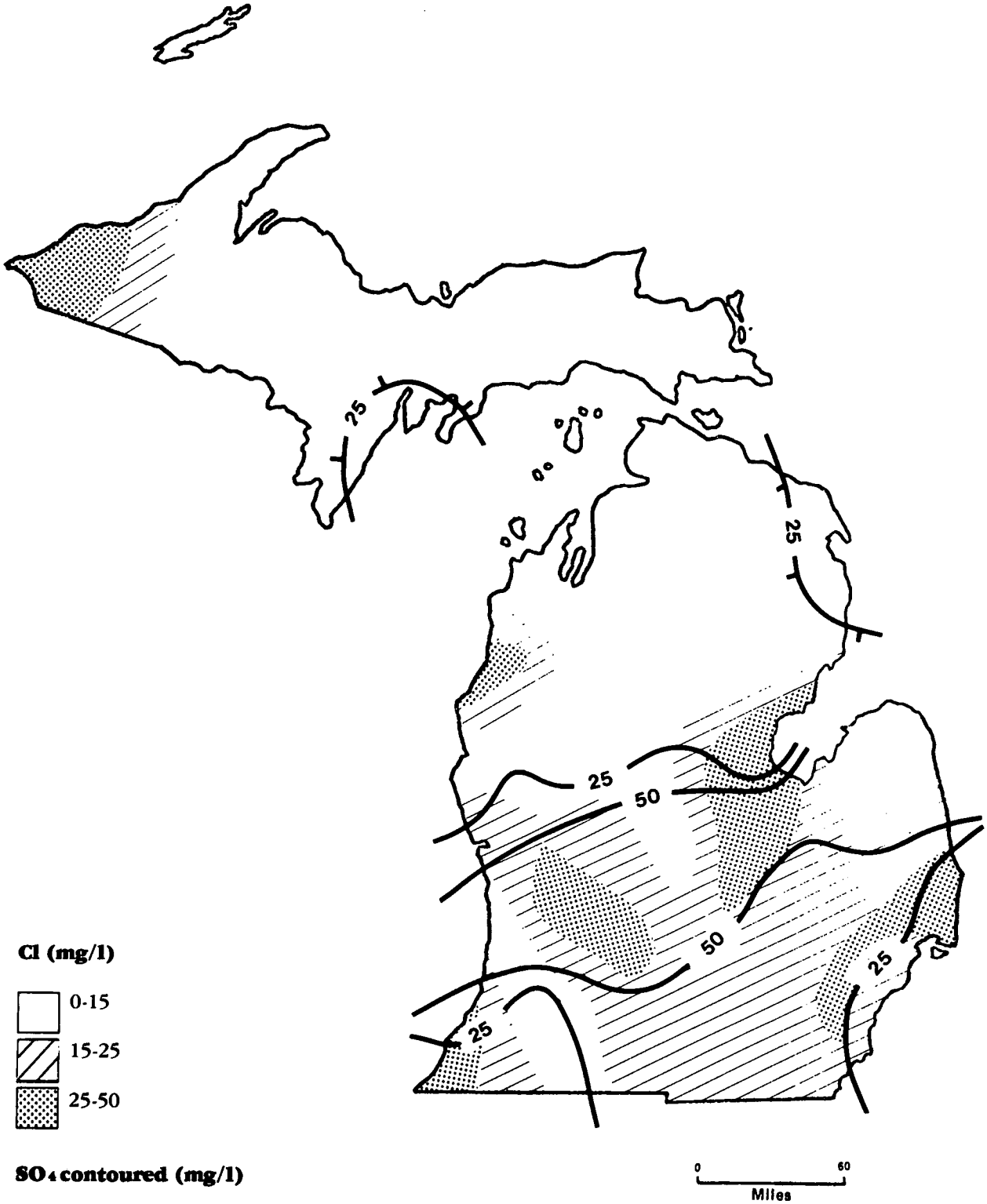
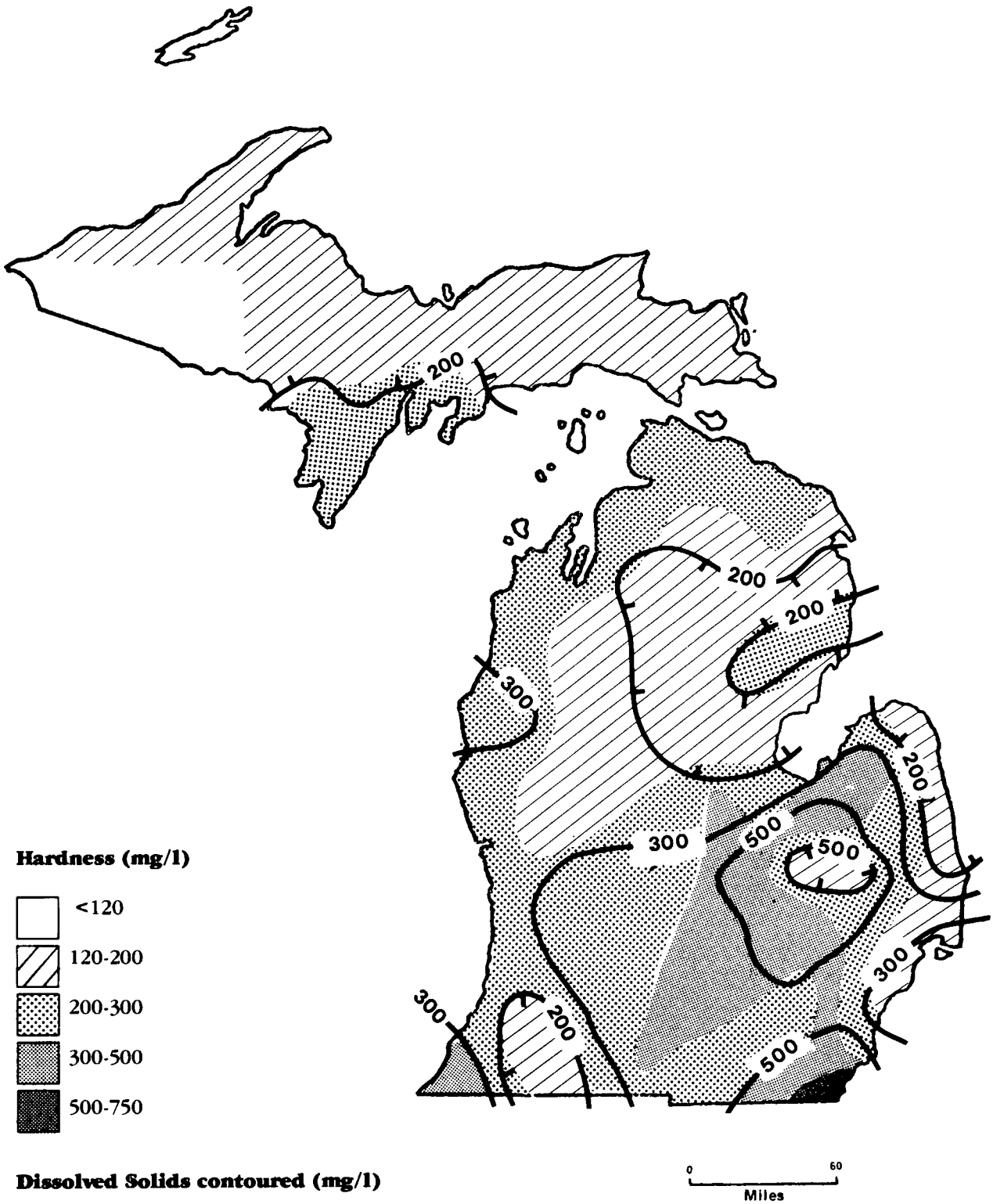
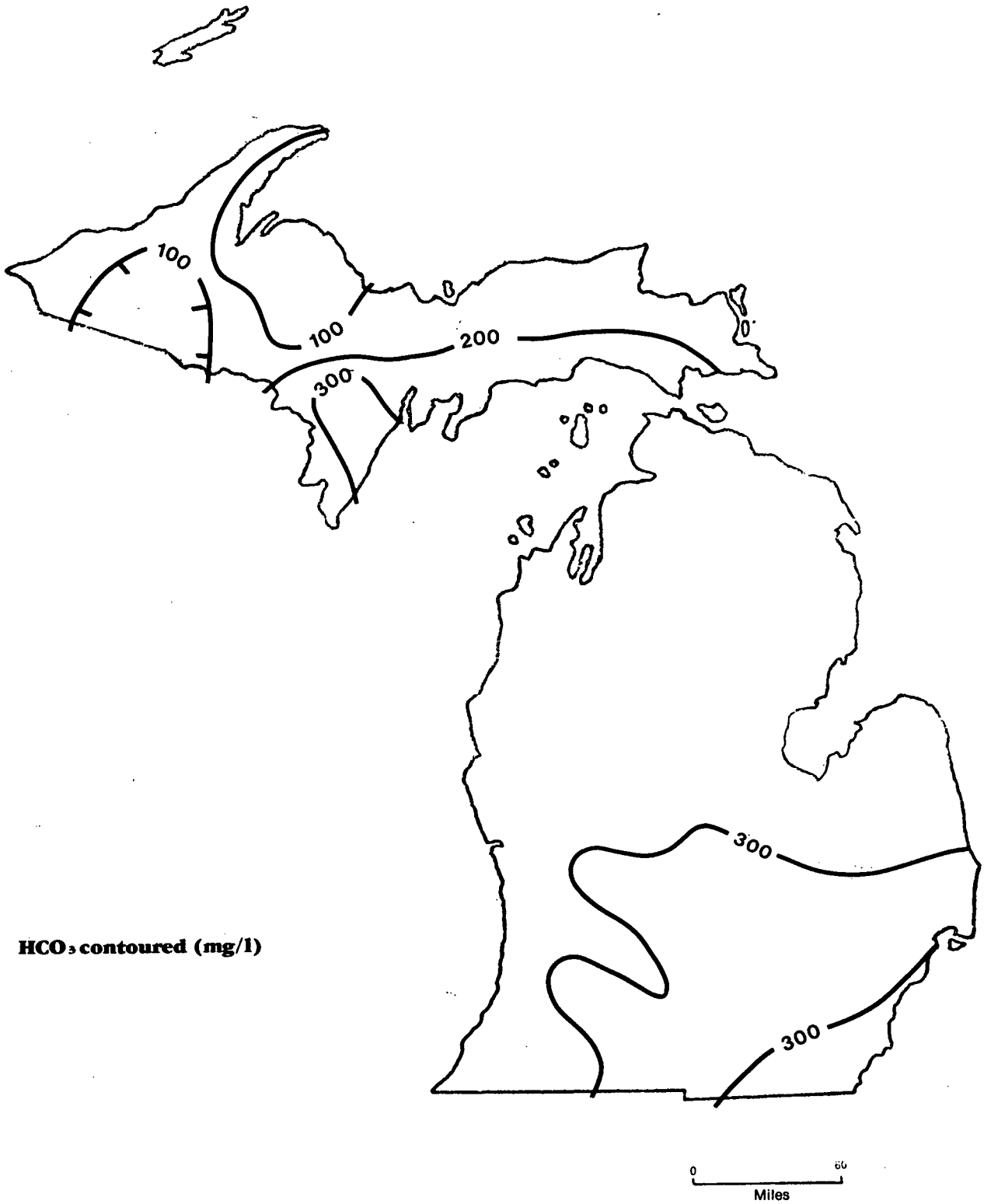


Plate 155

Michigan

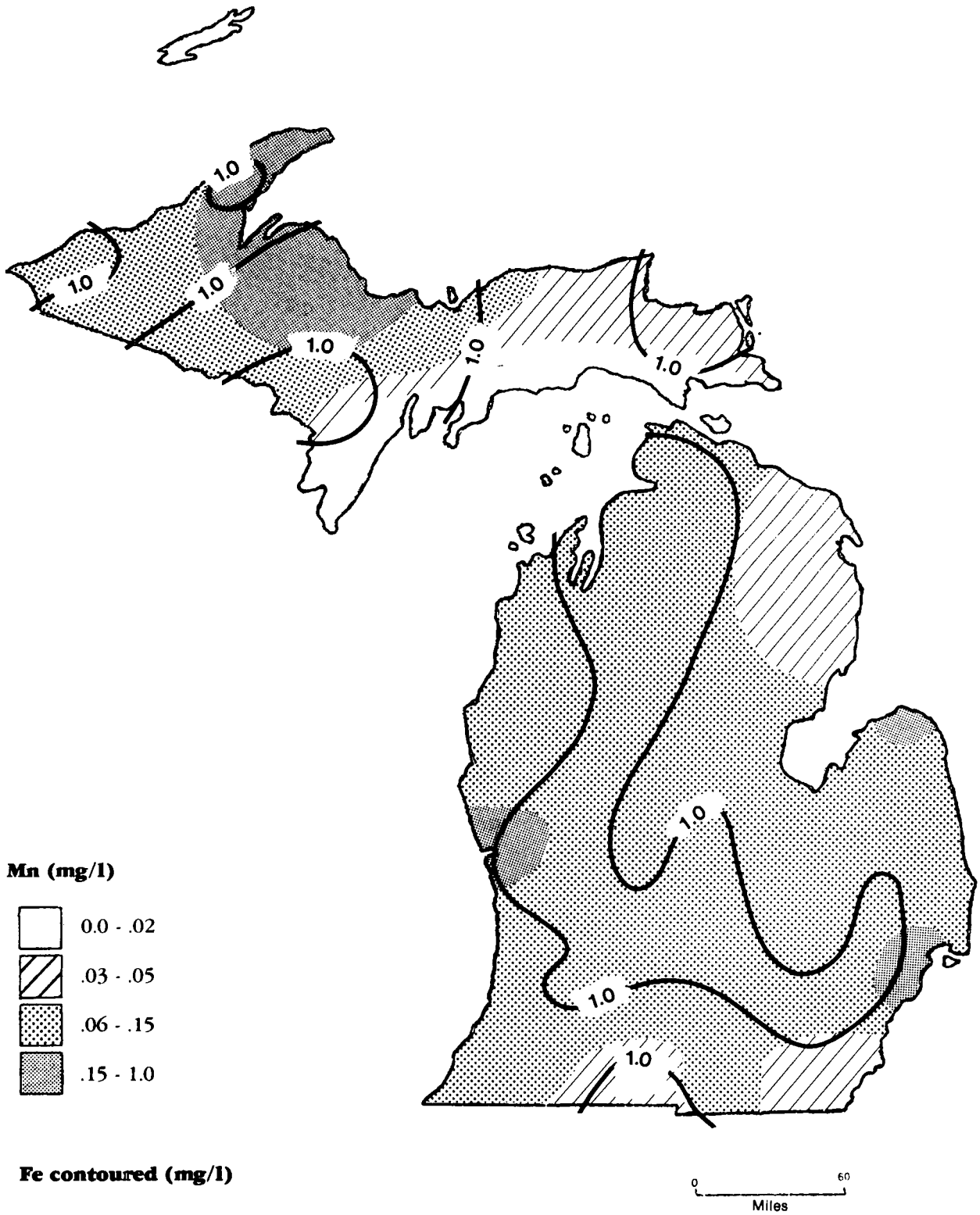

200
200
200
300
200
300
500
500
300
300
200
500
Hardness (mg/l)
<120
120-200
200-300
300-500
500-750
Dissolved Solids contoured (mg/l)
0
60
Miles

Michigan



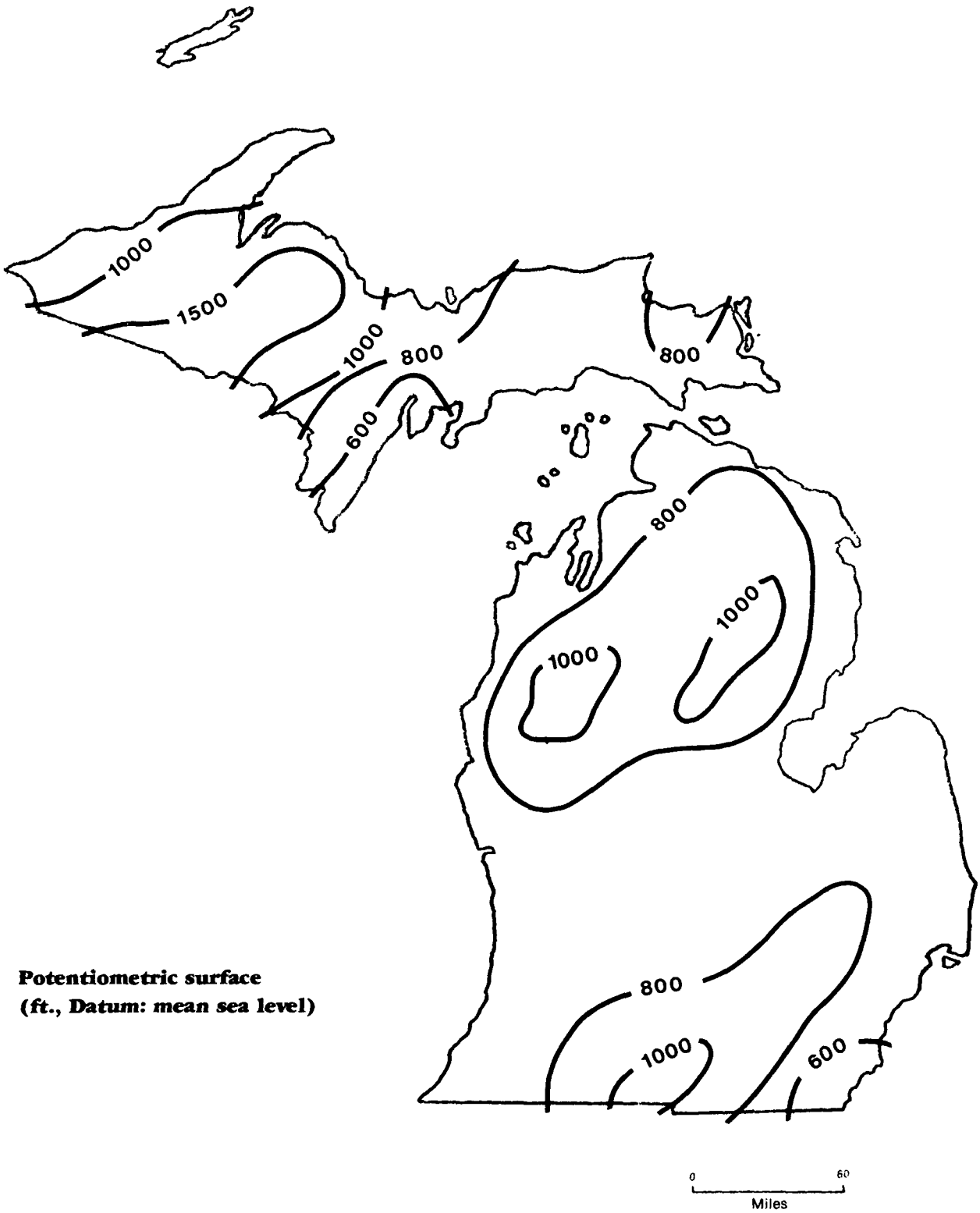
HCO_3 contoured (mg/l)

Michigan


1.0
1.0
1.0
1.0
1.0
1.0
1.0
1.0
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
60
Miles

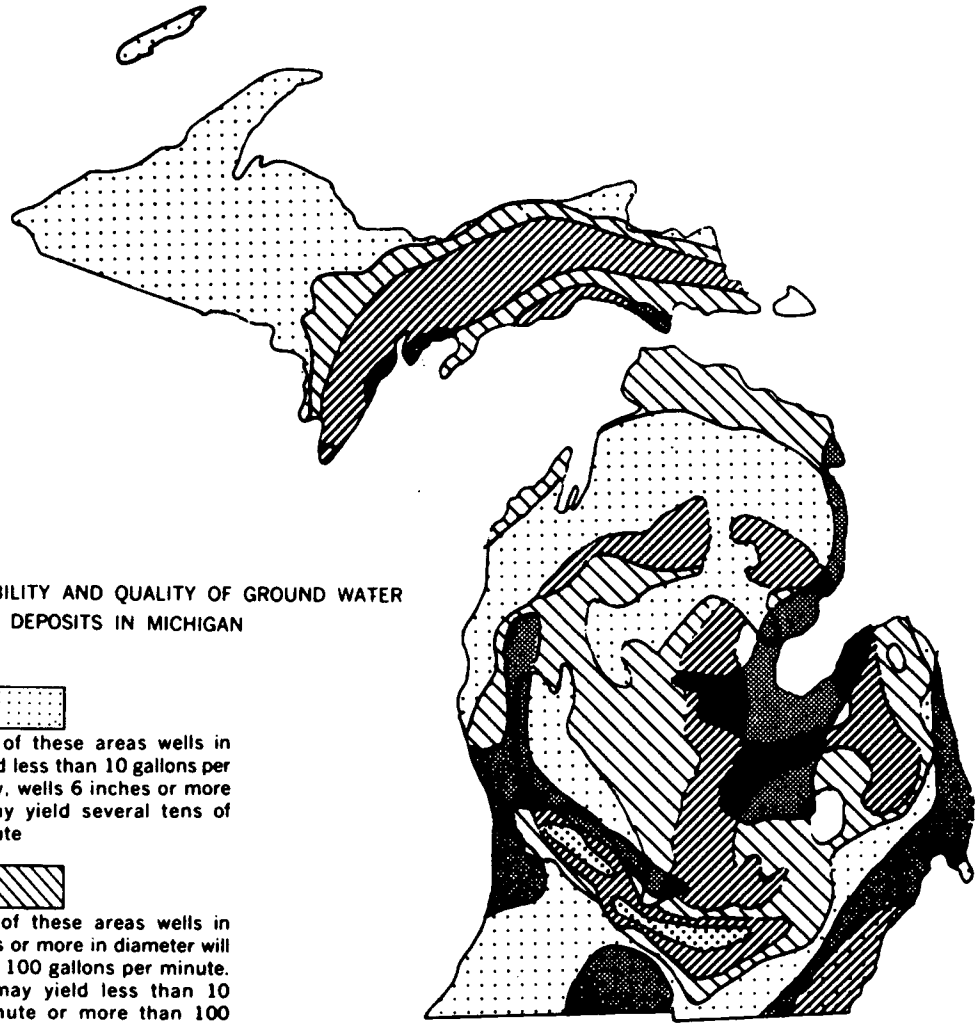
Michigan

Michigan



Potentiometric surface
(ft., Datum: mean sea level)

Michigan



GENERAL AVAILABILITY AND QUALITY OF GROUND WATER IN THE BEDROCK DEPOSITS IN MICHIGAN

Throughout most of these areas wells in bedrock will yield less than 10 gallons per minute. Locally, wells 6 inches or more in diameter may yield several tens of gallons per minute

Throughout most of these areas wells in bedrock 6 inches or more in diameter will yield from 10 to 100 gallons per minute. Locally, wells may yield less than 10 gallons per minute or more than 100 gallons per minute

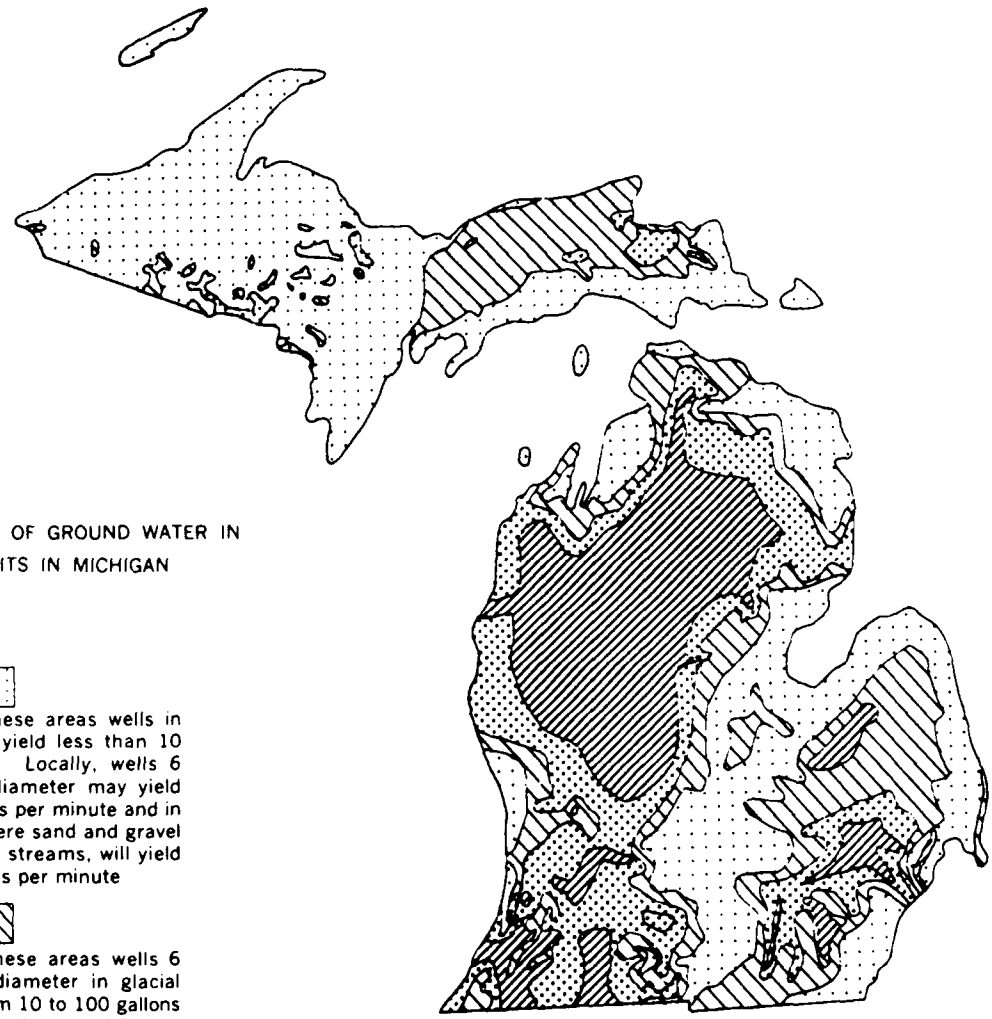
Throughout most of these areas wells in bedrock 8 inches or more in diameter will yield from 100 to 500 gallons per minute. Locally, wells will yield less than 100 or more than 500 gallons per minute

Throughout most of these areas wells in bedrock 10 inches or more in diameter will yield more than 500 gallons per minute

Throughout most of these areas wells in bedrock will yield water that is too highly mineralized for domestic or public supplies-dissolved solids content of more than 1,000 milligrams per liter. Locally, the water may be of relatively good chemical quality. In general, the water becomes more mineralized with an increase in depth

0 60
Miles

Michigan



GENERAL AVAILABILITY OF GROUND WATER IN GLACIAL DRIFT DEPOSITS IN MICHIGAN

Throughout most of these areas wells in glacial deposits will yield less than 10 gallons per minute. Locally, wells 6 inches or more in diameter may yield several tens of gallons per minute and in places, especially where sand and gravel deposits occur along streams, will yield more than 100 gallons per minute

Throughout most of these areas wells 6 inches or more in diameter in glacial deposits will yield from 10 to 100 gallons per minute. Locally wells may yield less than 10 gallons per minute, and in places, especially where sand and gravel deposits occur along streams, will yield several hundred gallons per minute

Throughout most of these areas wells 8 inches or more in diameter in glacial deposits will yield from 100 to 500 gallons per minute. Locally, wells will yield less than 100 gallons per minute, and in places, especially where sand and gravel deposits occur along streams, will yield more than 500 gallons per minute

Throughout most of these areas wells 10 inches or more in diameter in glacial deposits will yield more than 500 gallons per minute

0 60
Miles

Minnesota

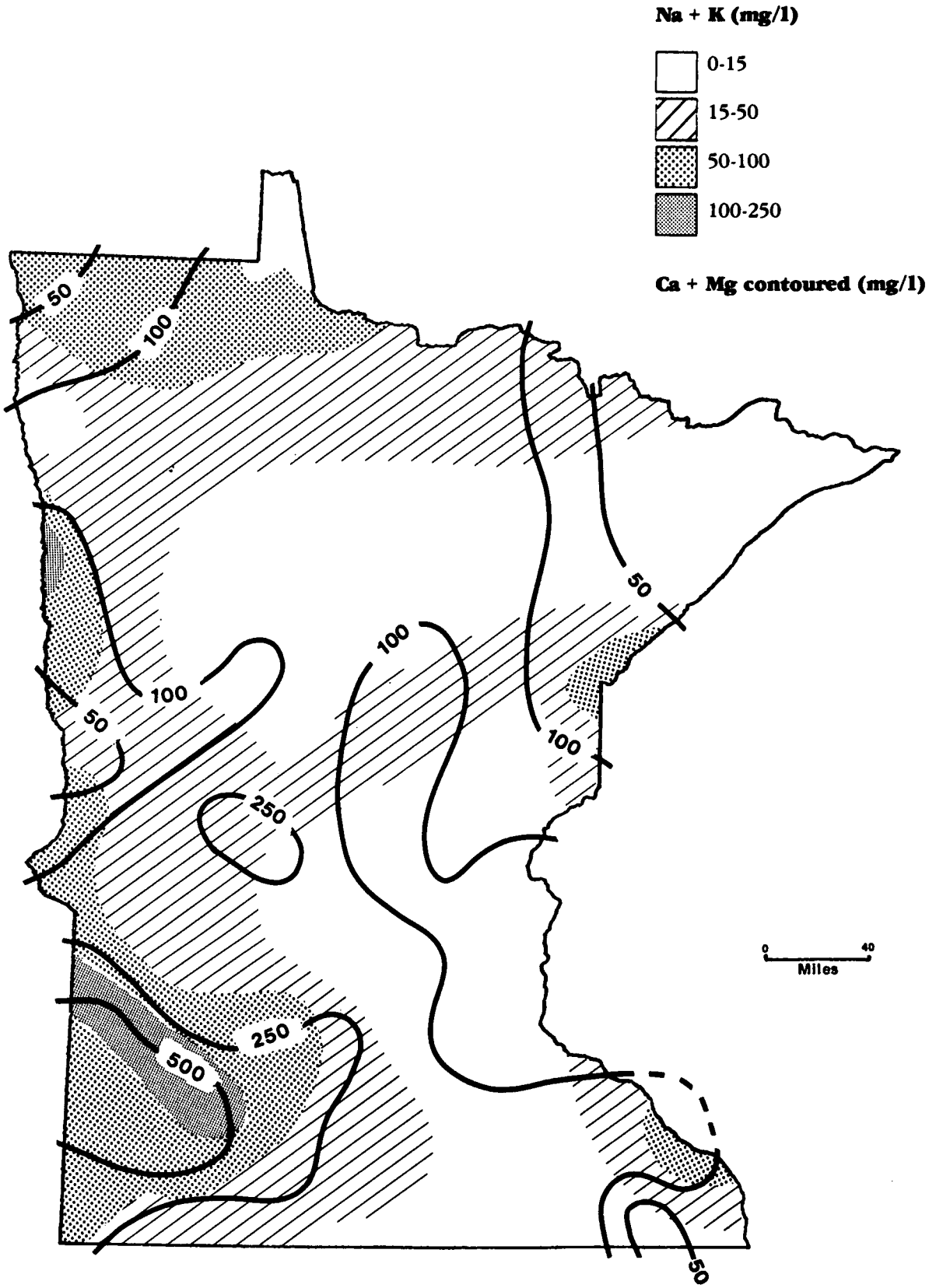


Plate 163

Minnesota

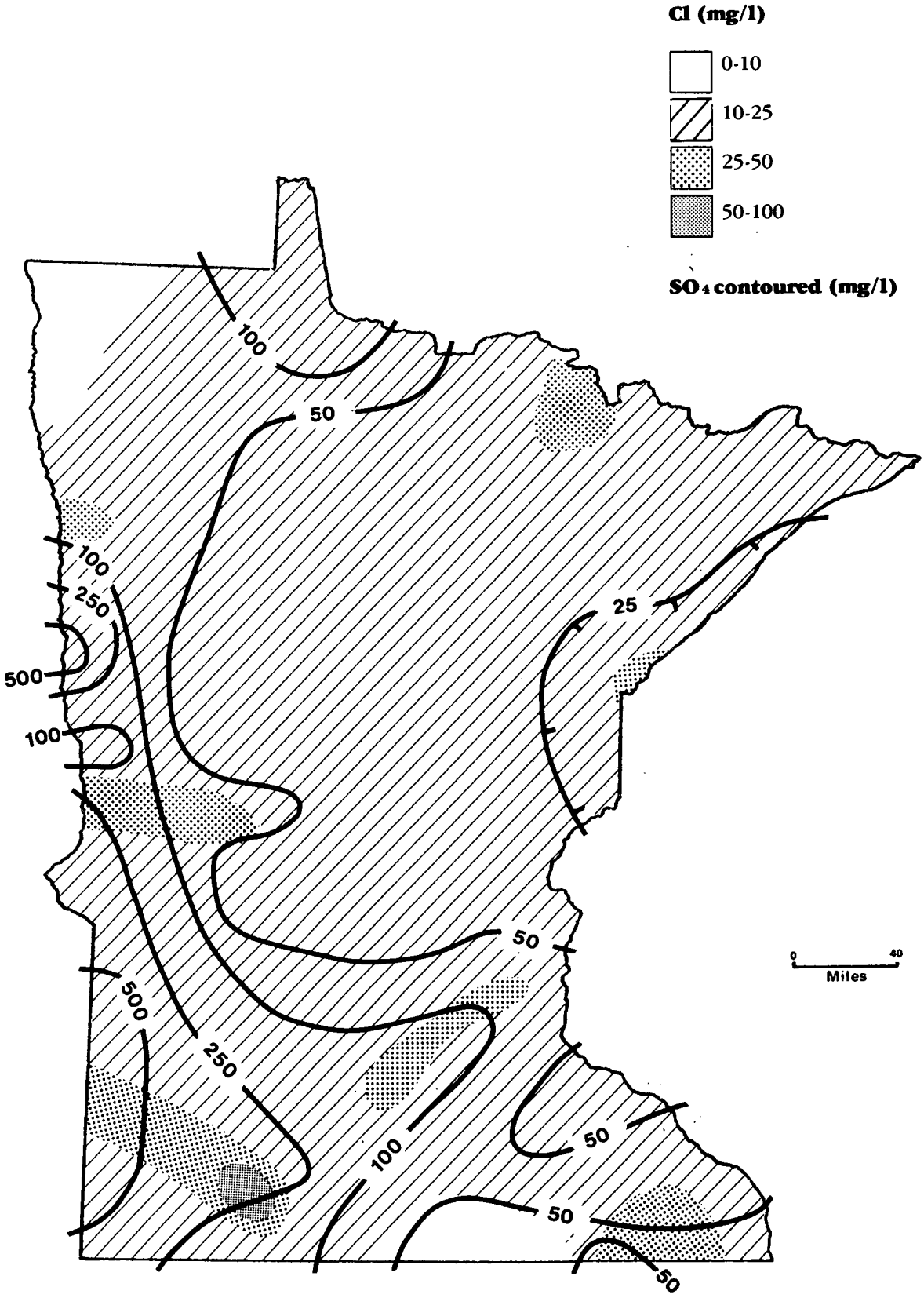


Plate 164

Minnesota

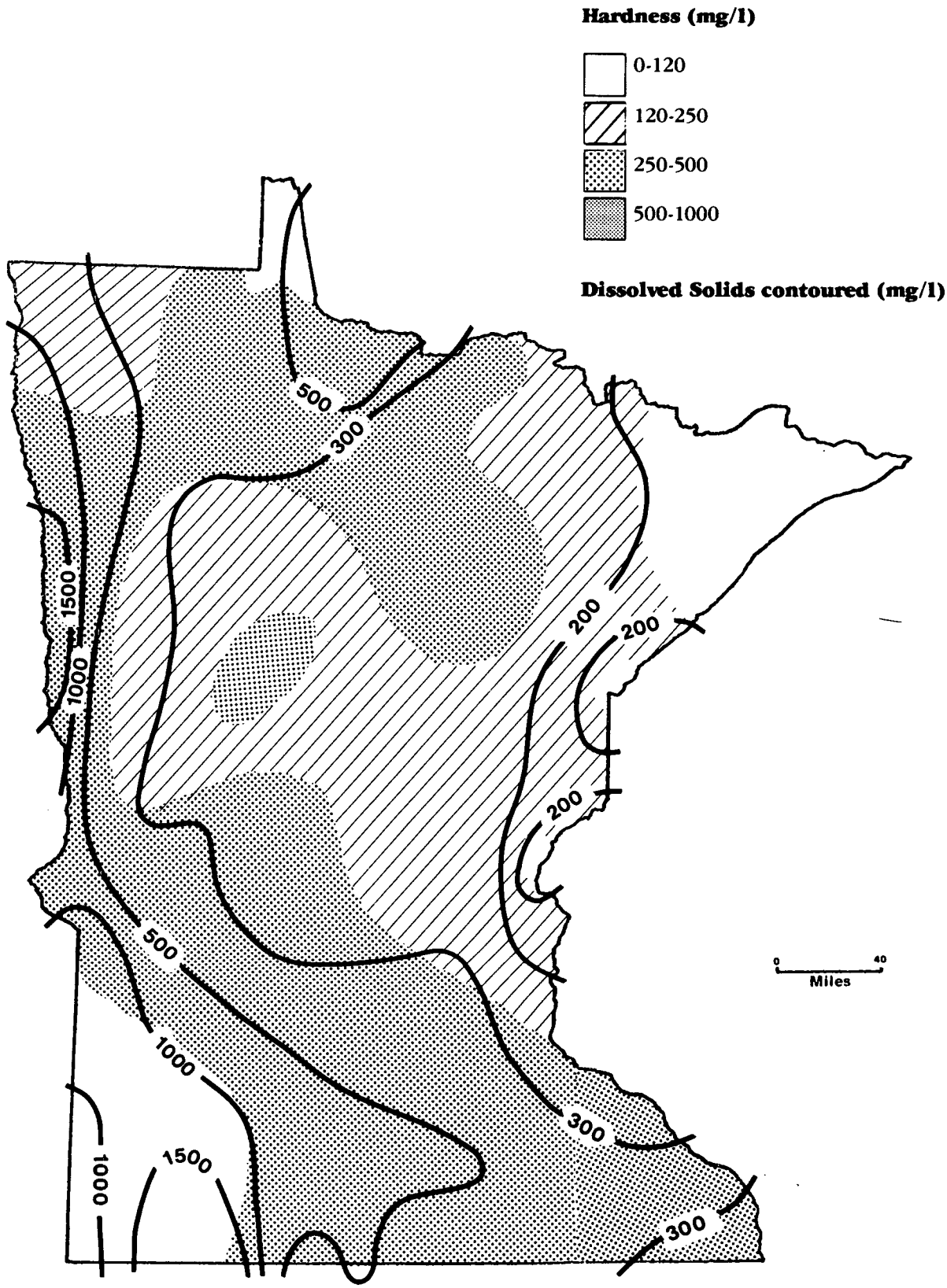


Plate 165

Minnesota

HCO_3 contoured (mg/l)

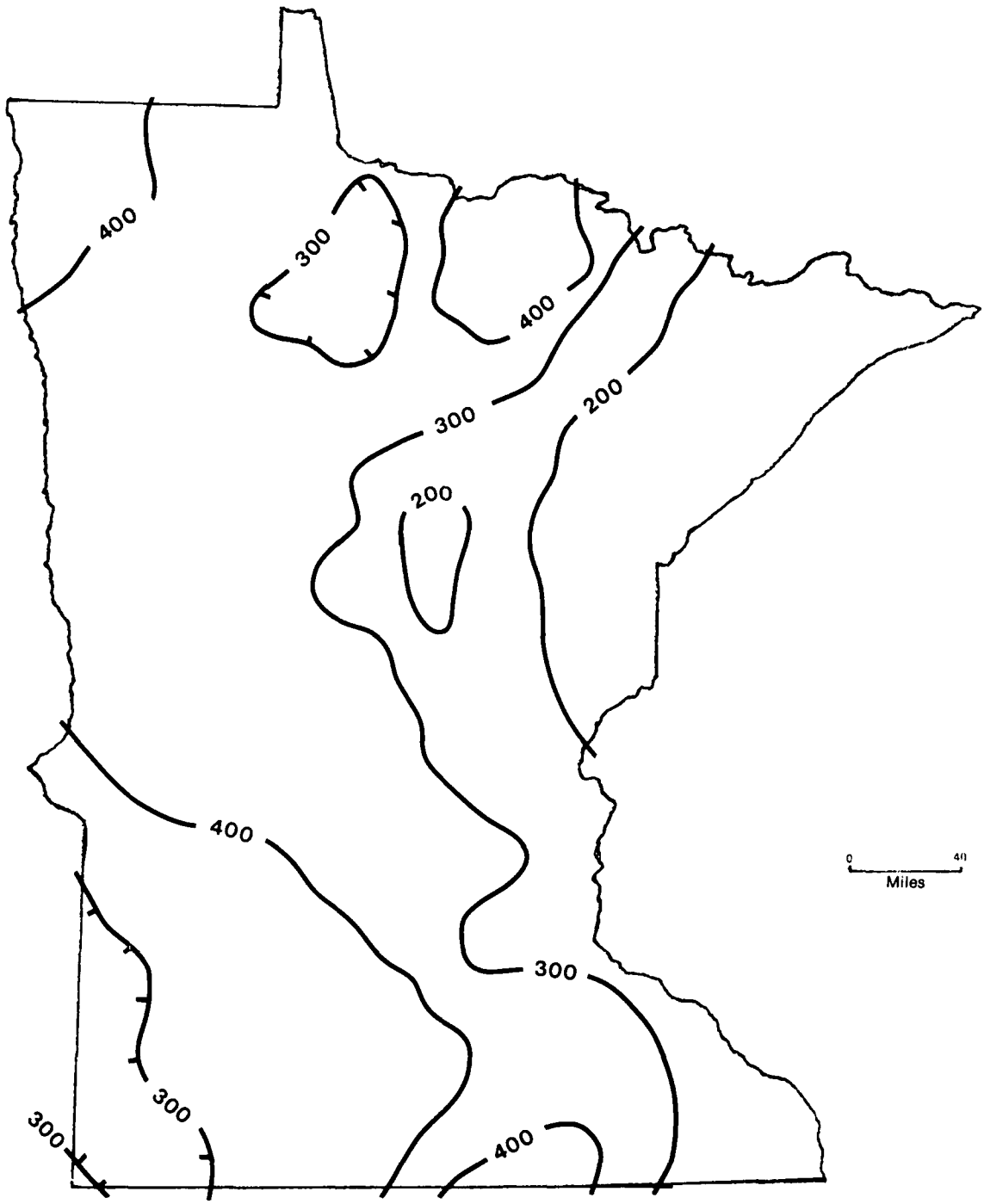
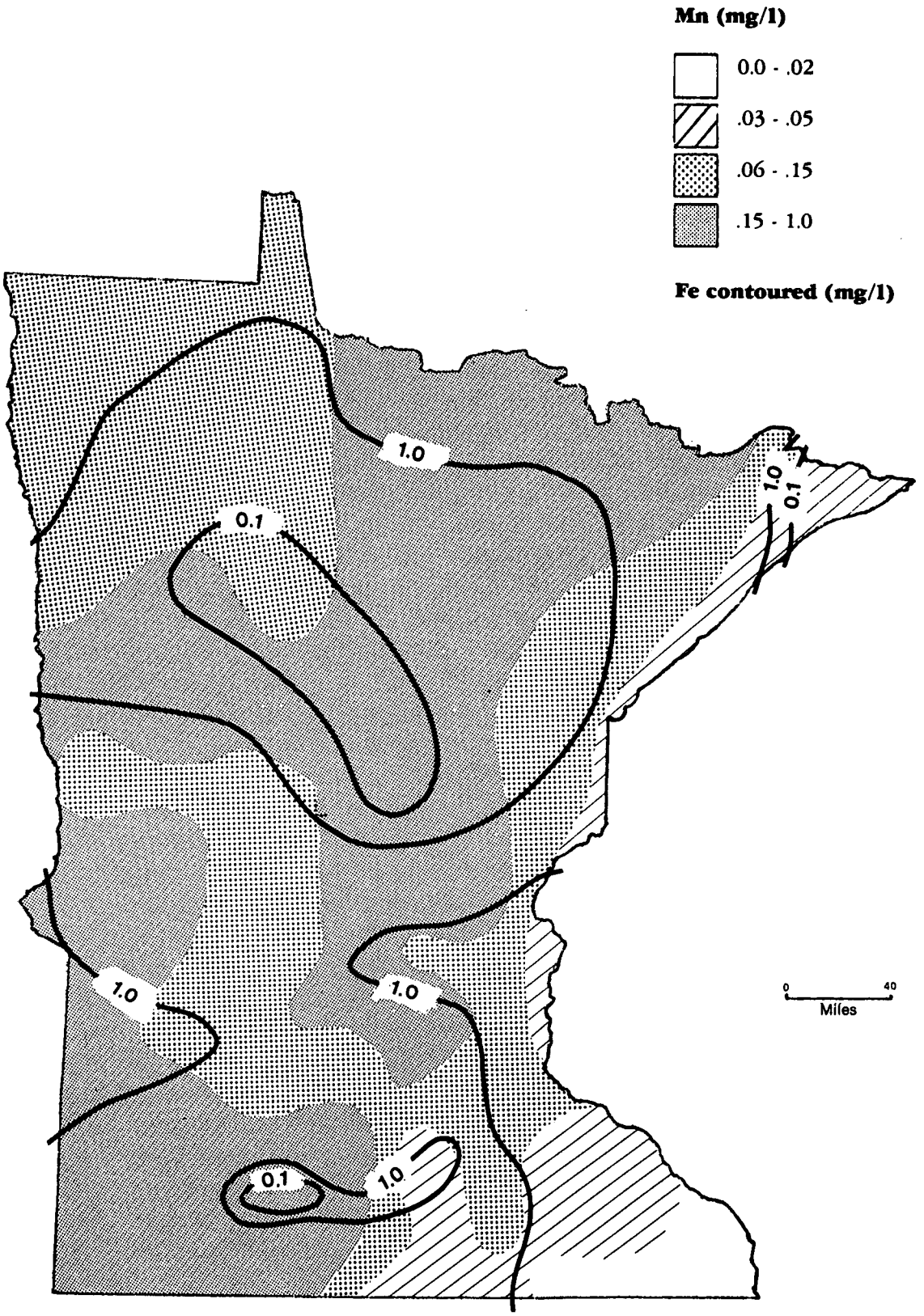


Plate 166

Minnesota


Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
1.0
0.1
1.0
0.1
1.0
1.0
0.1
1.0
0
40
Miles

Minnesota

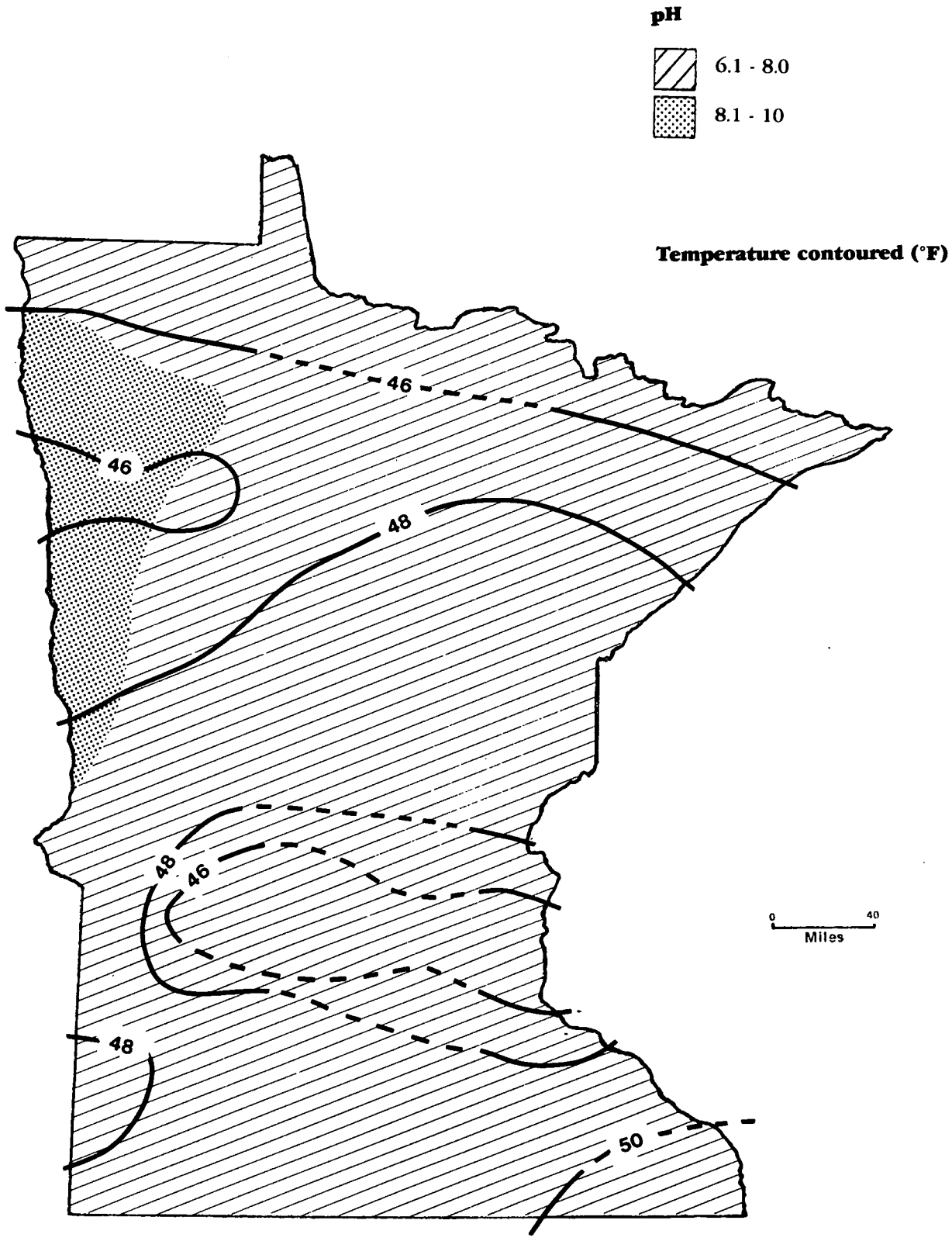
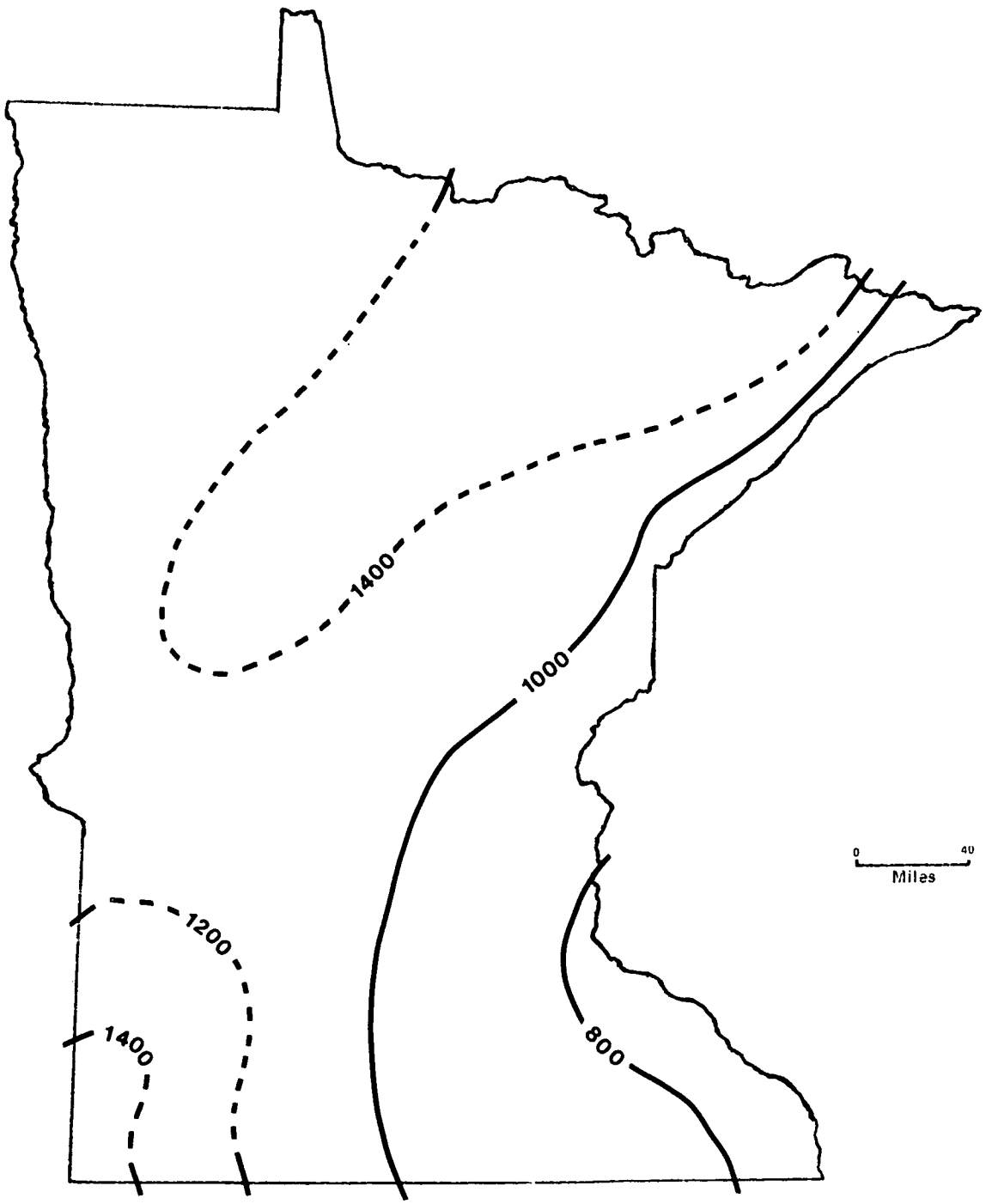


Plate 168

Minnesota

Potentiometric surface
(ft., Datum: mean sea level)



Minnesota

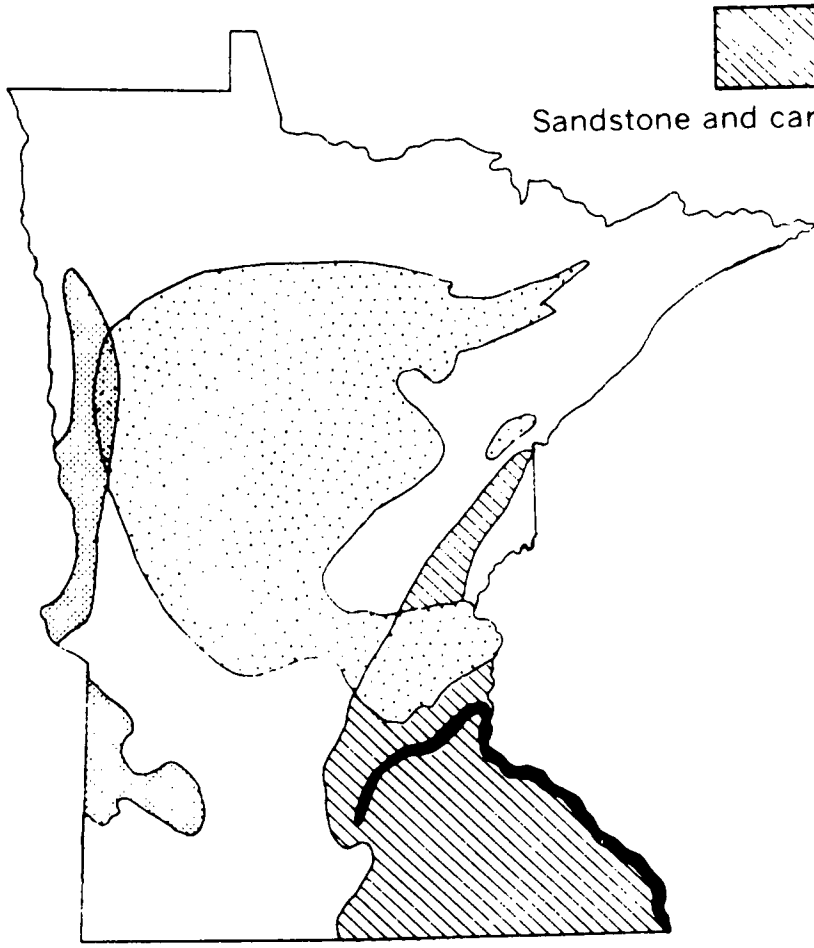
Aquifers generally capable of yielding to a well at least 50 gpm (gallons per minute) of water of good quality

Alluvial sand and gravel

Water course; sand and gravel

Sandstone

Sandstone and carbonate rocks



0 40
Miles

Mississippi

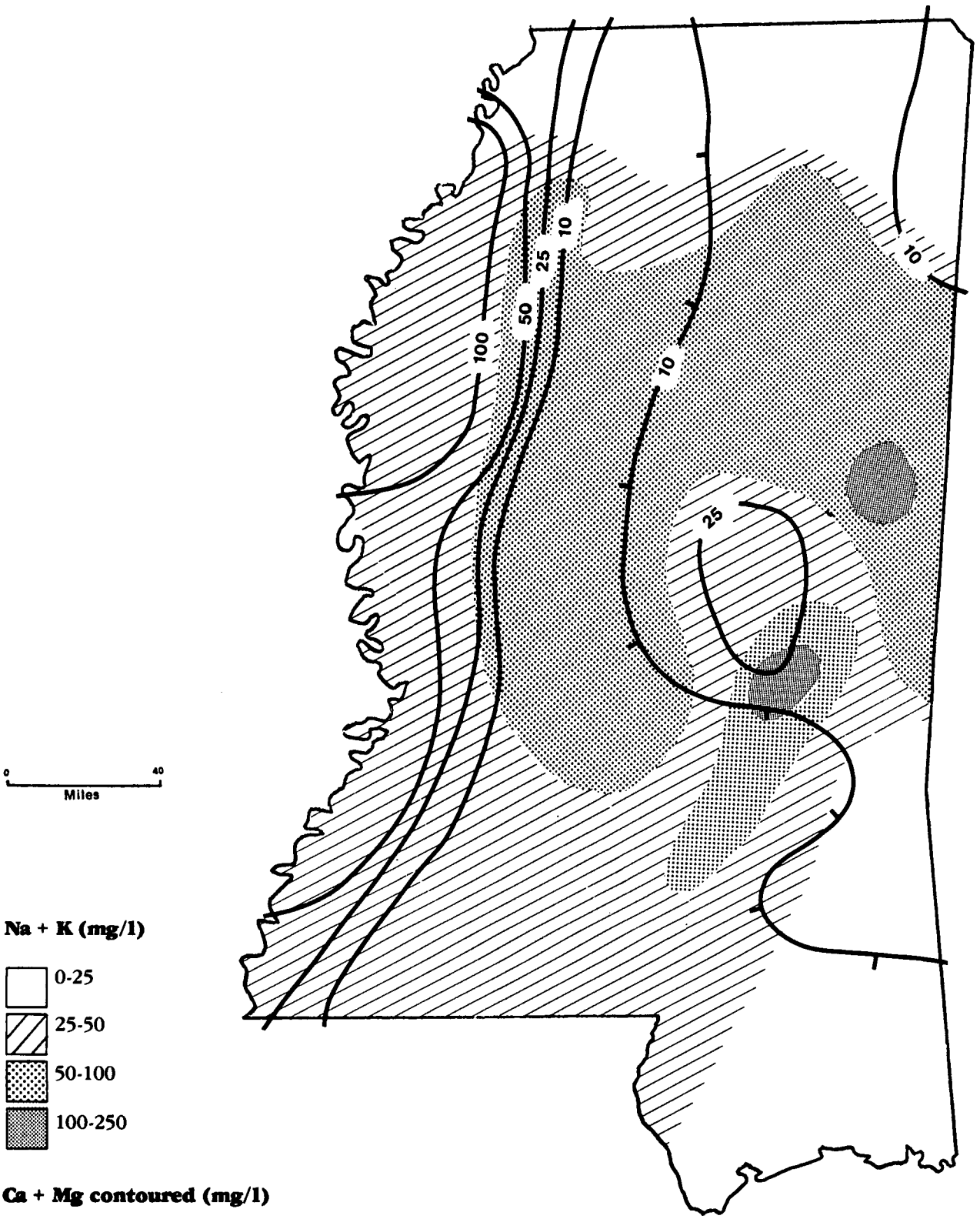
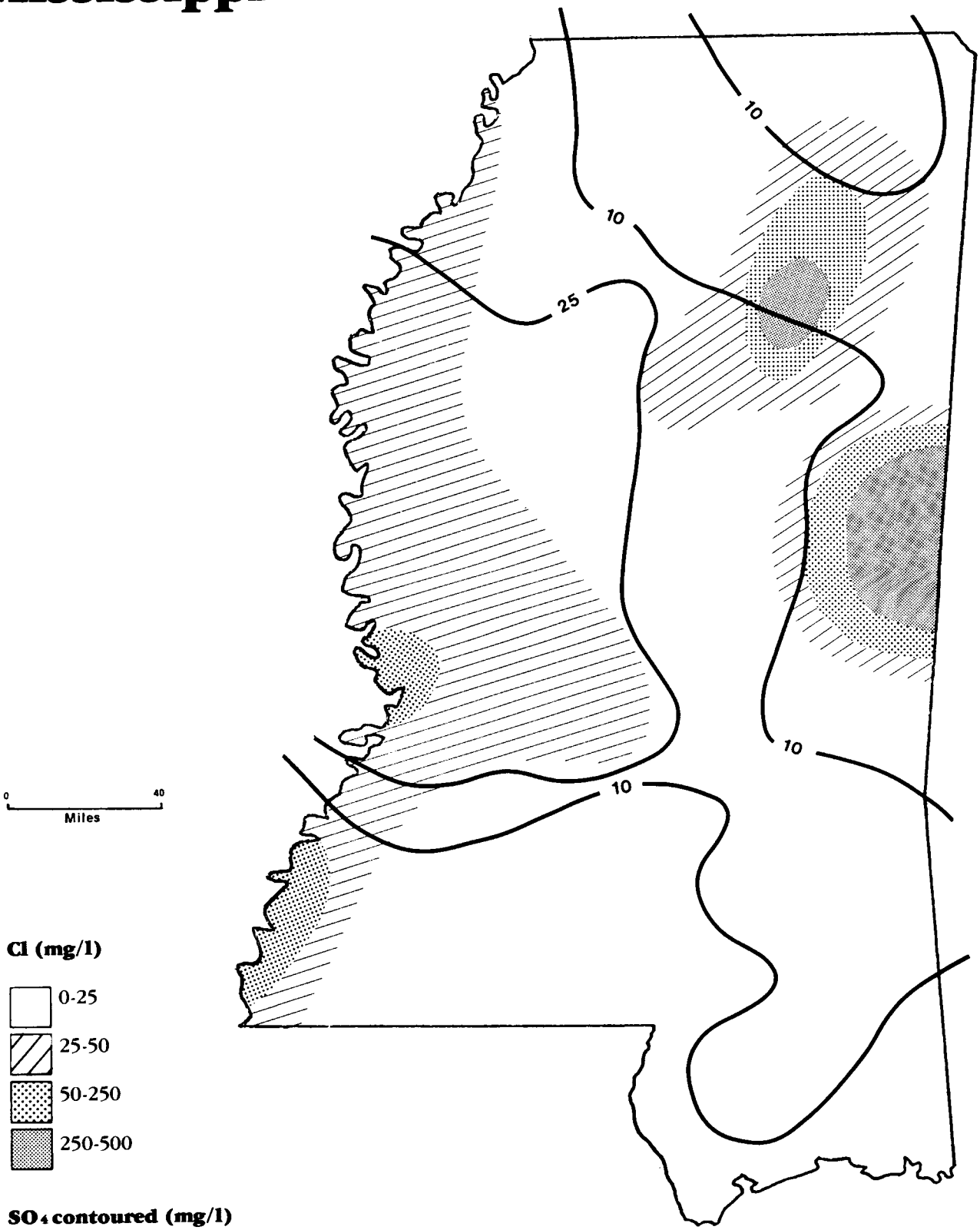
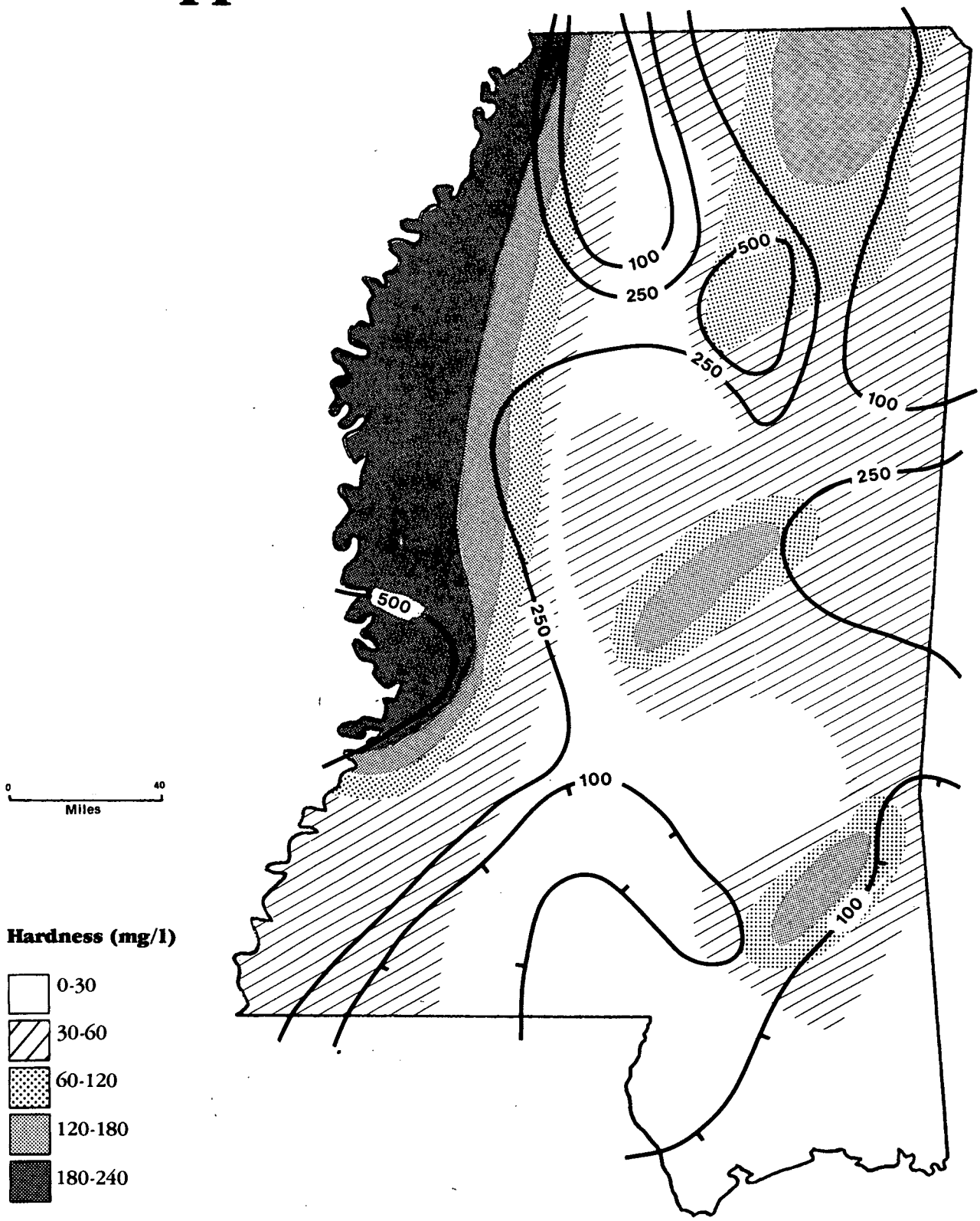


Plate 171

Mississippi

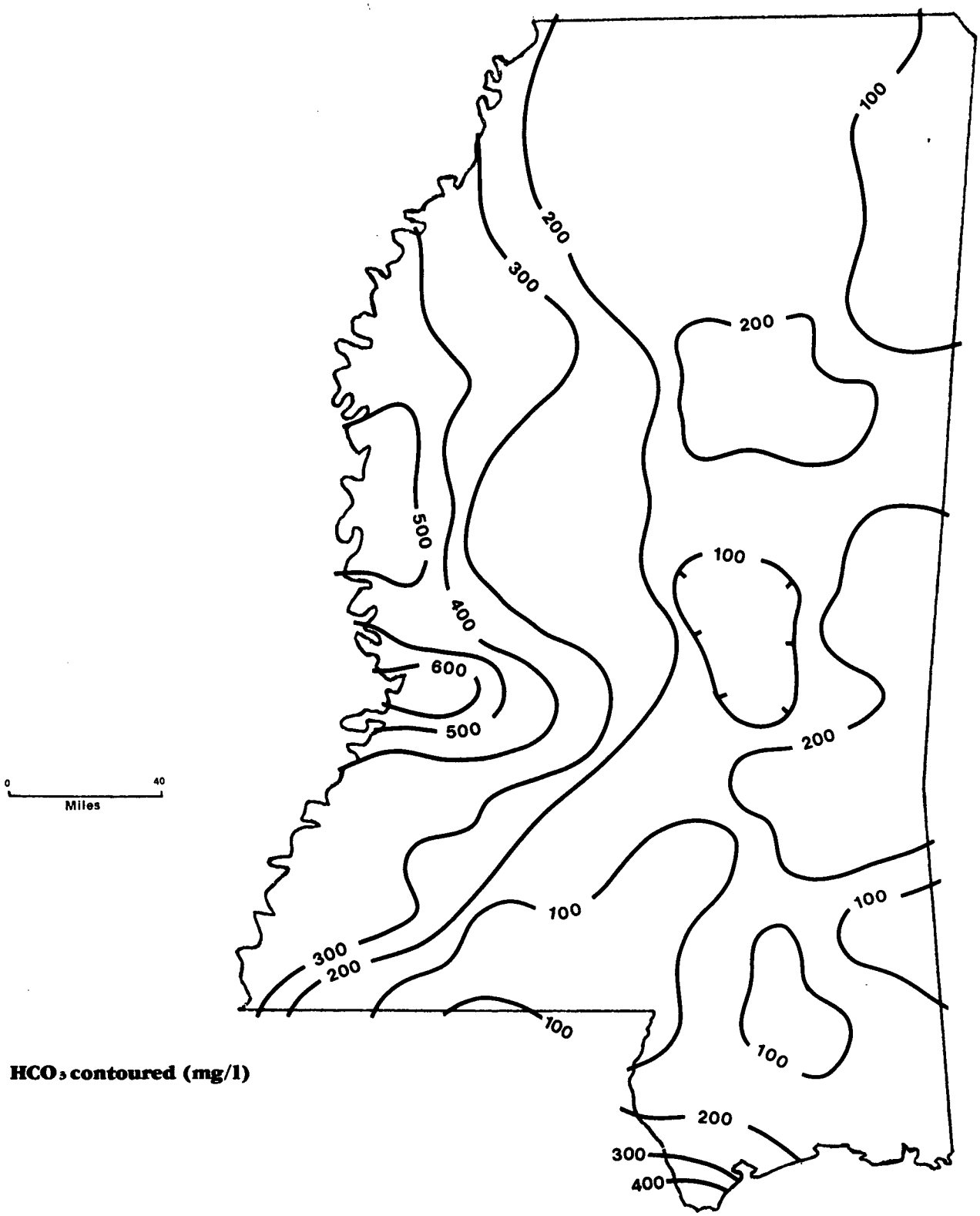


Mississippi



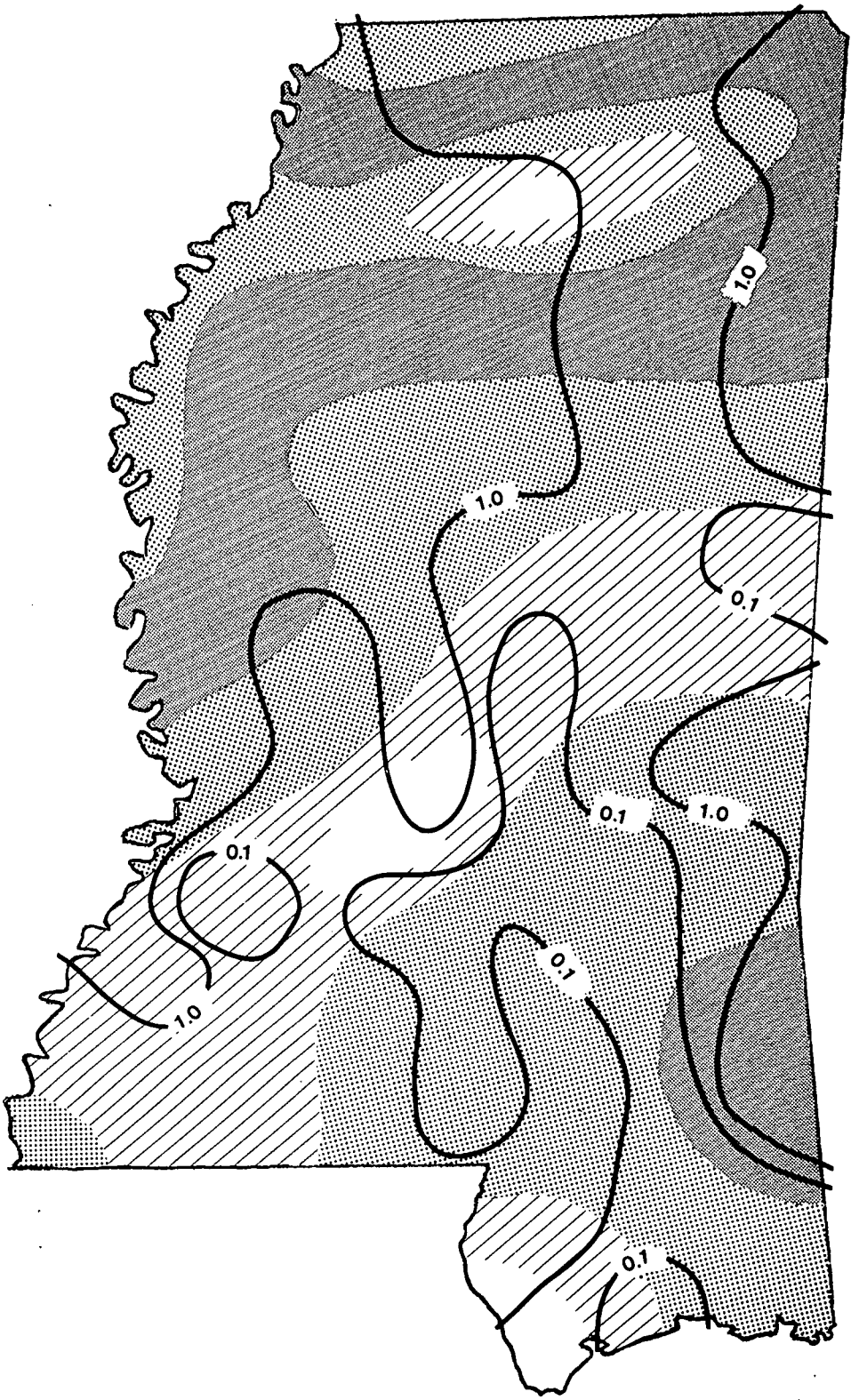
Dissolved Solids contoured (mg/l)

Mississippi



HCO_3 contoured (mg/l)

Mississippi



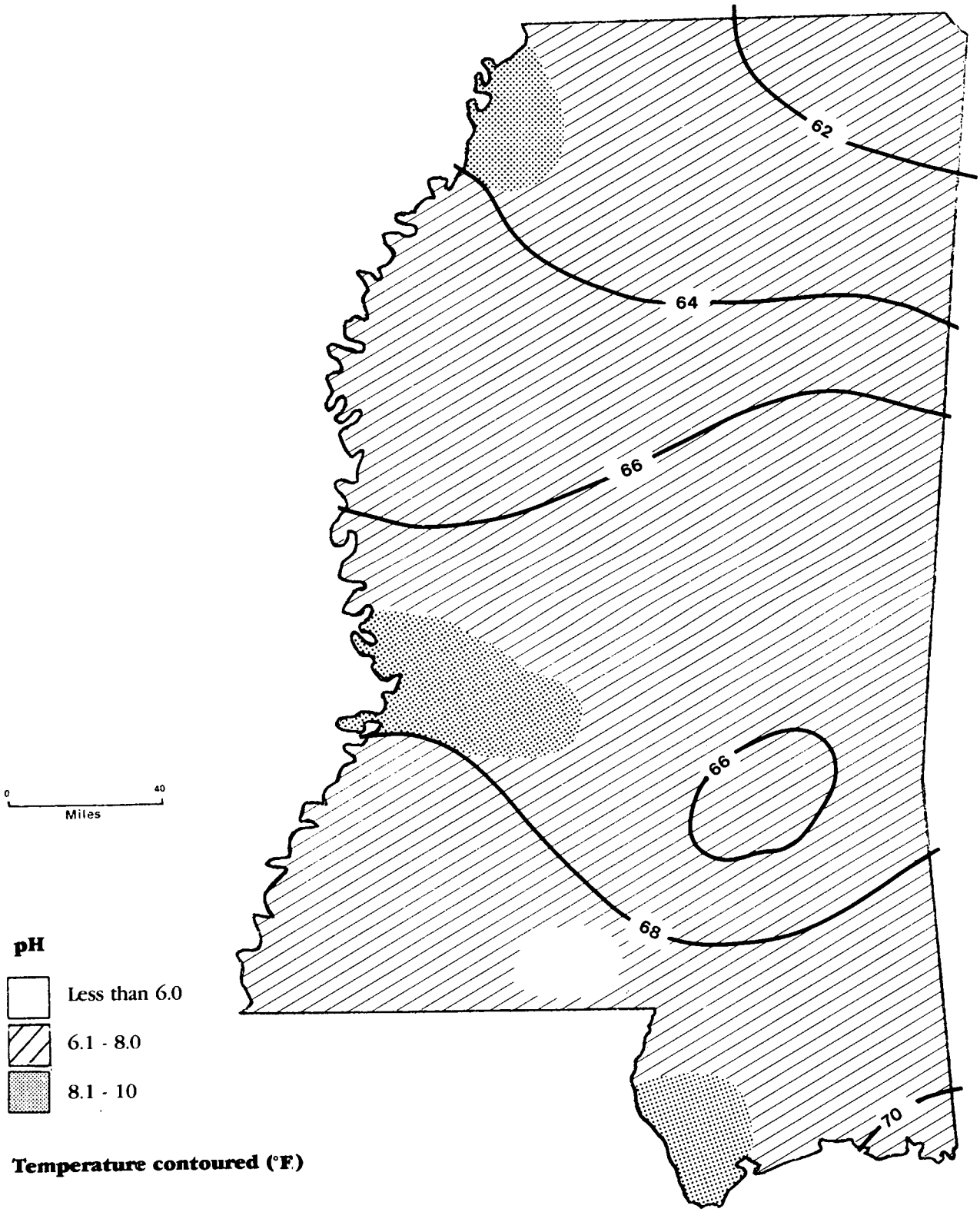
0 40
Miles

Mn (mg/l)

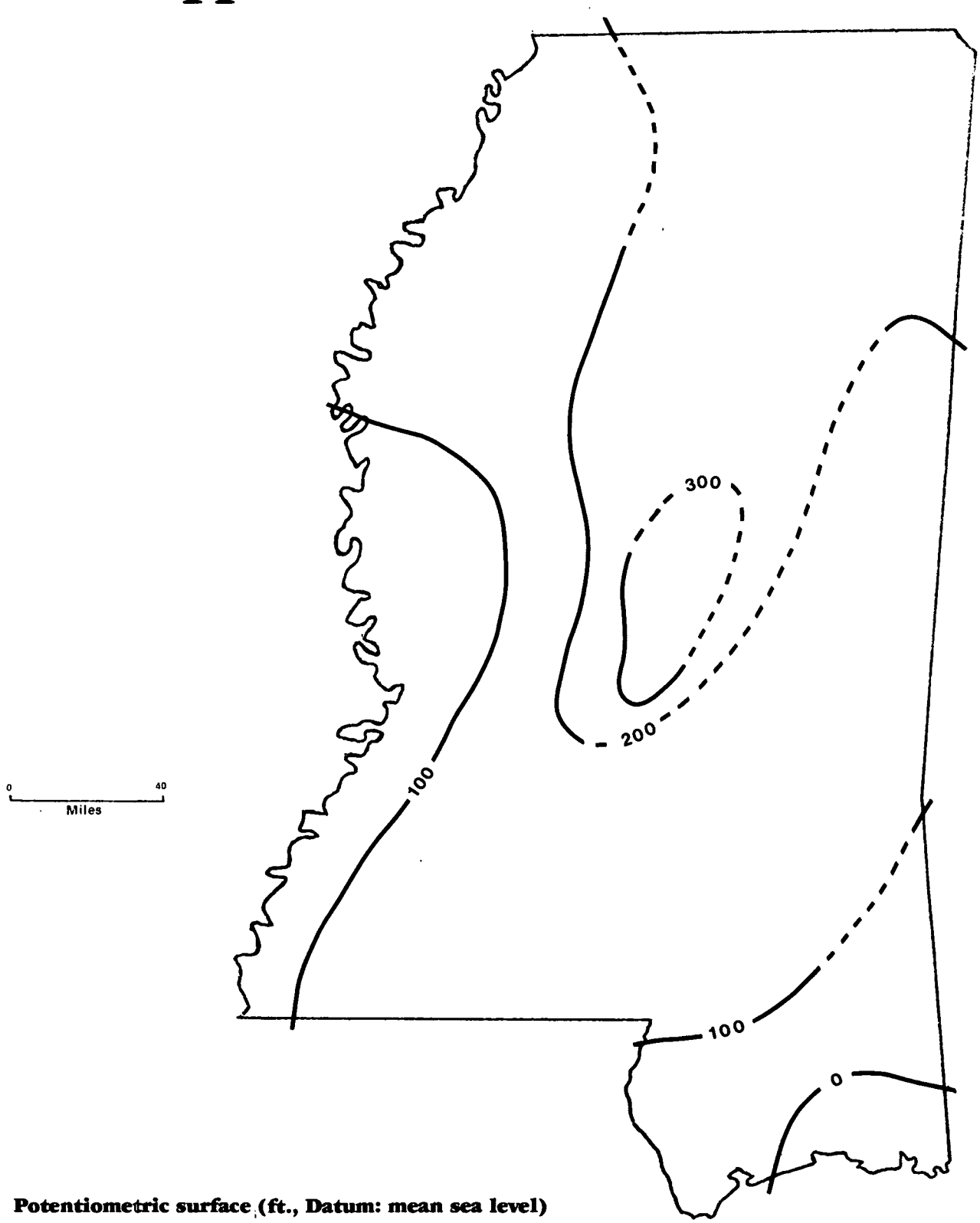
- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Mississippi

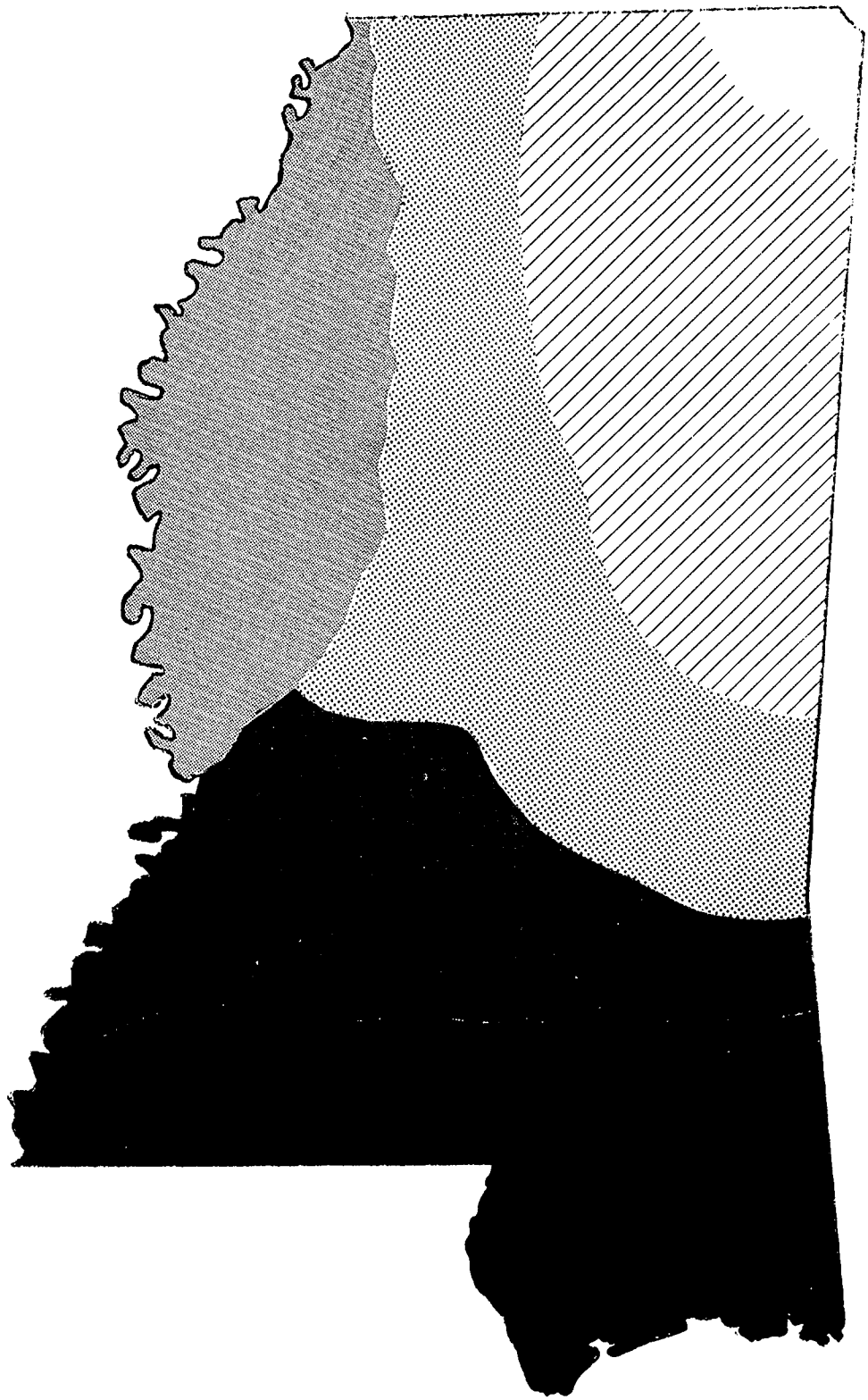


Mississippi



Potentiometric surface (ft., Datum: mean sea level)

Mississippi

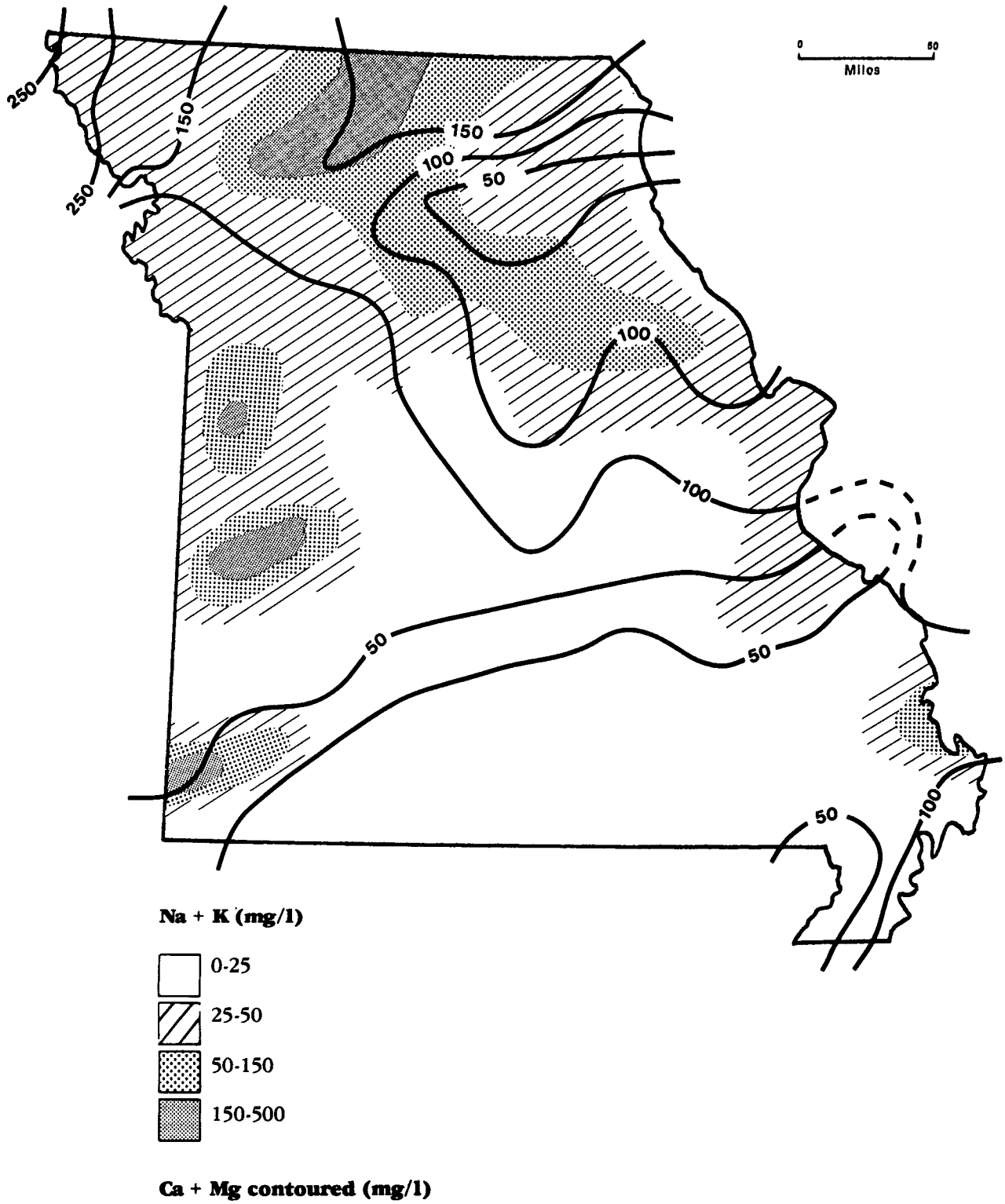


0 40
Miles

Yield (gpm)

- 50-200 gpm
- 200-500 gpm
- 20-500 gpm
- 100-1500 gpm
- 50-500 gpm
- 10-500 gpm Some areas subject to salt water encroachment.

Missouri


0
50
Miles
250
150
250
150
100
50
100
100
50
50
50
100
Na + K (mg/l)
0-25
25-50
50-150
150-500
Ca + Mg contoured (mg/l)

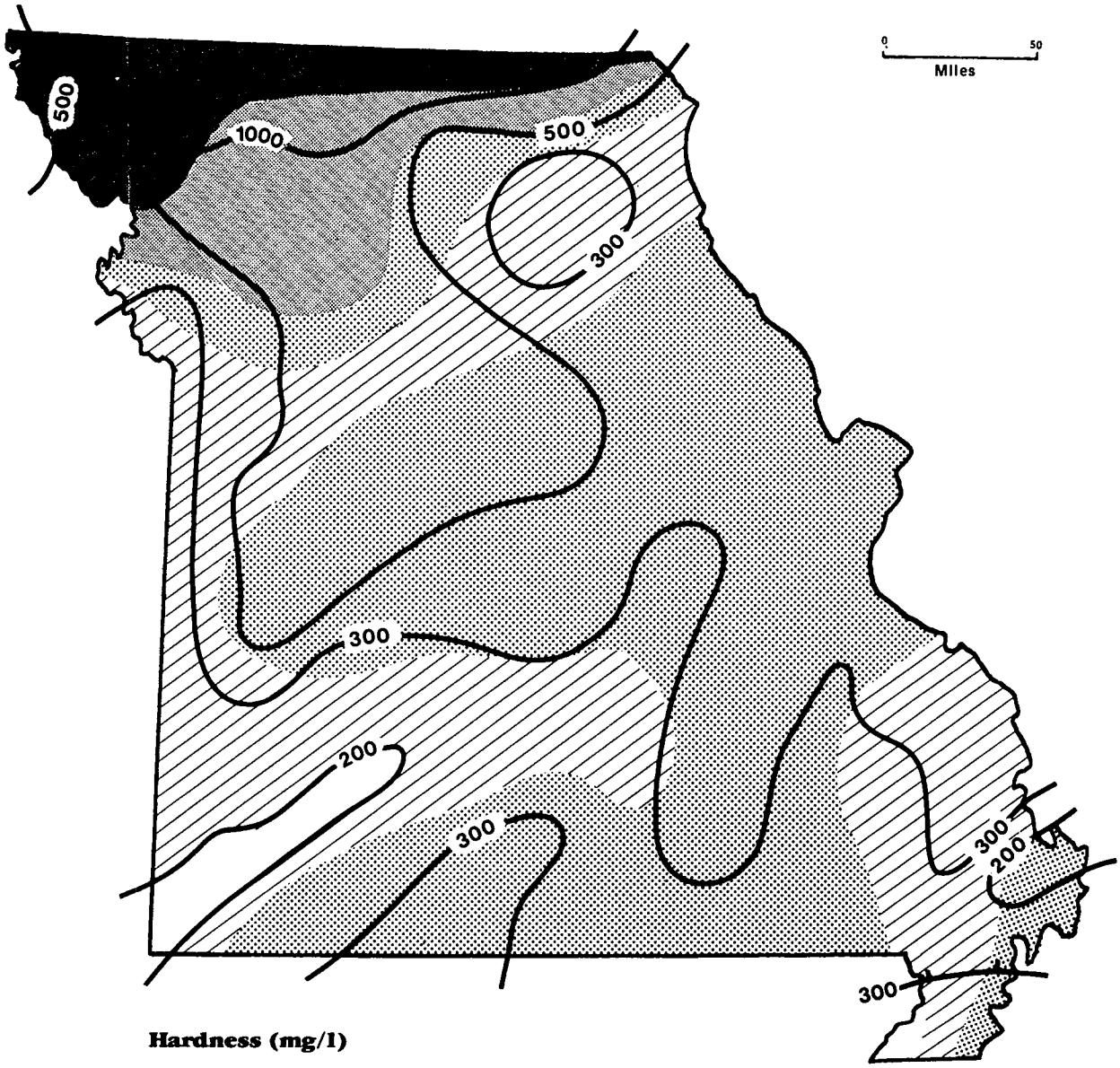
Missouri

Cl (mg/l)

- 0-10
- 10-25
- 25-50
- 50-100
- 100-250

SO_4 contoured (mg/l)

Missouri

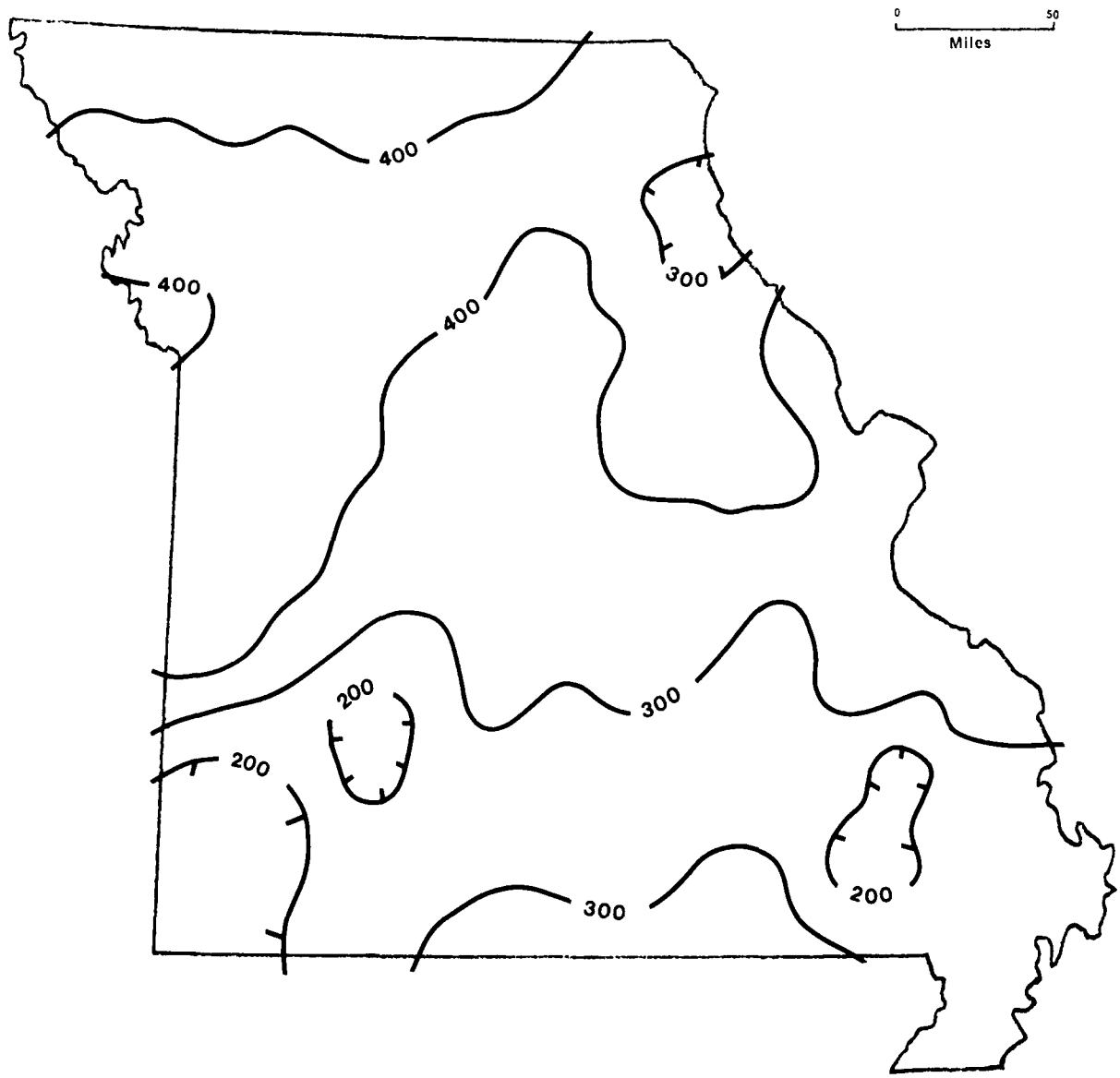


Hardness (mg/l)

- 120-180
- 180-240
- 240-300
- 300-500
- 500-1000

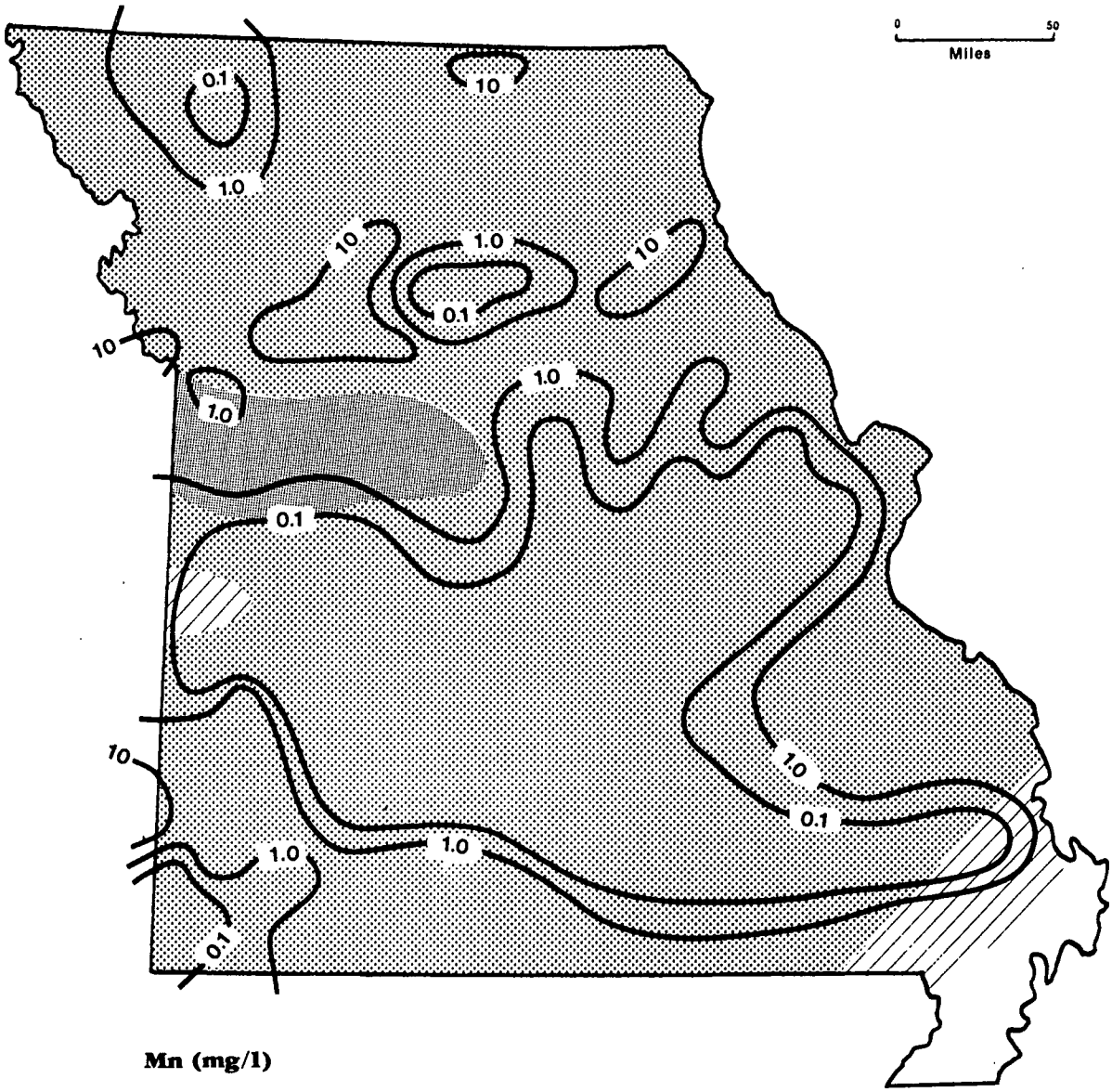
Dissolved Solids contoured (mg/l)

Missouri



HCO_3 contoured (mg/l)

