

INTRODUCTION

The Gulf Coast Regional Aquifer-System Analysis (Gulf Coast RASA) is a study of regional aquifers composed of sediments of mostly Cenozoic age that underlie about 230,000 square miles of the Gulf Coastal Plain in parts of Alabama, Arkansas, Florida, Illinois, Kentucky, Mississippi, Missouri, Tennessee, Texas, and all of Louisiana (fig. 1). The study also includes about 60,000 mi<sup>2</sup> of the Continental Shelf (Grubb, 1984). These regional aquifers, named the Gulf Coast aquifer systems, are part of three aquifer systems: the Mississippi embayment aquifer system, the Texas coastal uplands aquifer system, and the coastal lowlands aquifer system (fig. 2). The Gulf Coast aquifer systems have been divided into 10 water-yielding units based on geologic and hydraulic factors (Weiss and Williamson, 1985; Pettijohn and others, 1988; Hoeman and Weiss, 1991; Weiss, 1990).

Permeable zone B is part of the coastal lowlands aquifer system and is composed mostly of lower Pleistocene and upper Pliocene deposits. These deposits consist of interbedded clay, silt, and sand. Sand content is greater than 40 percent in most of the outcrop area of Texas and adjacent Louisiana and in two small isolated areas of Mississippi and southern Louisiana. Areas of sand percentage greater than 40 percent extend from the outcrop of Texas in several large lobes toward the coast. Sand content generally decreases from outcrop toward the edge of the Continental Shelf and sand percentage is less than 20 percent throughout large areas adjacent to the edge of the shelf. Permeable zone B has an average thickness of about 1,000 ft, a maximum thickness of about 5,600 ft, and generally dips from the outcrop area toward the Gulf of Mexico at about 6 to 8 ft/mi (Weiss, 1990). The relation to overlying and underlying units is shown in figure 3. Ground-water pumping from permeable zone B was about 420 Mgal/d during 1985 (Weiss and others, 1990).

The Gulf Coast RASA is part of the U.S. Geological Survey's Regional Aquifer-System Analysis program. The program began in 1978 and is designed to provide an understanding and assessment of the Nation's ground-water resources on a regional basis (Benett, 1979). A summary of progress on the RASA program through 1984 was given by Sun (1986), and progress on the Gulf Coast RASA was reported by Grubb (1987) and Williamson and others (1990).

Purpose and Scope

This report describes the water chemistry of permeable zone B (lower Pleistocene-upper Pliocene deposits). Maps in the report show the areal distribution of the concentration of dissolved solids, temperature, the primary water types, pH, and the concentrations of dissolved calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and silica. Also included are five maps showing the milliequivalent ratios of (1) magnesium to calcium, (2) magnesium plus calcium to bicarbonate, (3) magnesium plus calcium to sodium plus potassium, (4) bicarbonate to sulfate, and (5) bicarbonate to chloride. The maps of constituent ratios are included for comparing with the same constituent ratios commonly reported for sea water and for water used for specific purposes such as industry and public supply. The ratios also have been used to show trends that may indicate major controls on the chemistry of the ground water.

Compilation of Maps

The maps in this report are based primarily on data from the U.S. Geological Survey's National Water Data and Retrieval System (WATSTORE) and data from the Texas Department of Water Resources (Pettijohn, 1988). The data were screened as explained by Pettijohn (1988) and values were plotted on maps in each 100-square-mile area where data exist. The 100-square-mile area is the same as those illustrated by Grubb (1987, p. 112) and used for simulation of ground-water flow by Williamson (1987) and Williamson and others (1990).

These maps show regional trends in chemical properties. The concentrations of dissolved solids and major ions, pH, and temperature vary with depth within permeable zone B. Point values can be smaller or larger than the values shown on the maps, depending on whether the point is at the top or bottom of the aquifer. Because there are clusters of sampling sites at some locations, the median value of a property or constituent in each 100-square-mile area was selected for contouring maps. The density of sampling sites in each 100-square-mile area is shown as an inset on each of the maps of the respective property or constituent. The number of sampling sites per interval is indicated on the bar graph included with each map. The number of 100-square-mile areas and a summary of median values for each constituent, property, and ratio are shown in table 1.

The maximum values in table 1 are usually larger than the maximum line of equal concentration shown on the corresponding maps. In some instances the maximum value in the table is much larger than the maximum line shown on the map because the value in the table is for only one 100-square-mile area and there is not enough data of equal magnitude to justify adding additional lines.

The concentrations of major ions and pH are based on median values of all samples within each 100-square-mile area. The dissolved-solids concentrations greater than 10,000 mg/L and temperature are based on depth-averaged values from geophysical well logs (Pettijohn and others, 1988). The water type was computed from the cation and the anion that composed the largest percentage of milliequivalents per liter of the dissolved solids in a ground-water sample. Although water type was computed for each sampling site, only the most frequently observed water type (mode) in each 100-square-mile area is shown on the map. More detailed discussions of how the data were analyzed, processed, and mapped are given by Pettijohn (1988, 1989), Weiss (1987), and Pettijohn and others (1988).

Superimposed on selected maps are locations of geologic structures that are used as reference points in describing the chemistry of the ground water from east to west. Uplid, midlip, and downlip are used as reference areas in describing the chemistry of the ground water from north to south. Uplid areas include the areas adjacent to the uplip limit of permeable zone B; midlip refers to areas about midway between the uplip limit and the downlip limit of permeable zone B; and downlip refers to areas adjacent to the downlip limit of the data or the downlip limit of permeable zone B. A map showing the location of salt domes (Beckman and Williamson, 1990) and boundary of salt dome basins (fig. 4) is included for the purpose of relating salt structure to constituent concentrations.