Missouri

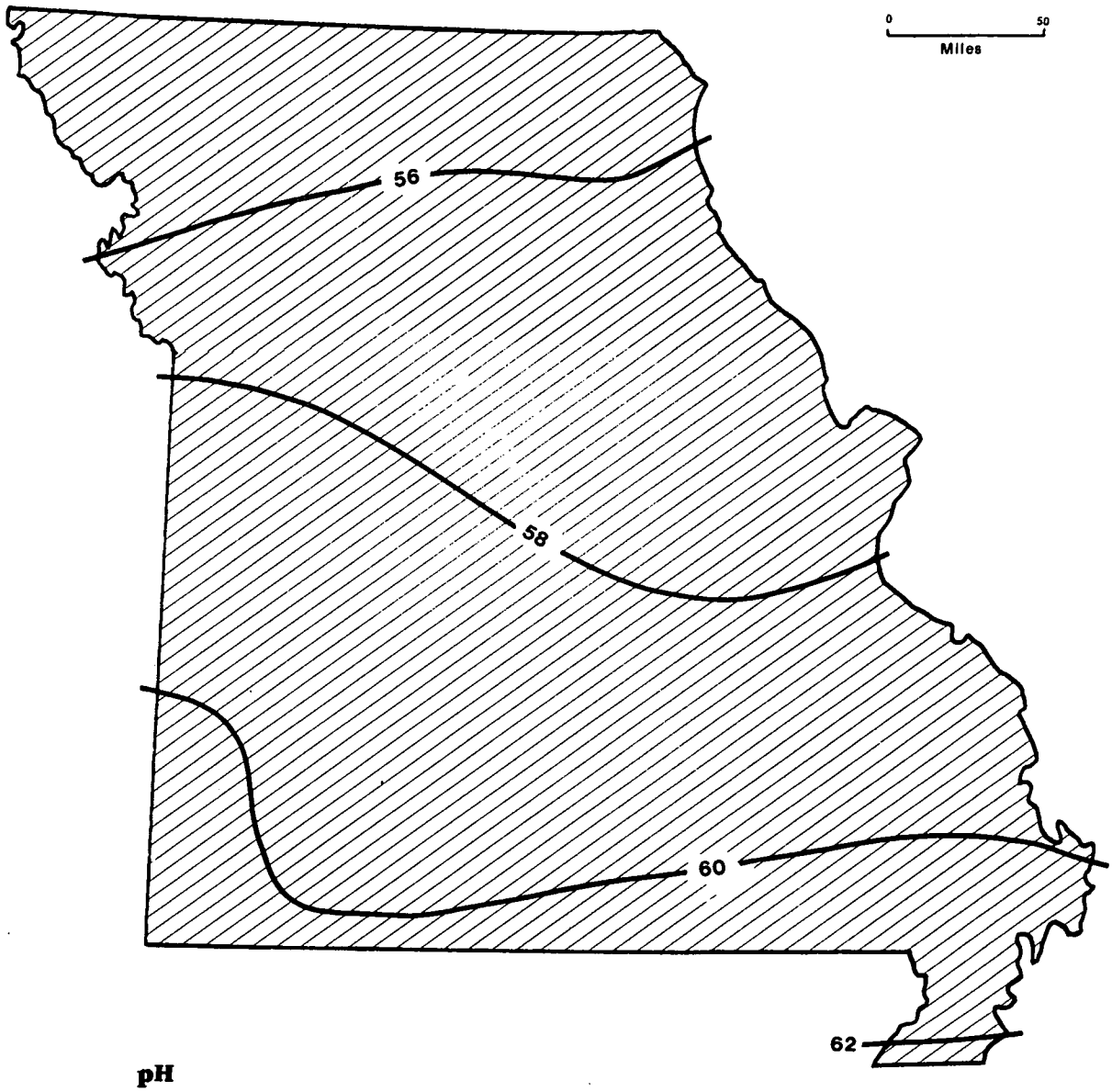


Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

Missouri

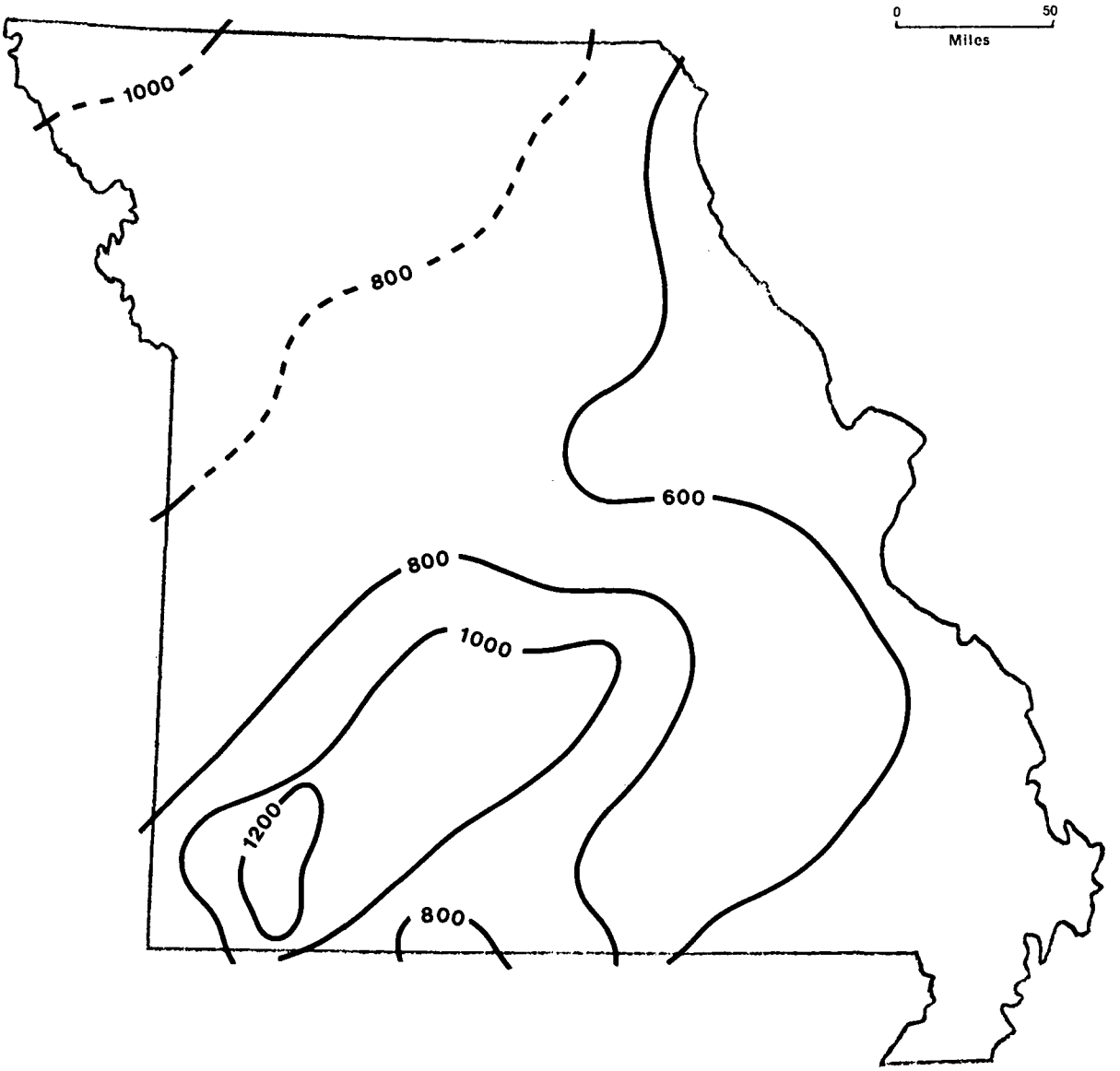


pH

6.1 - 8.0

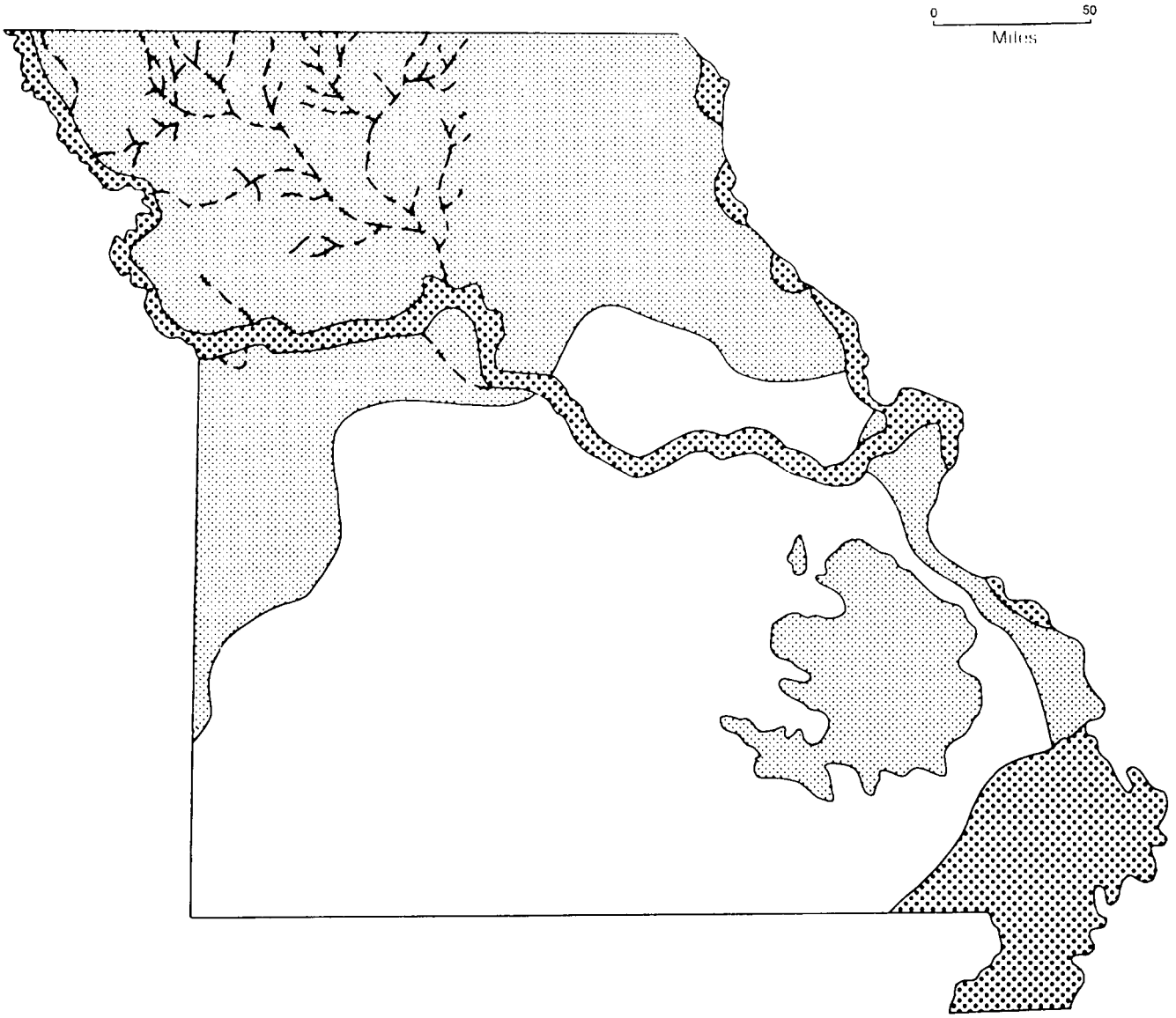
Temperature contoured (°F)

Missouri



Potentiometric surface (ft., Datum: mean sea level)

Missouri



Yield (gpm)

Up to 200 or more

Up to 500 (1000 locally)

1000 or greater

Buried glacial valley as much as 500

Plate 186

Montana

Plate 187

Montana

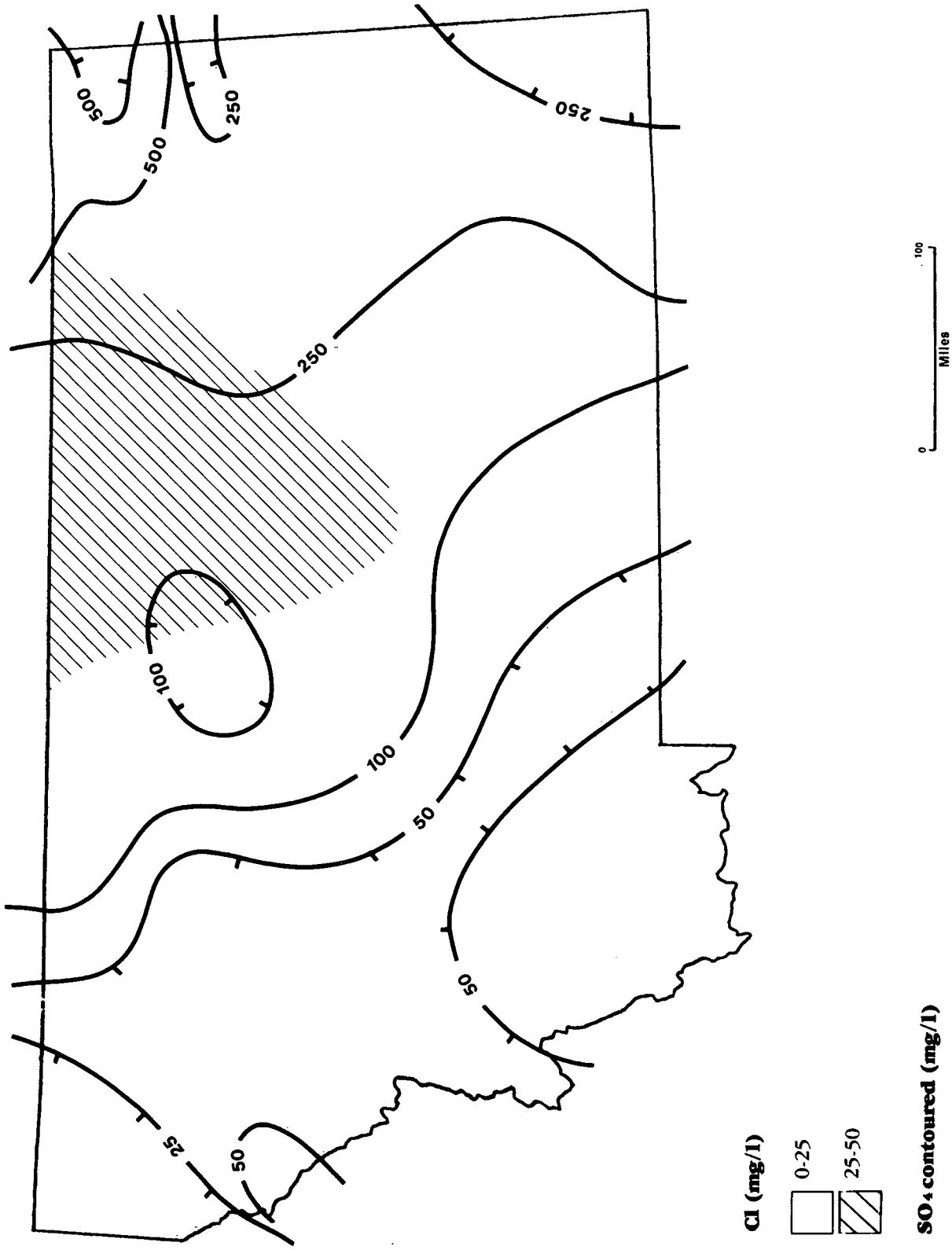
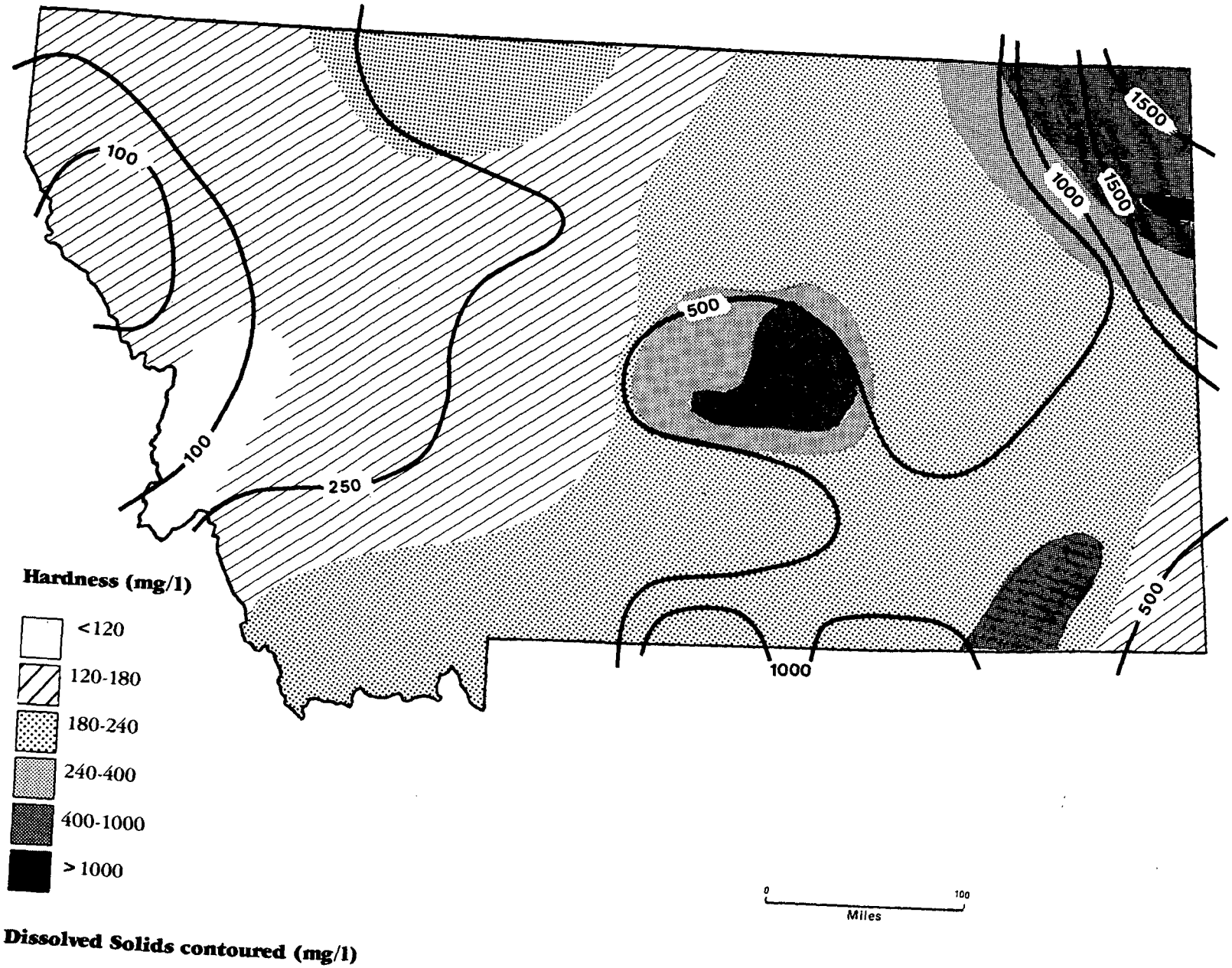
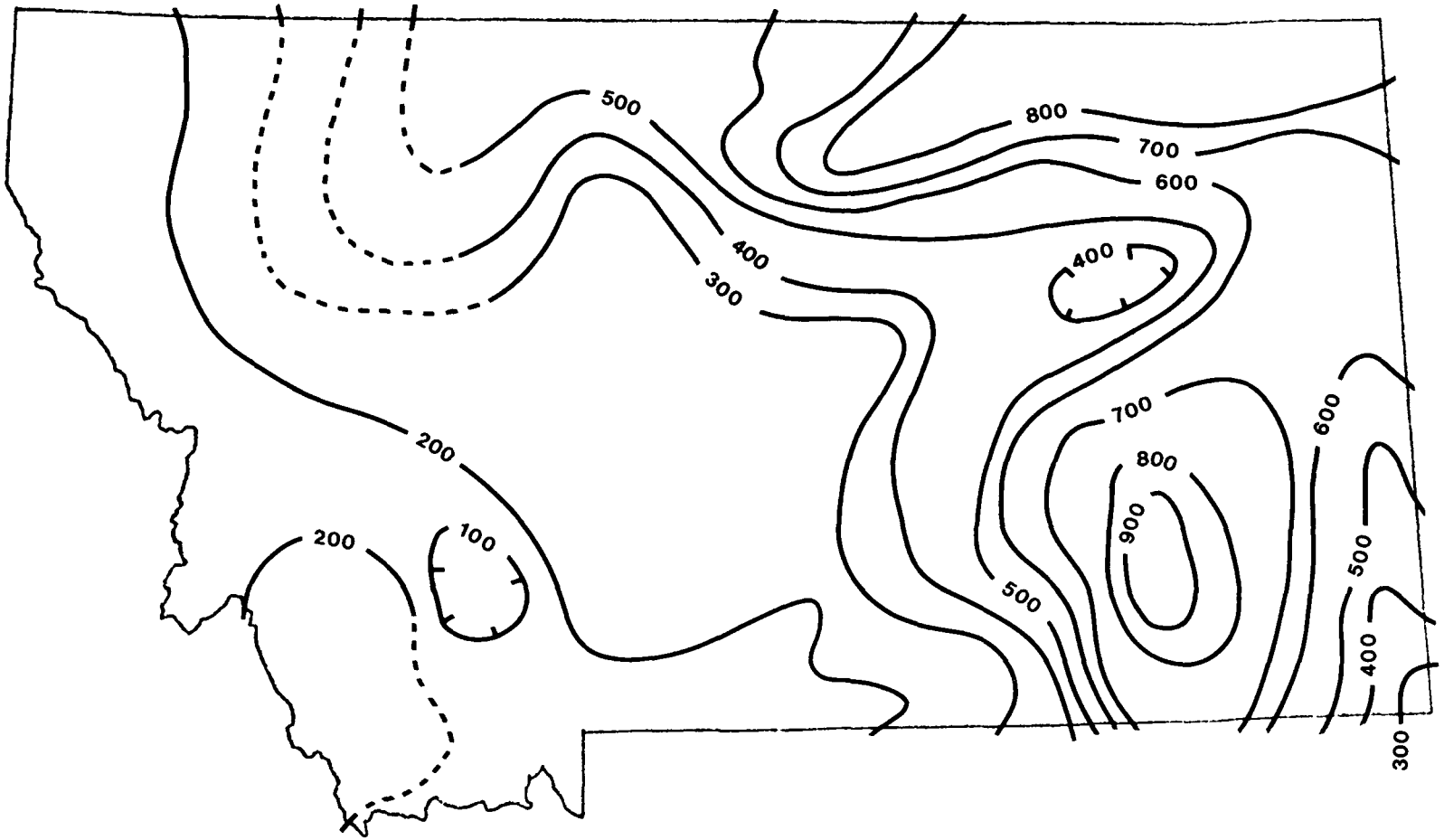


Plate 188

Montana


100
100
250
500
1000
1500
1500
1000
500
Hardness (mg/l)
<120
120-180
180-240
240-400
400-1000
>1000
0
100
Miles
Dissolved Solids contoured (mg/l)

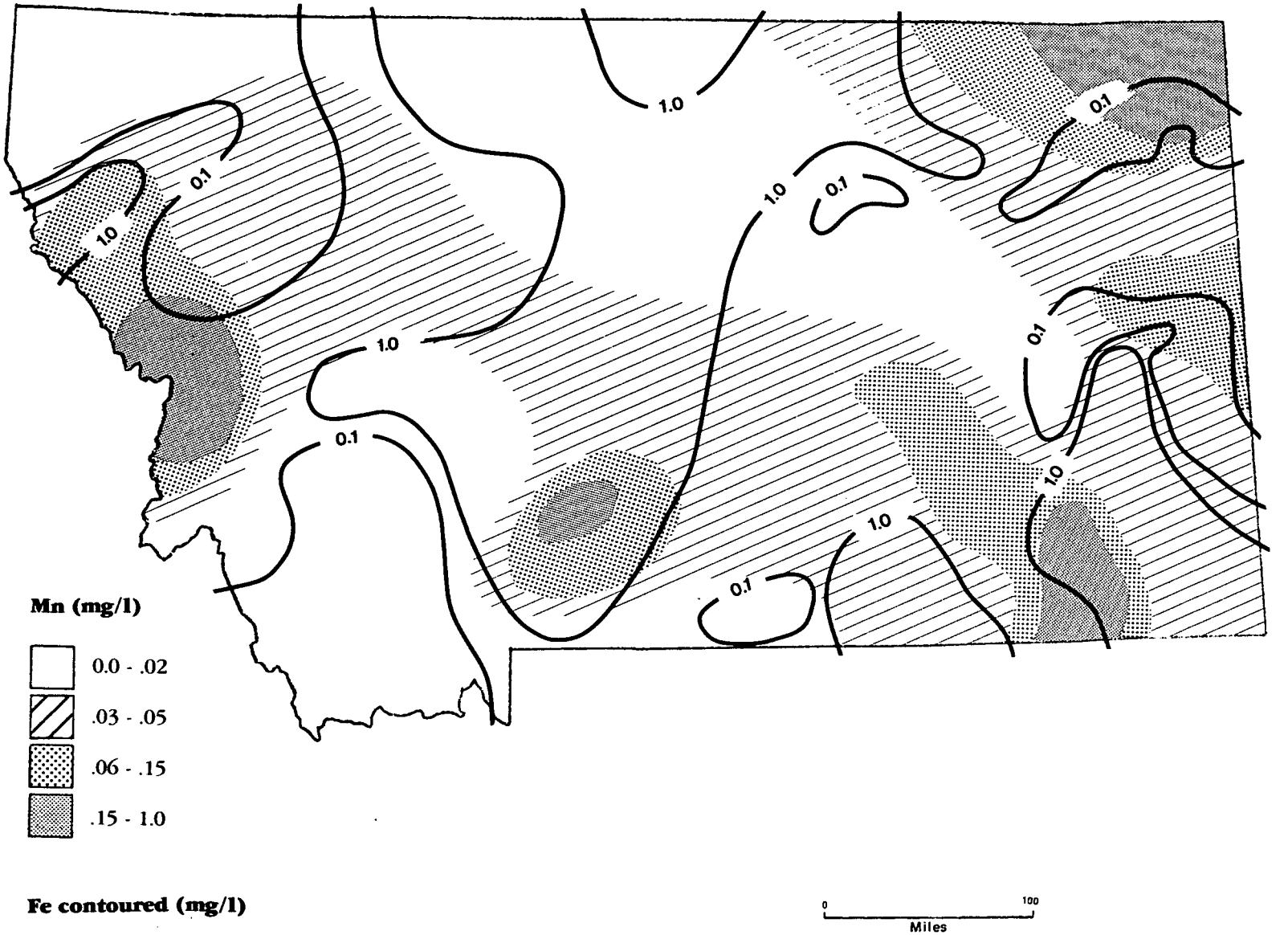
Montana



HCO_3 contoured (mg/l)

0 100
Miles

Montana


1.0
0.1
1.0
0.1
1.0
0.1
1.0
0.1
1.0
0.1
1.0
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
100
Miles

Montana

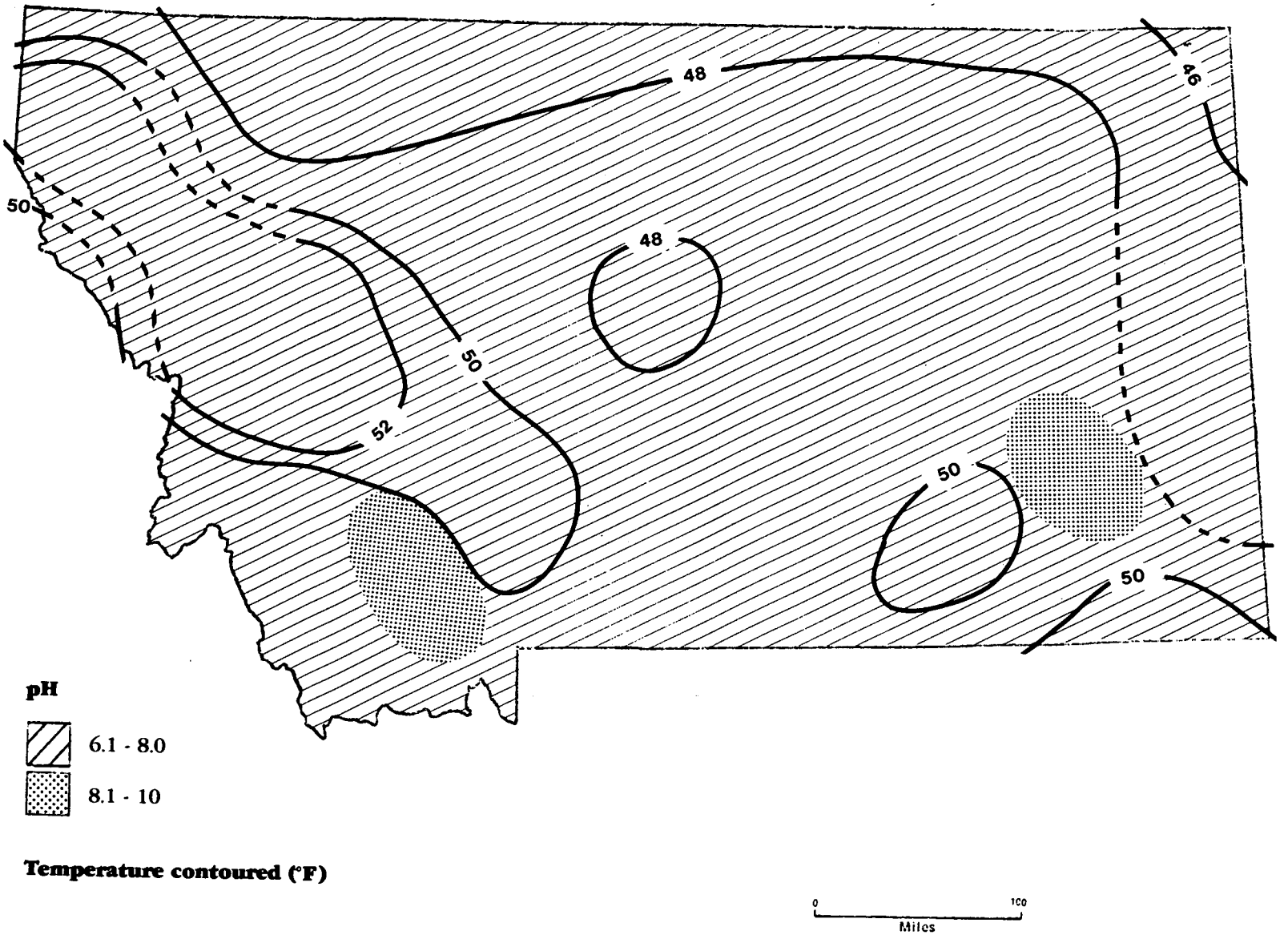
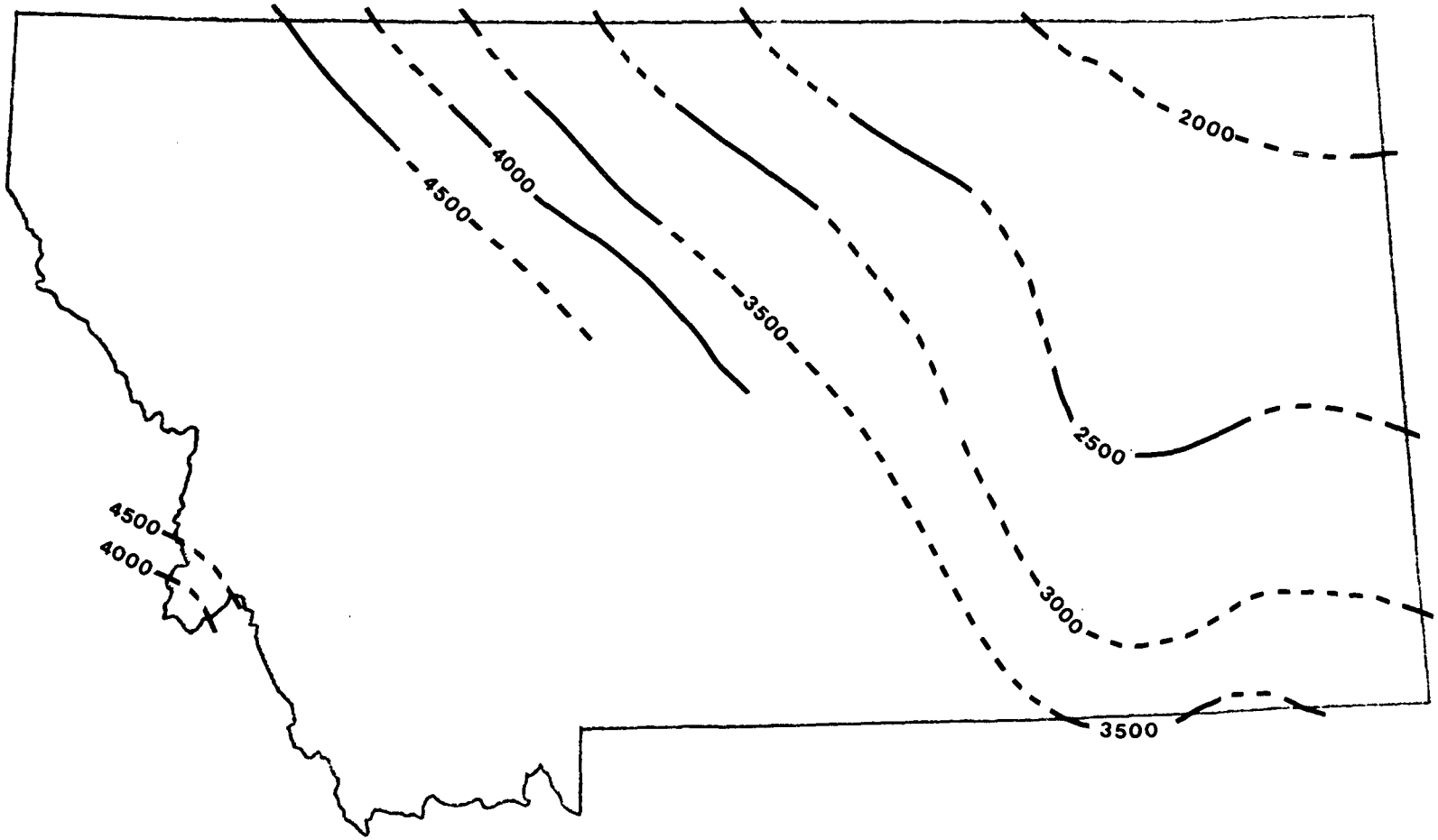


Plate 192

Montana



Potentiometric surface (ft., Datum: mean sea level)

0 100
Miles

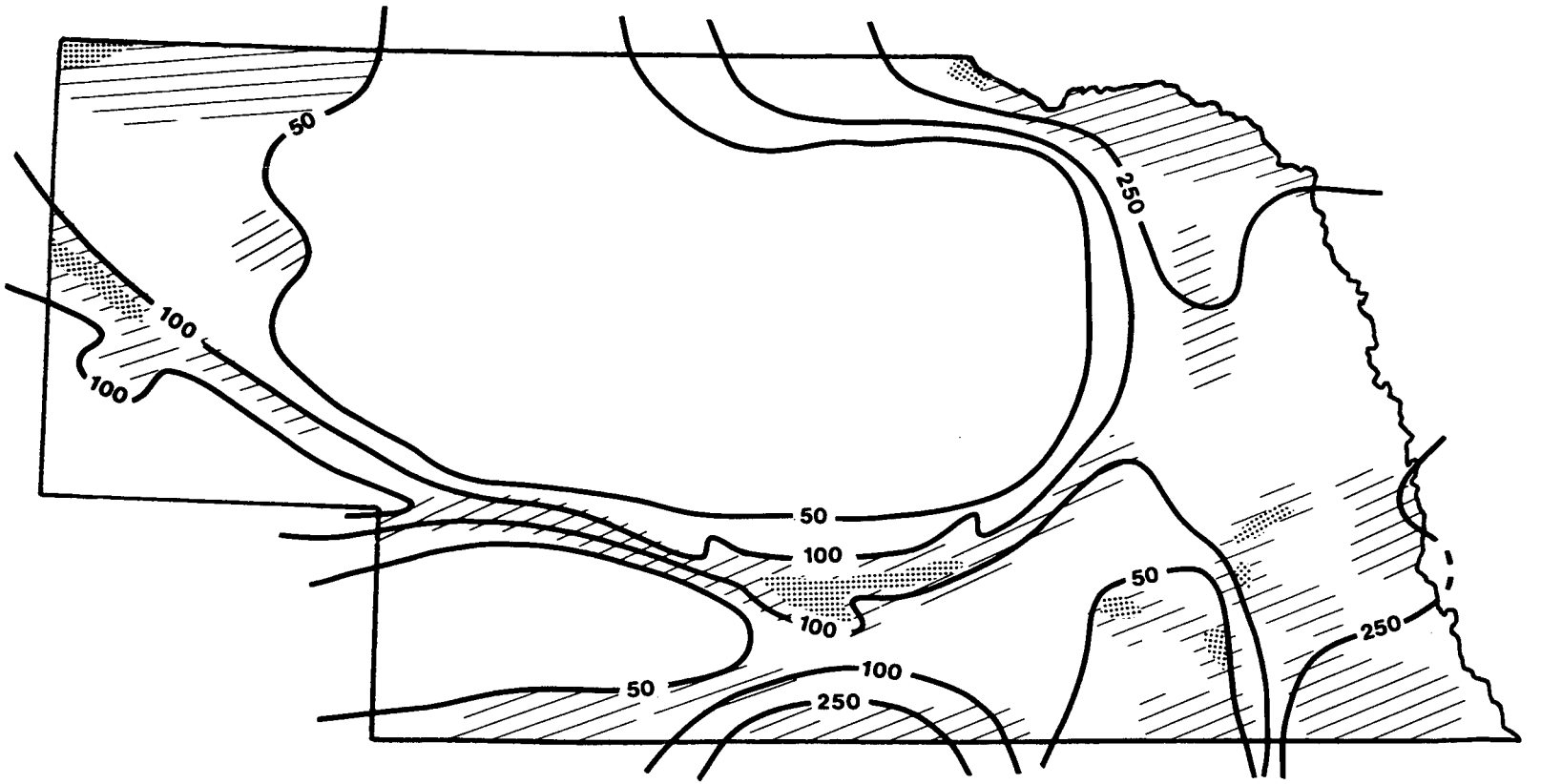
Montana

Yield (gpm)

- Cenozoic alluvium and lake beds 0-100 gpm
- High terrace gravels 10-500 gpm
- Fort Union Formation 10-20 gpm
- Paleozoic and Mesozoic stratified rocks 0-50 gpm
- Precambrian crystalline and tertiary igneous socks. Includes Paleozoic and Mesozoic strata in Western Montana 0-10 gpm

0 100
Miles

Nebraska



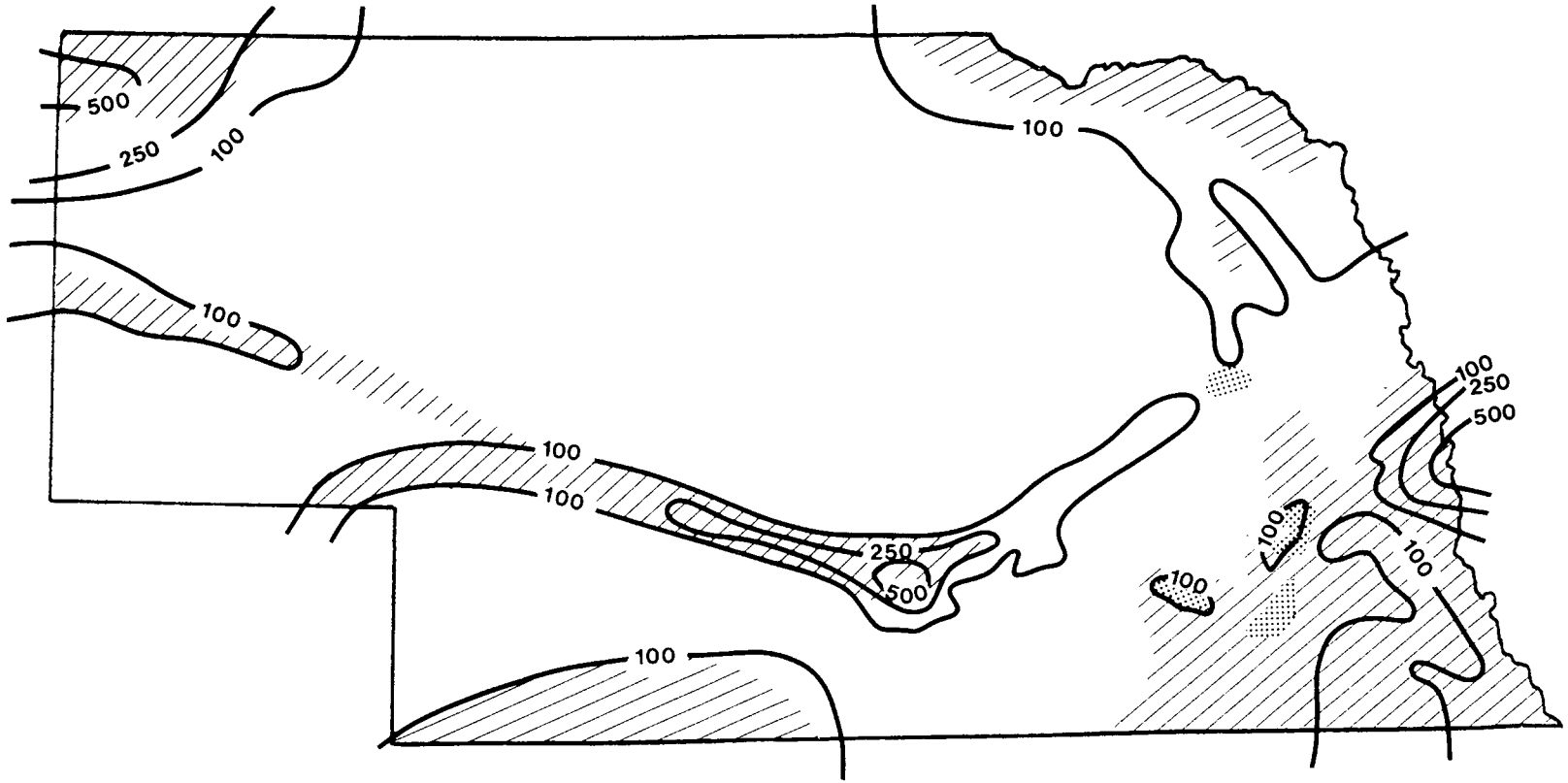
Na + K (mg/l)

- 0-50
- 50-100
- >100

Ca + Mg contoured (mg/l)

0 — 50 Miles

Nebraska



Cl (mg/l)

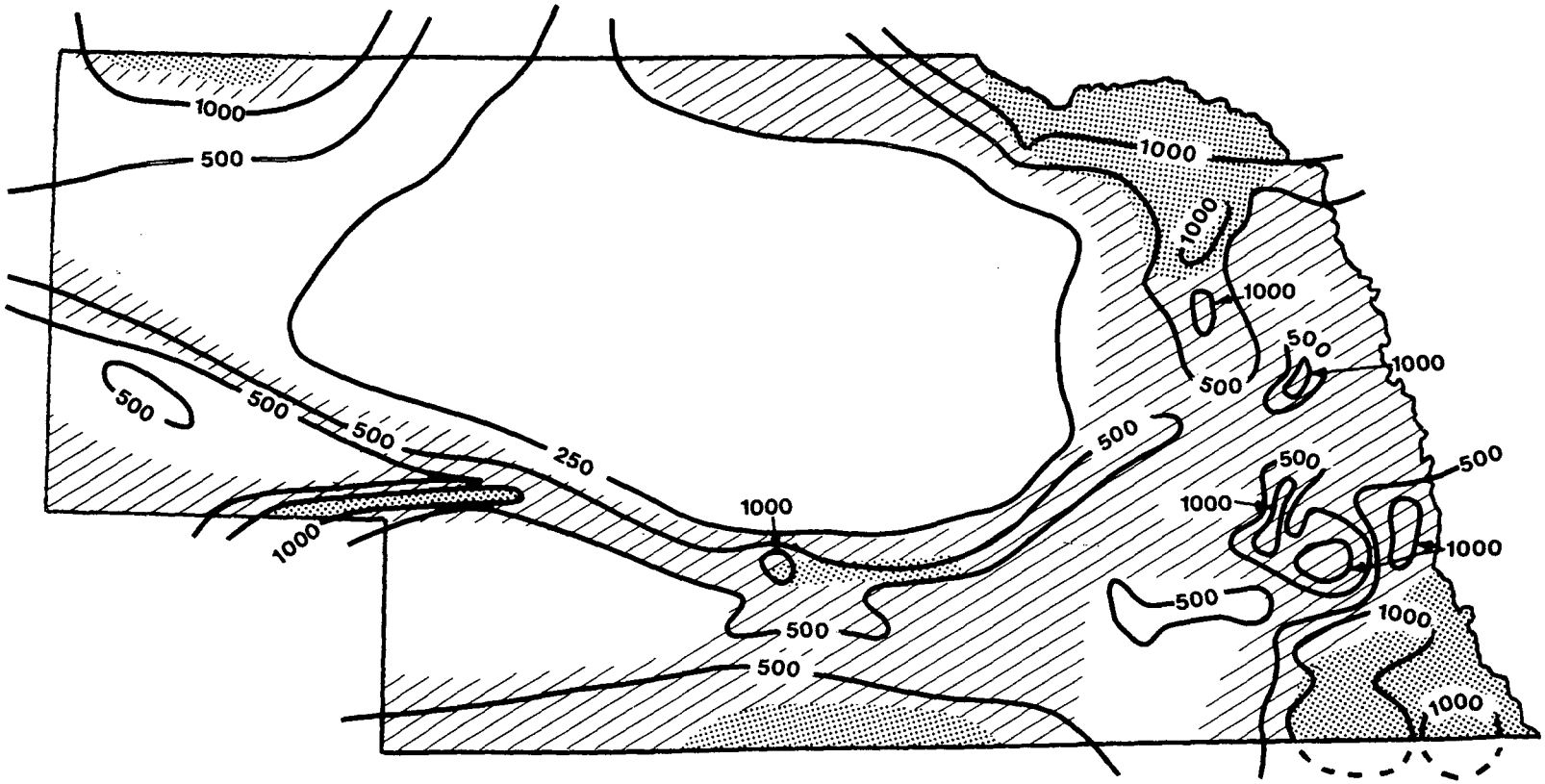
- 0-25
- 25-50
- 50-100

SO_4 contoured (mg/l)

0 50
Miles

Plate 196

Nebraska



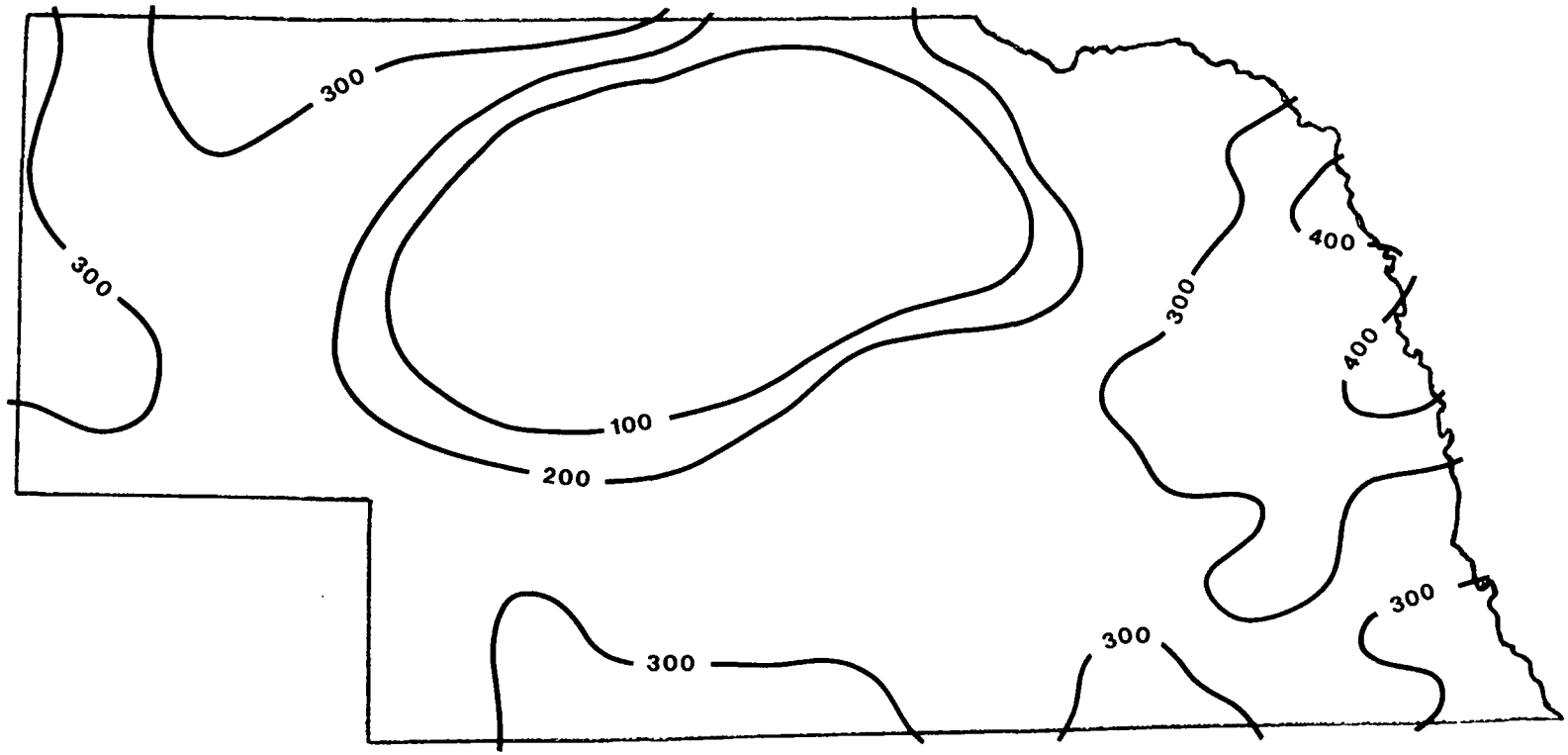
Hardness (mg/l)

- 120-240
- 240-500
- >500

0 50
Miles

Dissolved Solids contoured (mg/l)

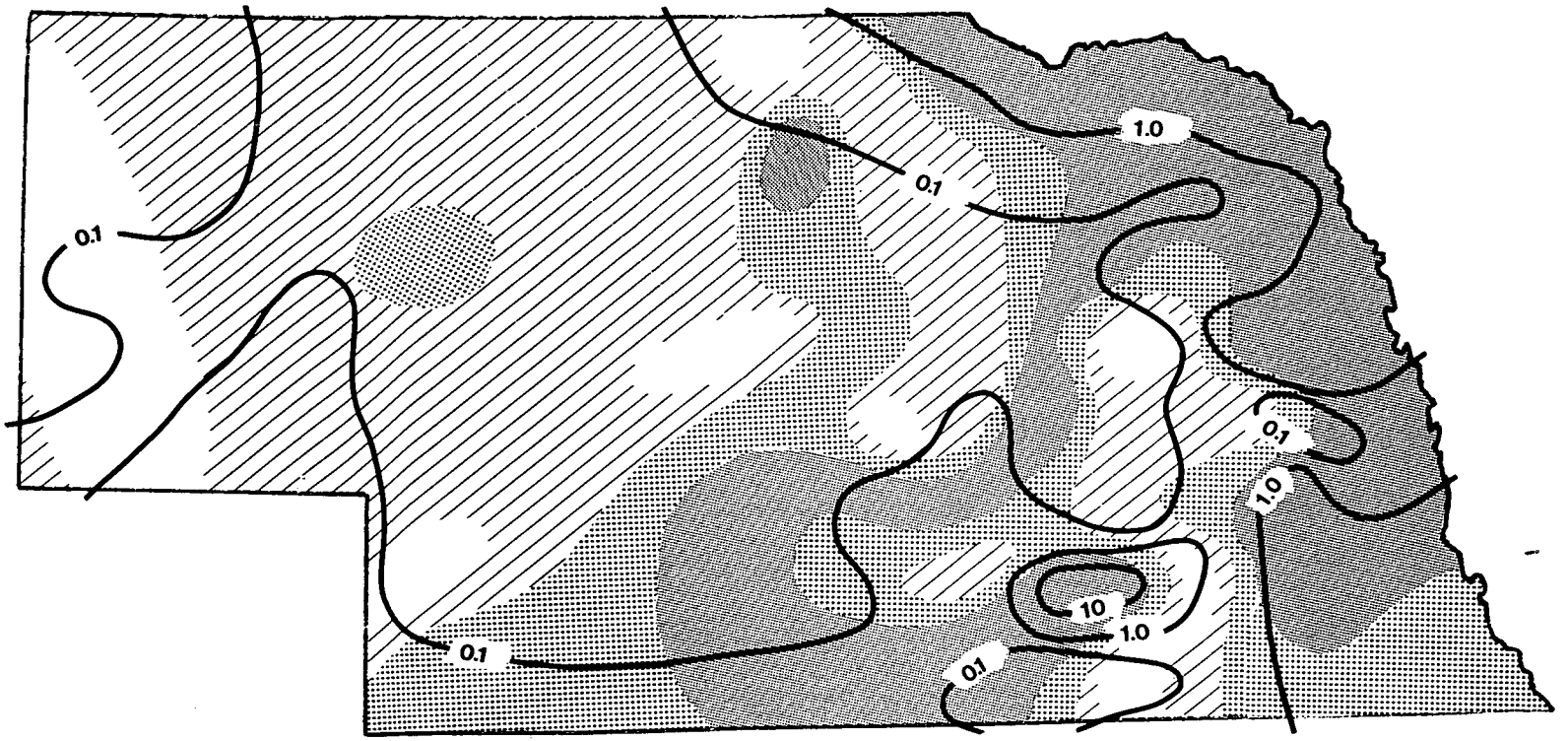
Nebraska



HCO_3 contoured (mg/l)

0 50
Miles

Nebraska



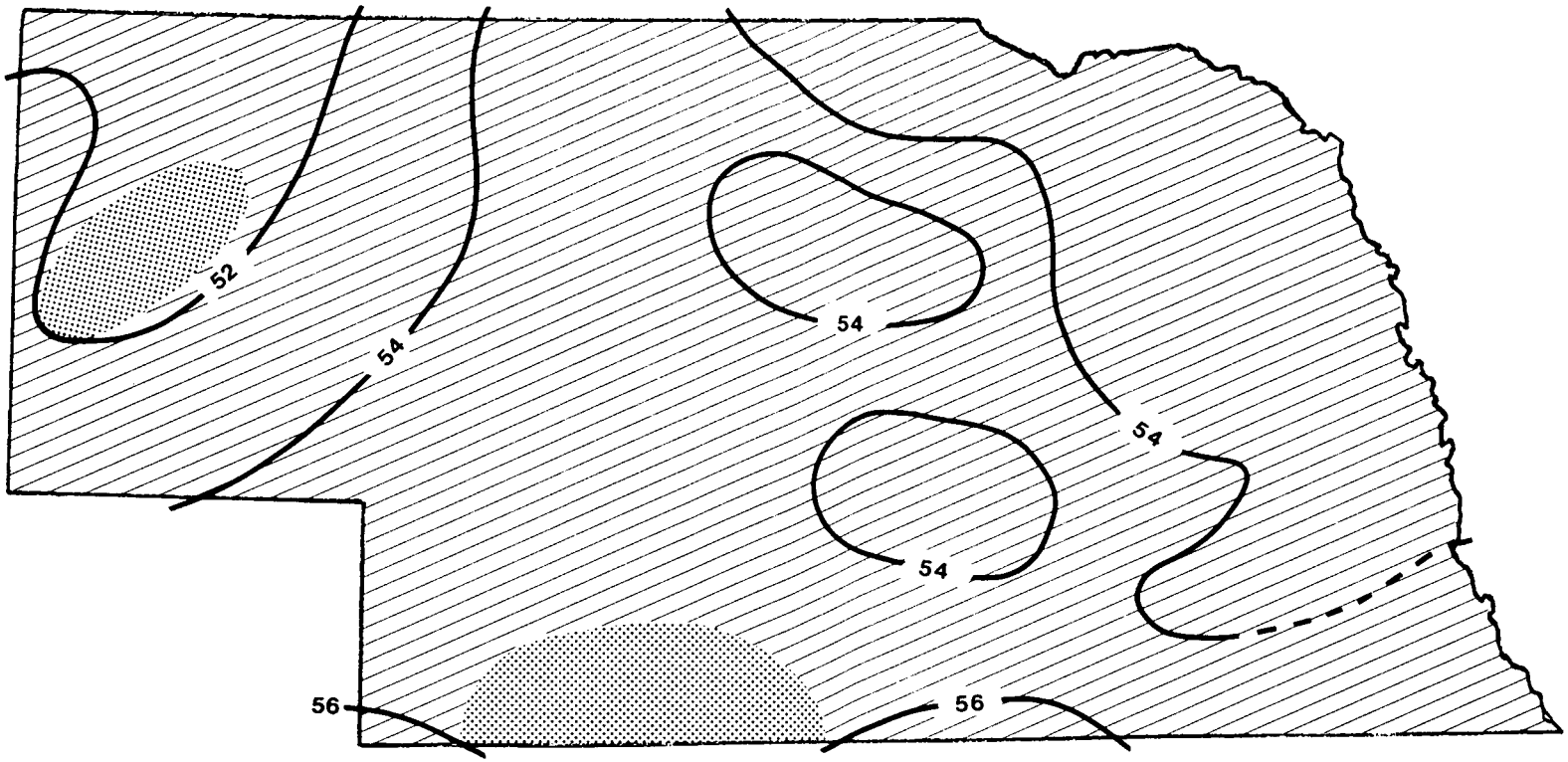
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

0 — 50 Miles

Nebraska



pH

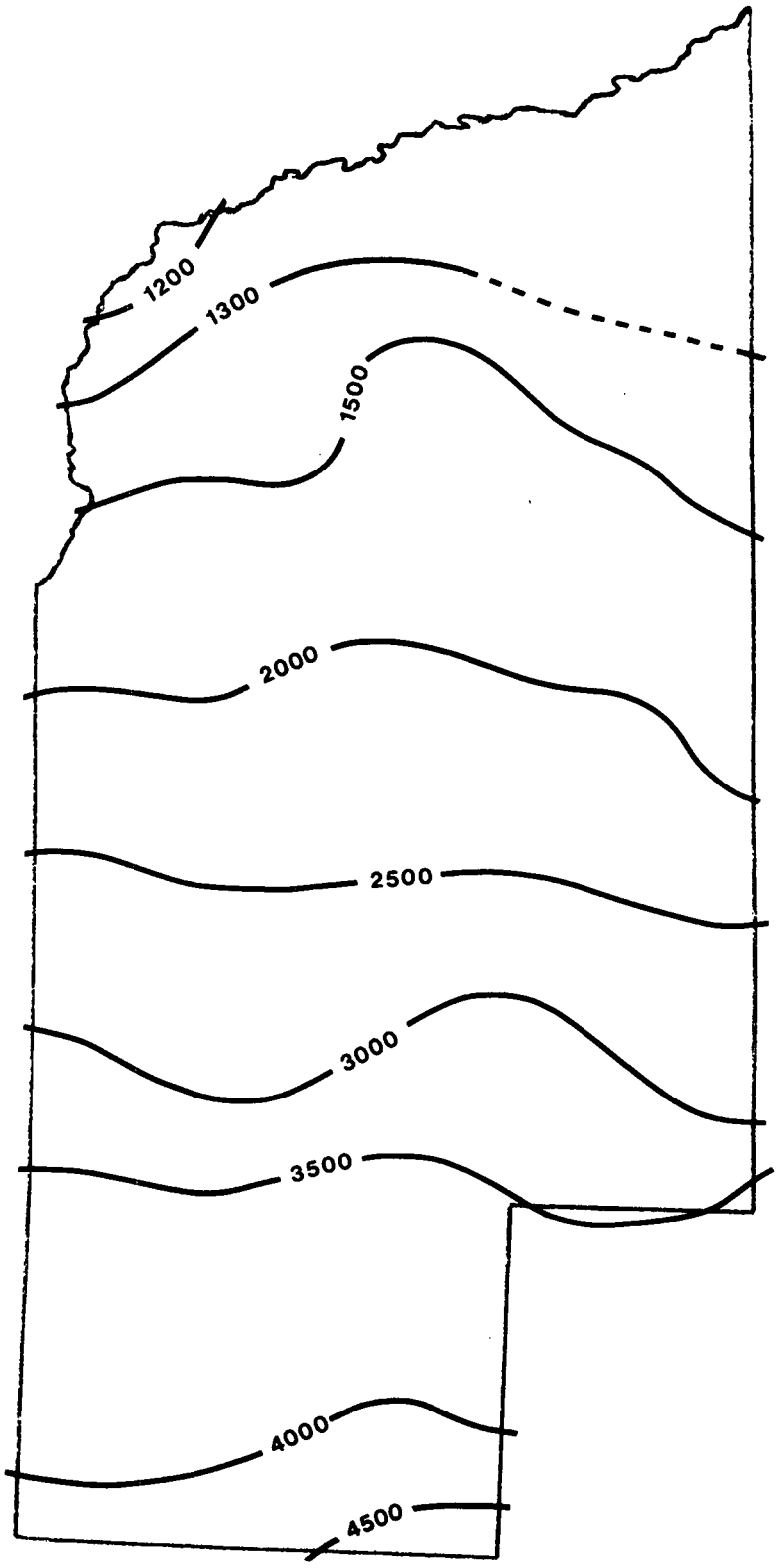
6.1 - 8.0

8.1 - 10

0 50
Miles

Temperature contoured (°F)

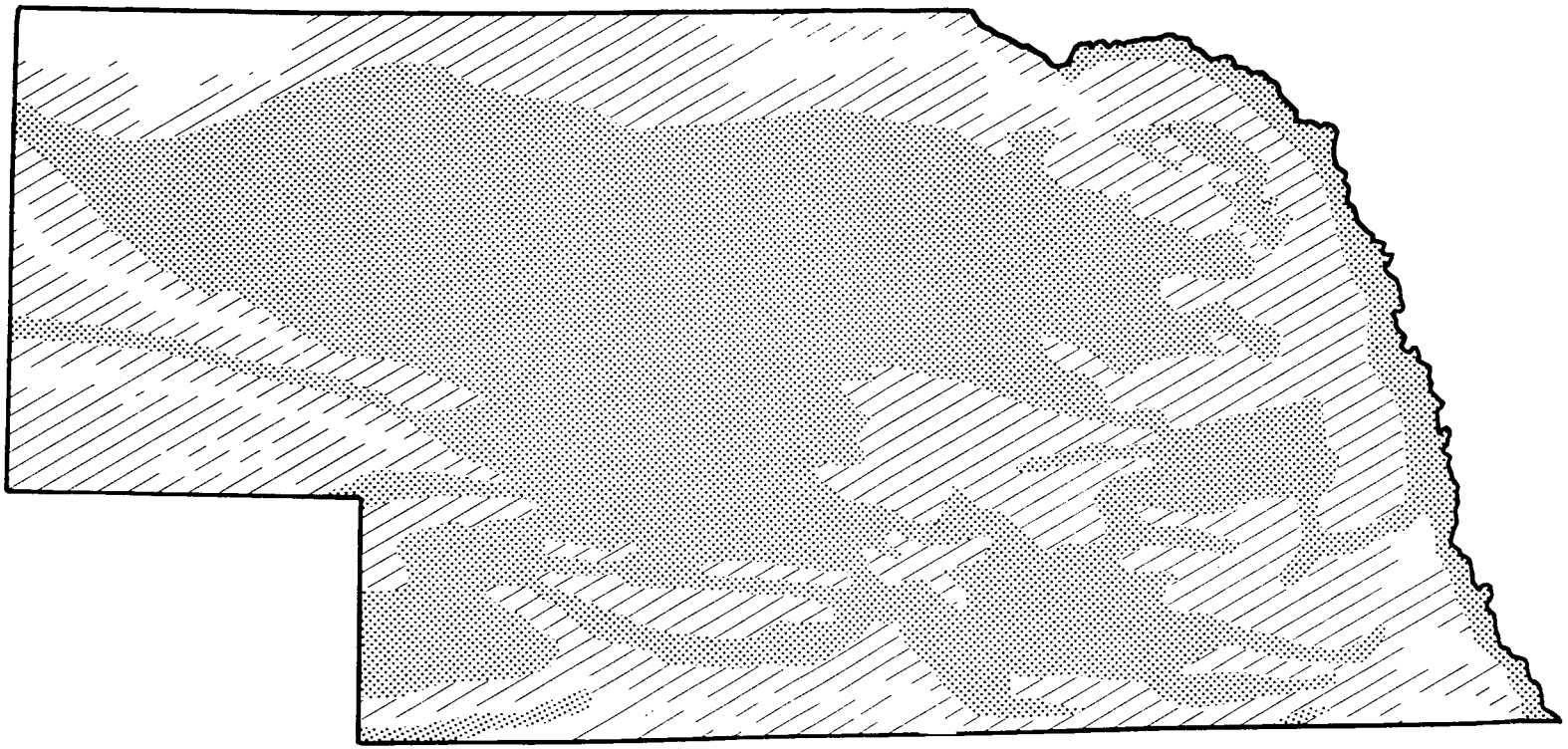
Nebraska



Potentiometric surface (ft., Datum: mean sea level)

0 50 Miles

Nebraska



AVAILABILITY OF GROUND WATER

- Less than 50 gpm
- 50-500 gpm
- Greater than 500 gpm

0 50
Miles

Nevada

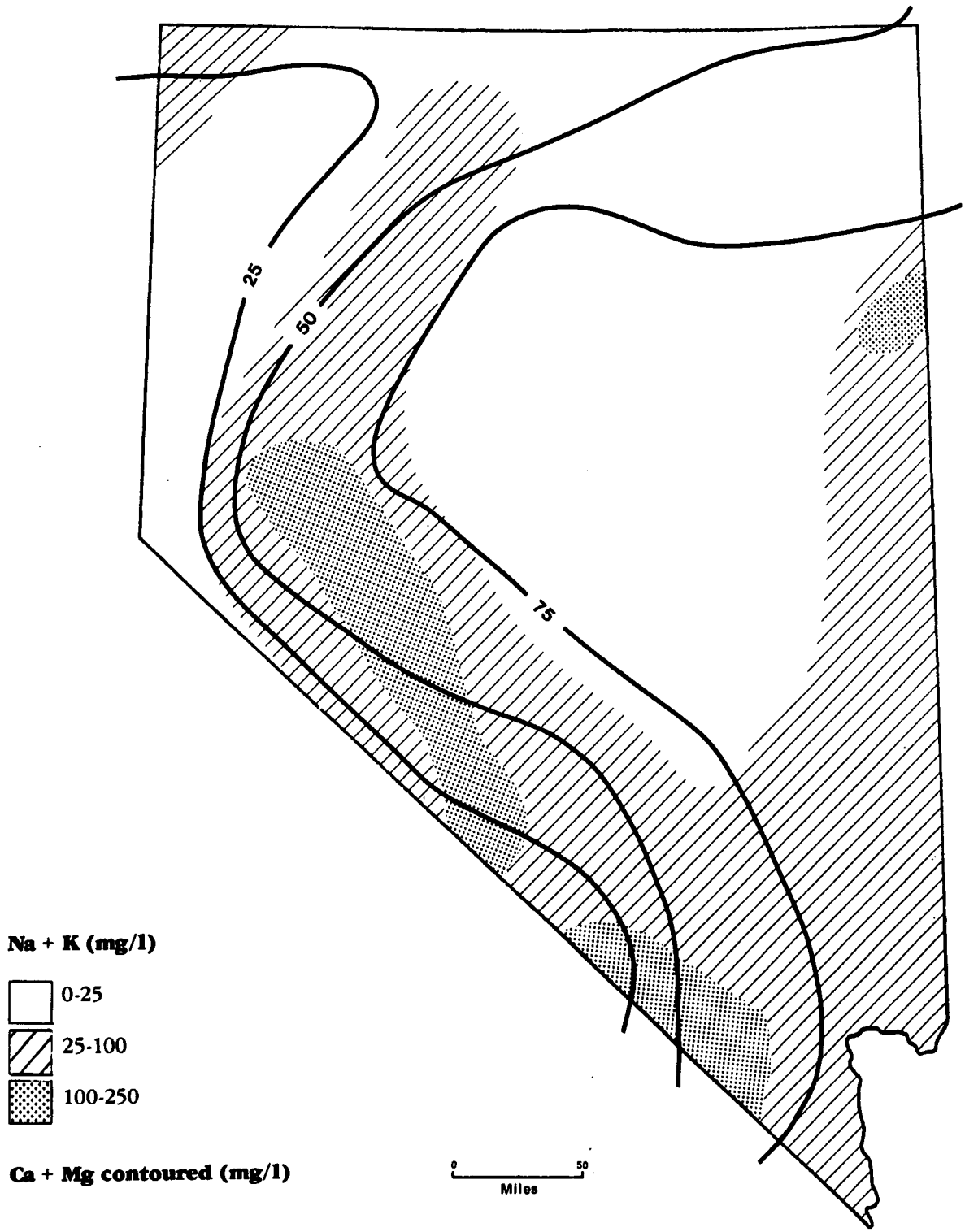


Plate 203

Nevada

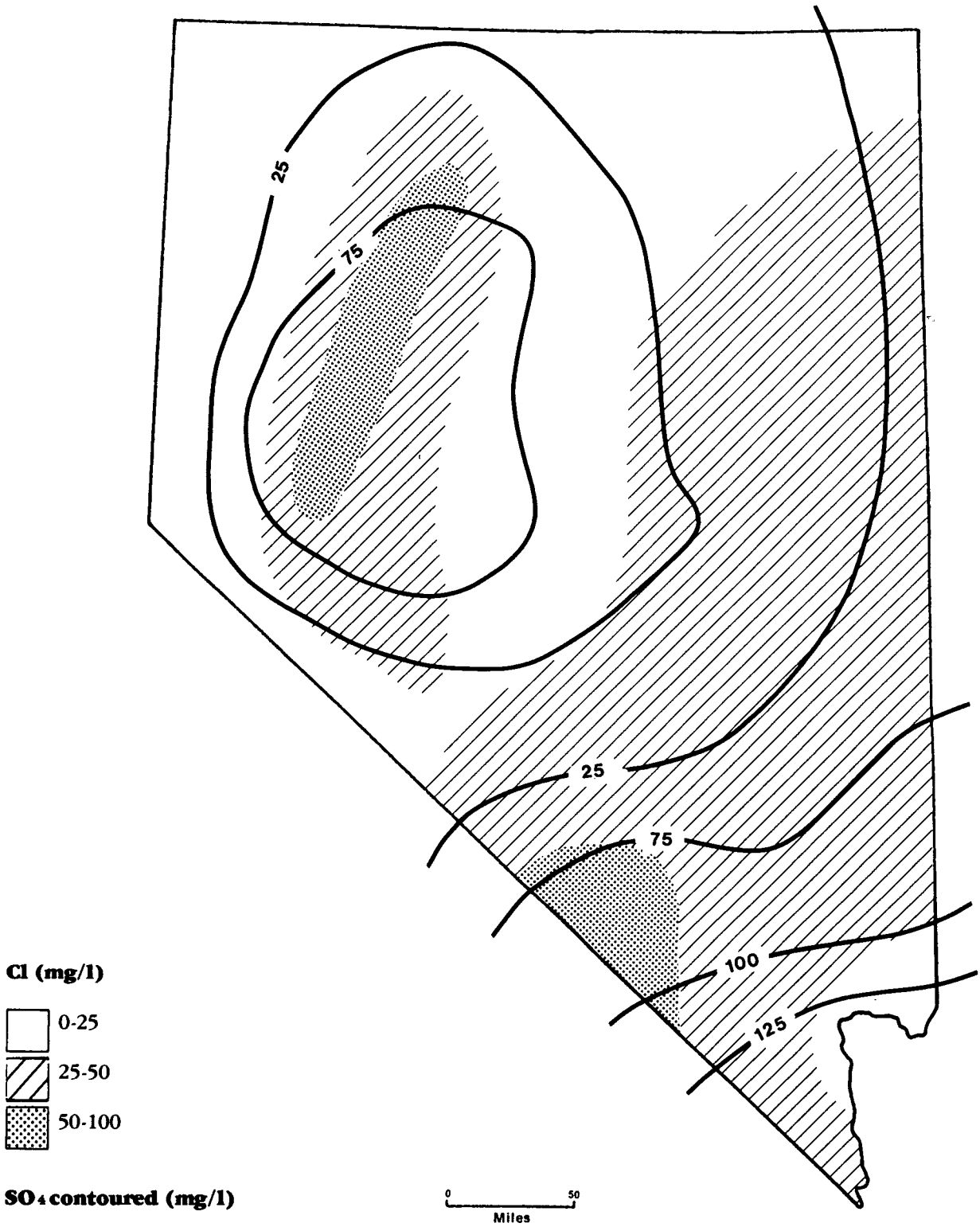


Plate 204

Nevada

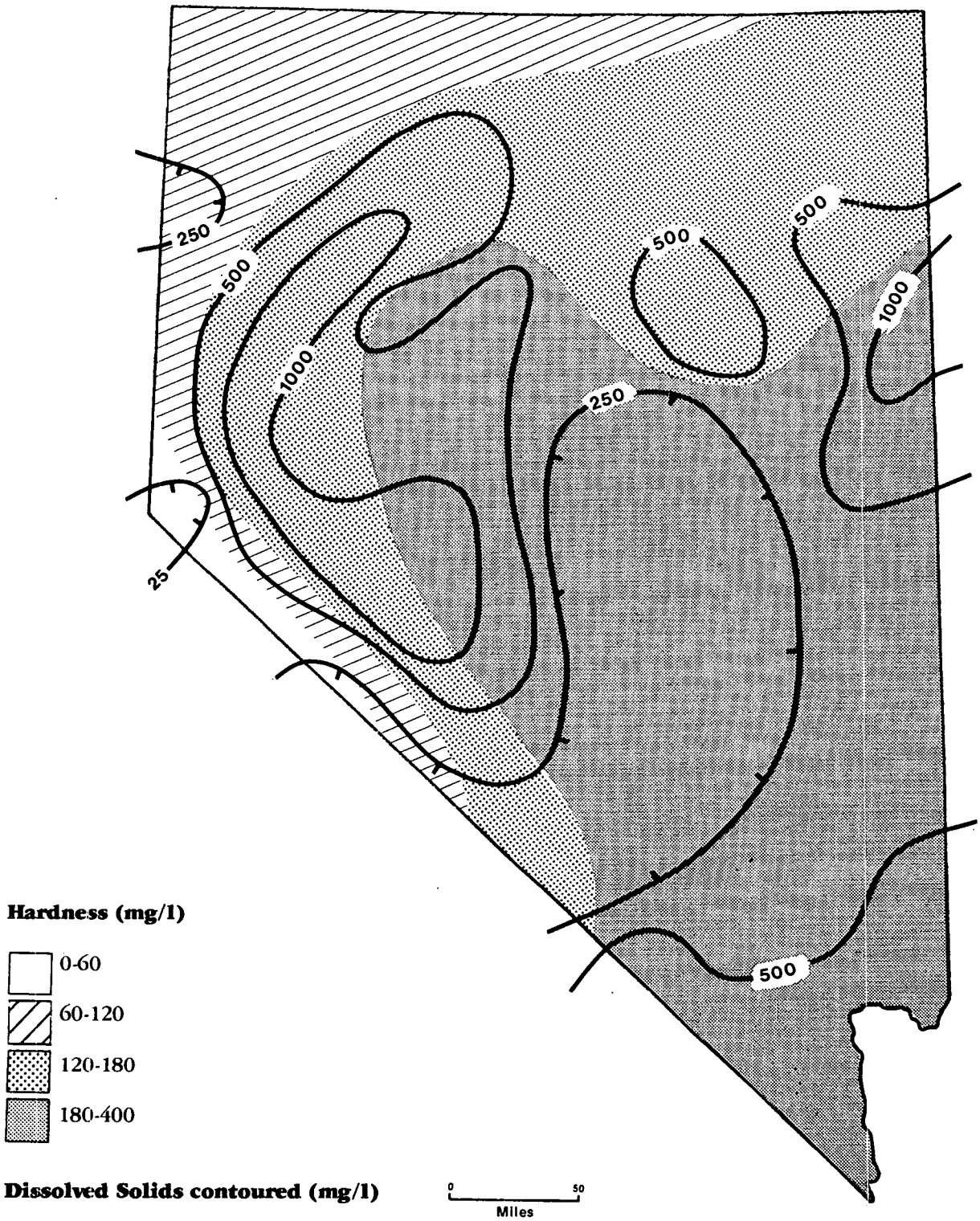
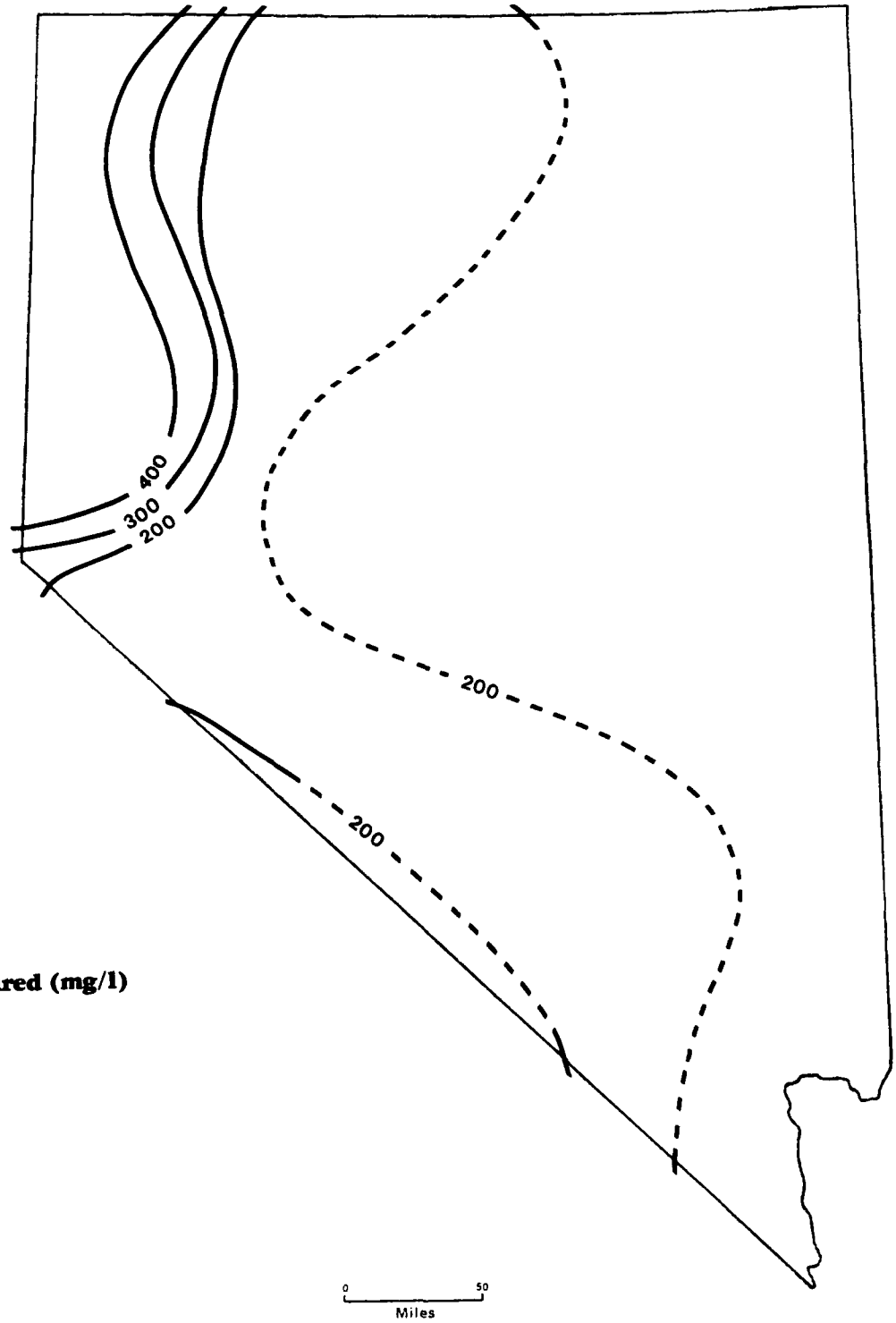


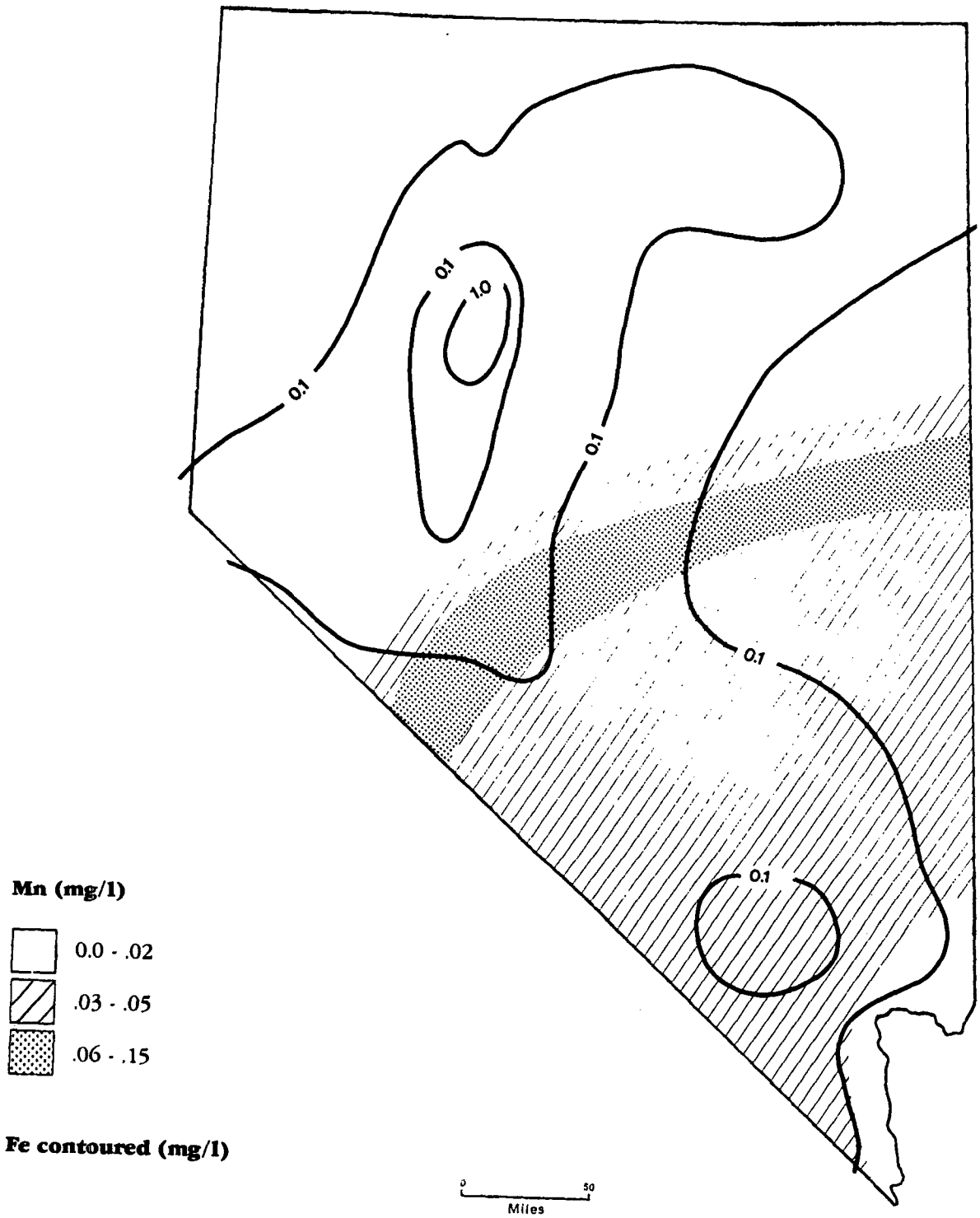
Plate 205

Nevada

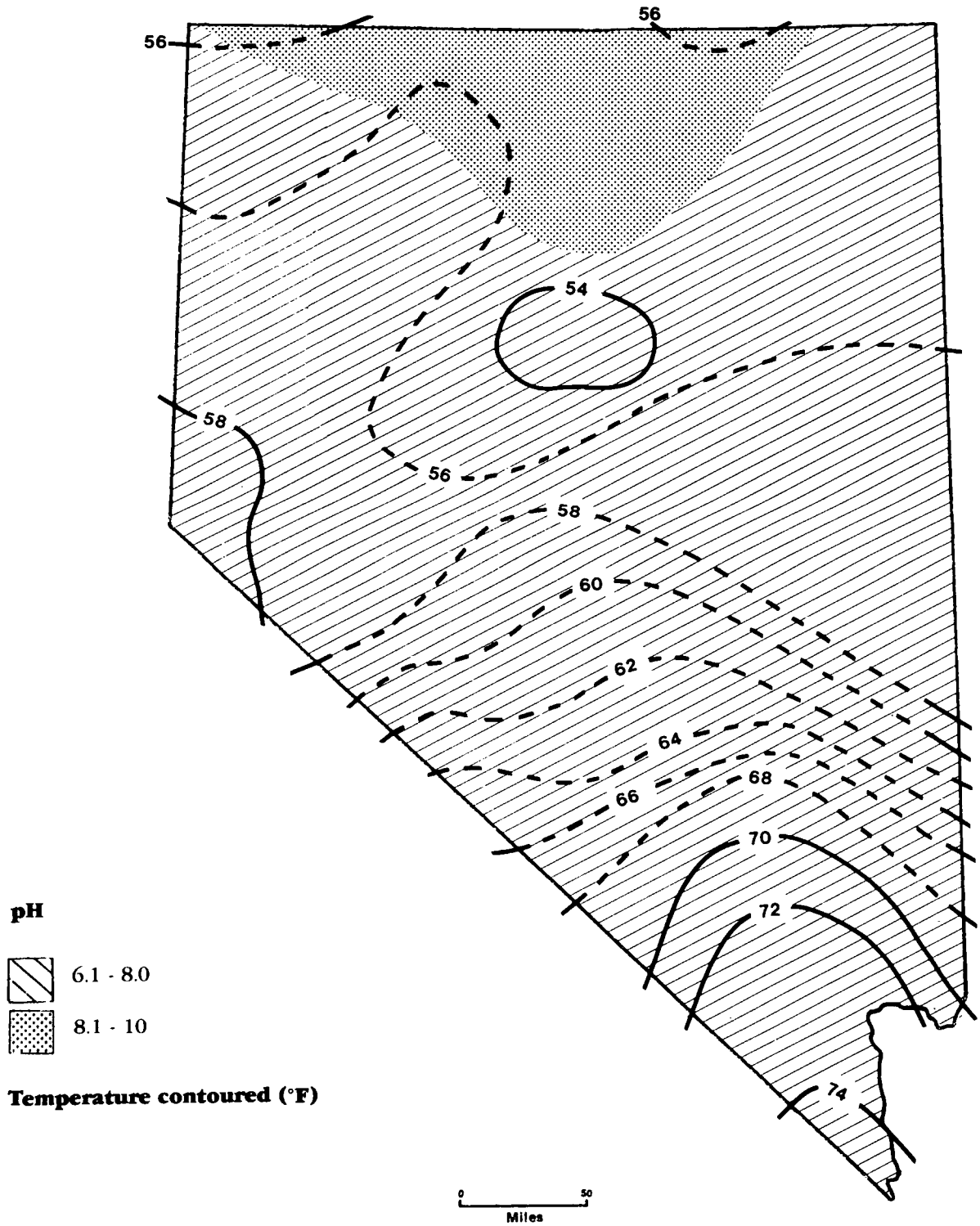


HCO_3 contoured (mg/l)

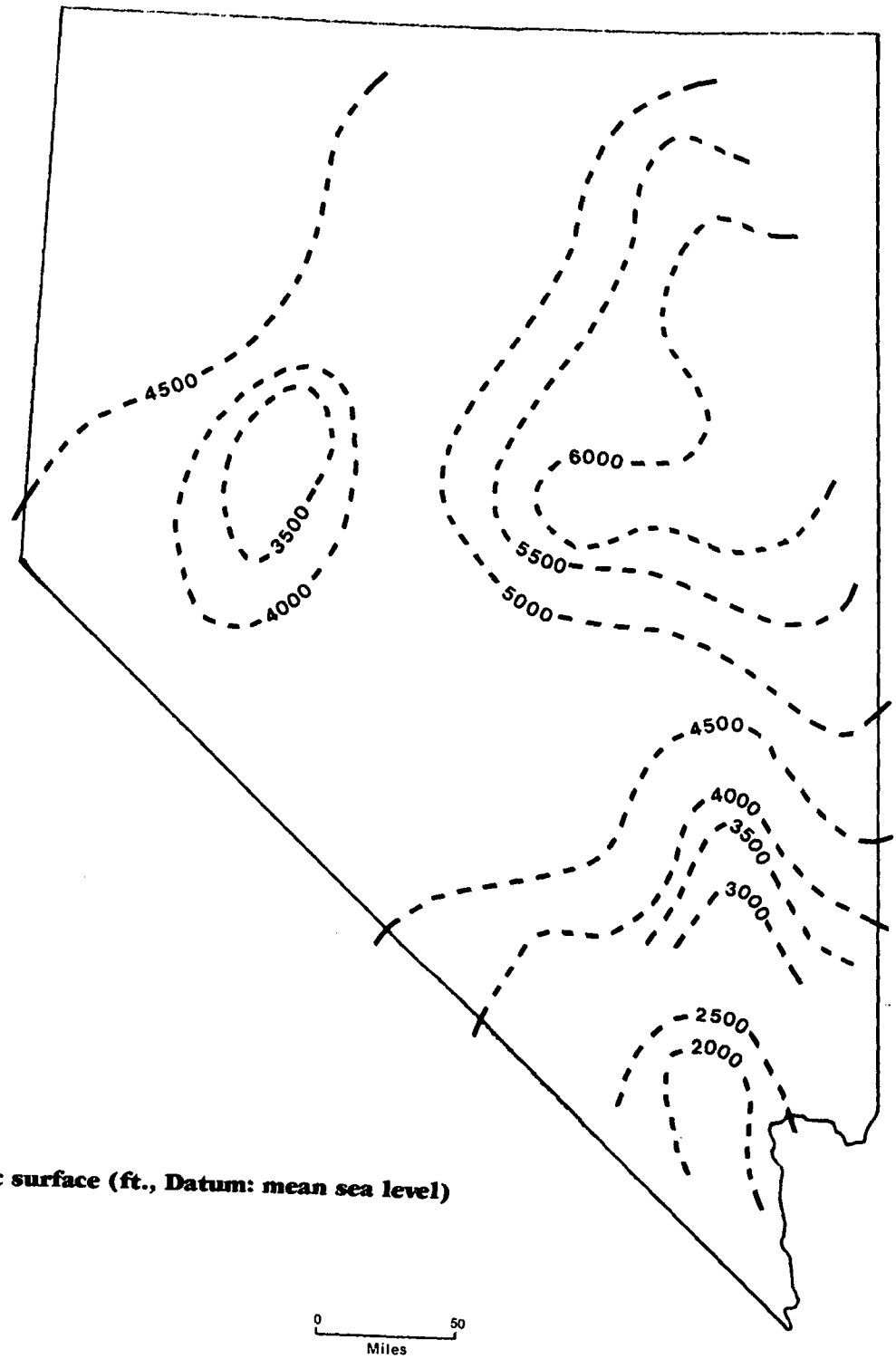
Nevada


0.1
1.0
0.1
0.1
0.1
0.1
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
Fe contoured (mg/l)
0
50
Miles

Nevada

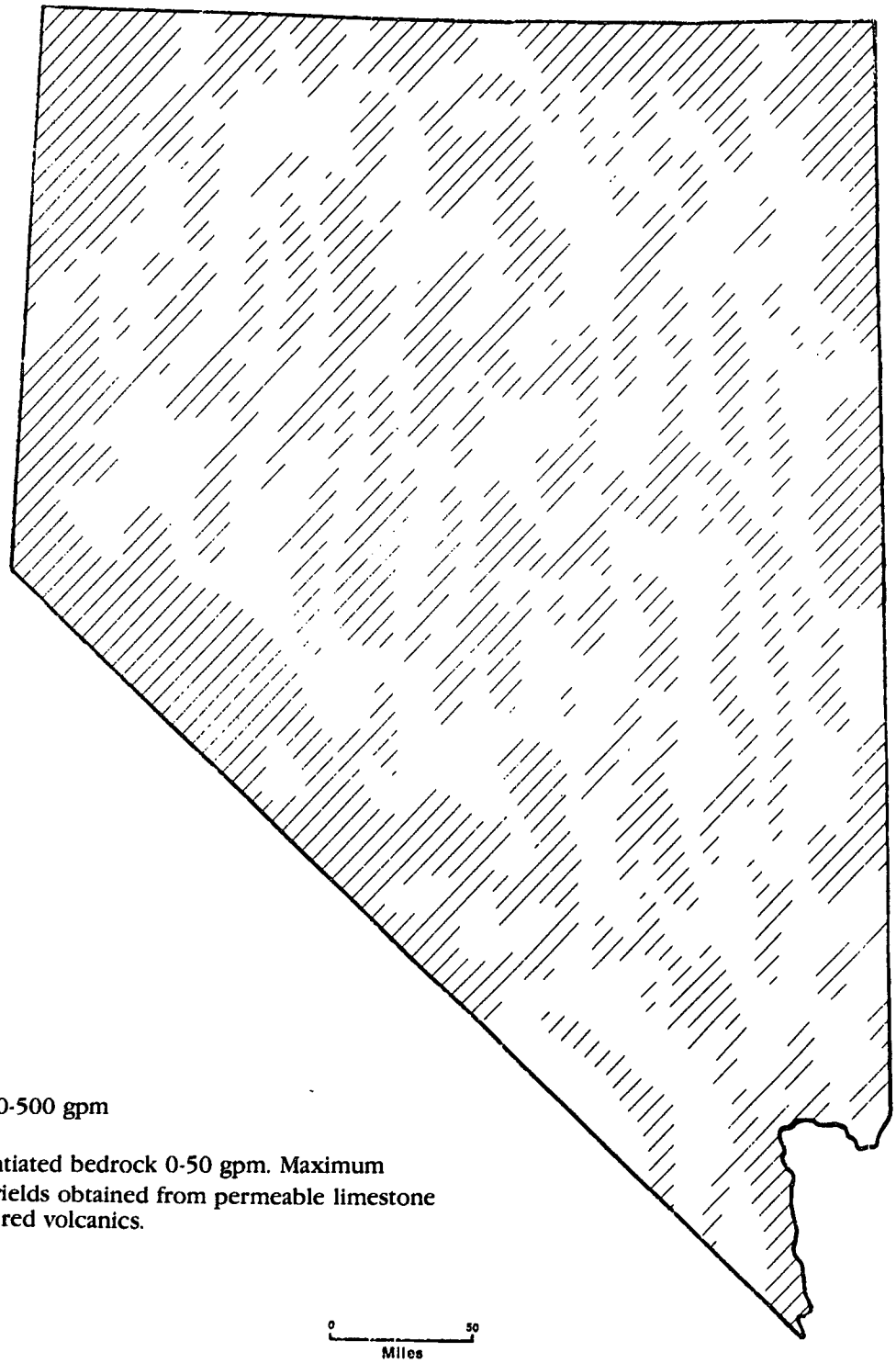

56
56
54
58
56
58
60
62
64
66
68
70
72
74
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles

Nevada



Potentiometric surface (ft., Datum: mean sea level)

Nevada



Yield (gpm)

Alluvium 0-500 gpm

Undifferentiated bedrock 0-50 gpm. Maximum bedrock yields obtained from permeable limestone and fractured volcanics.

New Hampshire

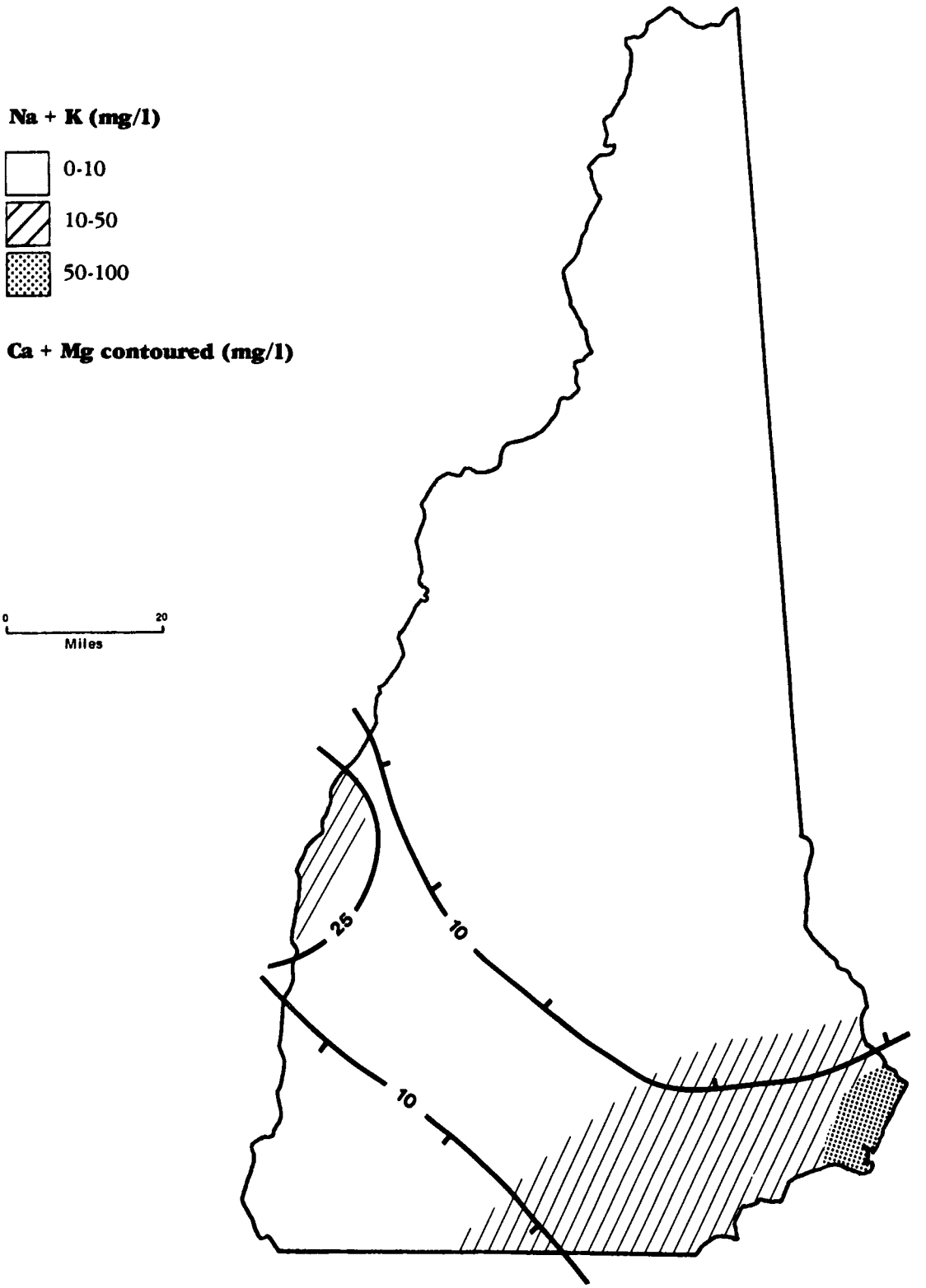


Plate 211

New Hampshrie

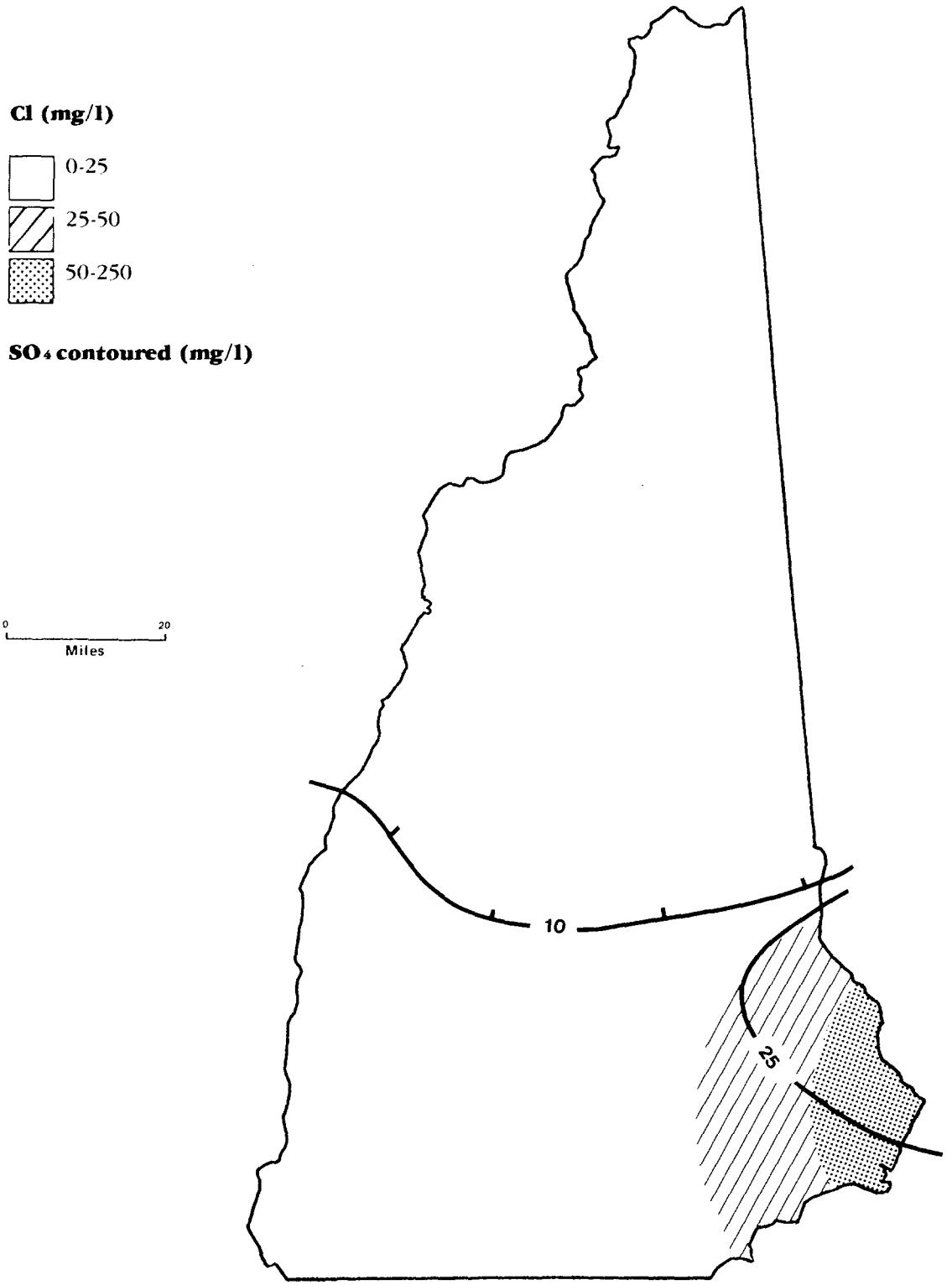


Plate 212

New Hampshire

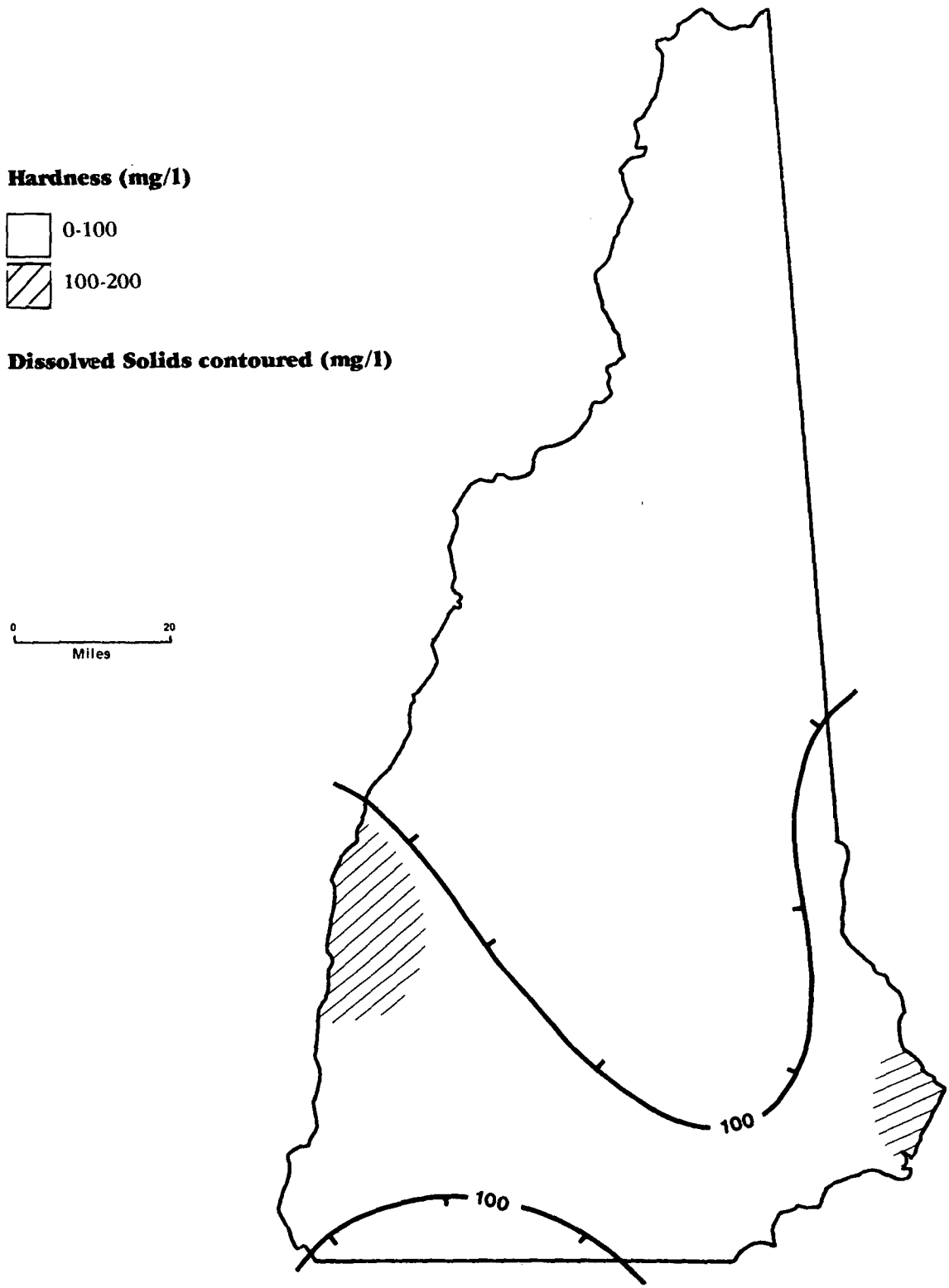


Plate 213

New Hampshire

HCO_3 contoured (mg/l)

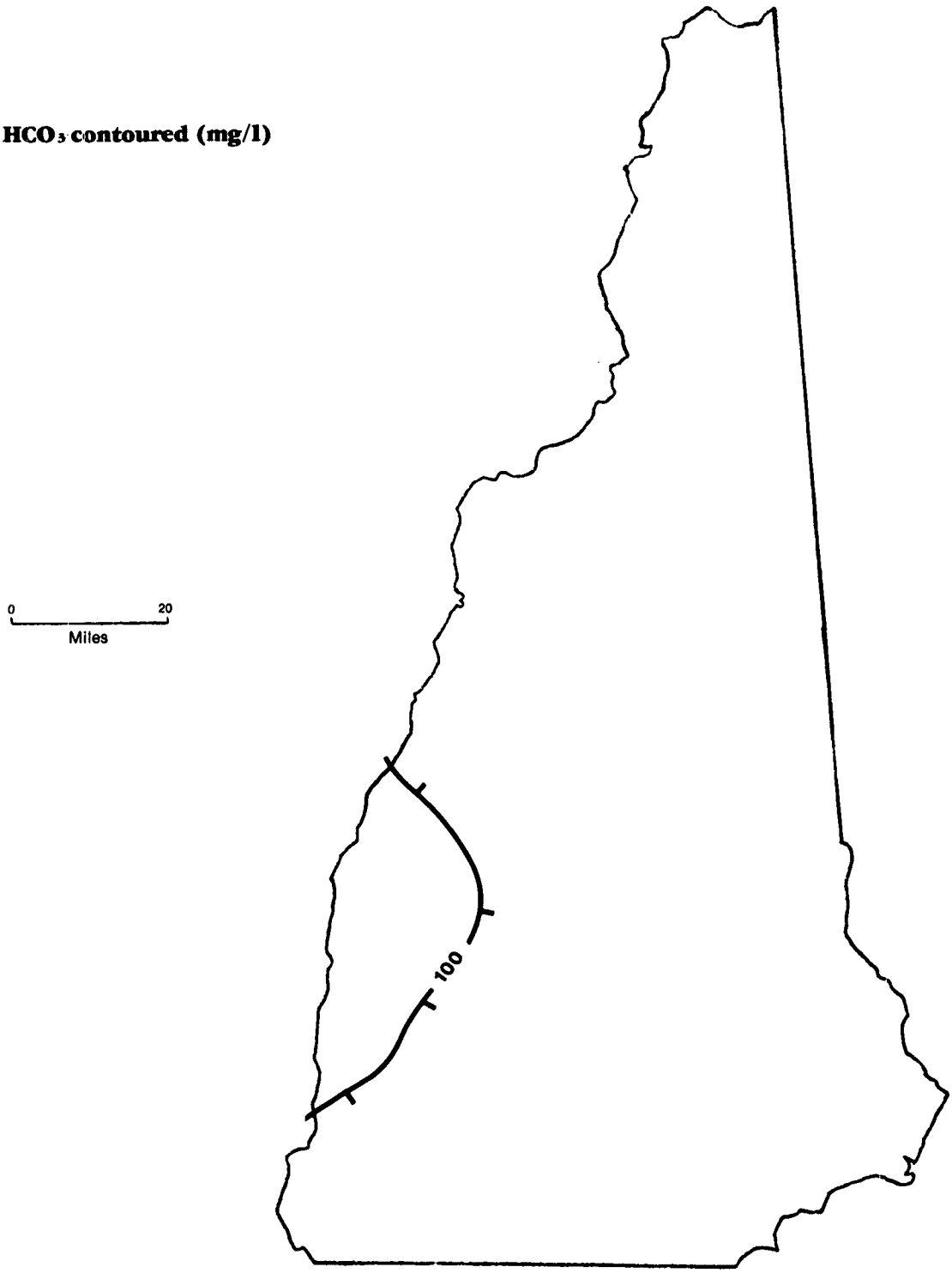
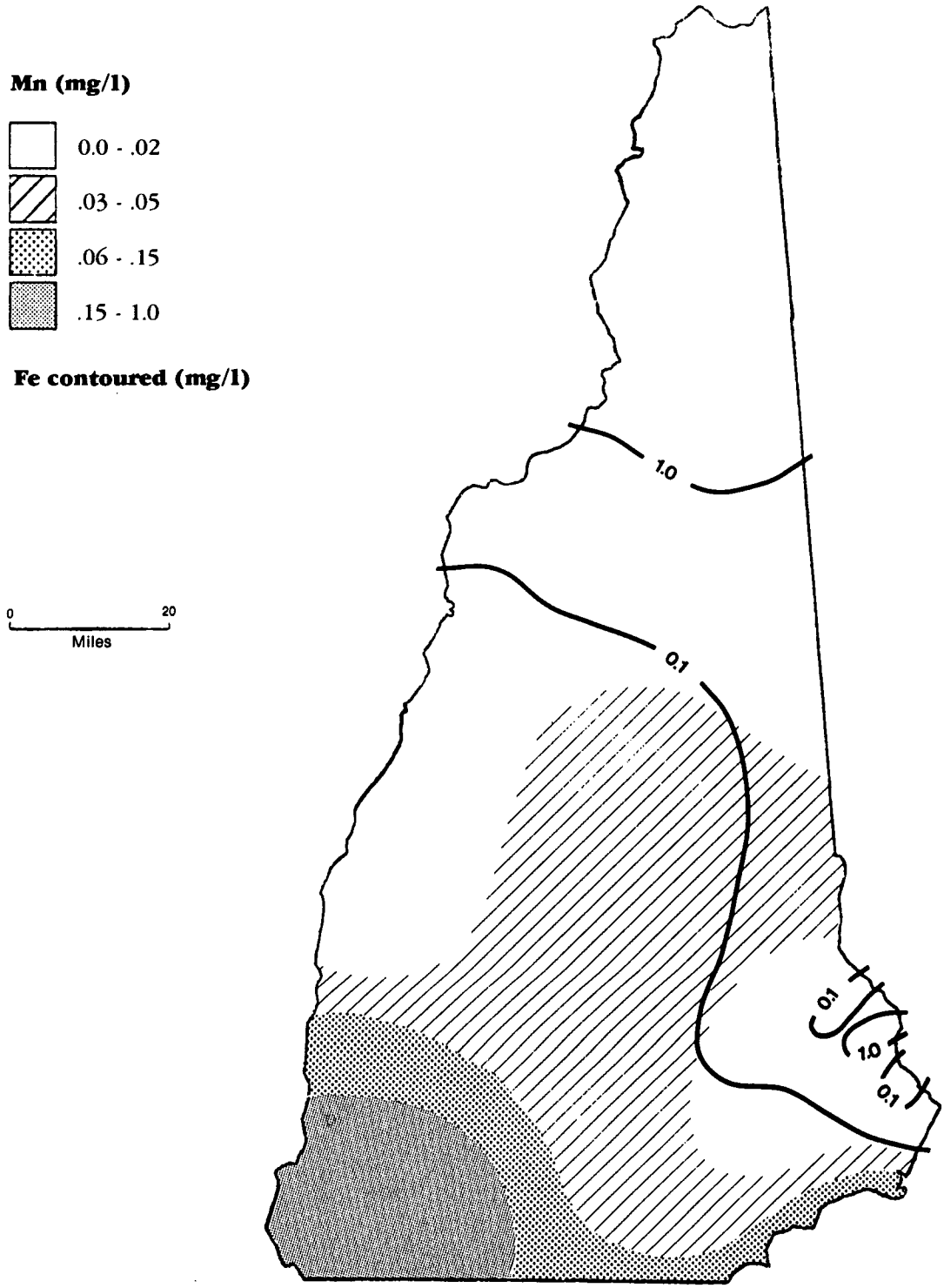


Plate 214

New Hampshire

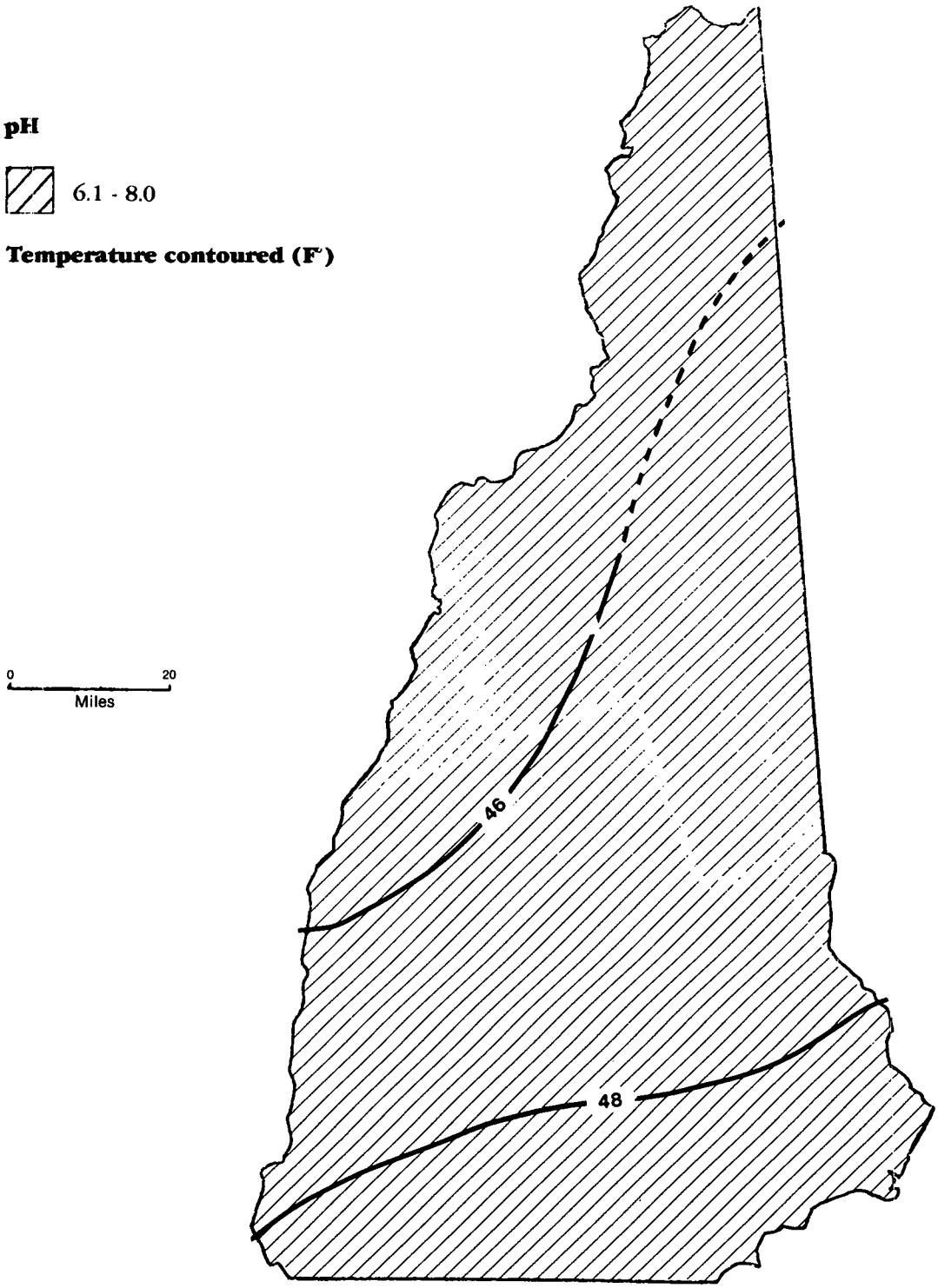


New Hampshire

pH

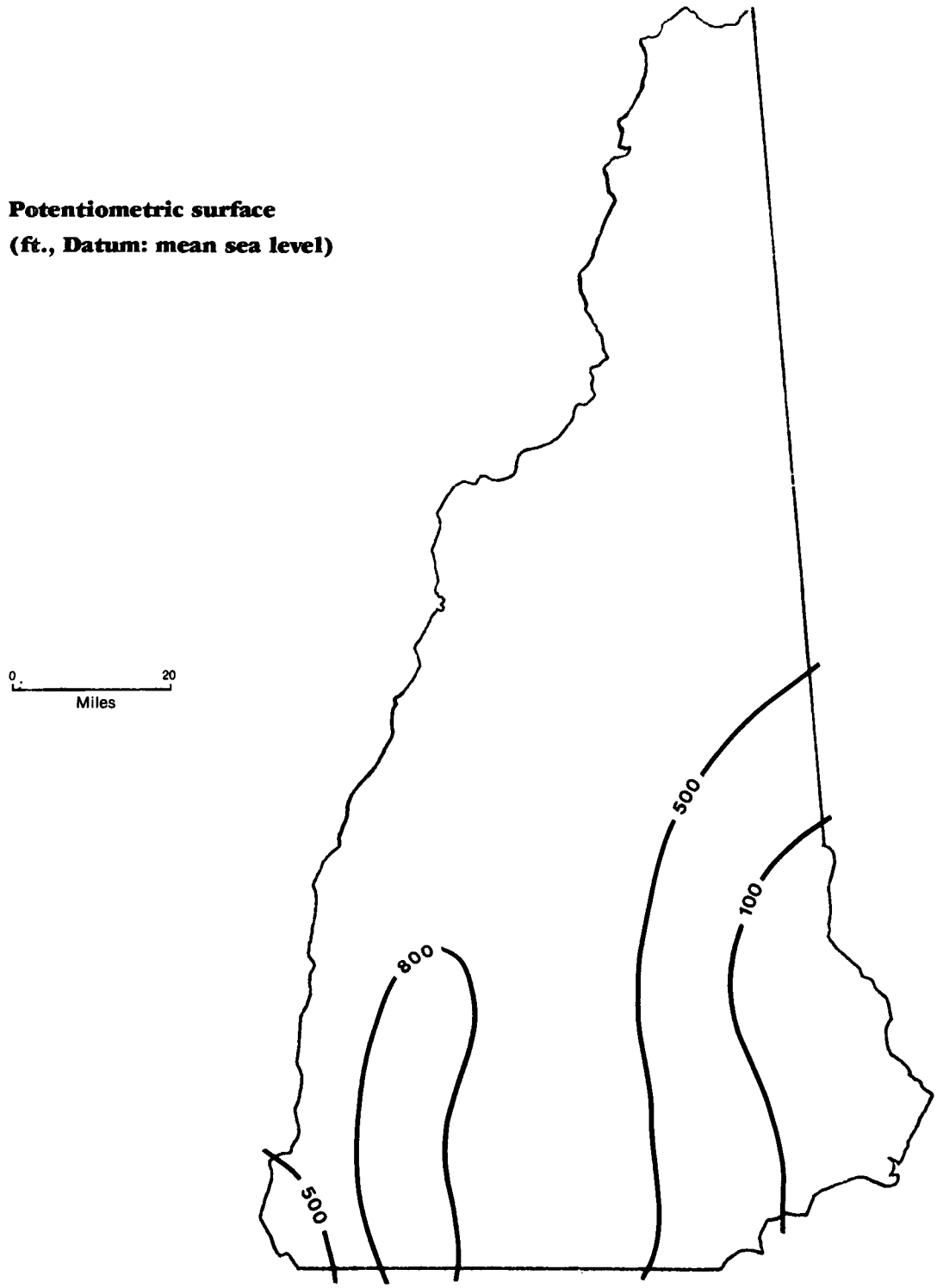
6.1 - 8.0

Temperature contoured (F°)



New Hampshire

Potentiometric surface
(ft., Datum: mean sea level)



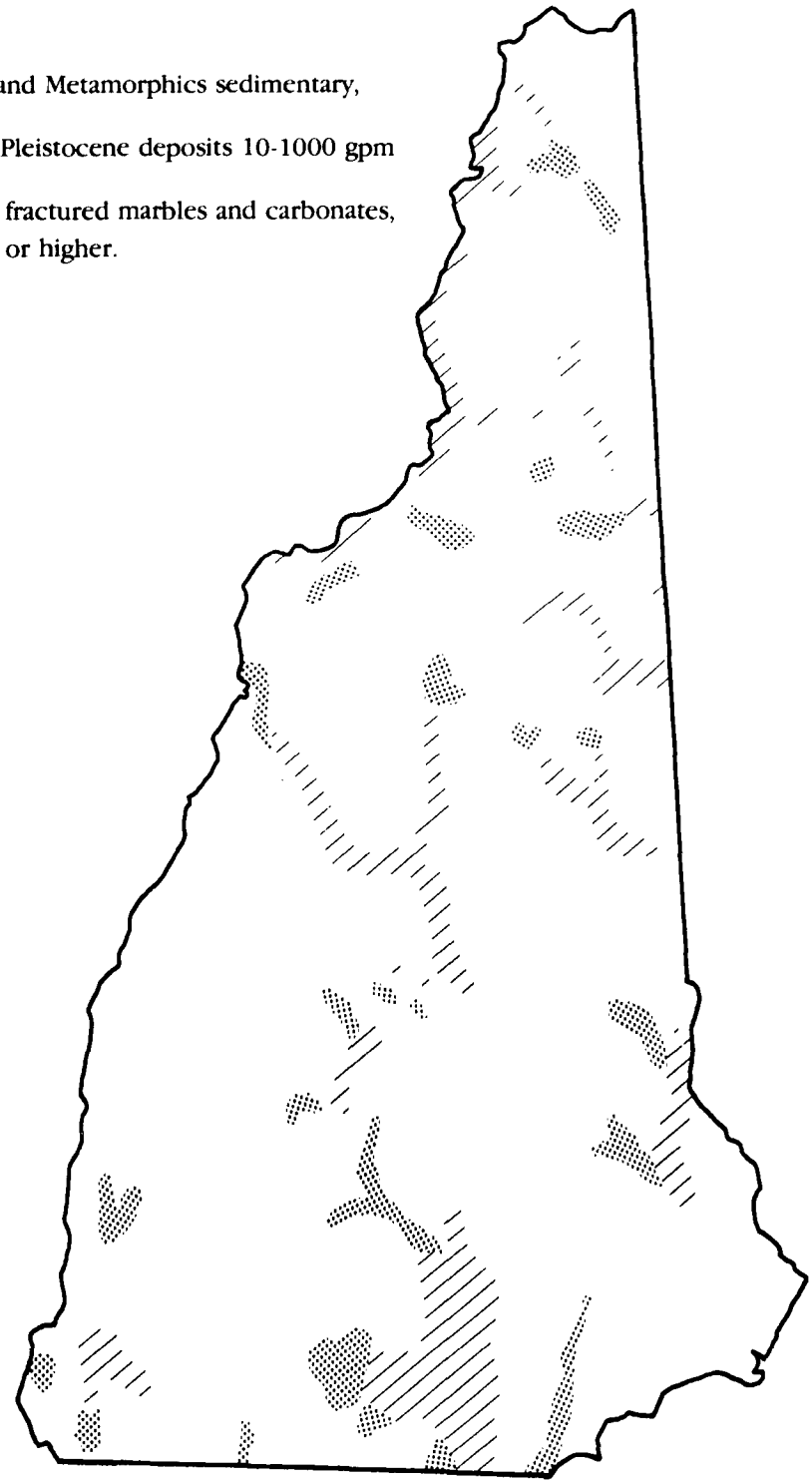
New Hampshire

Yield (gpm)

Undifferentiated Igneous and Metamorphics sedimentary, less than 10 gpm

Sand and gravel deposits, Pleistocene deposits 10-1000 gpm

Beach silt, clay, fine sand, fractured marbles and carbonates, generally average 10 gpm or higher.



New Jersey

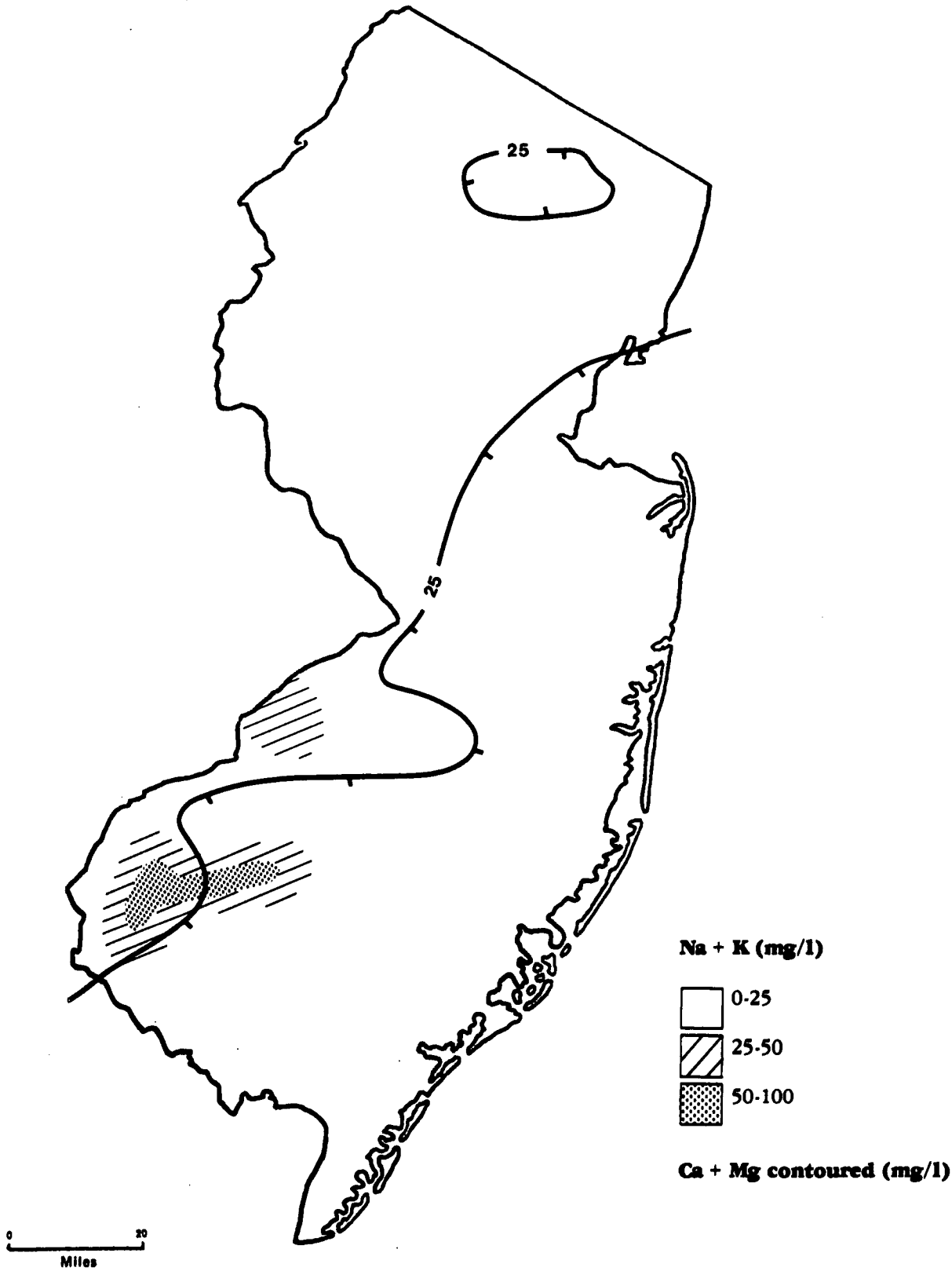


Plate 219

New Jersey

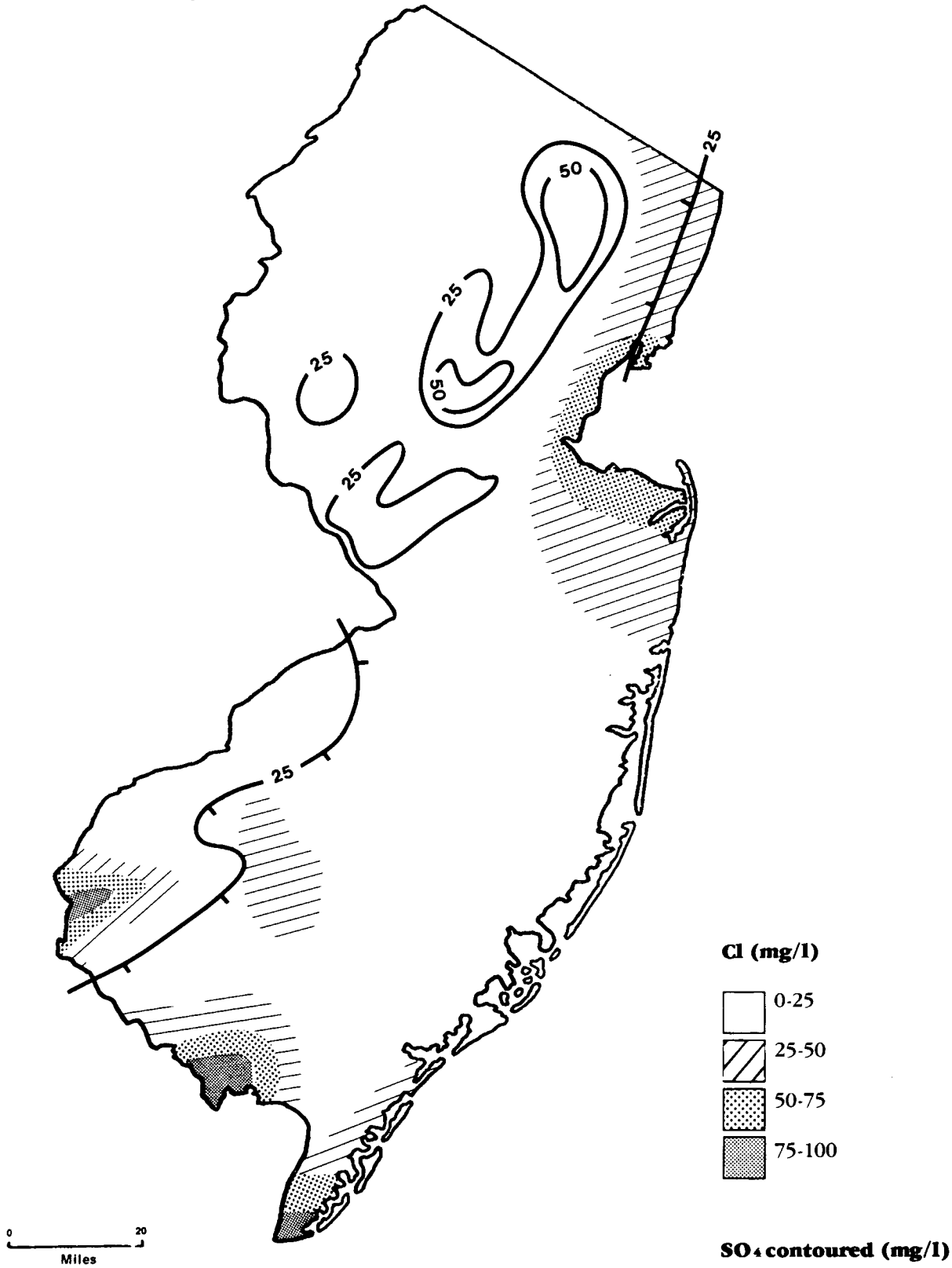
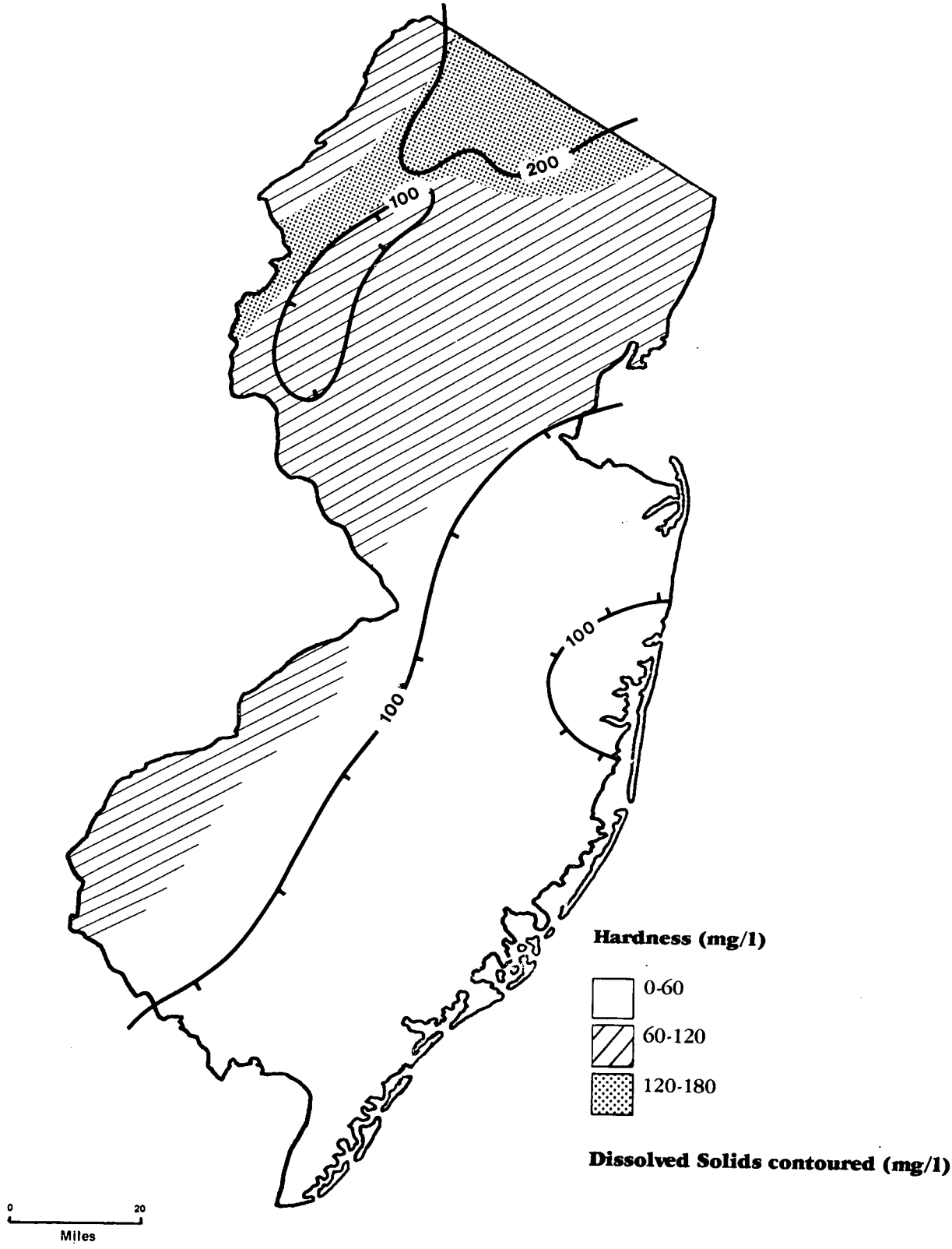
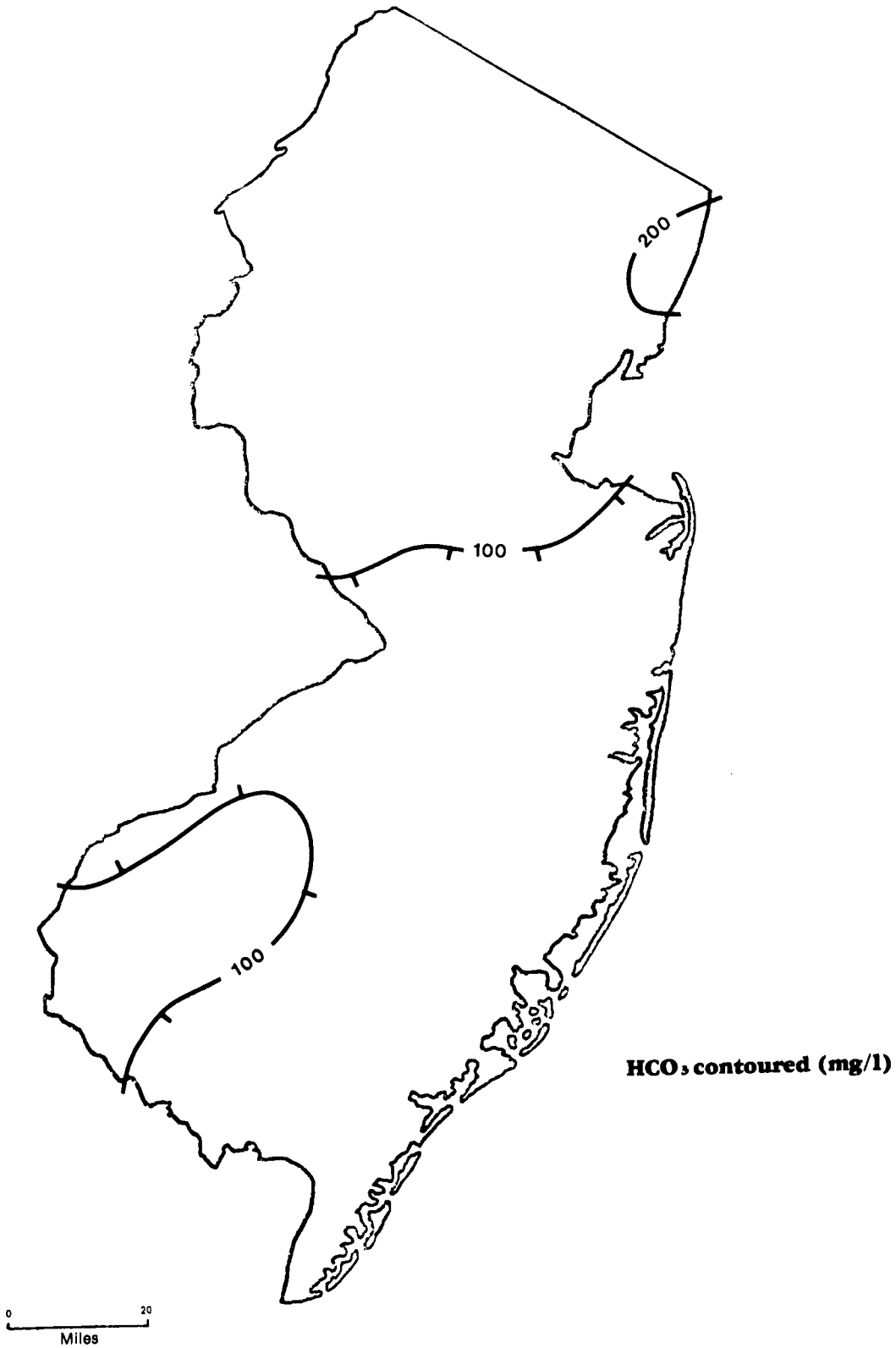


Plate 220

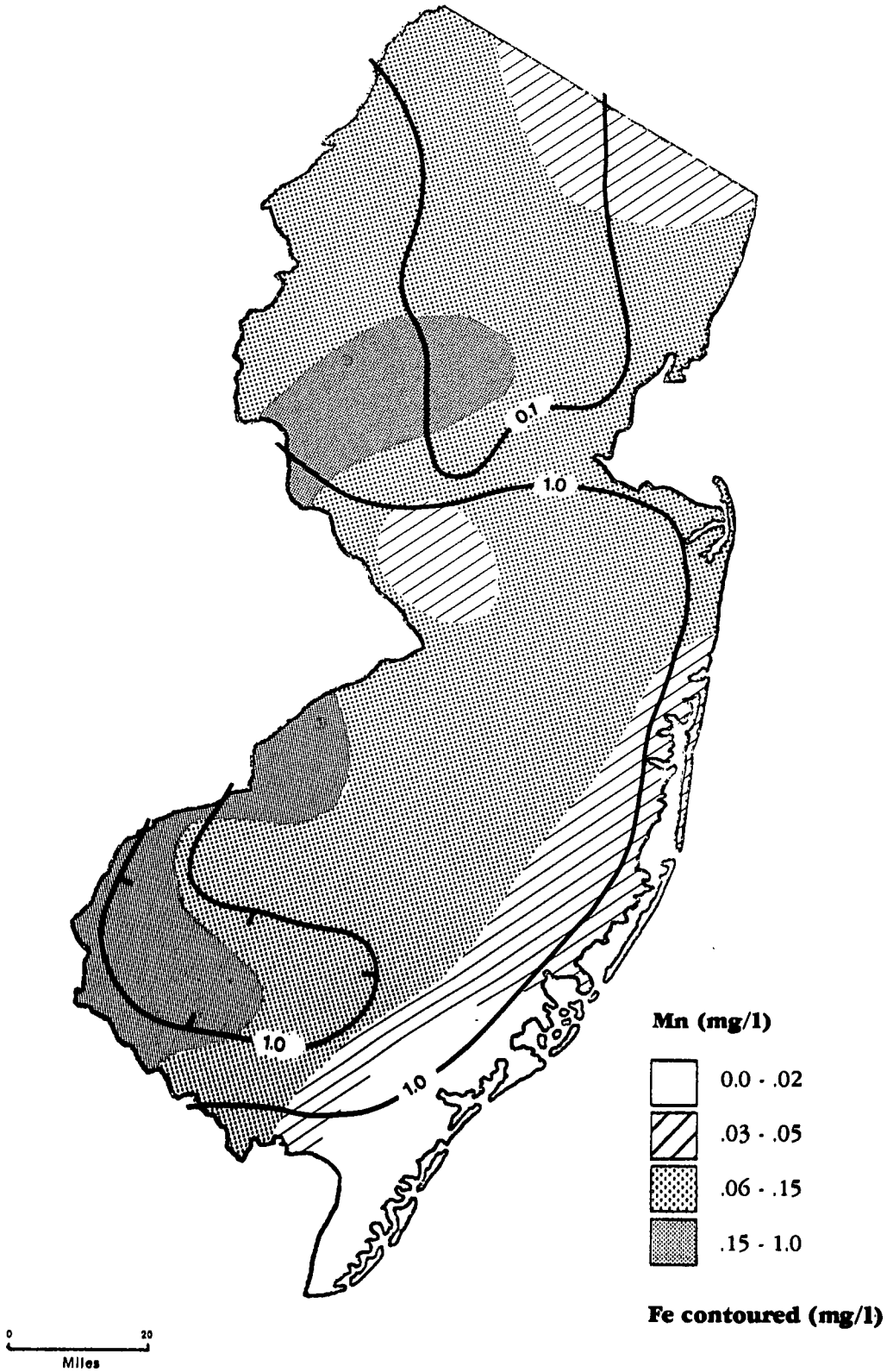
New Jersey


200
100
100
100
Hardness (mg/l)
0-60
60-120
120-180
Dissolved Solids contoured (mg/l)
0
20
Miles

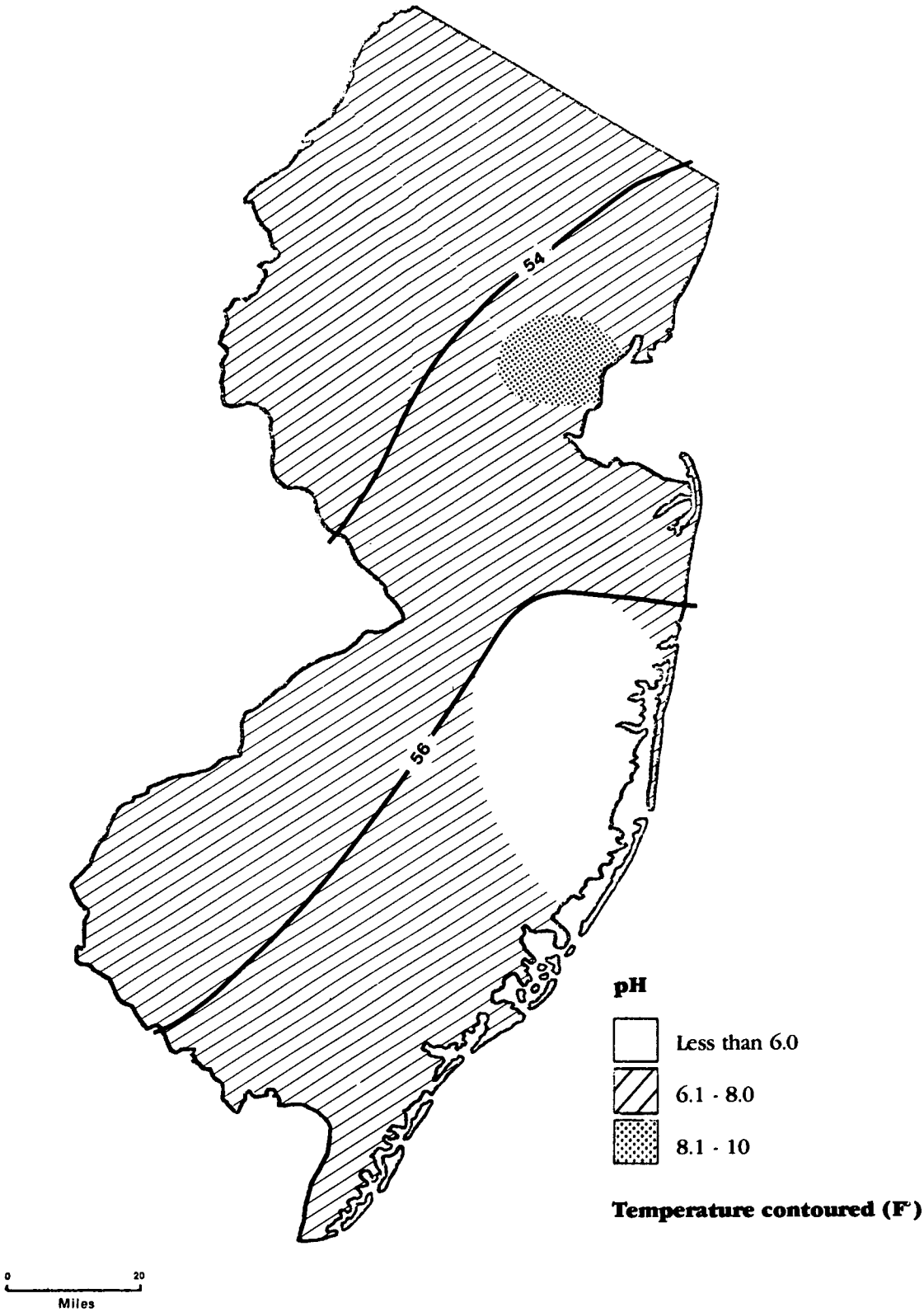
New Jersey



New Jersey


0.1
1.0
1.0
1.0
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
20
Miles

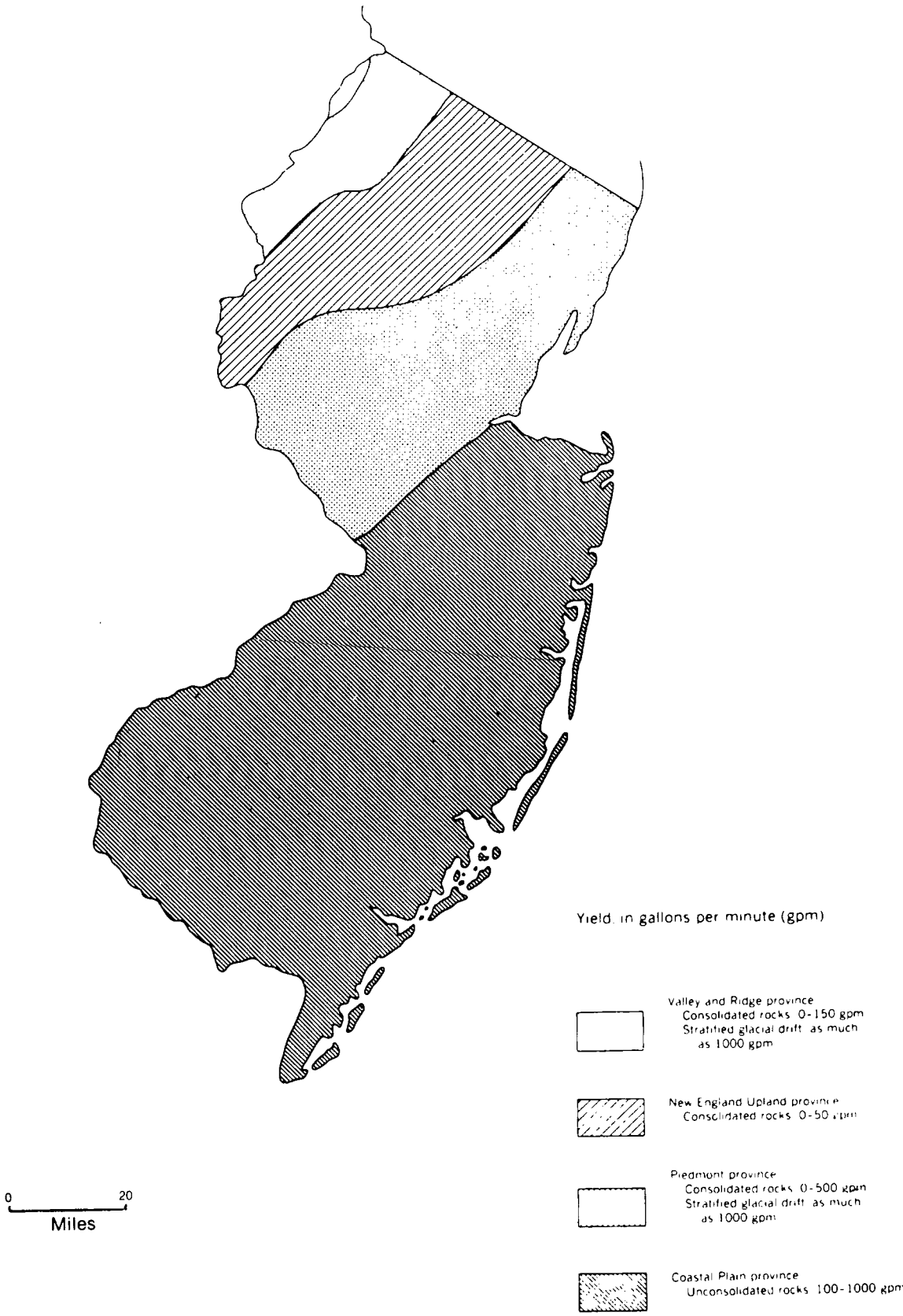
New Jersey


54
56
pH
Less than 6.0
6.1 - 8.0
8.1 - 10
Temperature contoured (F°)
0
20
Miles

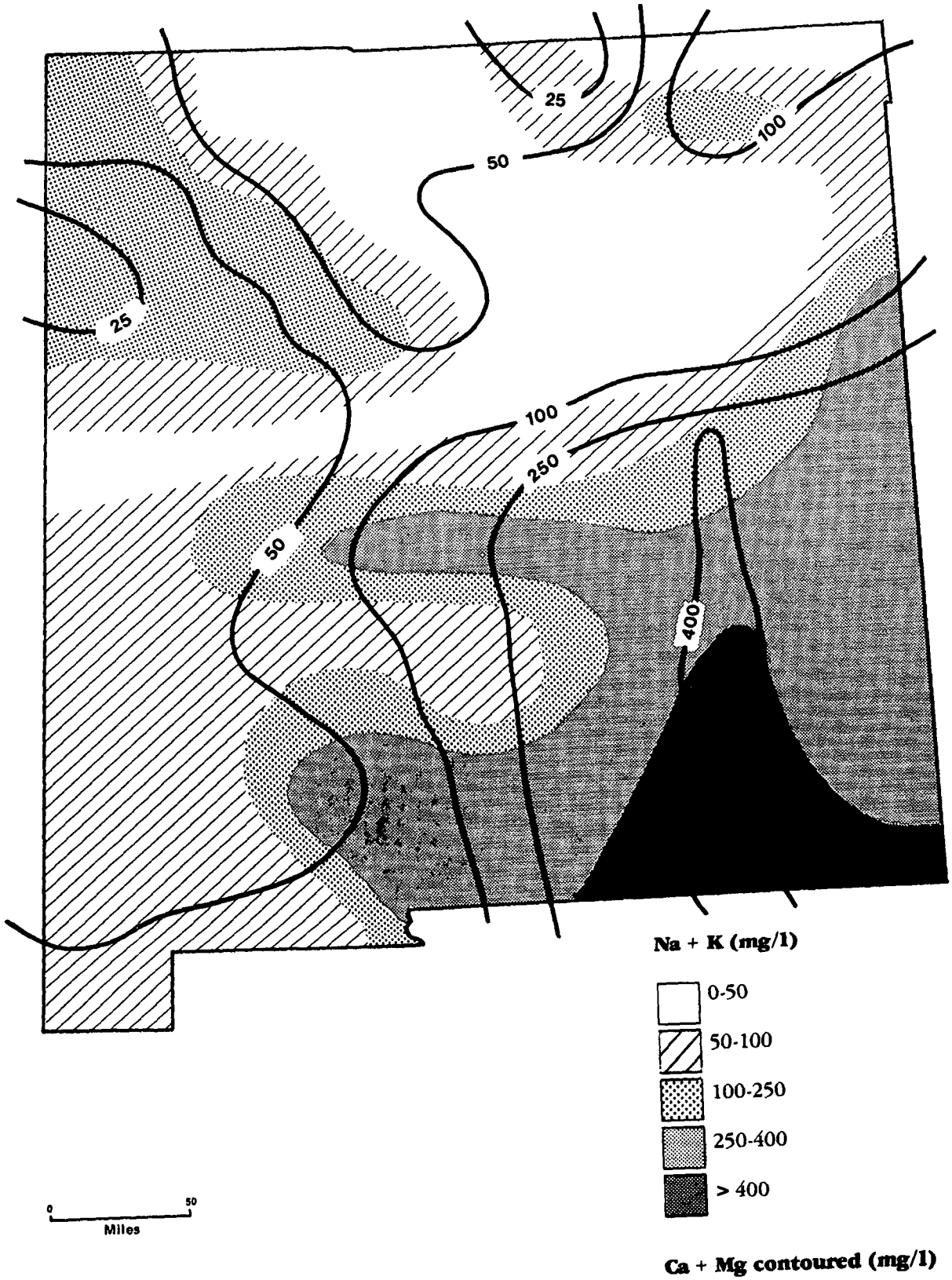
New Jersey

Potentiometric surface
(ft., Datum: mean sea level)

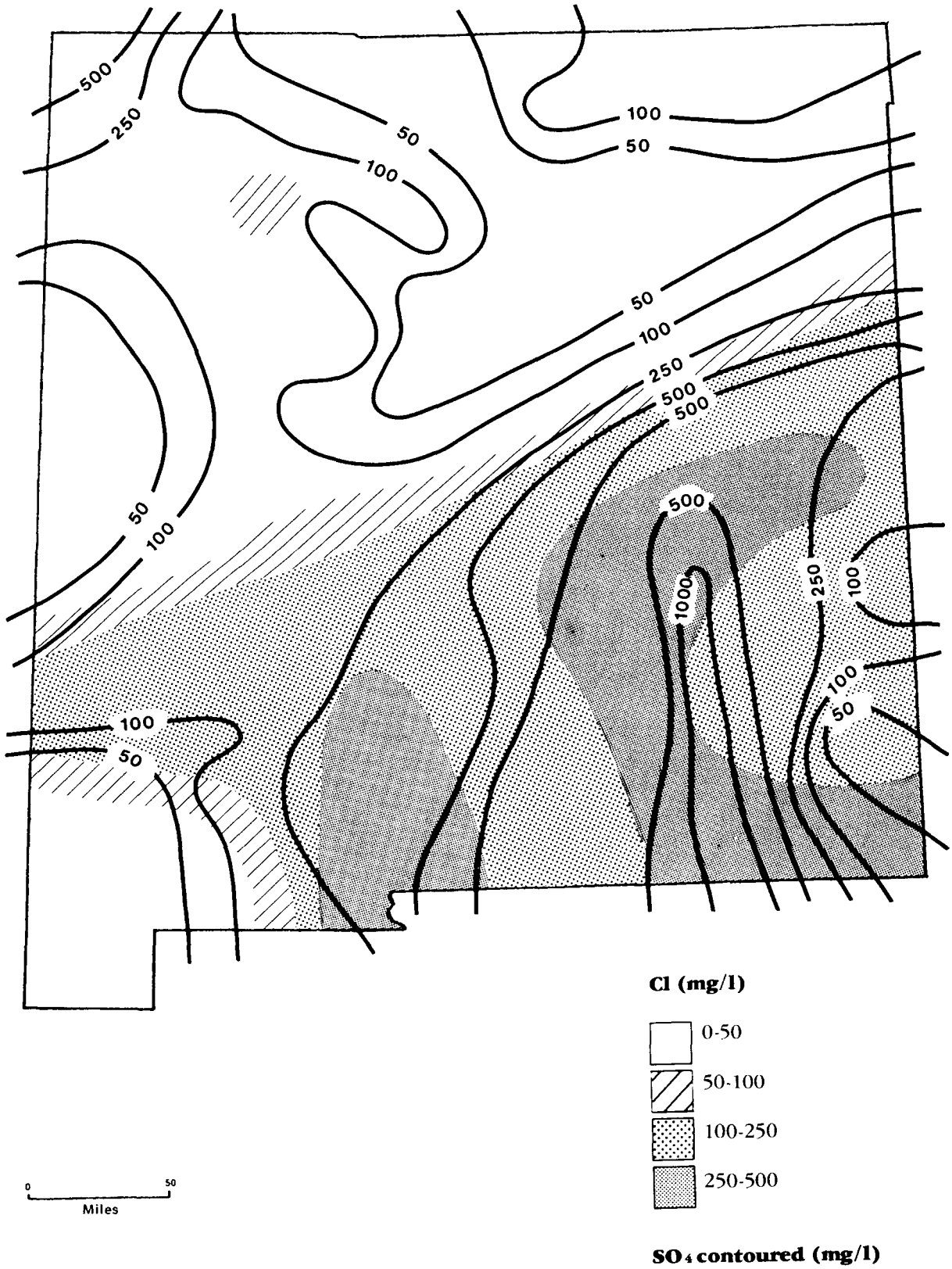
New Jersey


Yield, in gallons per minute (gpm)
Valley and Ridge province
Consolidated rocks 0-150 gpm
Stratified glacial drift as much as 1000 gpm
New England Upland province
Consolidated rocks 0-50 gpm
Piedmont province
Consolidated rocks 0-500 gpm
Stratified glacial drift as much as 1000 gpm
Coastal Plain province
Unconsolidated rocks 100-1000 gpm
0
20
Miles

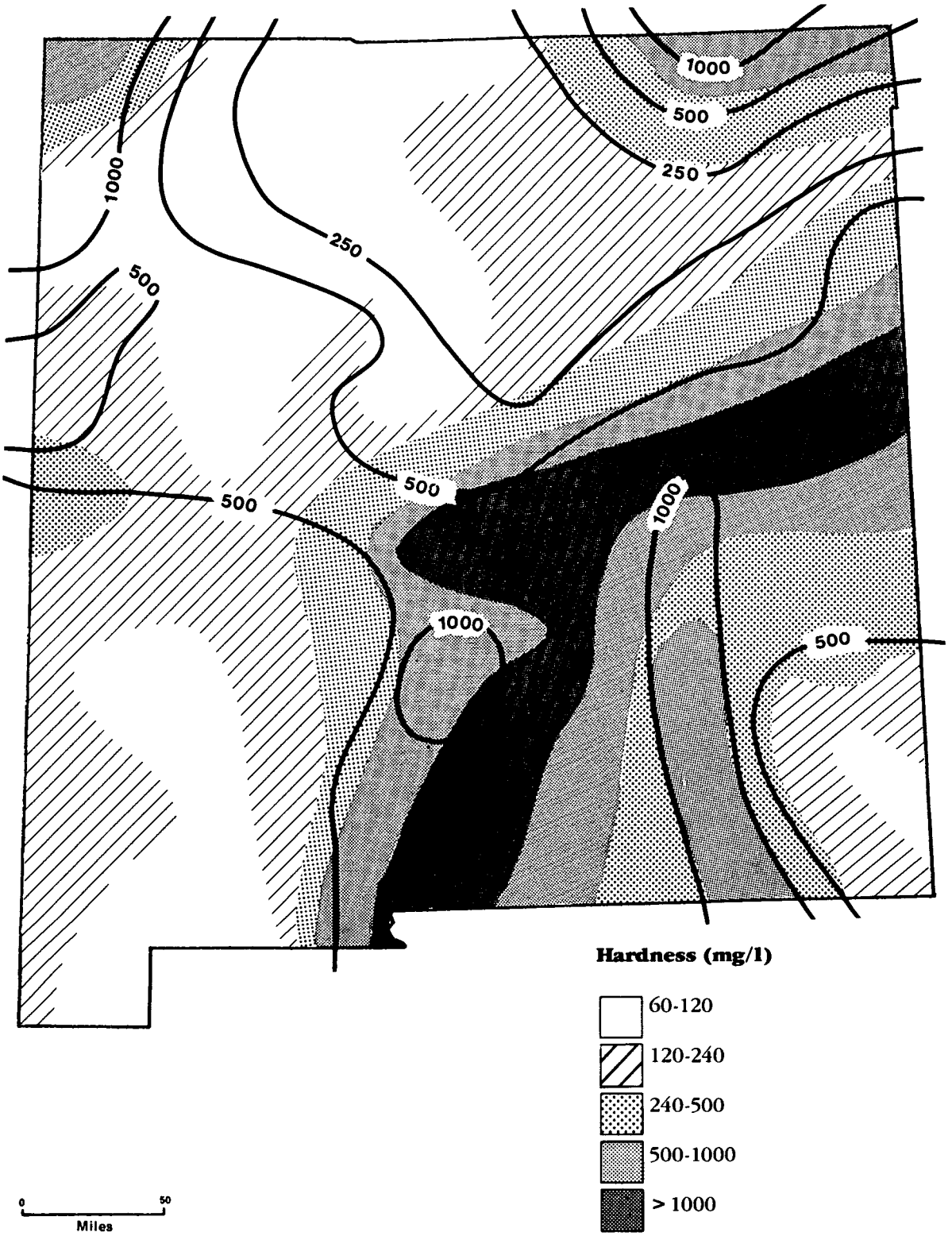
New Mexico


25
50
100
25
100
250
50
400
Na + K (mg/l)
0-50
50-100
100-250
250-400
> 400
0
50
Miles
Ca + Mg contoured (mg/l)

New Mexico

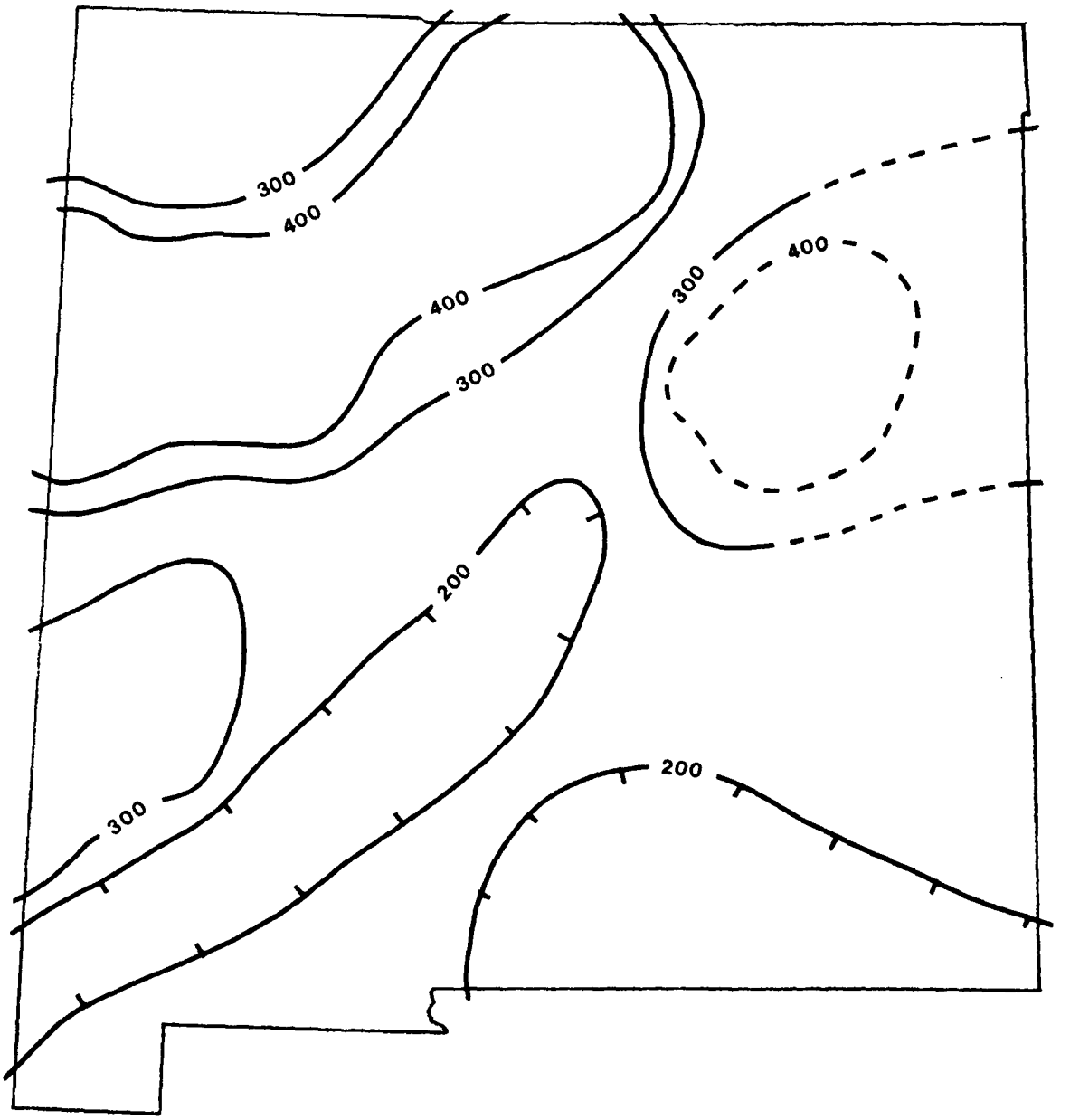

500
250
50
100
100
50
50
100
250
500
500
50
100
500
1000
250
100
100
50
100
50
Cl (mg/l)
0-50
50-100
100-250
250-500
0
50
Miles
SO4 contoured (mg/l)

New Mexico



Dissolved Solids contoured (mg/l)

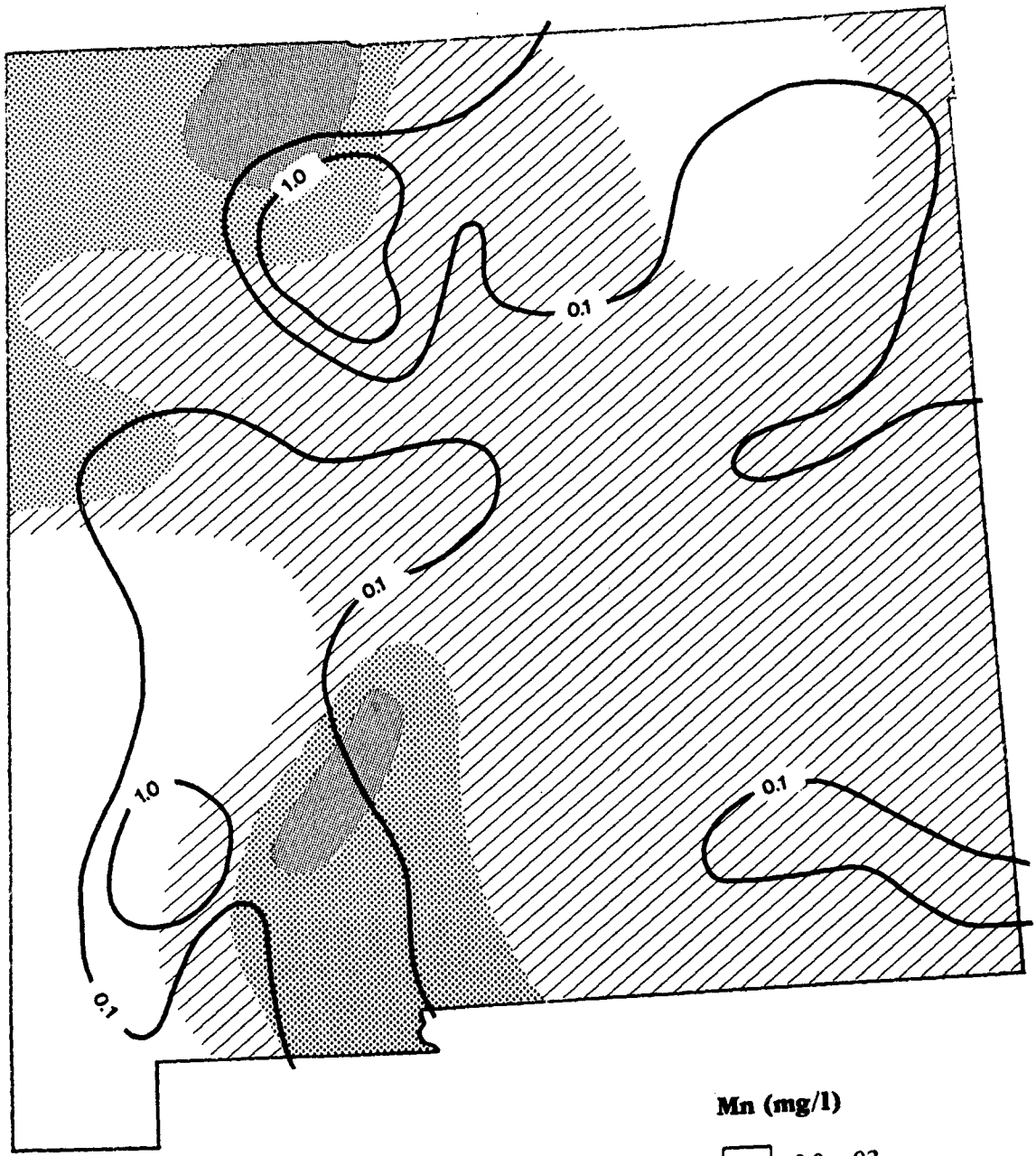
New Mexico



HCO_3 contoured (mg/l)

0 50
Miles

New Mexico



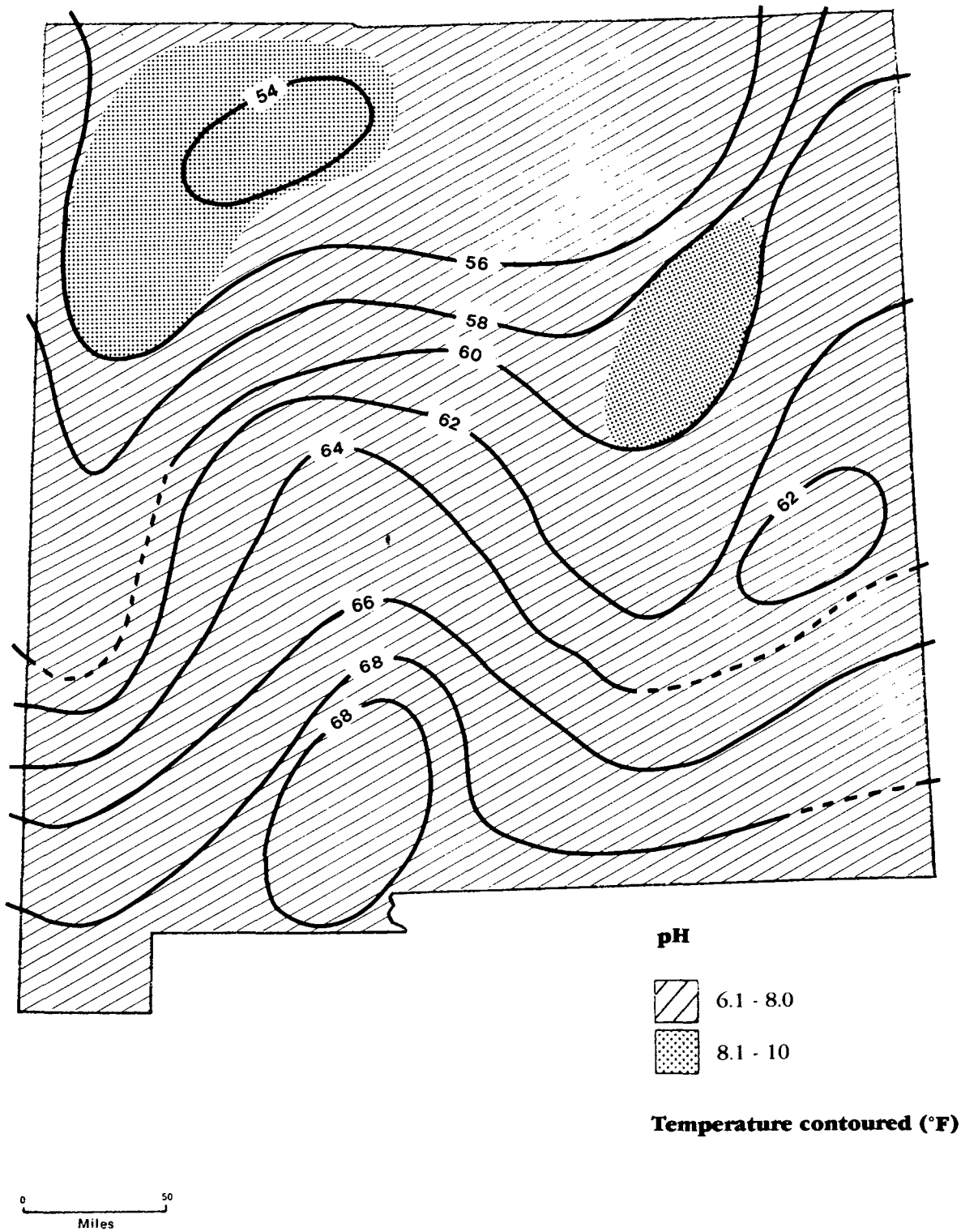
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

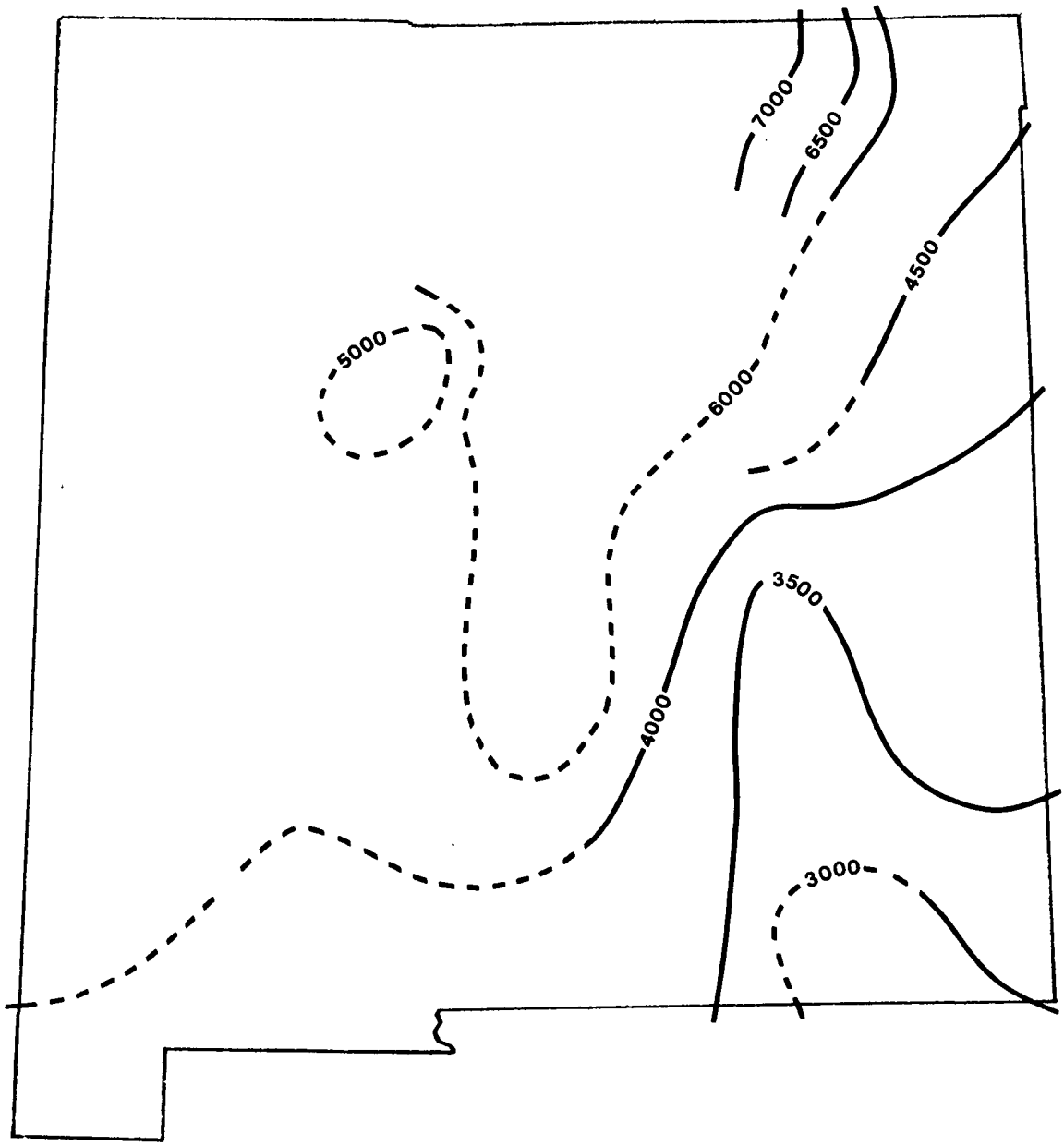
0 50
Miles

Fe contoured (mg/l)

New Mexico


54
56
58
60
62
64
62
66
68
68
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles

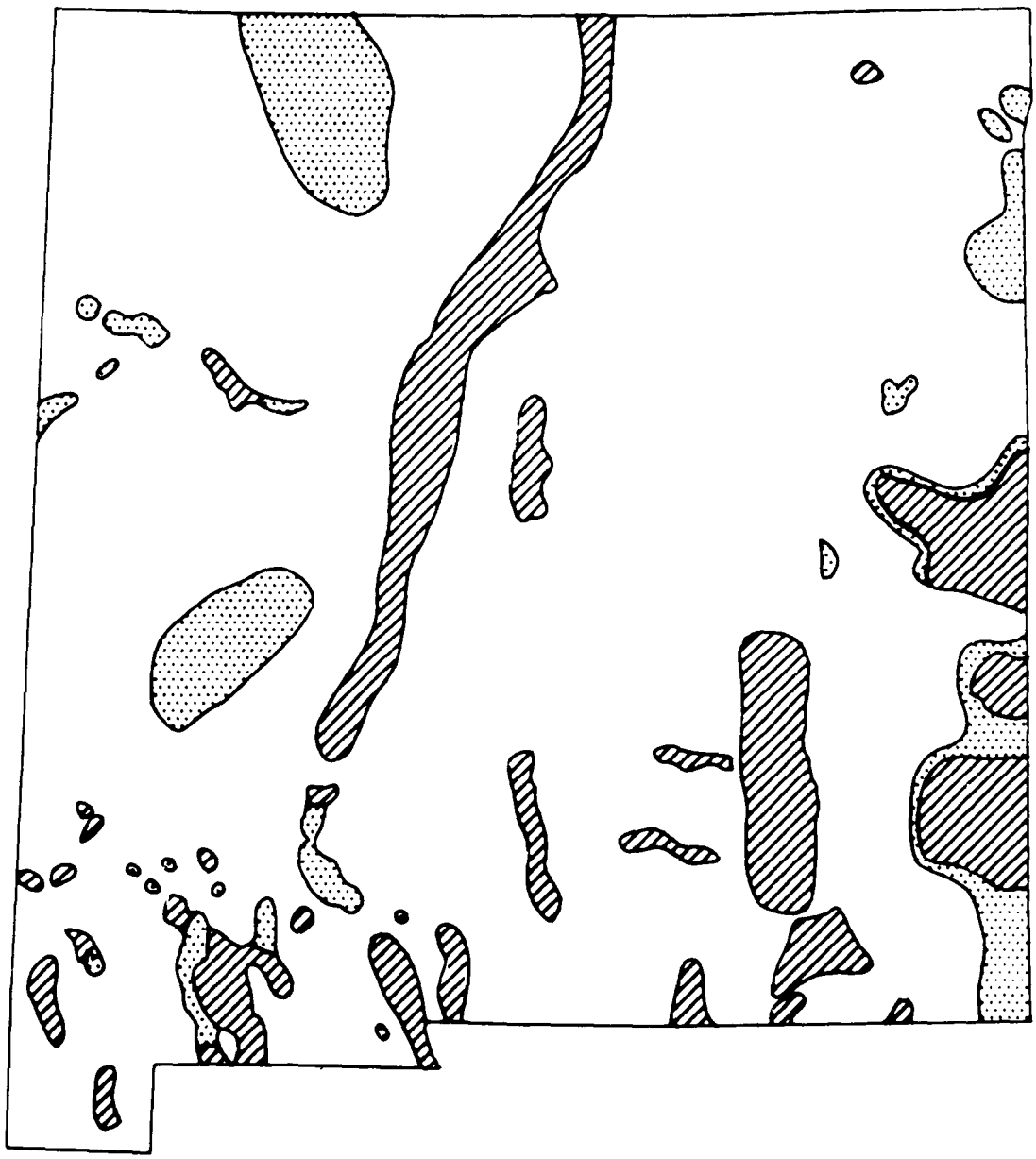
New Mexico



Potentiometric surface
(ft., Datum: mean sea level)

0 50
Miles

New Mexico



Potential yield of wells, in gallons per minute (gpm)

Less than 100 gpm, highly saline water areas, or areas for which data are inadequate for appraisal

100–300 gpm

More than 300 gpm

0 50
Miles

New York

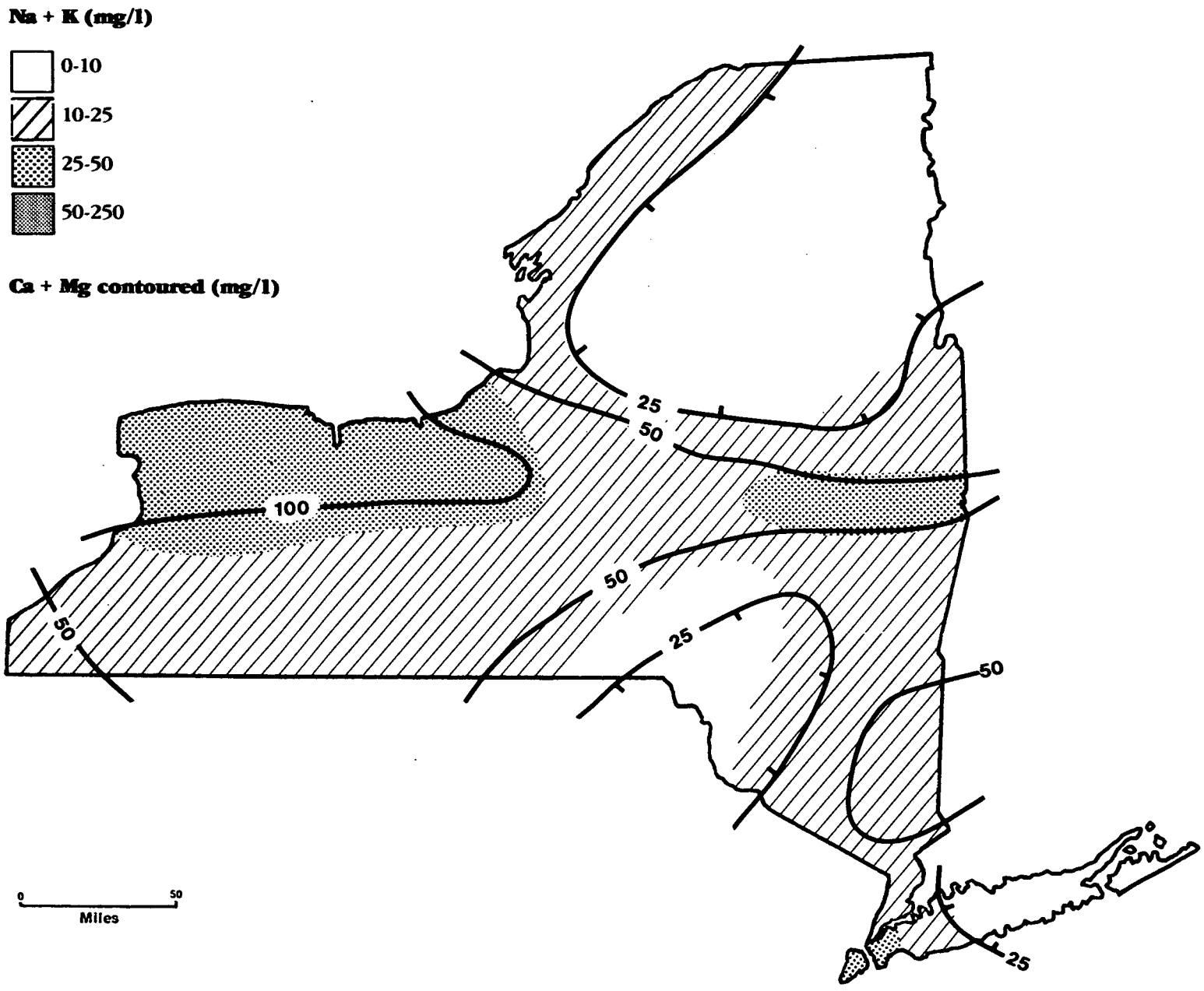


Plate 235

New York

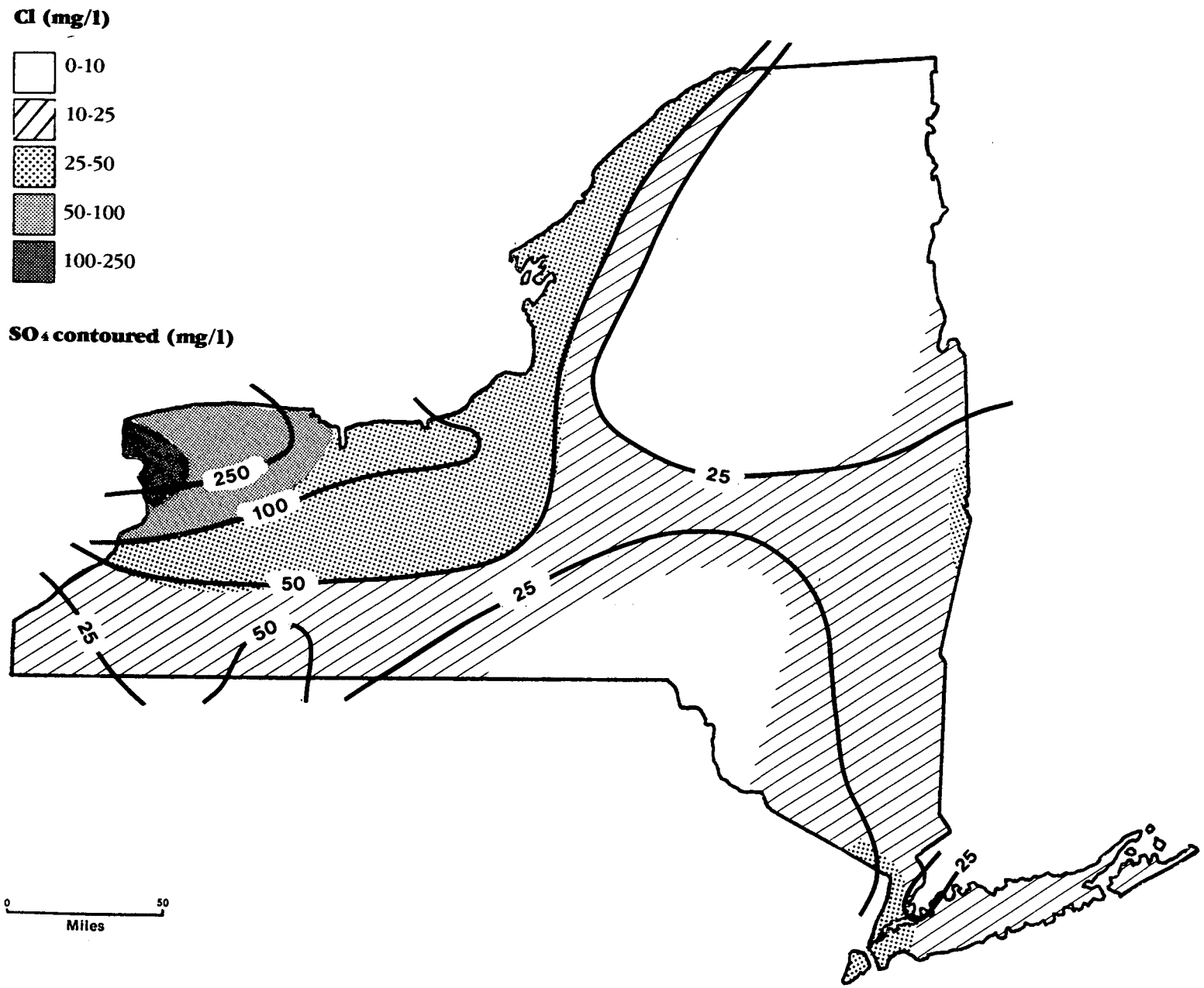
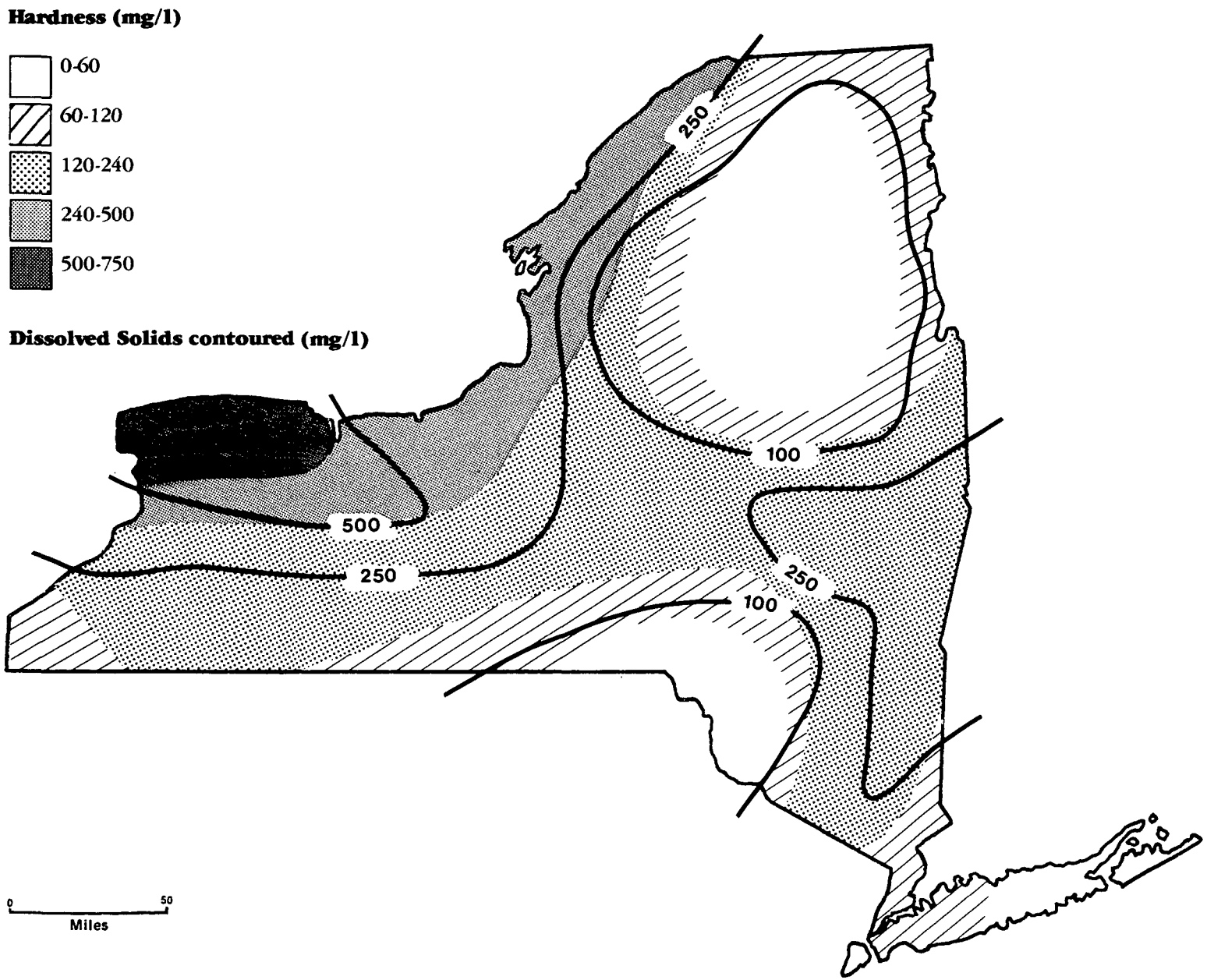
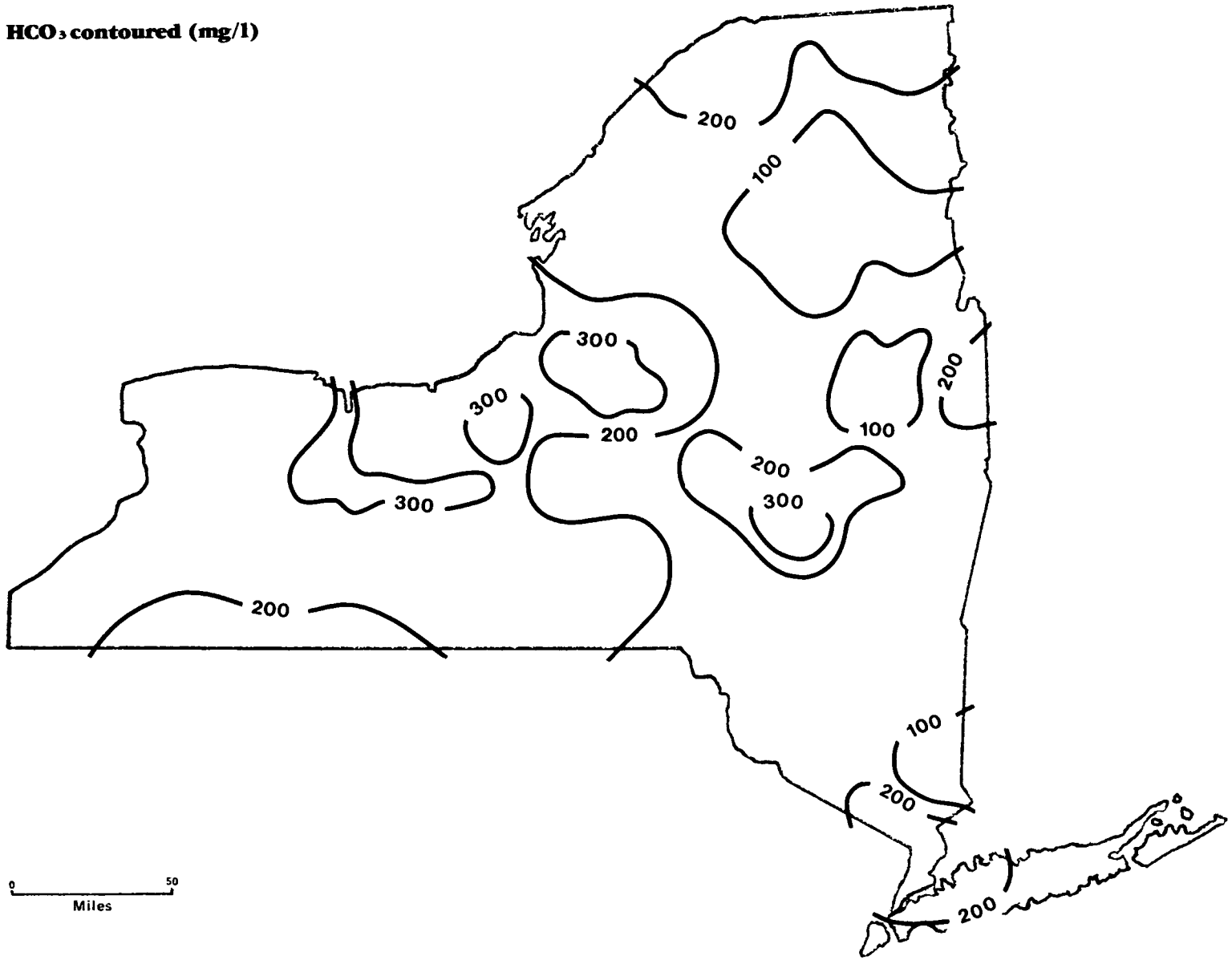


Plate 236

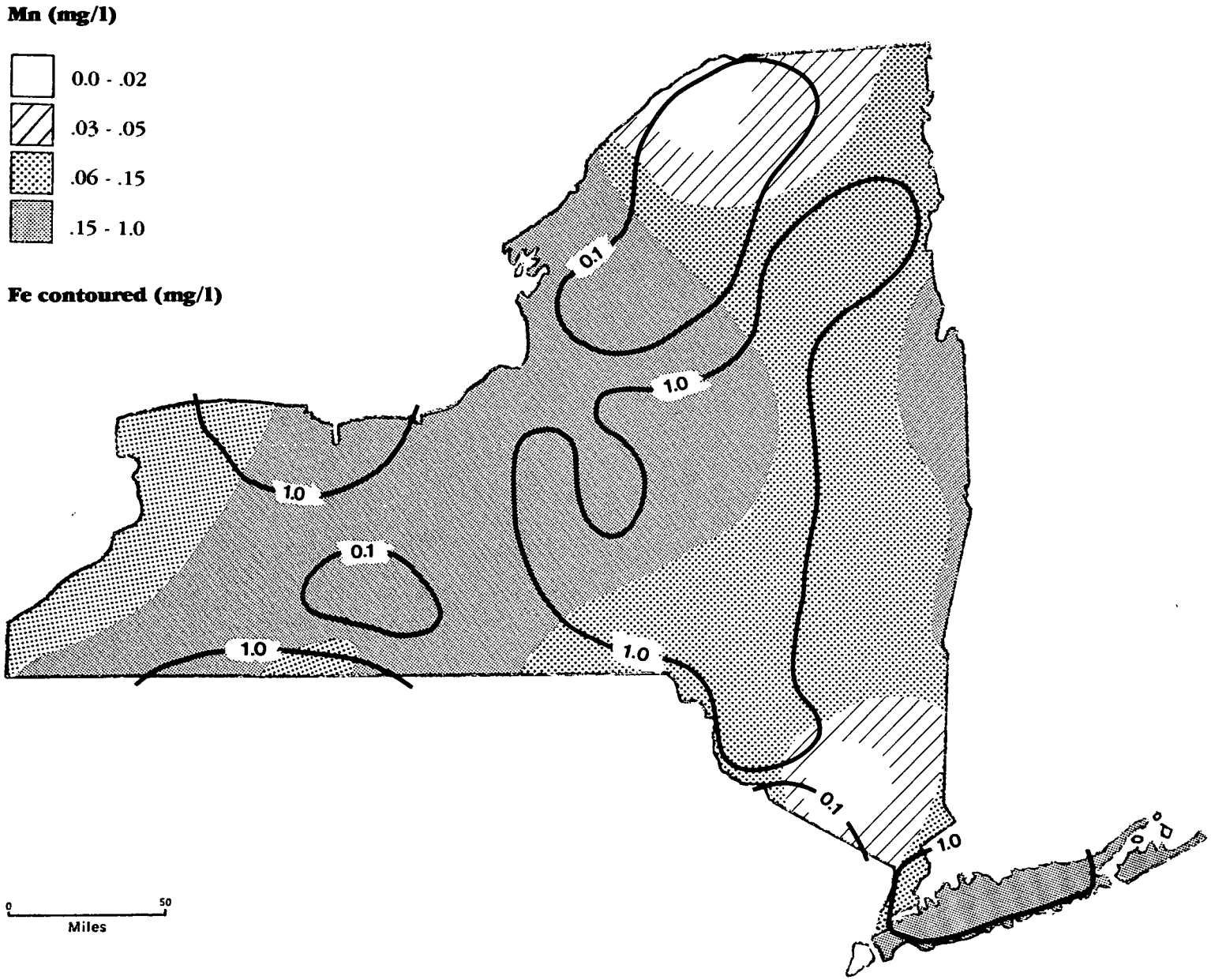
New York


Hardness (mg/l)
0-60
60-120
120-240
240-500
500-750
Dissolved Solids contoured (mg/l)
250
100
500
250
250
100
0
50
Miles

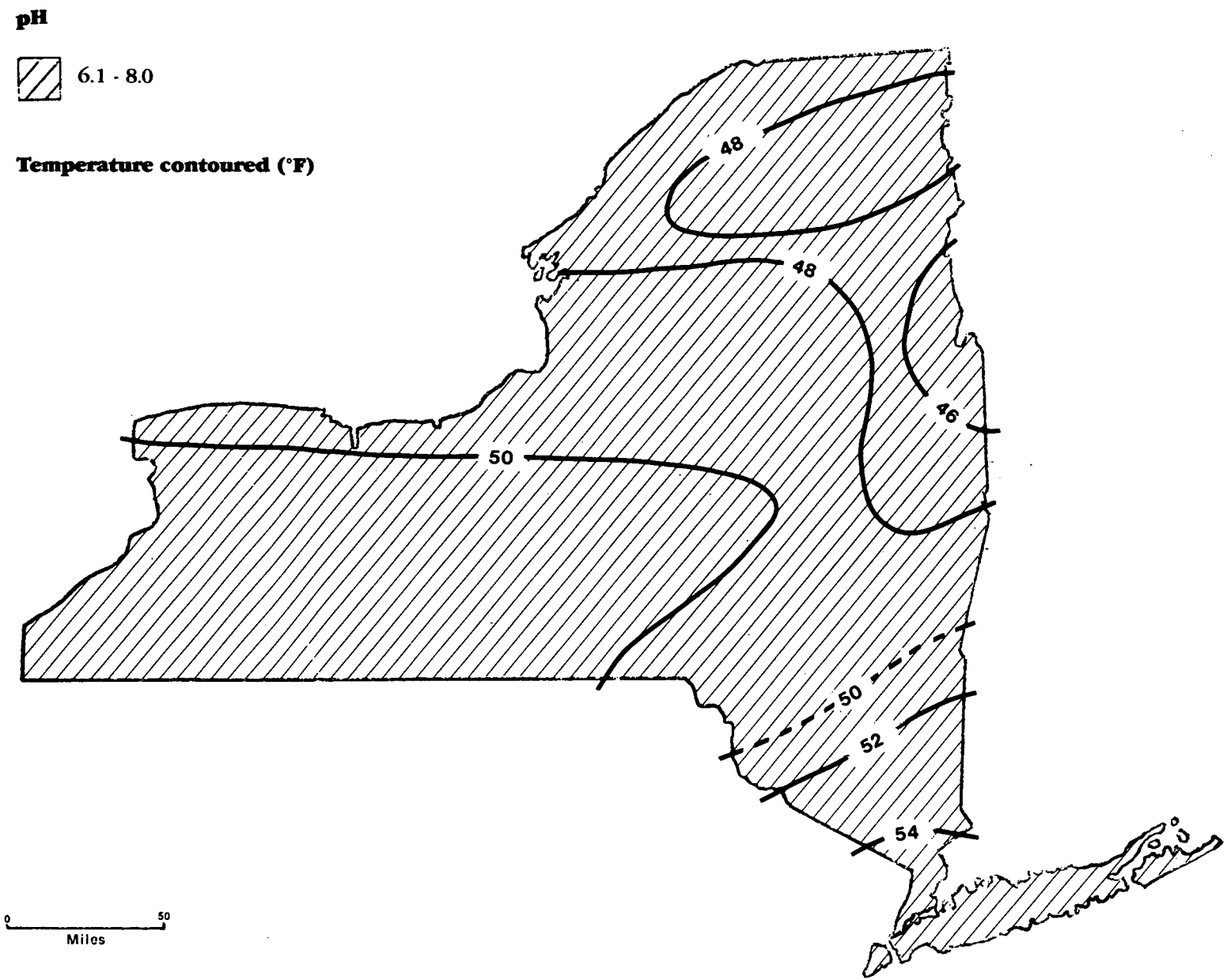
New York


HCO₃ contoured (mg/l)
200
100
300
300
200
100
200
200
300
300
200
100
200
200
0
50
Miles

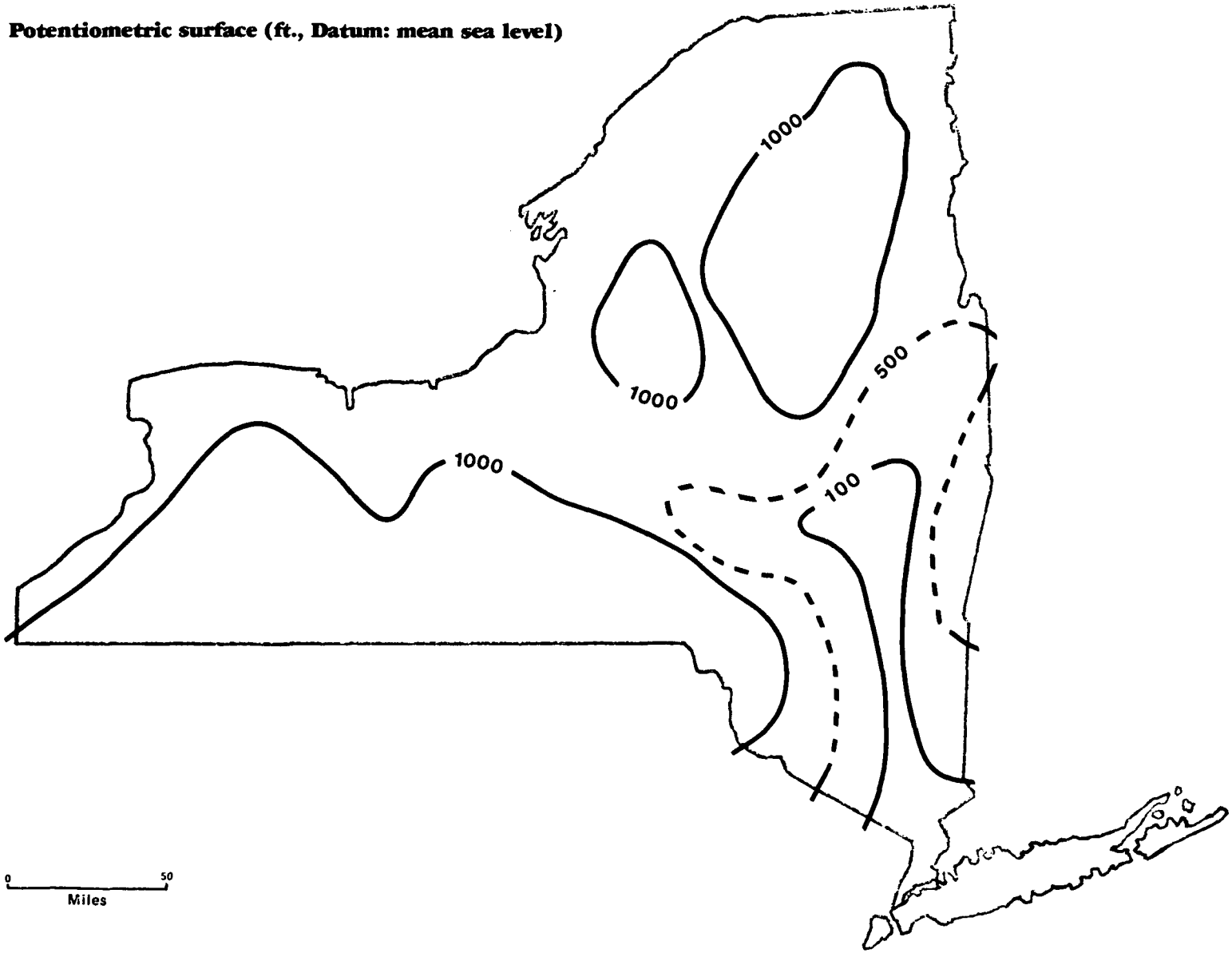
New York


Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0.1
1.0
1.0
0.1
1.0
1.0
0.1
1.0
0
50
Miles

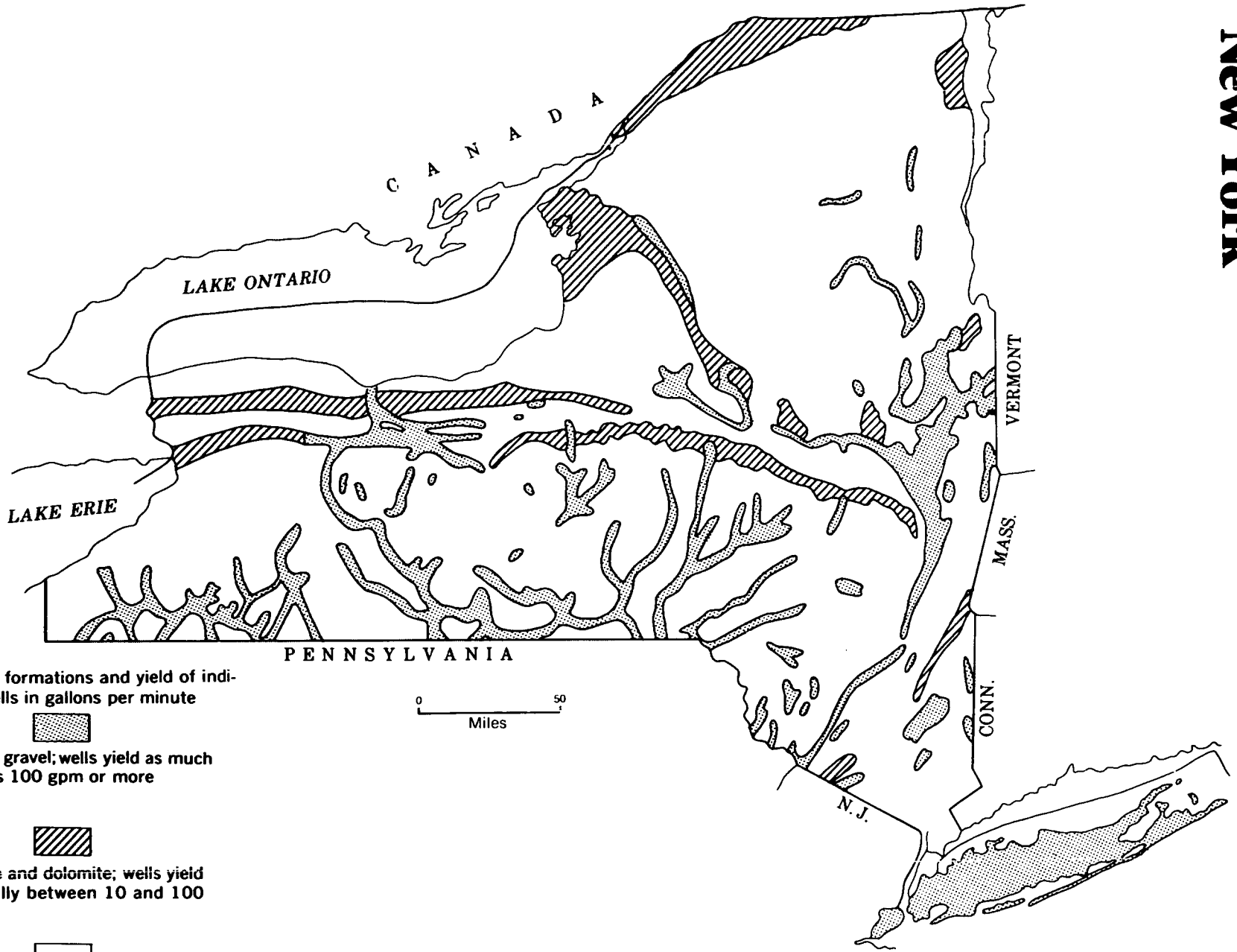
New York



New York


Potentiometric surface (ft., Datum: mean sea level)
1000
1000
1000
500
100
0
50
Miles