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
mile (mi)	1.609	kilometer
million gallons	0.04381	cubic meters per second
square mile (mi <sup>2</sup> )	2.590	square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first order level net of the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L). Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$T = 1.8(^{\circ}C) + 32$$

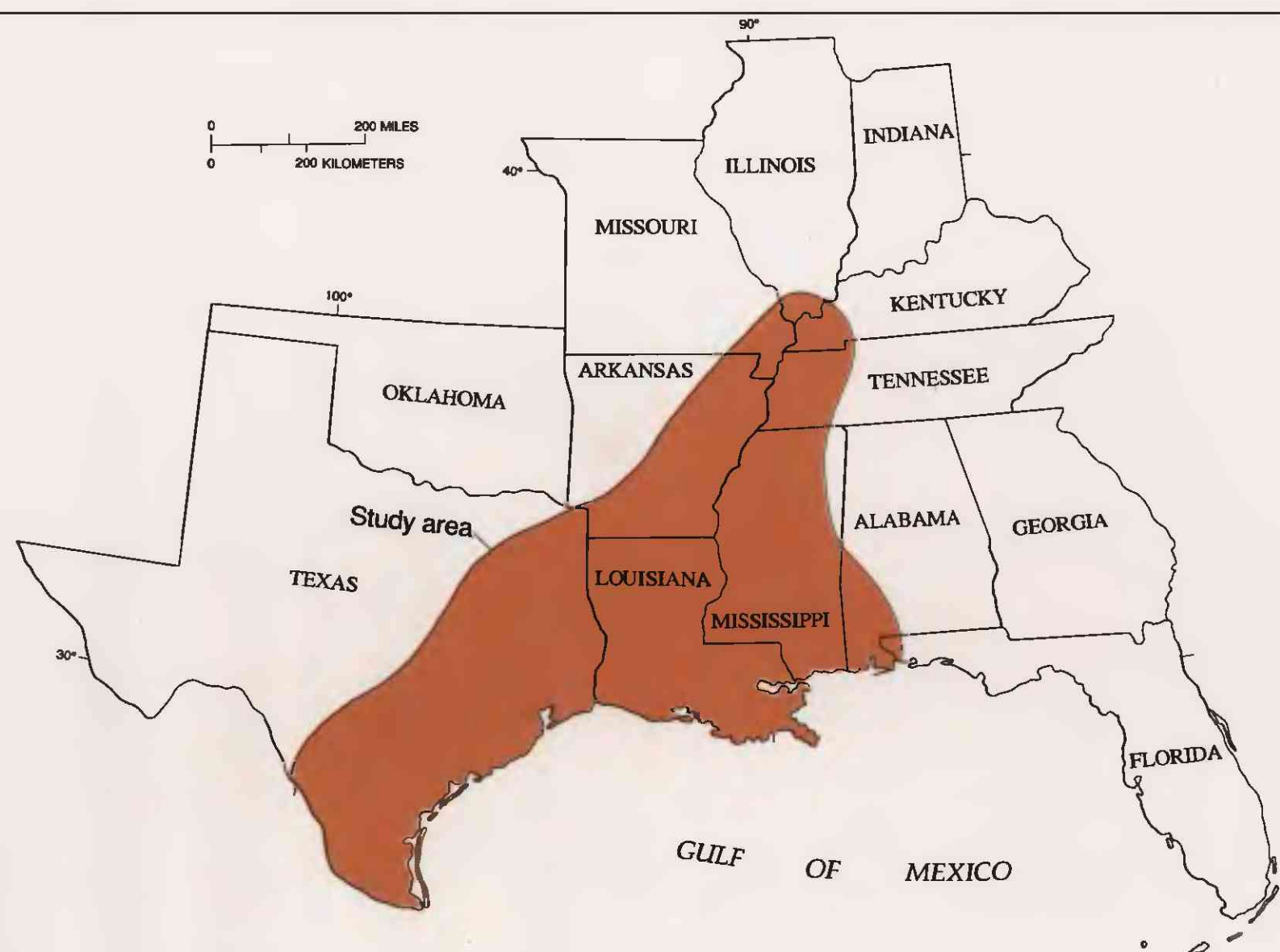


Figure 1.—Location of study area.

EXPLANATION

- COASTAL LOWLANDS AQUIFER SYSTEM
- OUTCROP OF PERMEABLE ZONE B
- VICKSBURG-JACKSON CONFINING UNIT
- MISSISSIPPI EMBAYMENT AQUIFER SYSTEM
- TEXAS COASTAL UPLANDS AQUIFER SYSTEM
- MIDWAY CONFINING UNIT
- UPPER CRETACEOUS AQUIFER

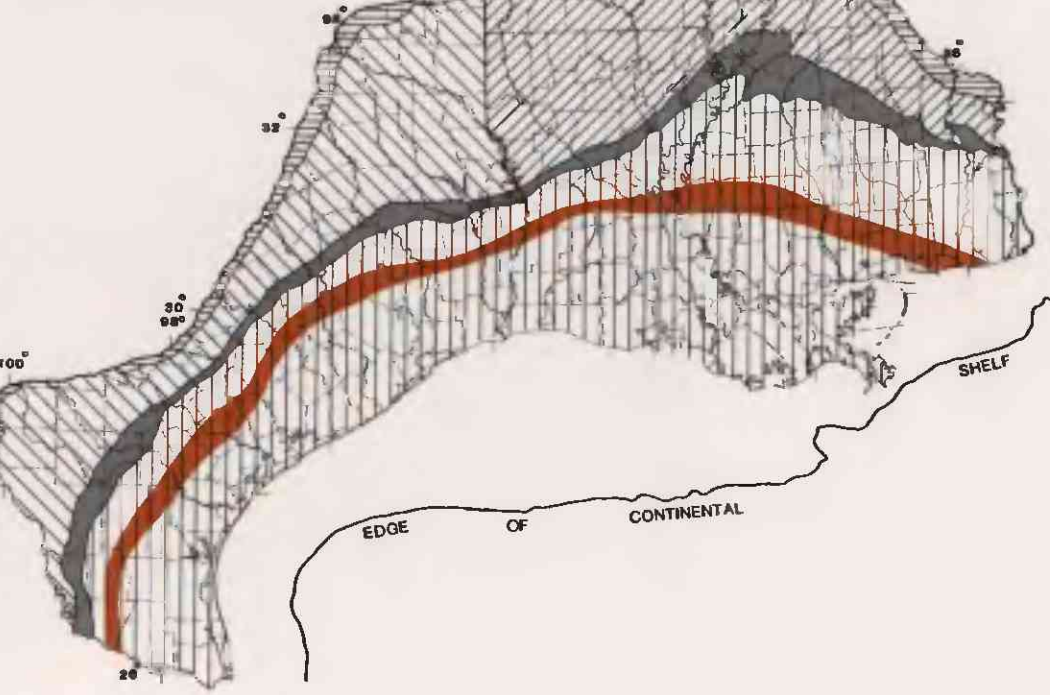
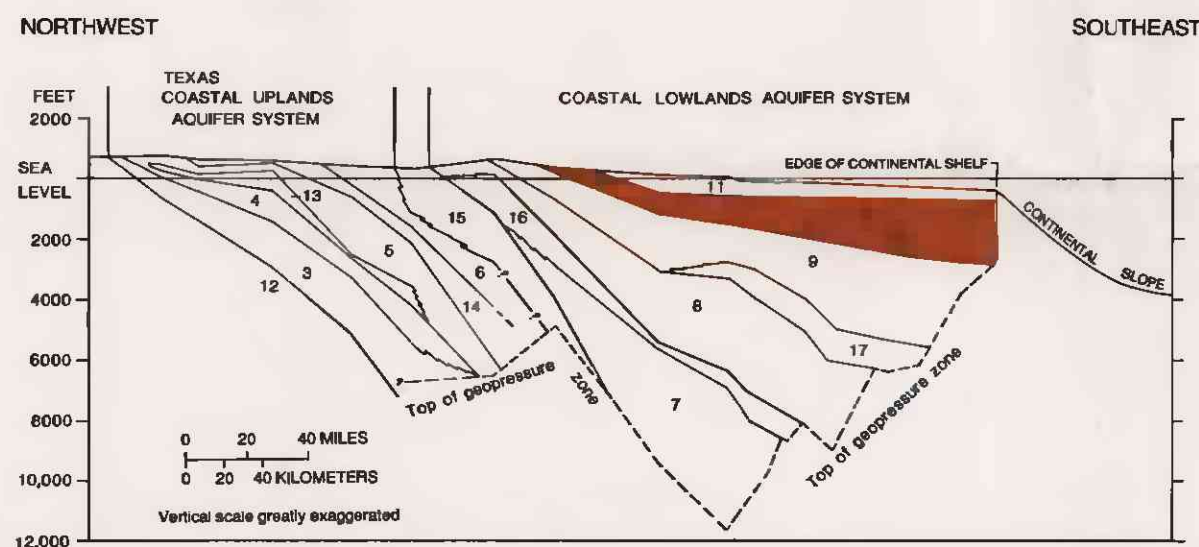


Figure 2.—Generalized outcrop of major aquifer systems and confining units in the Gulf Coast Regional Aquifer-System Analysis study area. Outcrop of permeable zone B (lower Pleistocene-upper Pliocene deposits) superimposed.



EXPLANATION

- 11 Permeable zone A (lower Pleistocene-upper Pliocene deposits)
- 10 Permeable zone B (lower Pleistocene-upper Pliocene deposits)
- 9 Permeable zone C (lower Pleistocene-upper Pliocene deposits)
- 17 Zone D confining unit
- 8 Permeable zone D (middle Miocene deposits)
- 16 Zone E confining unit
- 7 Permeable zone E (lower Miocene-upper Oligocene deposits)
- 15 VICKSBURG-JACKSON CONFINING UNIT—Base of the coastal lowlands aquifer system
- 6 Upper Claiborne aquifer
- 14 Middle Claiborne confining unit
- 5 Middle Claiborne aquifer
- 13 Lower Claiborne confining unit
- 4 Lower Claiborne-upper Wilcox aquifer
- 3 Middle Wilcox aquifer
- 12 MIDWAY CONFINING UNIT—Base of the Texas coastal uplands aquifer system

Figure 3.—Diagrammatic geohydrologic section through southwest part of study area.