New York



Water-bearing formations and yield of individual wells in gallons per minute

Sand and gravel; wells yield as much as 100 gpm or more

Limestone and dolomite; wells yield generally between 10 and 100 gpm

Other types of bedrock and till; wells yield generally less than 10 gpm

North Carolina

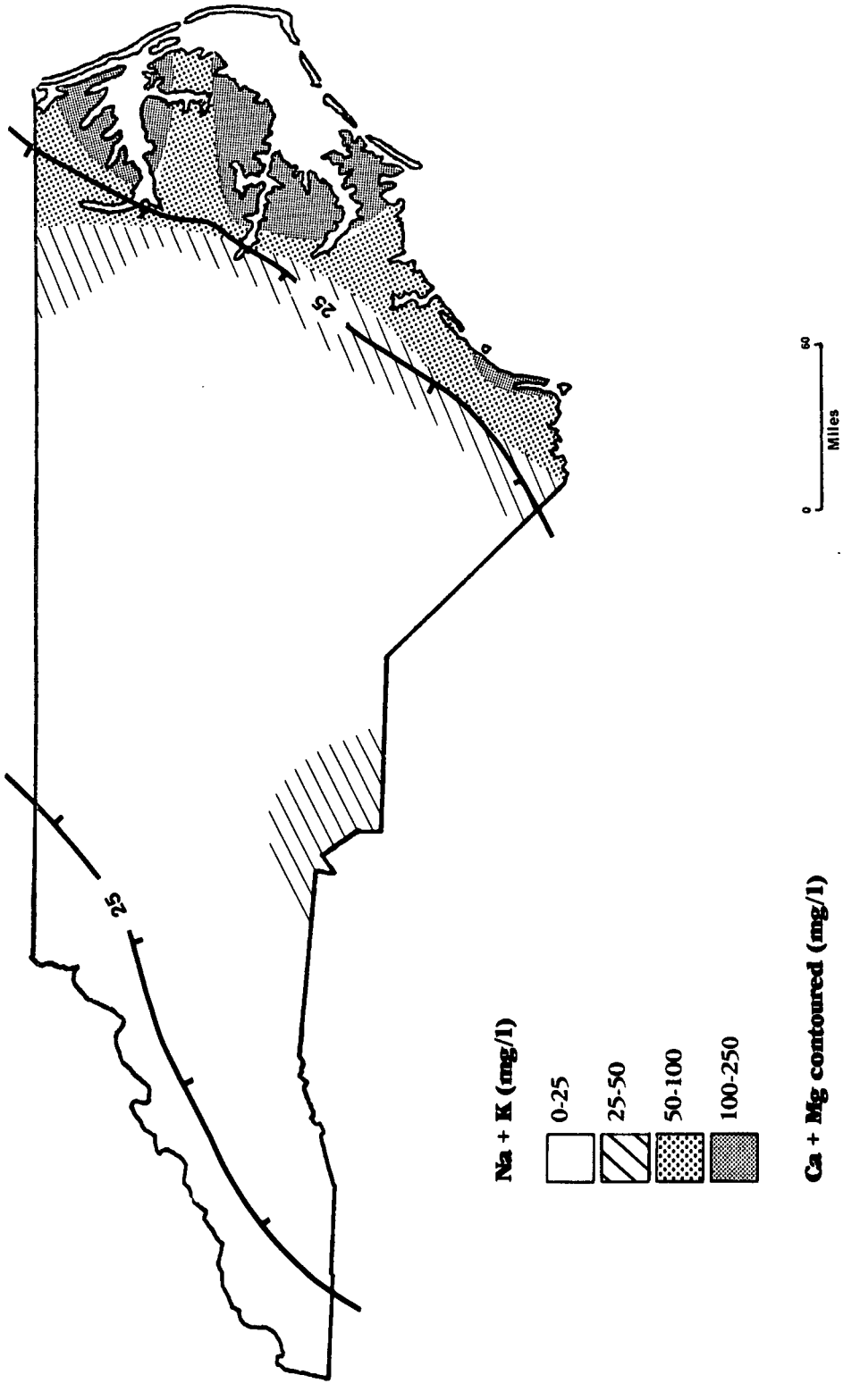


Plate 243

North Carolina

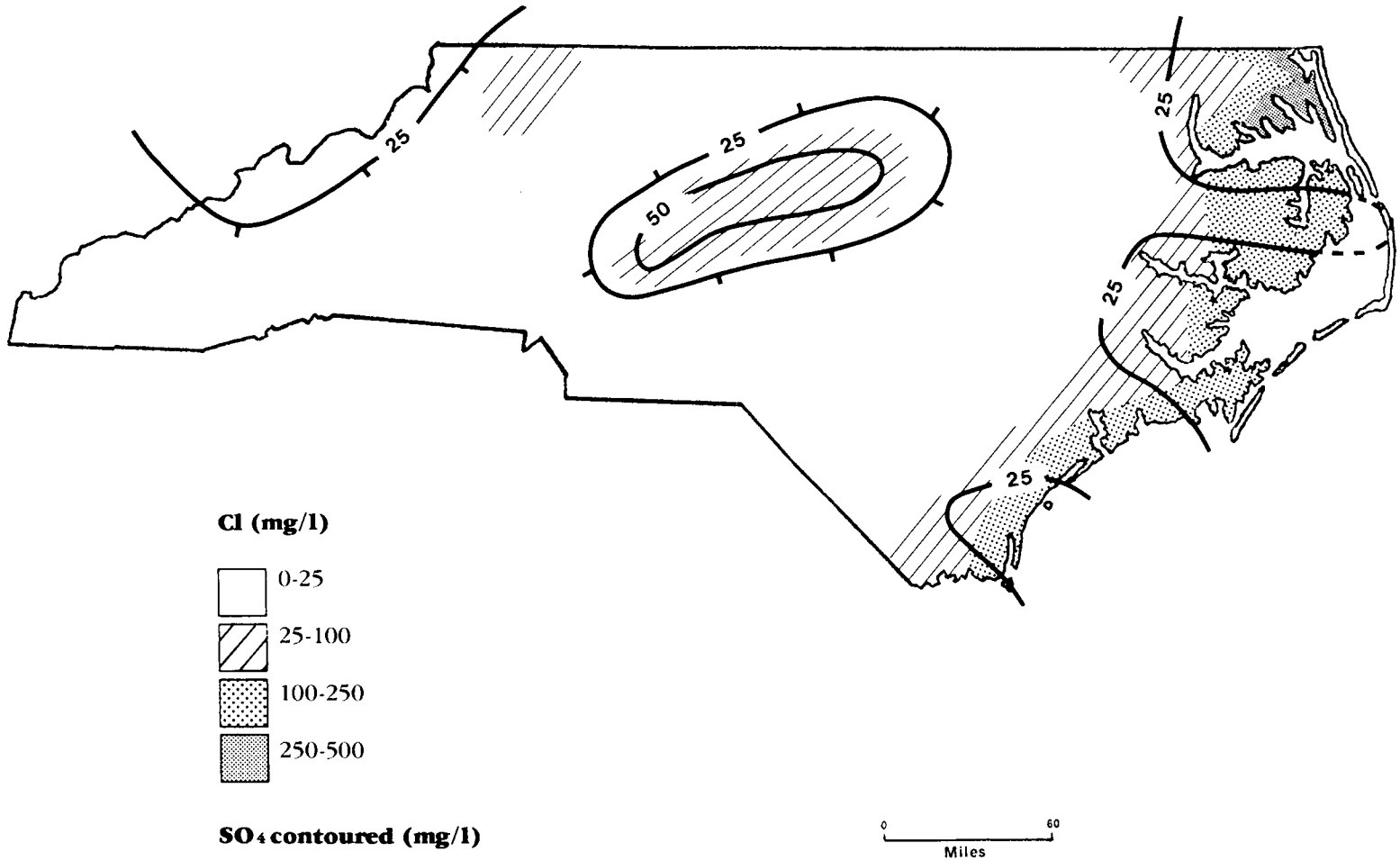
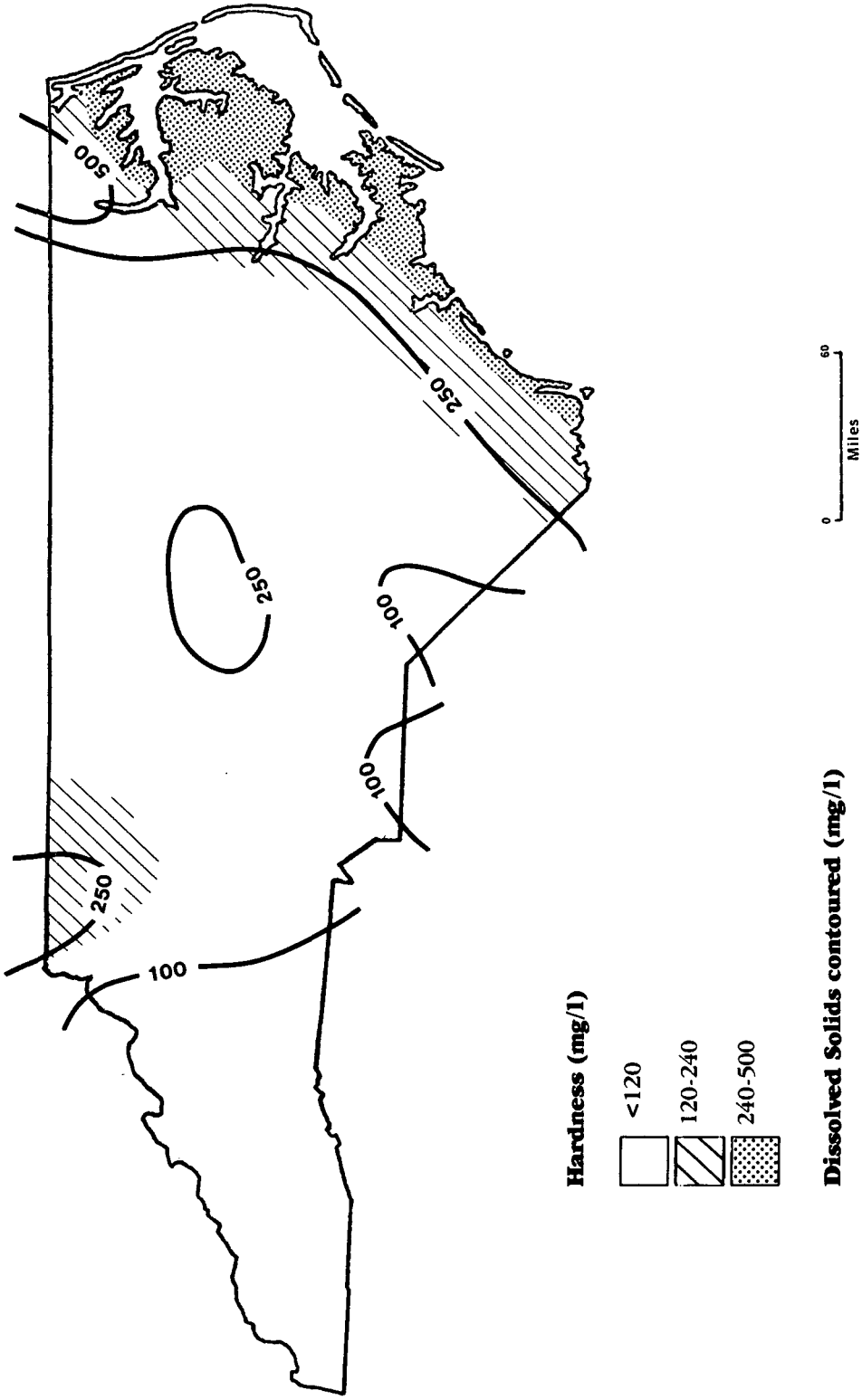
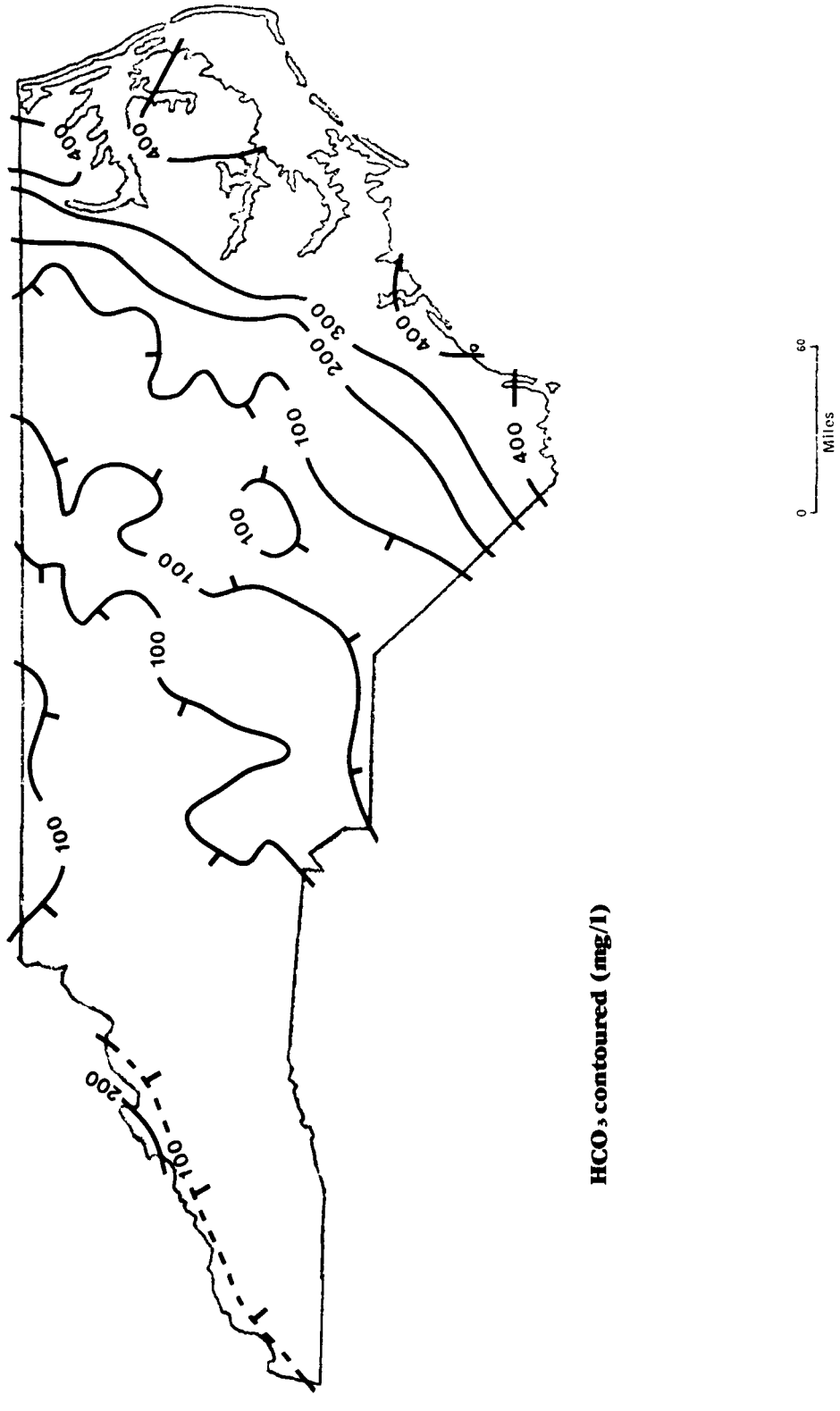


Plate 244

North Carolina

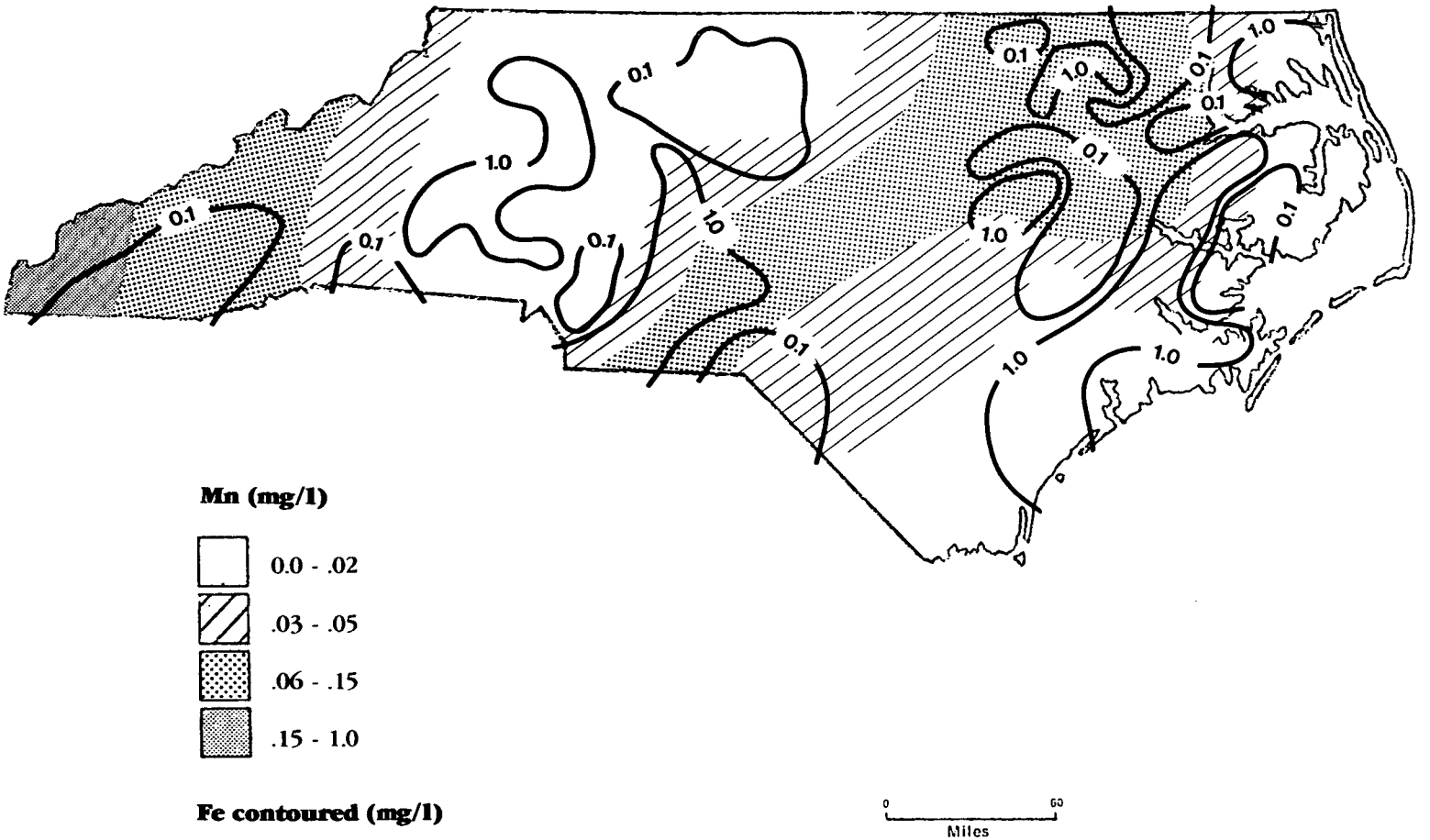


North Carolina

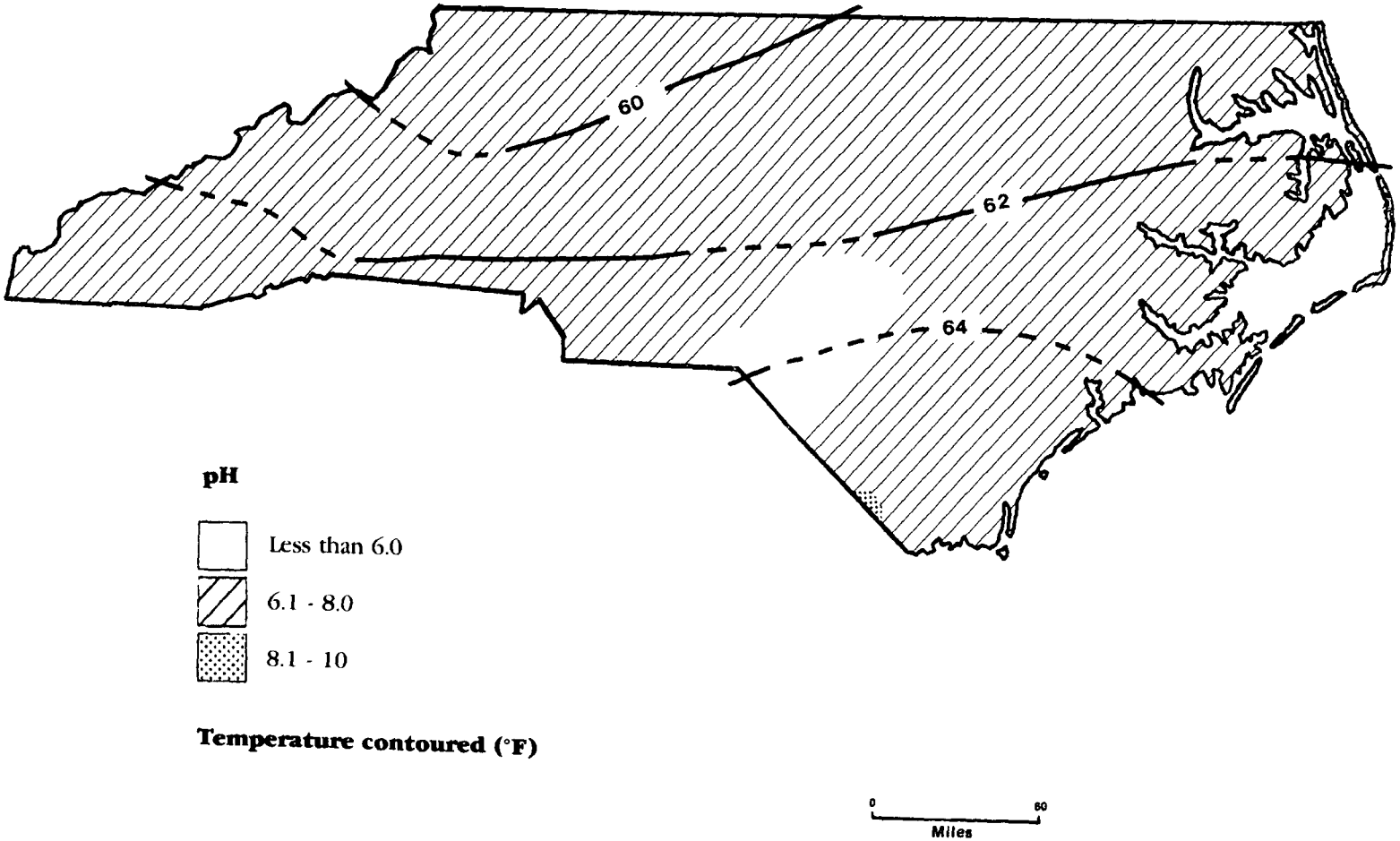


HCO_3 contoured (mg/l)

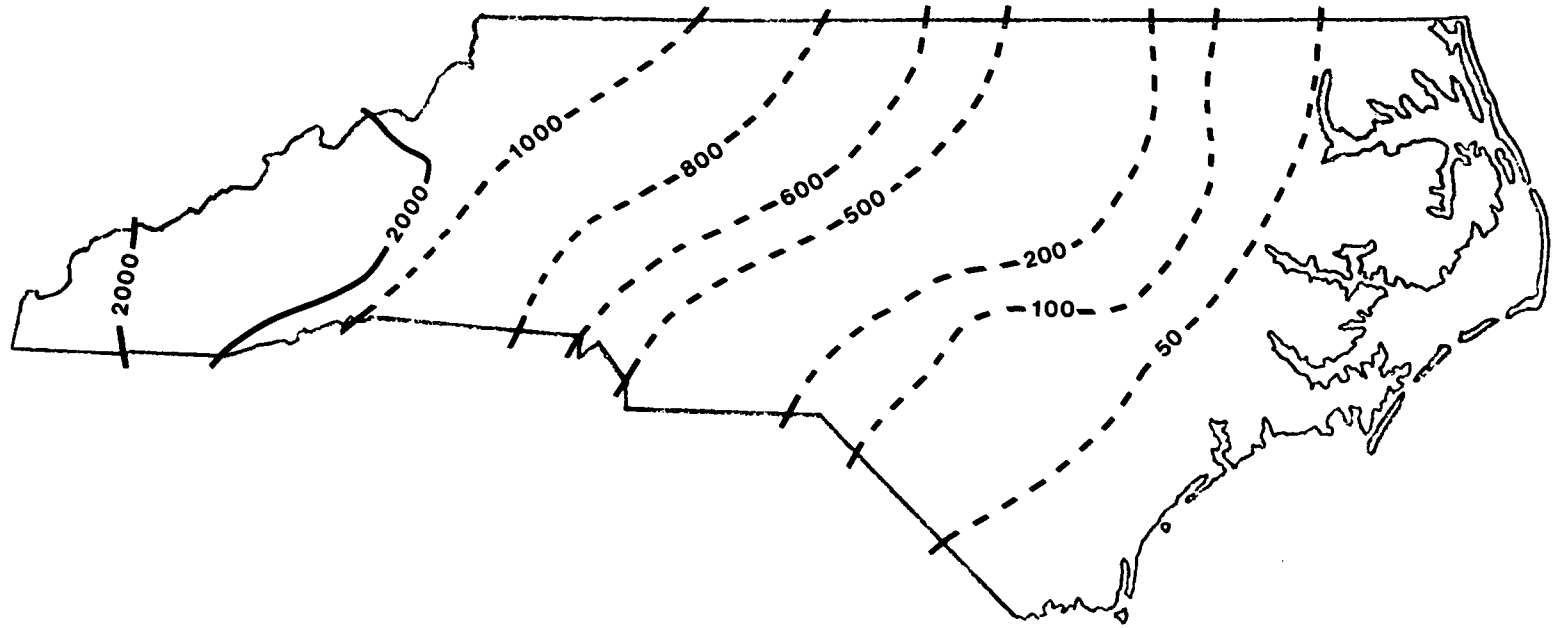
North Carolina



North Carolina



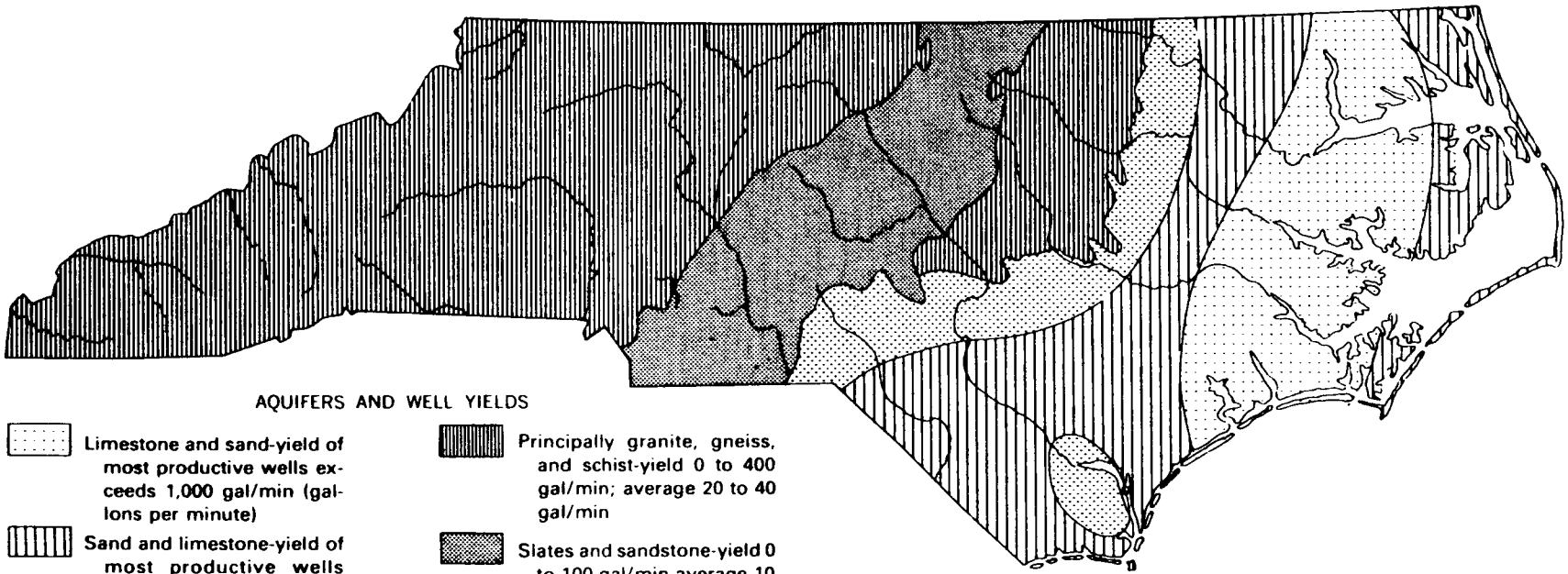
North Carolina



Potentiometric surface (ft., Datum: mean sea level)

0 60
Miles

North Carolina



AQUIFERS AND WELL YIELDS

- Limestone and sand-yield of most productive wells exceeds 1,000 gal/min (gallons per minute)
- Sand and limestone-yield of most productive wells from 250 to 1,000 gal/min
- Sand-yield of most productive wells from 50 to 250 gal/min
- Principally granite, gneiss, and schist-yield 0 to 400 gal/min; average 20 to 40 gal/min
- Slates and sandstone-yield 0 to 100 gal/min average 10 to 20 gal/min

0 60
Miles

North Dakota

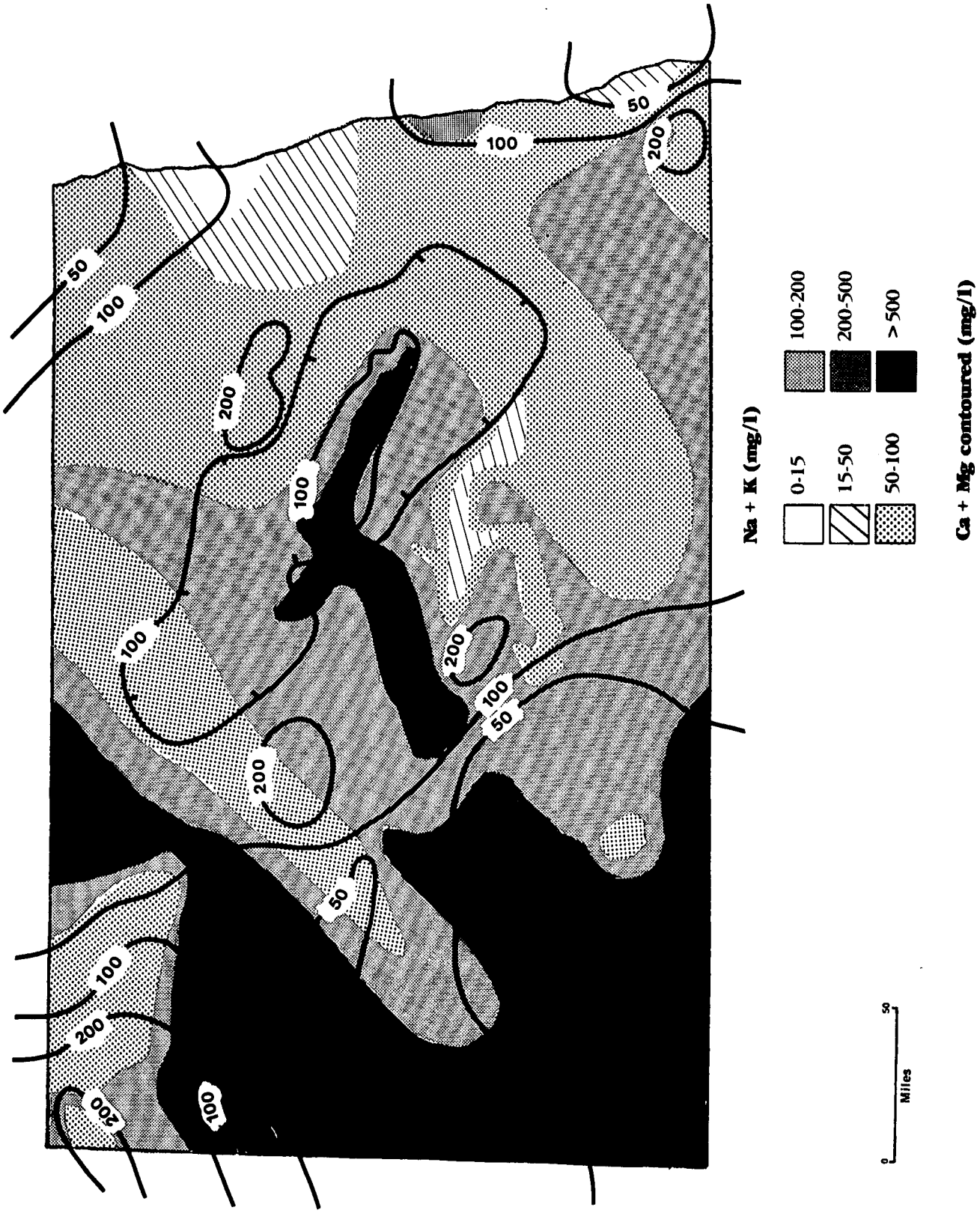
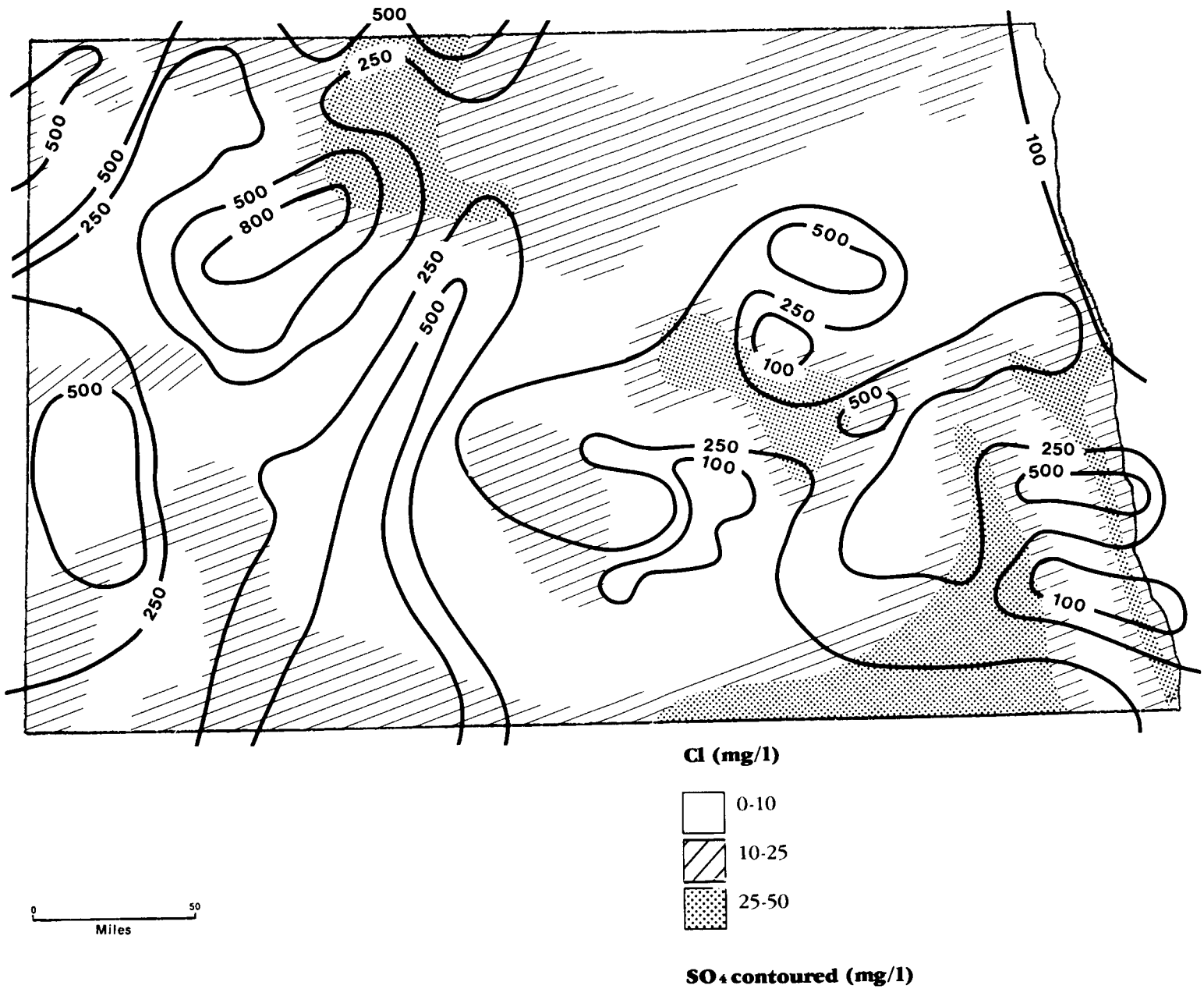


Plate 251

North Dakota



North Dakota

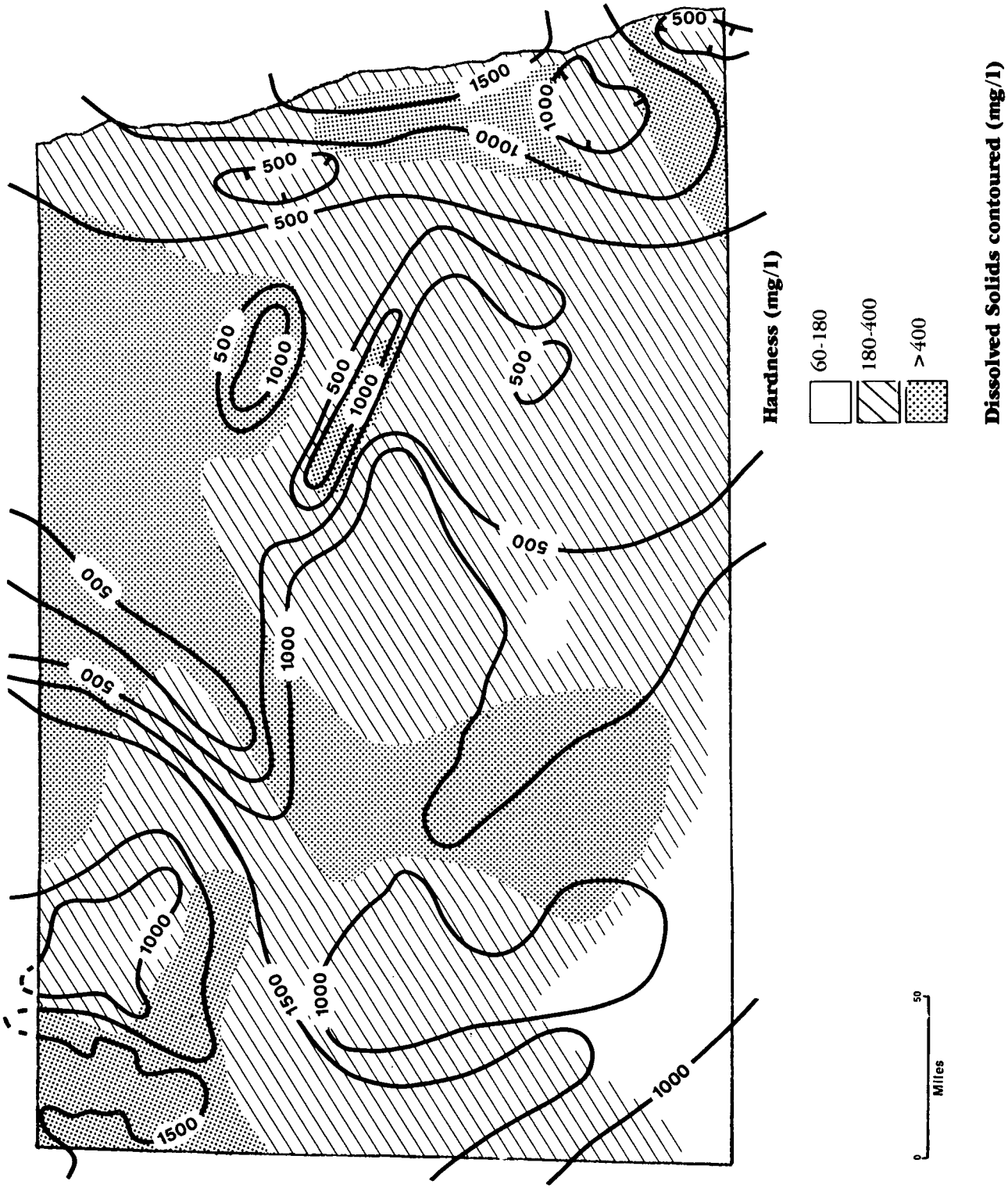
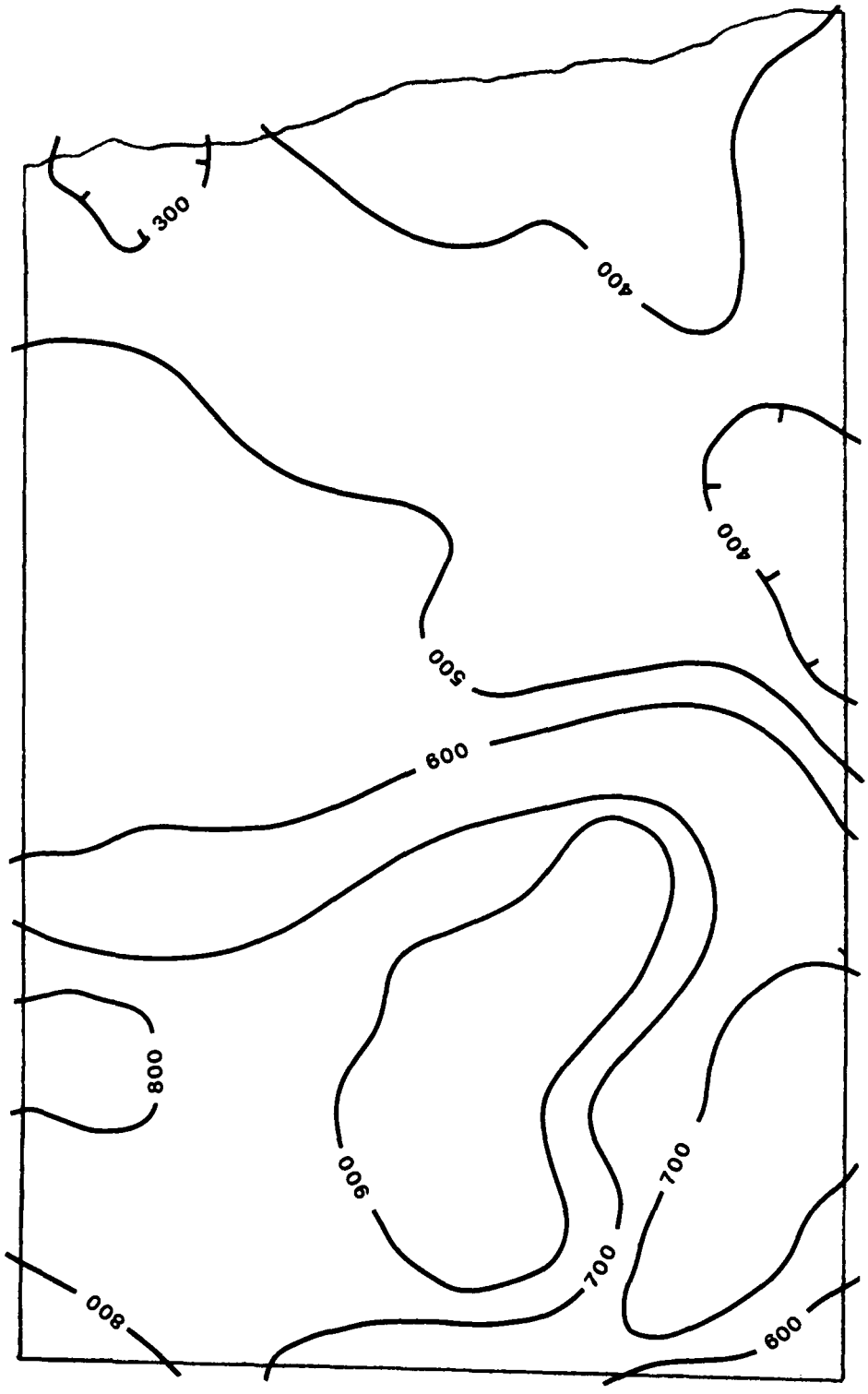


Plate 253

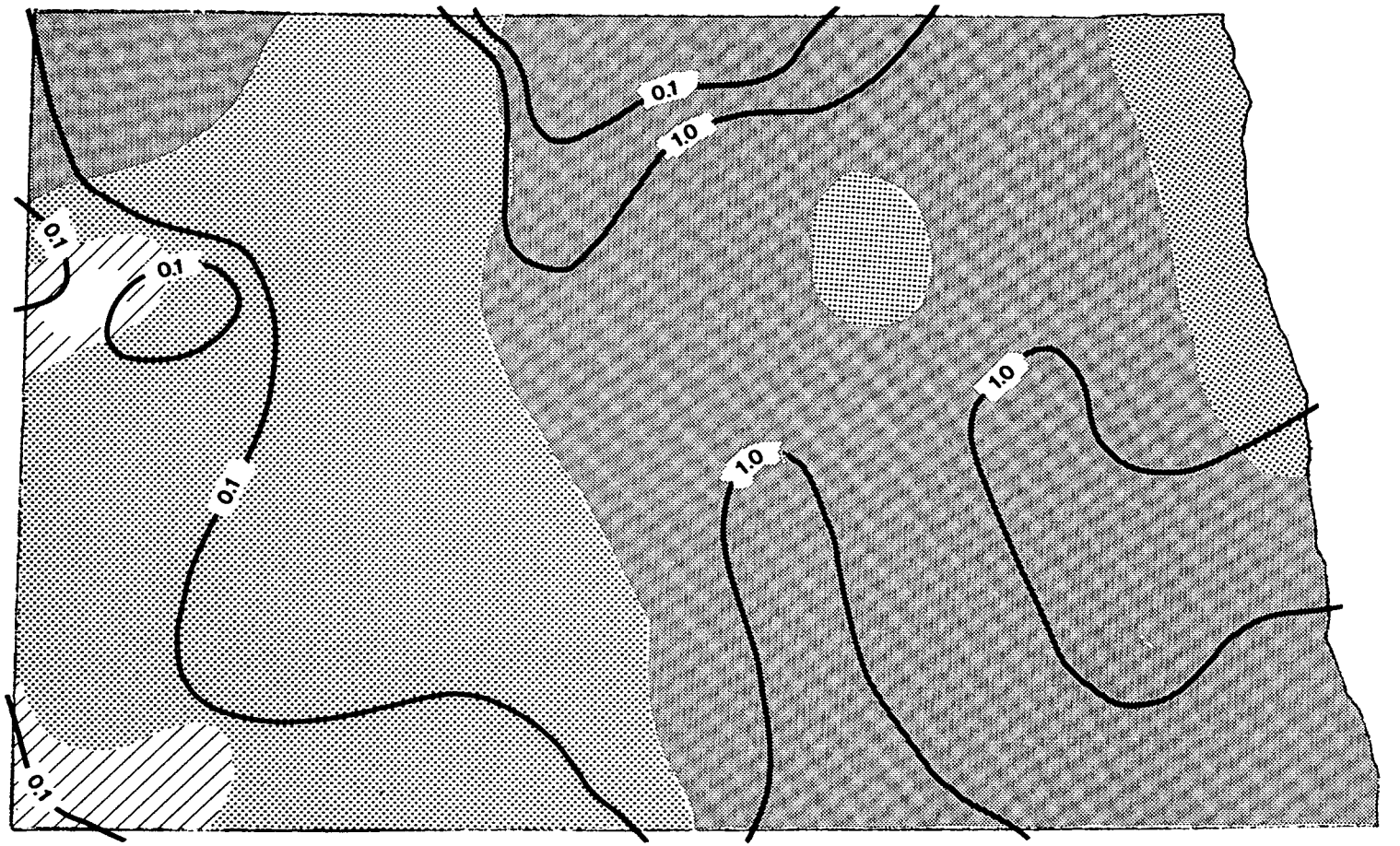
North Dakota



HCO_3 contoured (mg/l)

0 50 Miles

North Dakota



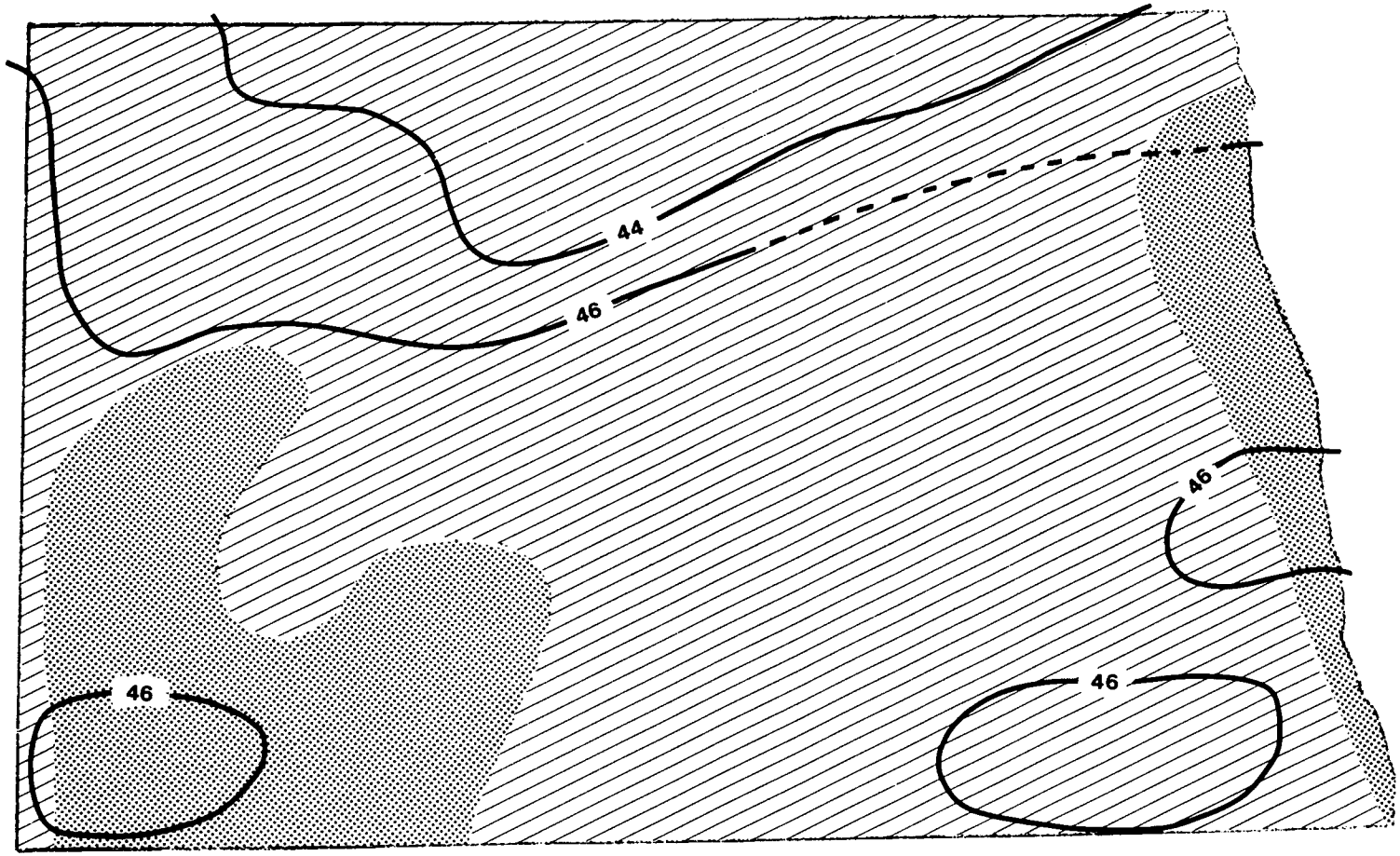
0 50
Miles

Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

North Dakota



Temperature contoured (°F)

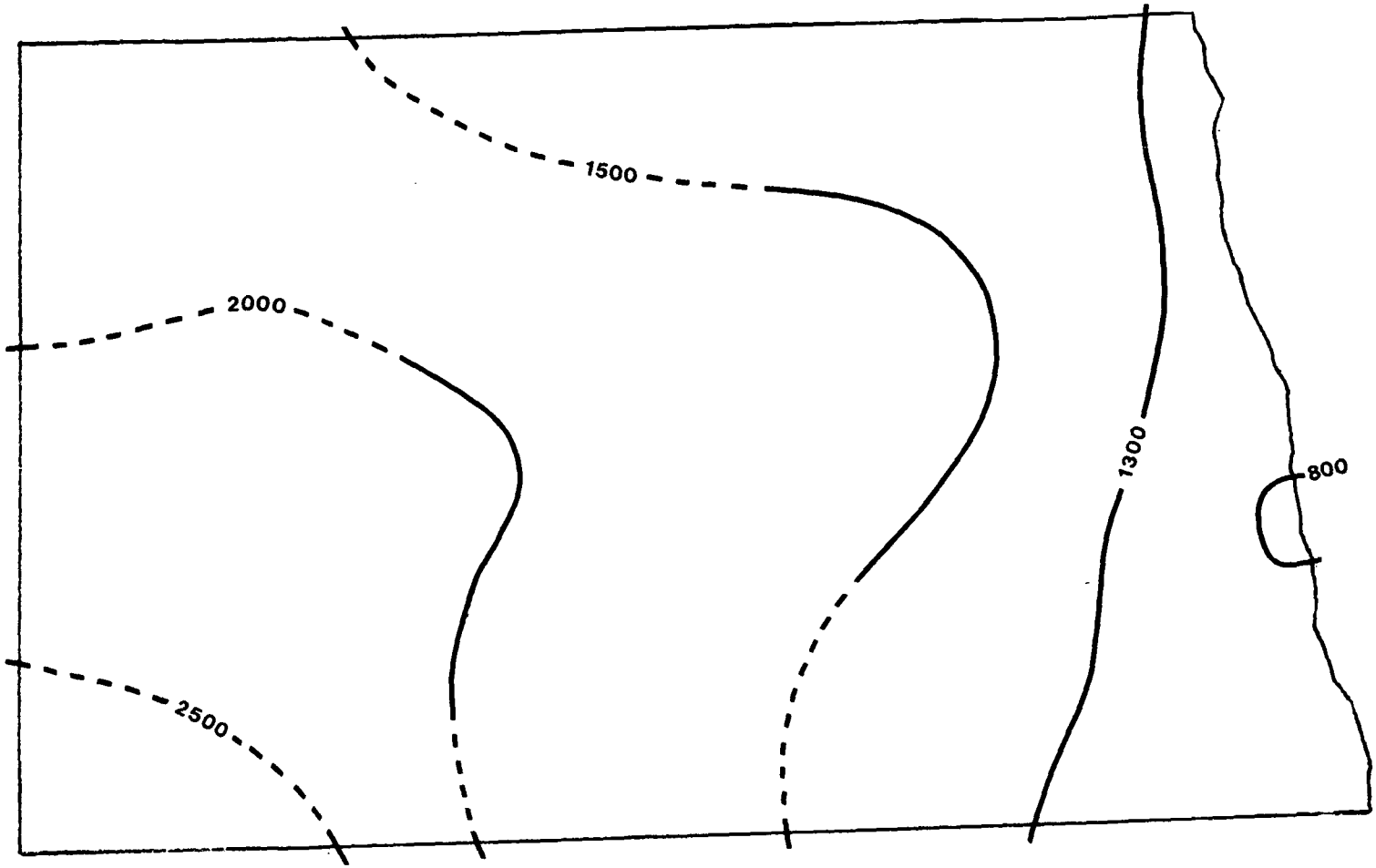
pH

6.1 - 8.0

8.1 - 10

0 50
Miles

North Dakota

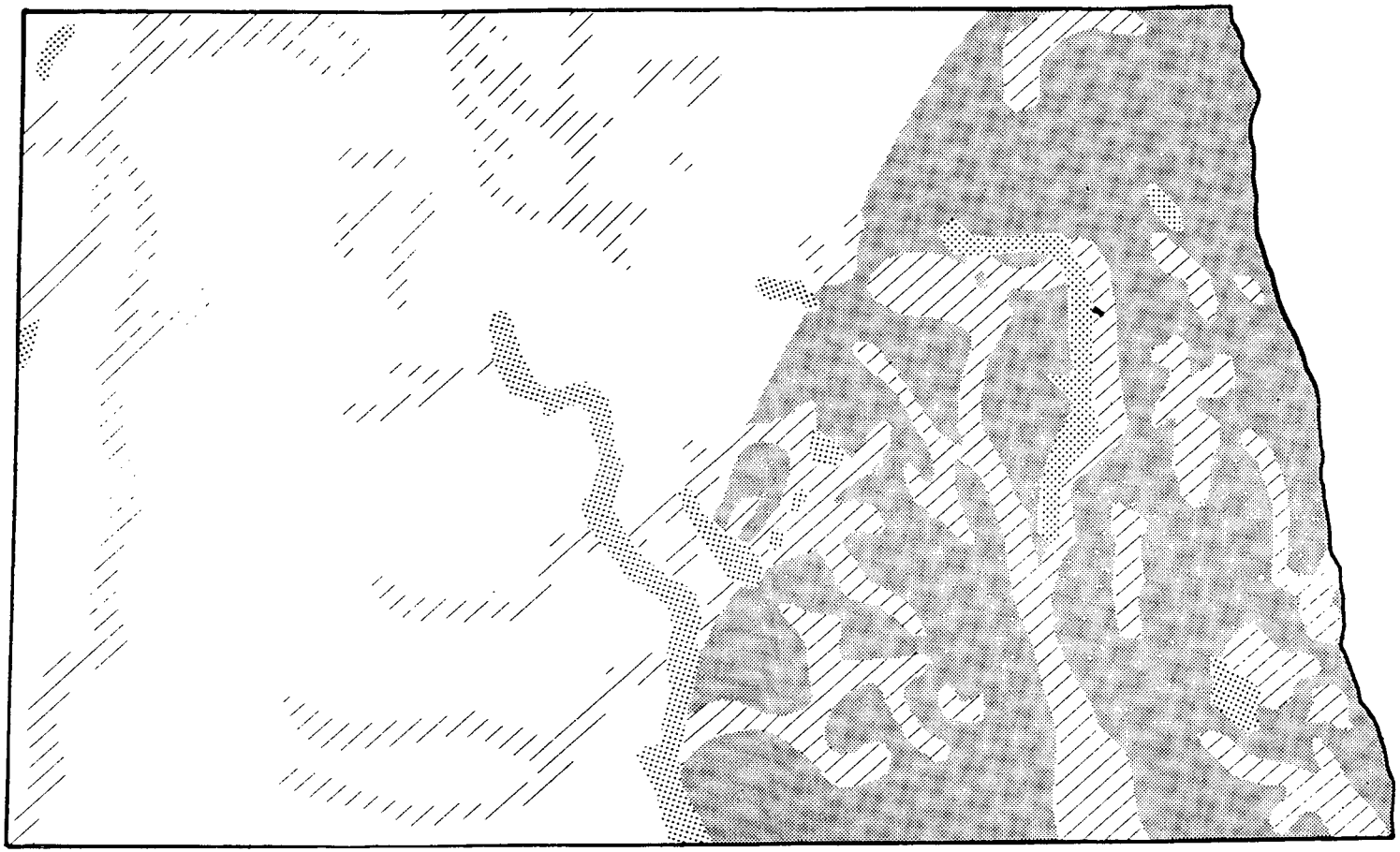


Potentiometric surface

(ft., Datum: mean sea level)

0 50
Miles

North Dakota

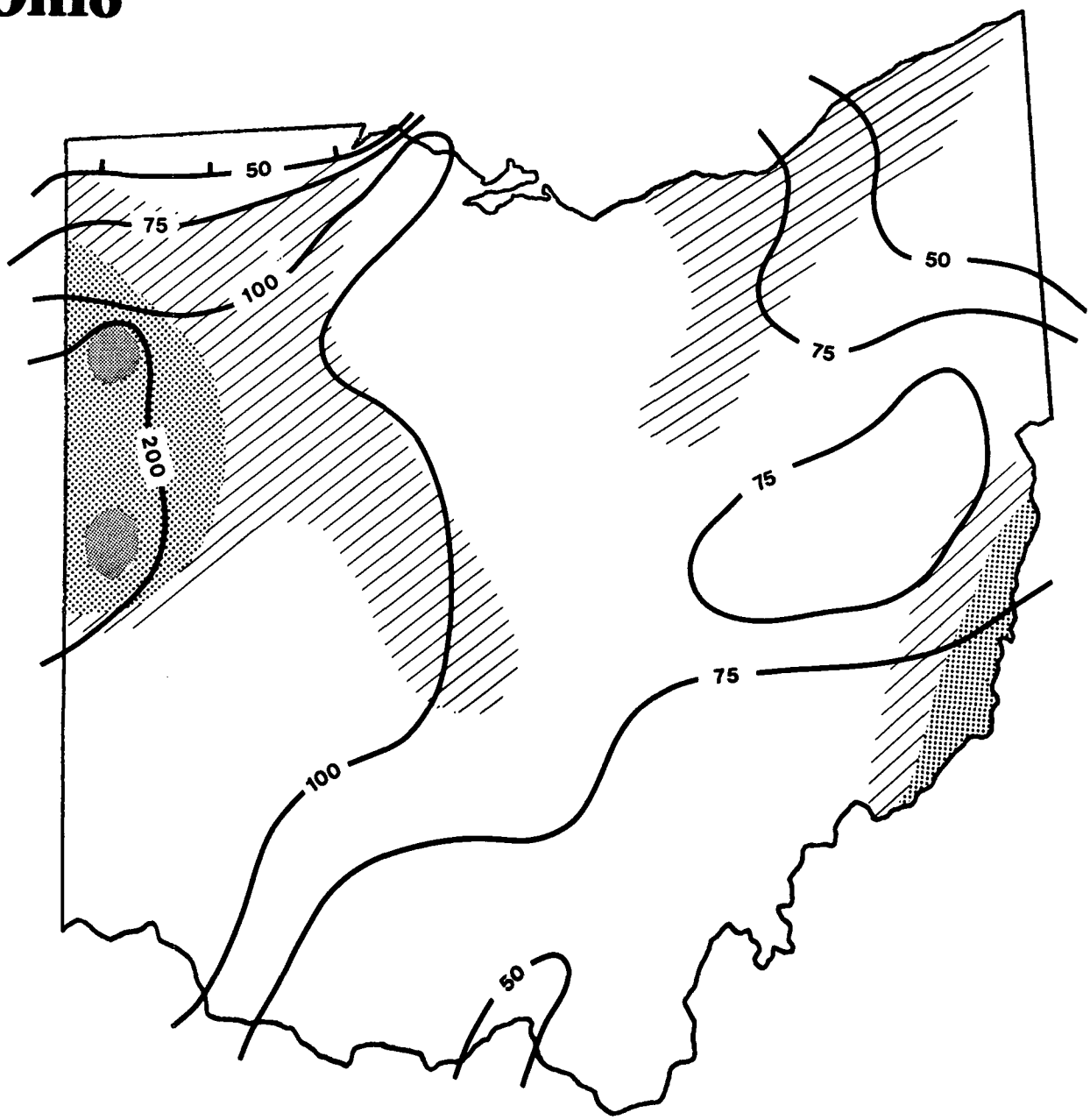


Yield (gpm)

- Less than 50 gpm
- 50-500 gpm
- Greater than 500 gpm
- Less than 50 gpm common, some wells may yield more than 50 gpm

0 50
Miles

Ohio



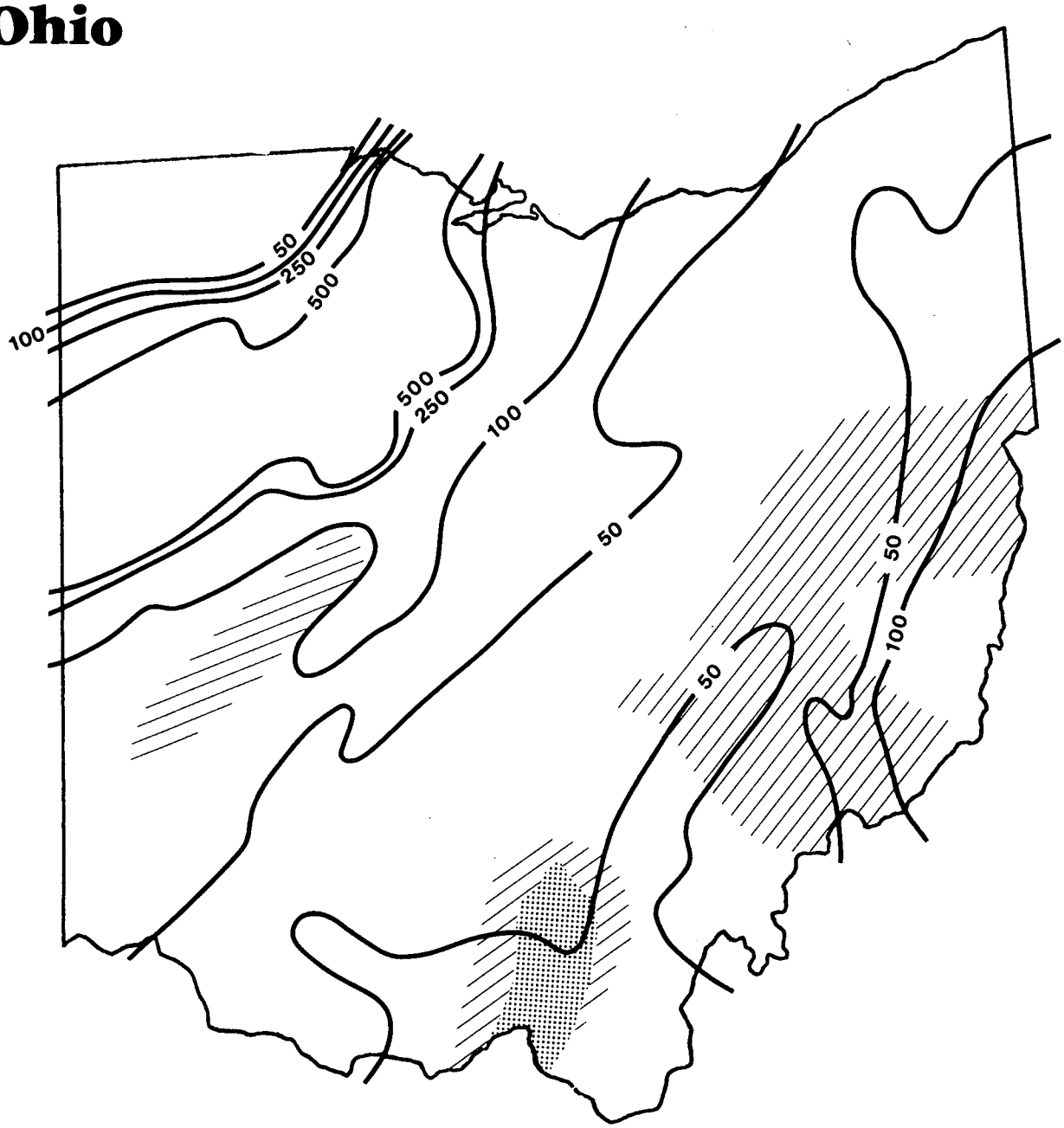
Na + K (mg/l)

- 0-25
- 25-50
- 50-100
- 100-200

0 40
Miles

Ca + Mg contoured (mg/l)

Ohio



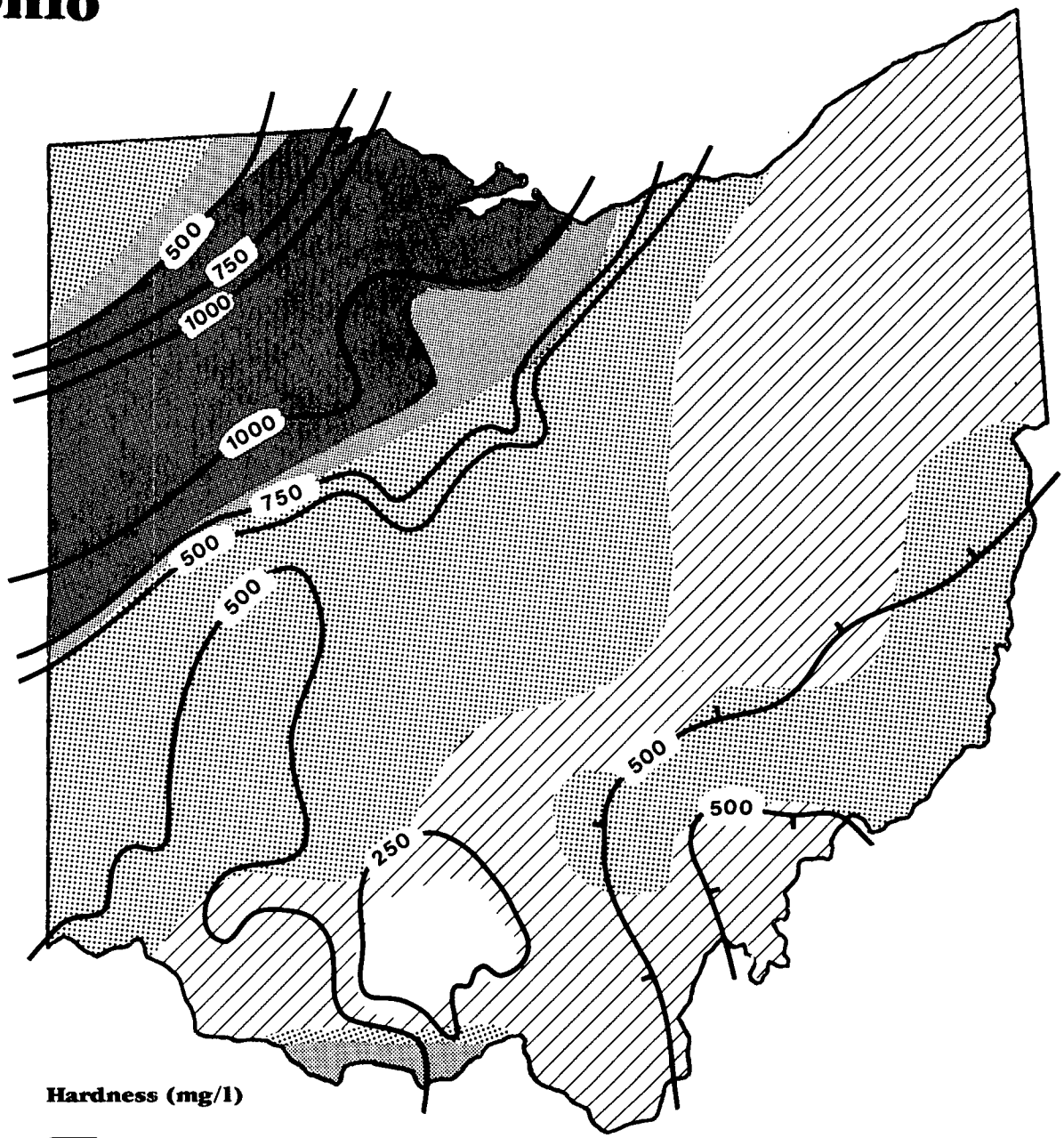
Cl (mg/l)

- 0-50
- 50-100
- 100-250

0 — 40 Miles

SO_4 contoured (mg/l)

Ohio



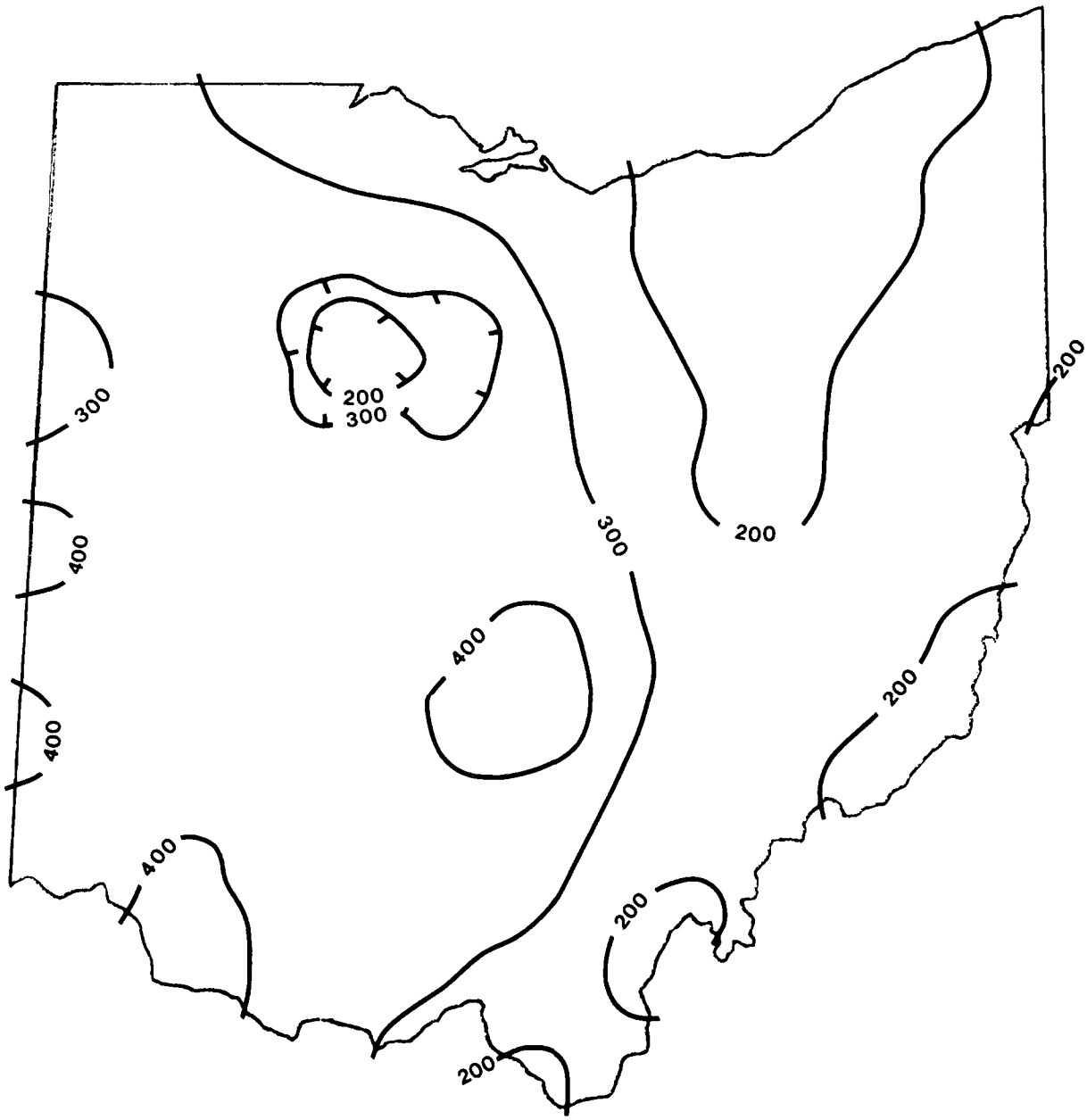
Hardness (mg/l)

- < 120
- 120-300
- 300-500
- 500-1000
- > 1000

0 40
Miles

Dissolved Solids contoured (mg/l)

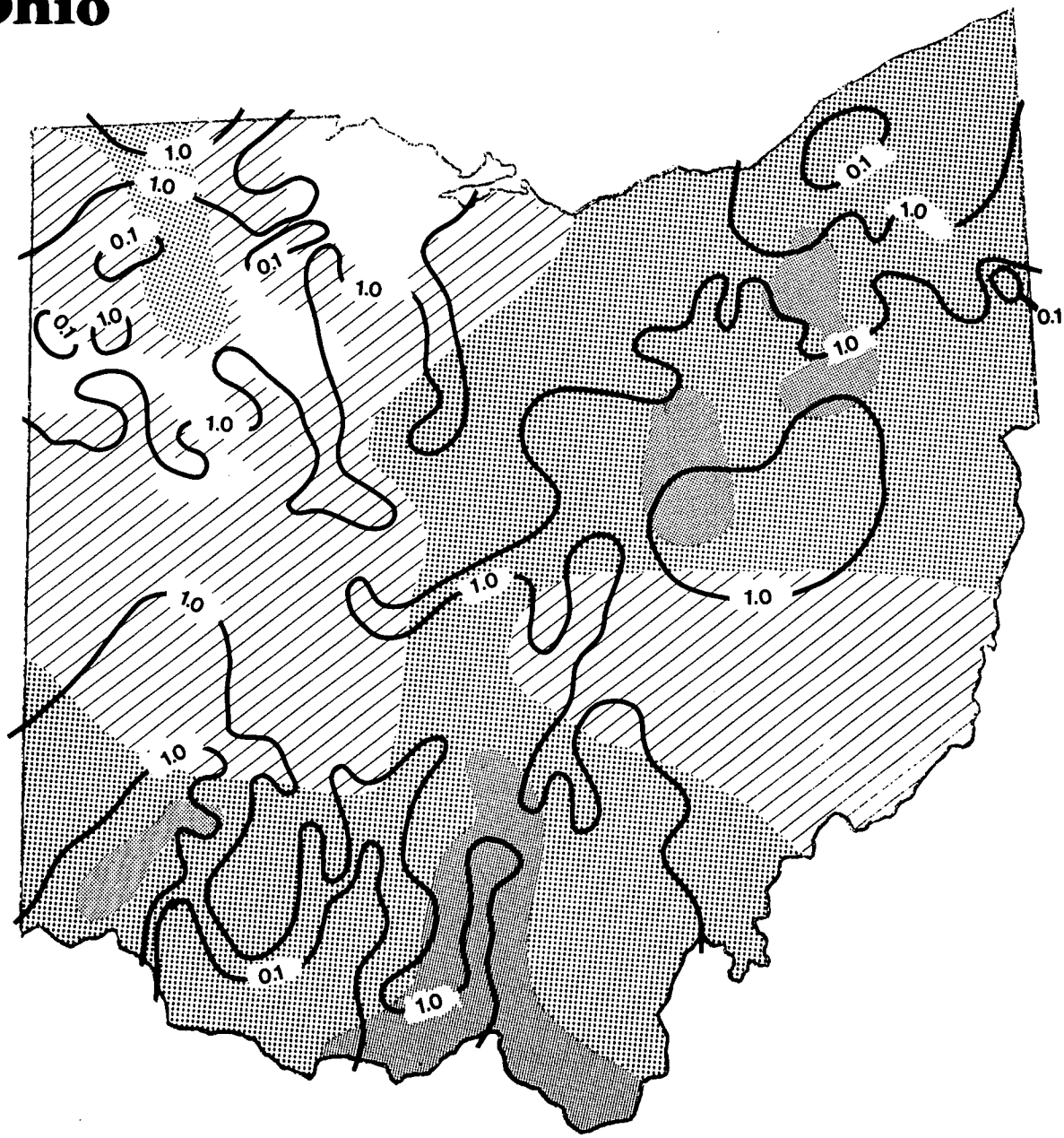
Ohio



HCO_3 contoured (mg/l)

0 40
Miles

Ohio



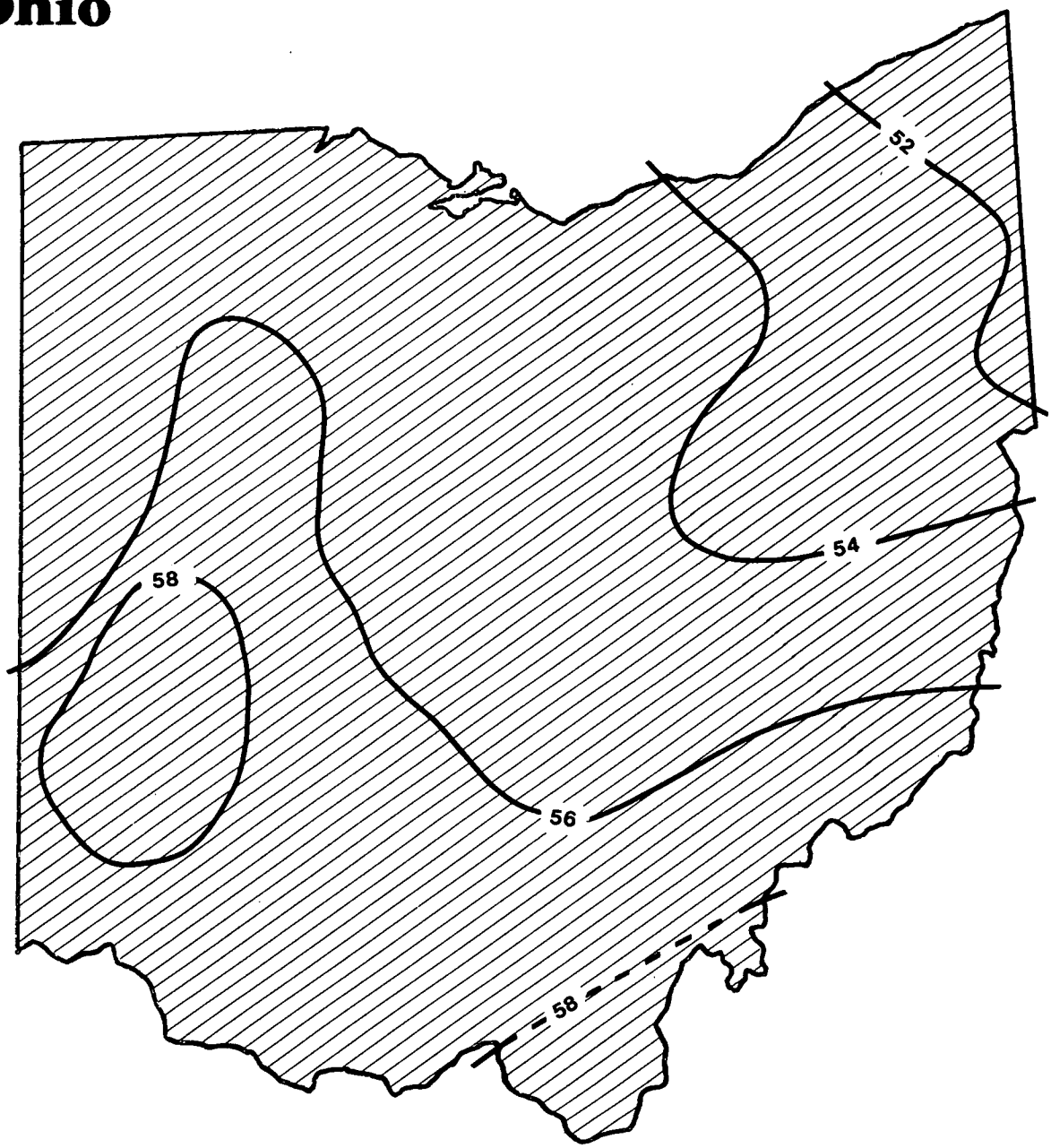
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

0 — 40 Miles

Fe contoured (mg/l)

Ohio



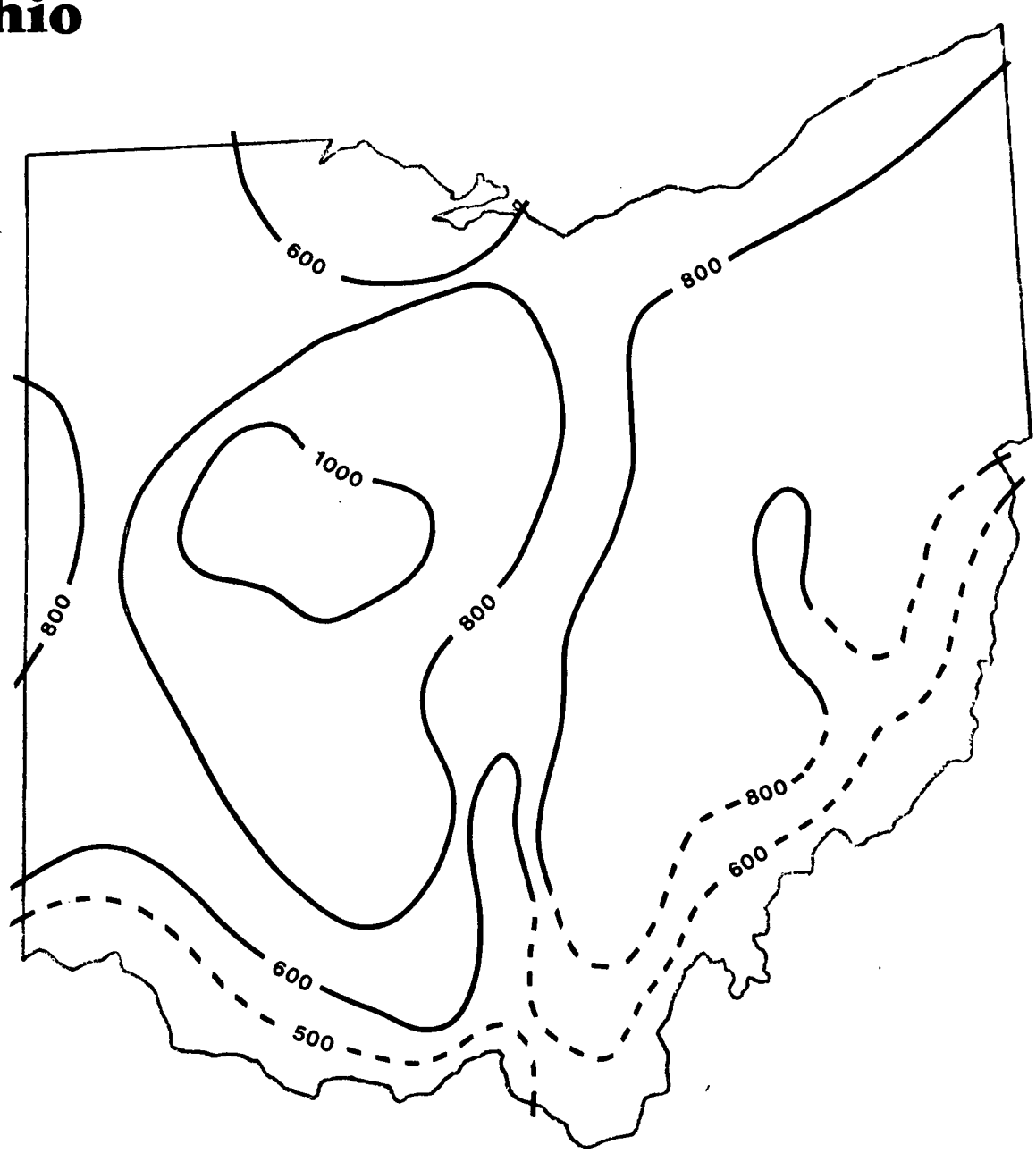
Temperature contoured (°F)

pH

6.1 - 8.0

0 40
Miles

Ohio

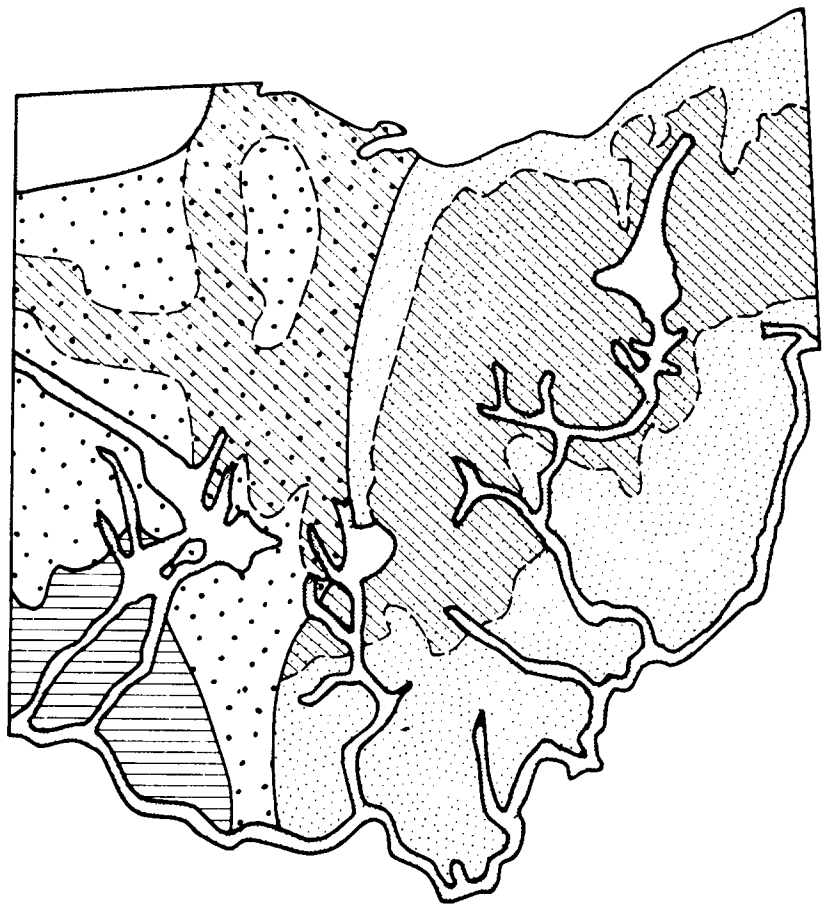


Potentiometric surface

(ft., Datum: mean sea level)

0 40
Miles

Ohio



Sand and gravel
Wells generally yield 100 or more gallons per minute

Carbonate
Wells generally yield 10 to 100 or more gallons per minute. The higher yield occurs in the diagonal pattern area.

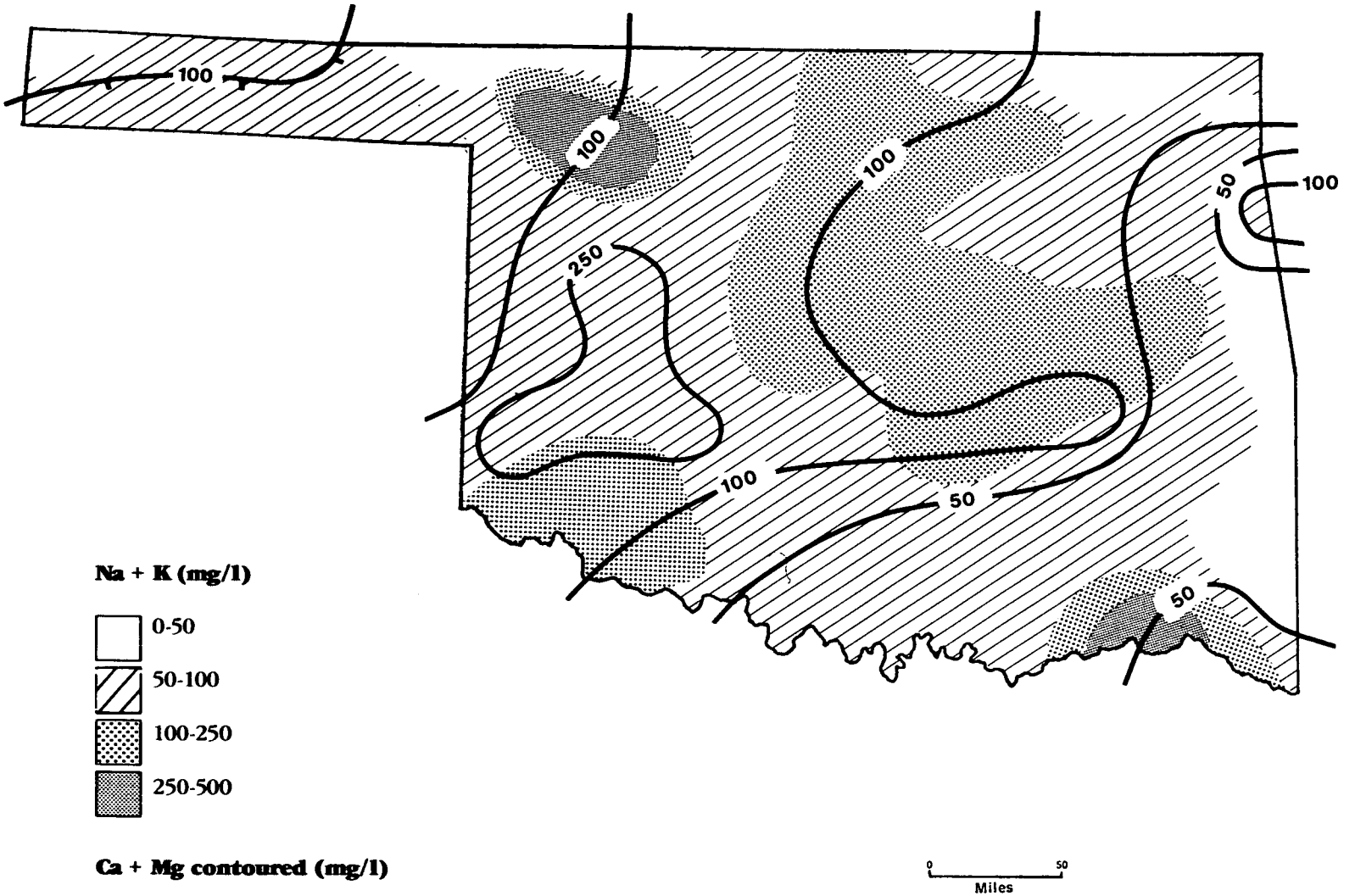
Sandstone or shale
Wells generally yield 1 to 25 gallons per minute. The higher yields occur in the diagonal pattern area.

Shale
Wells generally yield less than 5 gallons per minute

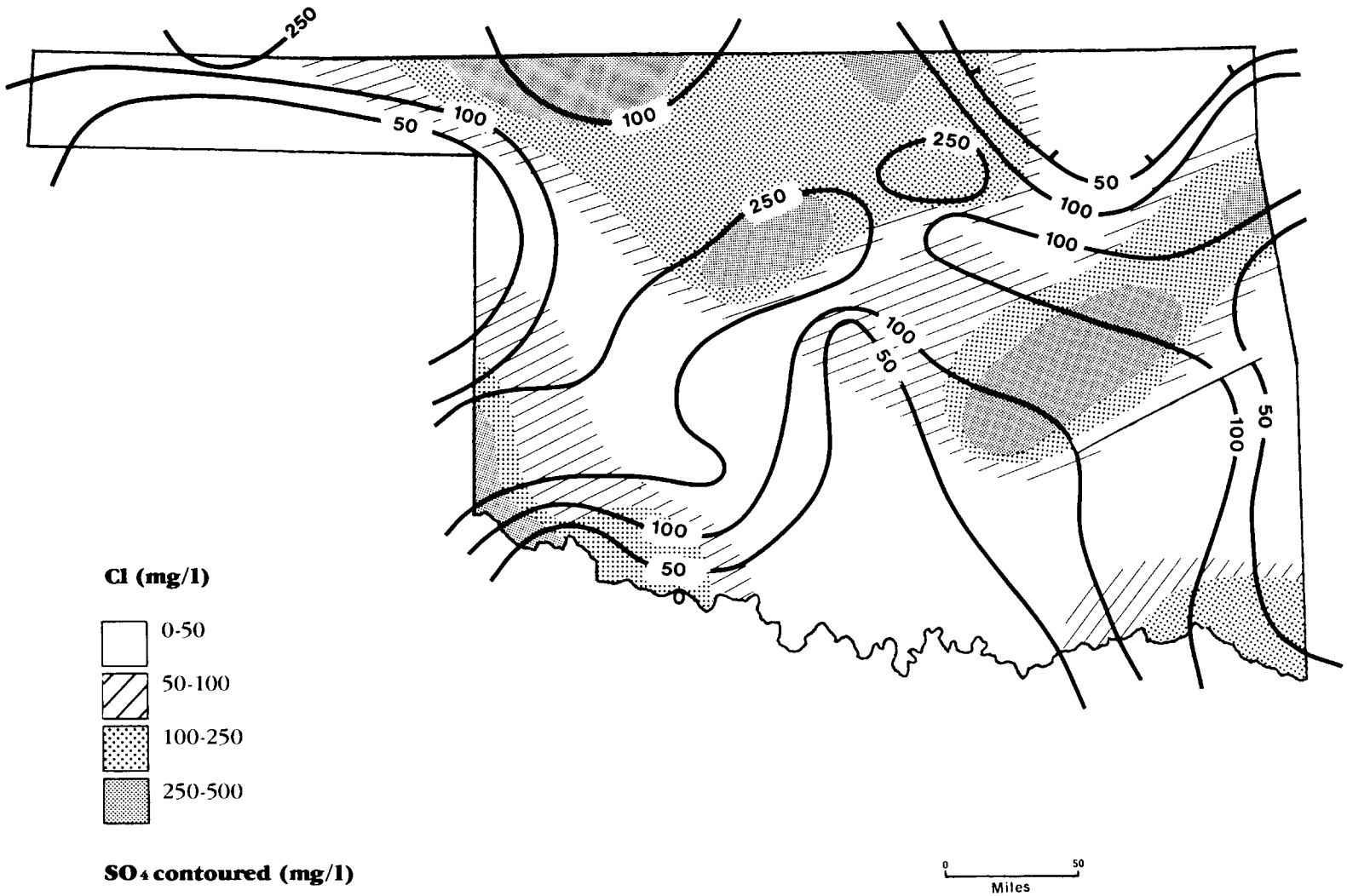
YIELD OF AQUIFERS

0 40
Miles

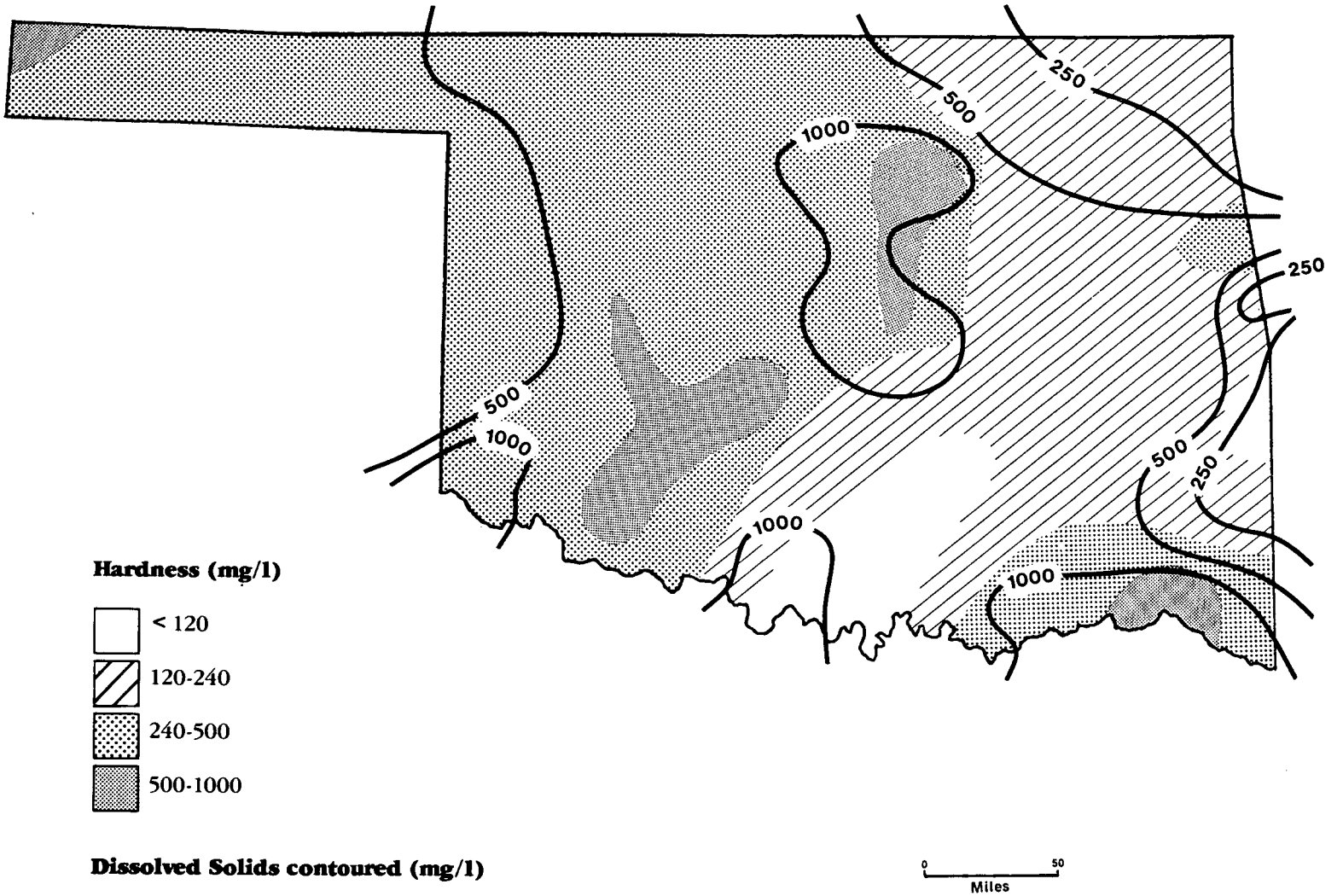
Oklahoma


100
100
100
250
100
50
50
100
50
Na + K (mg/l)
0-50
50-100
100-250
250-500
Ca + Mg contoured (mg/l)
0
50
Miles

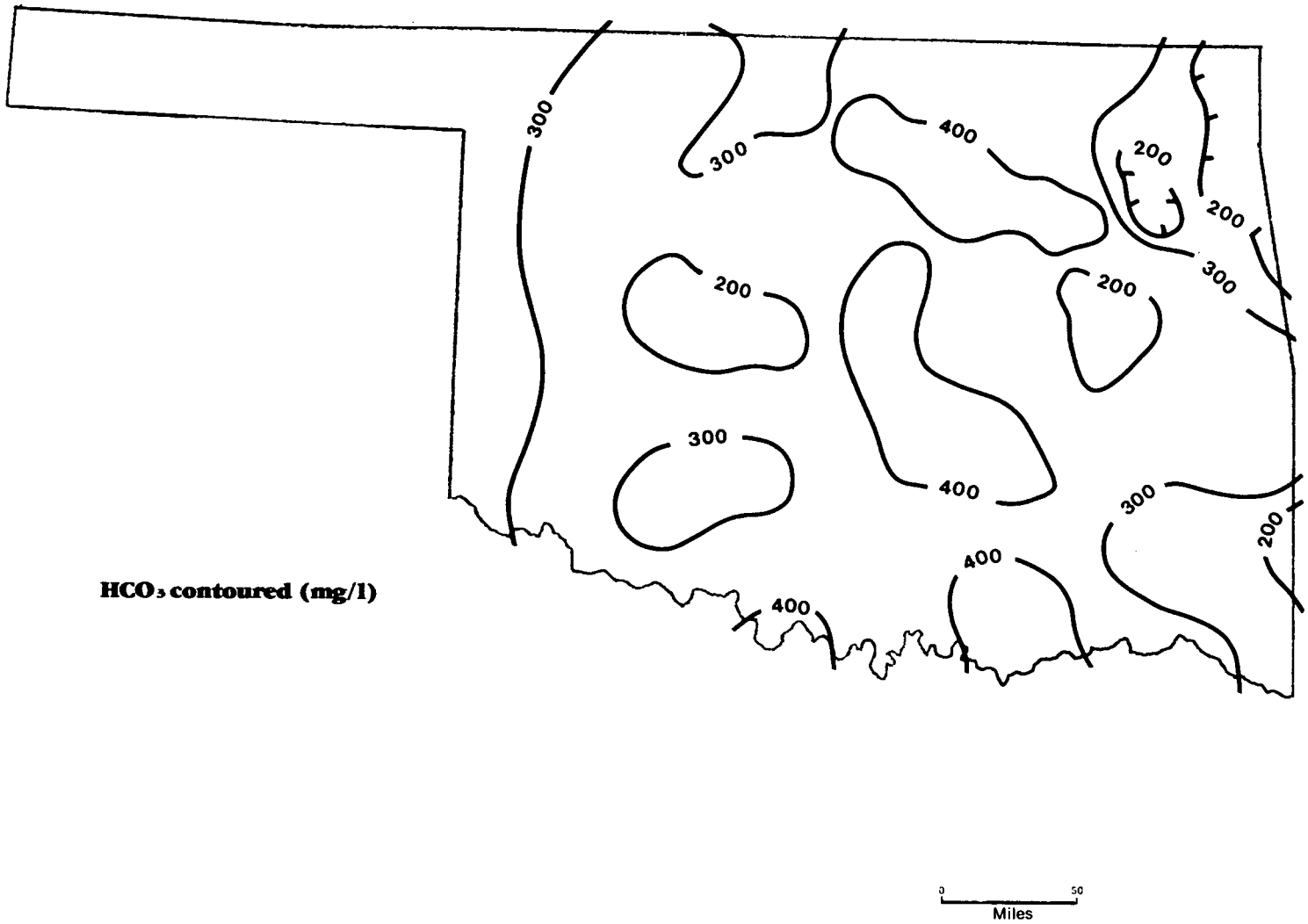
Oklahoma


250
50
100
100
250
250
50
100
100
100
50
50
100
100
50
0
Cl (mg/1)
0-50
50-100
100-250
250-500
SO4 contoured (mg/1)
0
50
Miles

Oklahoma

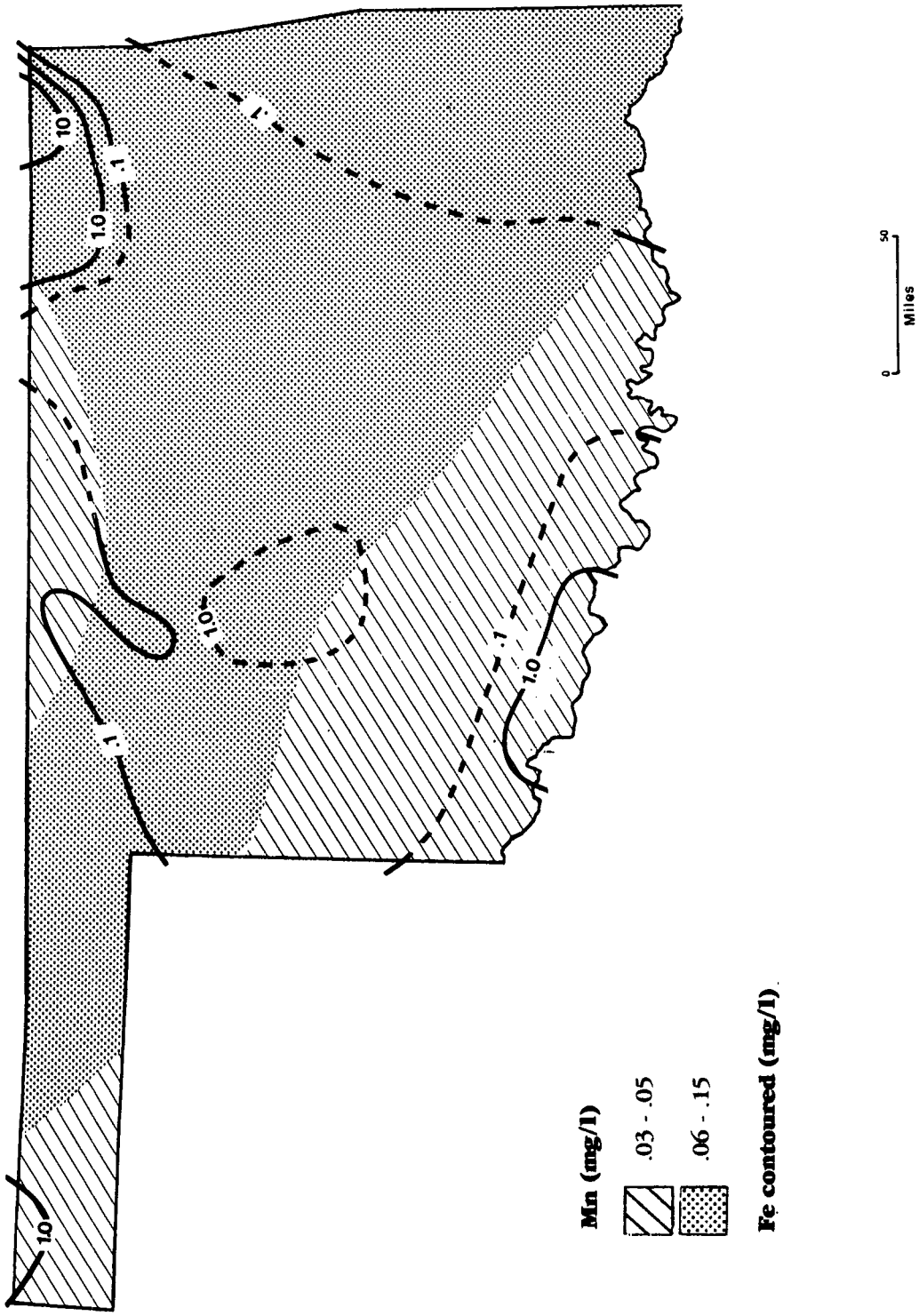

250
500
1000
250
500
1000
500
250
1000
1000
Hardness (mg/l)
< 120
120-240
240-500
500-1000
Dissolved Solids contoured (mg/l)
0
50
Miles