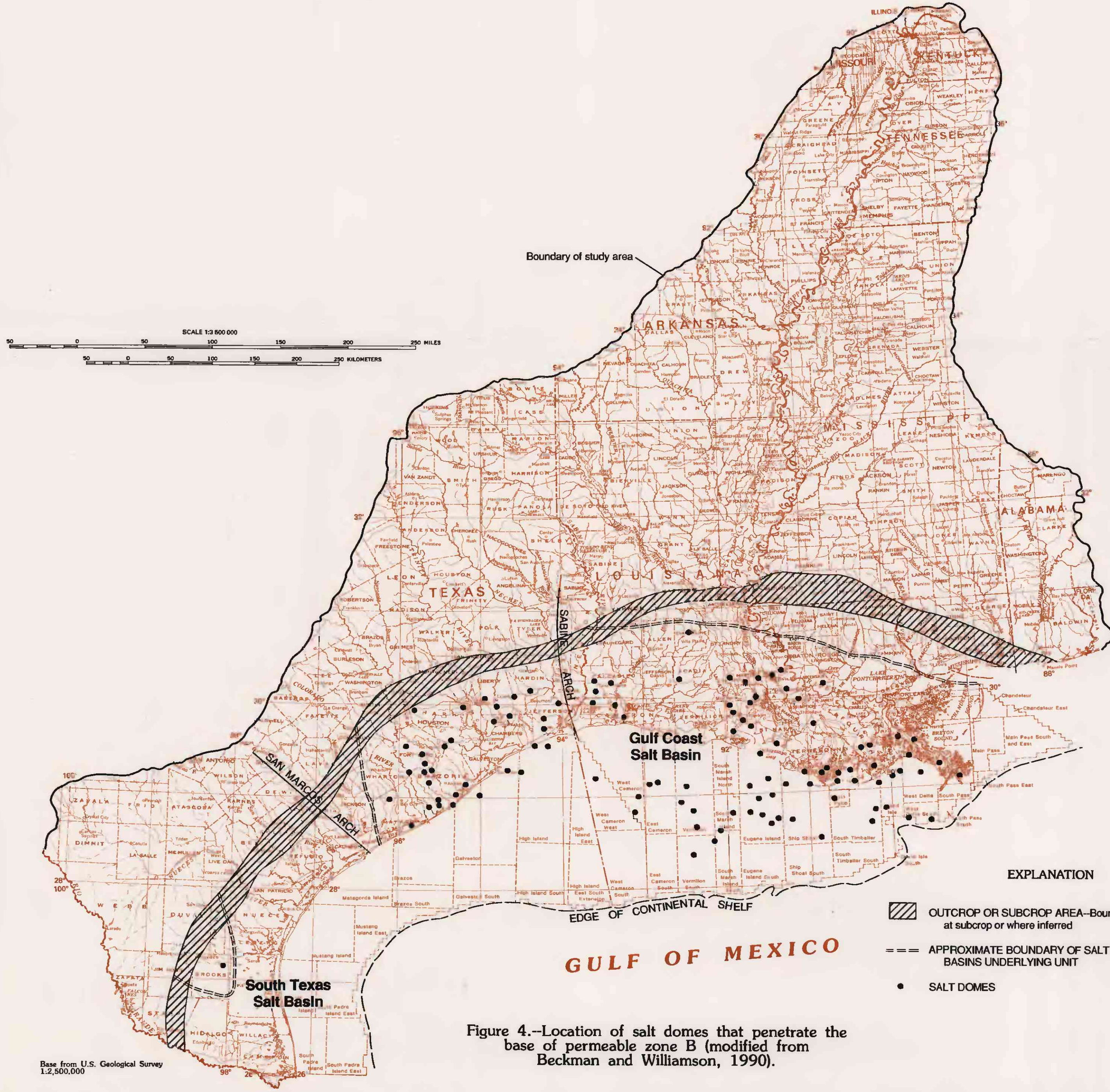


Figure 4.—Location of salt domes that penetrate the base of permeable zone B (modified from Beckman and Williamson, 1990).

SUMMARY AND CONCLUSIONS

The water chemistry of permeable zone B (lower Pleistocene-upper Pliocene deposits), which is part of the coastal lowlands aquifer system, is presented by a series of maps. These maps show the areal distribution of (1) the concentration of dissolved solids and temperature, (2) the primary water types and pH, (3) the concentrations of major ions and silica, and (4) the milliequivalent ratios of selected ions. Dissolved constituents, pH, temperature, and ratios are based on the median values of all samples in each 100-square-mile area.

The concentration of dissolved solids ranges from 15 to 3,000 mg/L in the outcrop, 10,000 to 35,000 mg/L in the area along the coastline, and 35,000 to 230,000 mg/L in the area of the Continental Shelf. The areas having the greatest concentration of dissolved solids are generally coincident with the deeper part of the permeable zone and with the location of salt domes and salt dome basins. Temperature ranges from 11.6 degrees Celsius in the outcrop area to about 59.9 degrees Celsius in the Continental Shelf area.

The primary water types in permeable zone B, which are based on the most frequently observed type (mode) in each 100-square-mile area, generally are calcium or sodium bicarbonate in the outcrop and midlip area east of the San Marcos arch and sodium chloride in areas south of the San Marcos arch and downlip along the coastline. The pH ranges from 4.3 in the outcrop area of southeastern Mississippi to 9.2 in the midlip area in southeastern Louisiana.

The concentrations of dissolved ions, except for silica, generally increase from the outcrop to the downlip limit of the data. The concentration of dissolved calcium ranges from 0.2 mg/L along the outcrop to 3,870 mg/L downlip along the coast of Louisiana. The concentration of dissolved magnesium ranges from 0.1 mg/L at the outcrop to 1,530 mg/L near the coastline in southeastern Louisiana. The concentration of dissolved sodium ranges from about 1.9 mg/L in outcrop area east of the Sabine arch to 92,300 mg/L in downlip areas in southeastern Louisiana. The concentration of dissolved potassium ranges from about 0.2 mg/L in the outcrop area to 277 mg/L in southeastern Louisiana. The concentration of dissolved bicarbonate ranges from 2 mg/L in the outcrop area of southeastern Mississippi to 1,270 mg/L in the area of the Continental Shelf. The concentration of dissolved sulfate ranges from about 0.2 mg/L in the outcrop area to 2,840 mg/L in a downlip area of southern Texas. The concentration of dissolved chloride ranges from 1.8 mg/L in the outcrop area east of the Sabine arch to 150,200 mg/L in the Continental Shelf area south of the Louisiana coastline. The concentration of dissolved silica ranges from 2 mg/L in the Continental Shelf area south of the Louisiana coastline to 90 mg/L in the outcrop area in southern Texas. However, the concentration of silica generally is near 20 mg/L for most of the permeable zone.

The milliequivalent ratio maps of constituents in water from permeable zone B show areal trends from uplip to the downlip limit of the data. The ratio of magnesium plus calcium to bicarbonate decreases from about 1 in the outcrop area to as low as 0.05 between the outcrop and midlip and then increases to 1.98 in an area south of the Louisiana coastline. The ratio of magnesium plus calcium to sodium plus potassium ranges from less than 0.01 in midlip and downlip areas to 6.1 in outcrop areas. The ratio of bicarbonate to sulfate ranges from 0.02 in southern Texas to 1.60 in south-central Louisiana. The ratio of bicarbonate to chloride ranges from about 0.01 in the downlip area near the coastline of Louisiana to 48.3 in the midlip area of south-central Louisiana.

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TABLE 1.—Summary of median values in 100-square-mile areas for selected properties and chemical constituents in ground water from permeable zone B (lower Pleistocene-upper Pliocene deposits)

[All dissolved ion concentrations are in milligrams per liter. All dissolved ion concentrations used to calculate ratios, for example Ca/Mg, are in milliequivalents per liter. Temperatures are in degrees Celsius. pH is in standard units. Chemical symbols: Ca, calcium; Mg, magnesium; Na, sodium; K, potassium; HCO<sub>3</sub>, bicarbonate; SO<sub>4</sub>, sulfate; Cl, chloride; <, less than]

Property or constituent	Statistics for median values of 100-square-mile areas			Number of 100-square-mile areas
	Median	Minimum	Maximum	
pH	7.5	4.8	9.2	327
Temperature	26.5	11.6	59.9	457
Dissolved-solids	901	15.0	230,000	442
Calcium	20.0	0.2	3,870	331
Magnesium	4.5	0.1	1,530	329
Sodium	120	1.9	92,300	328
Potassium	2.0	0.2	277	237
Bicarbonate	262	2.0	1,270	338
Sulfate	8.7	0.2	2,840	326
Chloride	64.4	1.8	150,000	372
Silica	24.0	2.0	90	304
Ratio Mg:Ca	0.46	0.04	6.5	329
Ratio Mg:Ca:HCO <sub>3</sub>	0.61	<0.01	198	321
Ratio Mg:Ca:Na	0.39	<0.01	6.1	235
Ratio HCO <sub>3</sub> :SO <sub>4</sub>	15.2	0.02	1,650	319
Ratio HCO <sub>3</sub> :Cl	1.7	<0.01	48.2	337

PROPERTIES AND CHEMICAL CONSTITUENTS IN GROUND WATER FROM PERMEABLE ZONE B (LOWER PLEISTOCENE-UPPER Pliocene DEPOSITS), COASTAL LOWLANDS AQUIFER SYSTEM, SOUTH-CENTRAL UNITED STATES

by

ROBERT A. PETTIJOHN, JOHN F. BUSBY, AND THOMAS B. LAYMAN

1993



CHEMICAL AND PHYSICAL PROPERTIES

The areal distribution of dissolved-solids concentrations, temperature, primary water type, and pH are shown on maps and discussed in the following sections. The dissolved-solids concentrations and temperature are shown on the downdip limit of the permeable zone. The abundance of geophysical well logs (Grubb, 1986, and Wilson and Homan, 1988), both onshore and offshore, make it possible to estimate both dissolved-solids concentrations and temperature throughout a large area where data from water samples are not available. Primary water type and pH generally are not shown offshore because of a lack of data.

Dissolved-Solids Concentration

The concentration of dissolved solids in water from permeable zone B, based on median values of all samples in each 100-square-mile area, ranges from 15 mg/L in the outcrop area to 230,400 mg/L in the Continental Shelf area (table 1). Concentrations larger than 10,000 mg/L are depth-averaged values as described by Pettijohn and others (1988). The trend noted above indicates that the concentration of dissolved solids increases in a downdip direction. The largest increase, 300 to 10,000 mg/L, occurs in about 40 mi in the area extending from the Sabine arch eastward to near the southwestern corner of Alabama.

From the Sabine arch eastward to near the southwestern corner of Alabama the concentration of dissolved solids in the outcrop and the area 10 to 30 mi south of the outcrop ranges from 15 to 500 mg/L. An exception is two areas, one in south-central Louisiana and the other at the Mississippi-Alabama border, where the concentration ranges from 500 to 1,000 mg/L. Most of permeable zone B located onshore in Mississippi and Alabama as well as one-third of Louisiana contains water with less than 1,000 mg/L concentration of dissolved solids. However, concentrations increase quickly in the downdip direction and reach about 35,000 mg/L at the coastline and 35,000 to 230,400 mg/L on the Continental Shelf. The areas having the greatest concentration of dissolved solids are generally coincident with the deeper parts of the permeable zone and with the location of salt domes and salt dome basins (fig. 6).