Oklahoma

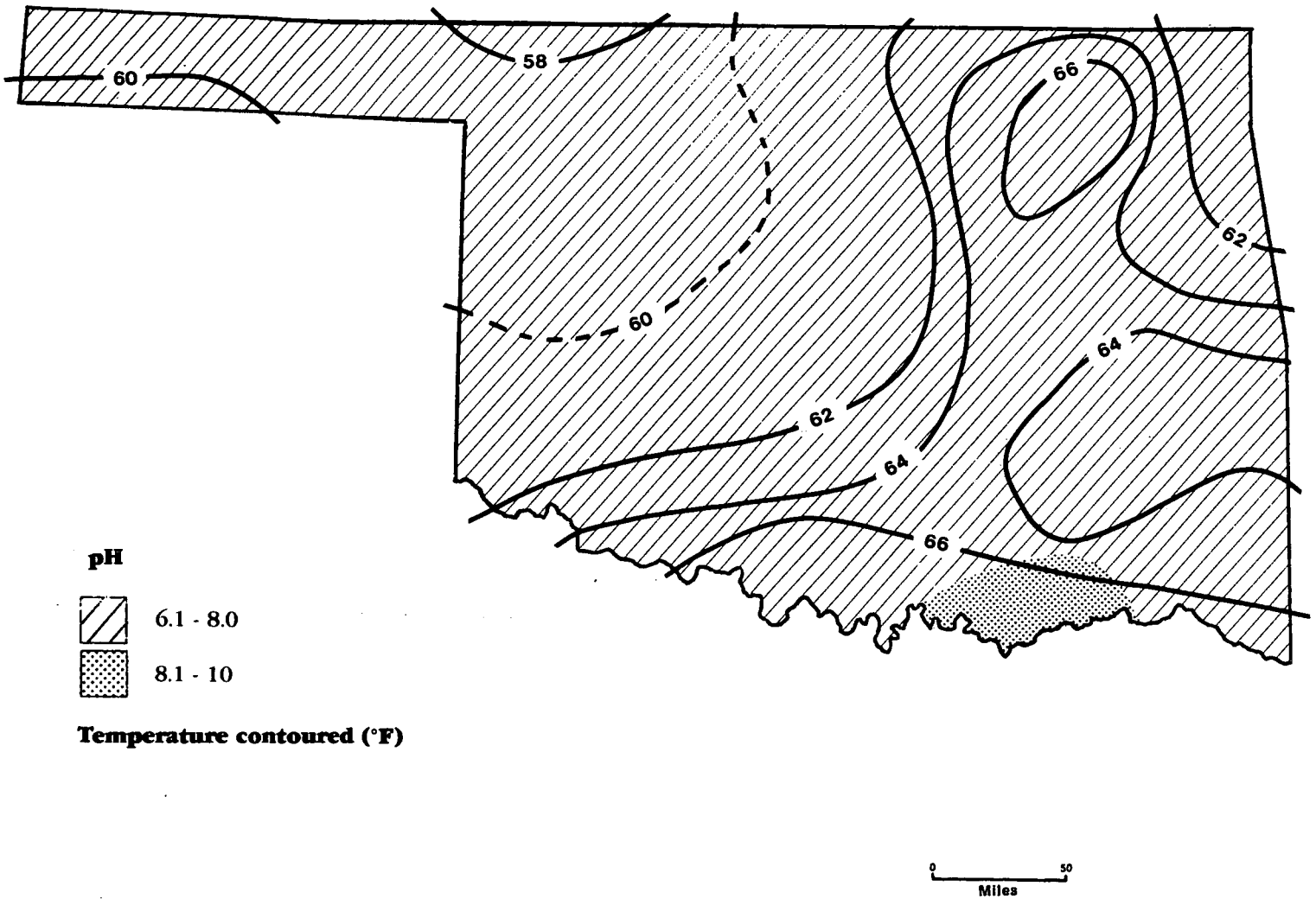


HCO_3 contoured (mg/l)

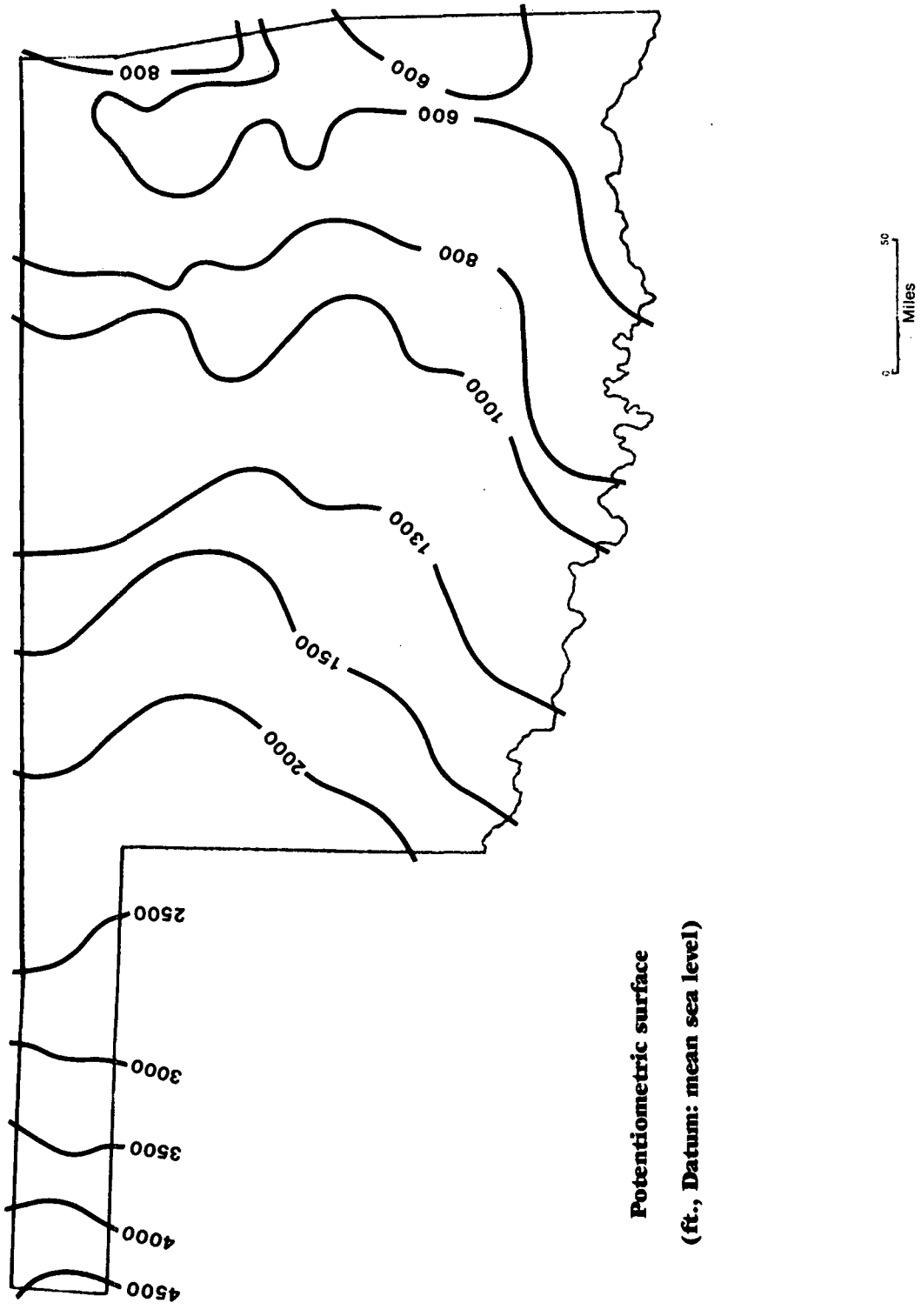
Oklahoma



Oklahoma


60
58
60
62
64
66
66
62
64
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles

Oklahoma



Potentiometric surface

(ft., Datum: mean sea level)

Oklahoma

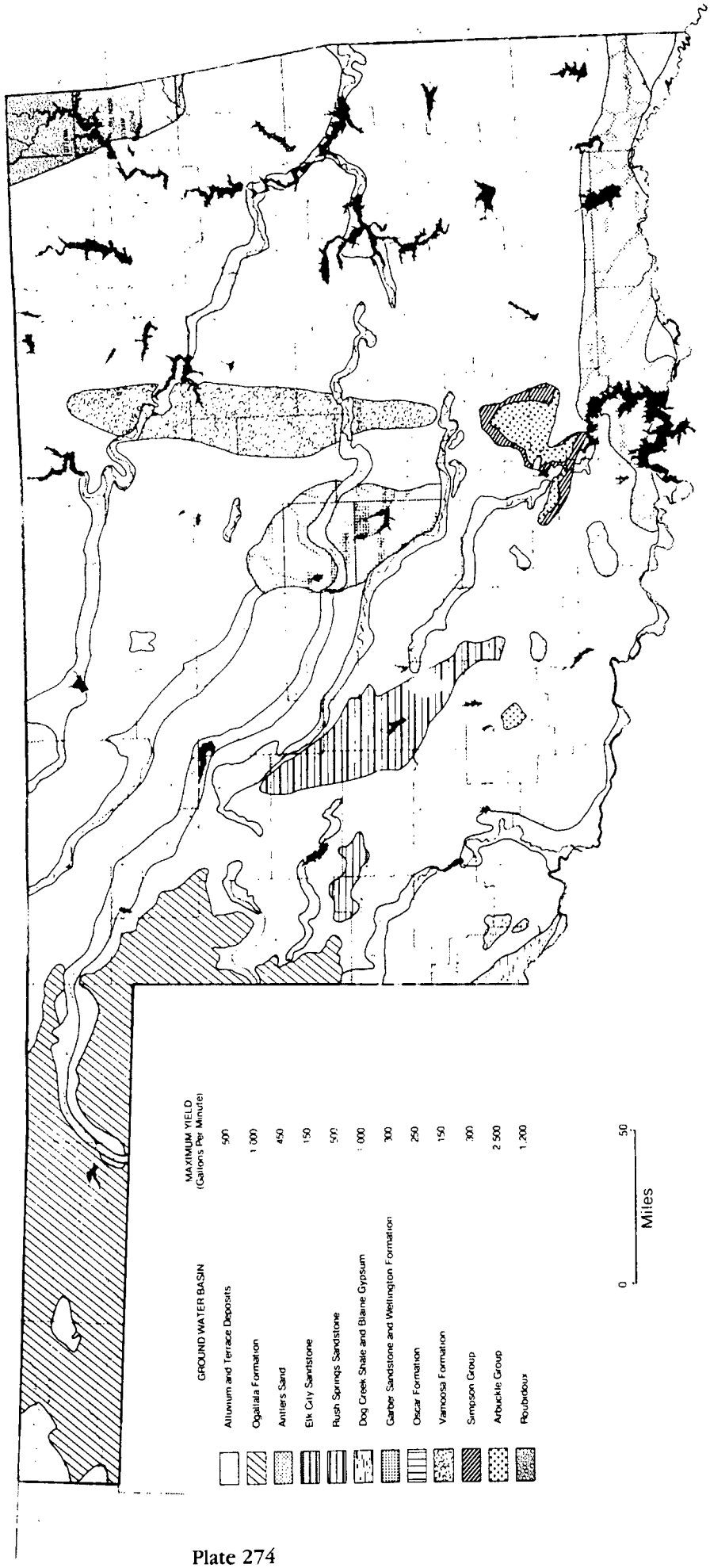
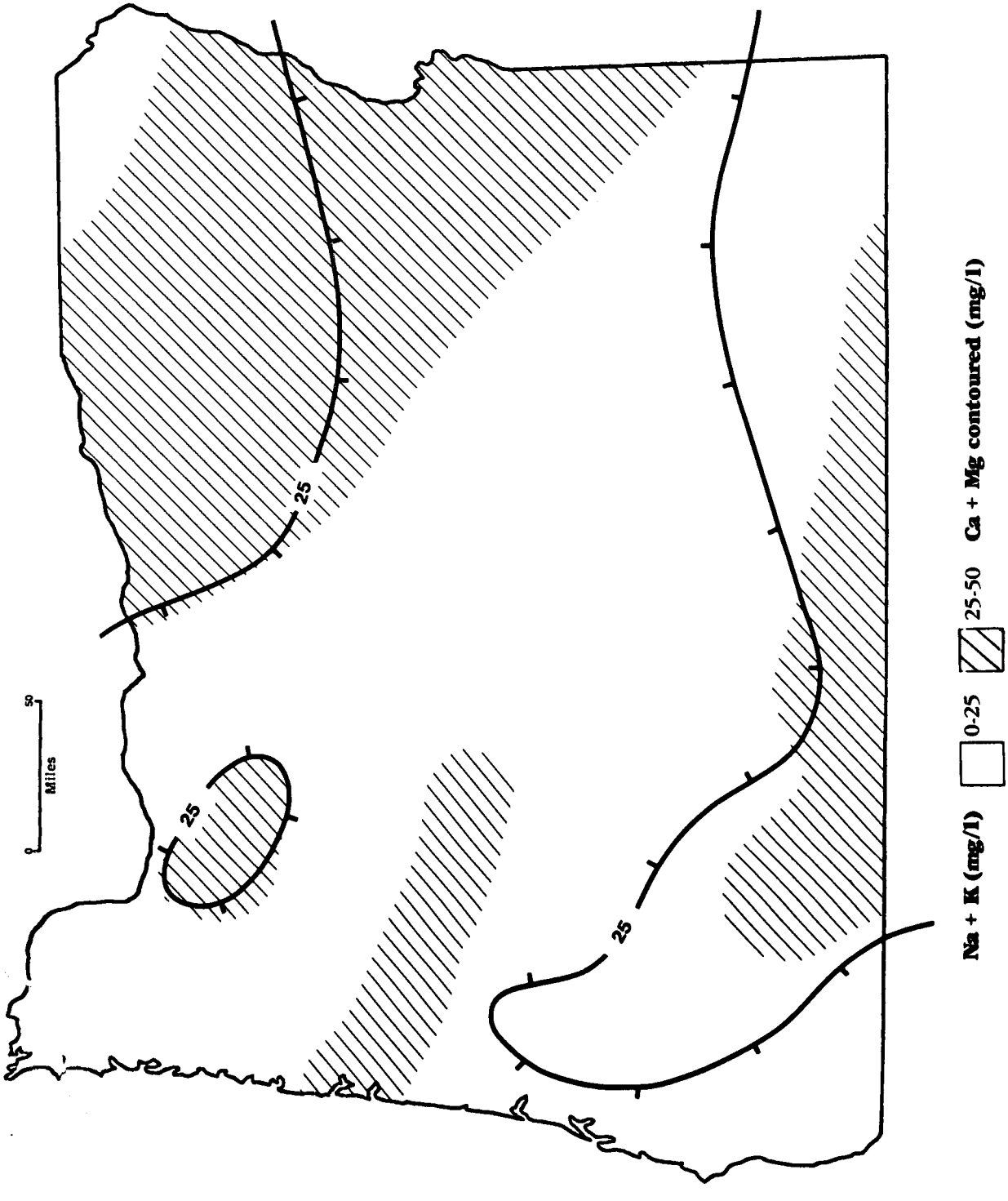


Plate 274

Oregon



Oregon

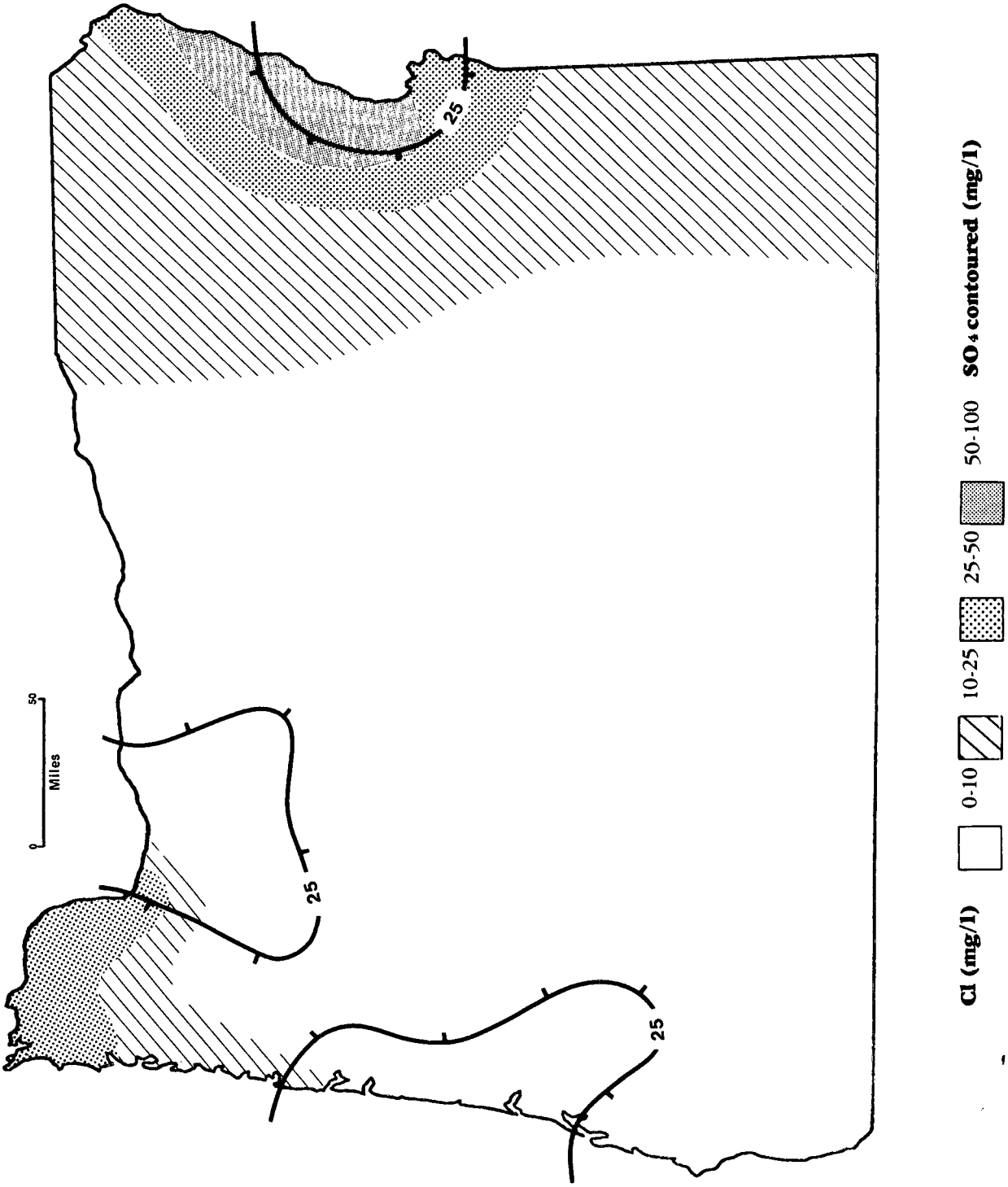
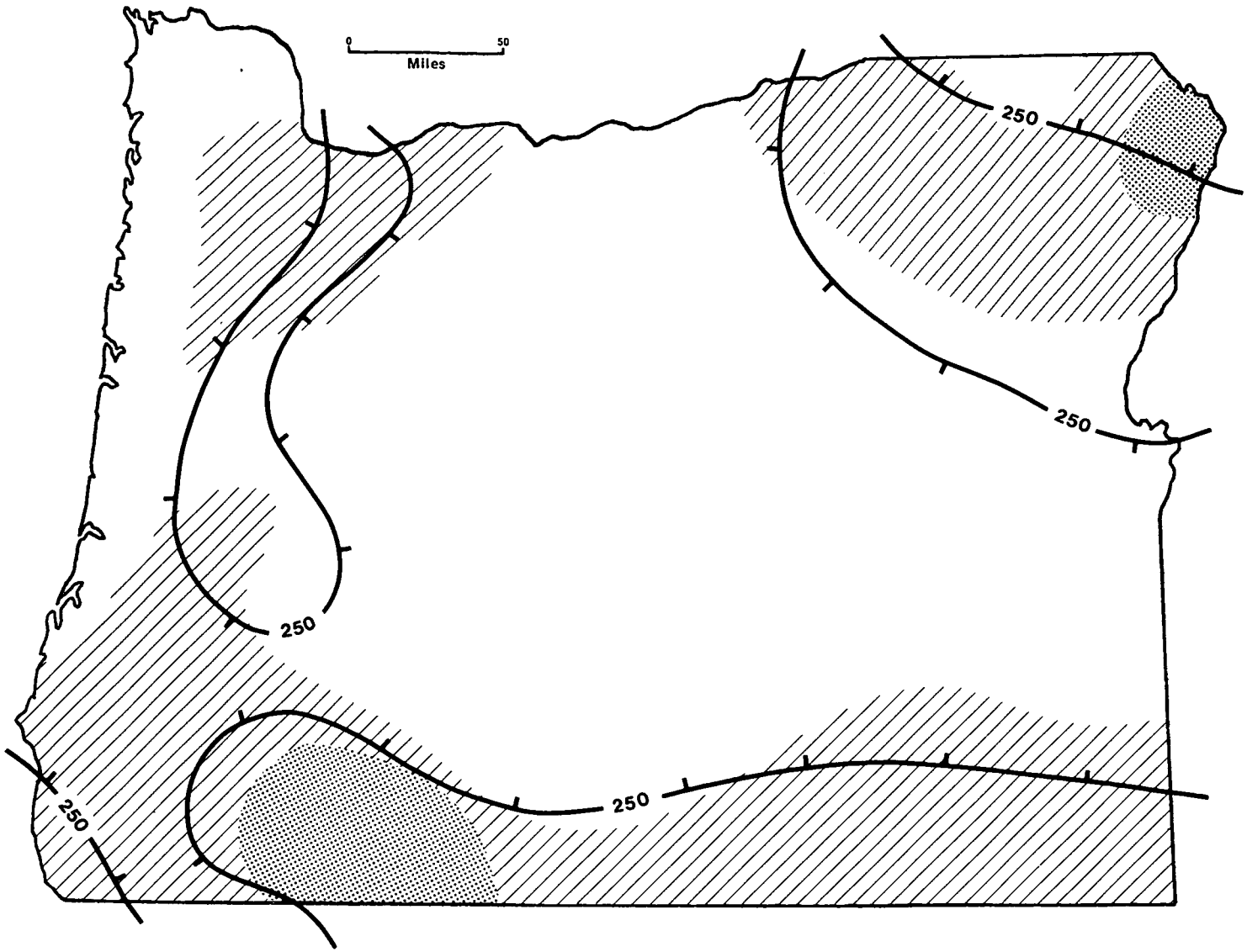


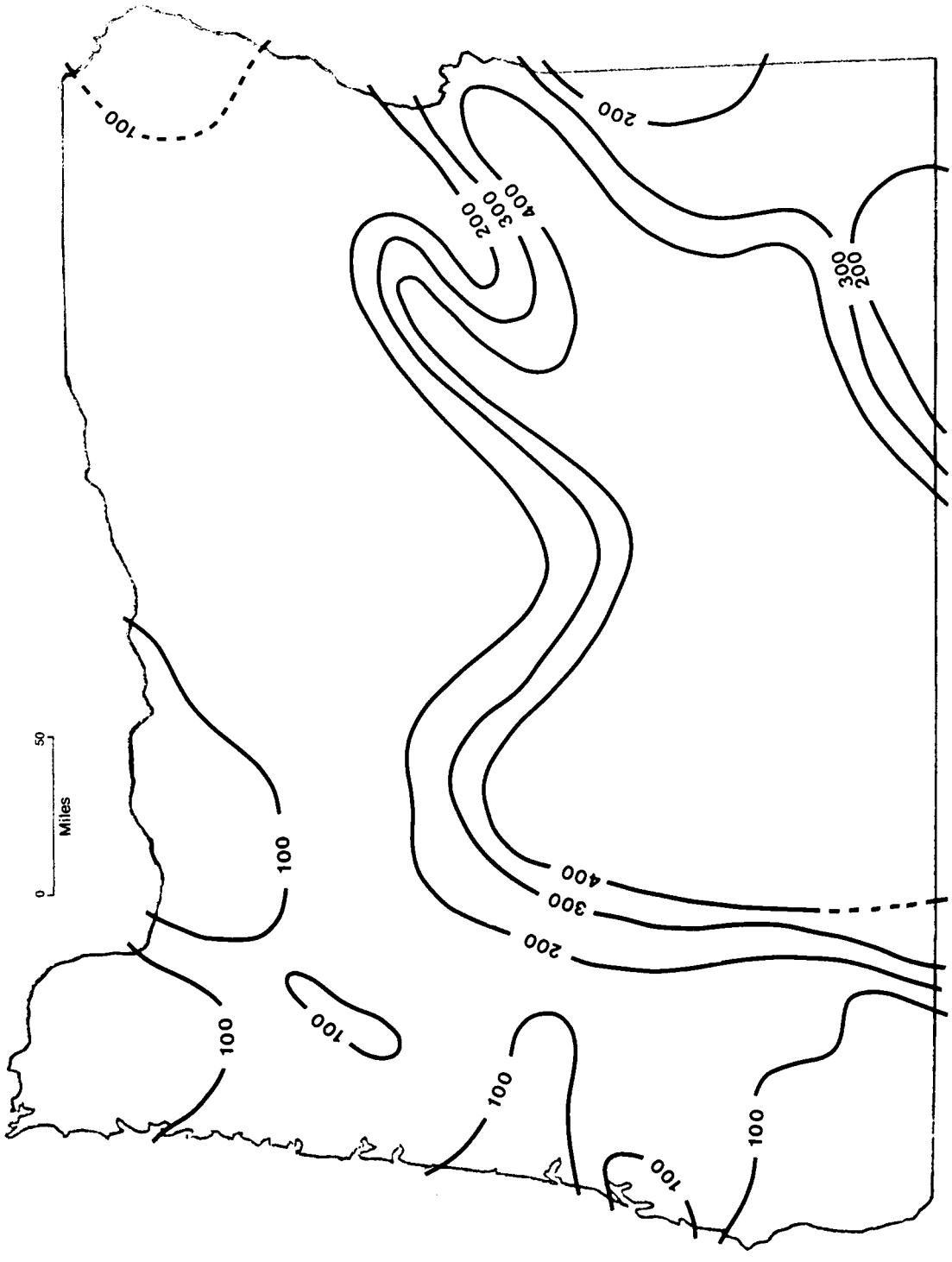
Plate 276

Oregon



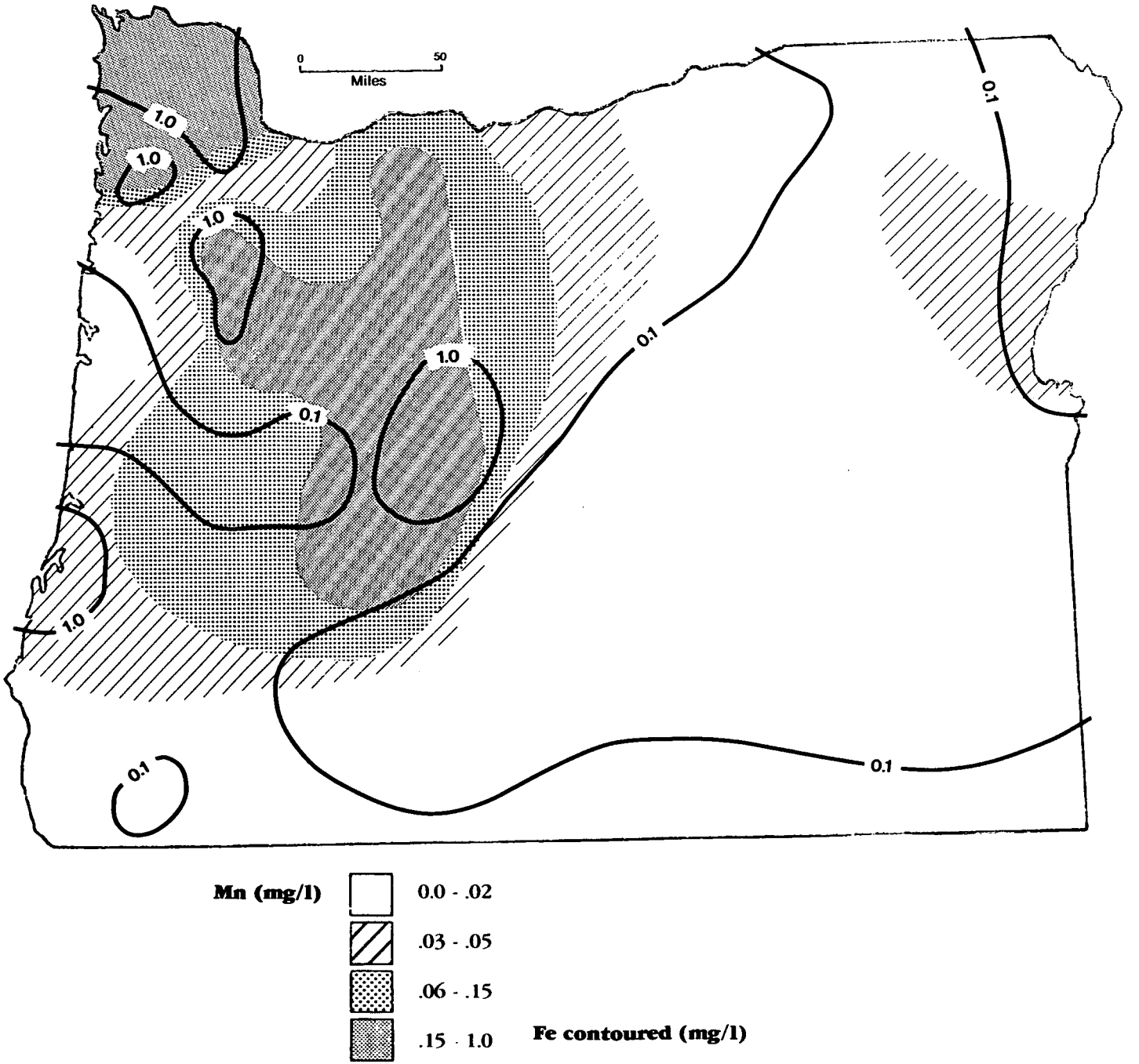
Hardness (mg/l) 0-60 60-120 120-240 **Dissolved Solids contoured (mg/l)**

Oregon

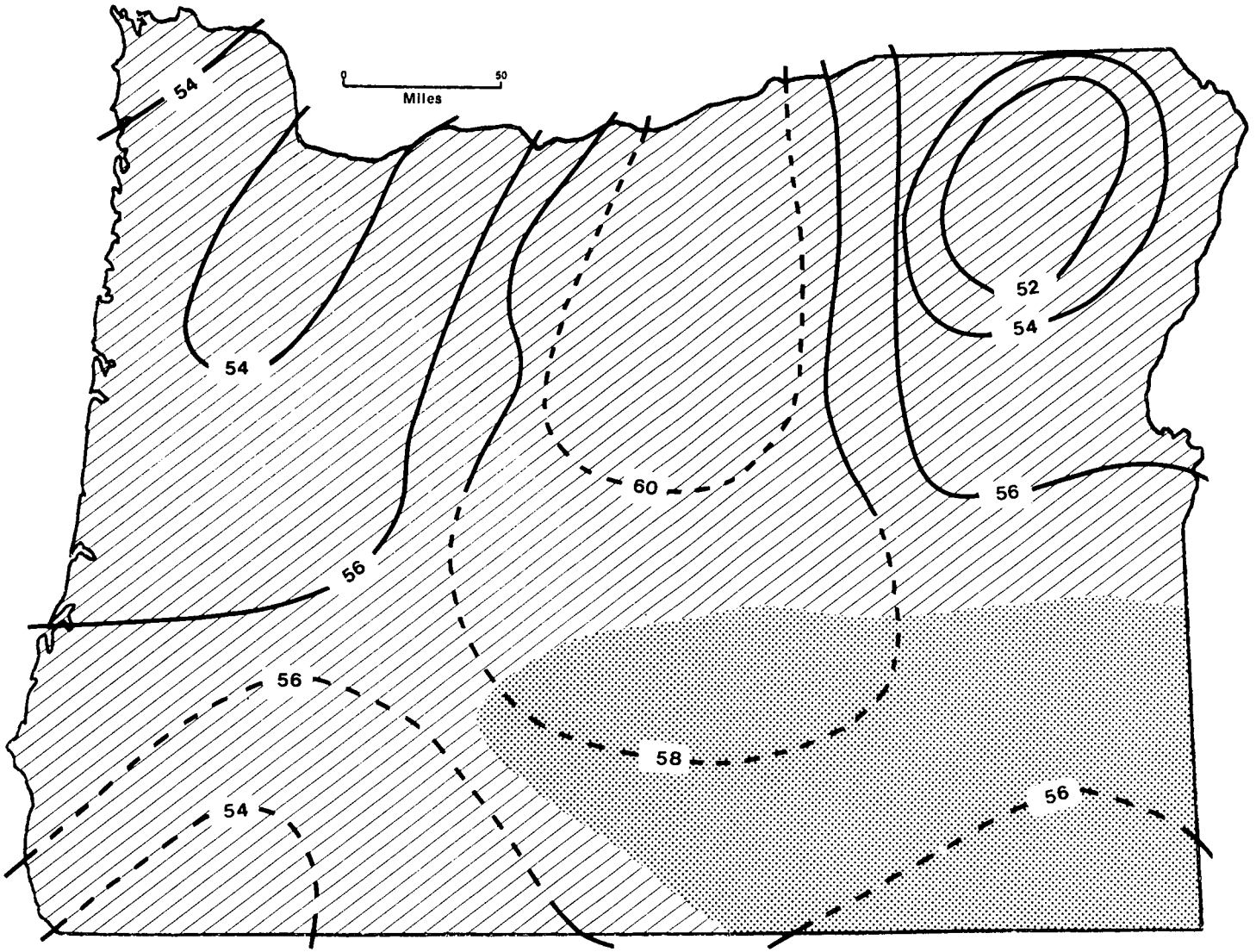


HCO_3 contoured (mg/l)

Oregon


0
50
Miles
1.0
1.0
1.0
1.0
0.1
1.0
0.1
0.1
0.1
0.1
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)

Oregon



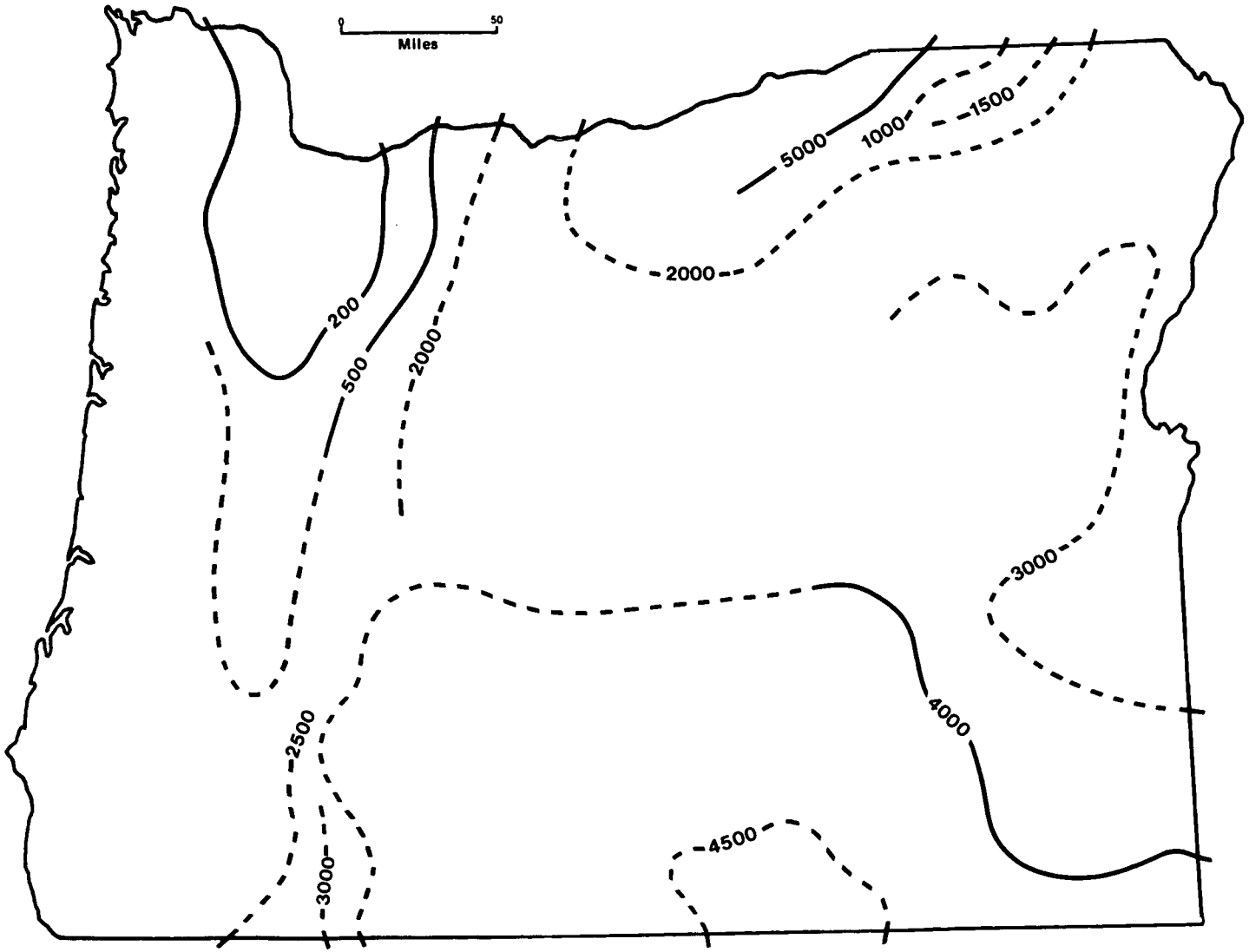
pH

6.1 - 8.0

8.1 - 10

Temperature contoured (°F)

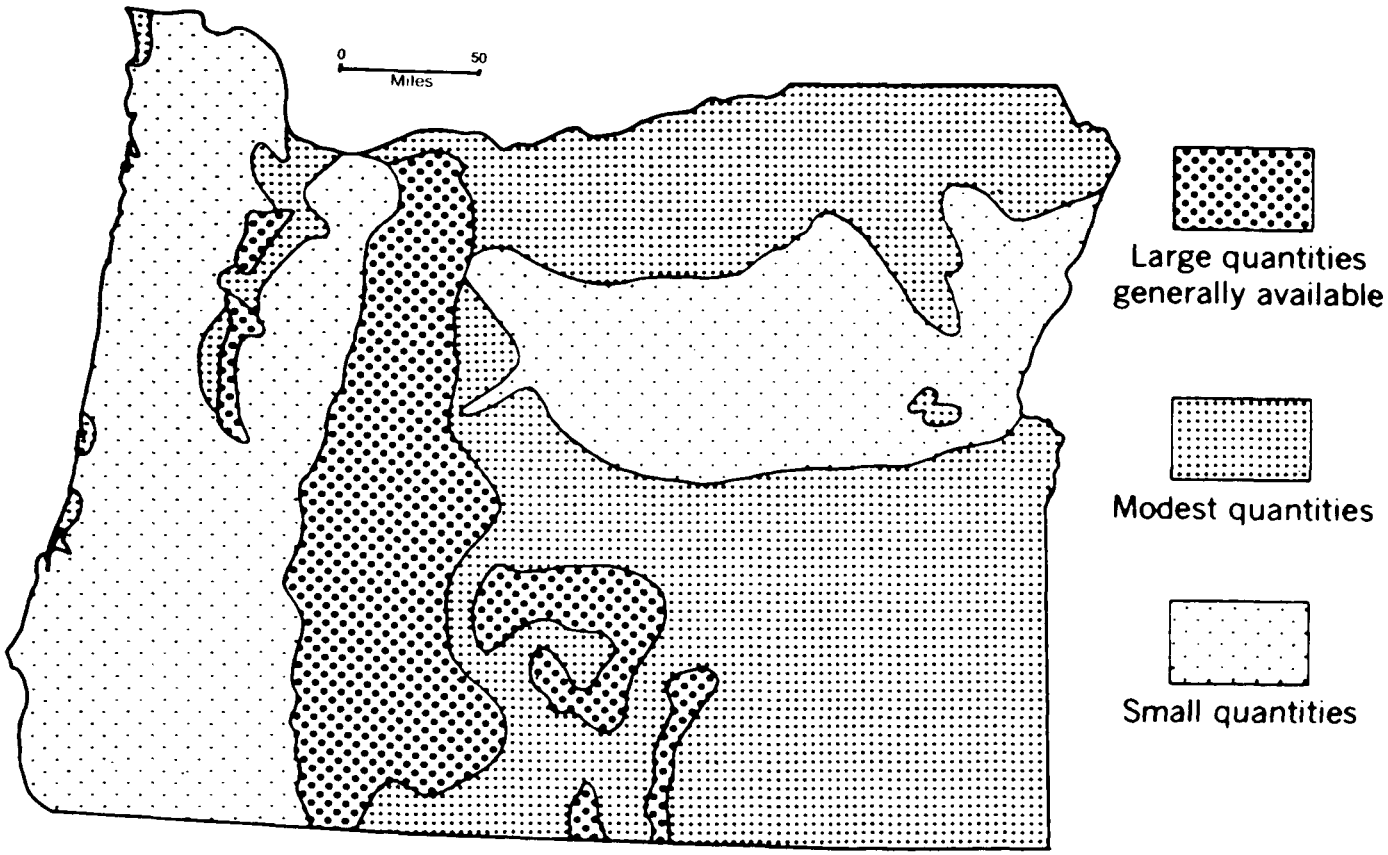
Oregon



Potentiometric surface

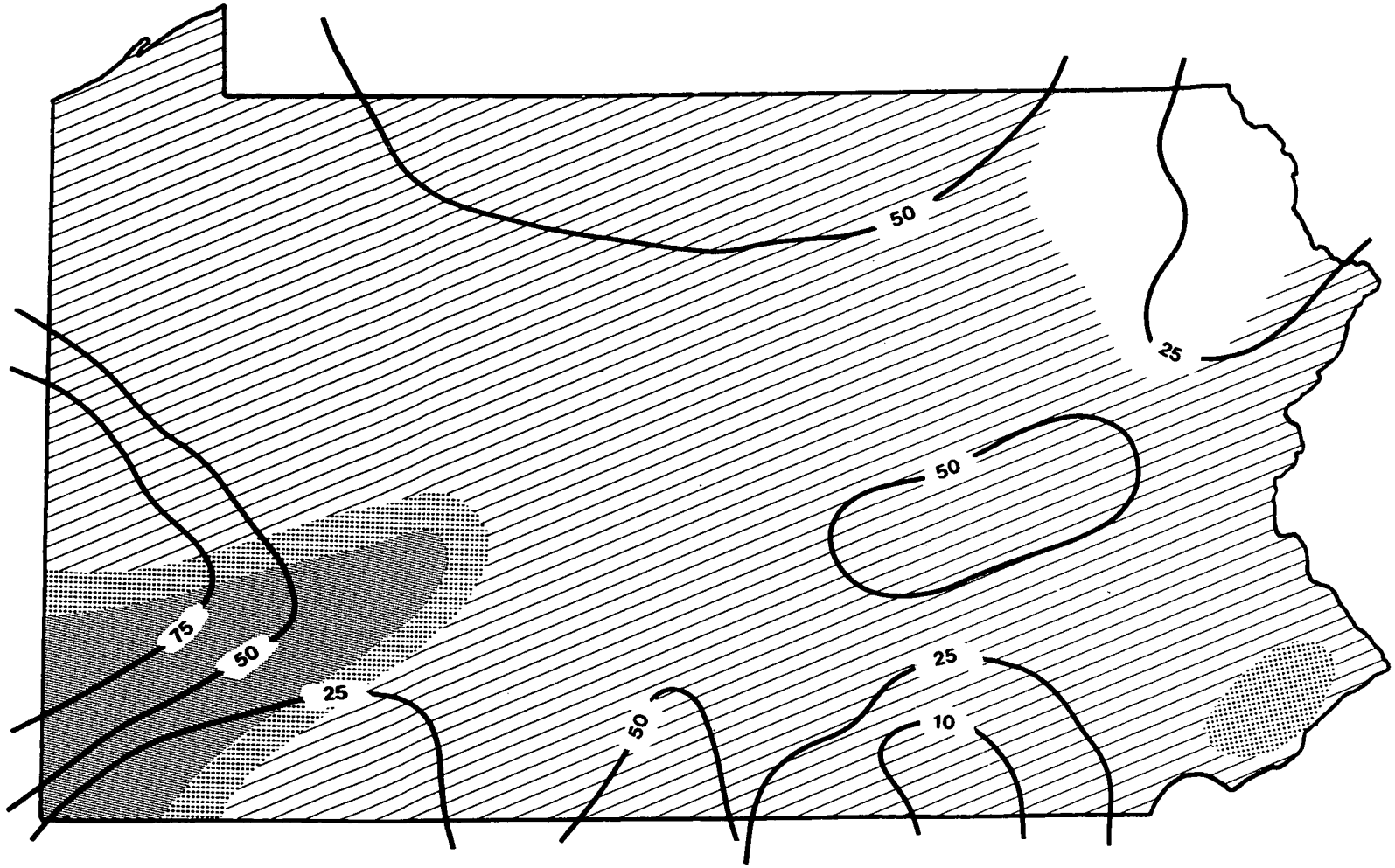
(ft., Datum: mean sea level)

Oregon



AVAILABILITY OF GROUND WATER

Pennsylvania



Na + K (mg/l)

- 0-10
- 10-25
- 25-50
- 50-100

Ca + Mg contoured (mg/l)

0 — 40 Miles

Plate 283

Pennsylvania

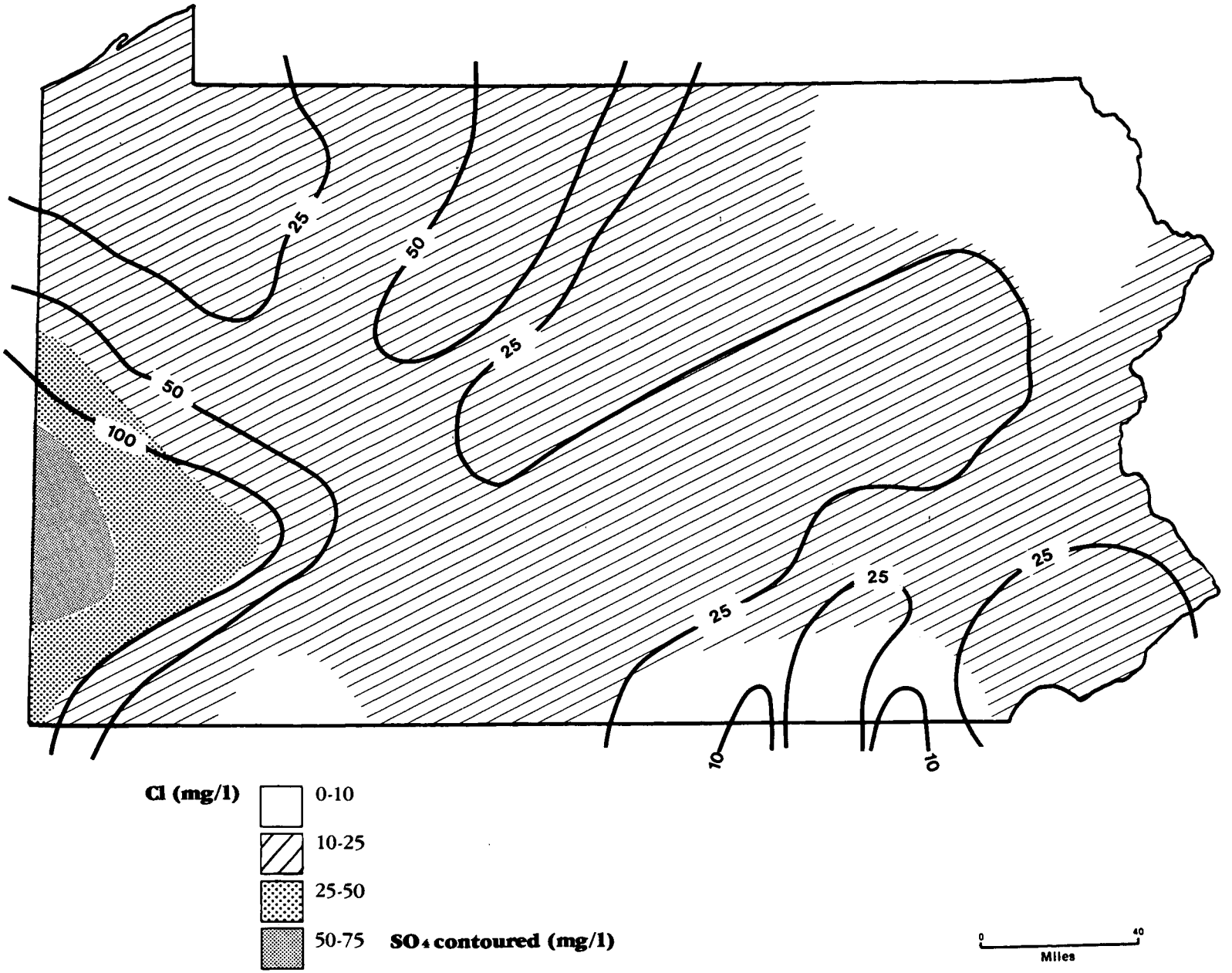
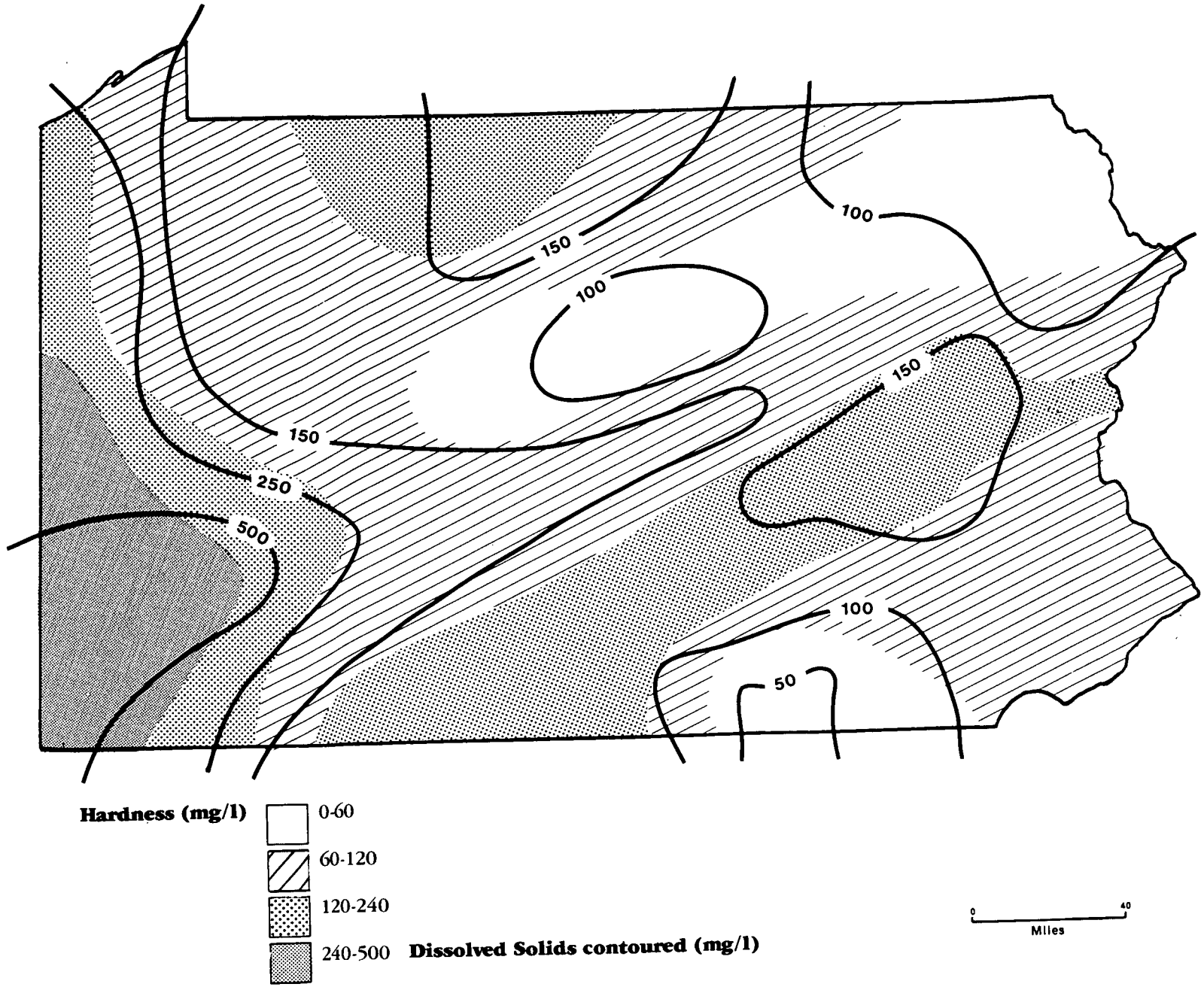
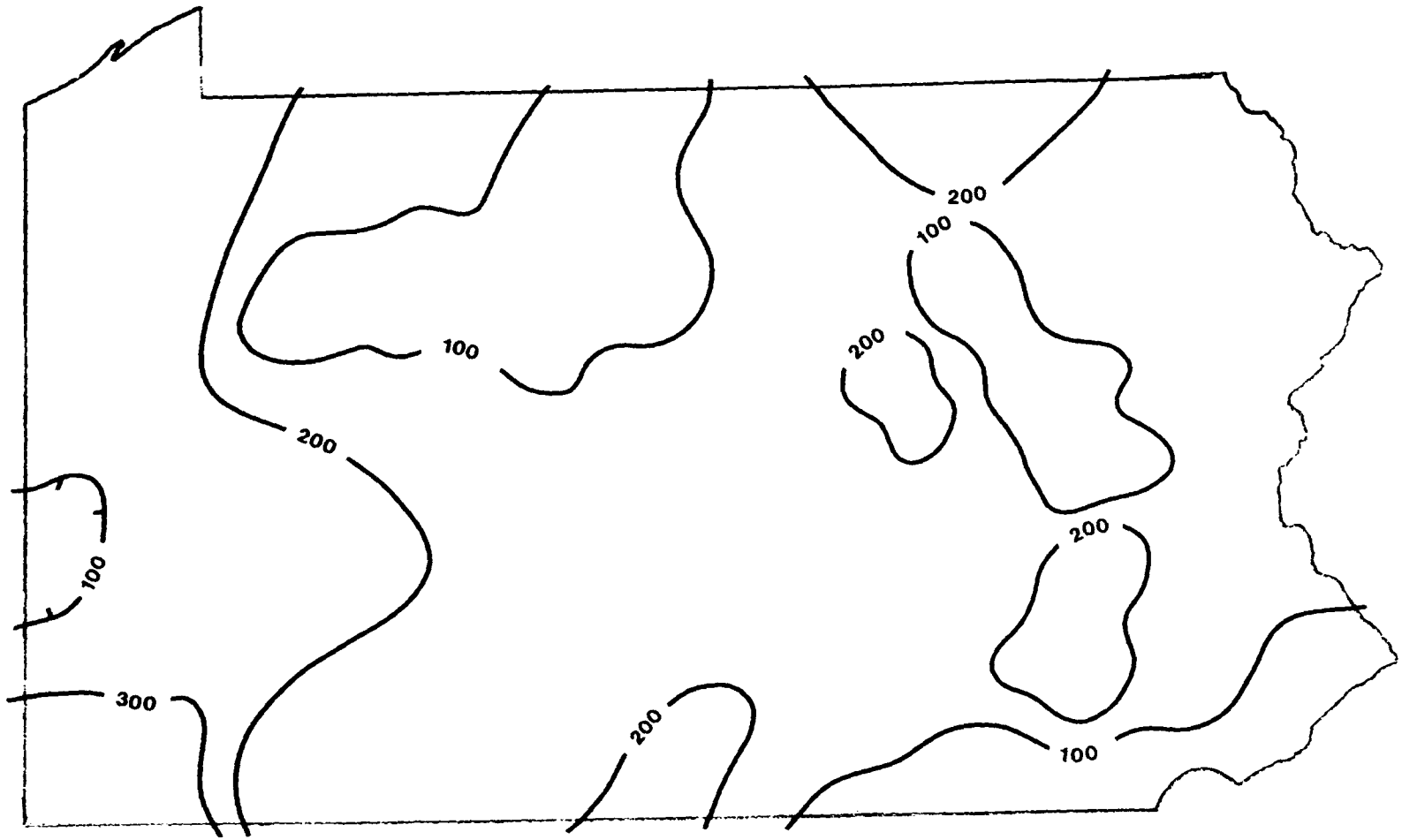


Plate 284

Pennsylvania



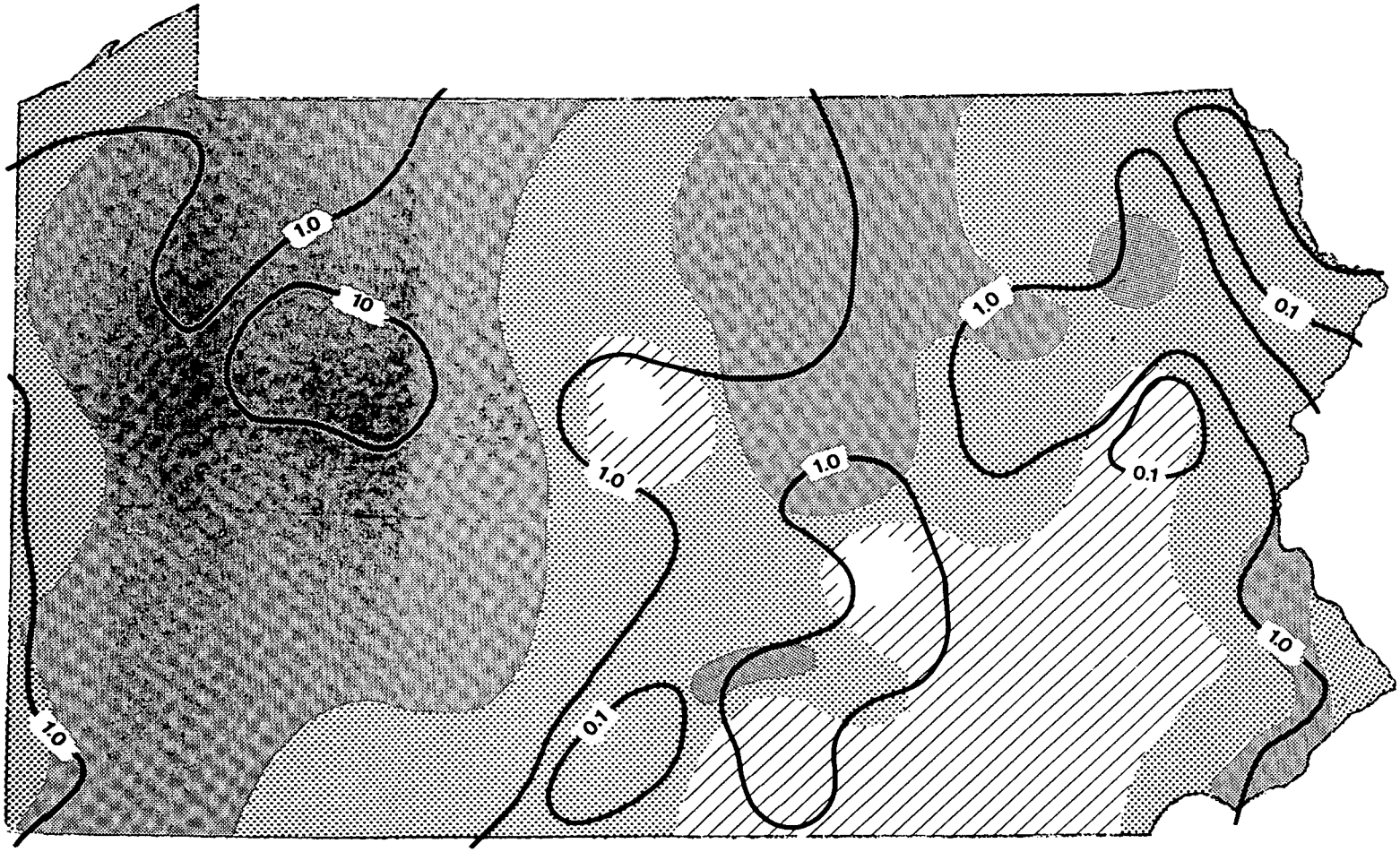
Pennsylvania



HCO_3 contoured (mg/l)

0 40
Miles

Pennsylvania



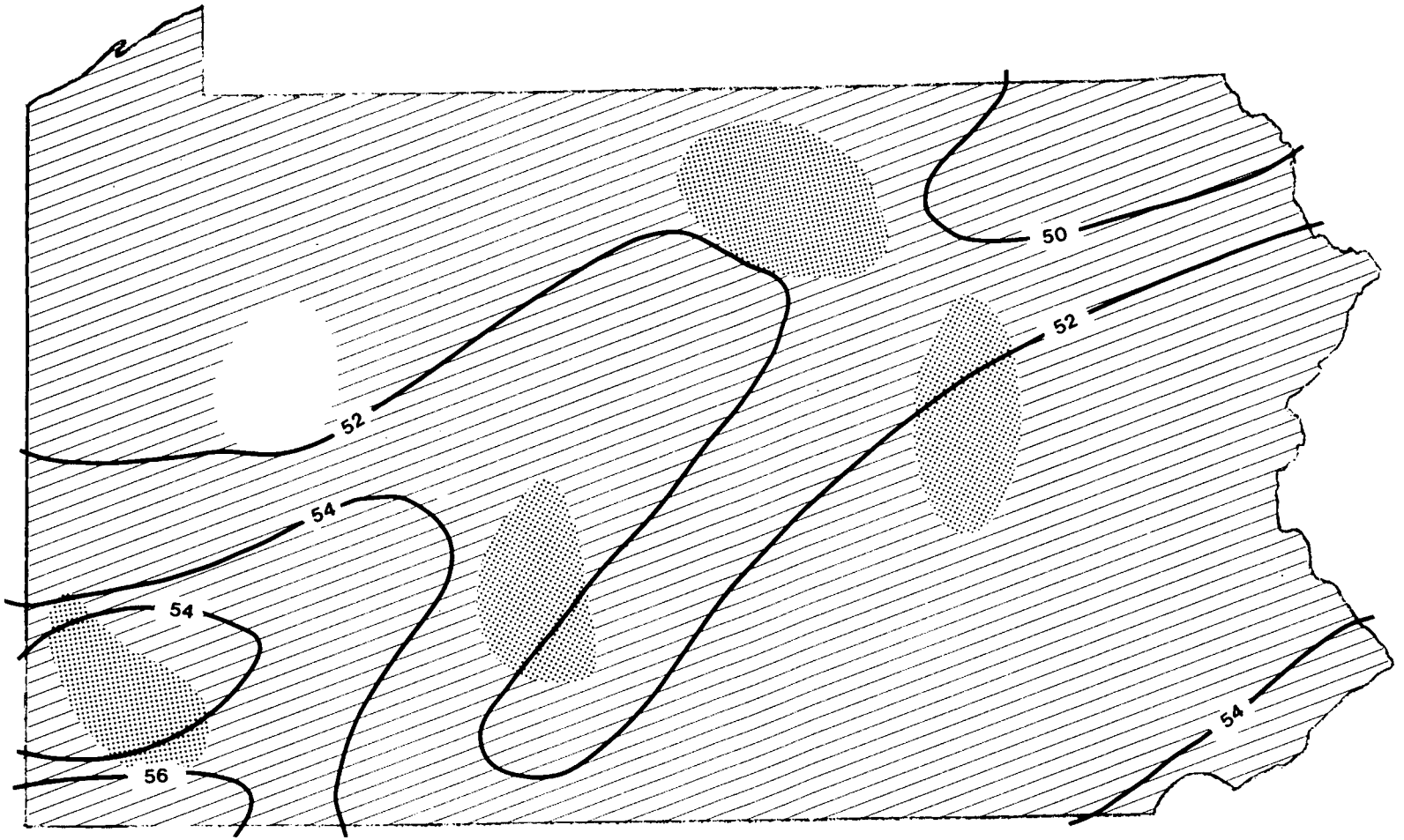
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

0 — 40 Miles

Pennsylvania



pH

Less than 6.0

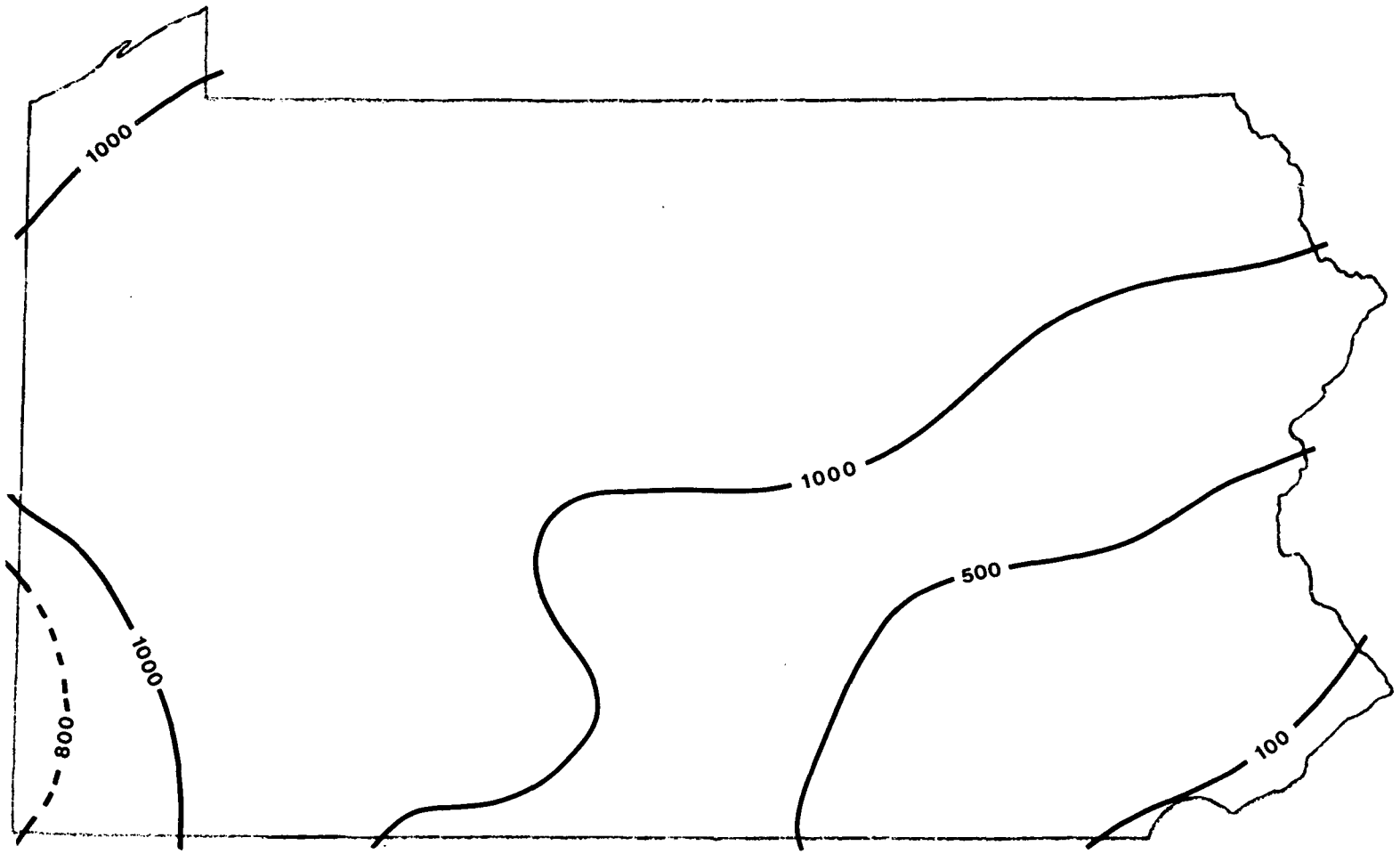
6.1 - 8.0

8.1 - 10

Temperature contoured (°F)

0 40
Miles

Pennsylvania

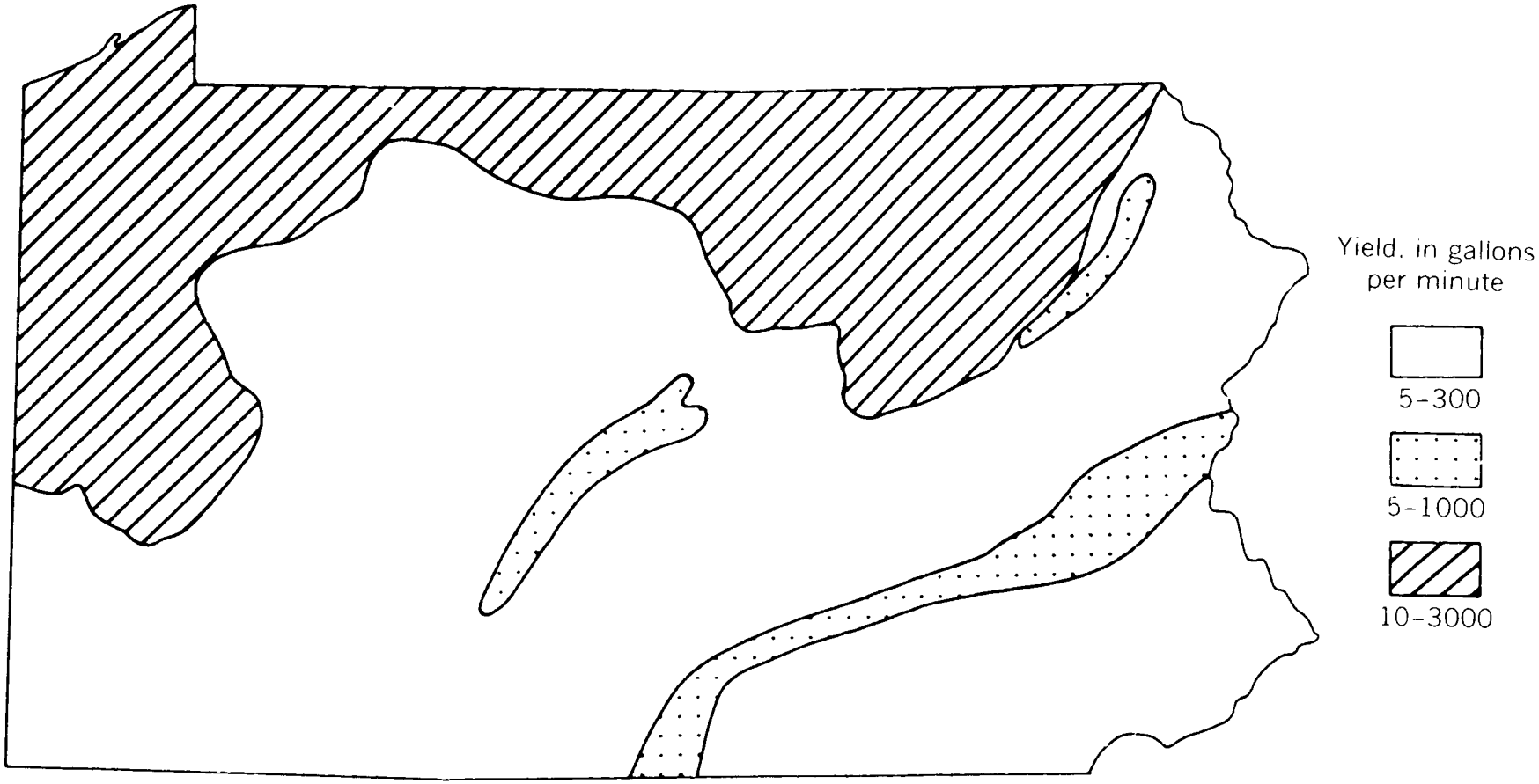


Potentiometric surface

(ft., Datum: mean sea level)

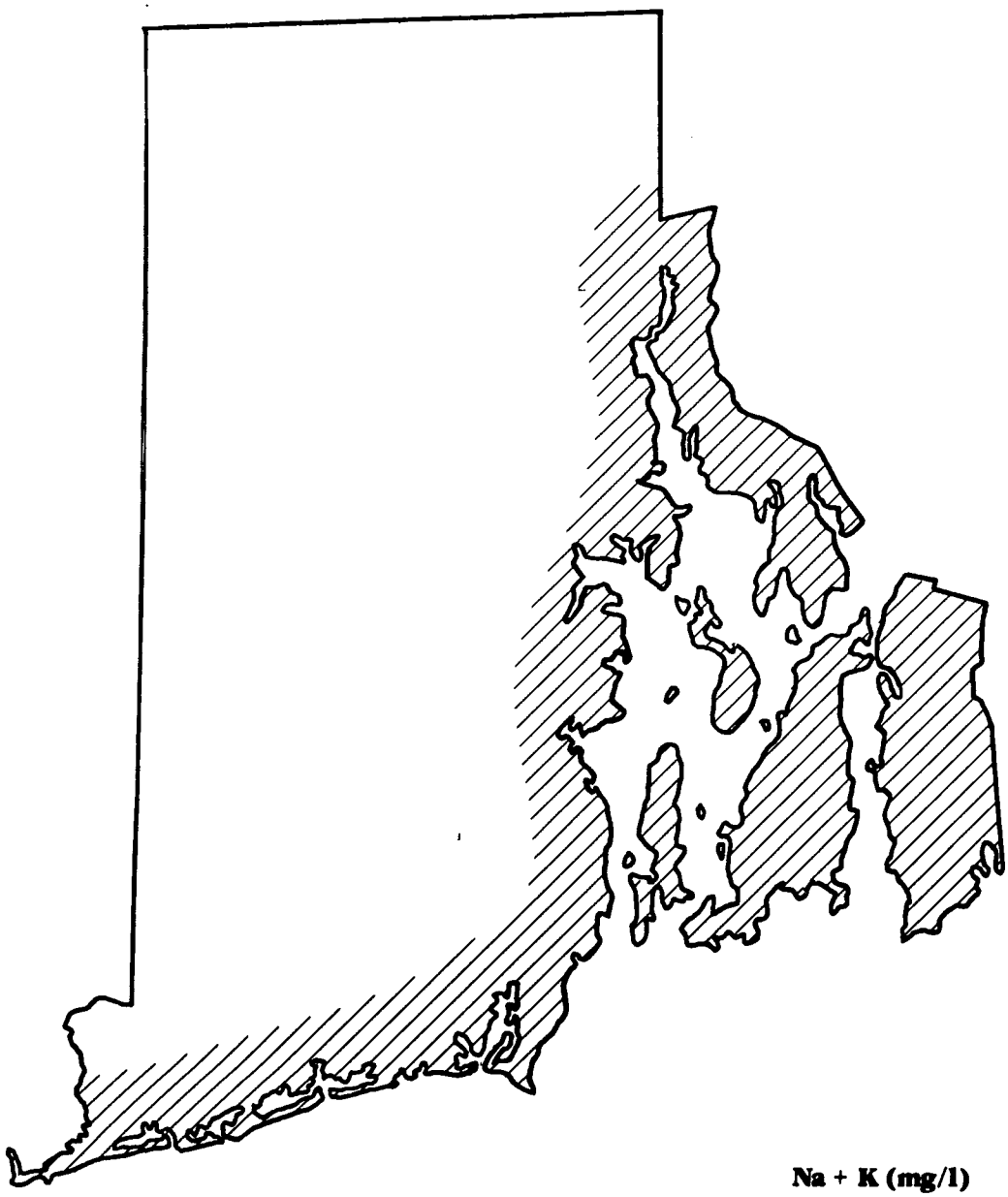
0 40
Miles

Pennsylvania



AVAILABILITY OF GROUND WATER

Rhode Island



Na + K (mg/l)

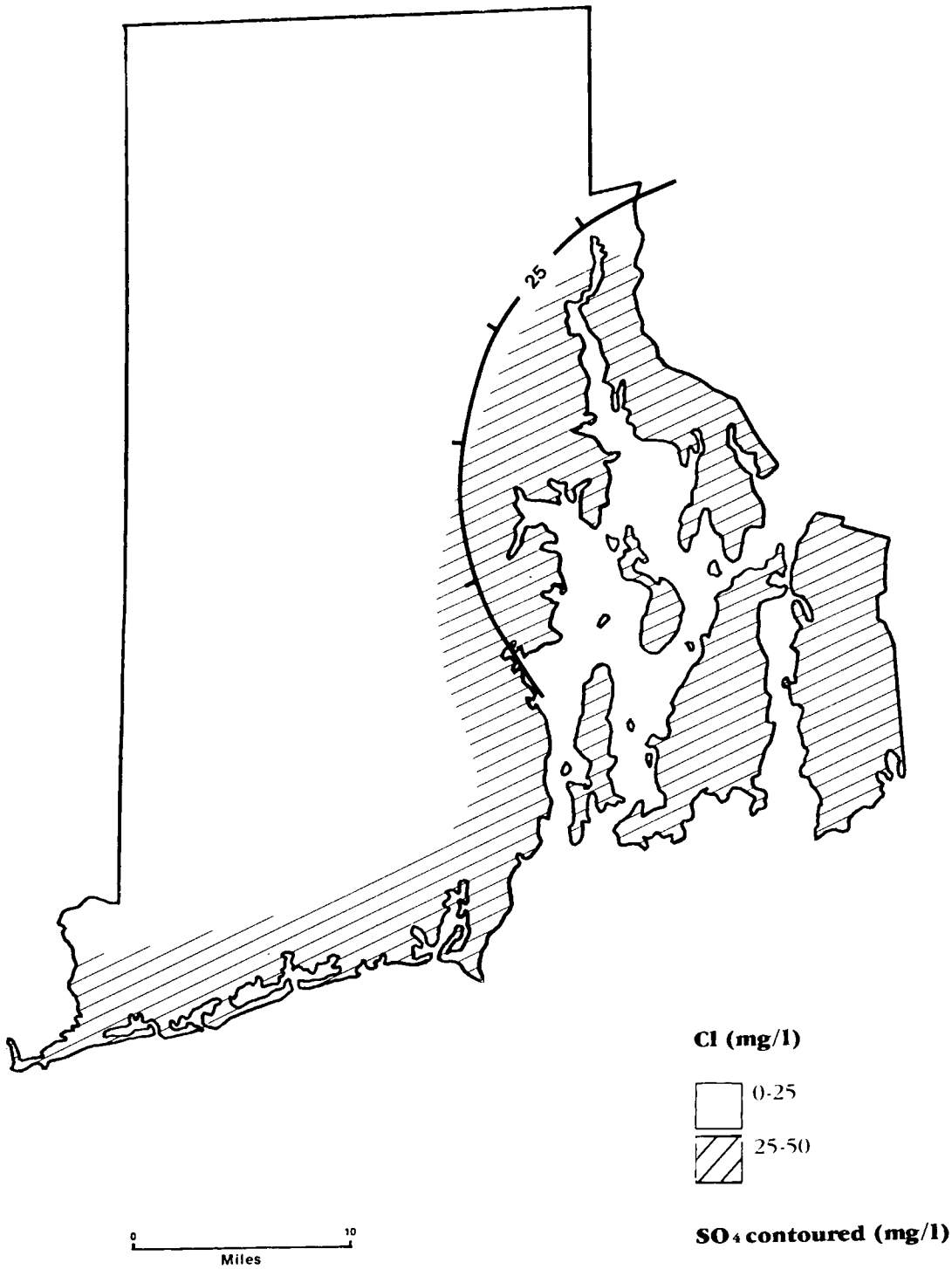
0-25

25-50

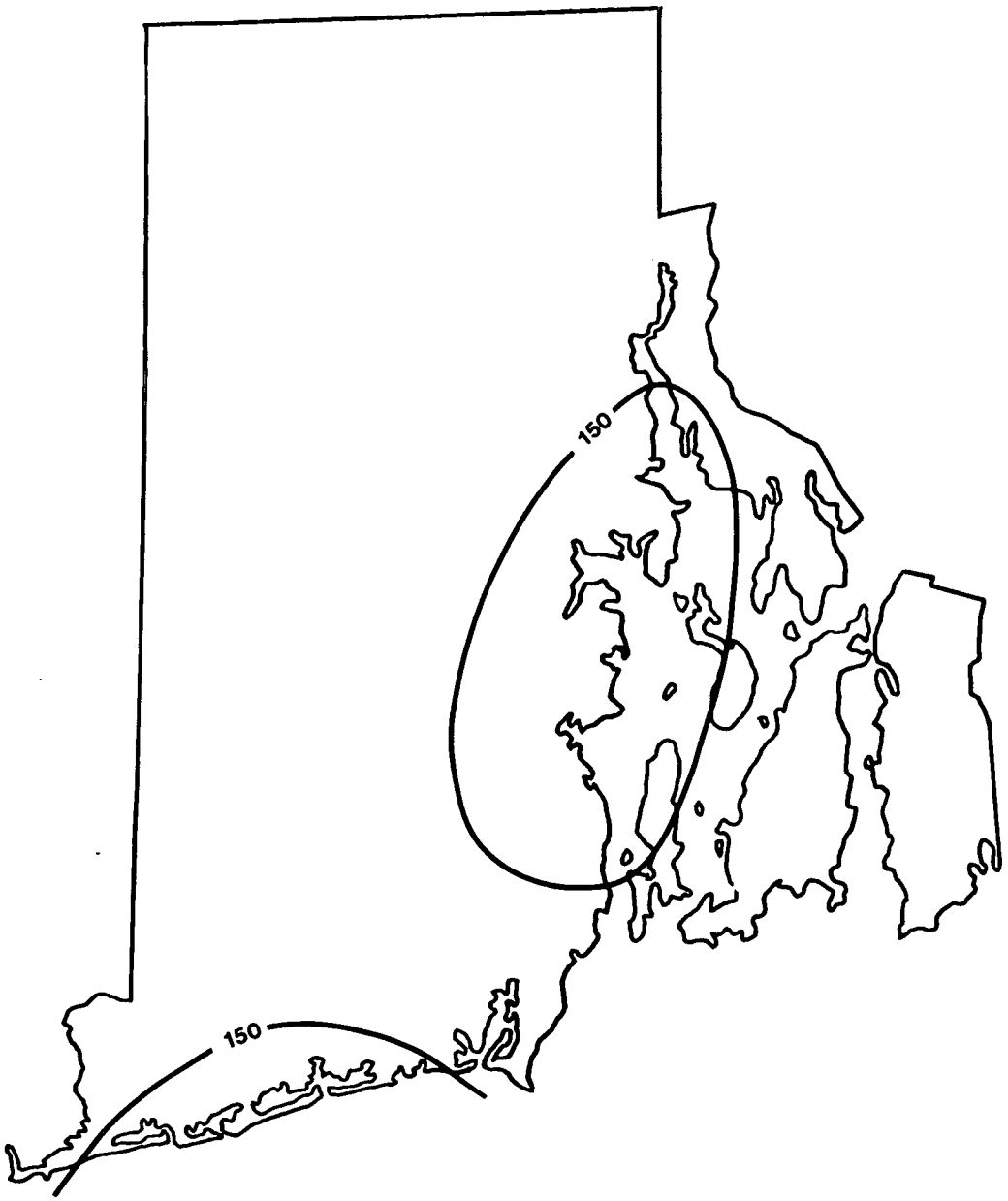
0 10
Miles

Ca + Mg contoured (mg/l)

Rhode Island



Rhode Island



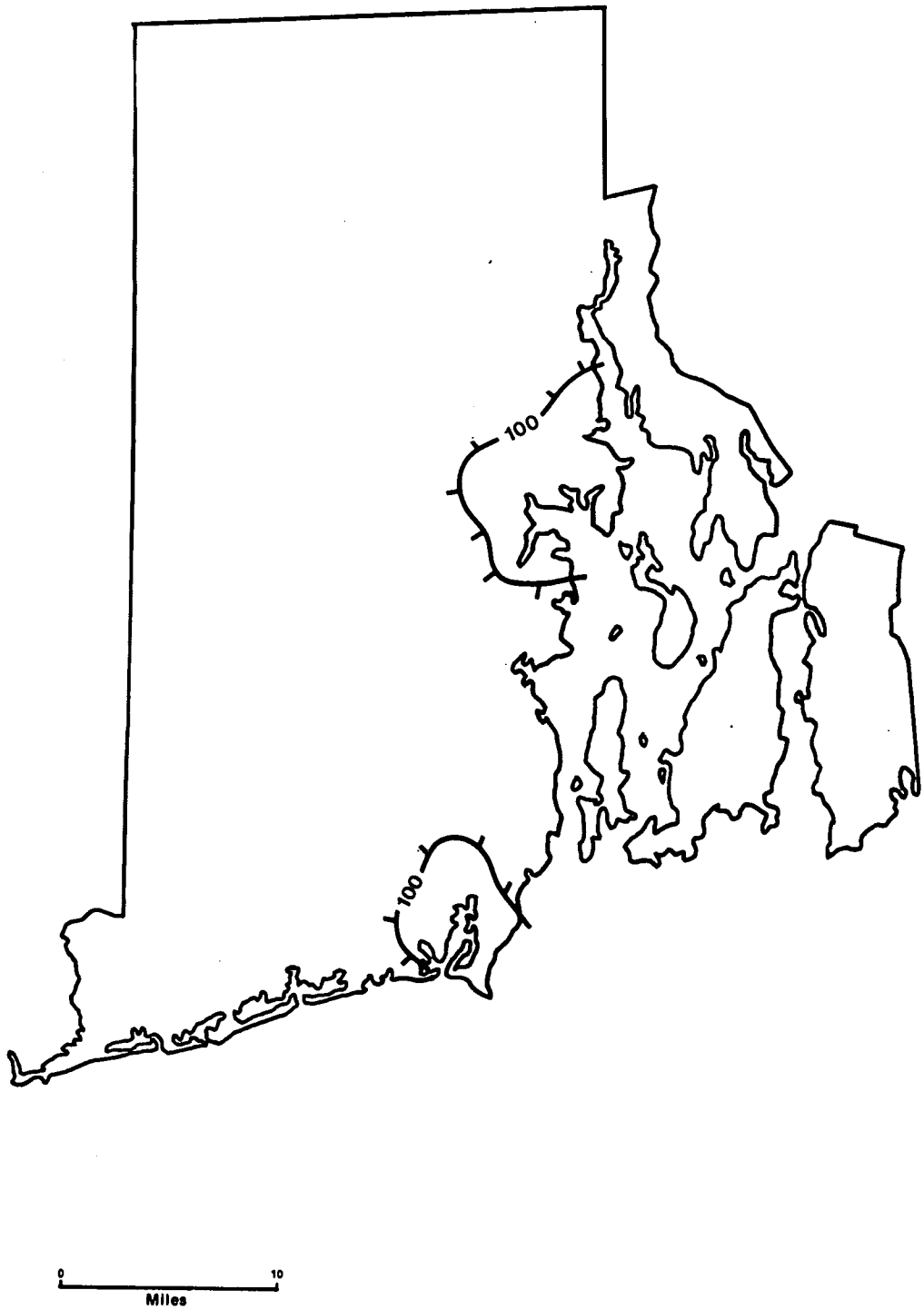
Hardness (mg/l)

<120

0 10
Miles

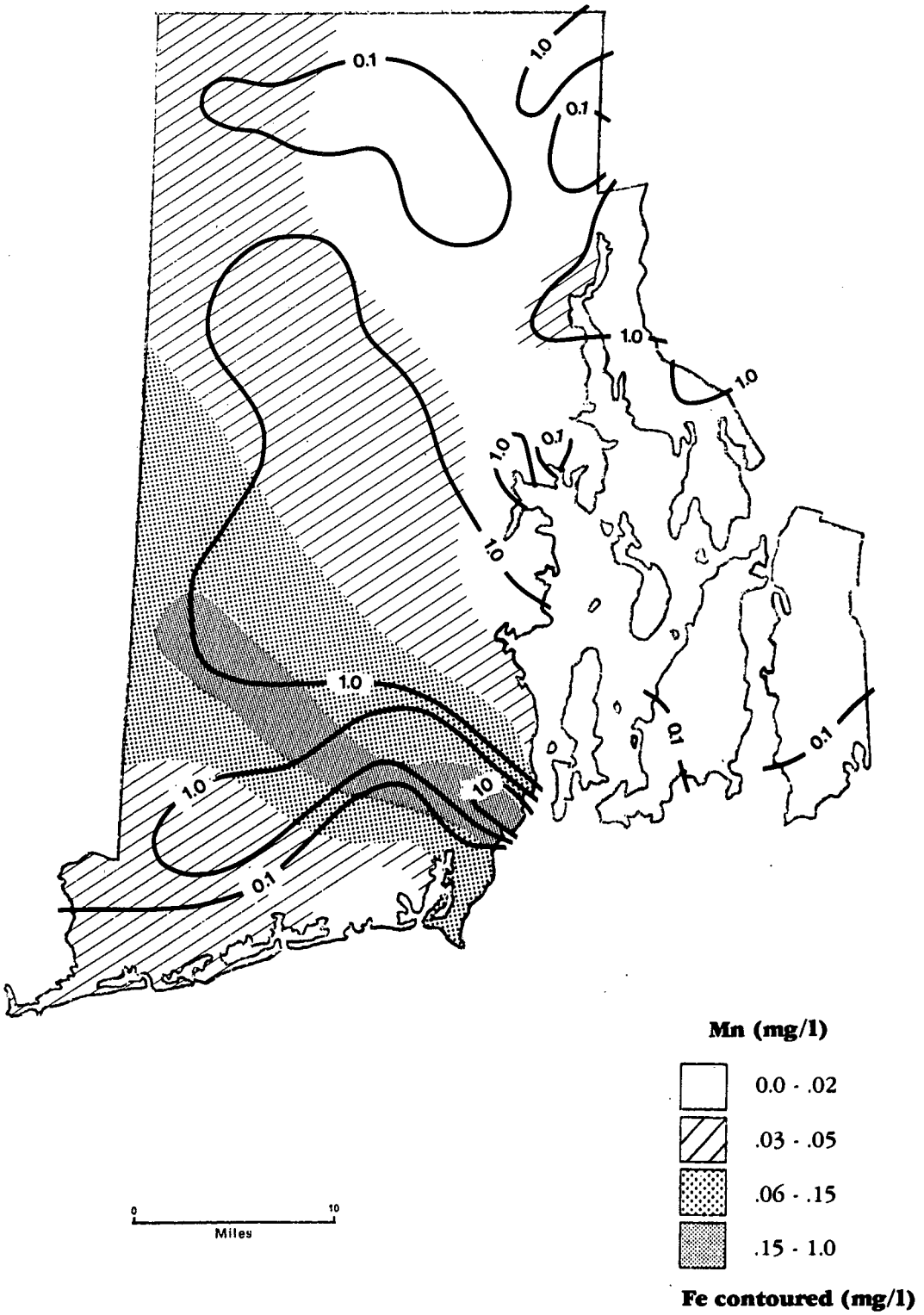
Dissolved Solids contoured (mg/l)

Rhode Island

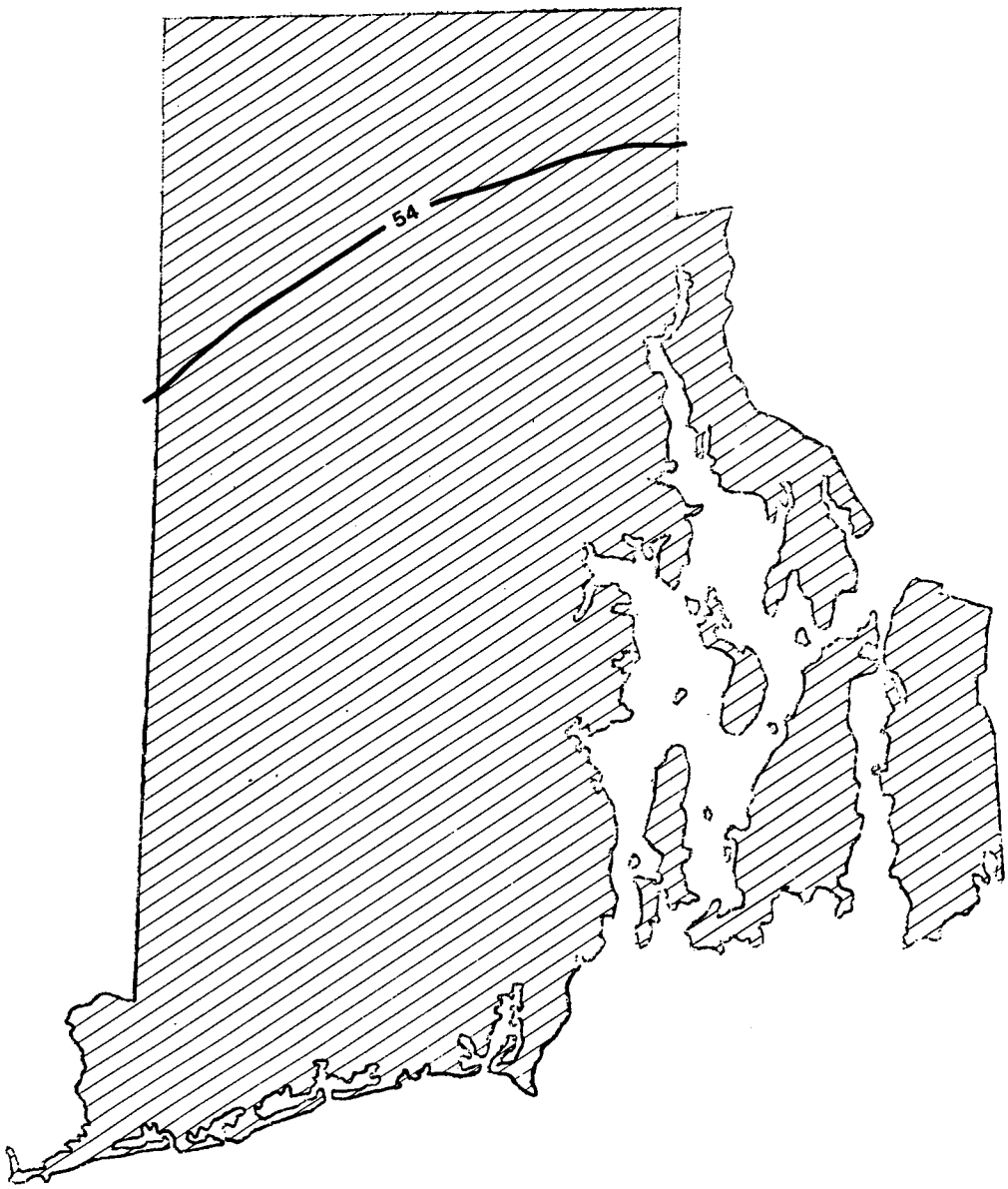


HCO_3 contoured (mg/l)

Rhode Island



Rhode Island



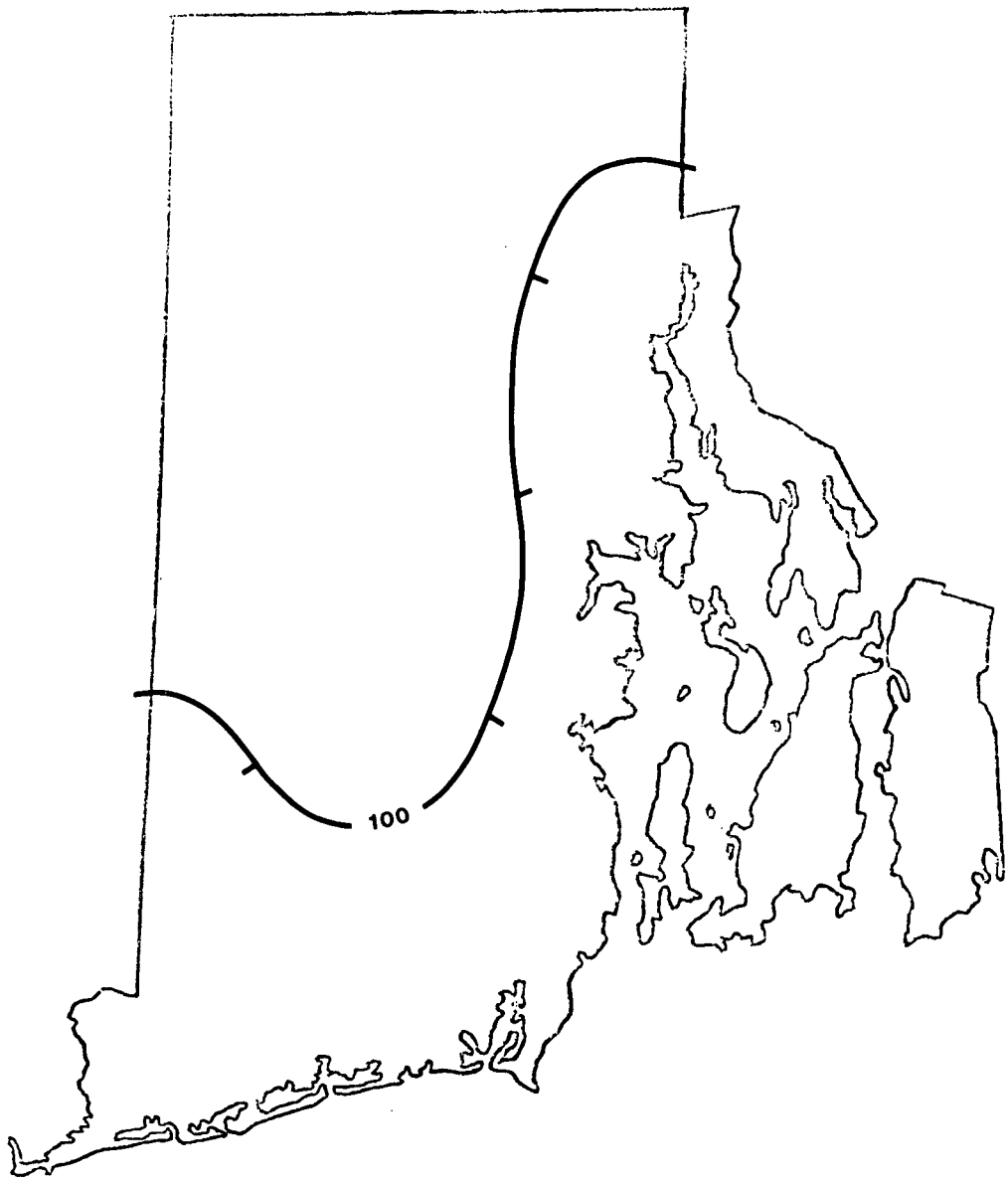
pH

6.1 - 8.0

Temperature contoured (°F)

0 10
Miles

Rhode Island

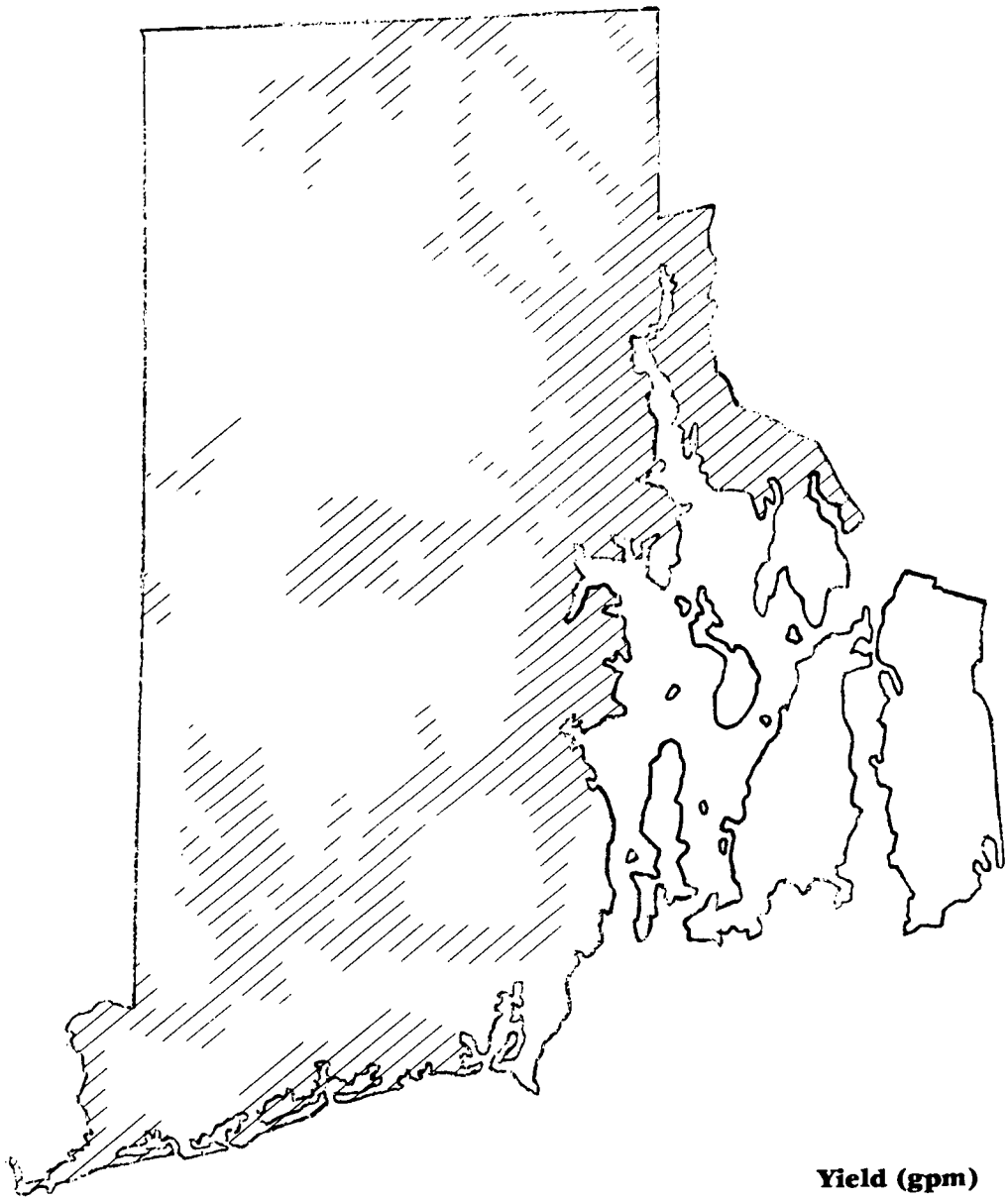


Potentiometric surface

(ft., Datum: mean sea level)

0 10
Miles

Rhode Island



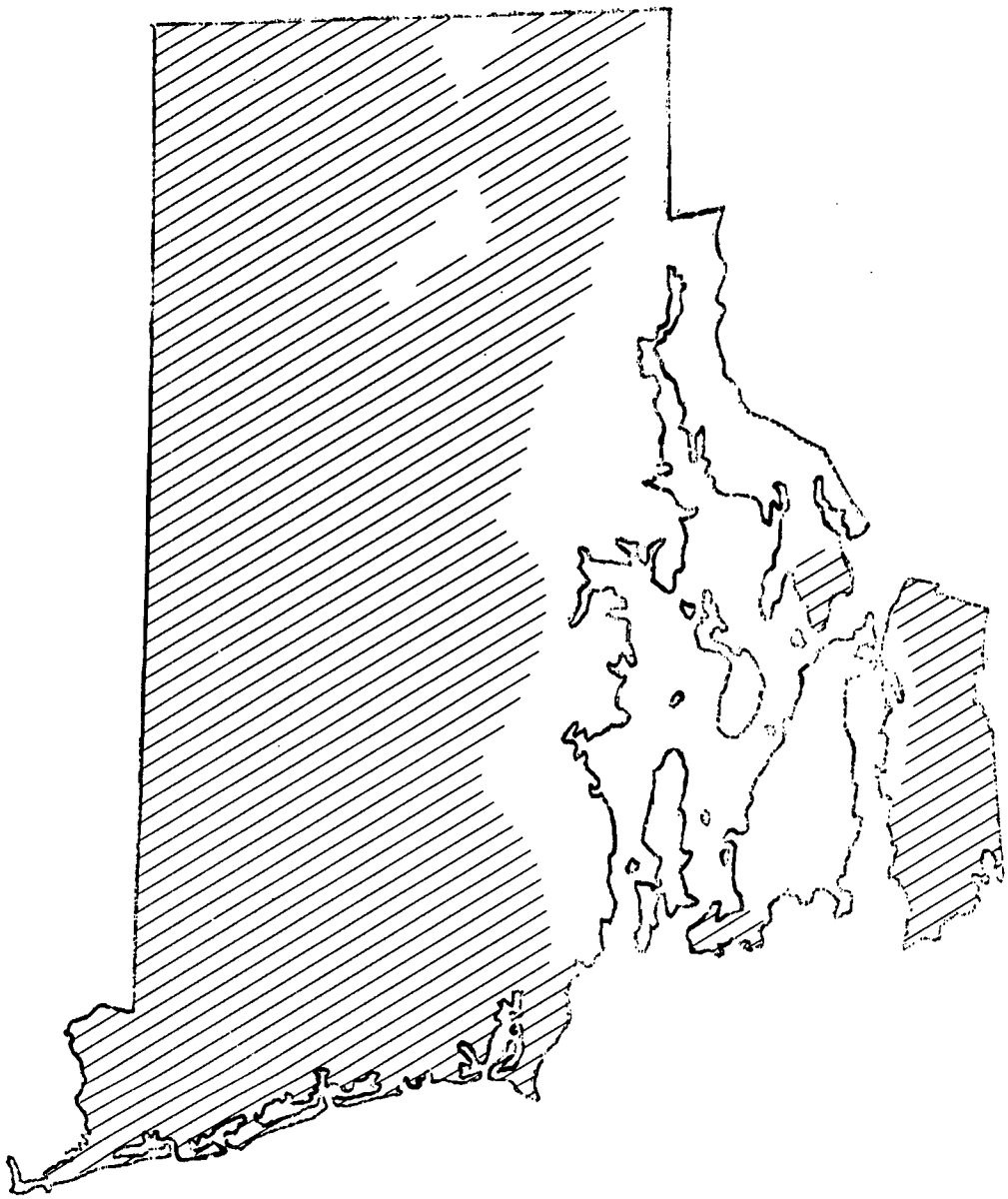
Yield (gpm)

Till, greater than 10 gpm

Outwash, 10-1000 gpm

0 10
Miles

Rhode Island



Yield (gpm)

0 10
Miles

Sedimentary rocks, 30 gpm average

Crystalline rocks (igneous and metamorphic) 12 gpm average

South Carolina

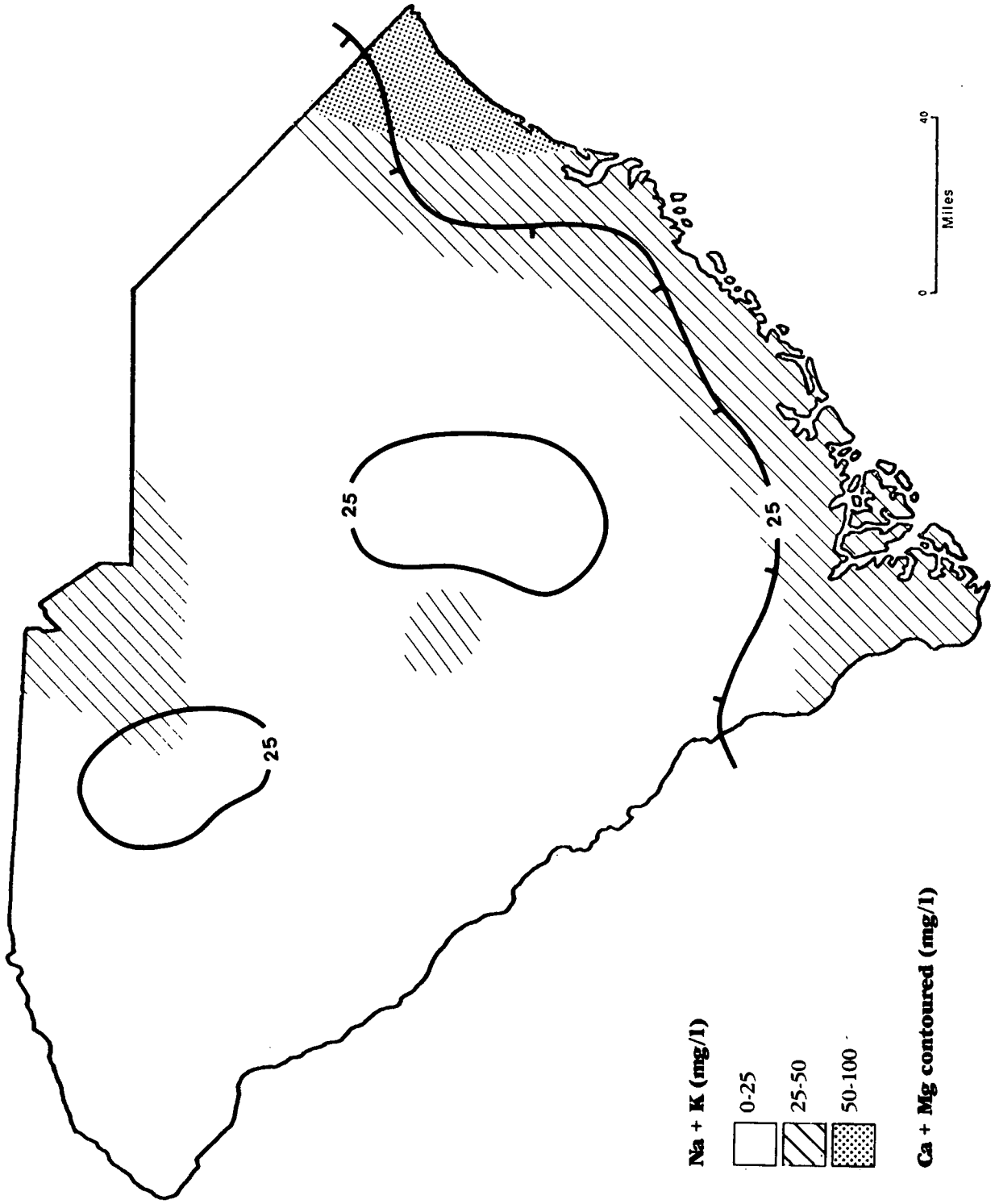
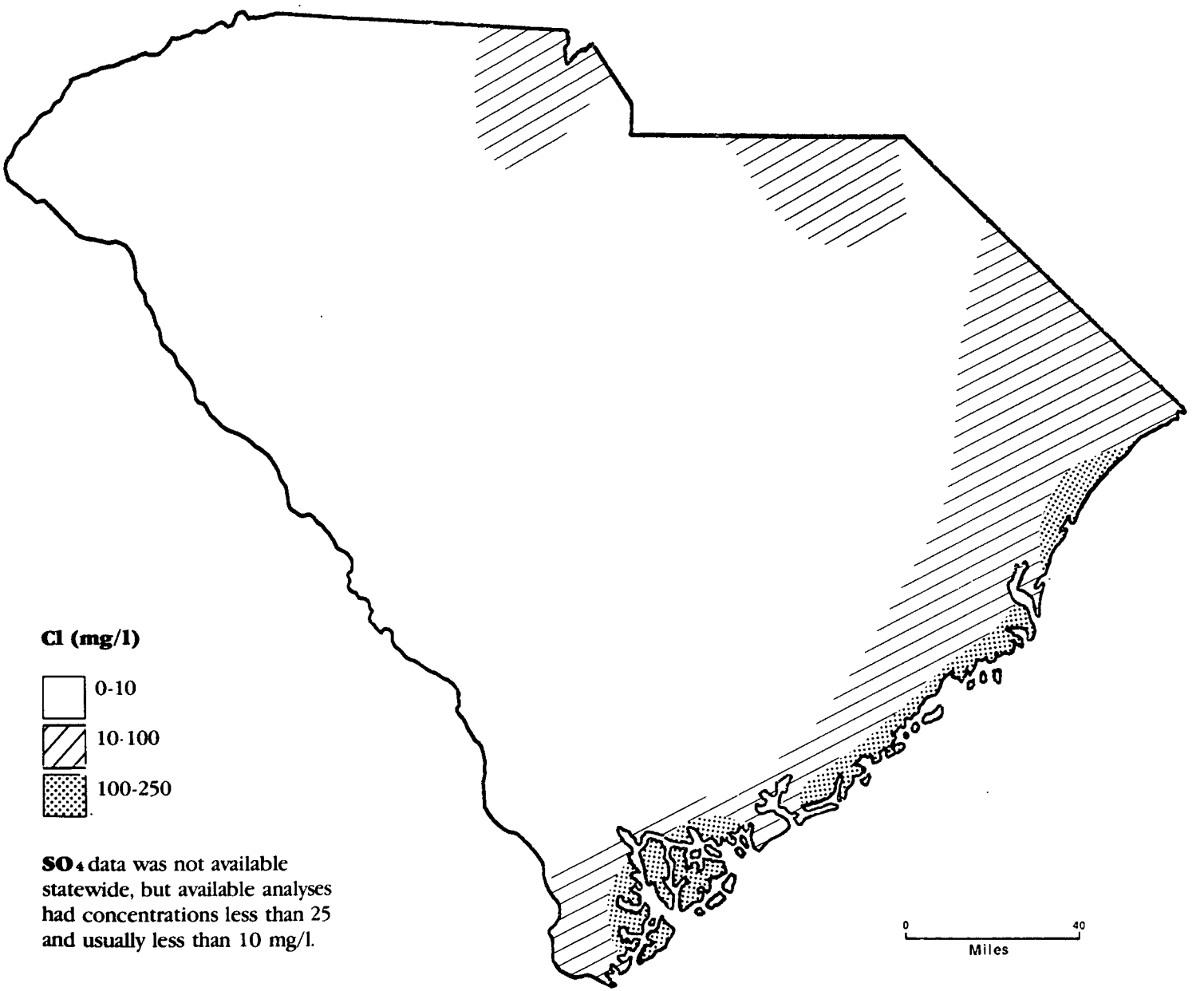


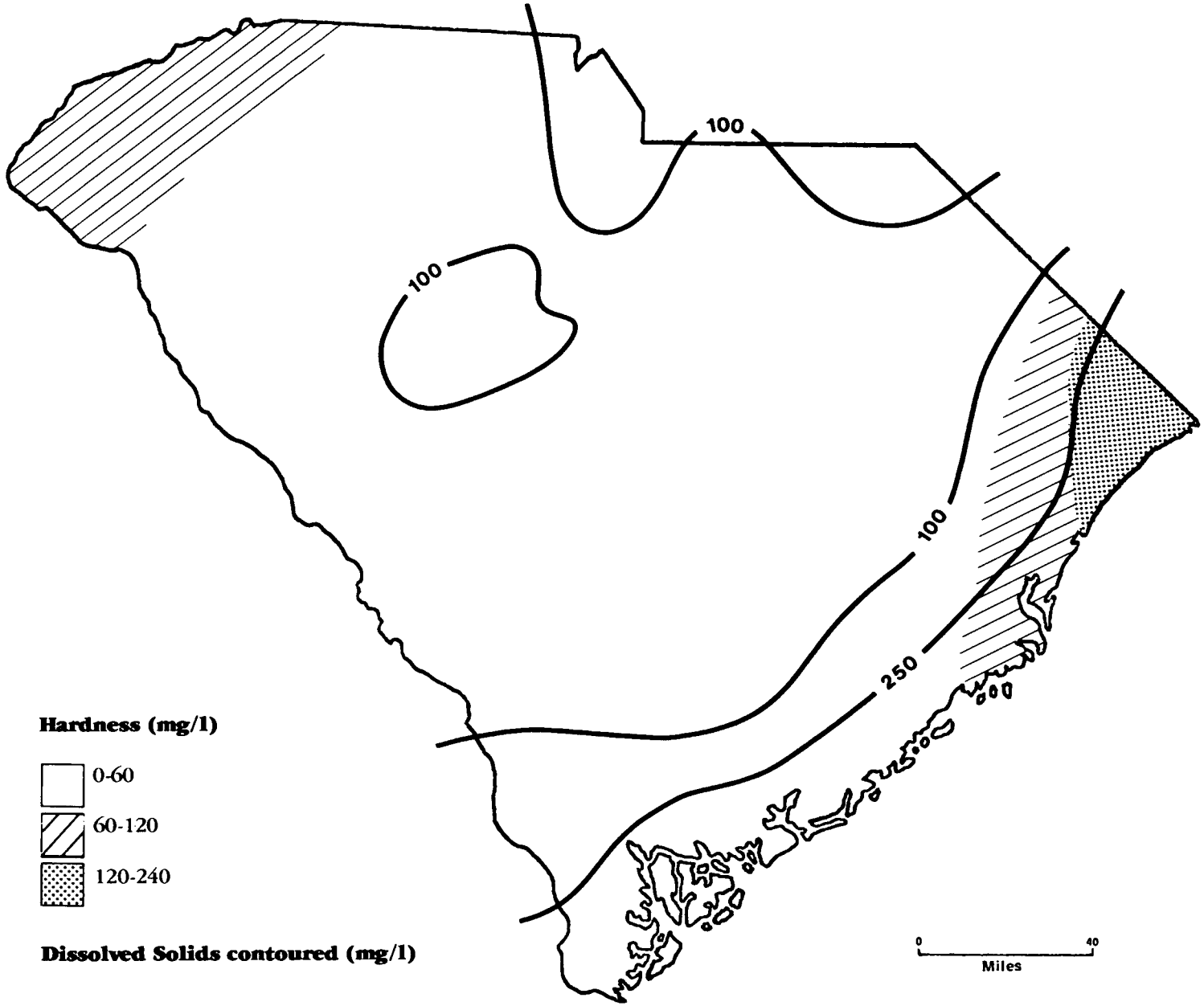
Plate 300

South Carolina

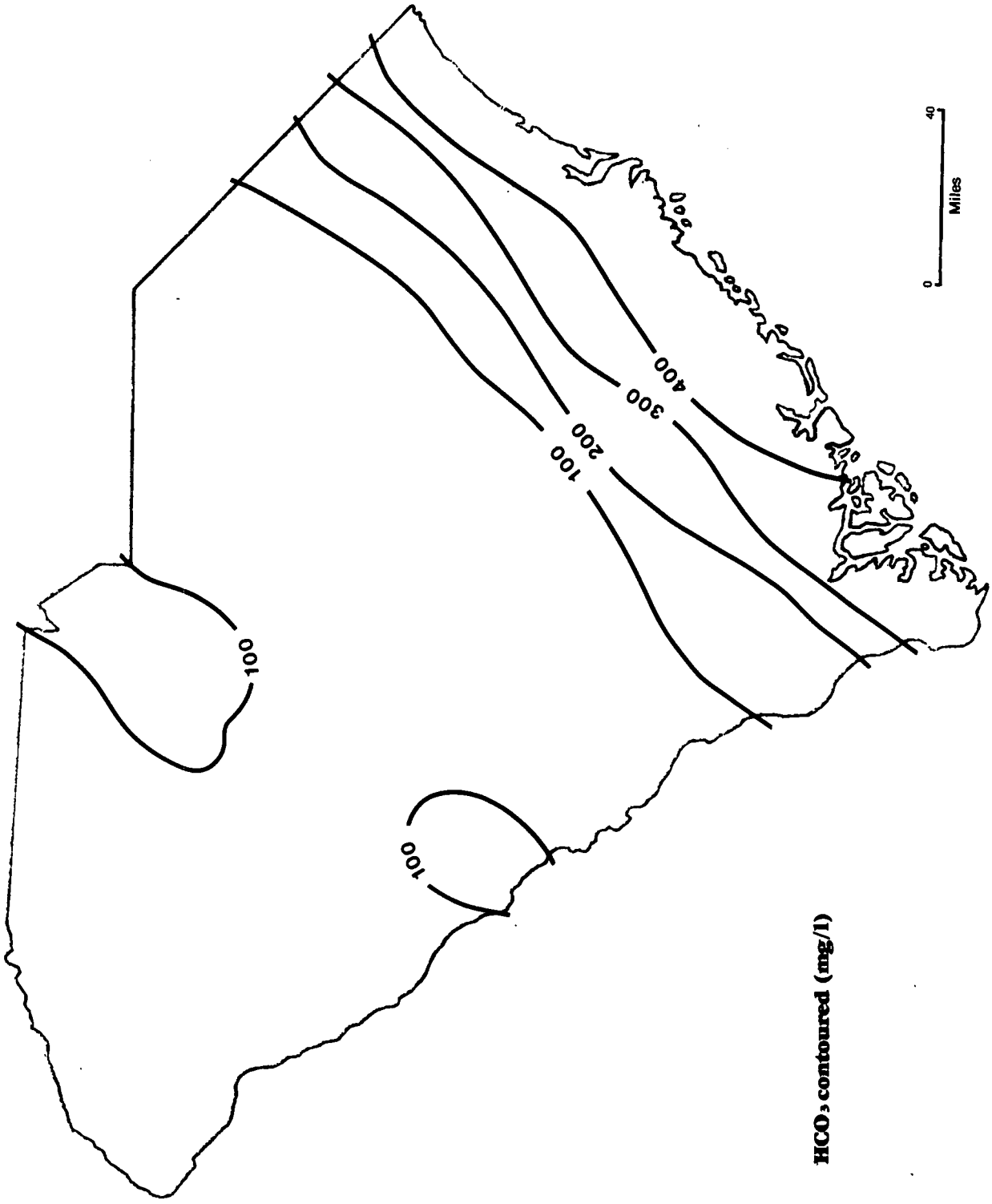


SO_4 data was not available statewide, but available analyses had concentrations less than 25 and usually less than 10 mg/l.