From the Sabine arch southward to about 50 mi east of the San Marcos arch the concentration of dissolved solids in the outcrop is between 15 and 500 mg/L. Downdip from the outcrop the concentration increases to about 10,000 mg/L at the coastline and to 35,000 mg/L or more on the Continental Shelf. From about 50 mi east of the San Marcos arch southward to the Rio Grande the concentration increases to about 1,000 mg/L along the outcrop. Downdip from the outcrop the concentration increases to about 35,000 mg/L at the coastline and to more than 35,000 mg/L on the Continental Shelf.

Temperature

The temperature of water from permeable zone B, based on combined depth-averaged values and the median values of all samples in each 100-square-mile area, ranges from 11.6 degrees Celsius in the outcrop area to 59.9 degrees Celsius in the Continental Shelf area (table 1). In areas where the concentration of dissolved solids is about 10,000 mg/L or more, the temperature is about 30 degrees Celsius (fig. 5). In areas where the concentration of dissolved solids increases from 10,000 to 139,800 mg/L, the temperature of the ground water increases from 30 degrees to about 46 degrees Celsius.

Primary Water Type

The primary water types in permeable zone B, which are based on the most frequently observed type (mode) in each 100-square-mile area, are generally calcium or sodium bicarbonate in the outcrop and midtip areas east of the San Marcos arch and sodium chloride in areas south of the San Marcos arch and downdip along the coastline (fig. 6). Calcium bicarbonate water is most prevalent between the Sabine arch and the San Marcos arch in outcrop and up-dip areas. Elsewhere east of the San Marcos arch the water type is generally sodium bicarbonate in outcrop, up-dip, and midtip areas.

The pH of water from permeable zone B, based on median values of all samples in each 100-square-mile area, ranges from 4.8 in the outcrop area in southwestern Mississippi to 9.2 in the midtip areas in southeastern Louisiana (table 1). From the Sabine arch eastward to the southwestern corner of Alabama the pH increases from about 5.0 in the outcrop area to about 8.0 at midtip and then decreases to about 7.0 downdip and southward to the Louisiana coastline (fig. 7). West of the Sabine arch in southeastern Texas the pH generally increases in the downdip direction from about 6.0 in the outcrop area to 8.0 along the coastline. From southeastern Texas to southwestern Texas the pH ranges from 7.0 to 8.0 in outcrop and midtip areas and slightly more than 8.0 in areas from midtip to the downdip limit of the data.

CHEMICAL CONSTITUENTS

The areal distribution of eight constituents in ground water is shown on maps and discussed below. The constituents mapped are the major chemical components in ground water of the Gulf Coastal Plain. Lines of equal concentration of constituents are generally limited to onshore areas of permeable zone B because chemical data generally are not available for the Continental Shelf areas.

Calcium

The concentration of dissolved calcium in water from permeable zone B, based on median values of all samples in each 100-square-mile area, ranges from 0.2 mg/L along the outcrop to 3,870 mg/L downdip along the coast of Louisiana (table 1). Concentration increases in a downdip direction in all areas except west of the San Marcos arch in southern Texas where it decreases in a downdip direction (fig. 8).

From the Sabine arch eastward to the southwestern corner of Alabama the concentration of dissolved calcium generally ranges from about 1 to 30 mg/L from the outcrop to about midtip near the Mississippi River where concentrations are about 90 mg/L. From midtip southward to the coastline of Louisiana the concentration of dissolved calcium increases to more than 2,000 mg/L. Areas in Louisiana with the largest concentration of dissolved calcium are coincident with the deeper part of permeable zone B and with the location of salt domes (fig. 9).

From the Sabine arch southward to the Rio Grande the concentration of dissolved calcium generally increases along the outcrop area from 30 mg/L in Montgomery County, Texas, to 100 mg/L in the outcrop area south of the San Marcos arch. Concentration from the outcrop to downdip areas near the coastline ranges from 10 to 100 mg/L. There appears to be no trend in concentration of dissolved calcium in the downdip direction between the Sabine arch and the San Marcos arch. However, from the San Marcos arch southward to the Rio Grande the concentration decreases in a downdip direction from about 100 mg/L near the outcrop to about 50 mg/L or less at the coastline of Texas.

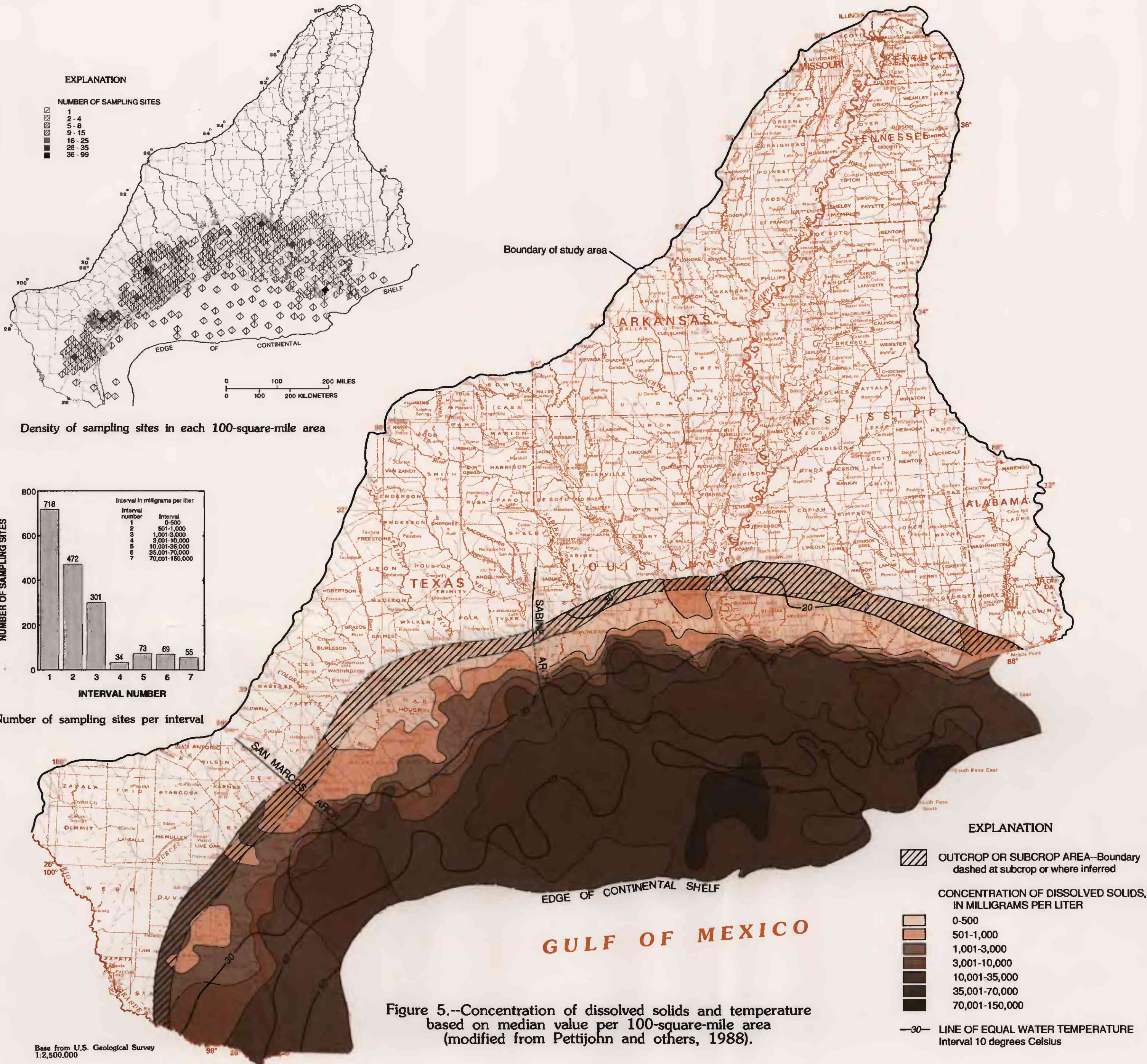


Figure 5.—Concentration of dissolved solids and temperature based on median value per 100-square-mile area (modified from Pettijohn and others, 1988).