South Carolina



South Carolina



HCO_3 contoured (mg/l)

South Carolina

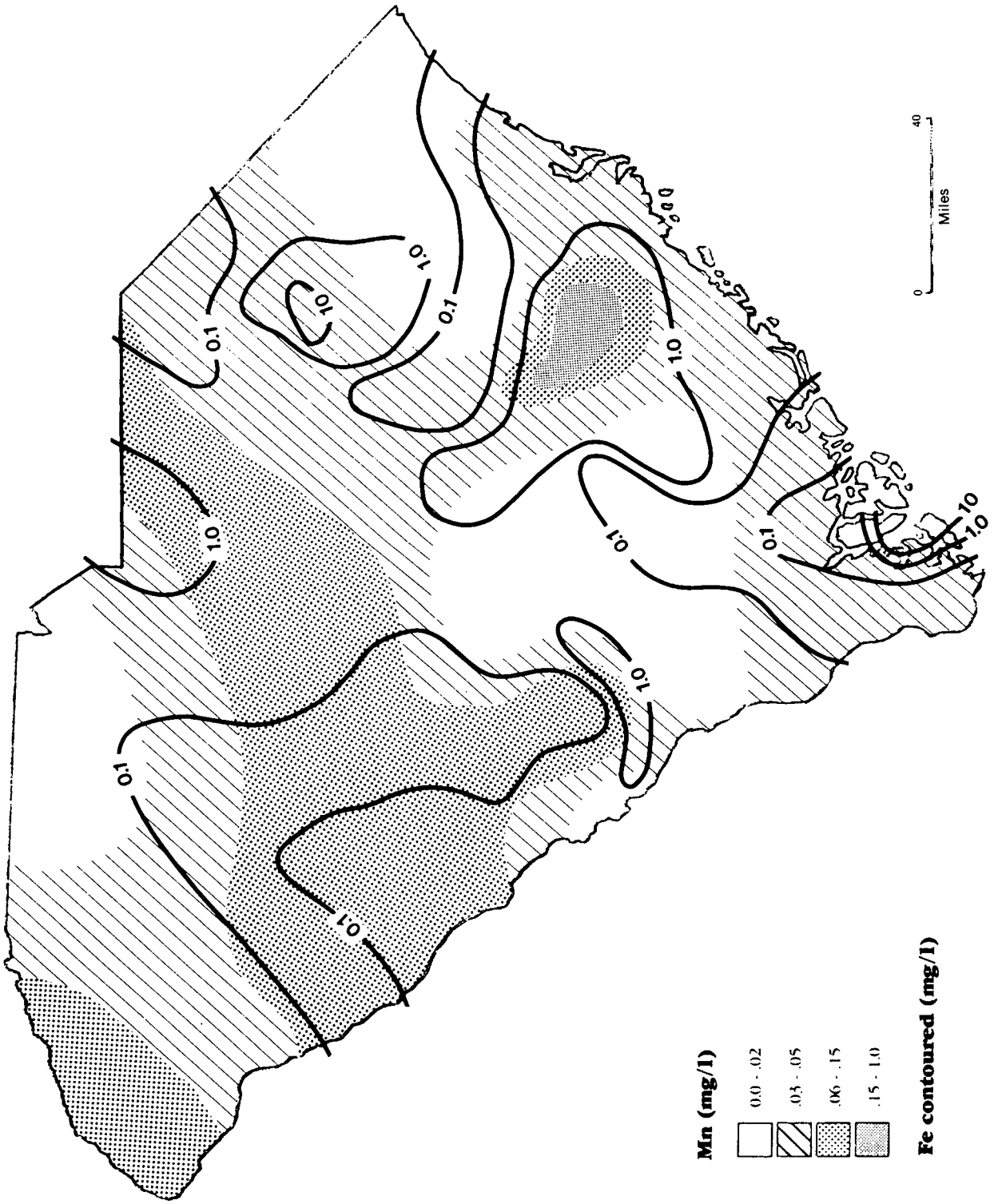
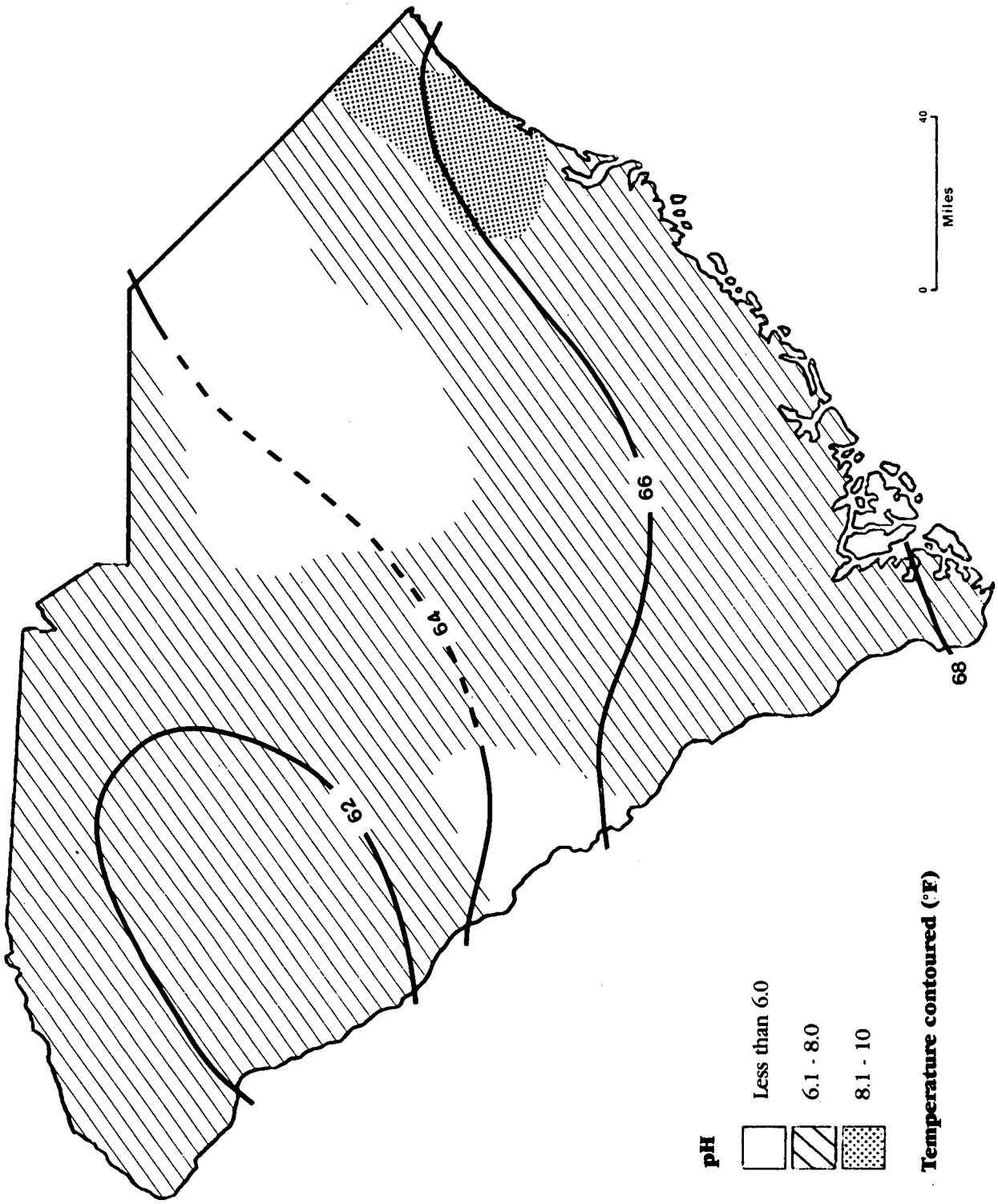
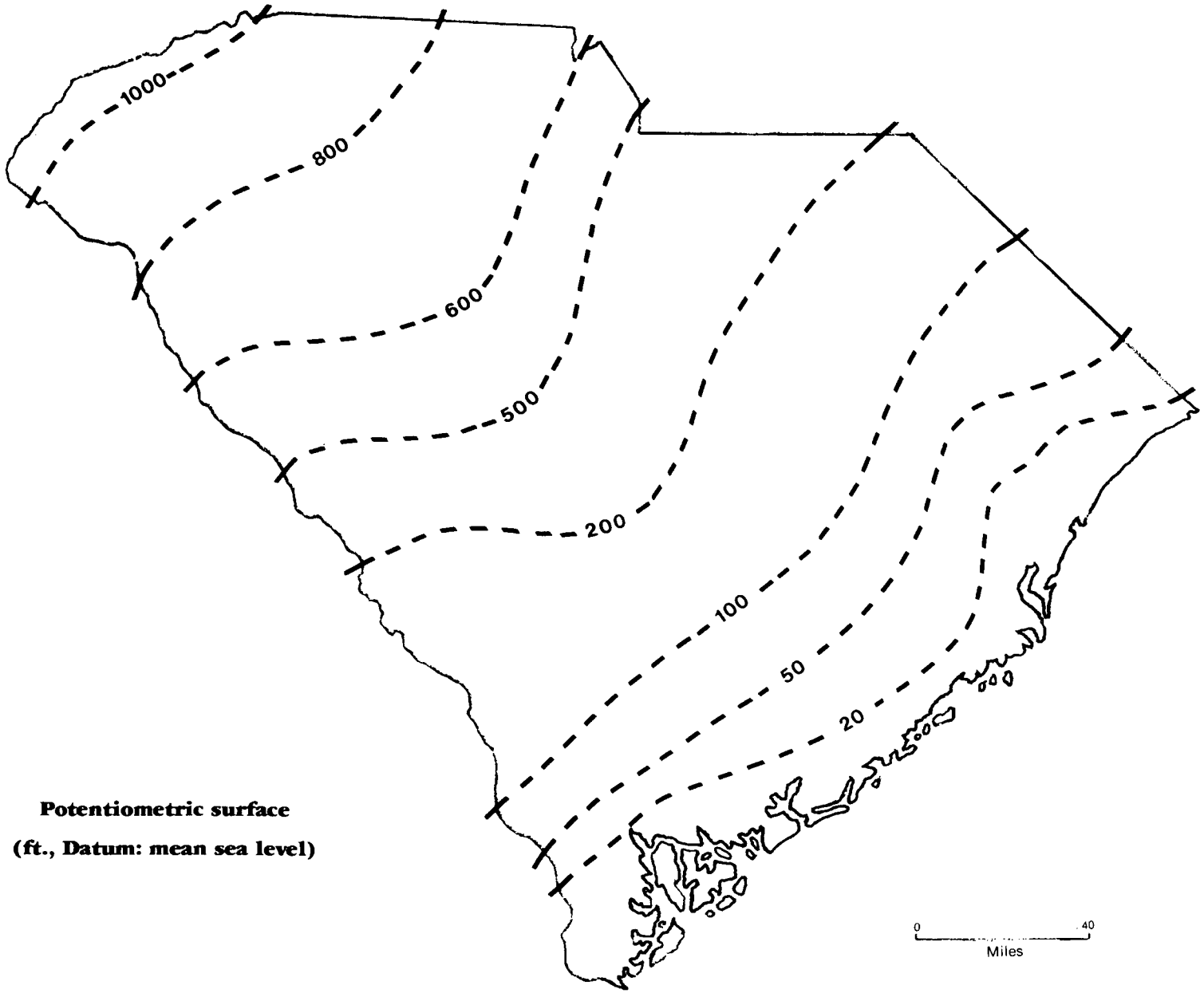


Plate 304

South Carolina

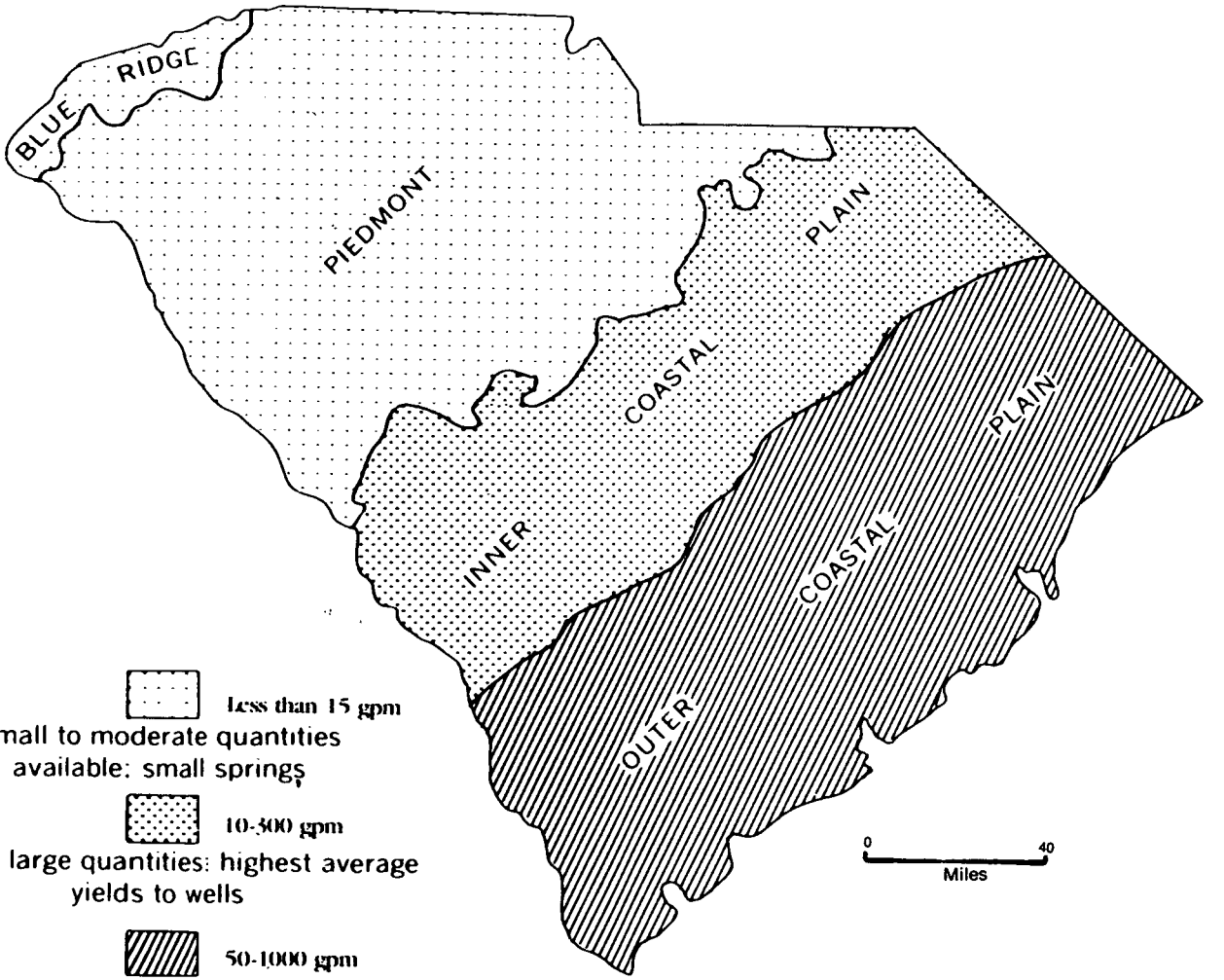


South Carolina



Potentiometric surface
(ft., Datum: mean sea level)

South Carolina



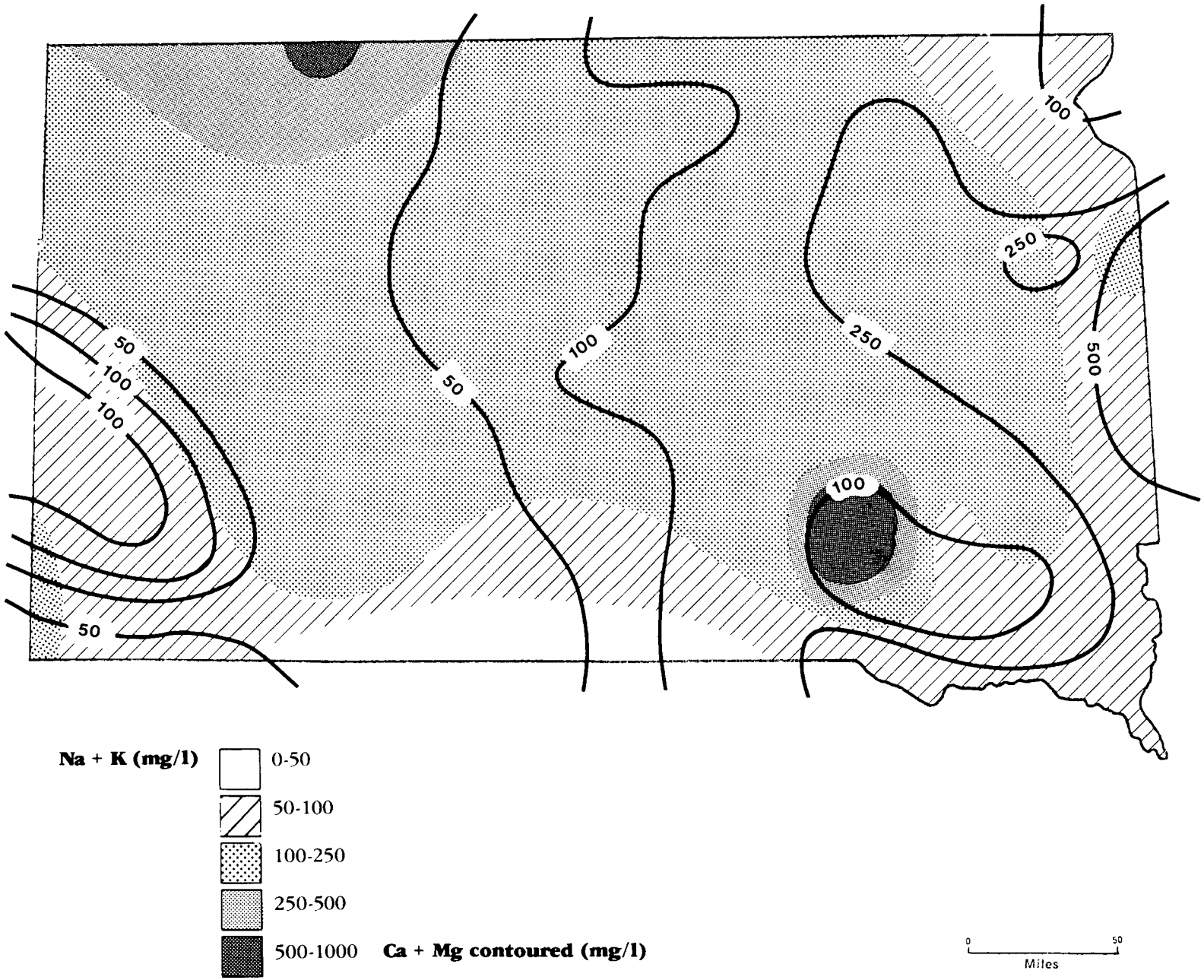
Less than 15 gpm
Small to moderate quantities available: small springs

10-300 gpm
Small to large quantities: highest average yields to wells

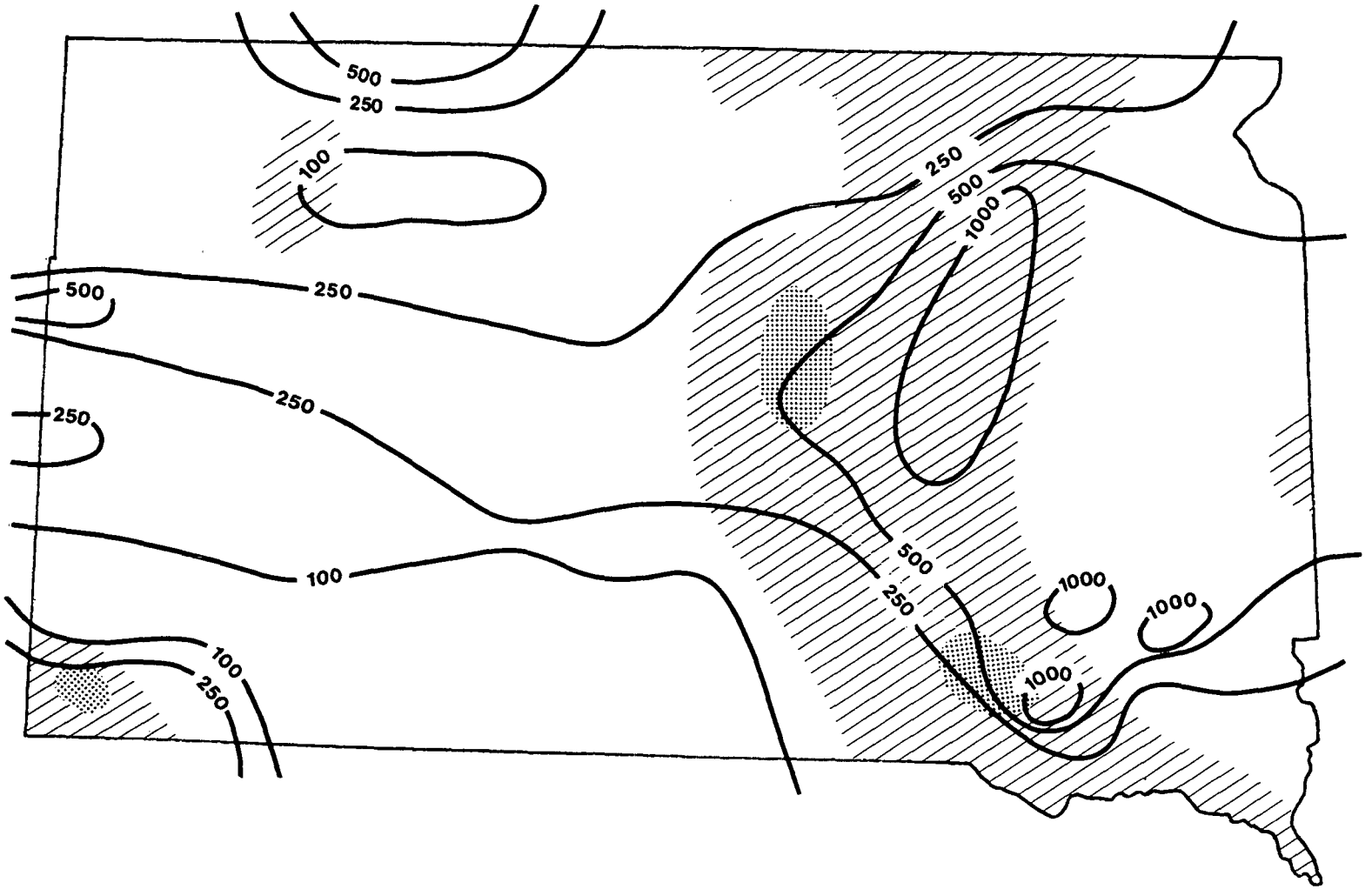
50-1000 gpm
Moderate to large quantities: some coastal areas subject to brackish-water encroachment

AVAILABILITY OF GROUND WATER IN THE PHYSIOGRAPHIC PROVINCES IN SOUTH CAROLINA

South Dakota



South Dakota



Cl (mg/l)

- 0-25
- 25-250
- 250-500

SO_4 contoured (mg/l)

0 — 50 Miles

South Dakota

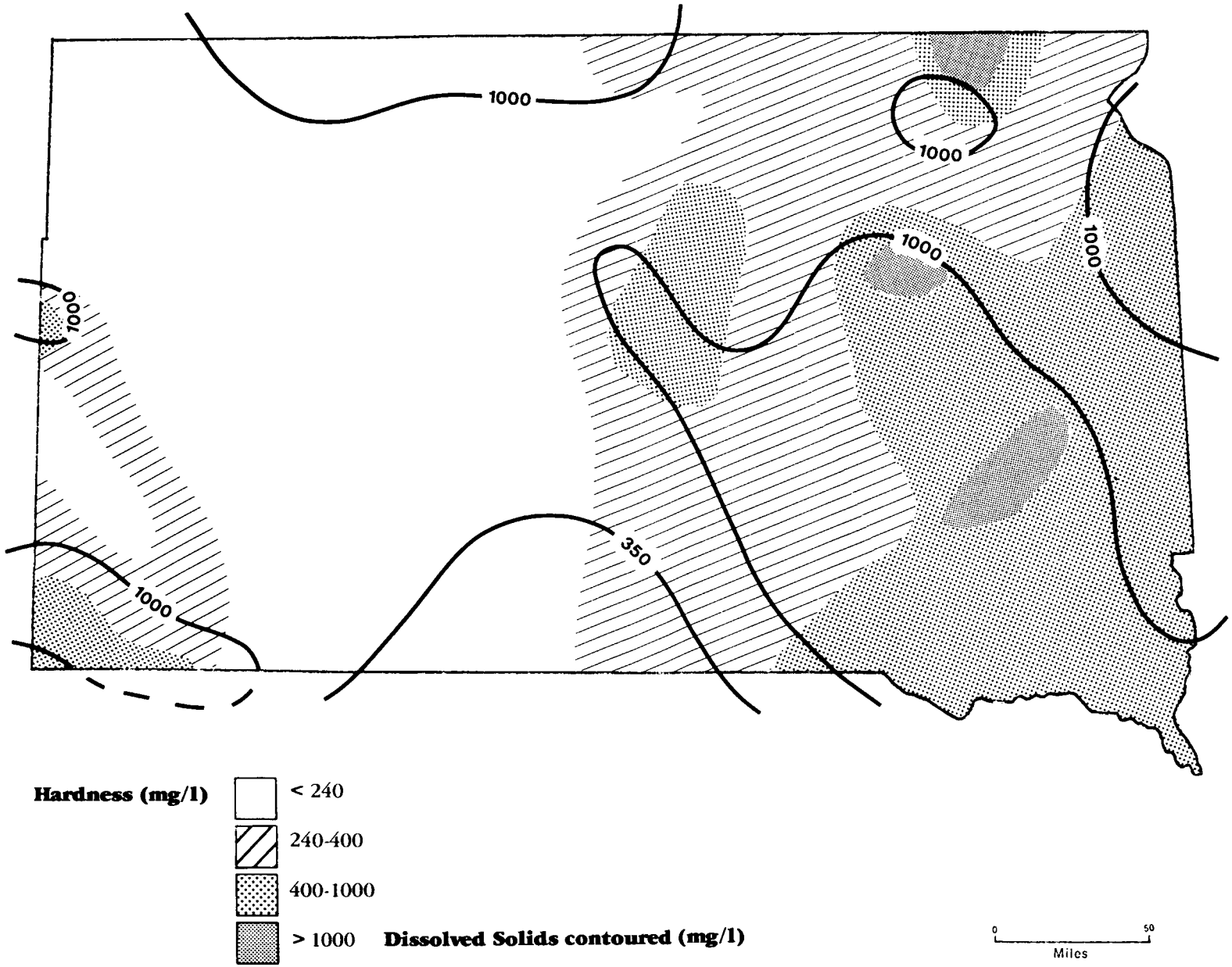
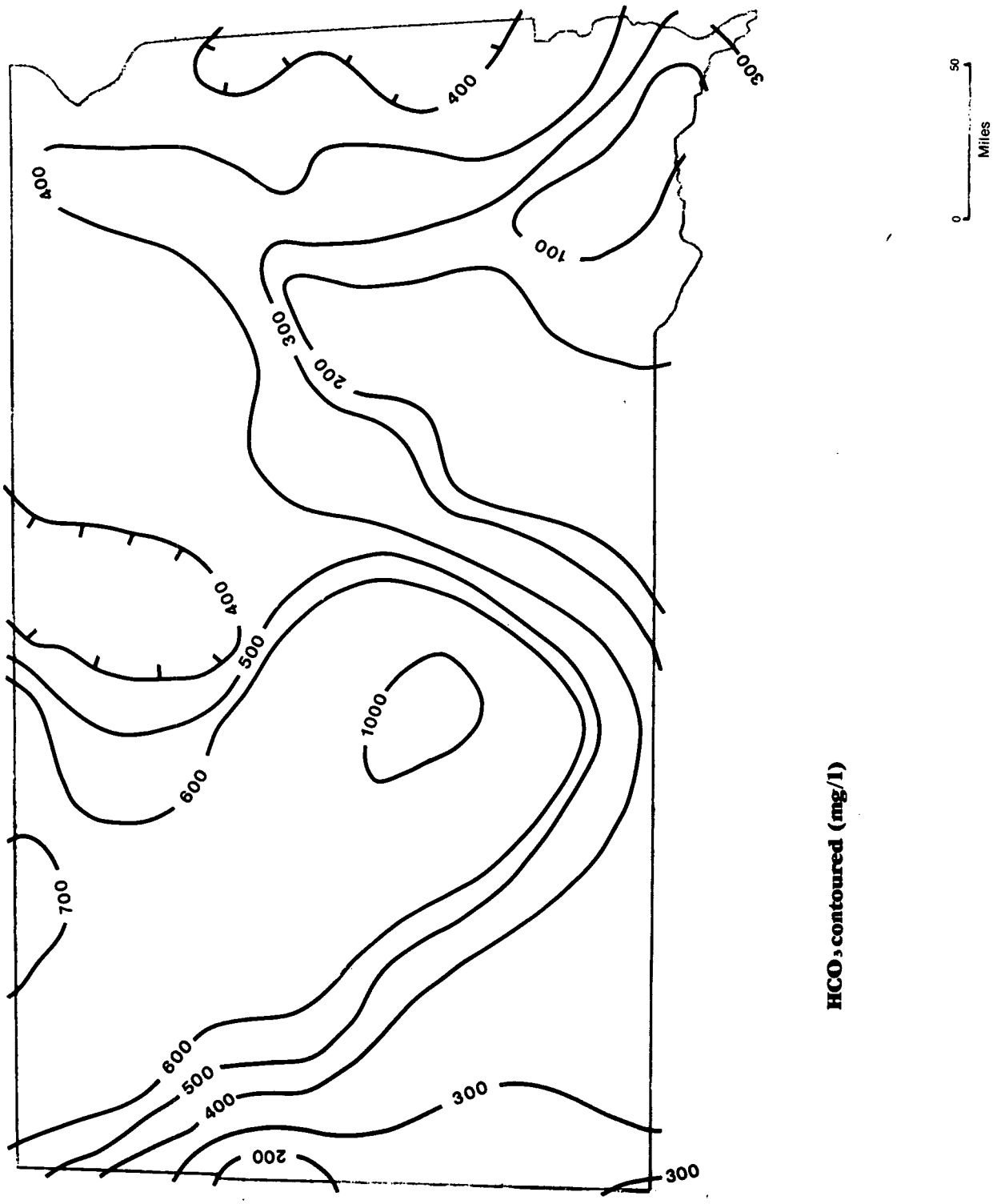


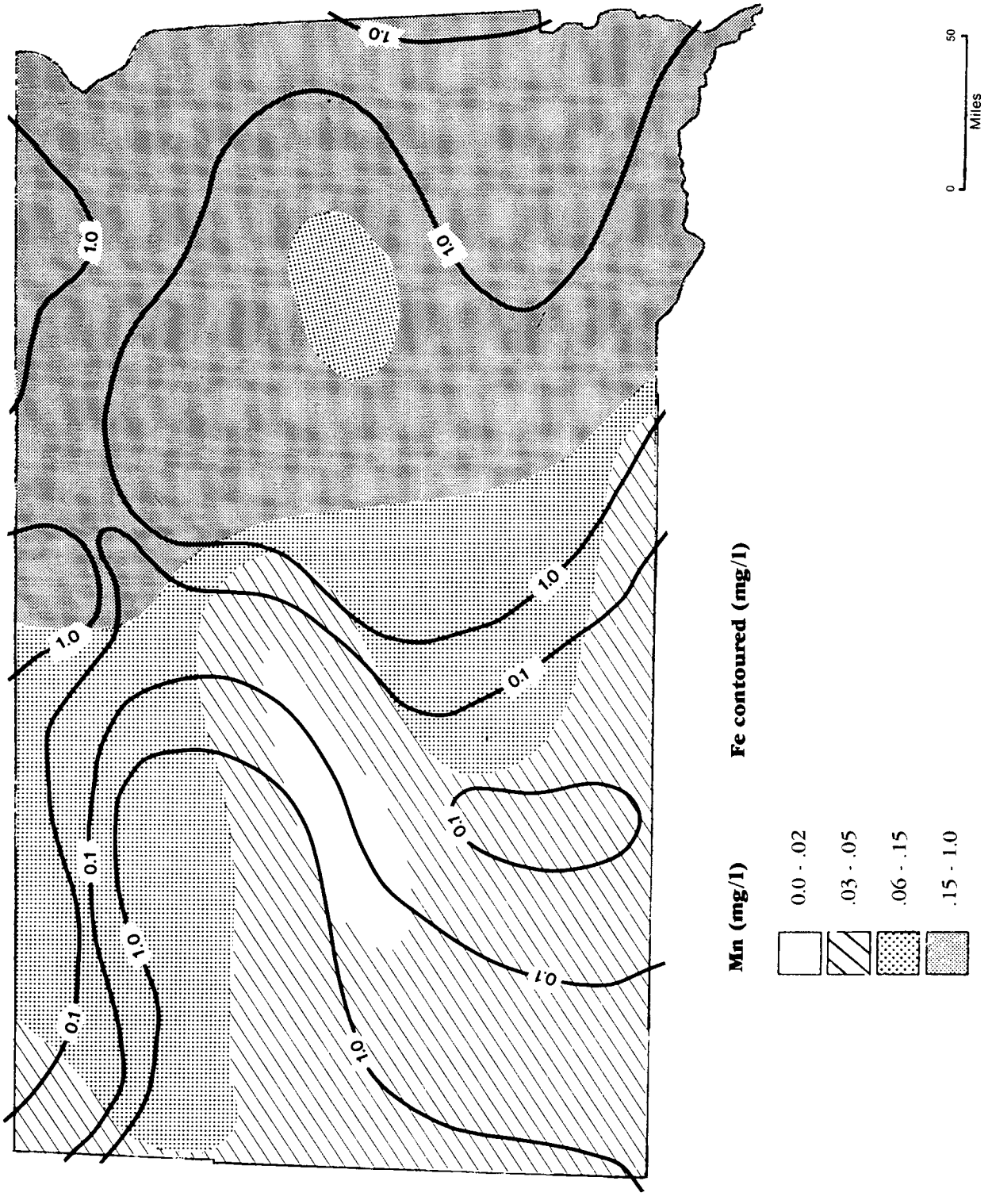
Plate 310

South Dakota

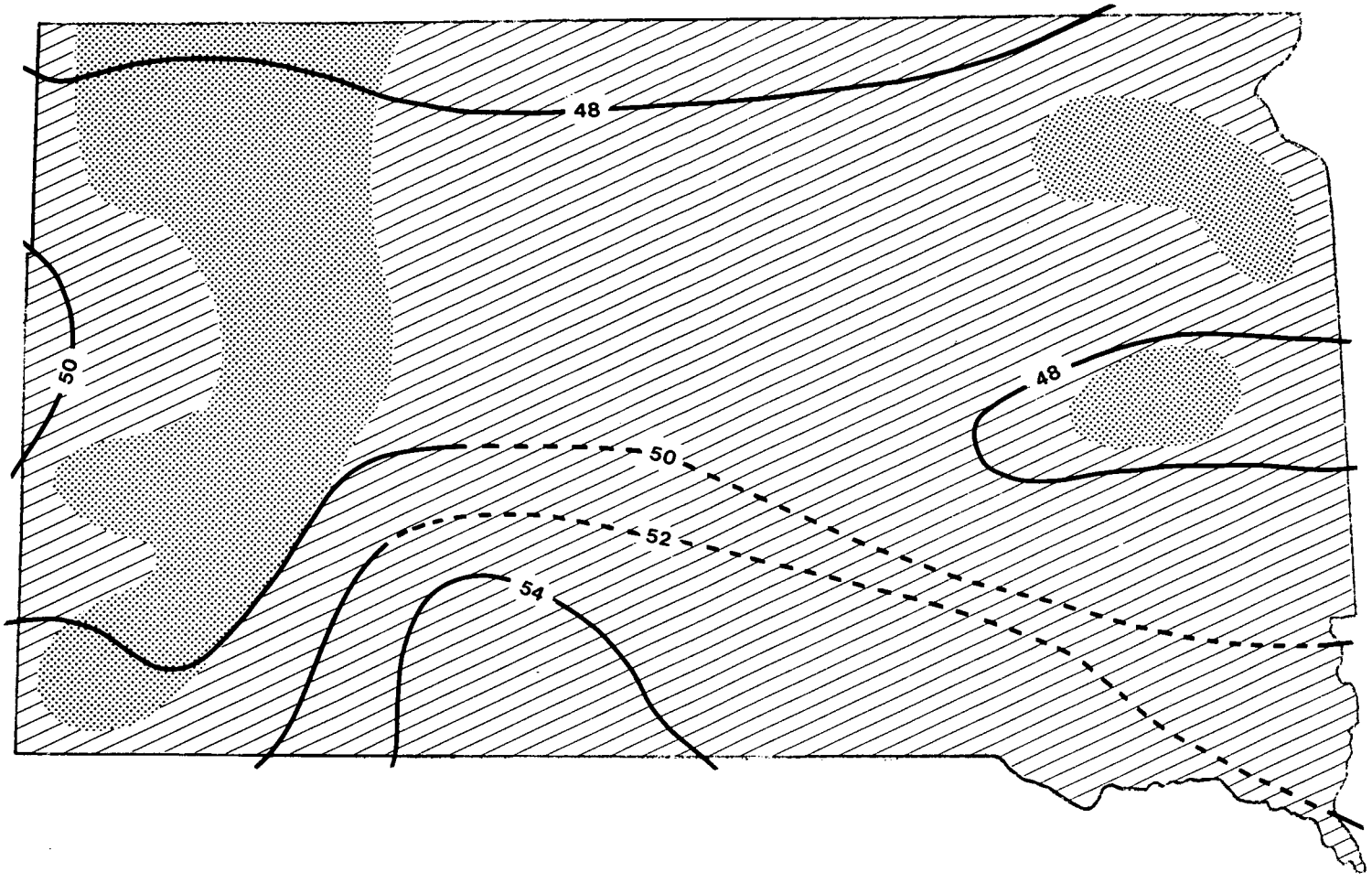


HCO_3 contoured (mg/l)

South Dakota



South Dakota



pH

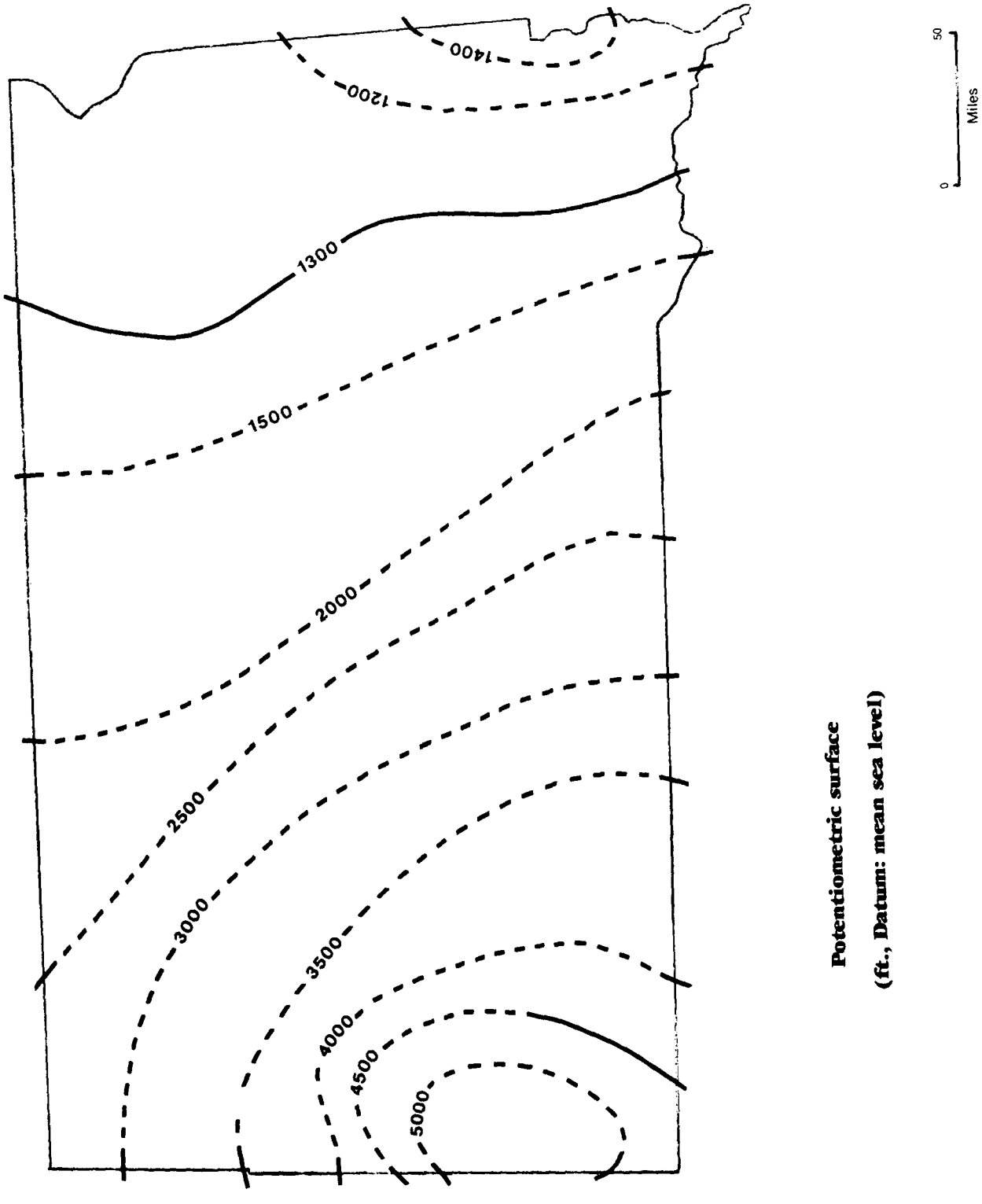
6.1 - 8.0

8.1 - 10

Temperature contoured (°F)

0 50
Miles

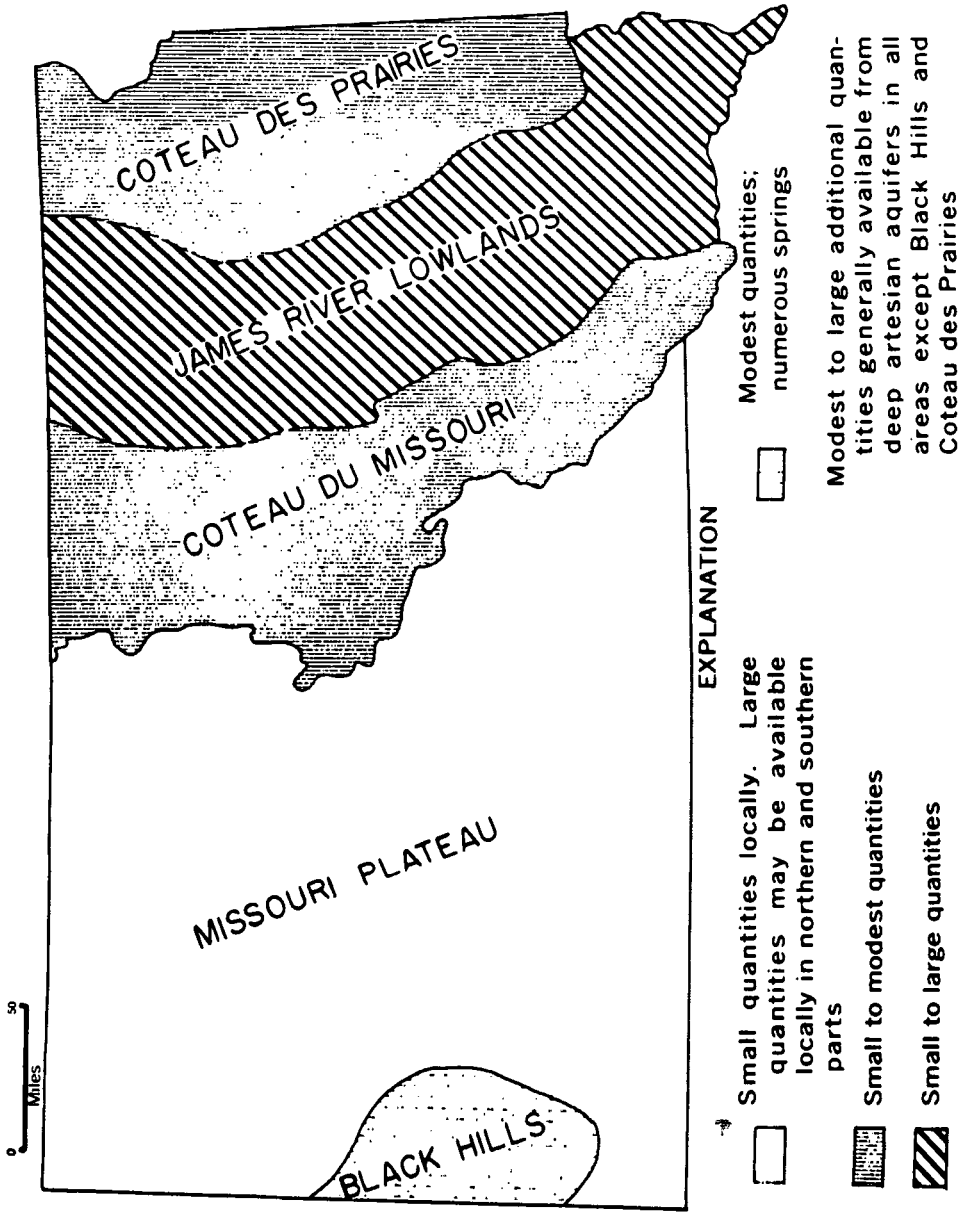
South Dakota



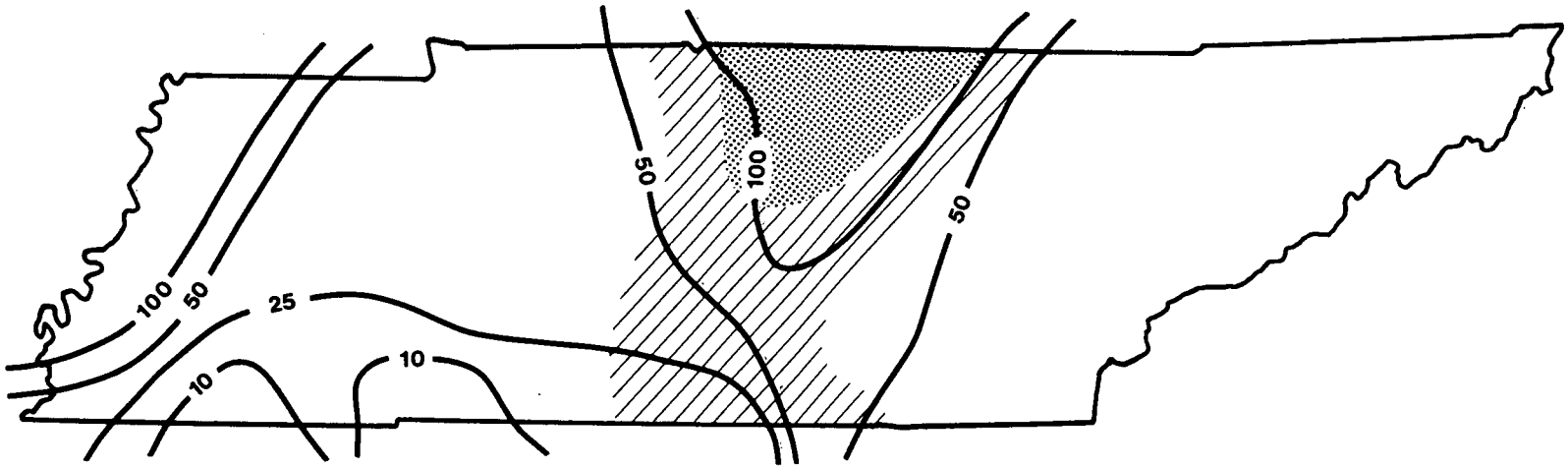
Potentiometric surface

(ft., Datum: mean sea level)

South Dakota



Tennessee



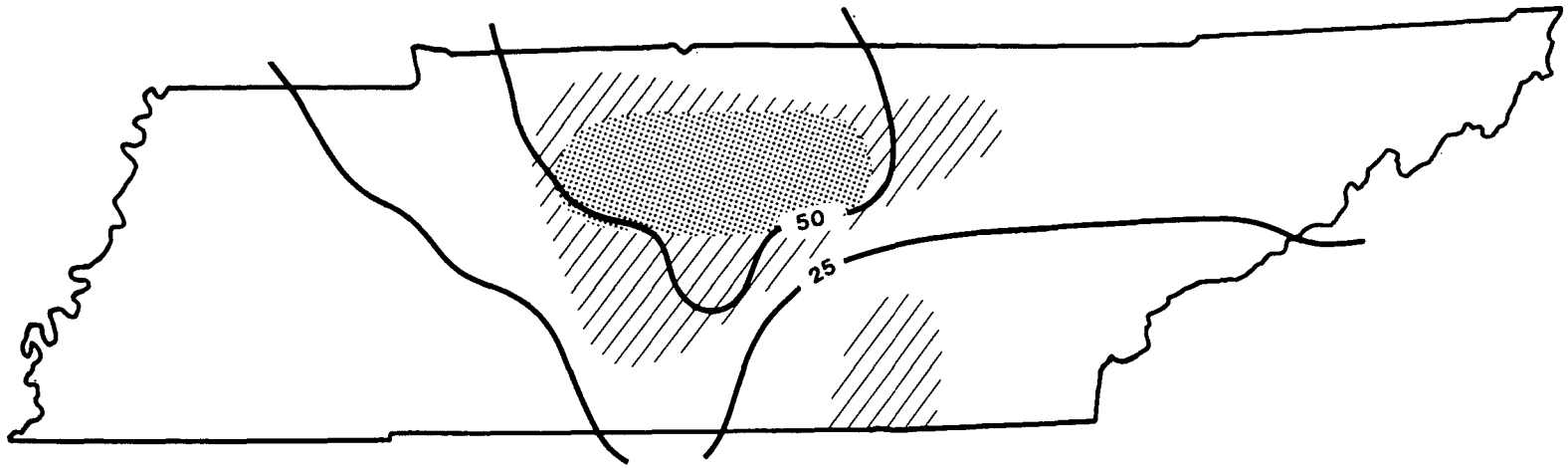
Na + K (mg/l)

- 0-25
- 25-100
- 100-250

Ca + Mg contoured (mg/l)

0 — 50
Miles

Tennessee



Cl (mg/l)

- 0-25
- 25-50
- 50-100

SO_4 contoured (mg/l)

0 50
Miles

Tennessee

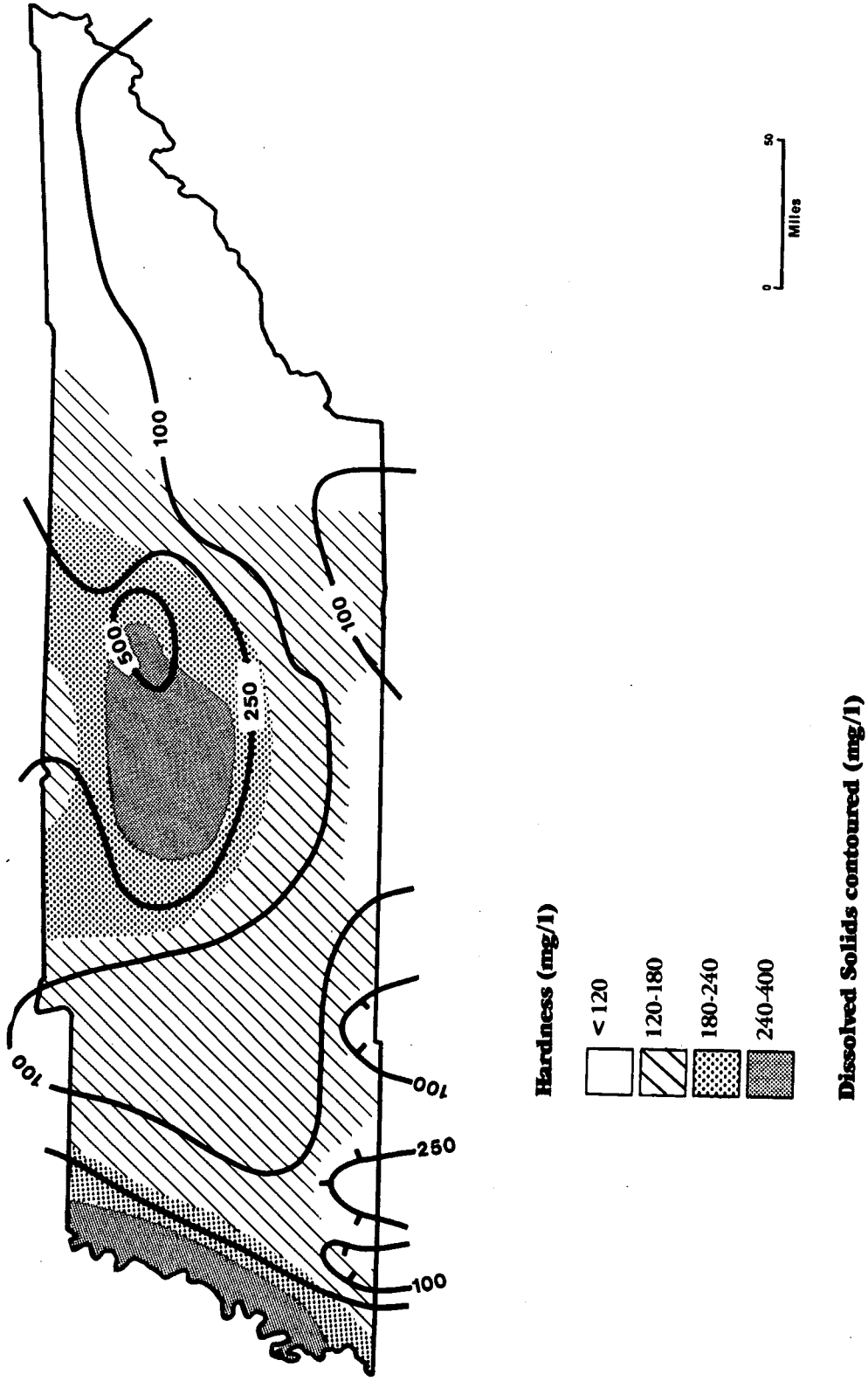
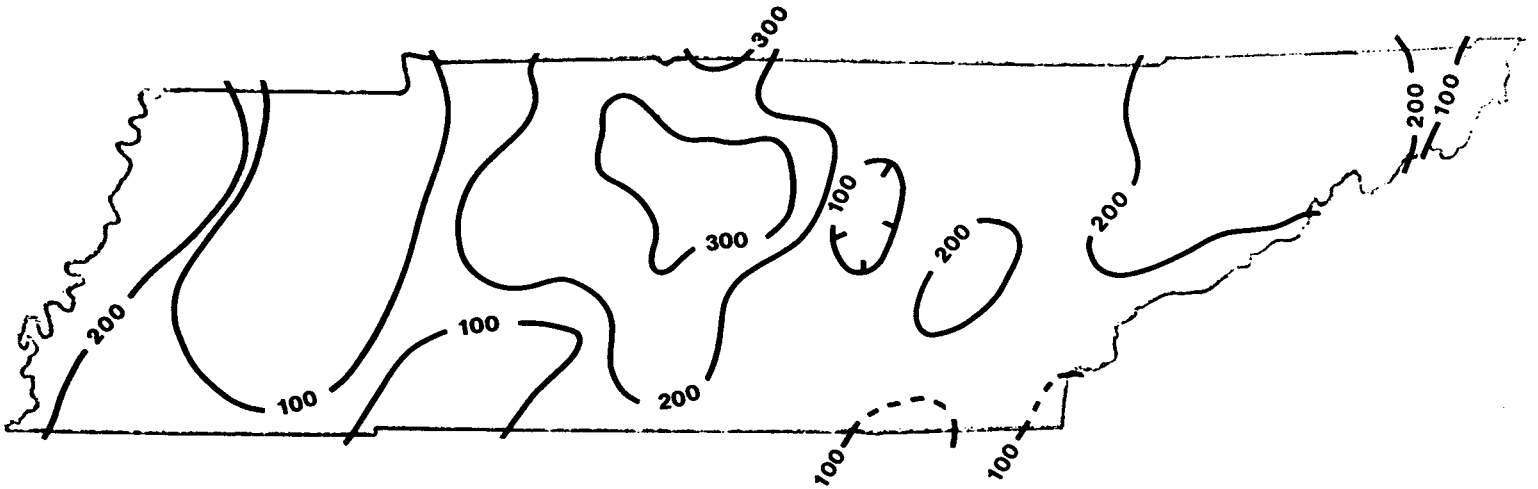


Plate 318

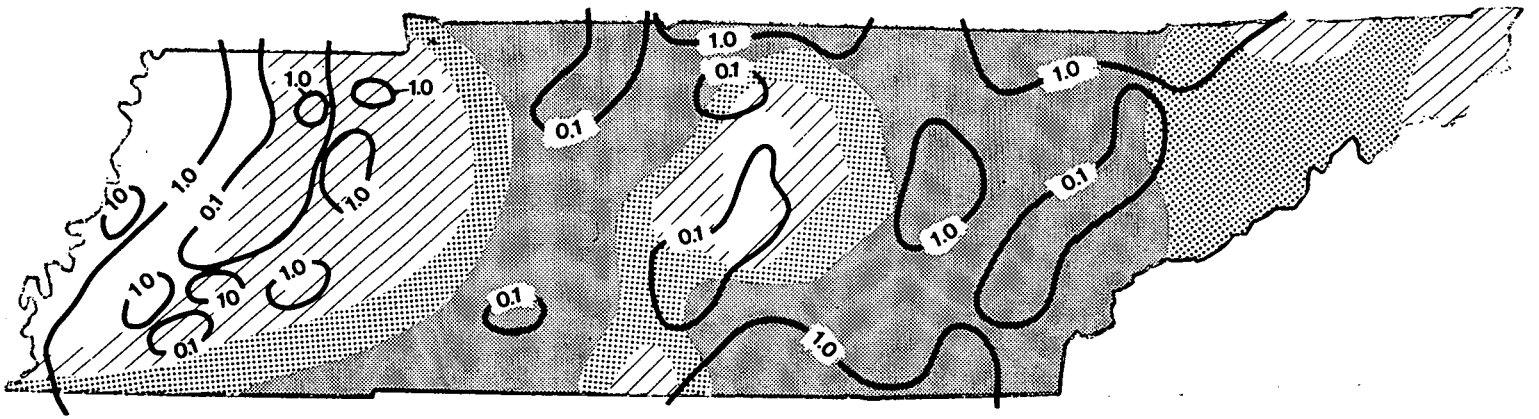
Tennessee



HCO_3 contoured (mg/l)

0 50
Miles

Tennessee



Mn (mg/l)

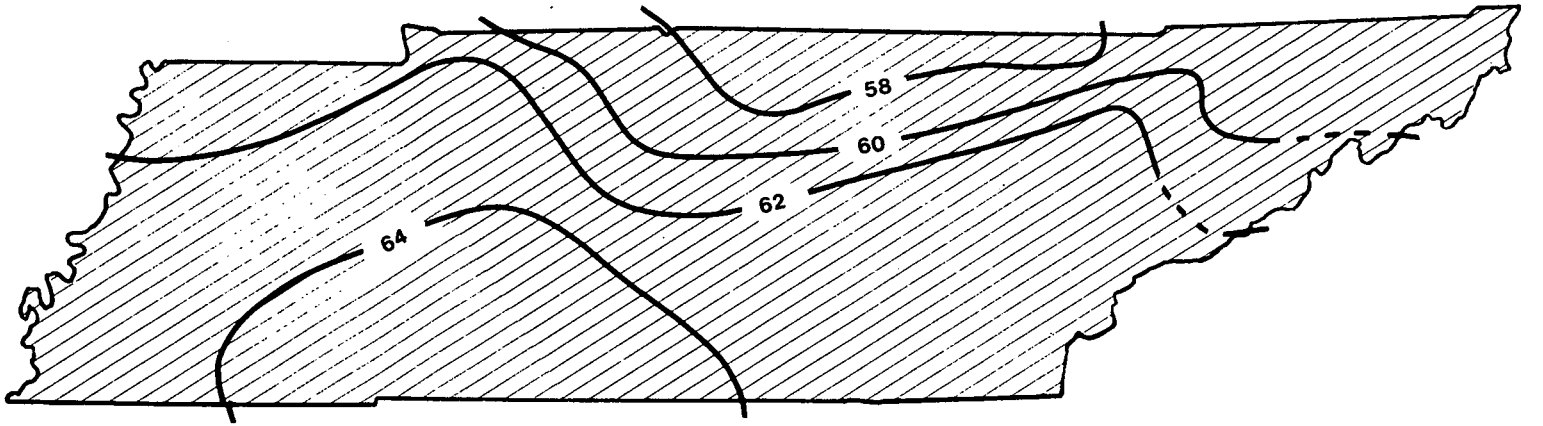
- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

0 — 50 Miles

Plate 320

Tennessee



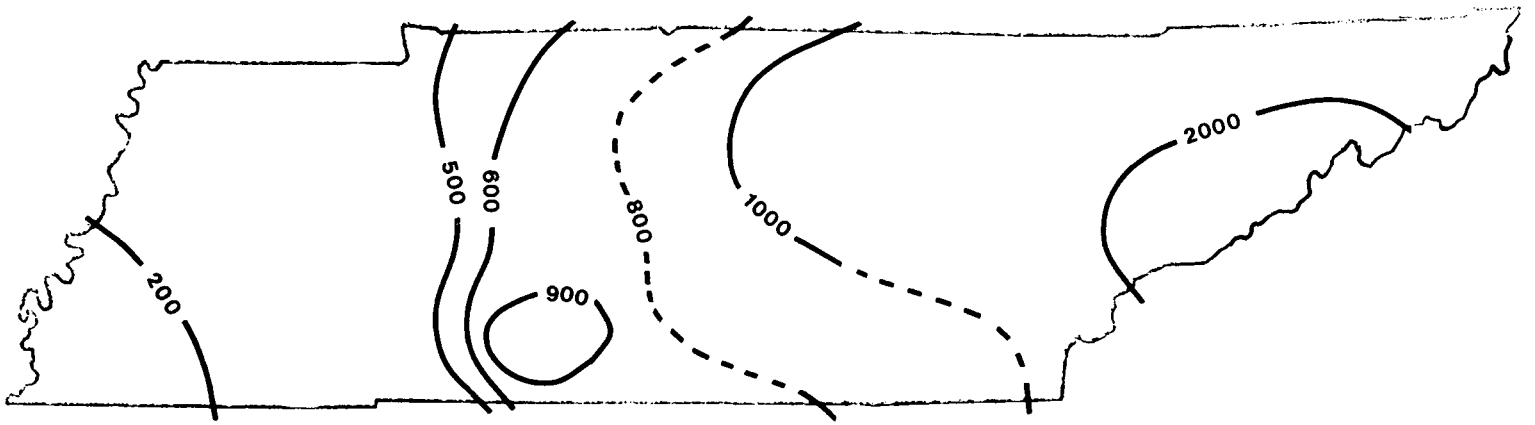
pH

6.1 - 8.0

Temperature contoured (°F)

0 50
Miles

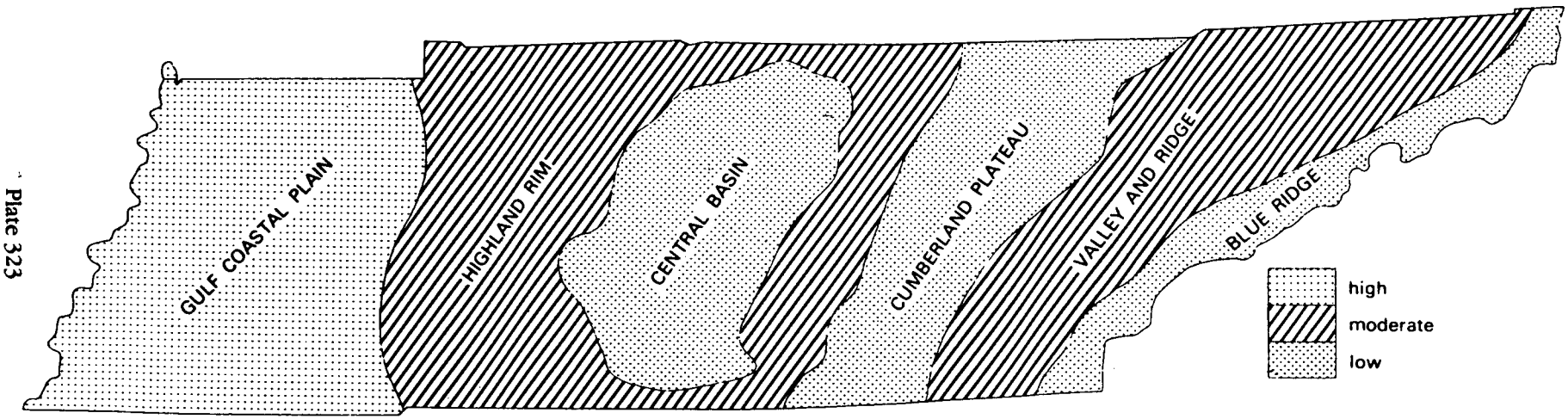
Tennessee



Potentiometric surface (ft., Datum: *mean sea level*)

0 50
Miles

Tennessee

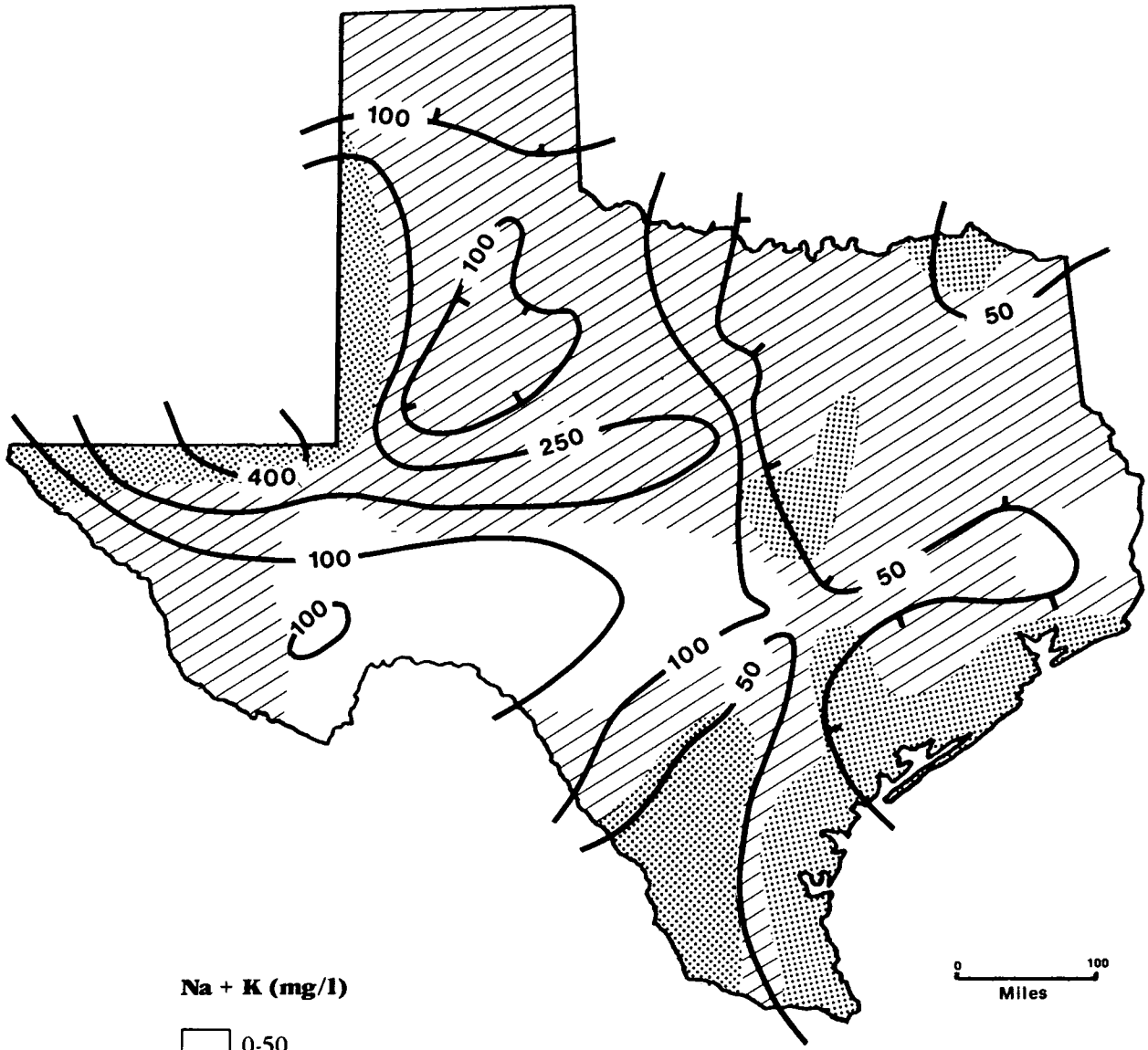


RELATIVE POTENTIAL FOR DEVELOPMENT OF LARGE GROUND-WATER SUPPLIES

0 50
Miles

Plate 323

Texas



Na + K (mg/l)

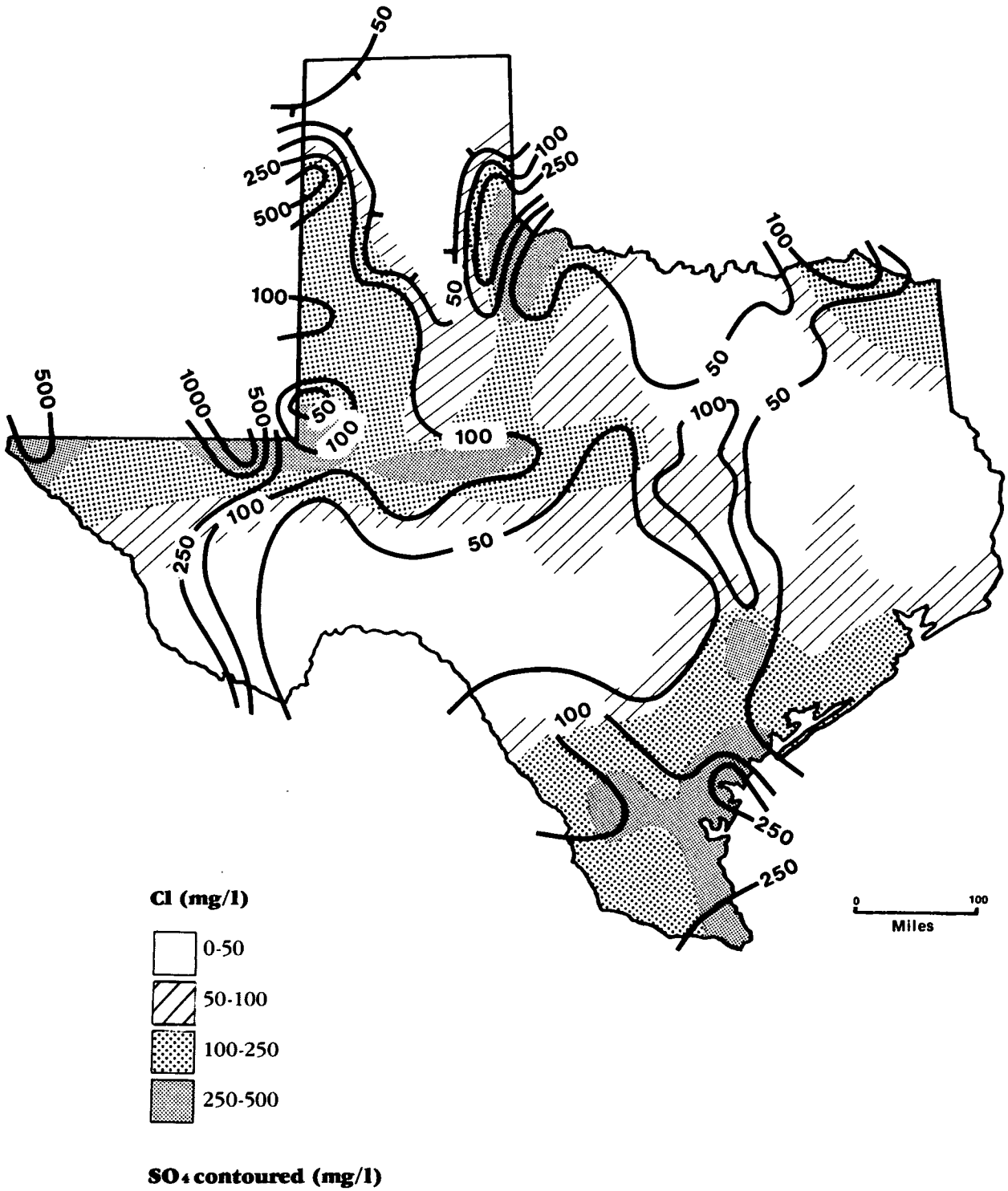
0-50

50-250

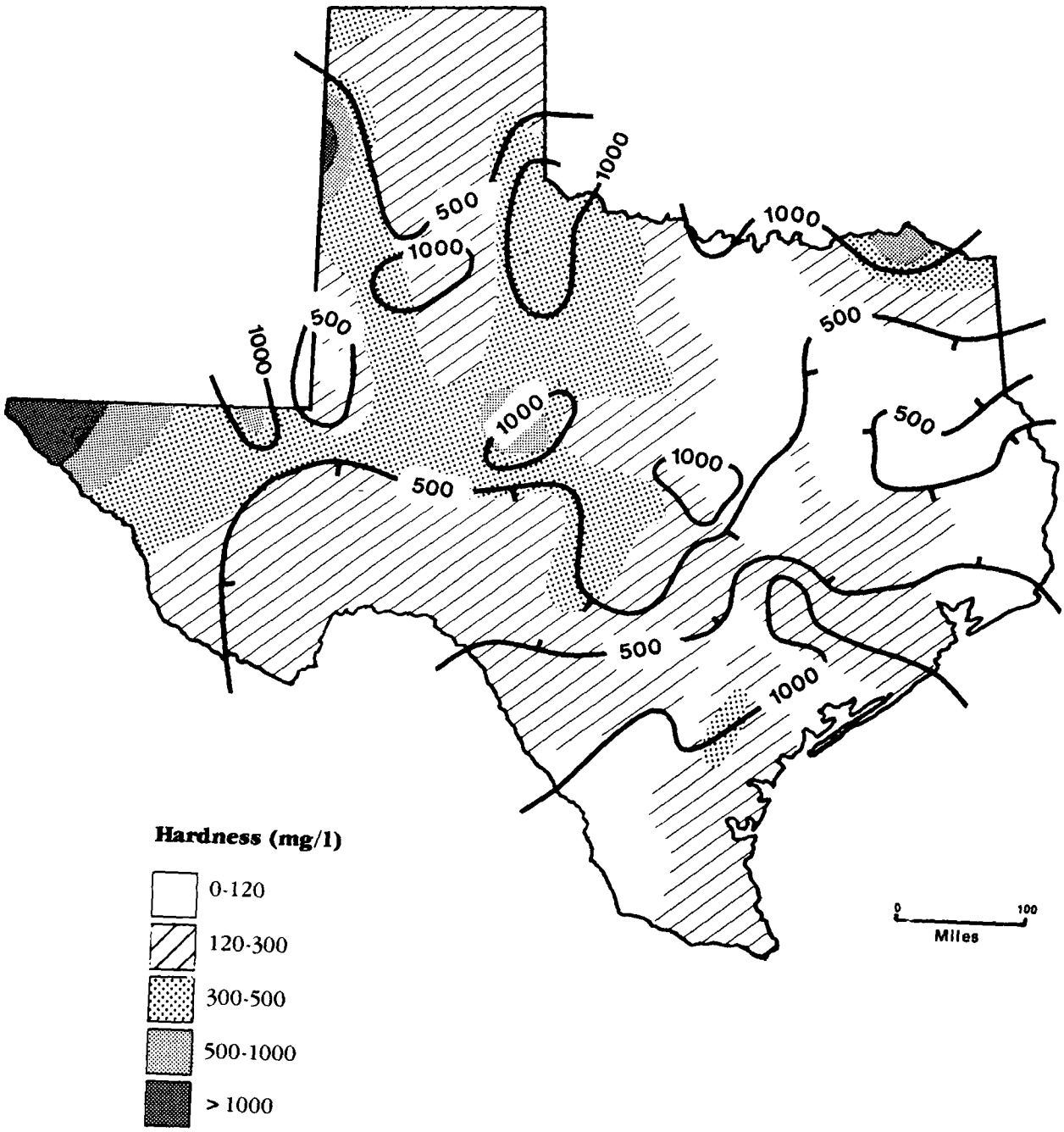
250-500

Ca + Mg contoured (mg/l)

Texas

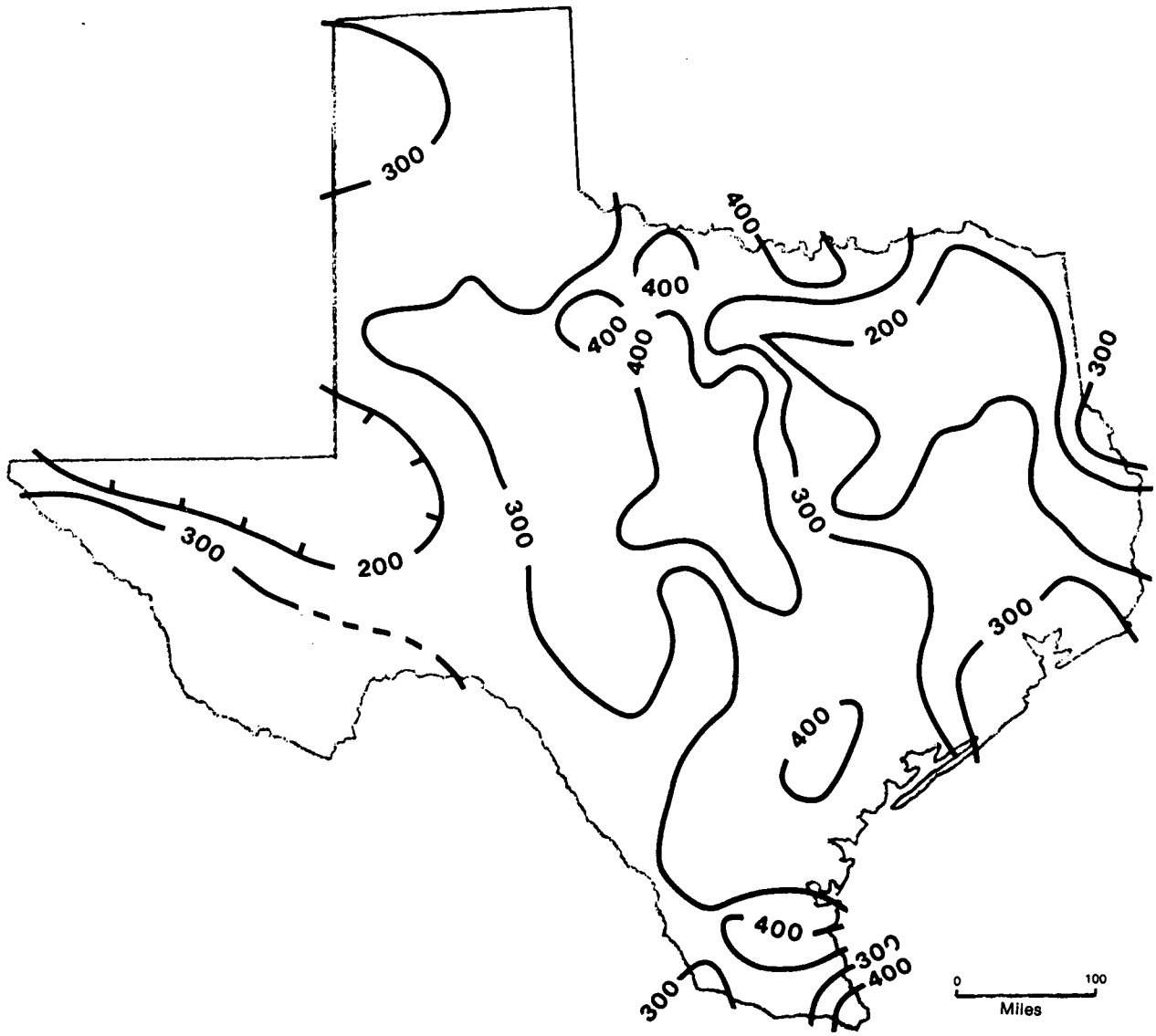

50
250
500
100
100
250
50
100
500
1000
500
50
100
100
100
50
50
100
50
250
100
50
100
250
250
0
100
Miles
Cl (mg/l)
0-50
50-100
100-250
250-500
SO4 contoured (mg/l)

Texas



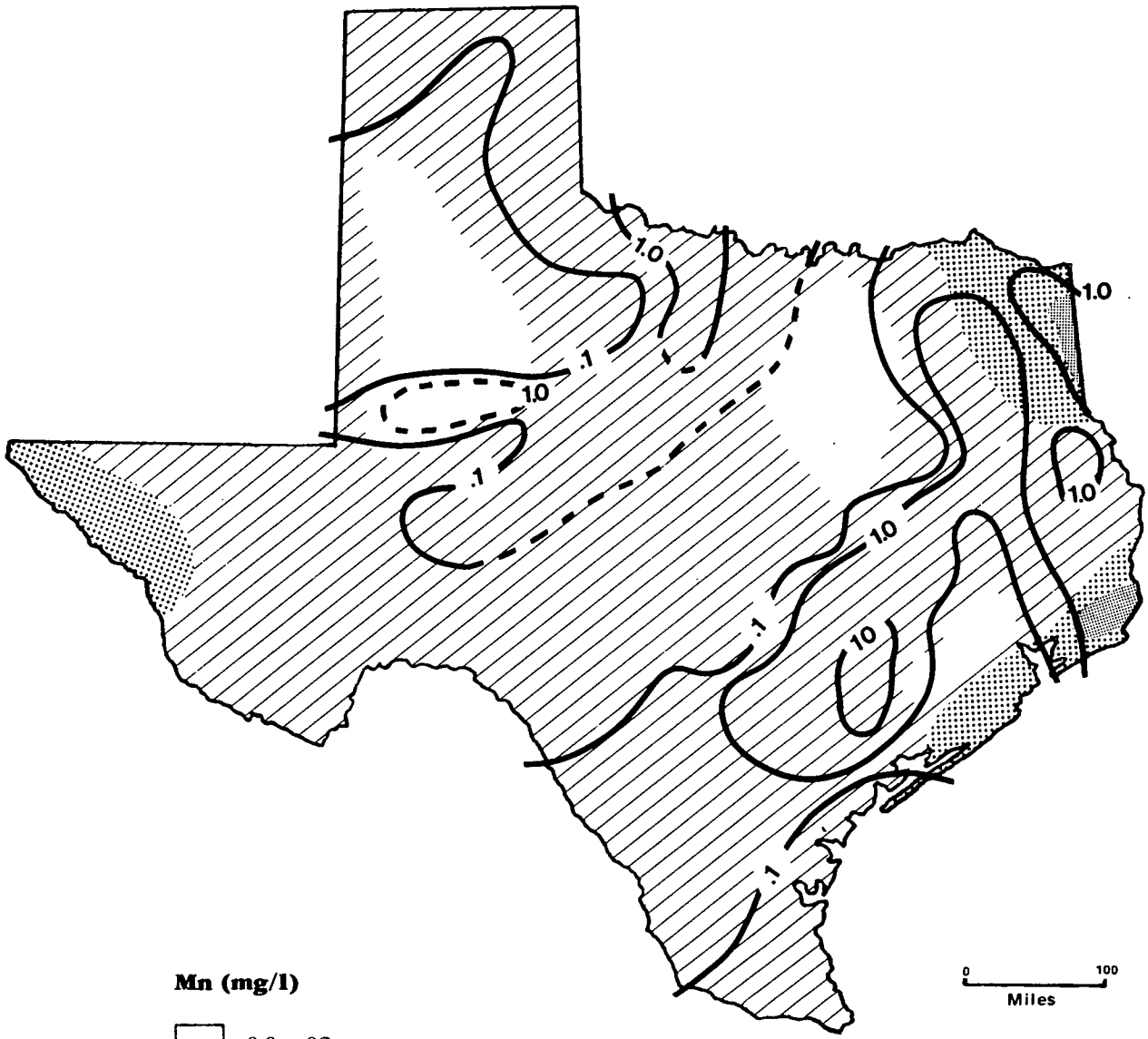
Dissolved Solids contoured (mg/l)

Texas



HCO_3 contoured (mg/l)

Texas

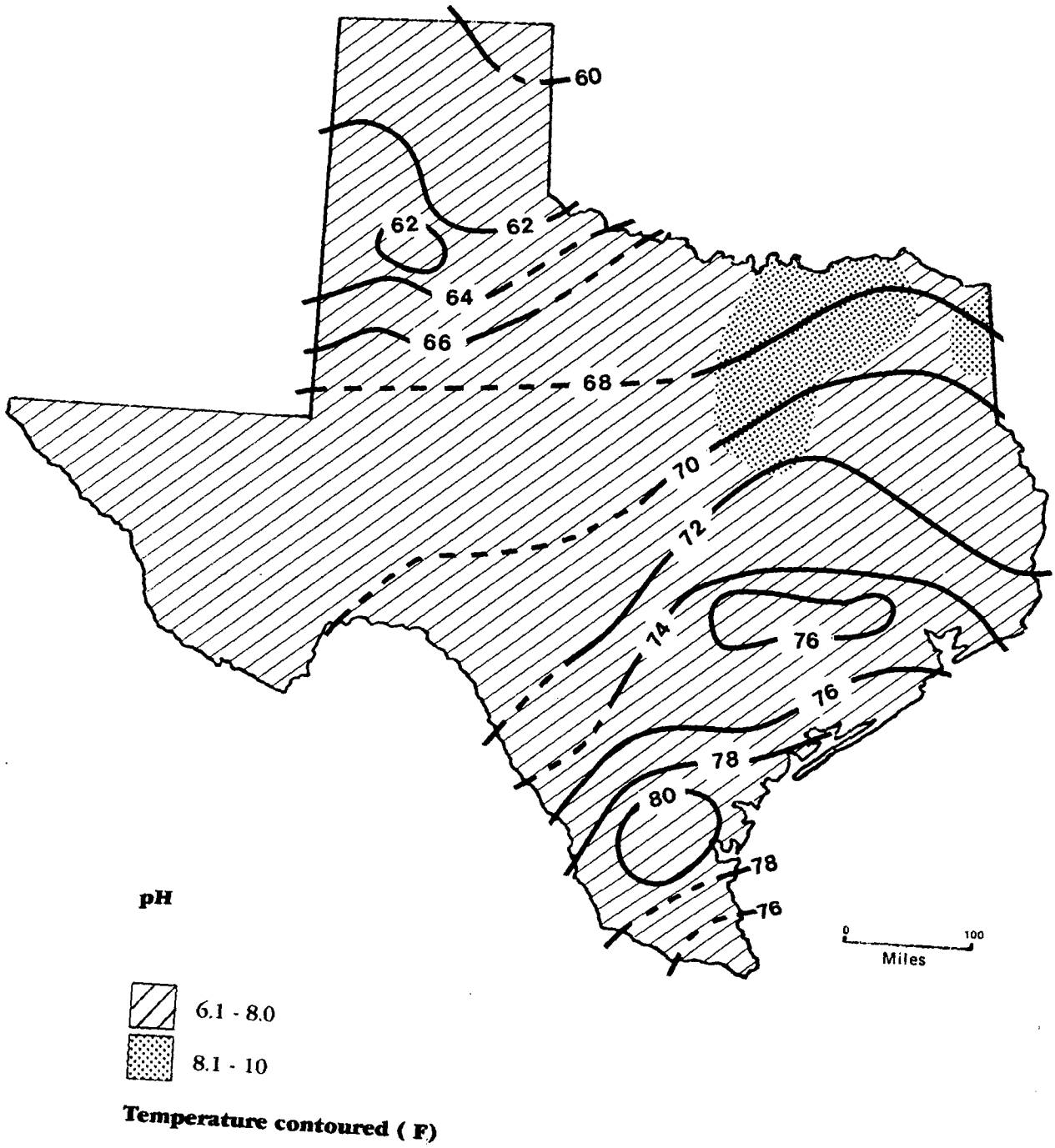


Mn (mg/l)

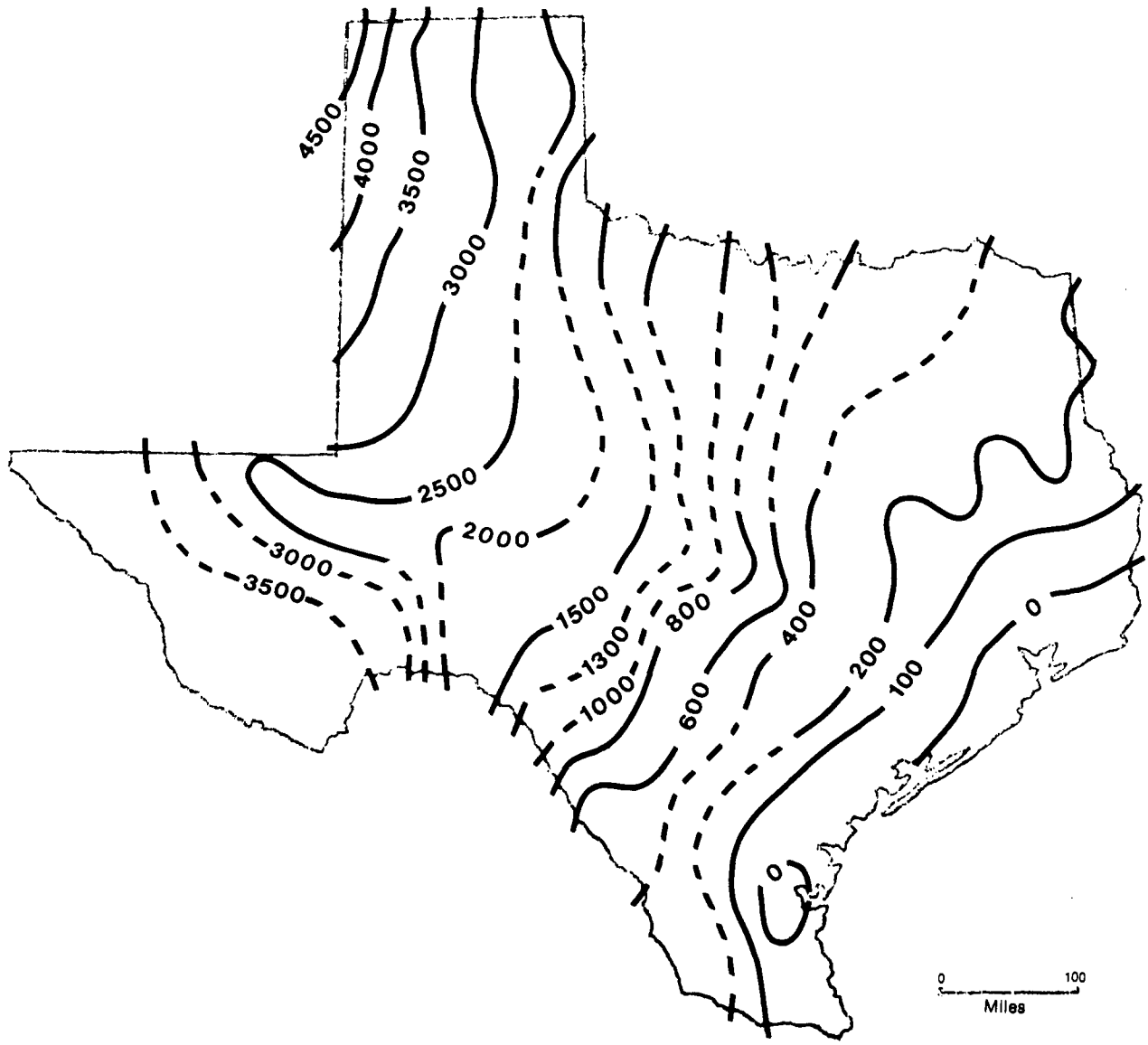
- 0.0 - .02
- .03 - .05
- .06 - .15

Fe contoured (mg/l)

Texas

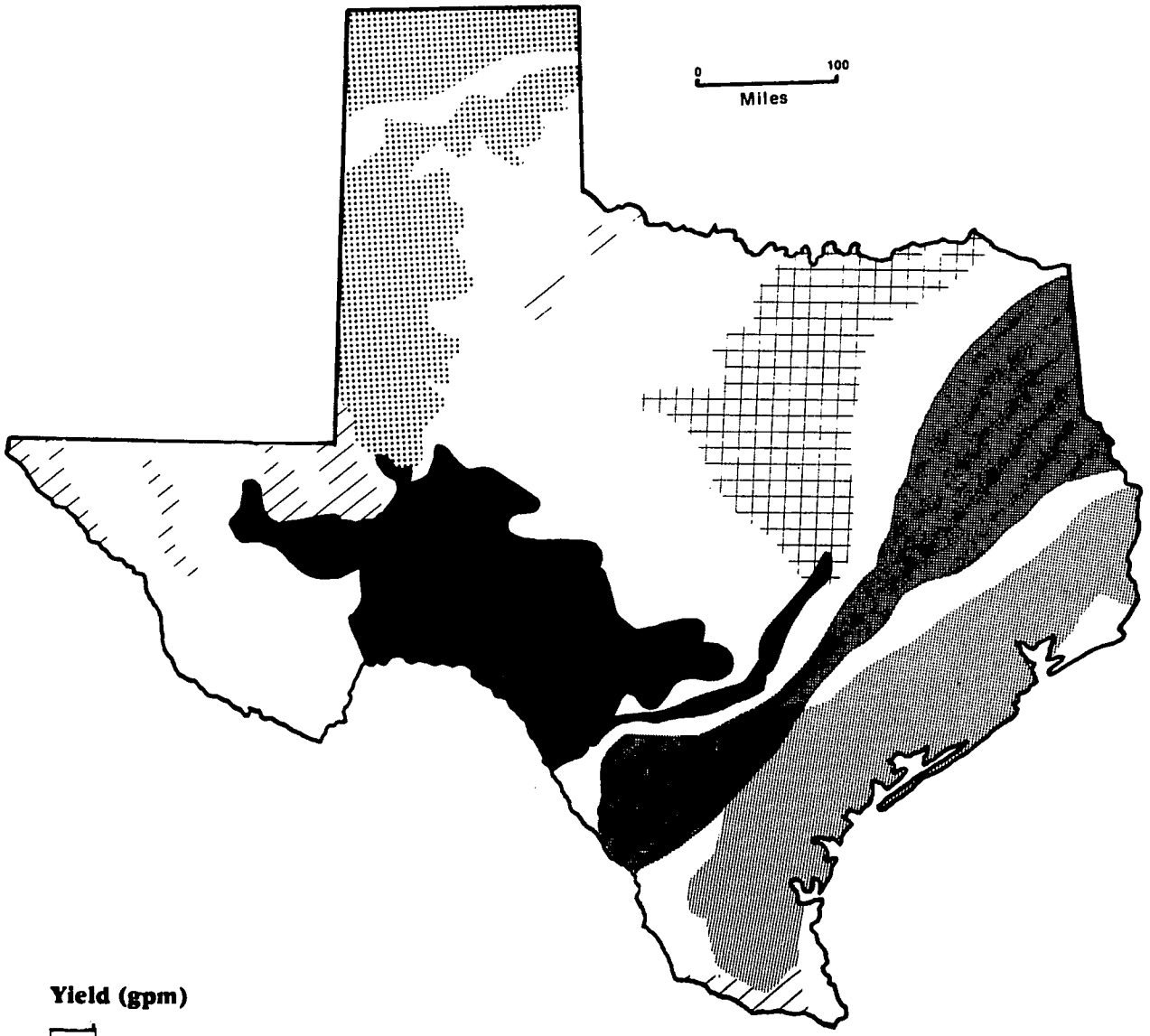

60
62
62
64
66
68
70
72
74
76
76
78
80
78
76
0
100
Miles
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (F)

Texas



Potentiometric surface (ft., Datum: mean sea level)

Texas



Yield (gpm)

- Less than 10 gpm
- Alluvium 60-2000 gpm
- Pleistocene, Miocene coastal sands 10-4500 gpm
- Carrizo sand & Wilcox group 20-1000 gpm
- Edwards and associated limestone (fault zone) 10-500 gpm
- Edwards and associated limestone, Trinity groups 50-500 gpm
- Woodbine formation and Trinity group 10-1000 gpm

Utah

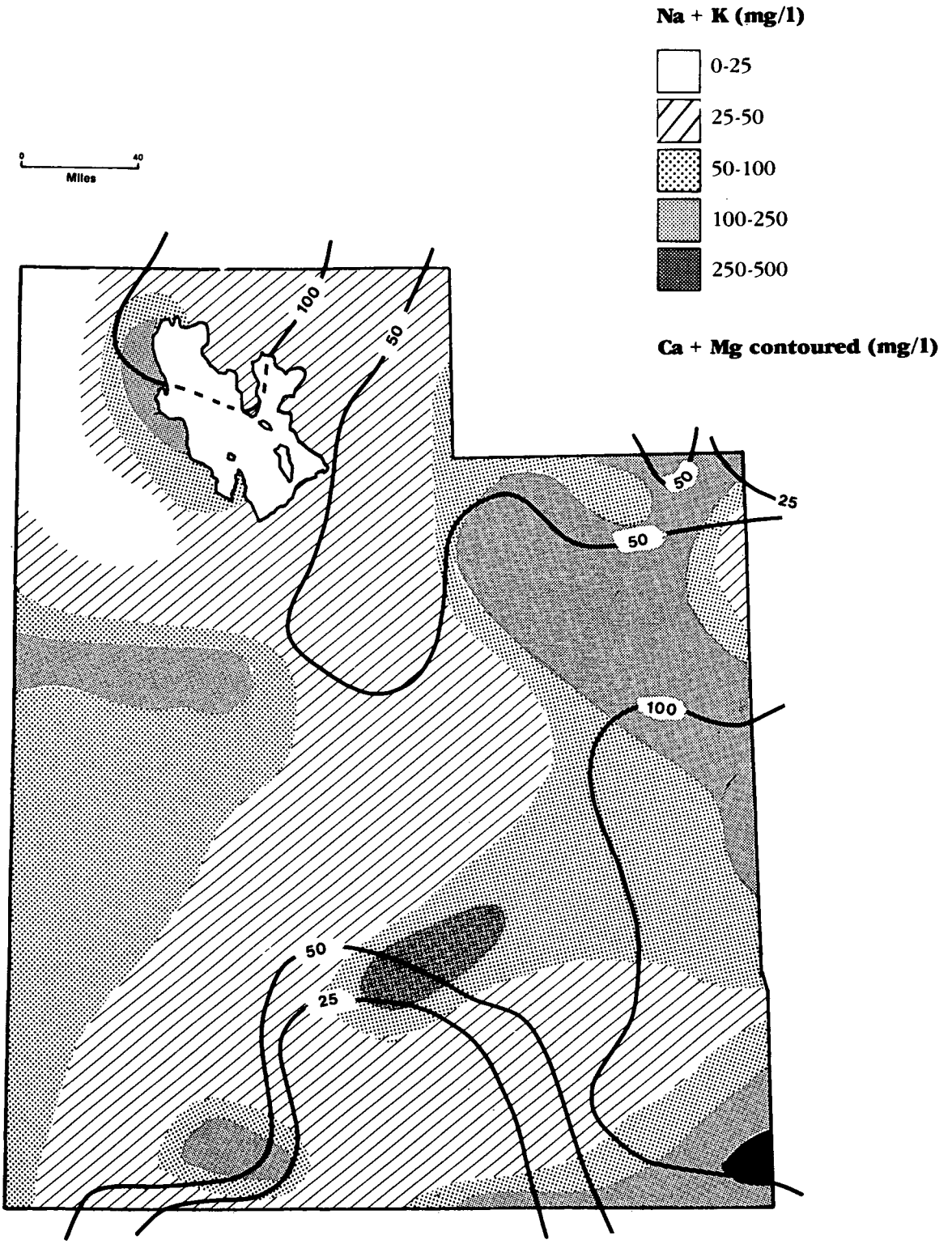


Plate 332

Utah

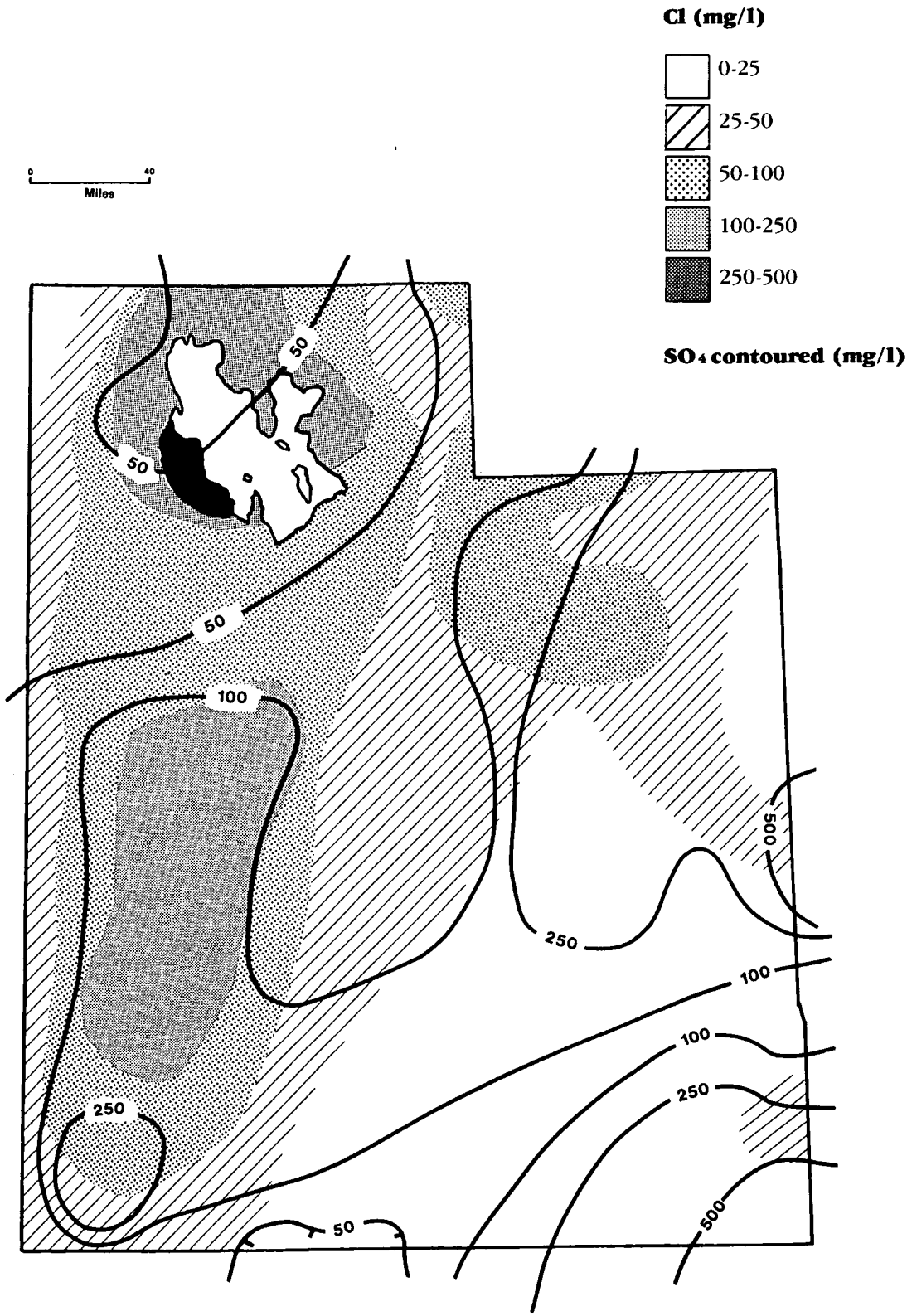


Plate 333

Utah

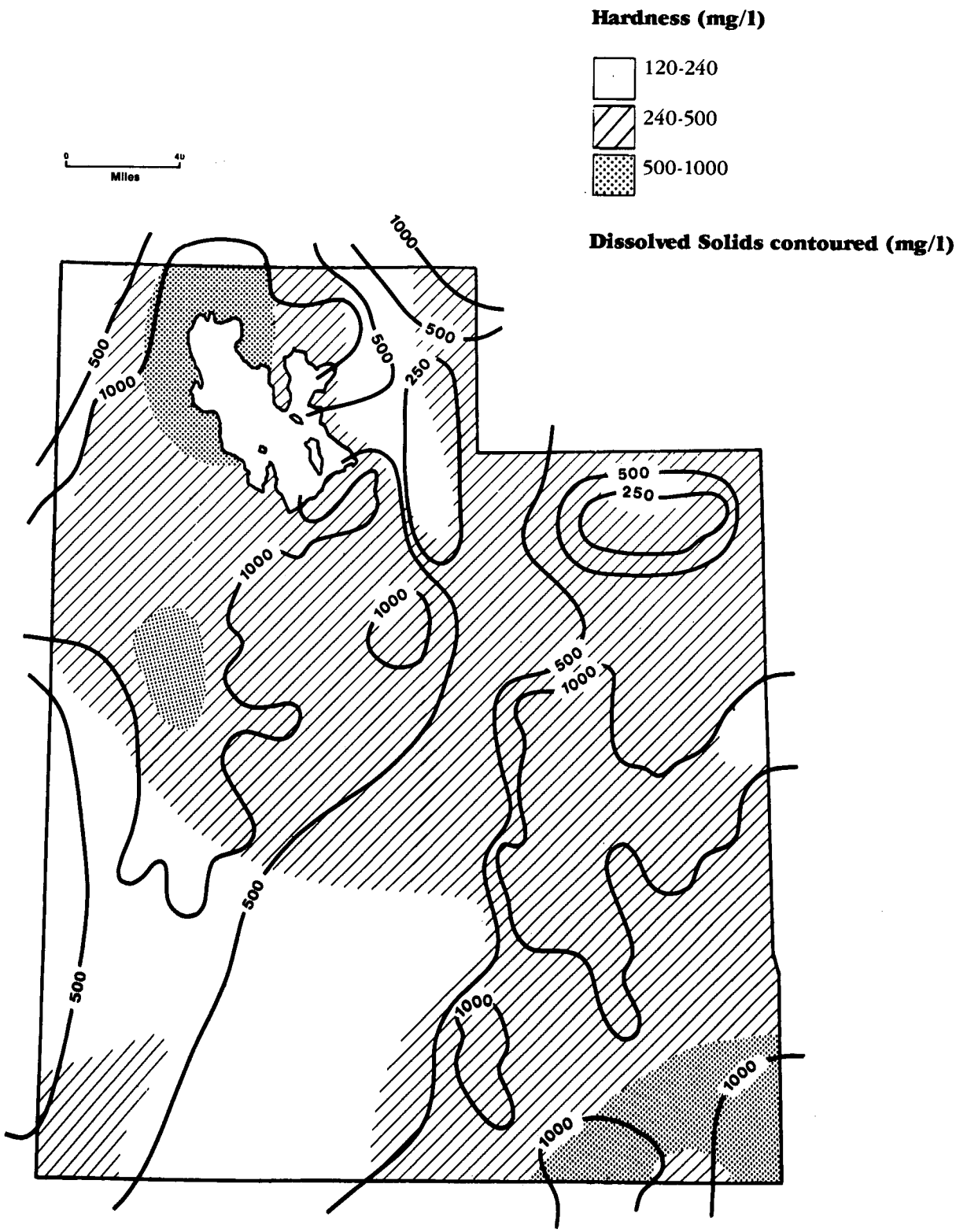
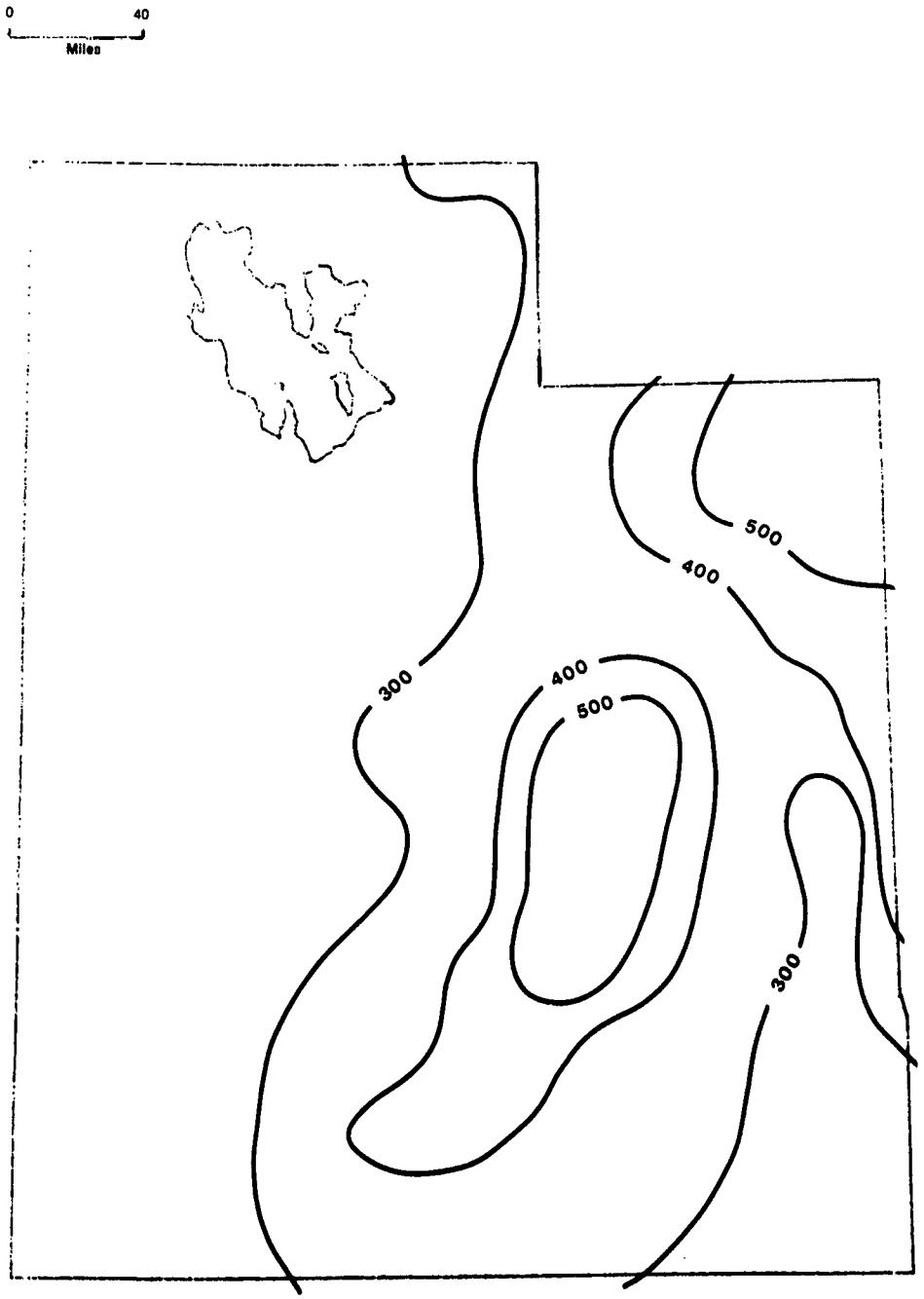


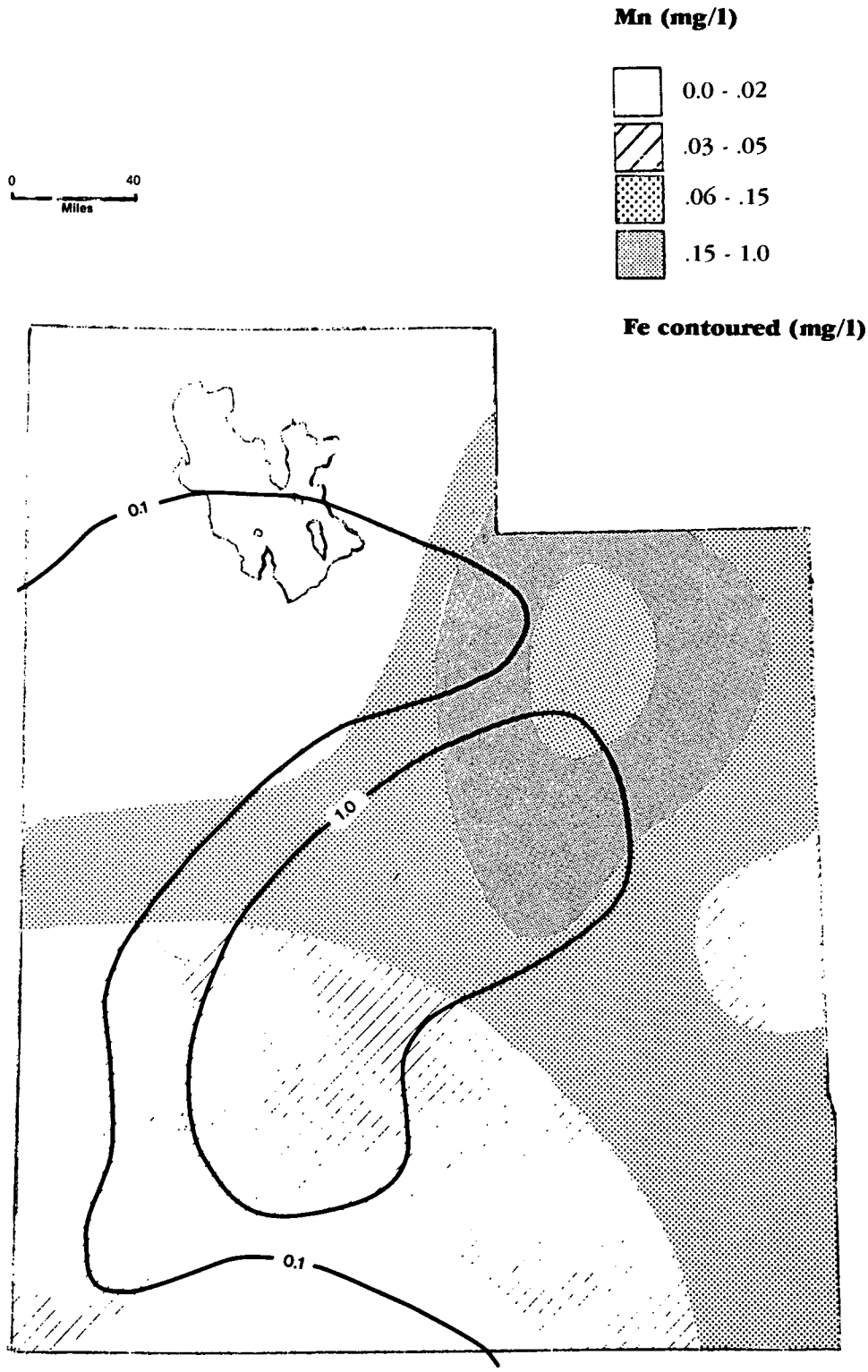
Plate 334

Utah

HCO_3 contoured (mg/l)



Utah

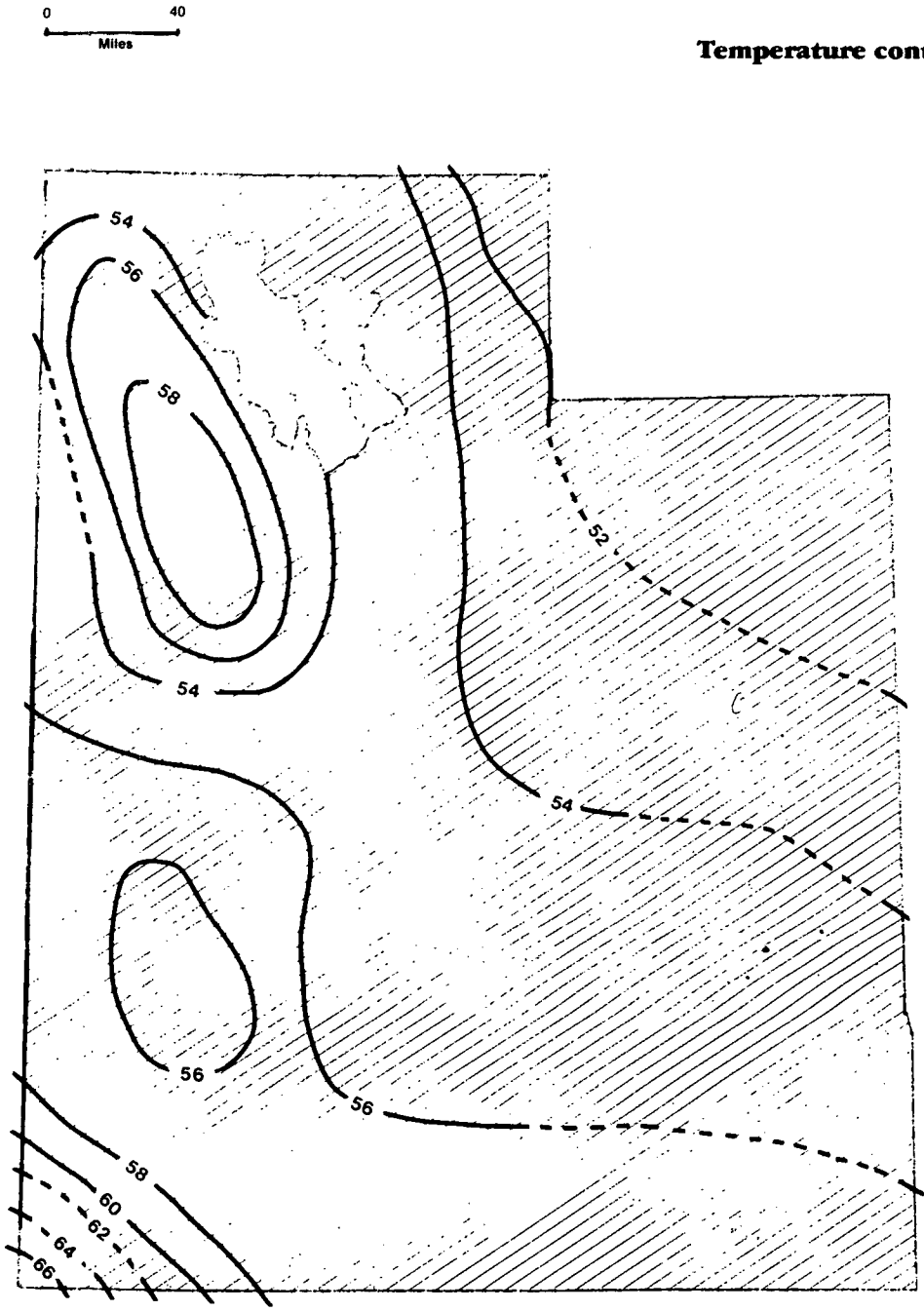


Utah

pH

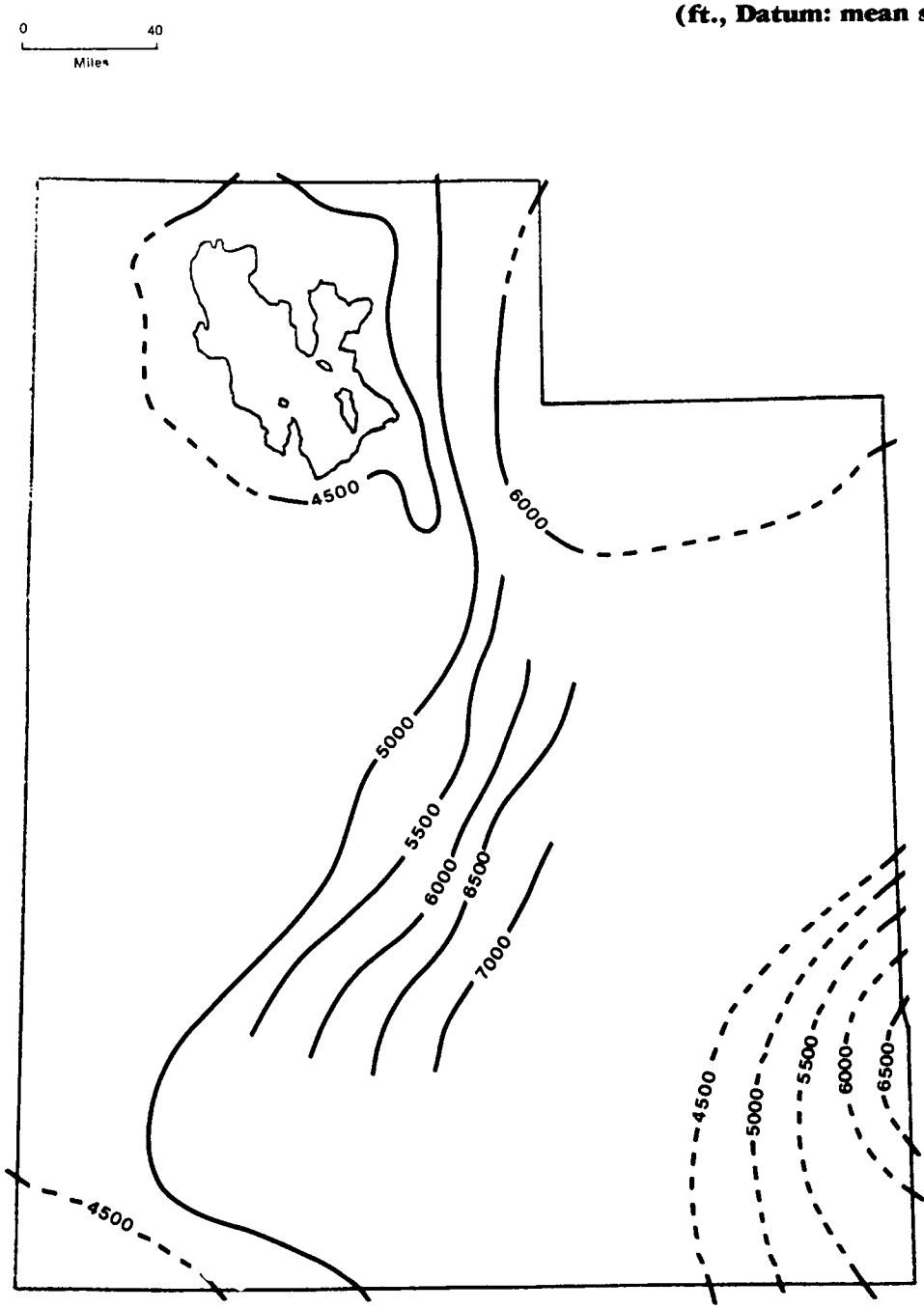
6.1 - 8.0

Temperature contoured (F°)

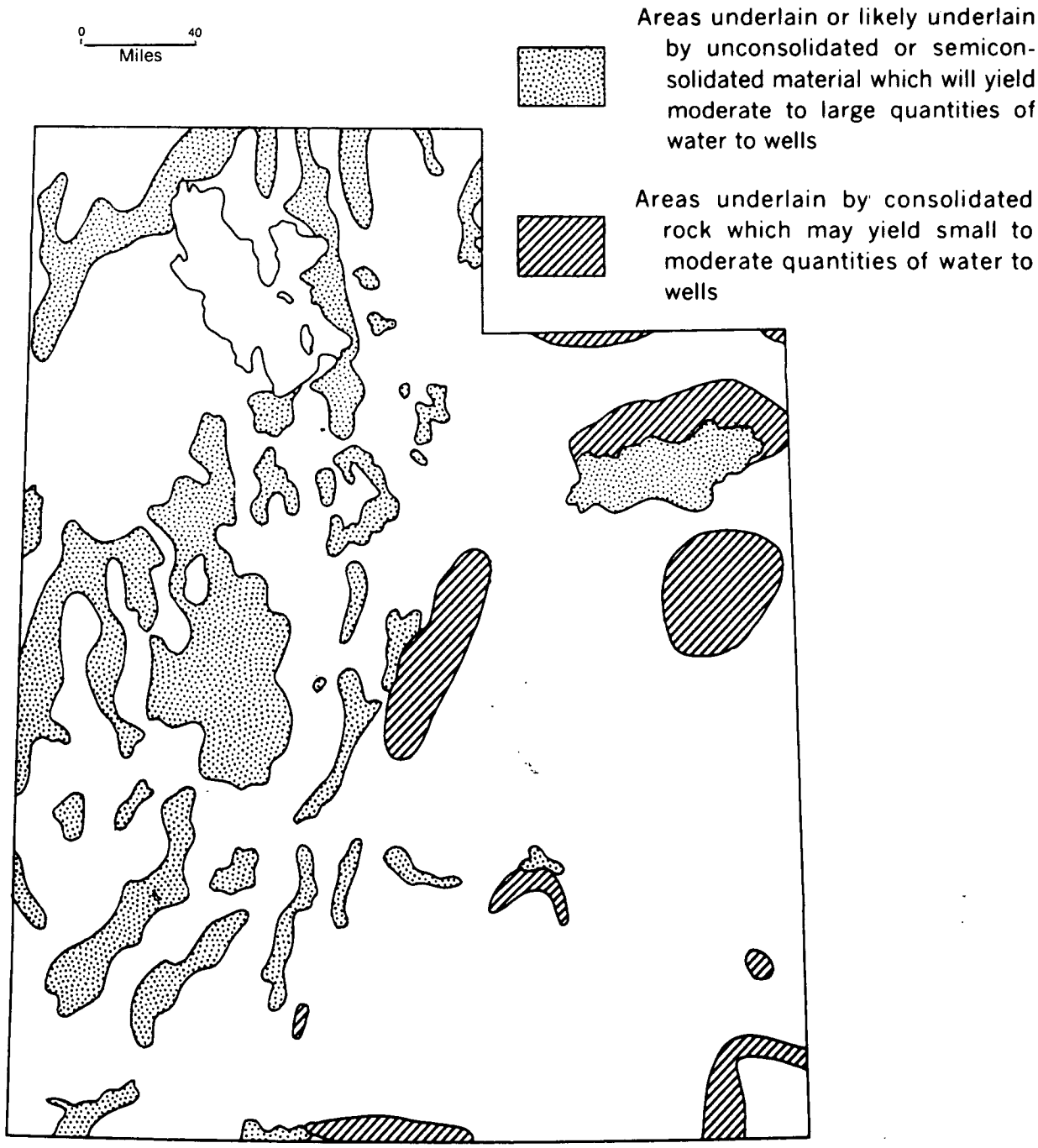


Utah

Potentiometric surface
(ft., Datum: mean sea level)



Utah



AREAS OF KNOWN OR POTENTIAL GROUND-WATER DEVELOPMENT

Vermont

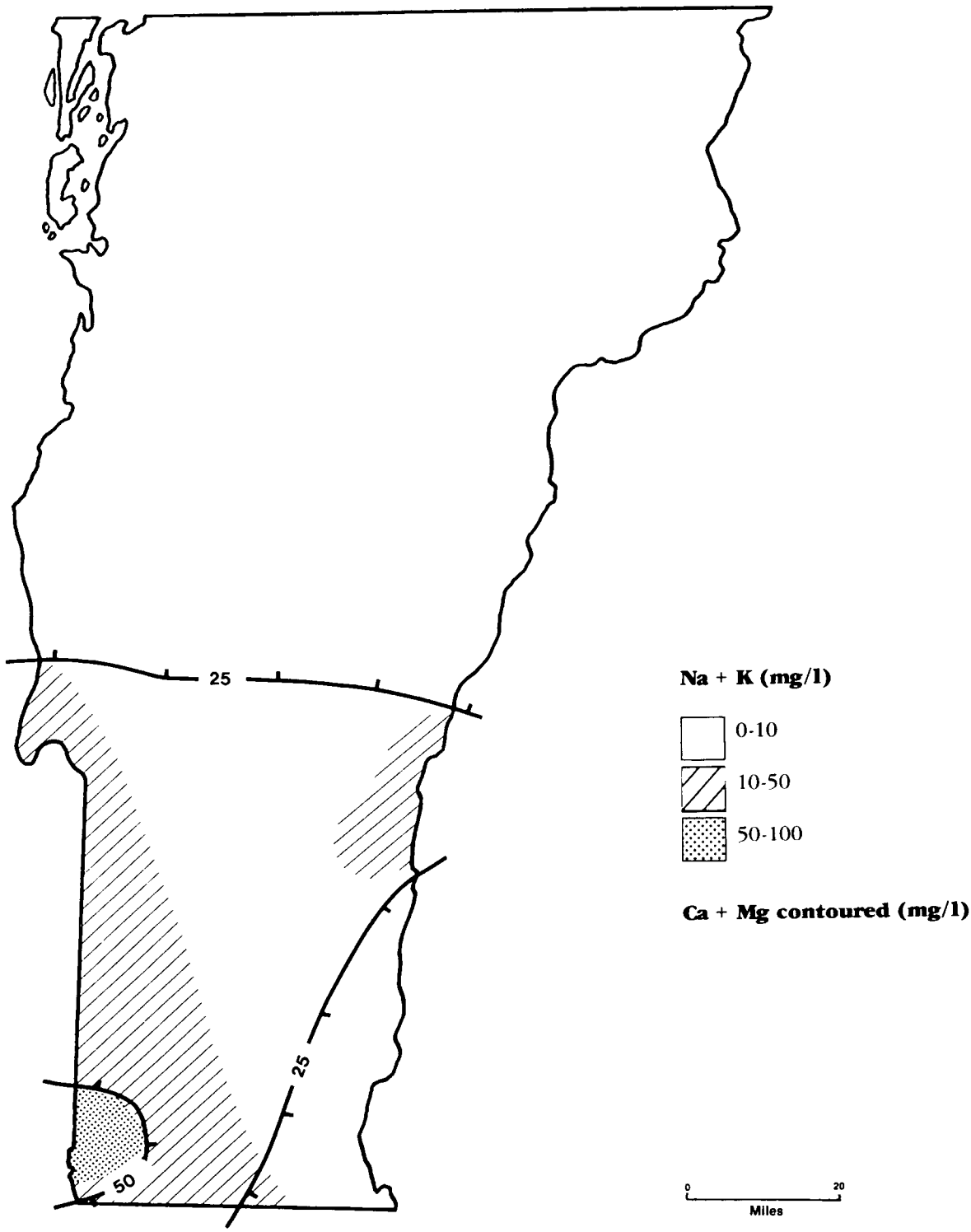


Plate 340

Vermont

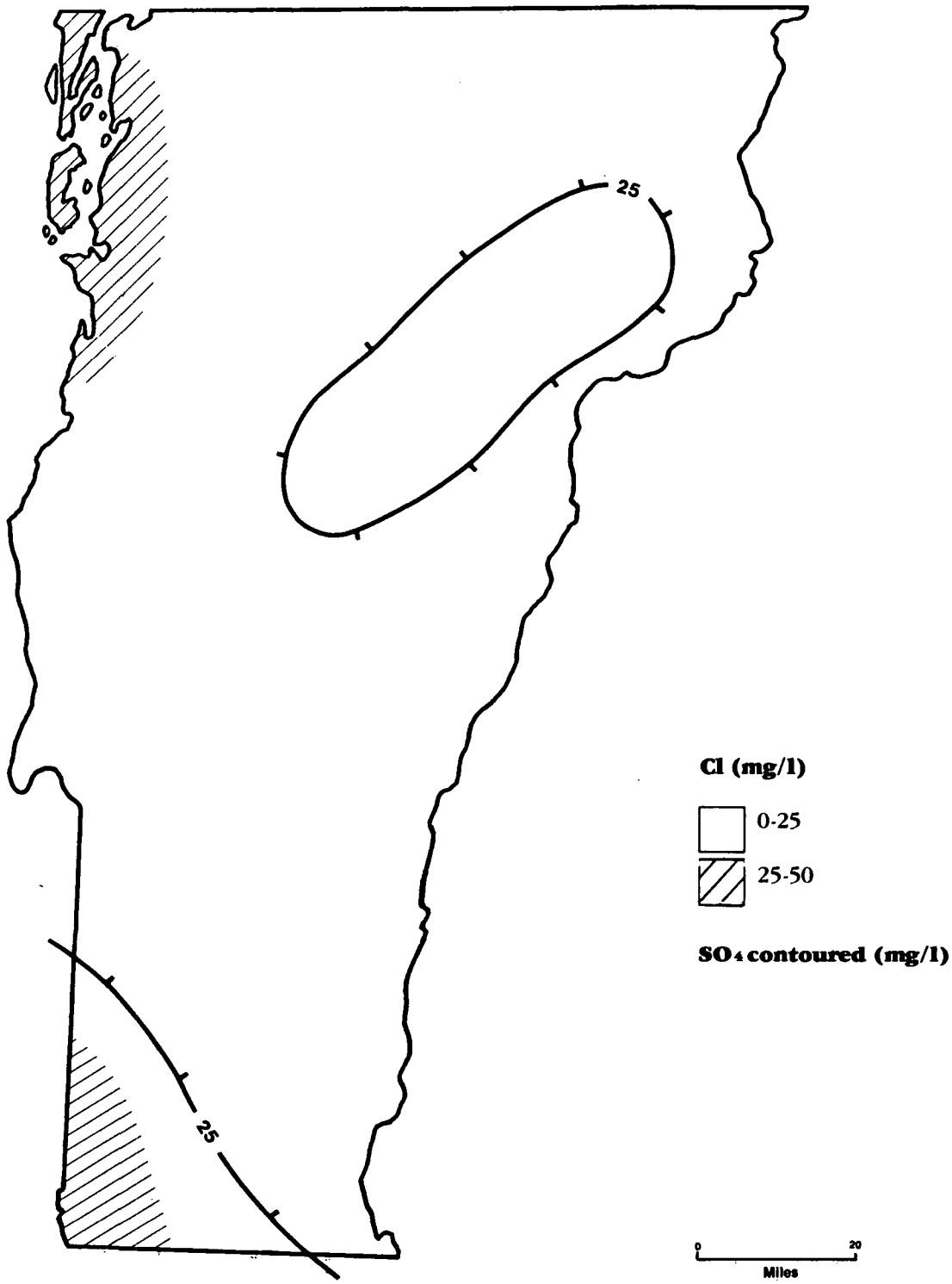


Plate 341

Vermont

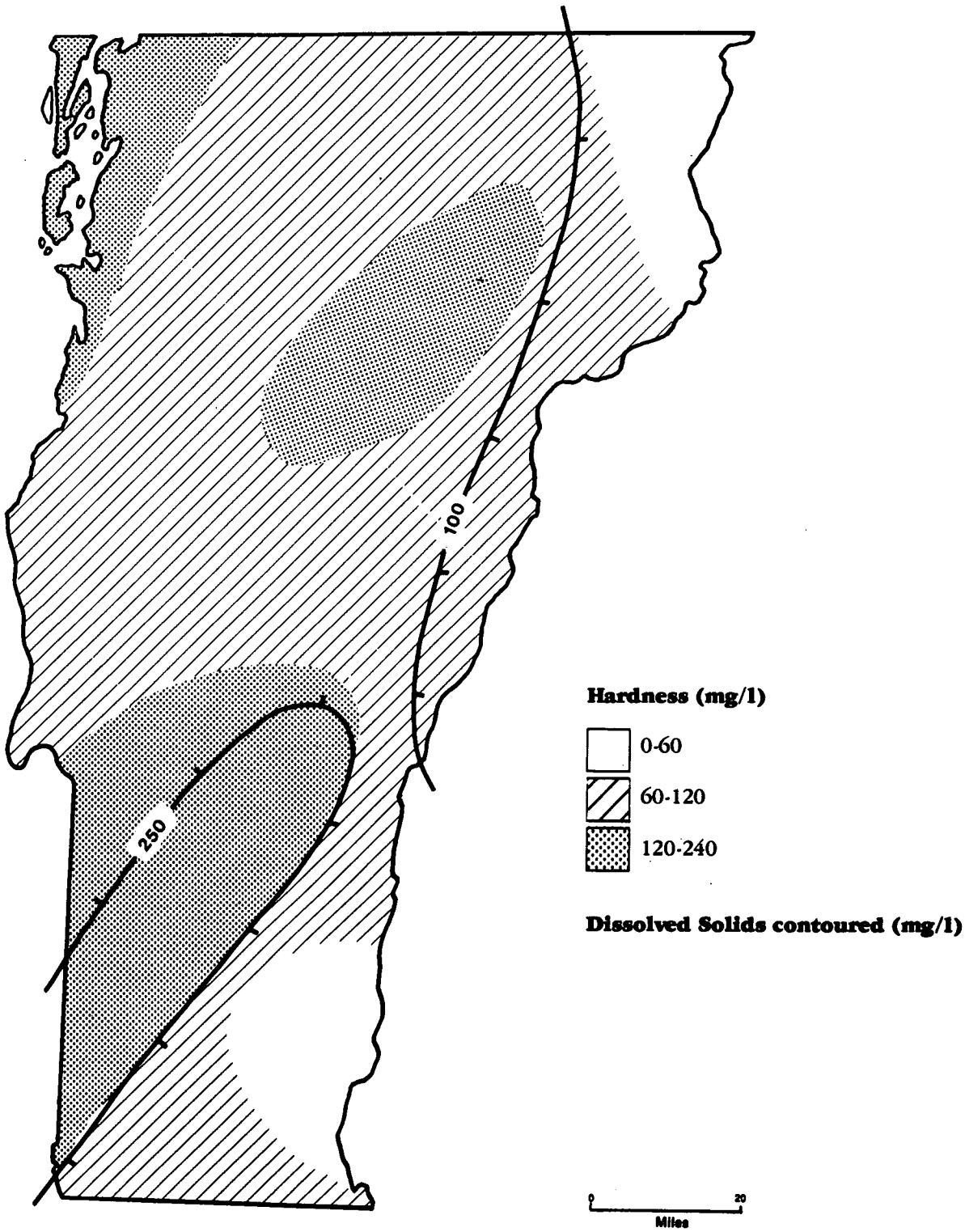


Plate 342

Vermont

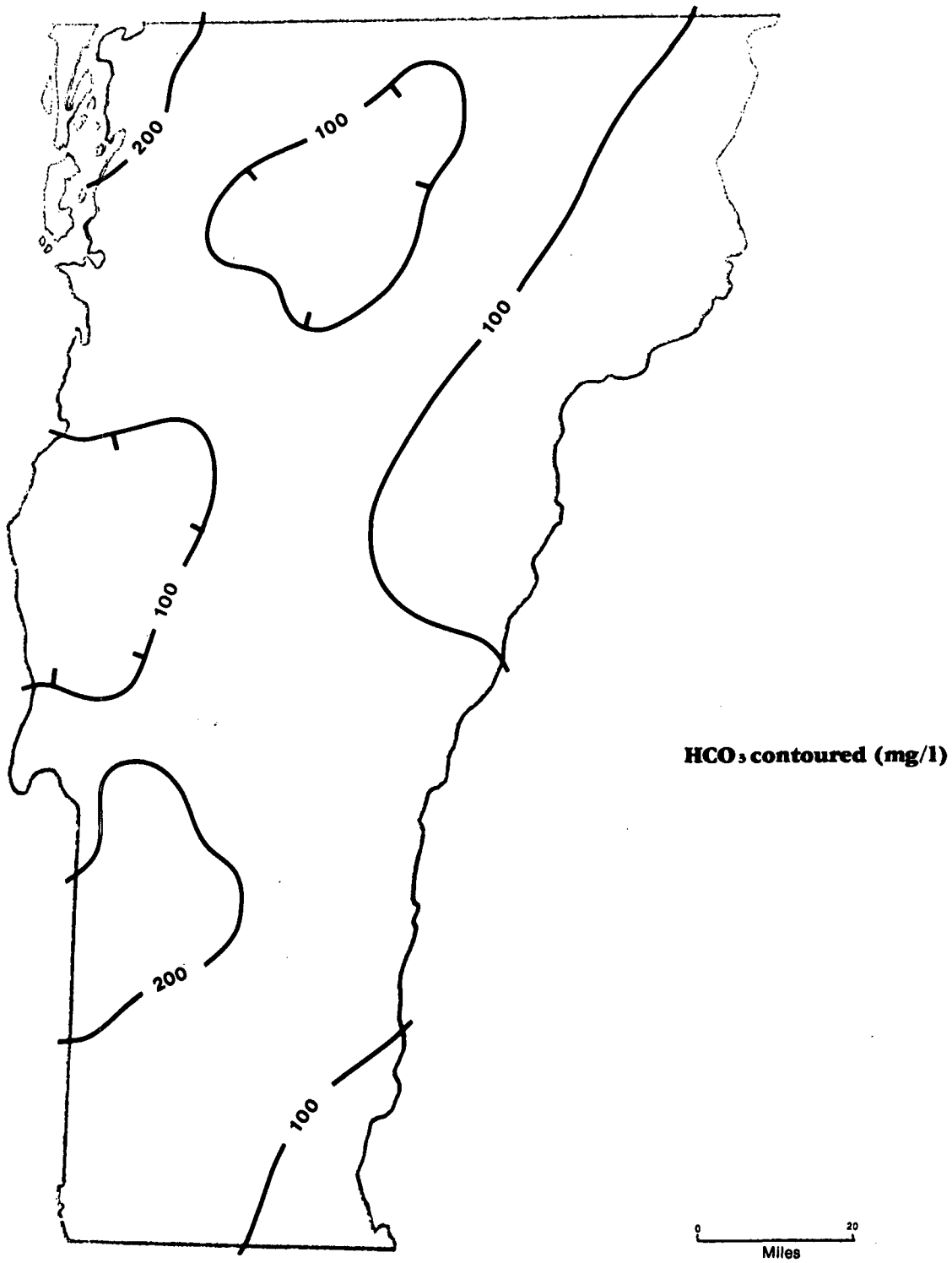
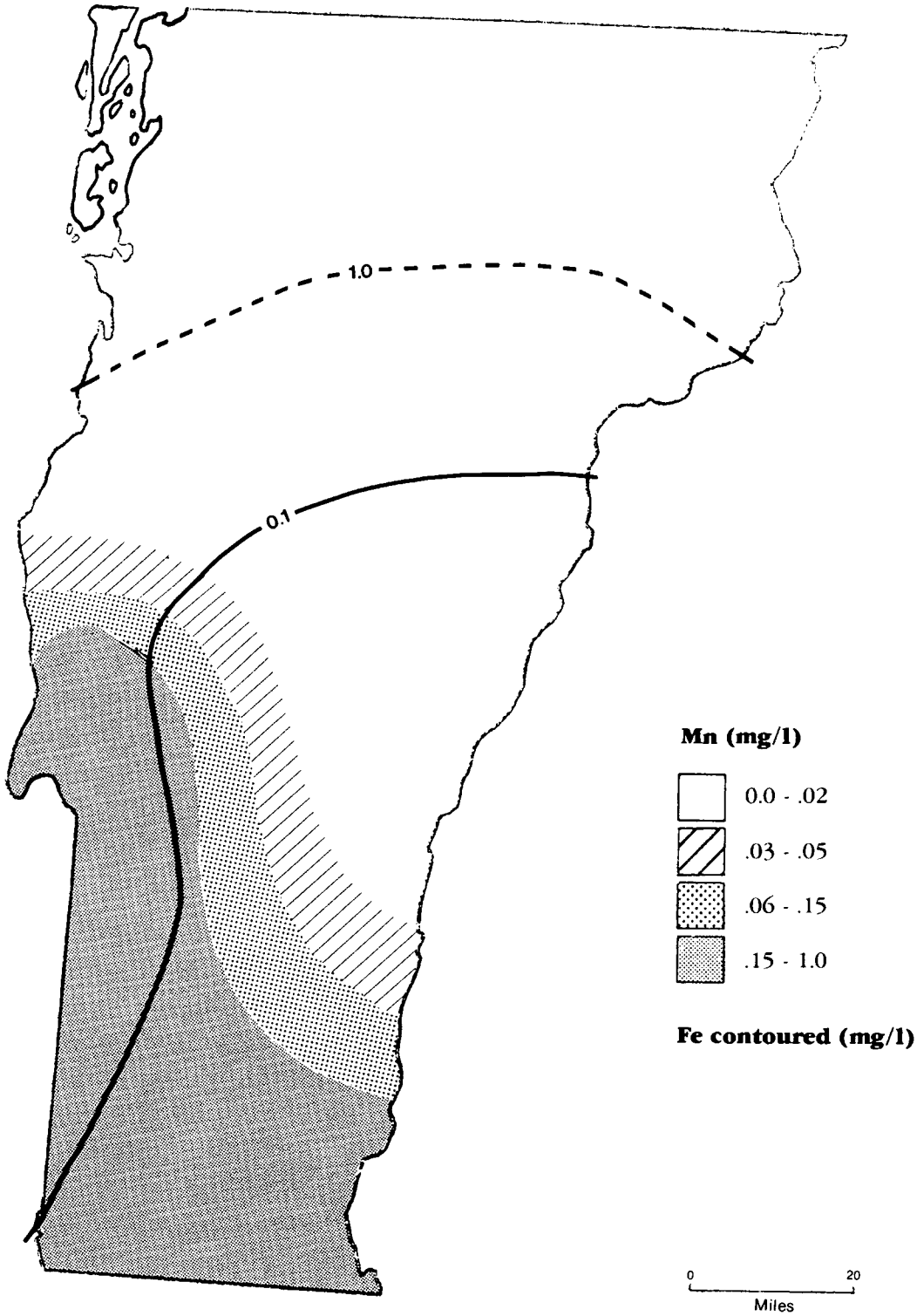
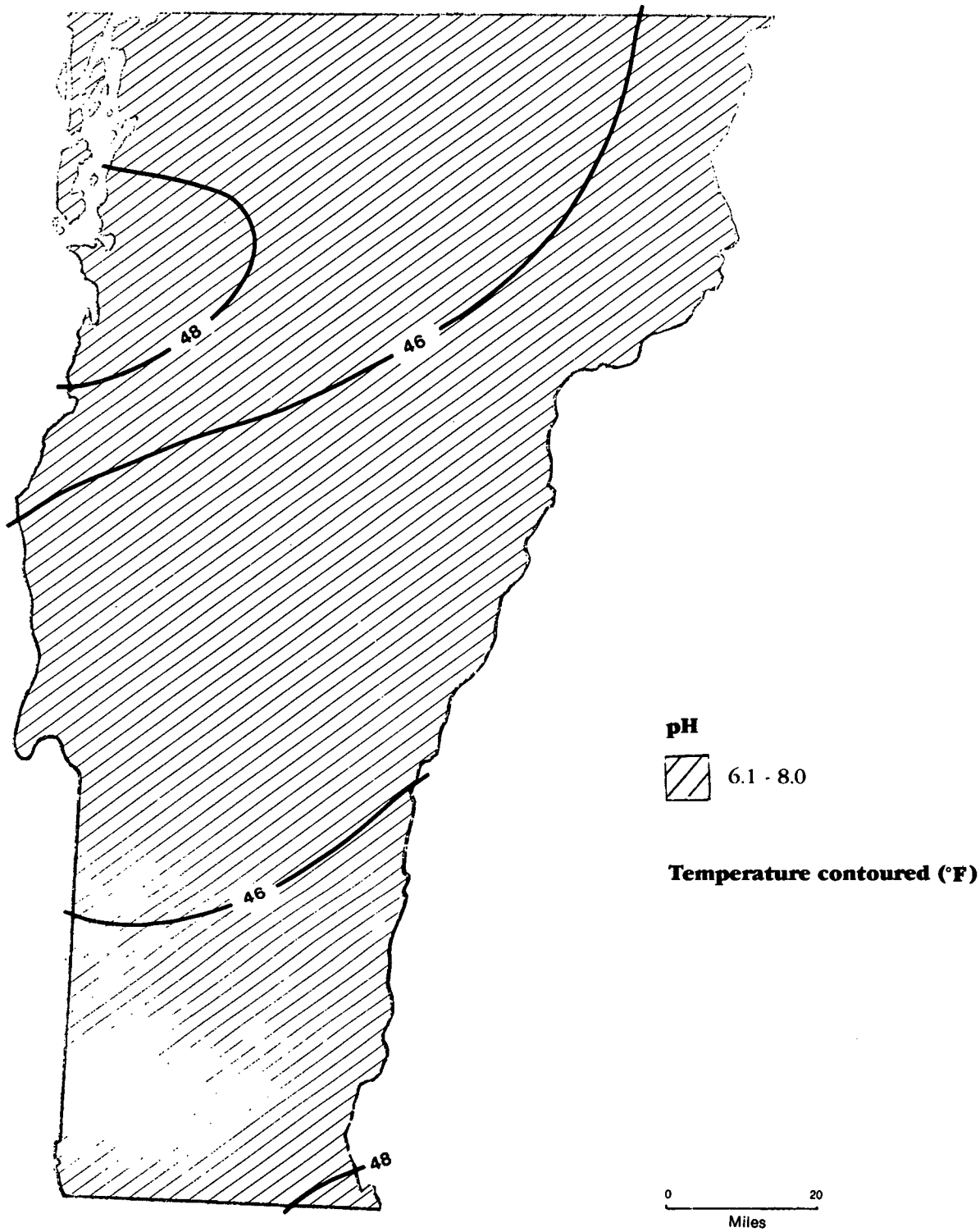


Plate 343

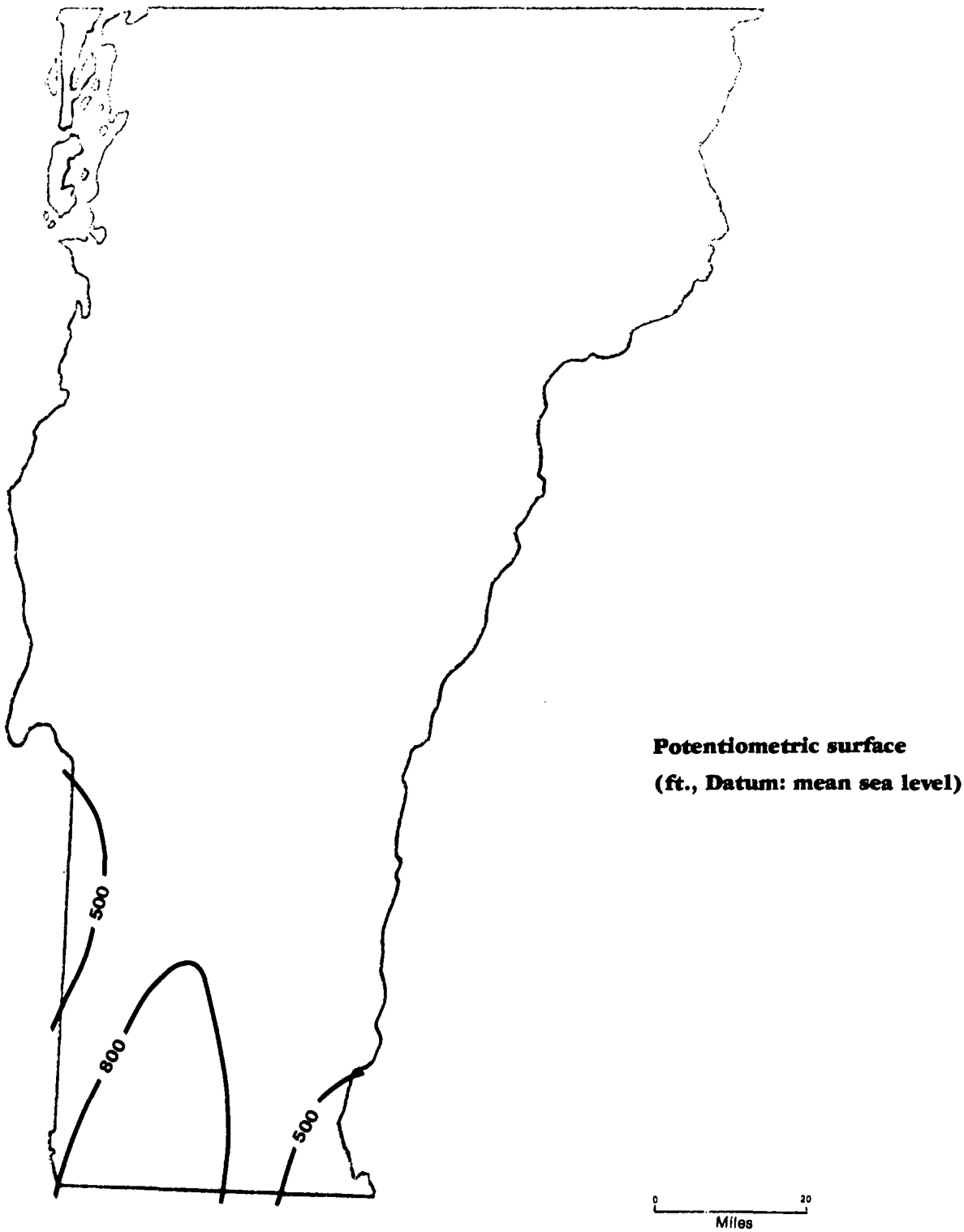
Vermont



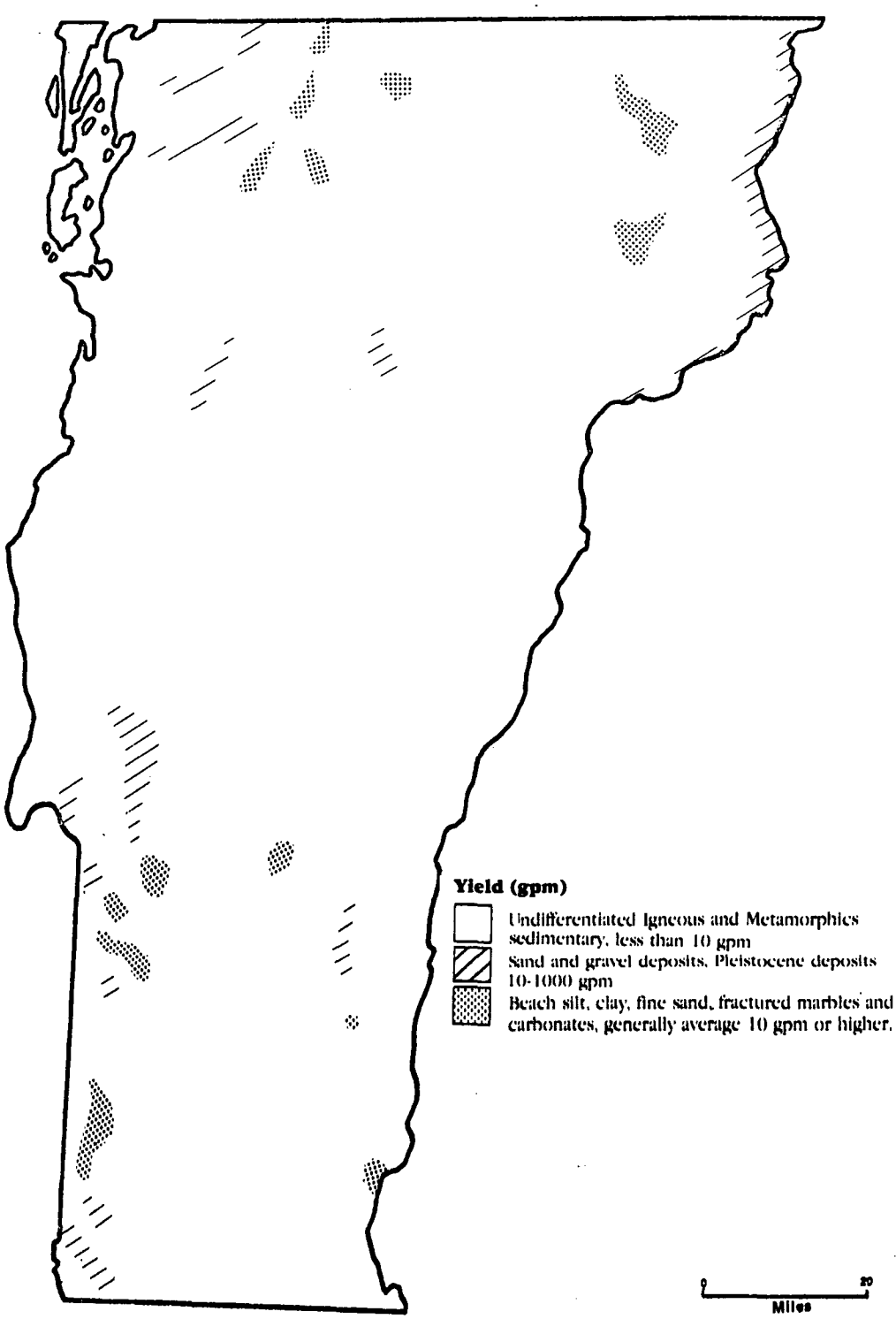
Vermont



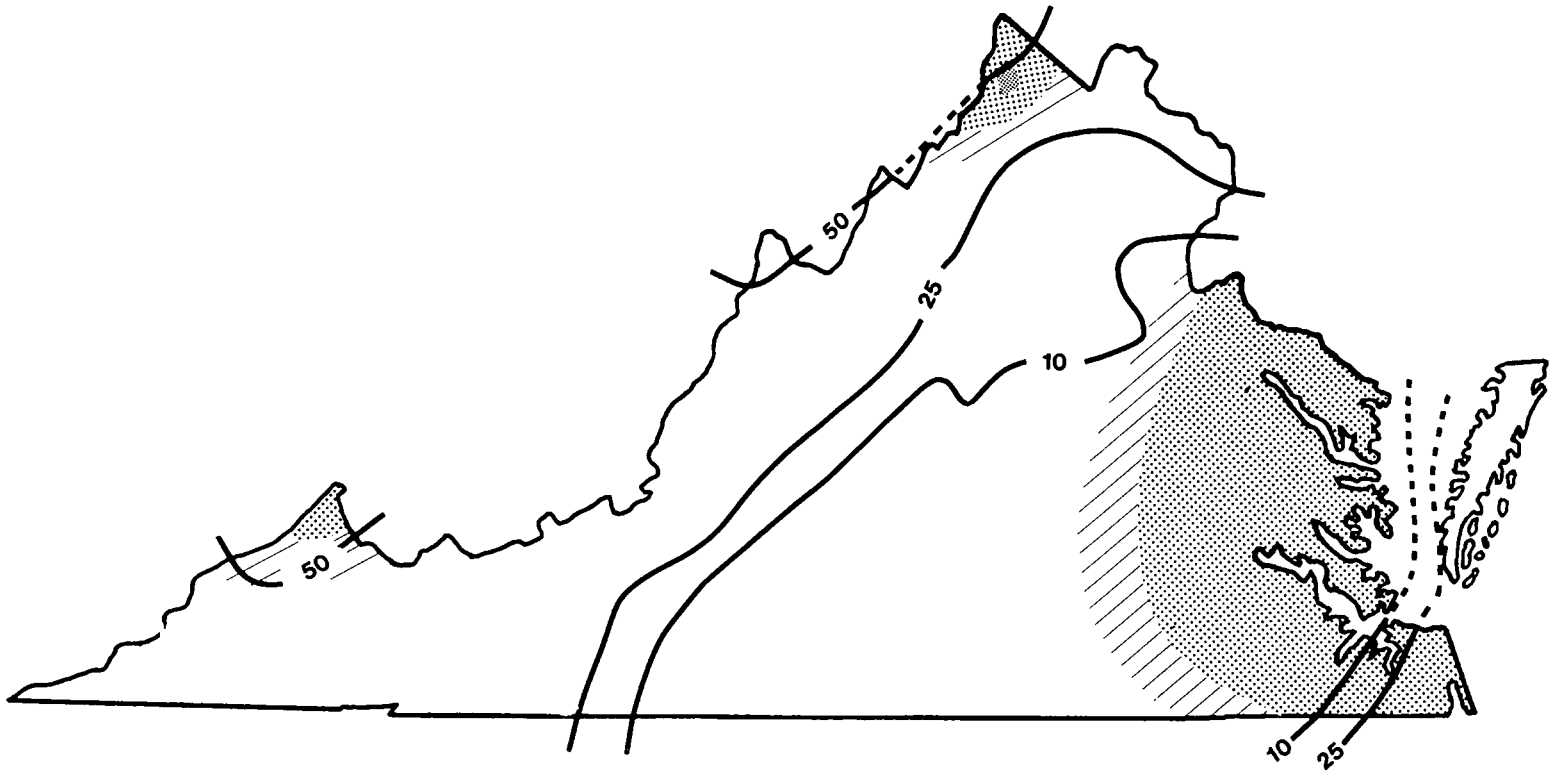
Vermont


500
800
500
Potentiometric surface
(ft., Datum: mean sea level)
0
20
Miles

Vermont


Yield (gpm)
Undifferentiated Igneous and Metamorphics sedimentary, less than 10 gpm
Sand and gravel deposits, Pleistocene deposits 10-1000 gpm
Beach silt, clay, fine sand, fractured marbles and carbonates, generally average 10 gpm or higher.
0
20
Miles

Virginia



Na + K (mg/l)

- 0-25
- 25-50
- 50-100
- 100-250

Ca + Mg contoured (mg/l)

0 50
Miles

Virginia

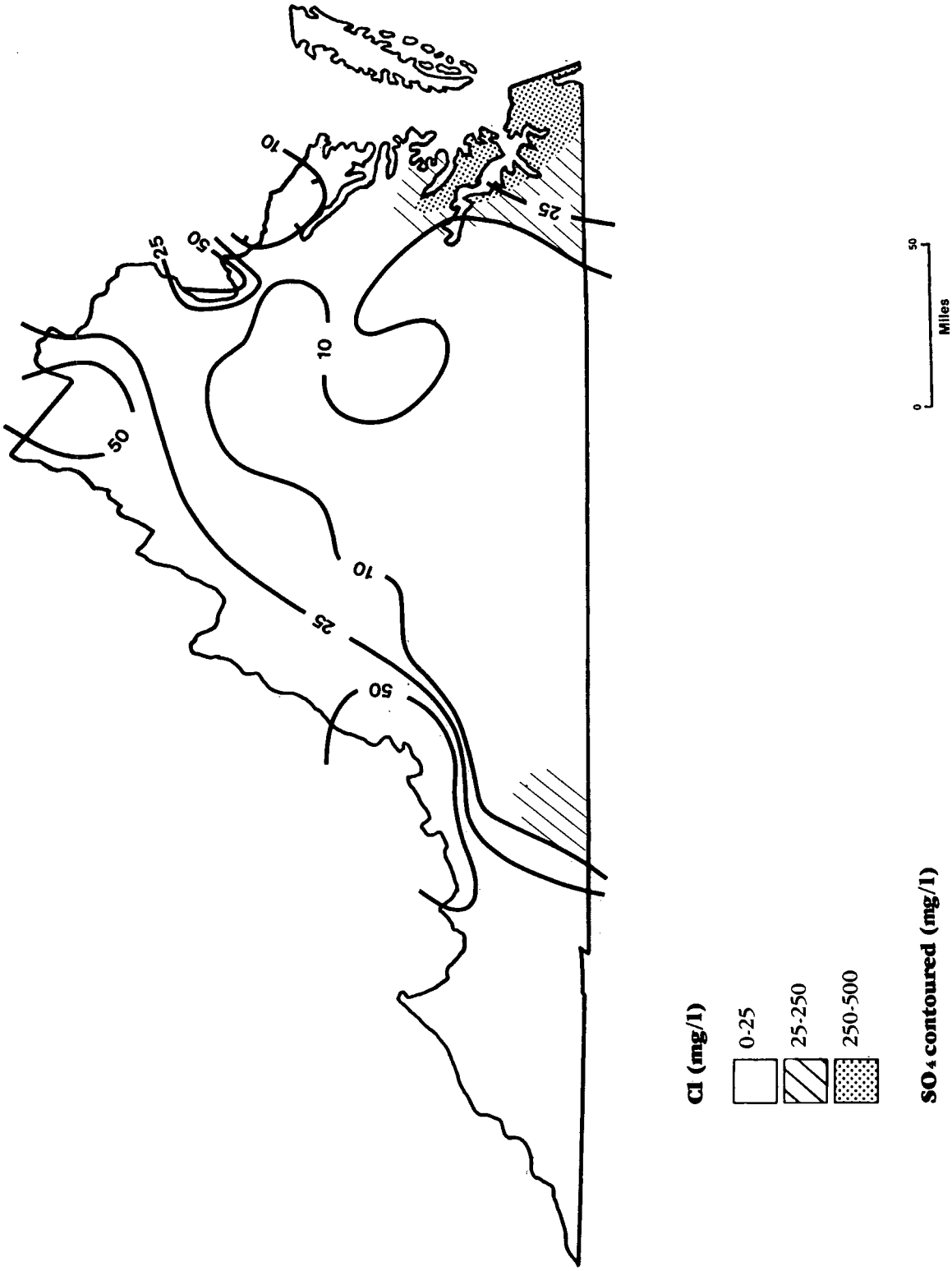
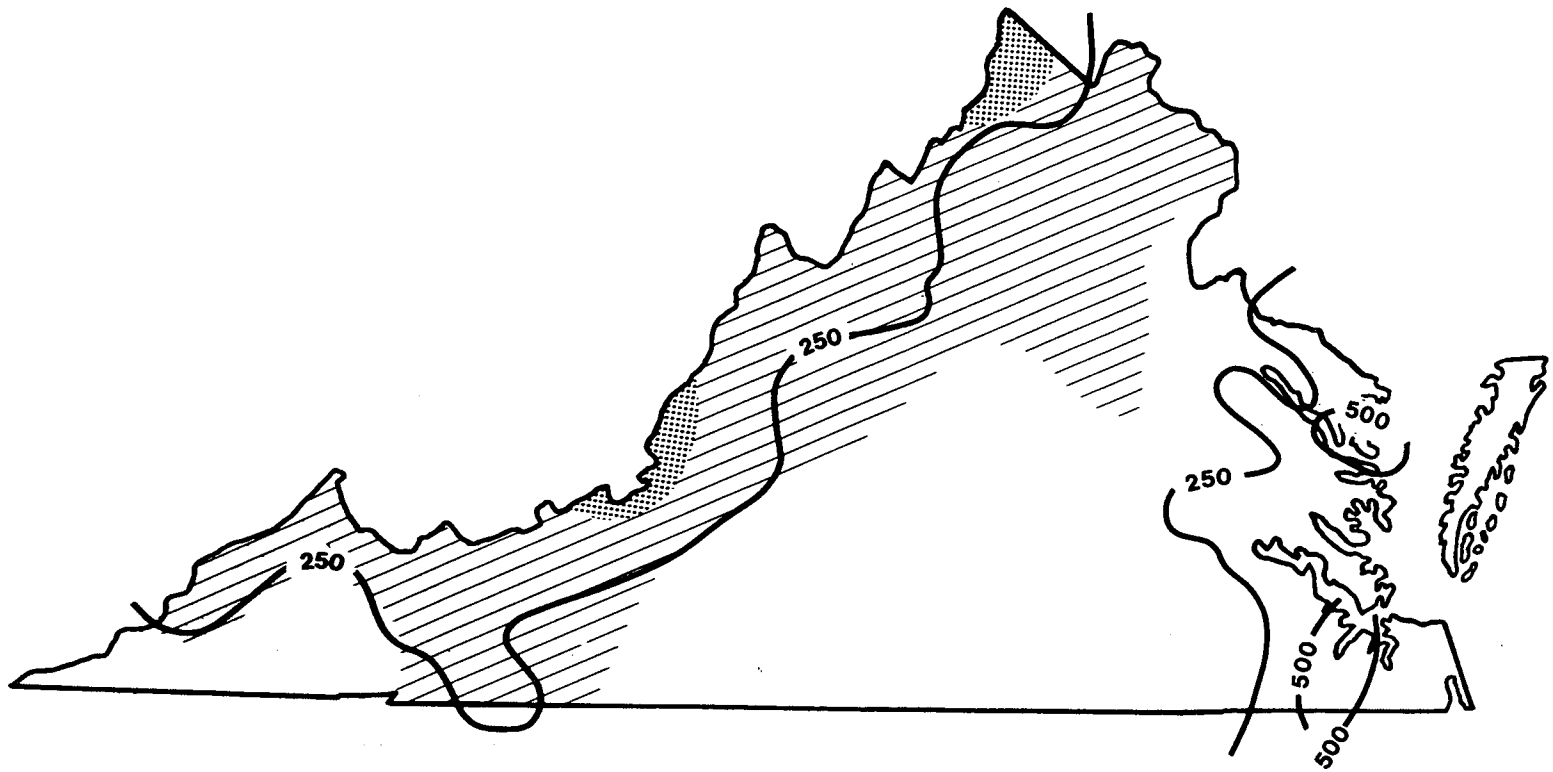


Plate 349

Virginia



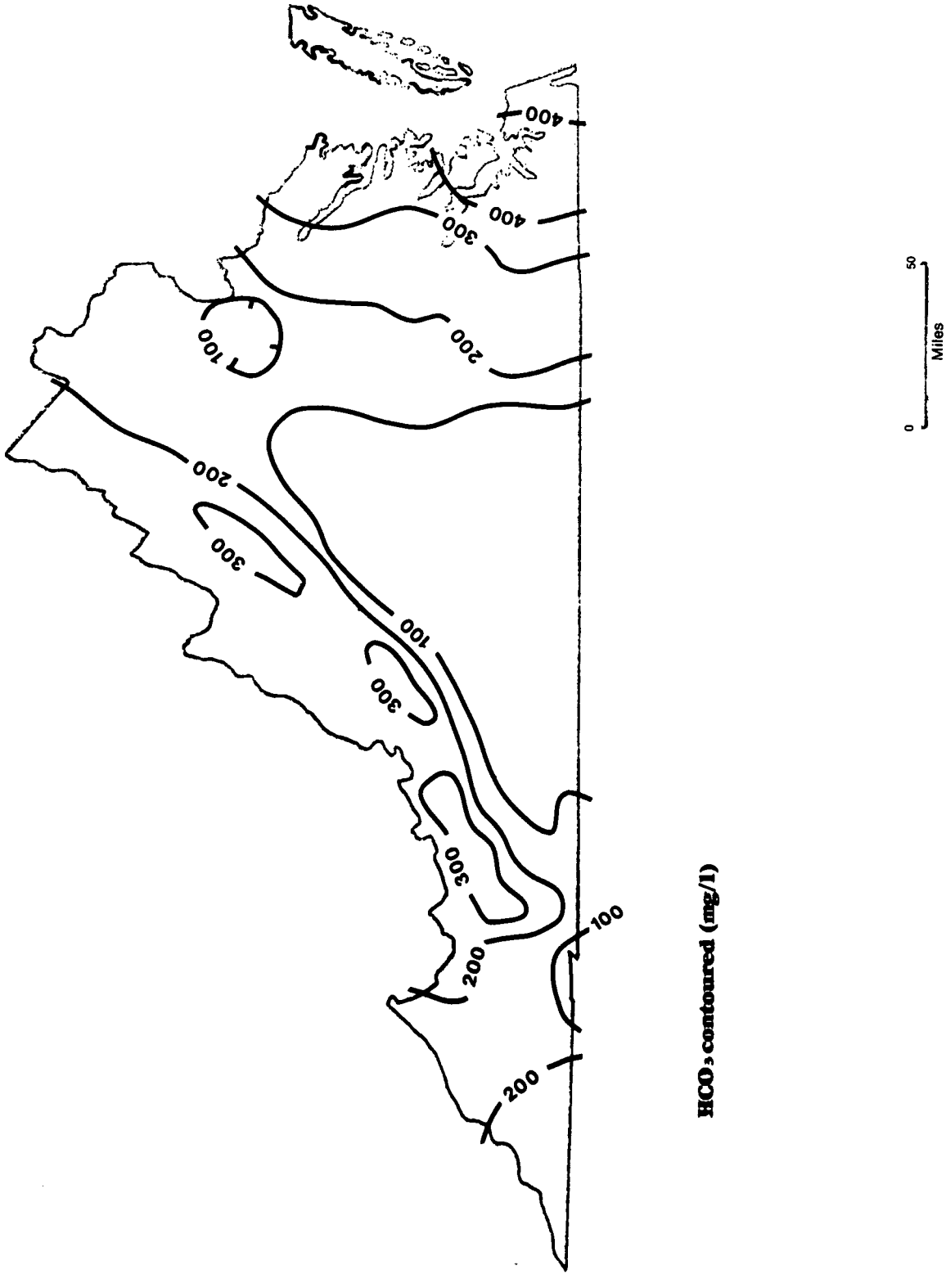
Hardness (mg/l)

- 0-120
- 120-240
- 240-500

Dissolved Solids contoured (mg/l)

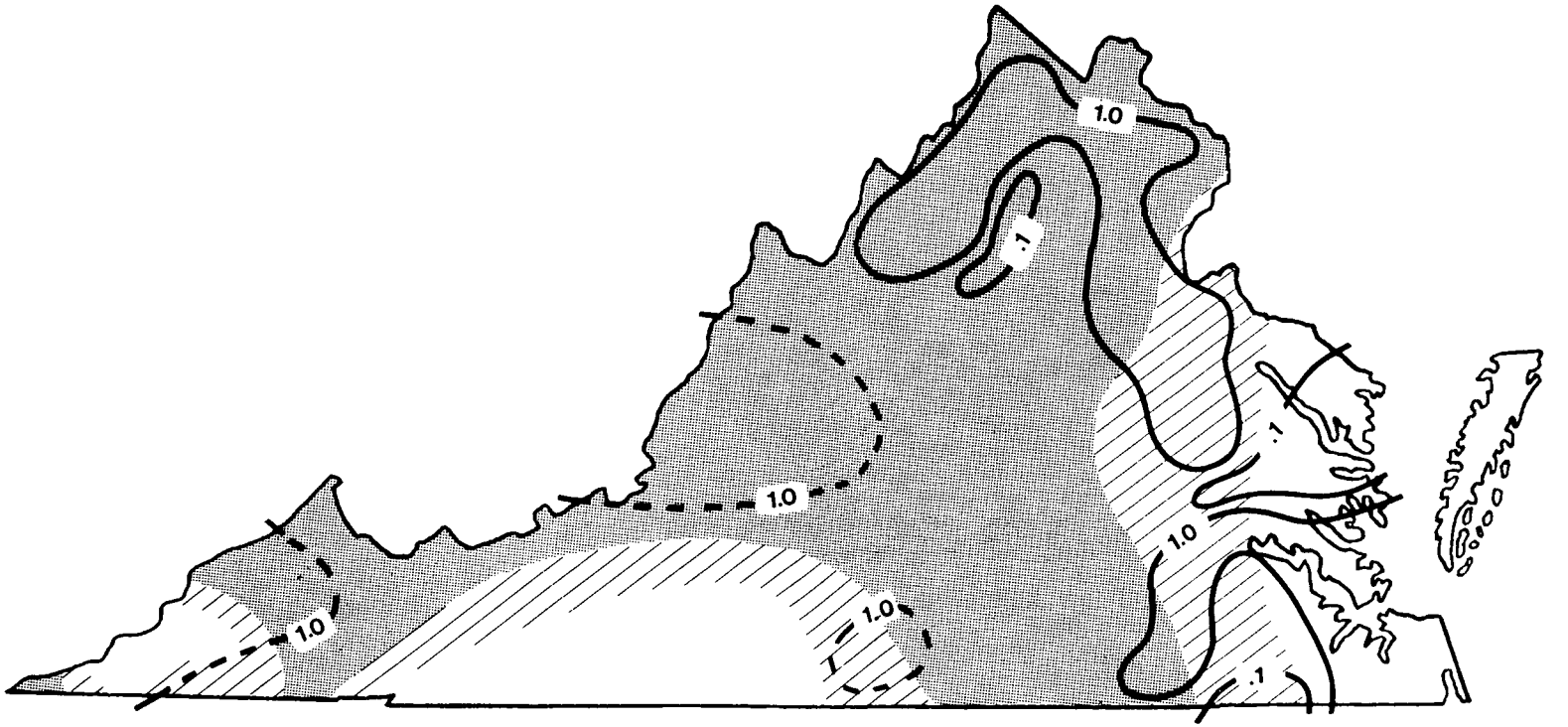
0 — 50
Miles

Virginia



HCO_3 contoured (mg/l)

Virginia



Mn (mg/l)

0.0 - .02

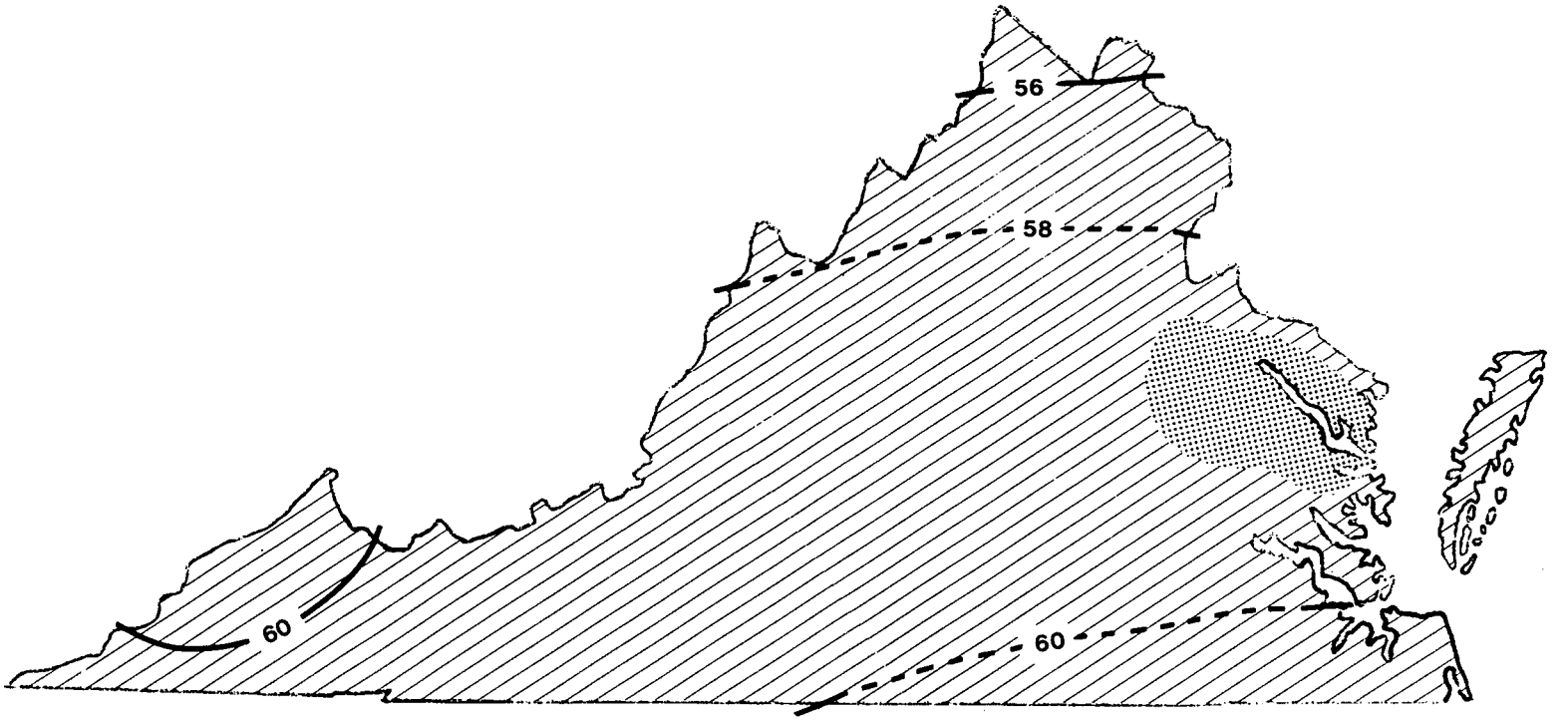
.03 - .05

.06 - .15

Fe contoured (mg/l)

0 50
Miles

Virginia



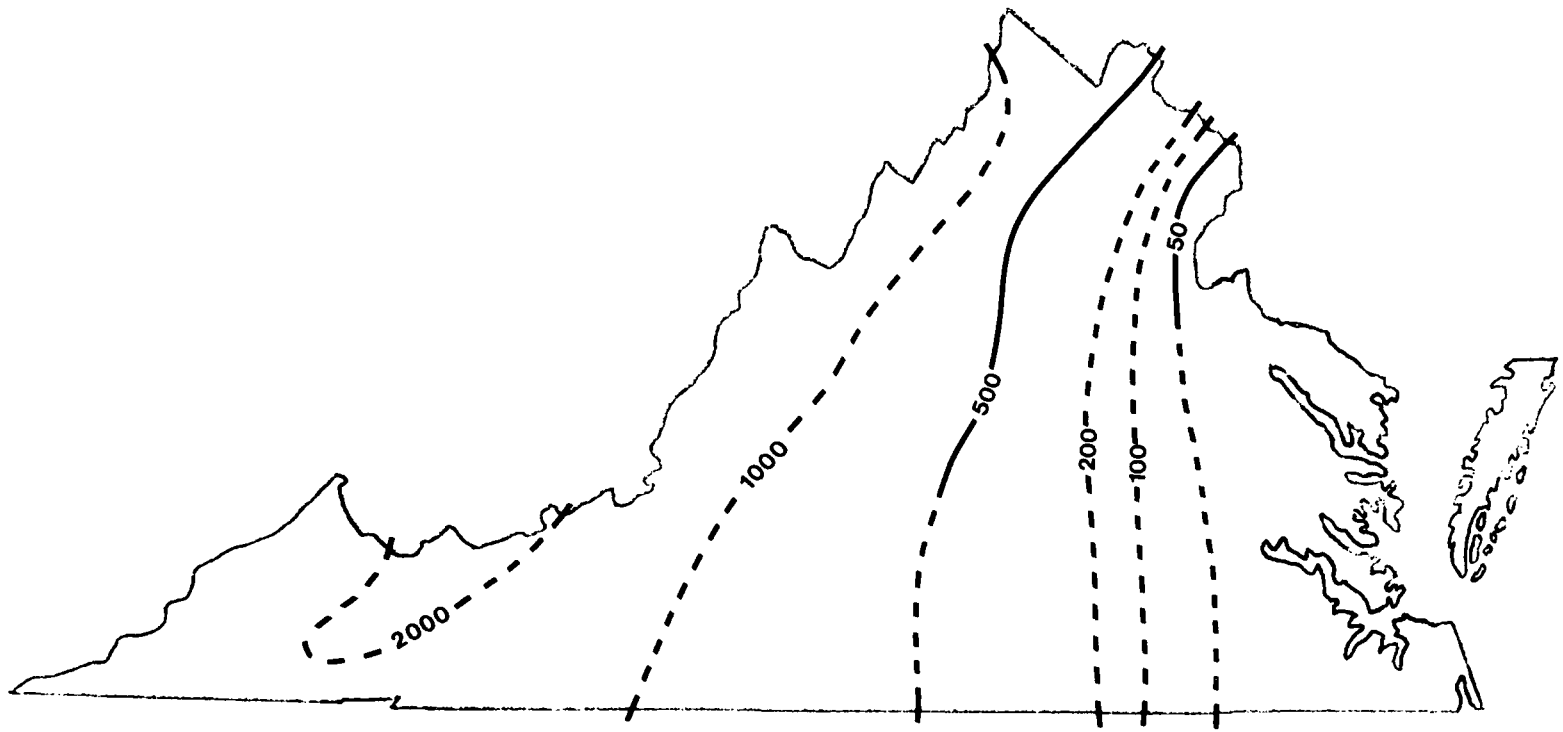
pH

6.1 - 8.0

8.1 - 10

Temperature contoured (°F)

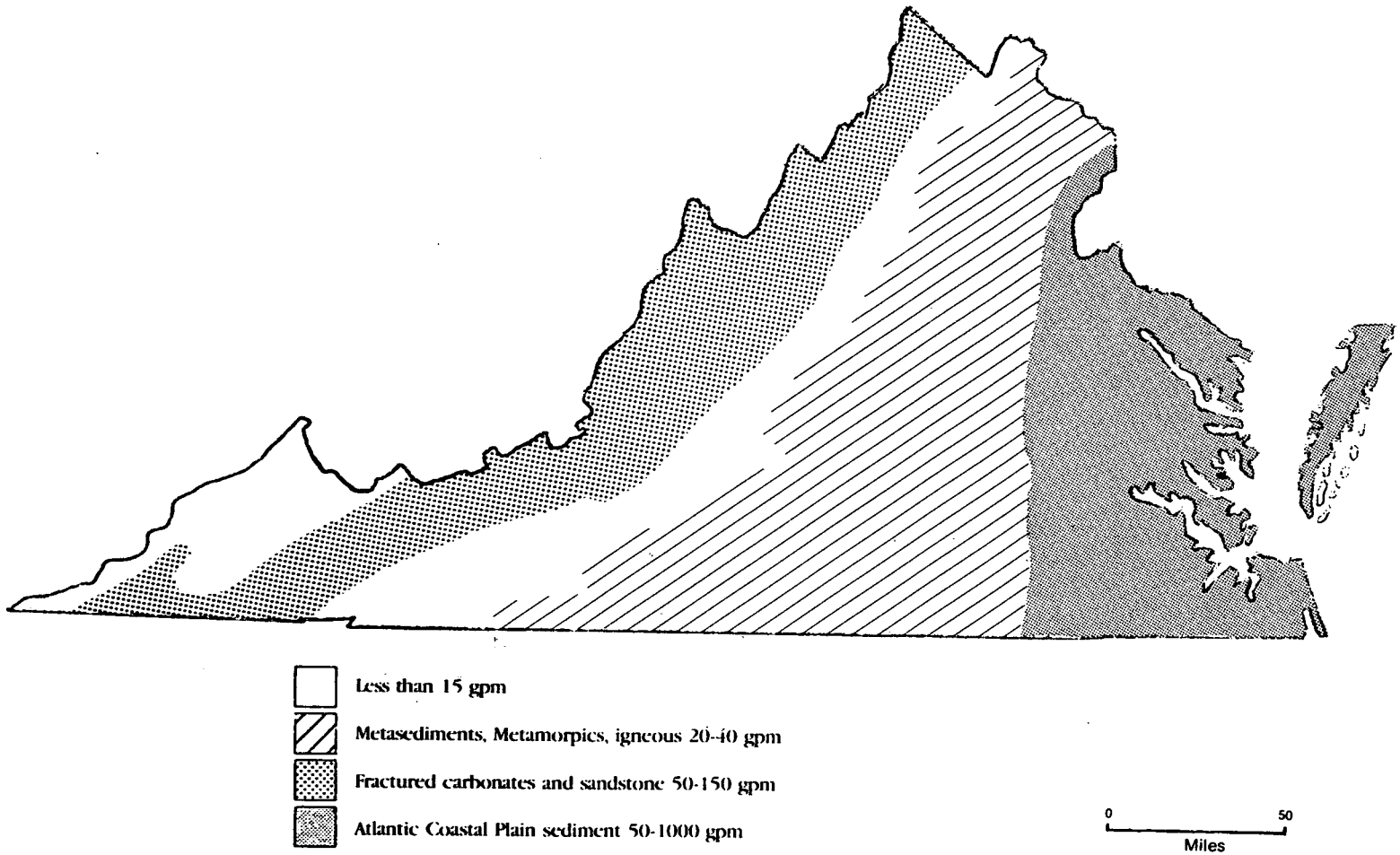
Virginia



Potentiometric surface (ft., Datum: mean sea level)

0 50
Miles

Virginia


Less than 15 gpm
Metasediments, Metamorpics, igneous 20-40 gpm
Fractured carbonates and sandstone 50-150 gpm
Atlantic Coastal Plain sediment 50-1000 gpm
0
50
Miles

Washington

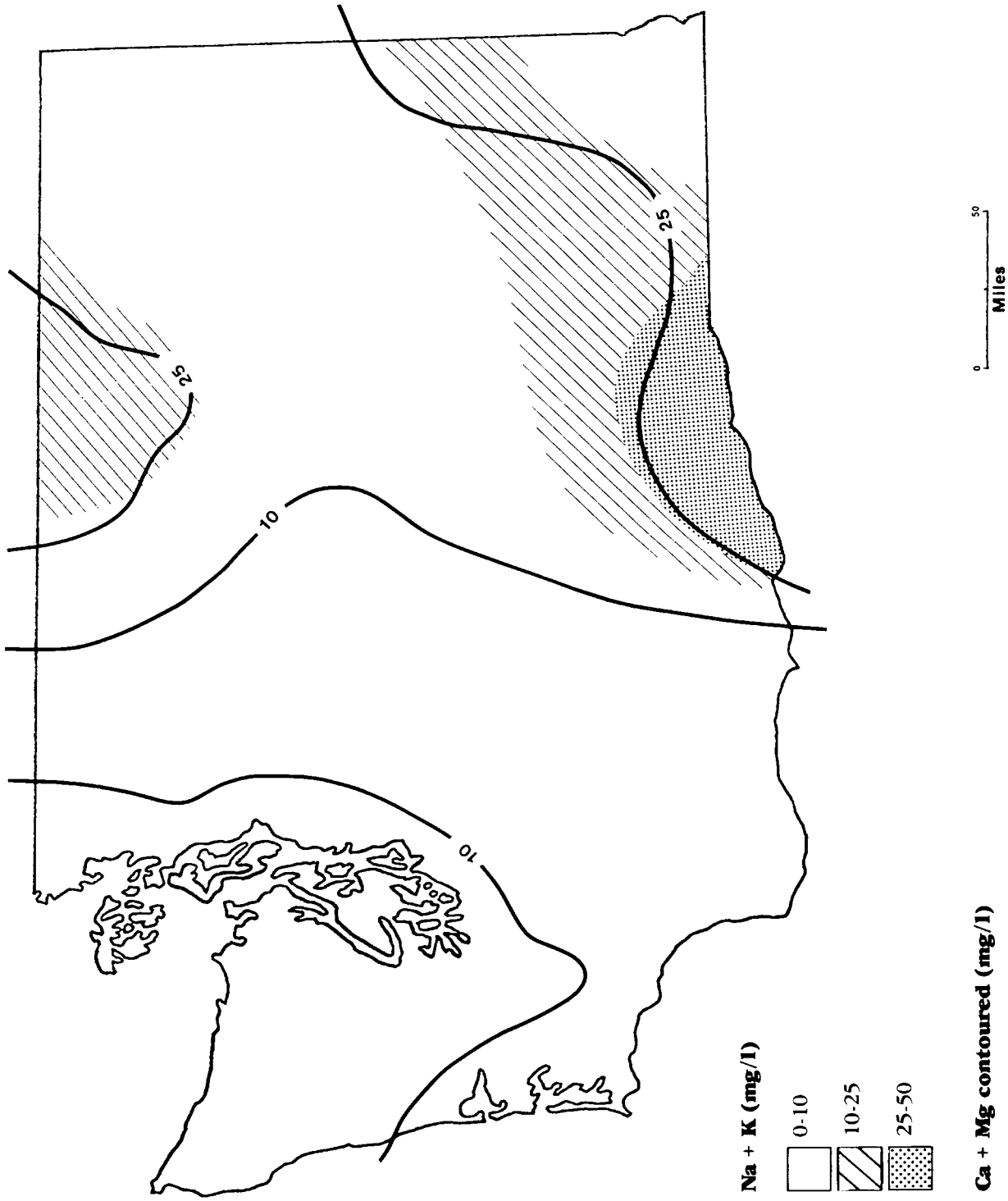


Plate 356

Washington

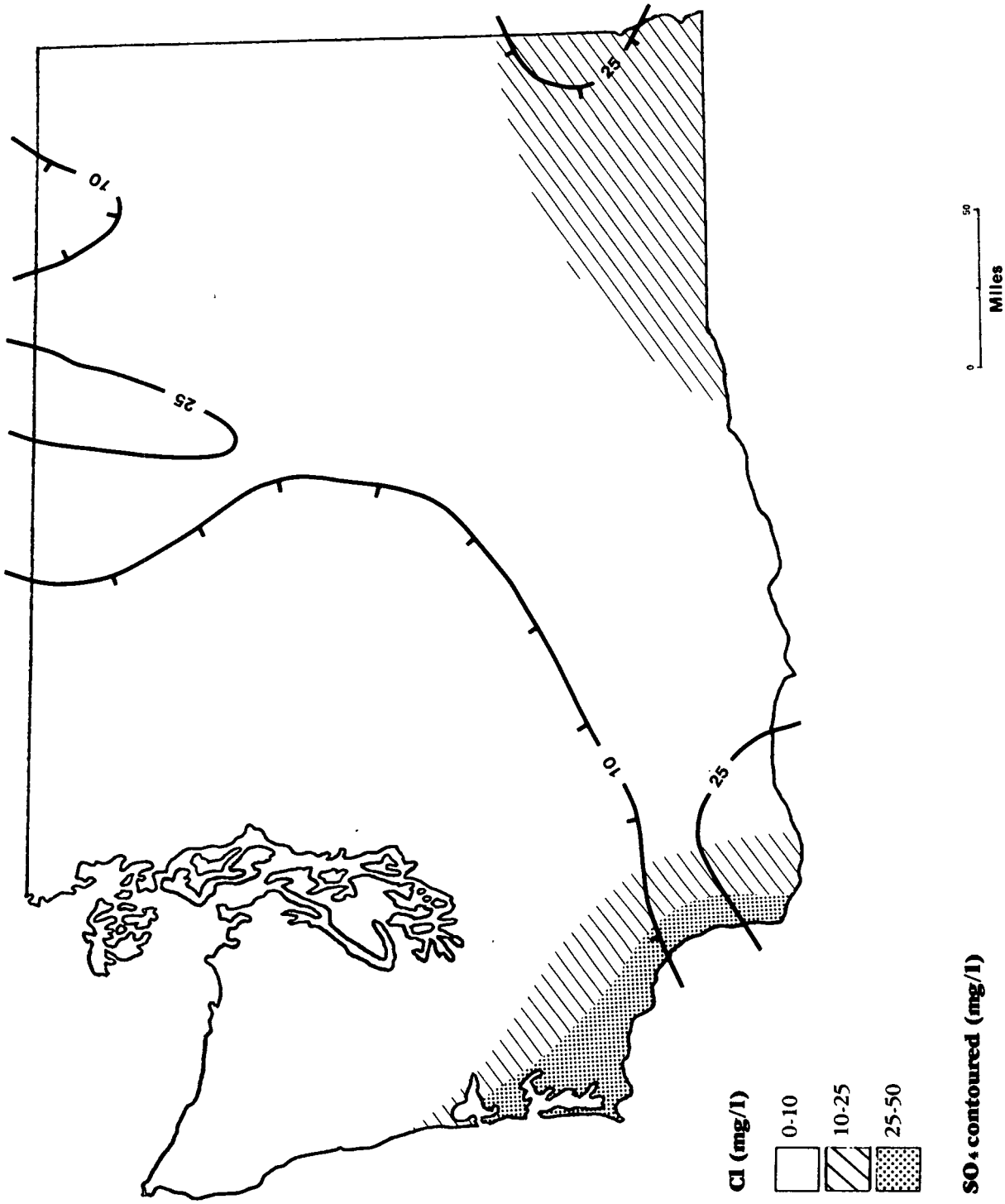


Plate 357

Washington

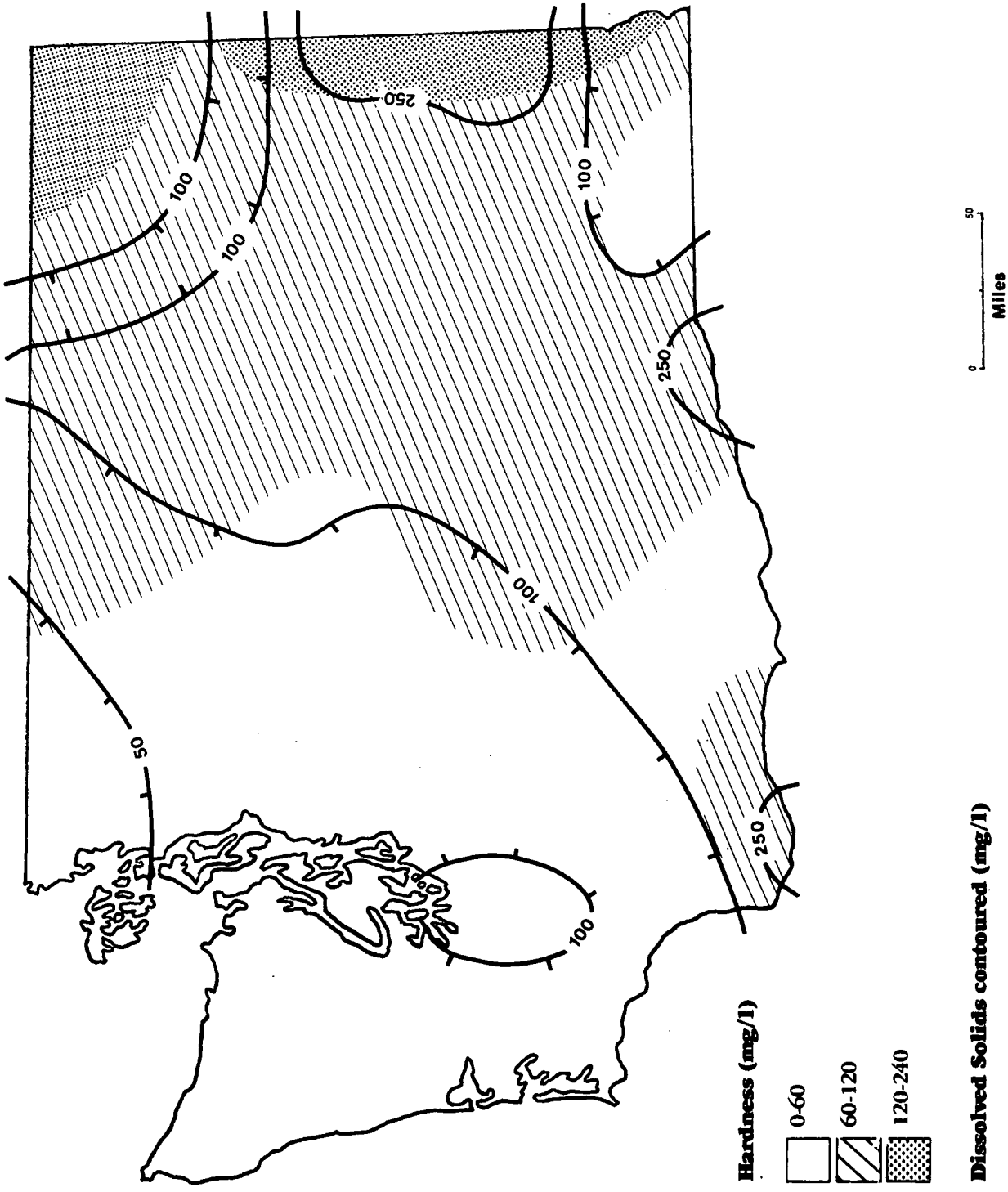
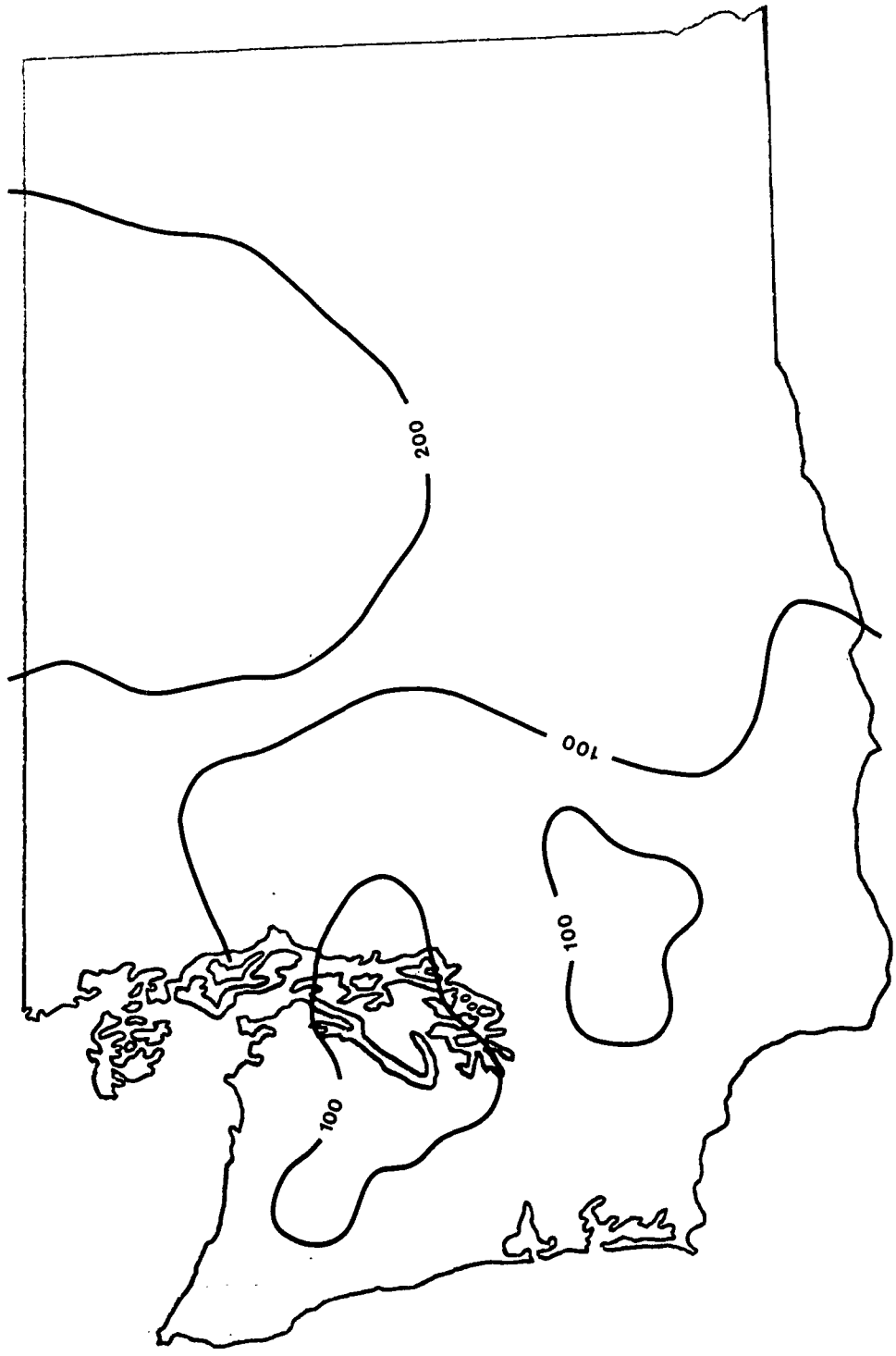


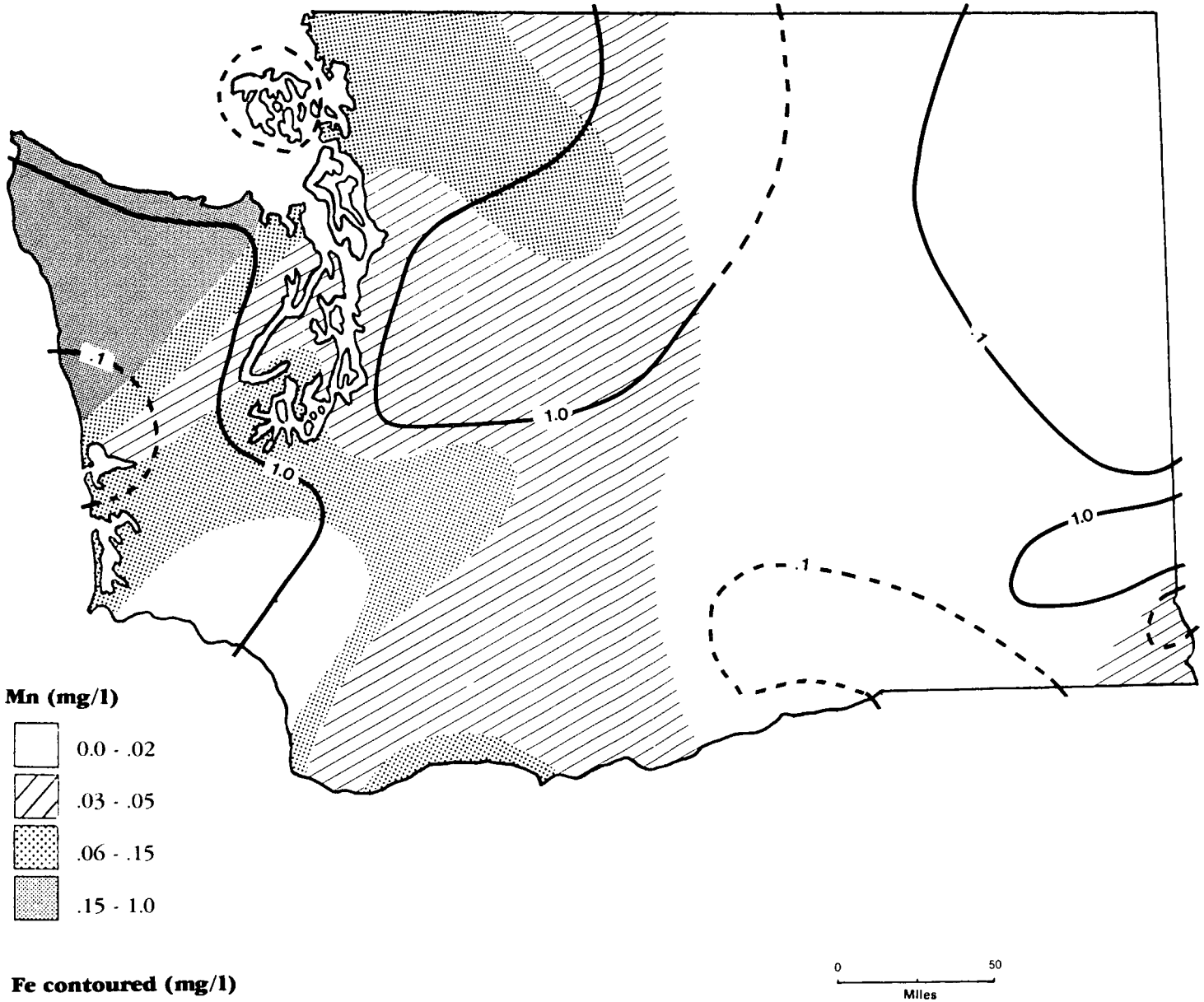
Plate 358

Washington

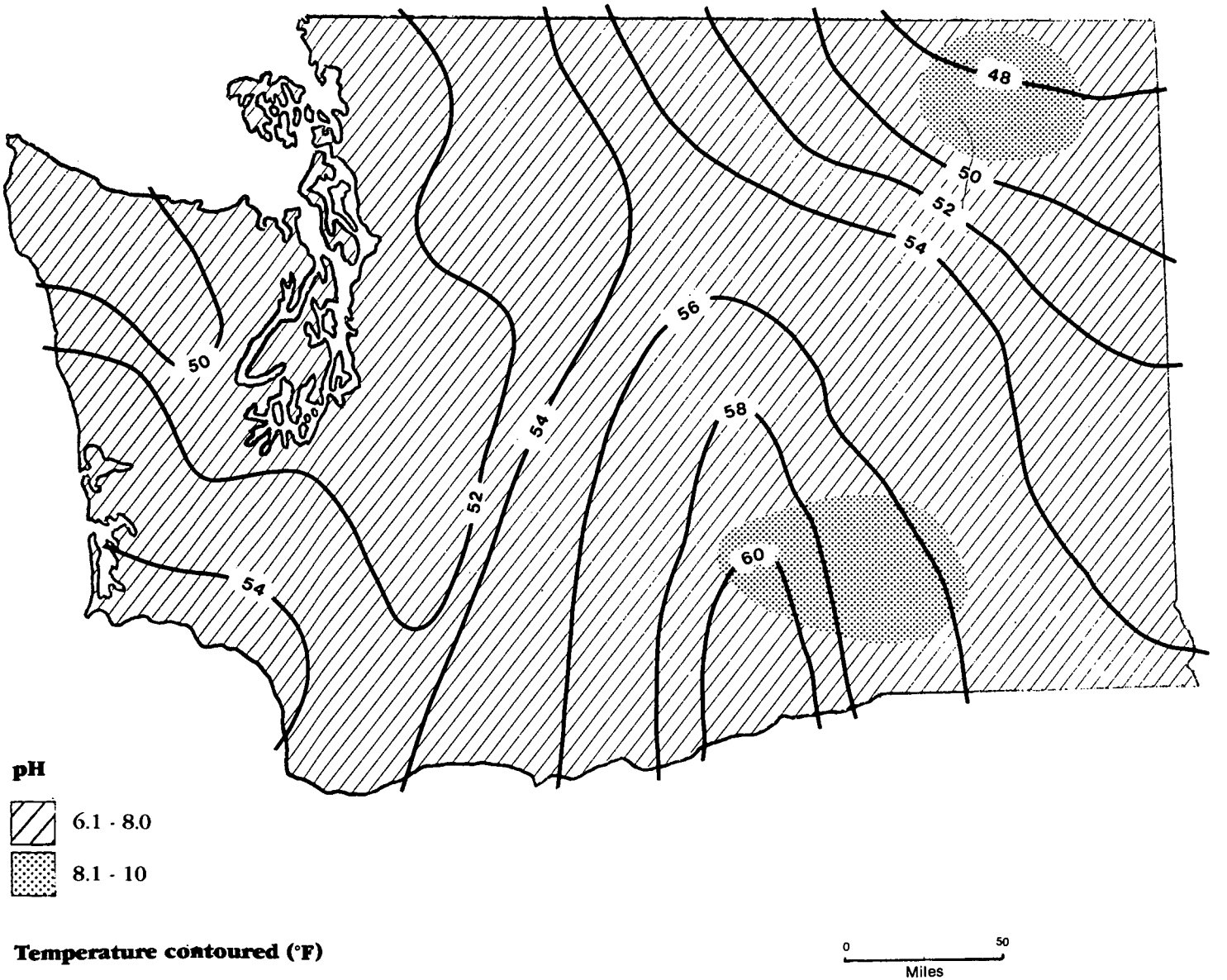


HCO_3 contoured (mg/l)

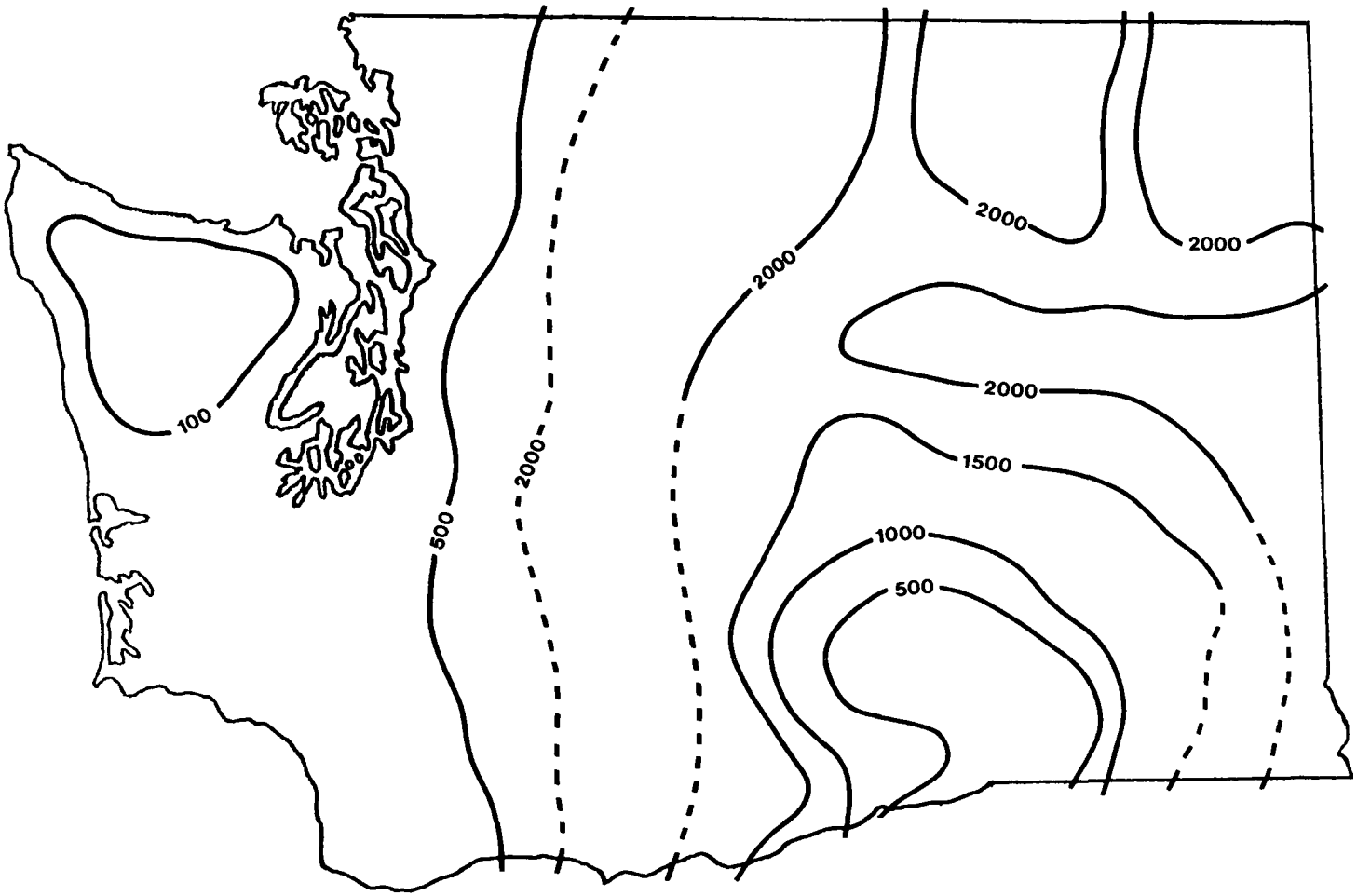
Washington


.1
1.0
1.0
.1
1.0
.1
Mn (mg/l)
0.0 - .02
.03 - .05
.06 - .15
.15 - 1.0
Fe contoured (mg/l)
0
50
Miles

Washington


48
50
52
54
56
58
60
50
52
54
54
pH
6.1 - 8.0
8.1 - 10
Temperature contoured (°F)
0
50
Miles

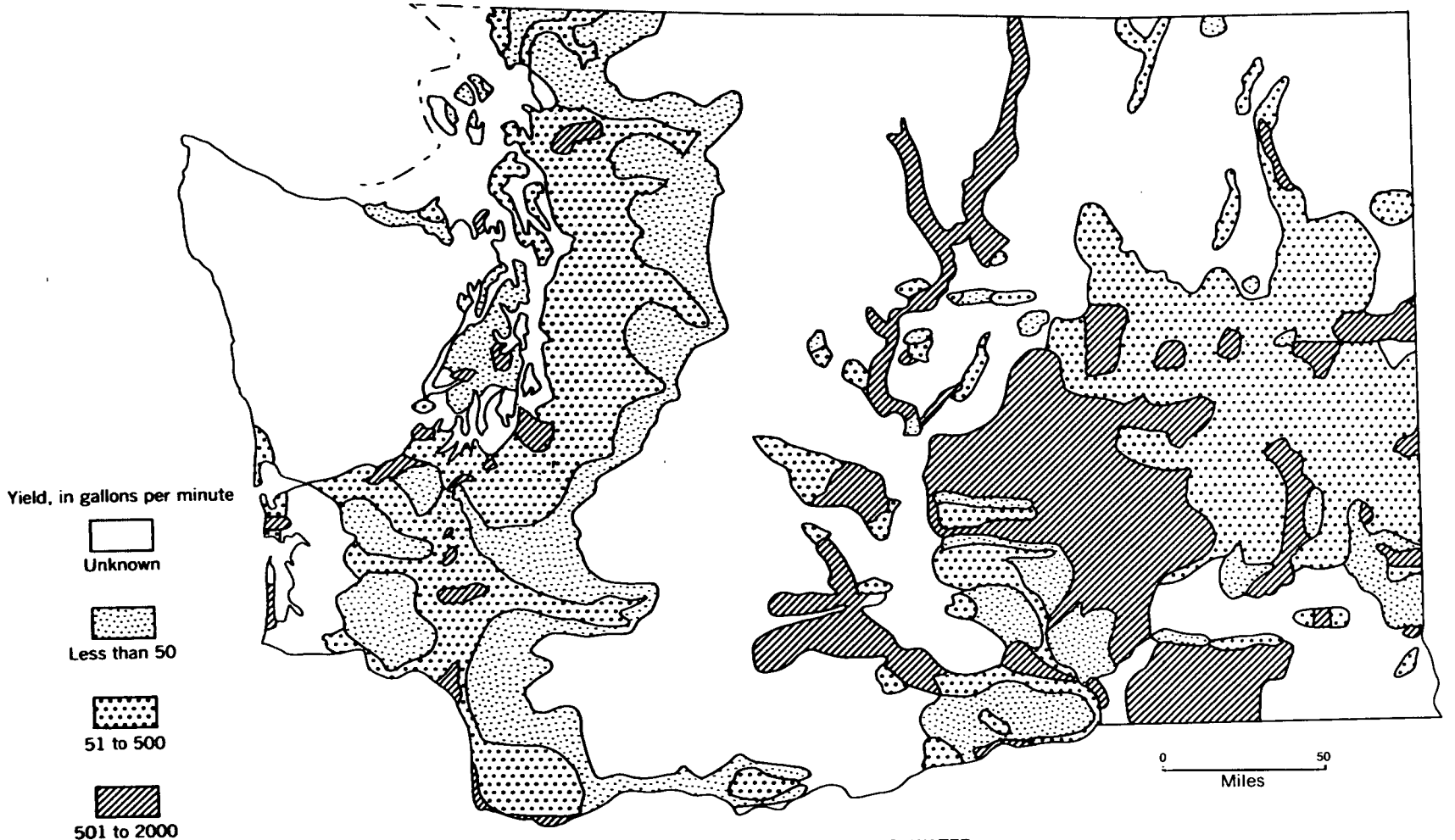
Washington



Potentiometric surface (ft., Datum: mean sea level)

0 50
Miles

Washington



AVAILABILITY OF GROUND WATER

West Virginia

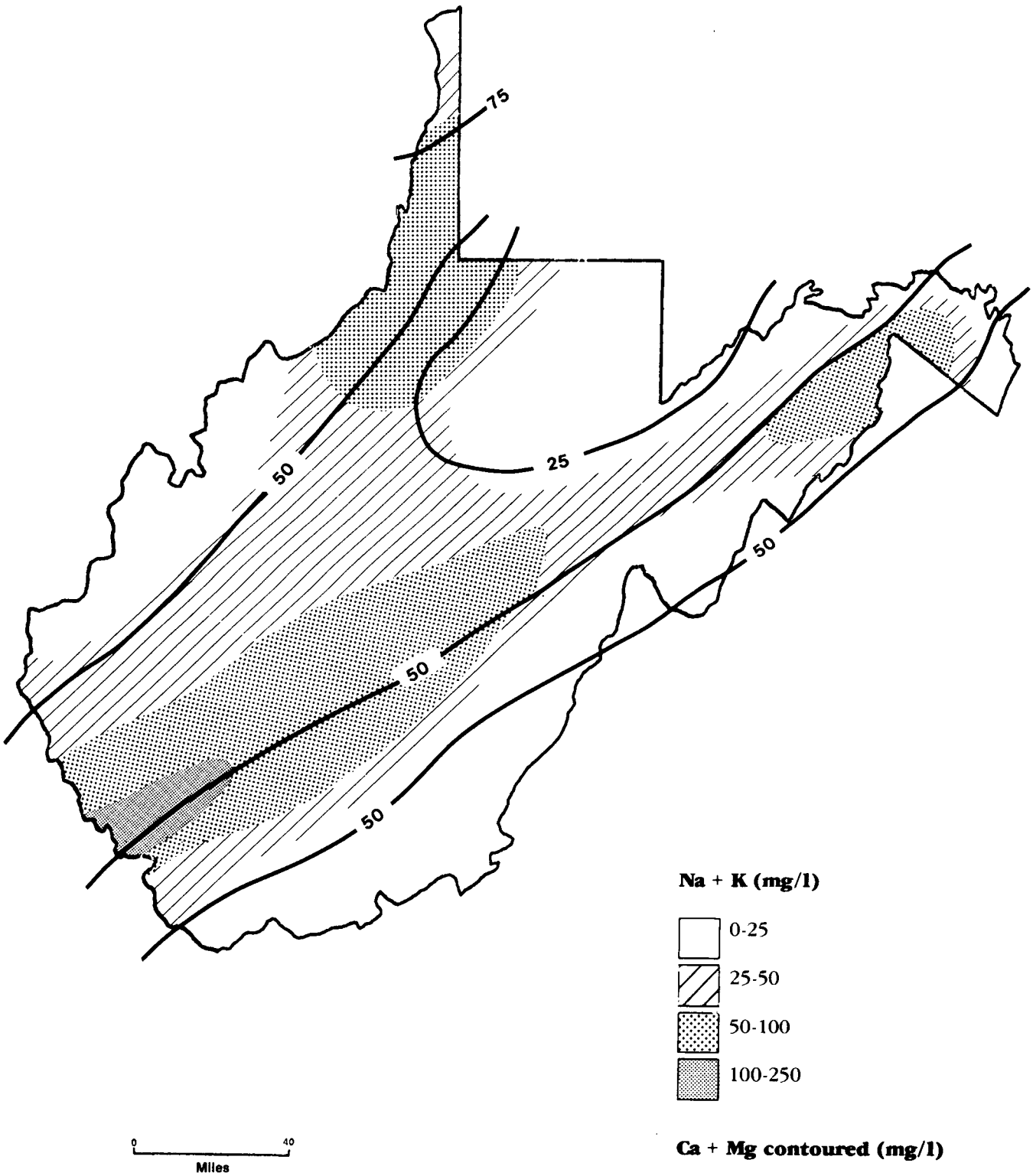


Plate 364

West Virginia

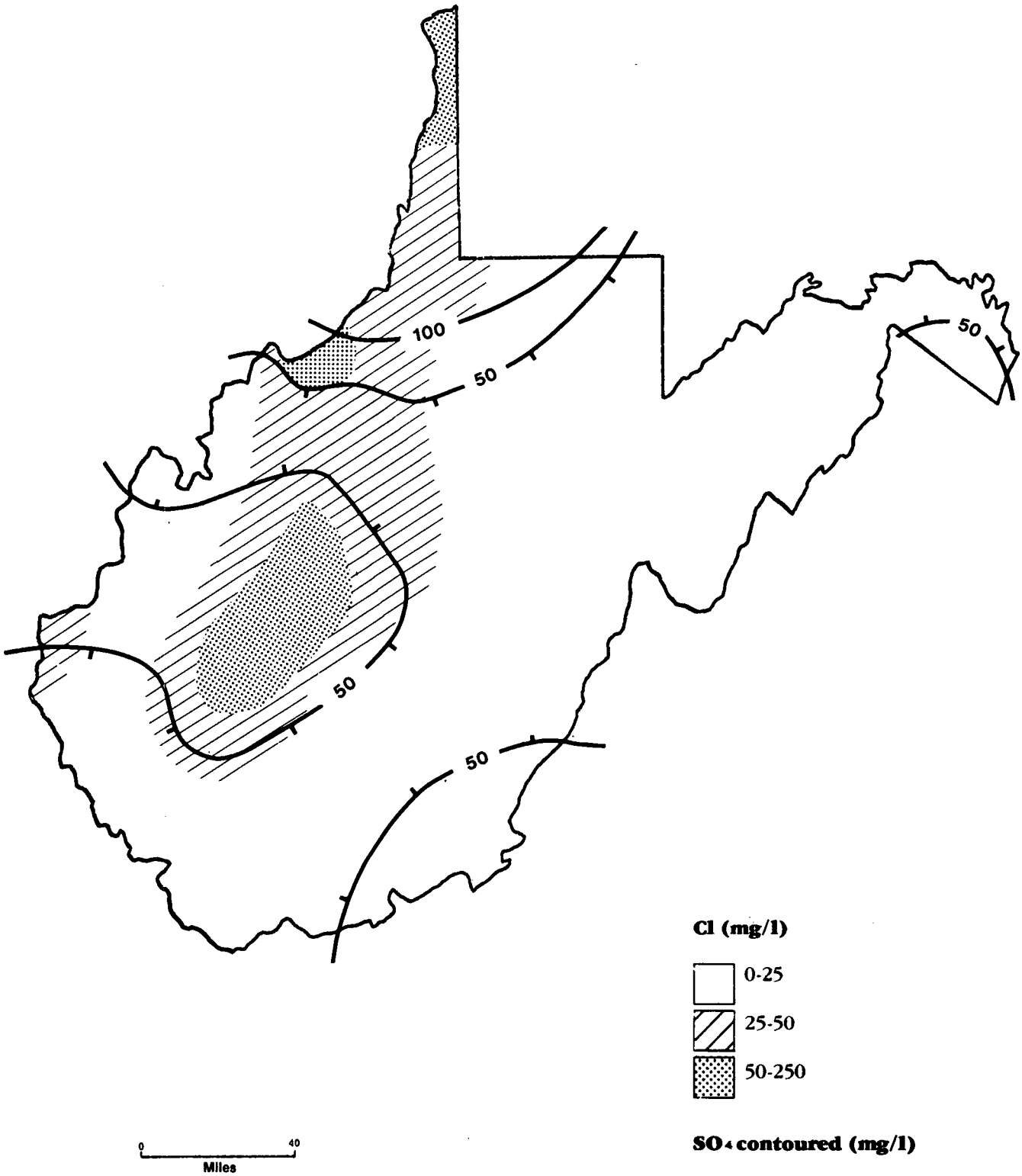
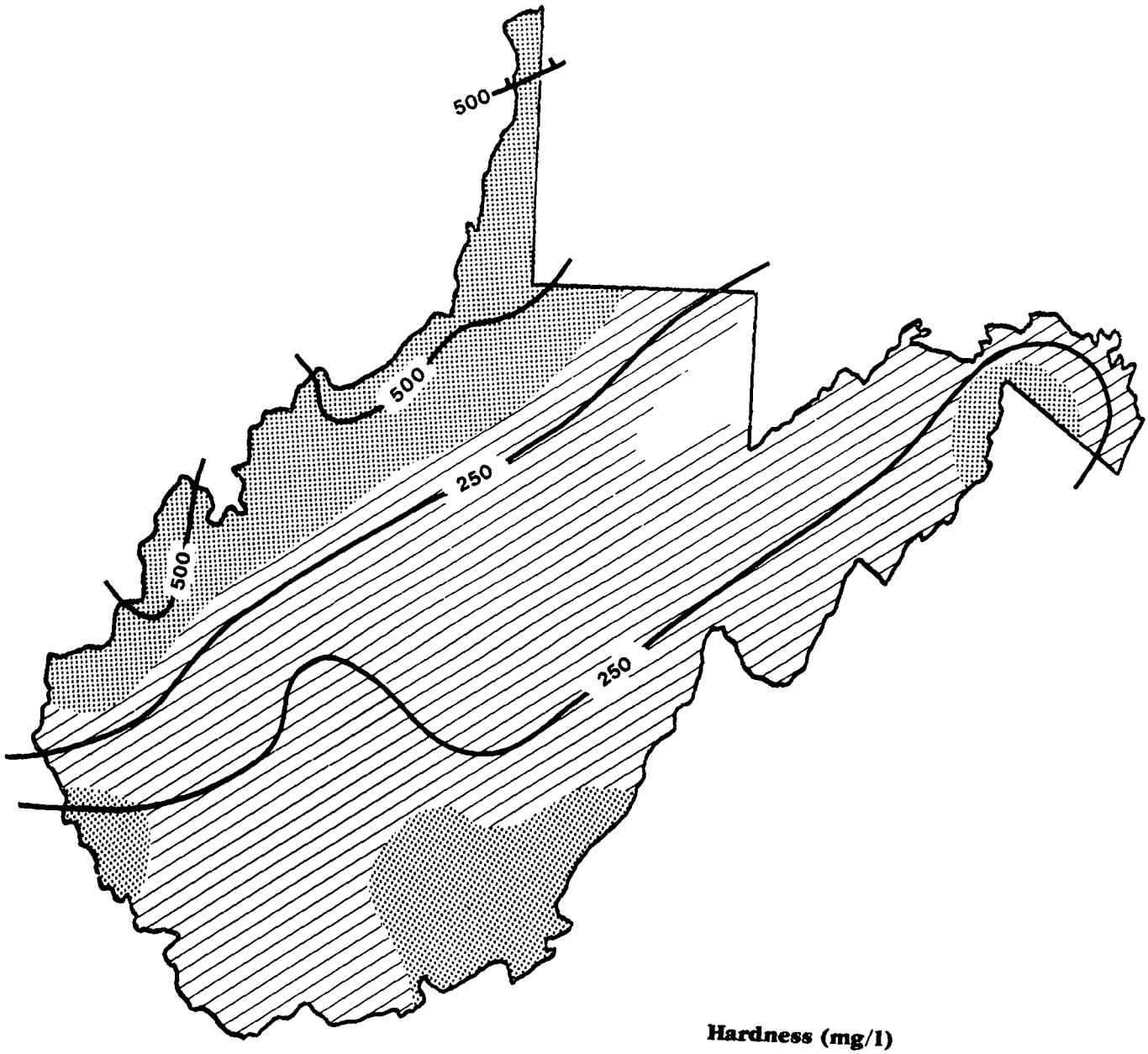


Plate 365

West Virginia



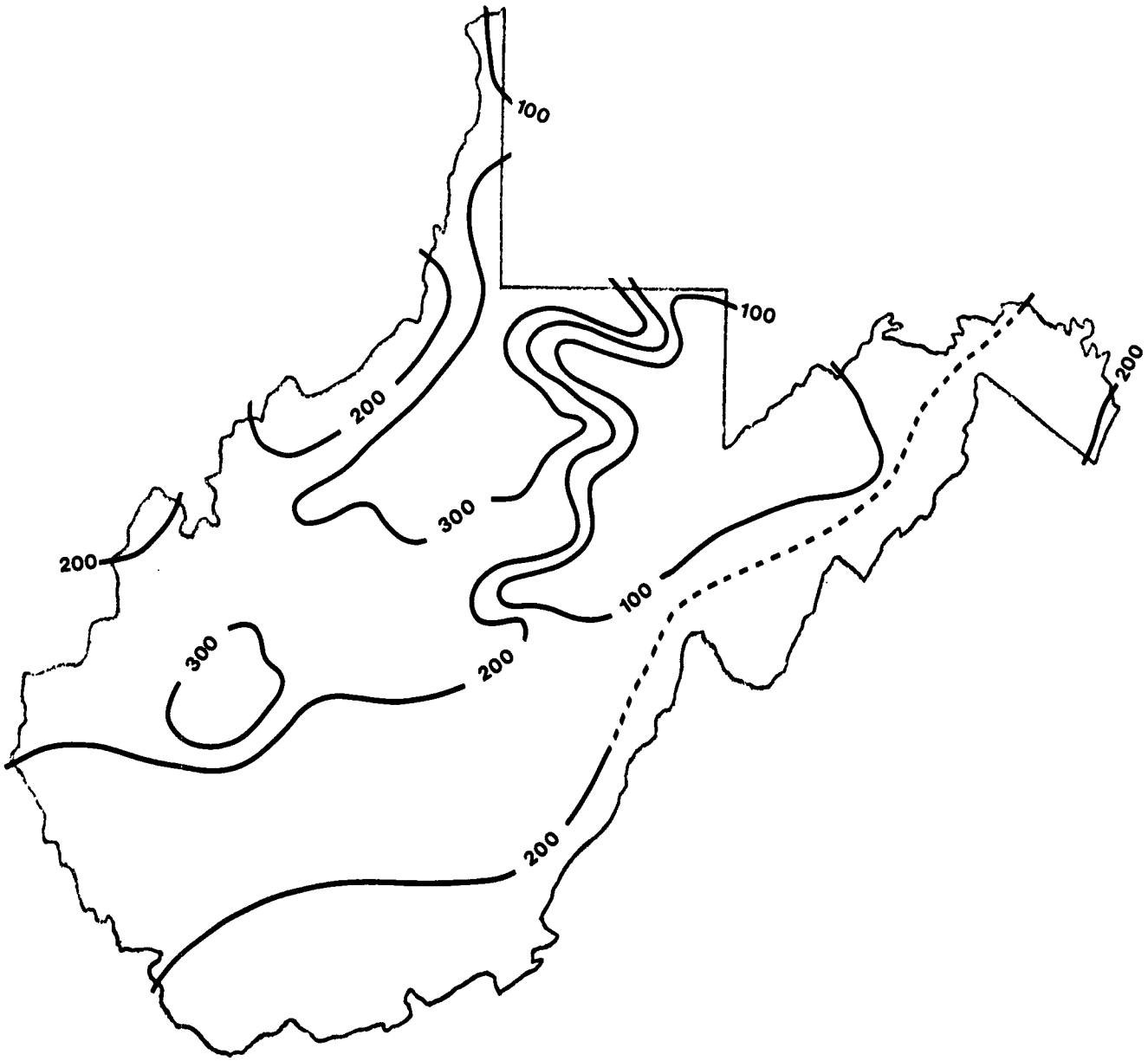
Hardness (mg/l)

- < 120
- 120-240
- 240-500

0 40
Miles

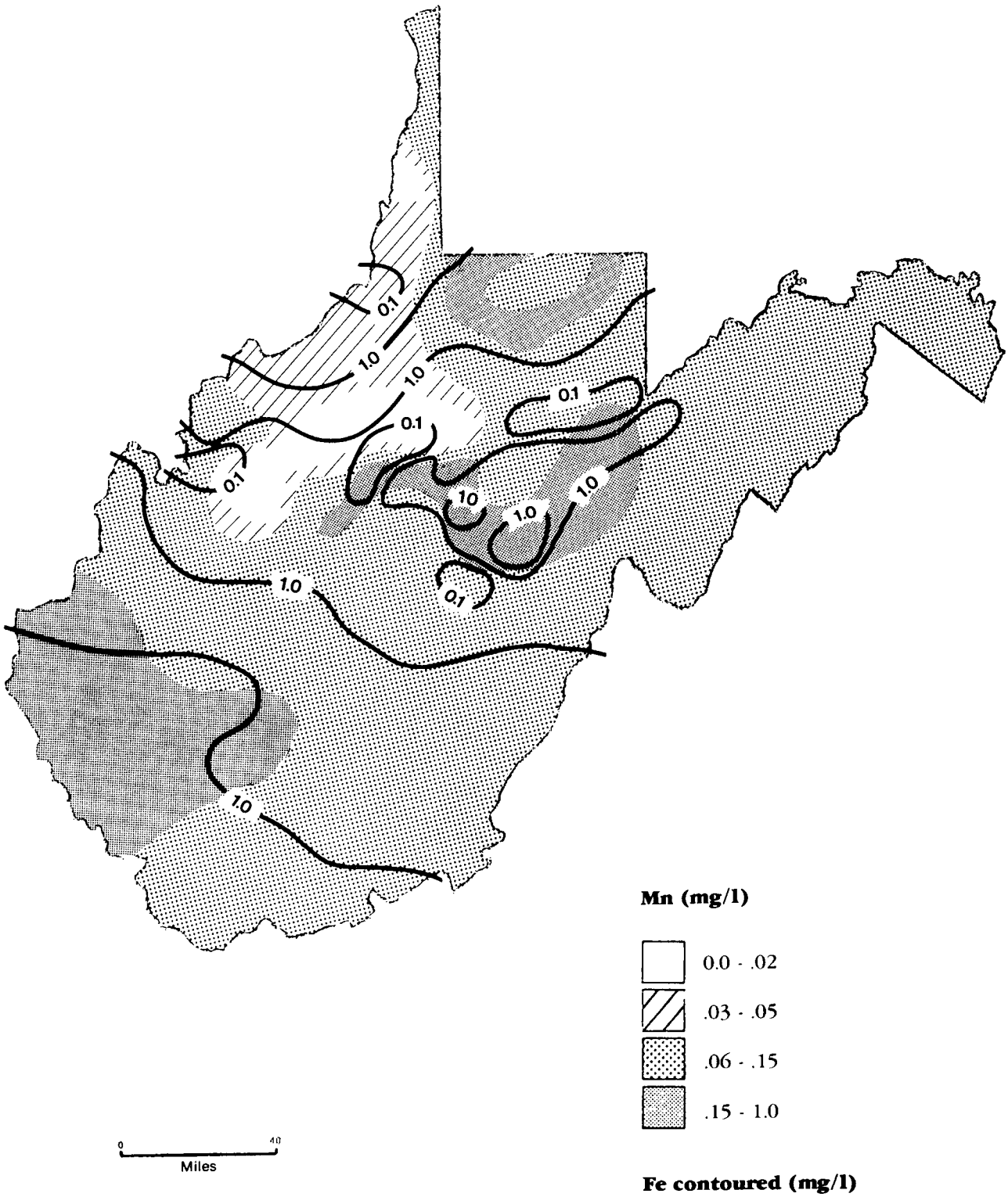
Dissolved Solids contoured (mg/l)

West Virginia

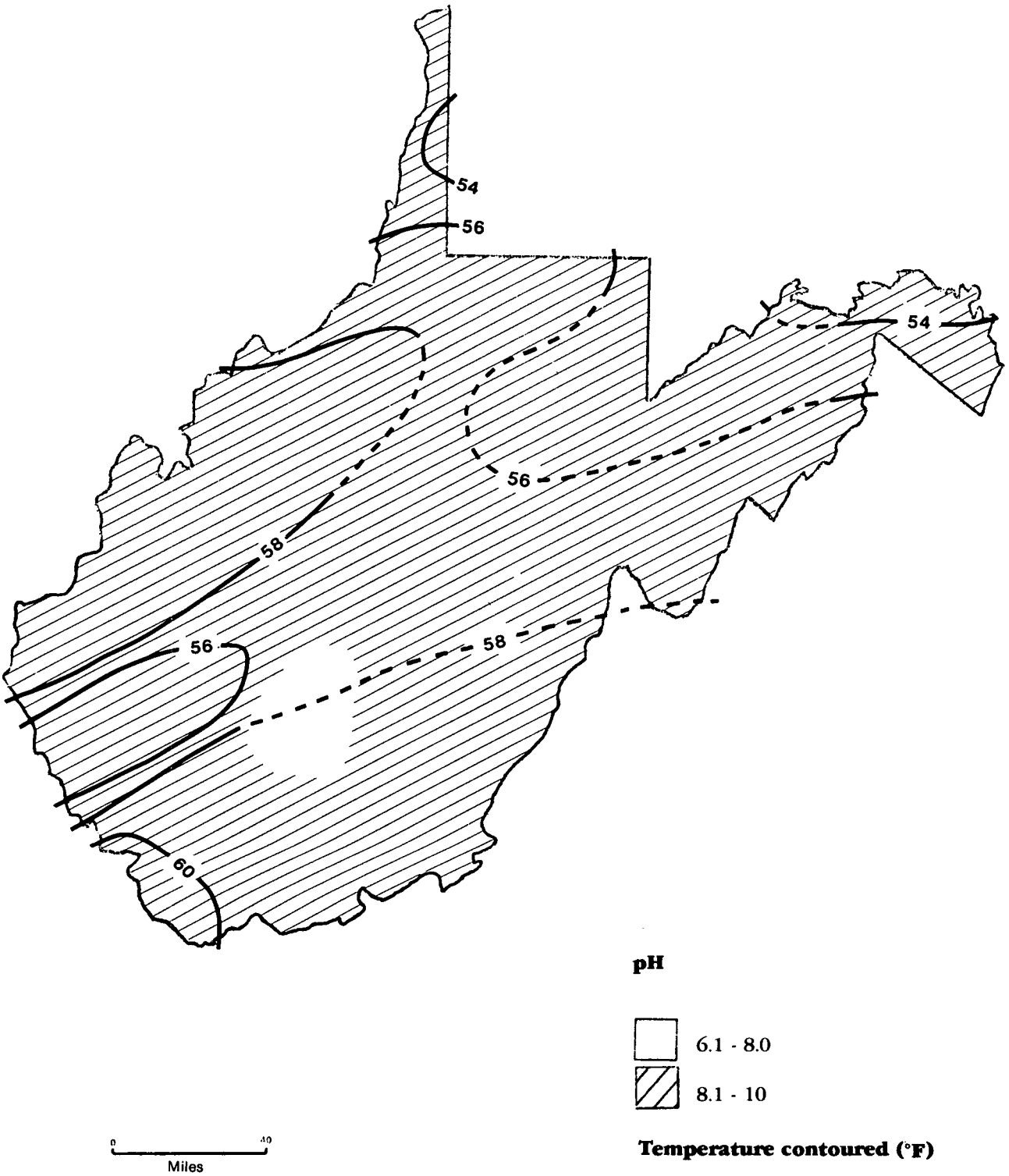


HCO_3 contoured (mg/l)

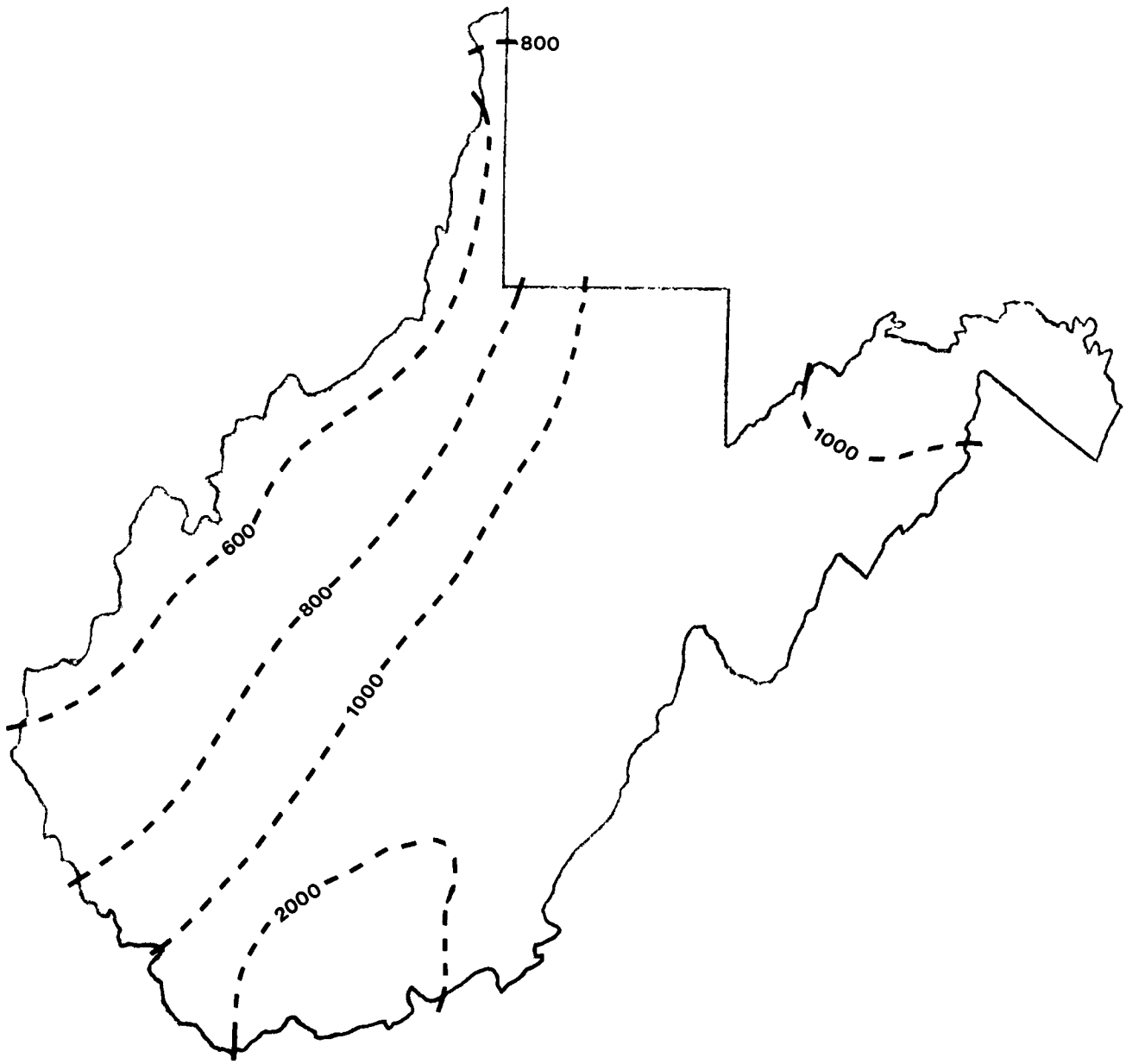
West Virginia



West Virginia



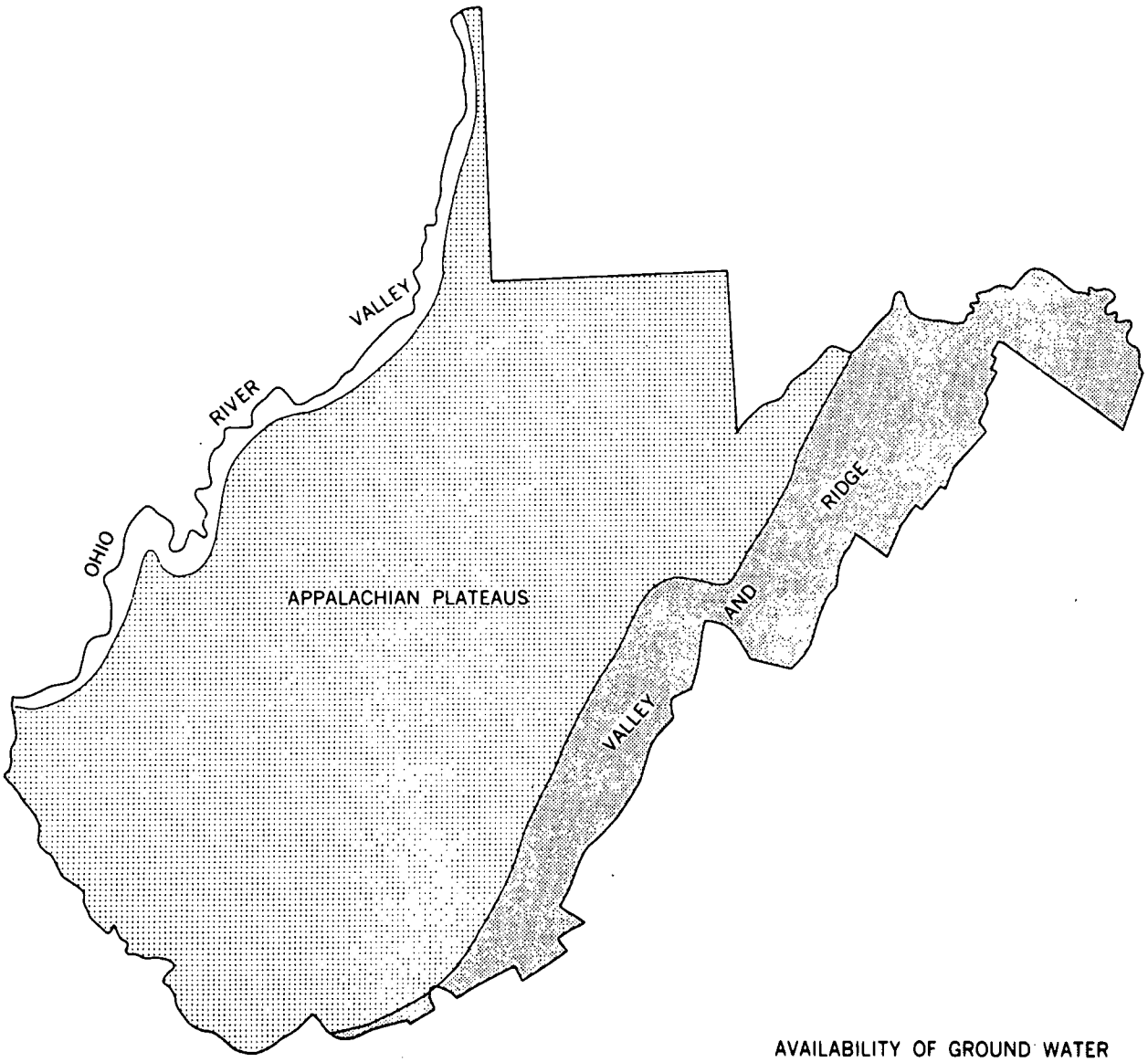
West Virginia



Potentiometric surface
(ft., Datum: mean sea level)

0 40
Miles

West Virginia



AVAILABILITY OF GROUND WATER

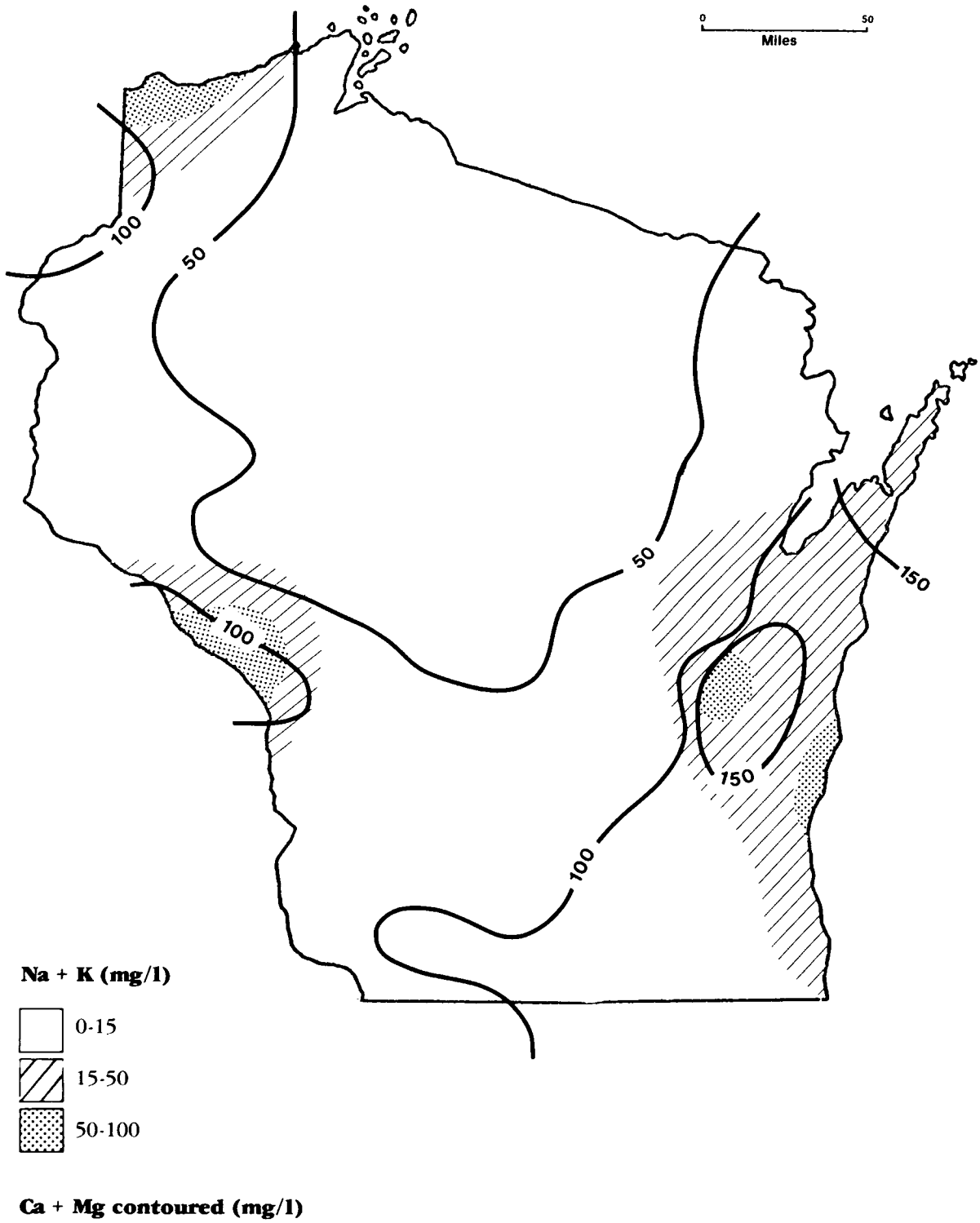
Large quantities available in Shenandoah Valley and other limestone areas but occurrence of good water-bearing zones is irregular Many large springs

Modest quantities available everywhere. Locally wells yield as much as 300 gpm. Generally several aquifers at different depths in a given locality

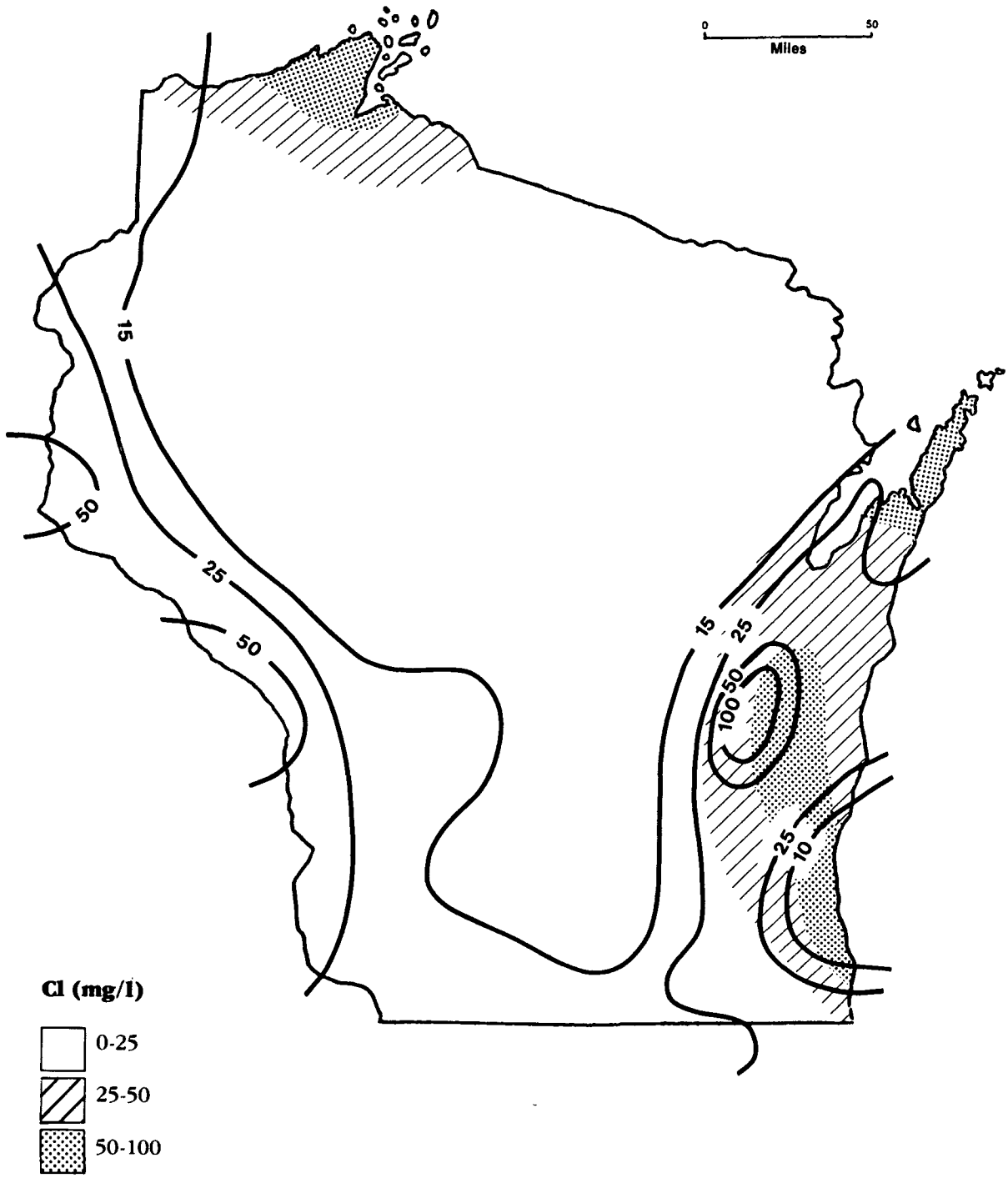
Large quantities available in alluvial deposits along Ohio River. Wells yield as much as 3000 gpm by induced infiltration. Best source of ground water in State

0 40
Miles

Wisconsin


0
50
Miles
100
50
50
100
150
150
100
Na + K (mg/l)
0-15
15-50
50-100
Ca + Mg contoured (mg/l)

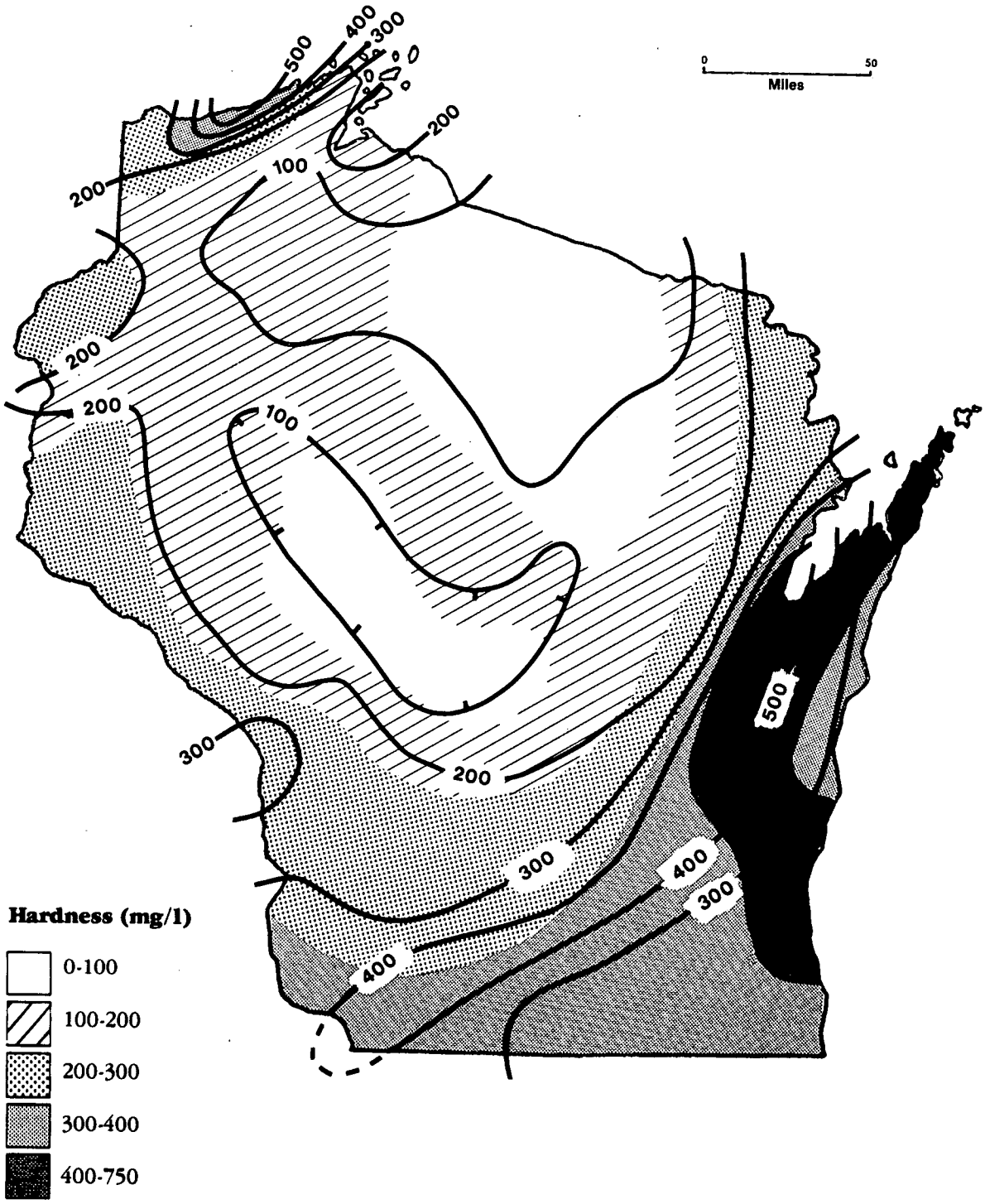
Wisconsin



SO_4 contoured (mg/l)

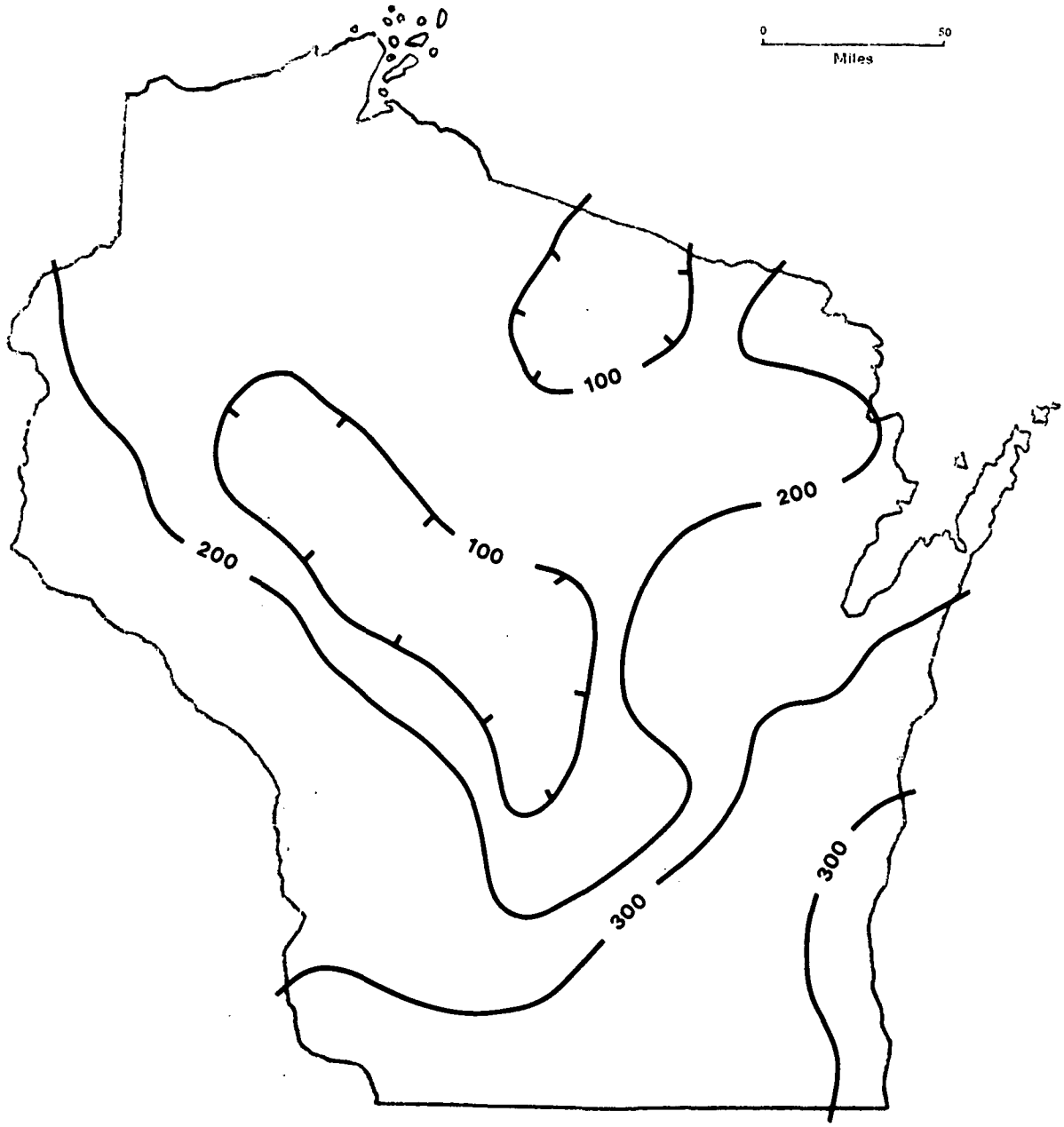
Plate 373

Wisconsin



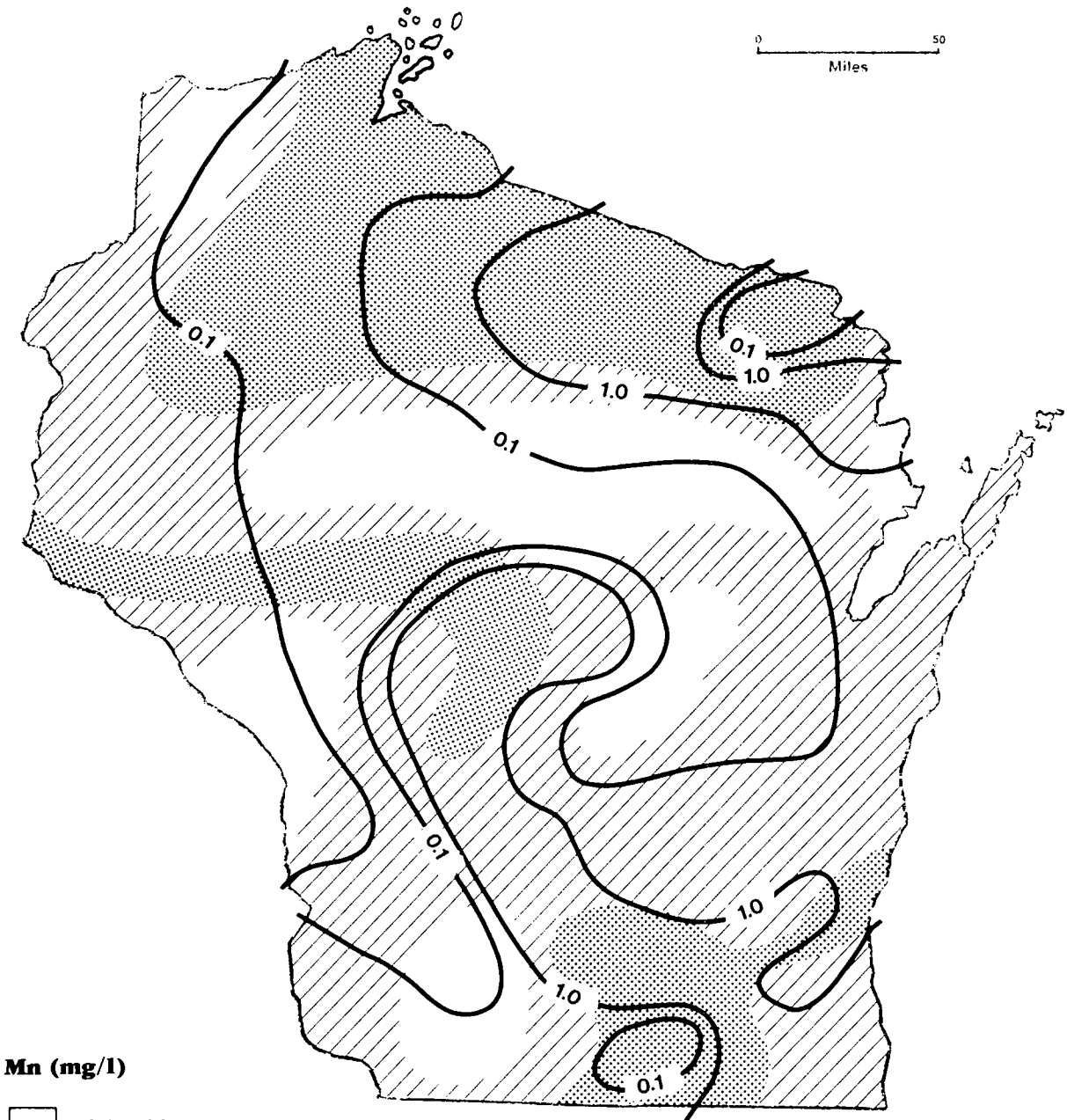
Dissolved Solids contoured (mg/l)

Wisconsin



HCO_3 contoured (mg/l)

Wisconsin

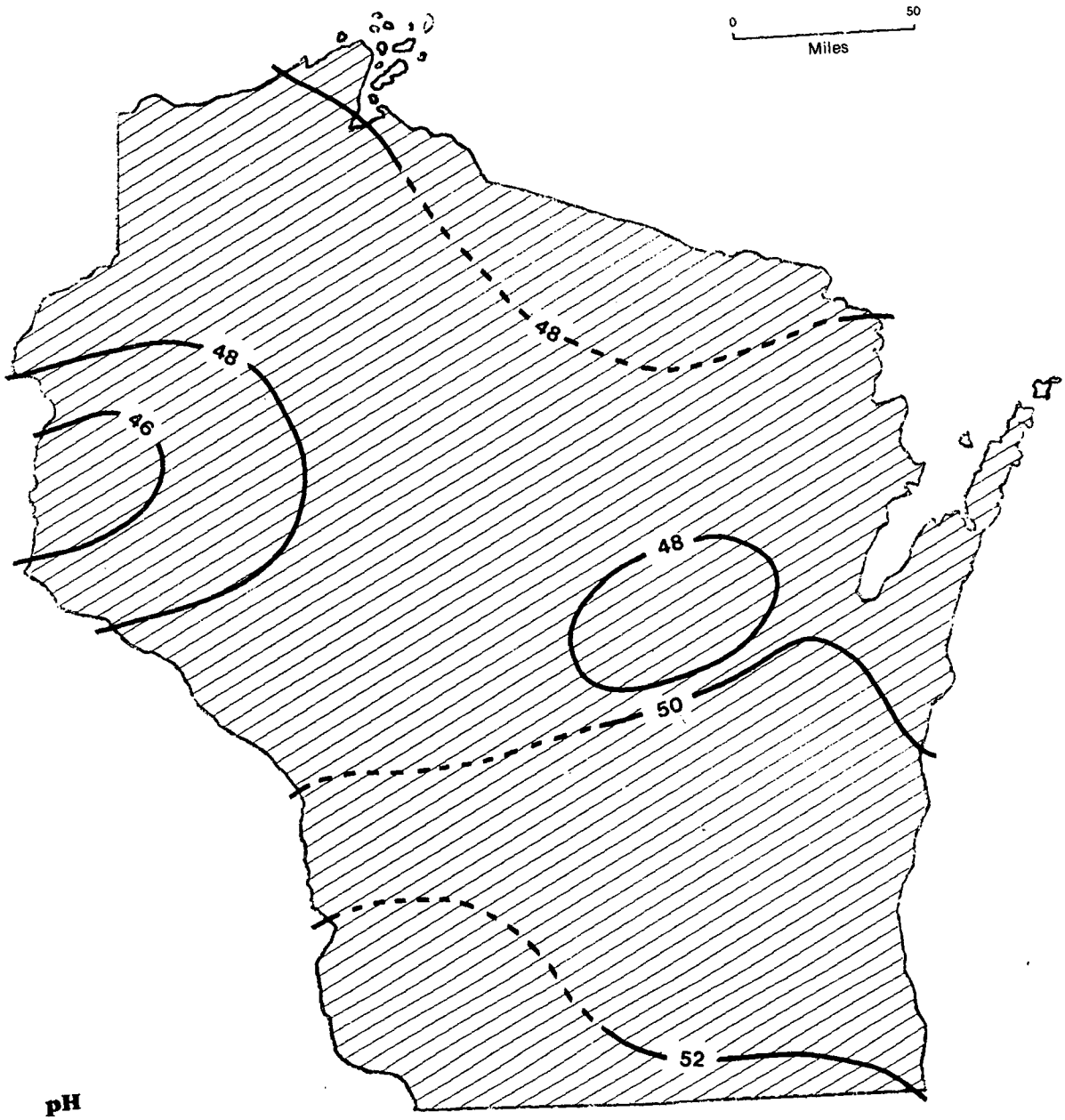


Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15

Fe contoured (mg/l)

Wisconsin

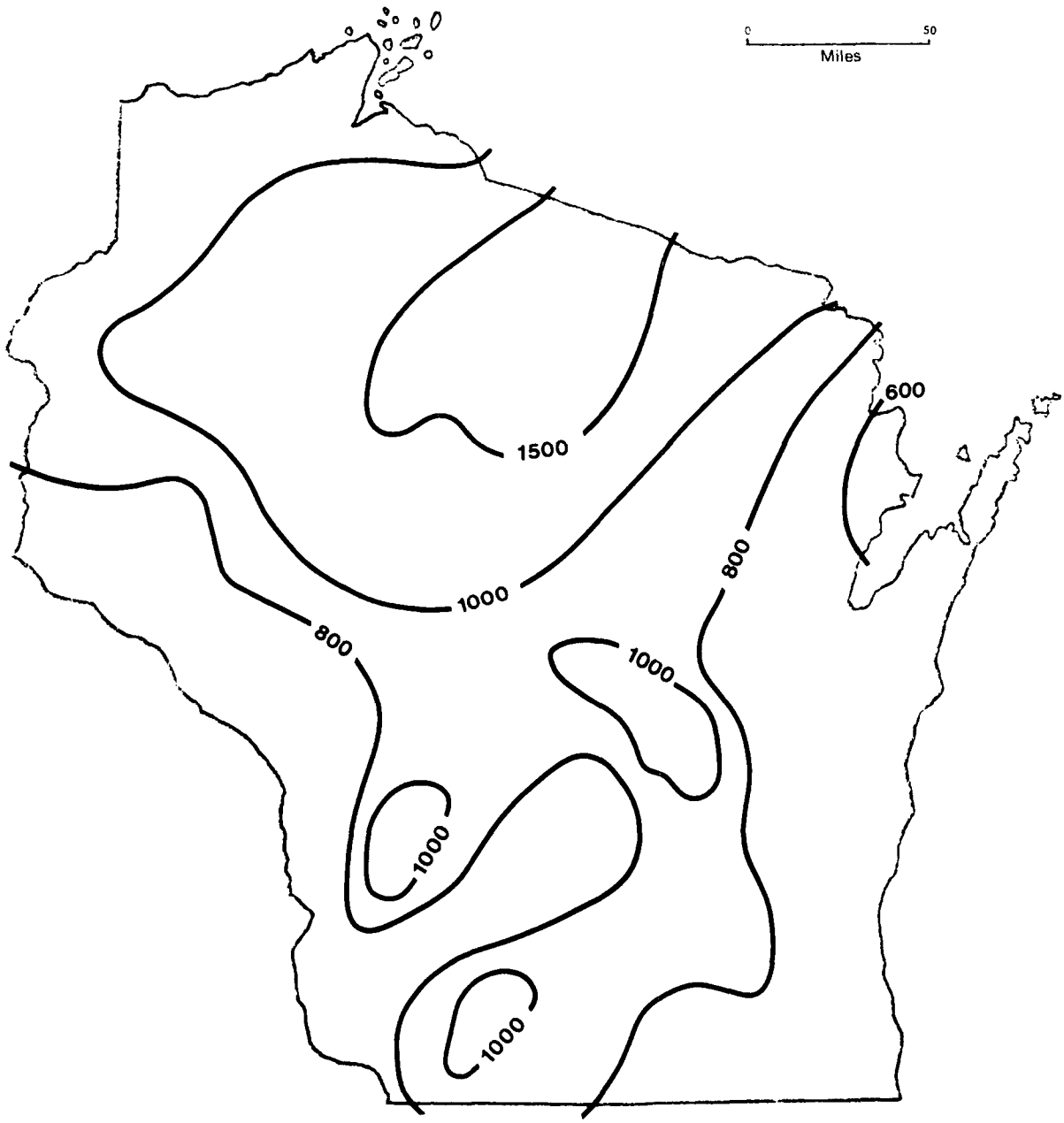


pH

6.1 - 8.0

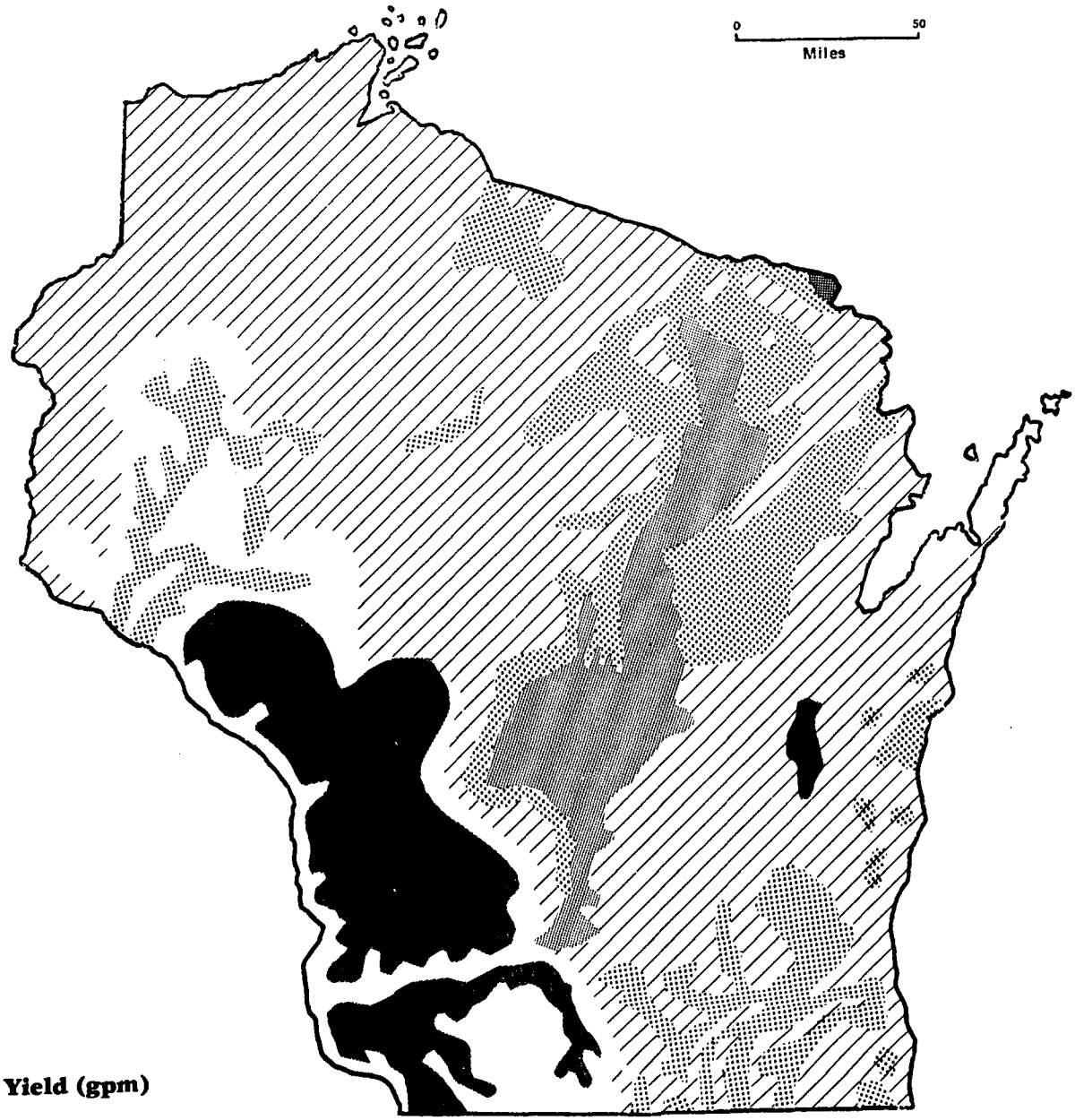
Temperature contoured (°F)

Wisconsin



Potentiometric surface (ft., Datum: mean sea level)

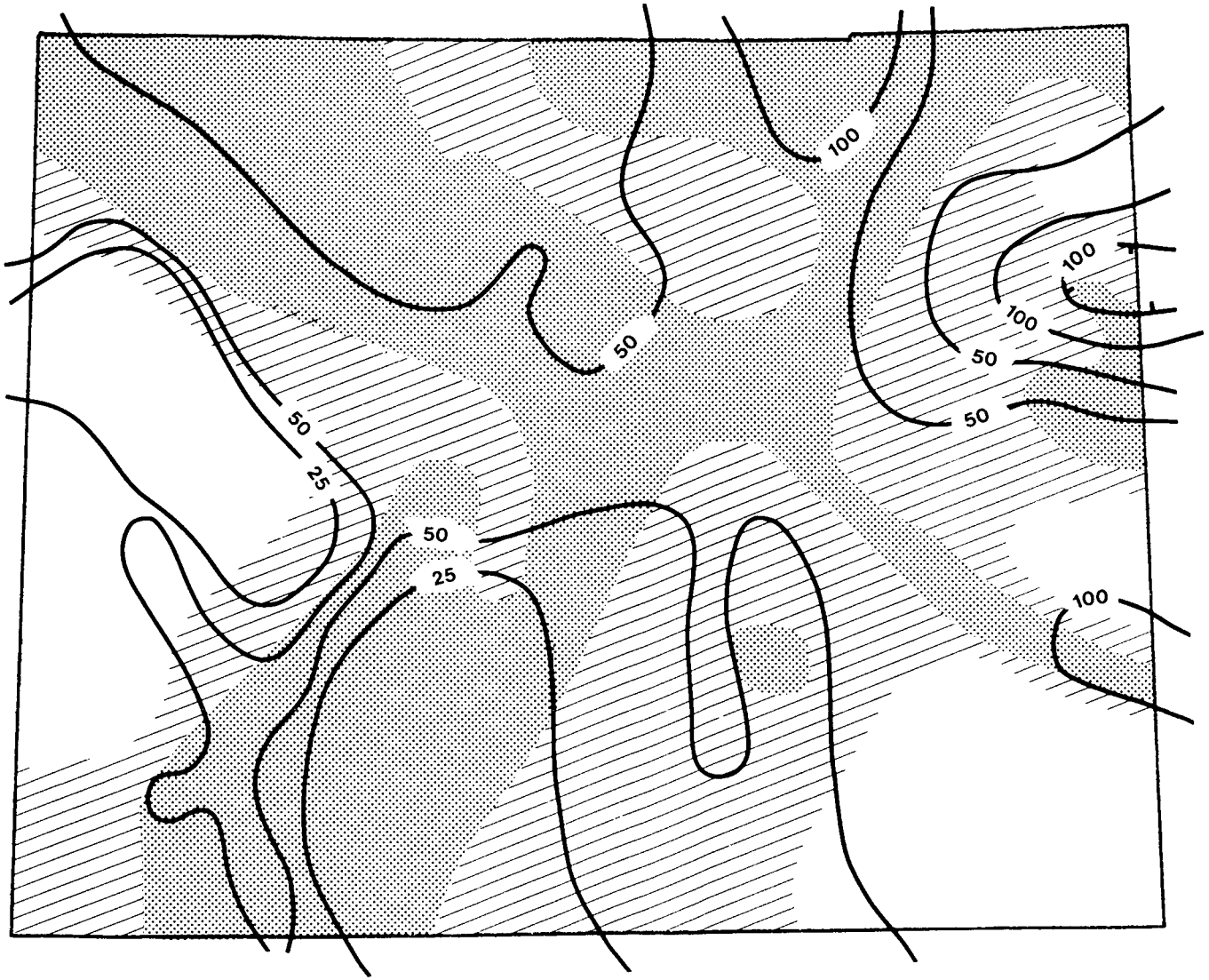
Wisconsin



Yield (gpm)

- 0-100 gpm
- 10-100 gpm
- 100-500 gpm
- Greater than 500 gpm
- Driftless area

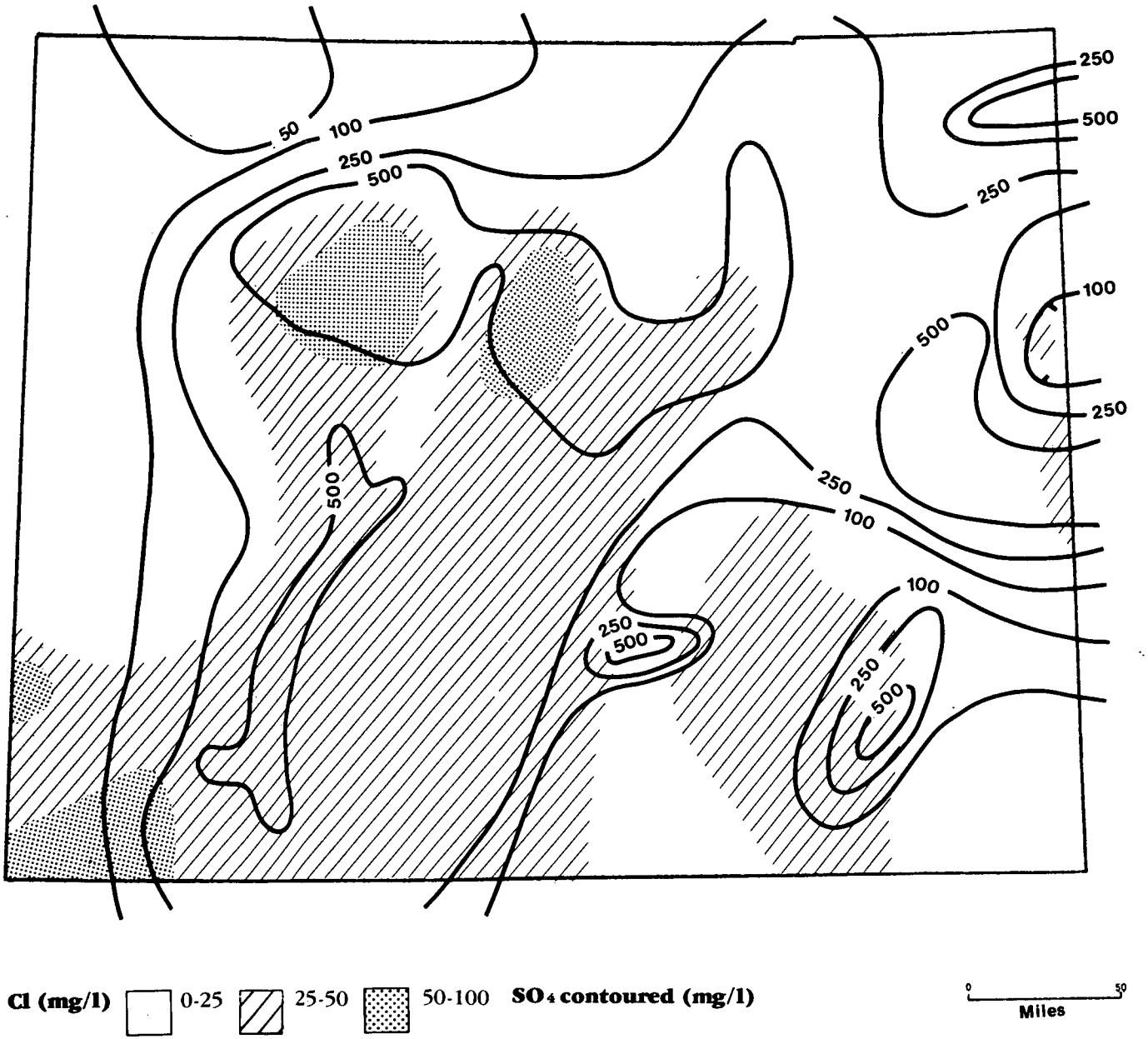
Wyoming



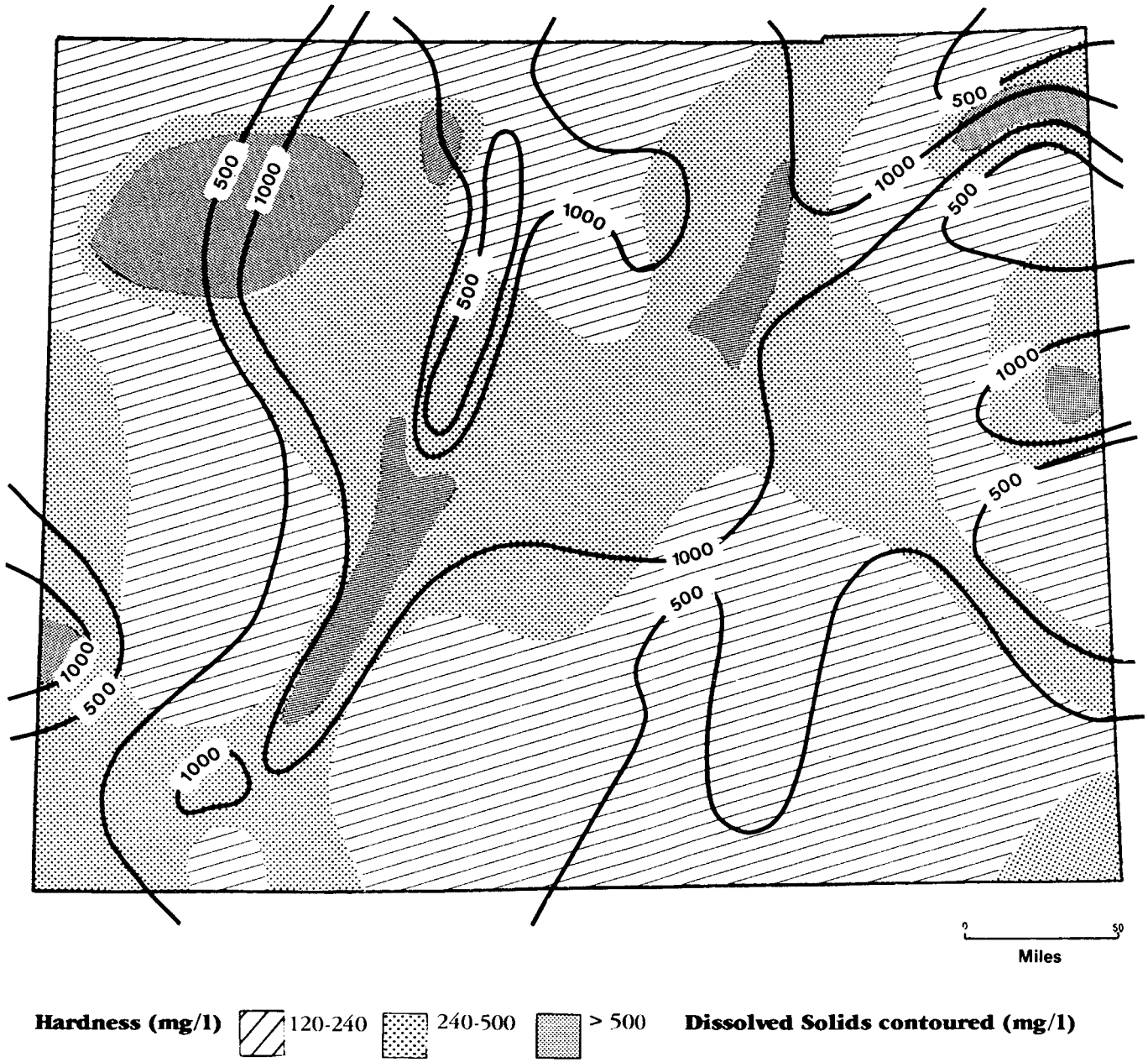
Na + K (mg/l) 0-50 50-100 100-250 **Ca + Mg contoured (mg/l)**

0 50
Miles

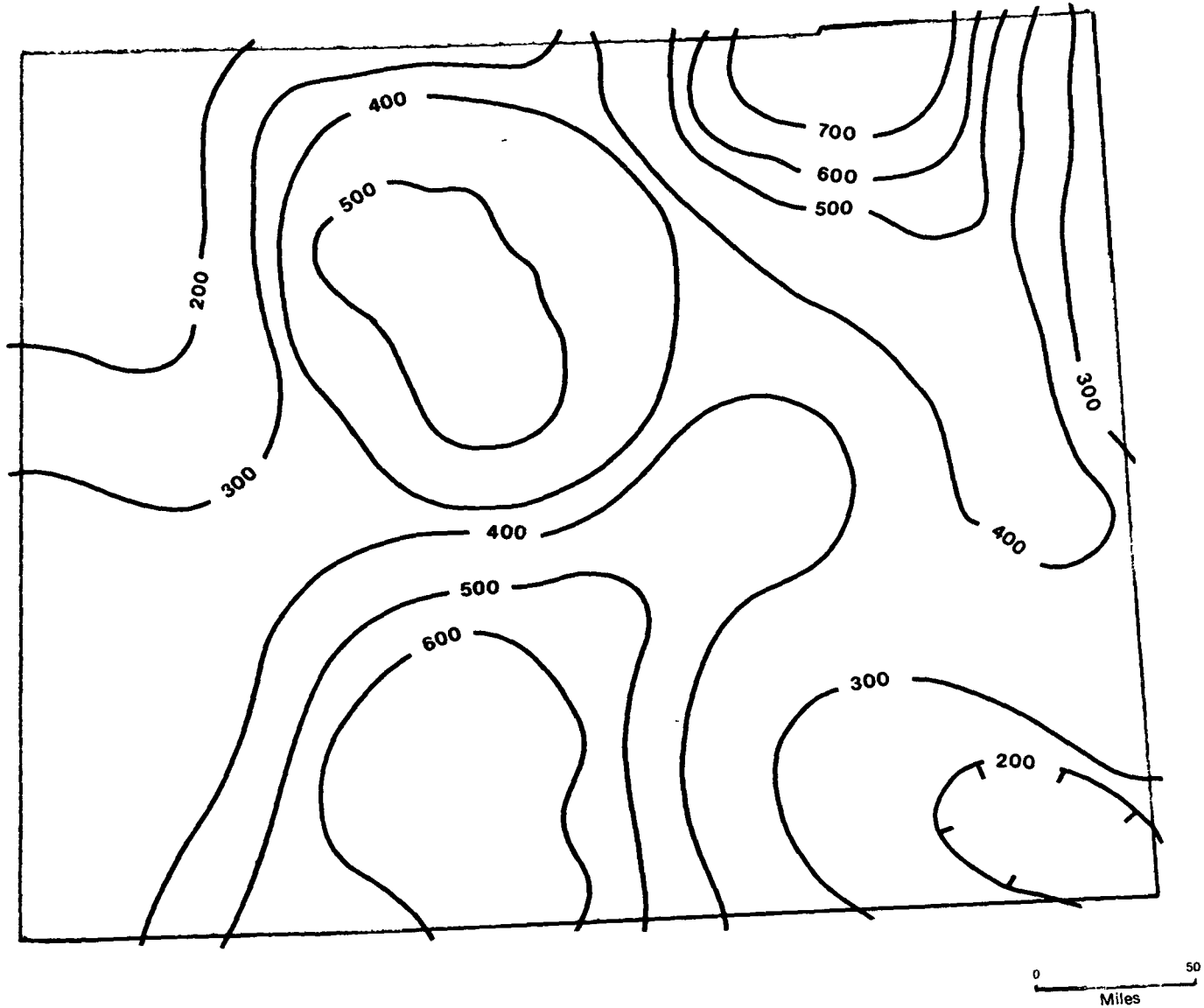
Wyoming


50
100
250
500
250
500
250
100
500
250
500
250
100
100
250
500
250
500
Cl (mg/l)
0-25
25-50
50-100
SO4 contoured (mg/l)
0
50
Miles

Wyoming


500
1000
1000
500
1000
500
1000
500
1000
500
1000
500
1000
0
50
Miles
Hardness (mg/l)
120-240
240-500
> 500
Dissolved Solids contoured (mg/l)

Wyoming



HCO_3 contoured (mg/l)

Wyoming

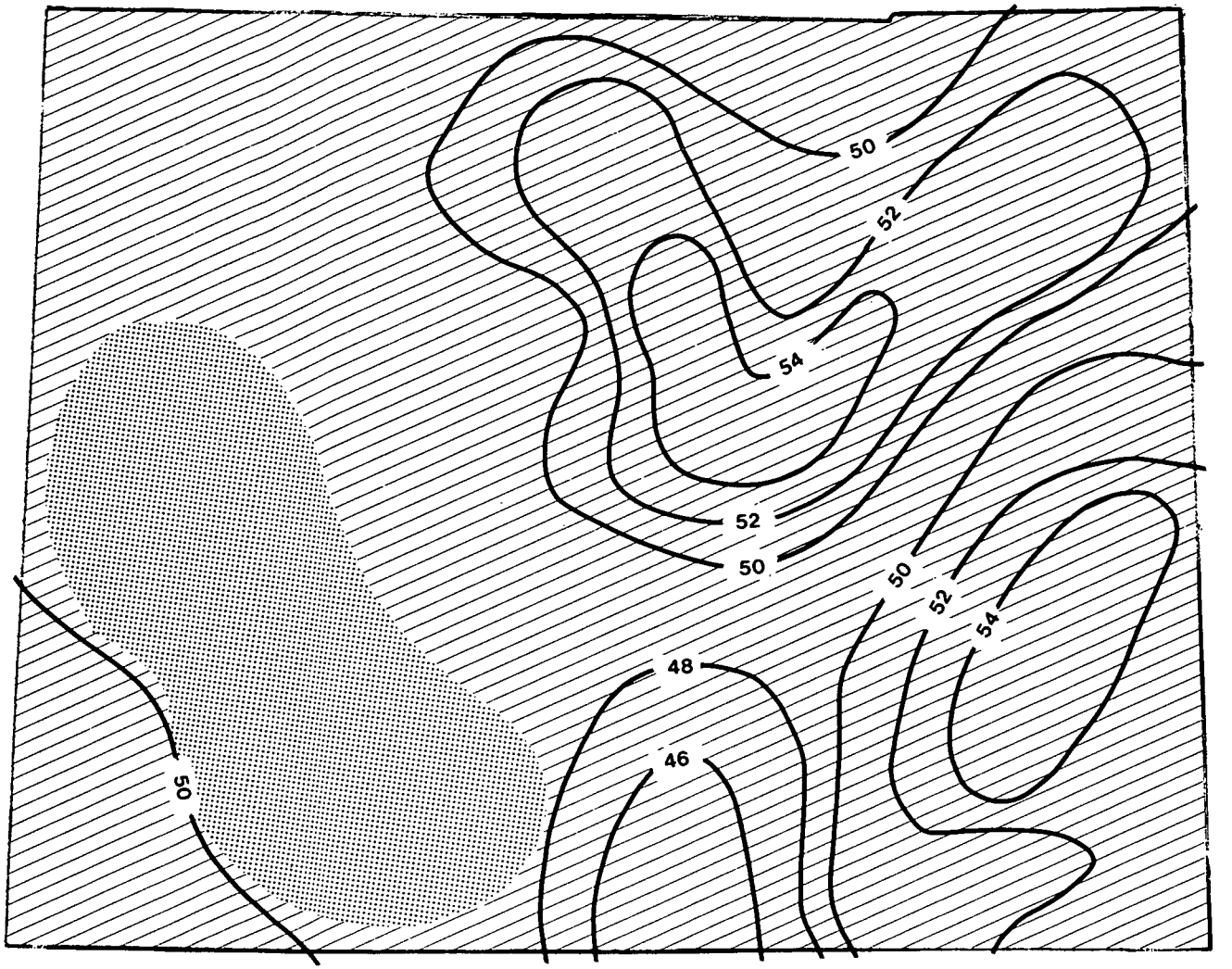
Mn (mg/l)

- 0.0 - .02
- .03 - .05
- .06 - .15
- .15 - 1.0

Fe contoured (mg/l)

0 — 50 Miles

Wyoming



0 50
Miles

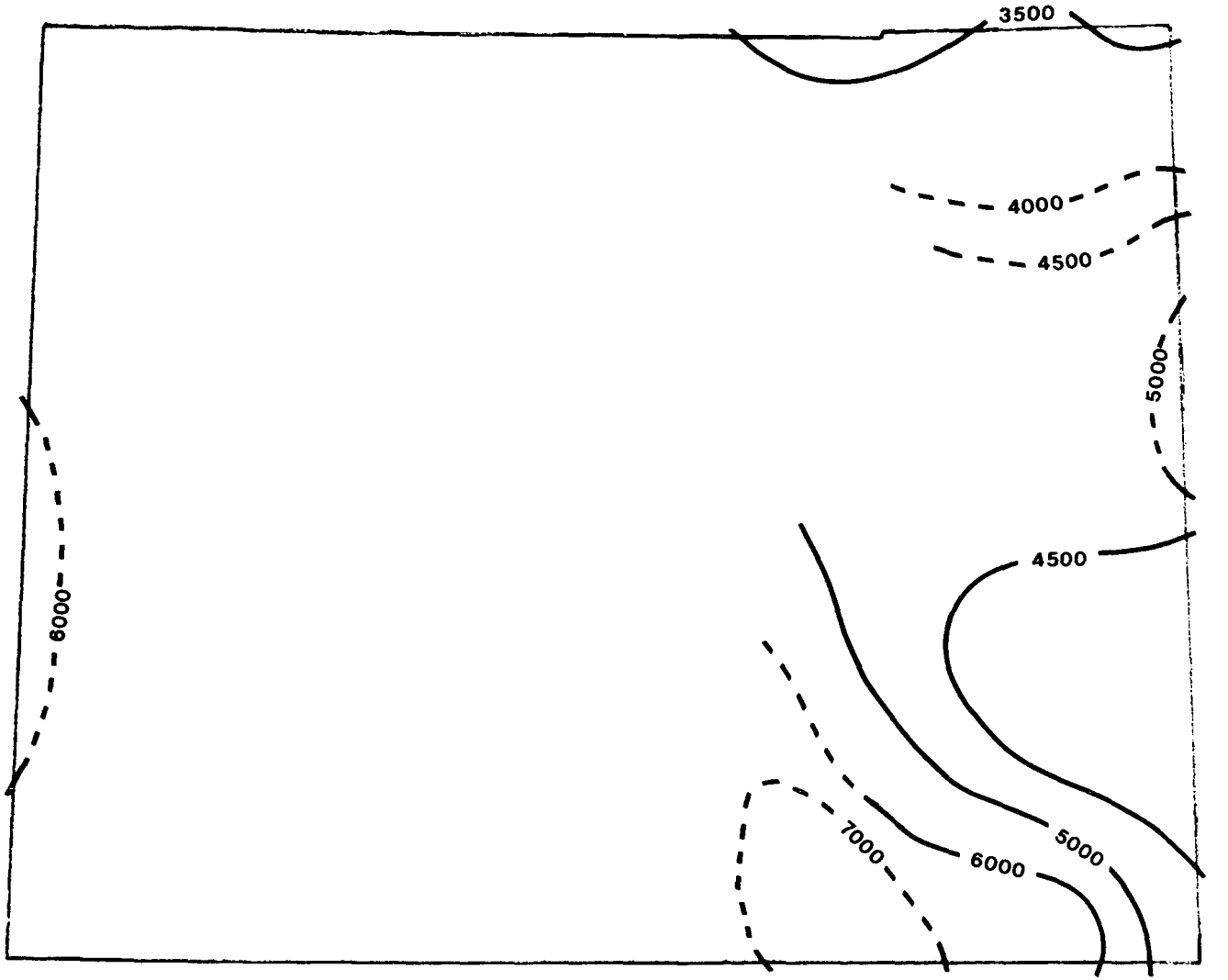
Temperature contoured (°F)

pH

6.1 - 8.0

8.1 - 10

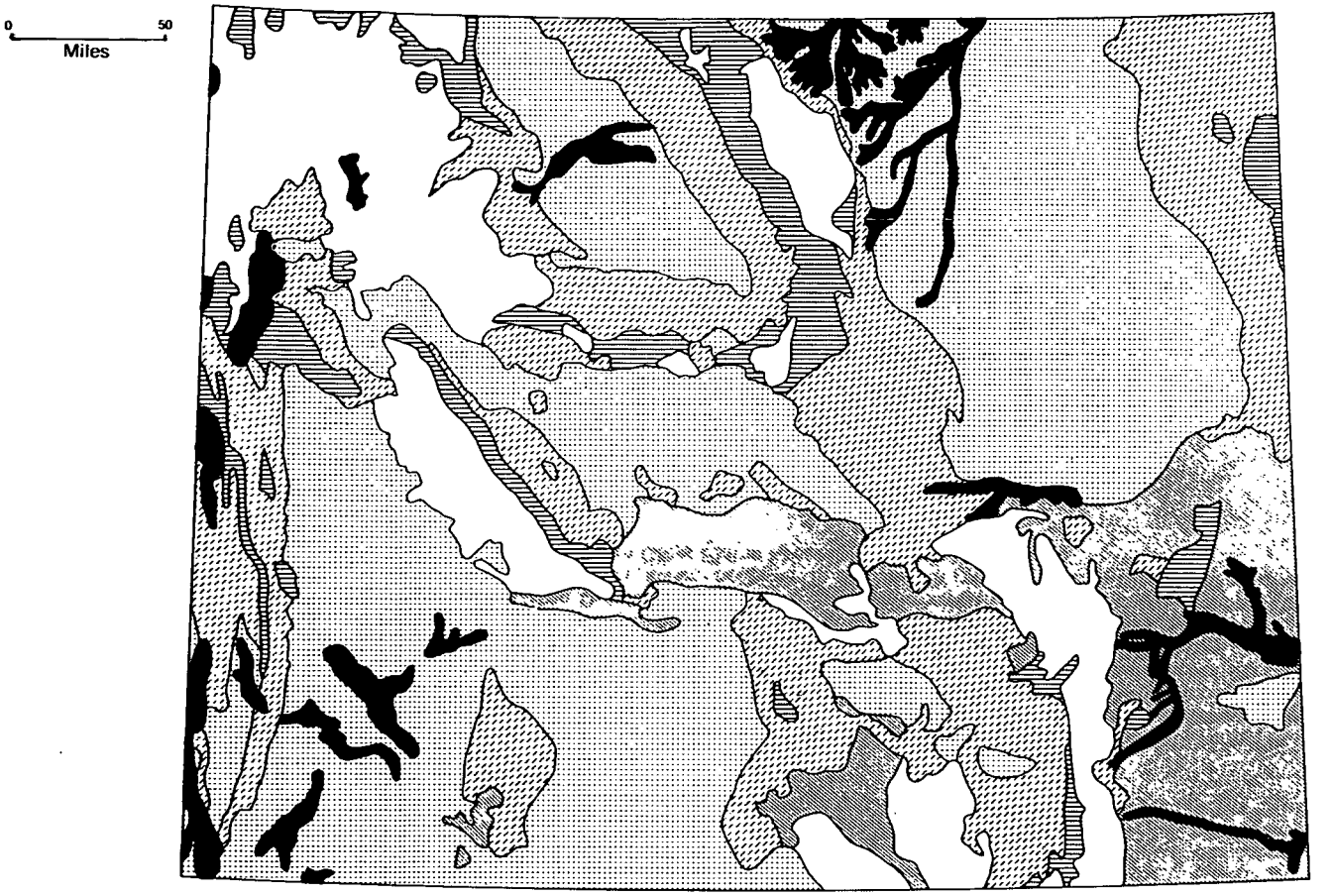
Wyoming



Potentiometric surface (ft., Datum: mean sea level)

0 50
Miles

Wyoming



PRINCIPAL GEOLOGIC SOURCES OF WATER IN WYOMING

Alluvial deposits. Shown only where yields greater than 500 gpm have been developed

Late Tertiary sandstone, conglomerate, and siltstone. Yields of 500–1,000 gpm can be obtained, except in the southwestern part of the state where yields of less than 50 gpm can be expected

Early Tertiary and Late Cretaceous sandstone, shale, carbonaceous shale, and coal. Yields of 5–10 gpm can be obtained nearly everywhere from 100–500 feet of saturated material. Yields in excess of 100 gpm can be developed from deep wells in most of the area

Early and Late Cretaceous shales. Very poor aquifer yields of 5–10 gpm possible in places from lenticular sandstones. Early and Late Cretaceous, Jurassic, and Triassic sandstone, shale, and gypsum yield mostly less than 100 gpm from sandstone

Paleozoic sandstone, carbonate, and calcareous shale. Yields in excess of 1,000 gpm are possible in much of the area. Large yields are dependent on secondary permeability

Igneous and metamorphic rocks. Yields generally less than 25 gpm

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