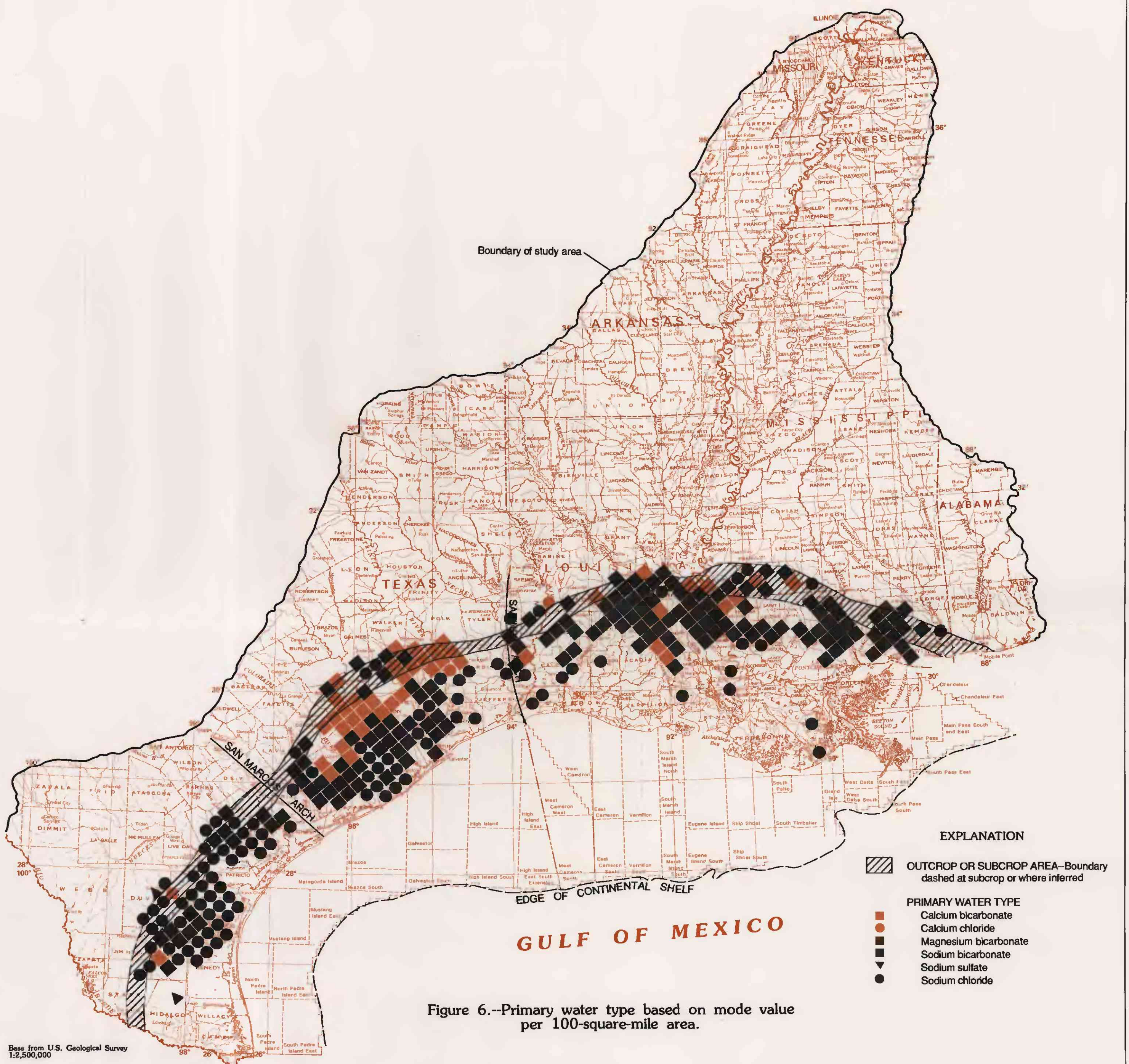


Figure 6.—Primary water type based on mode value per 100-square-mile area.

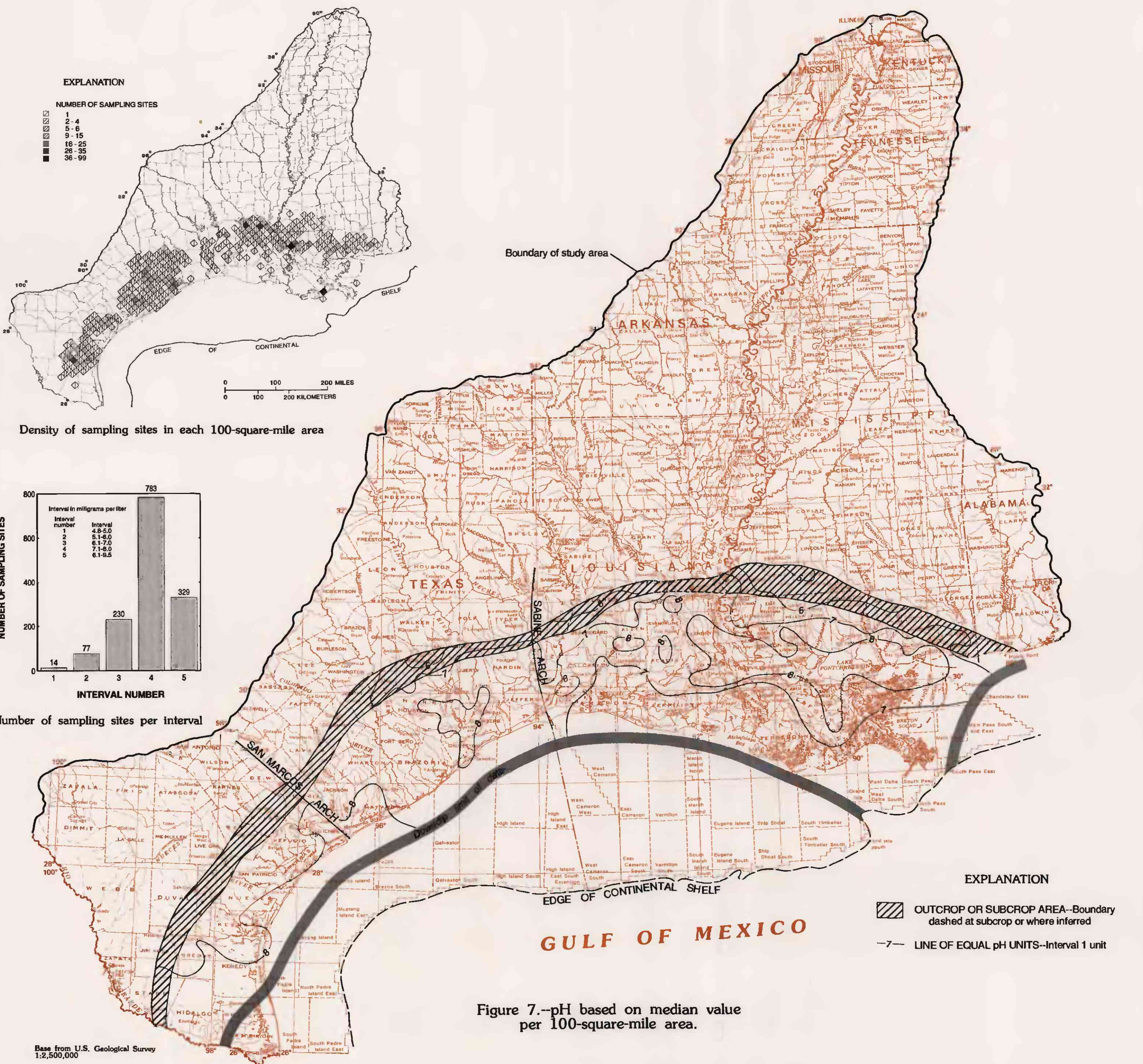


Figure 7.—pH based on median value per 100-square-mile area.

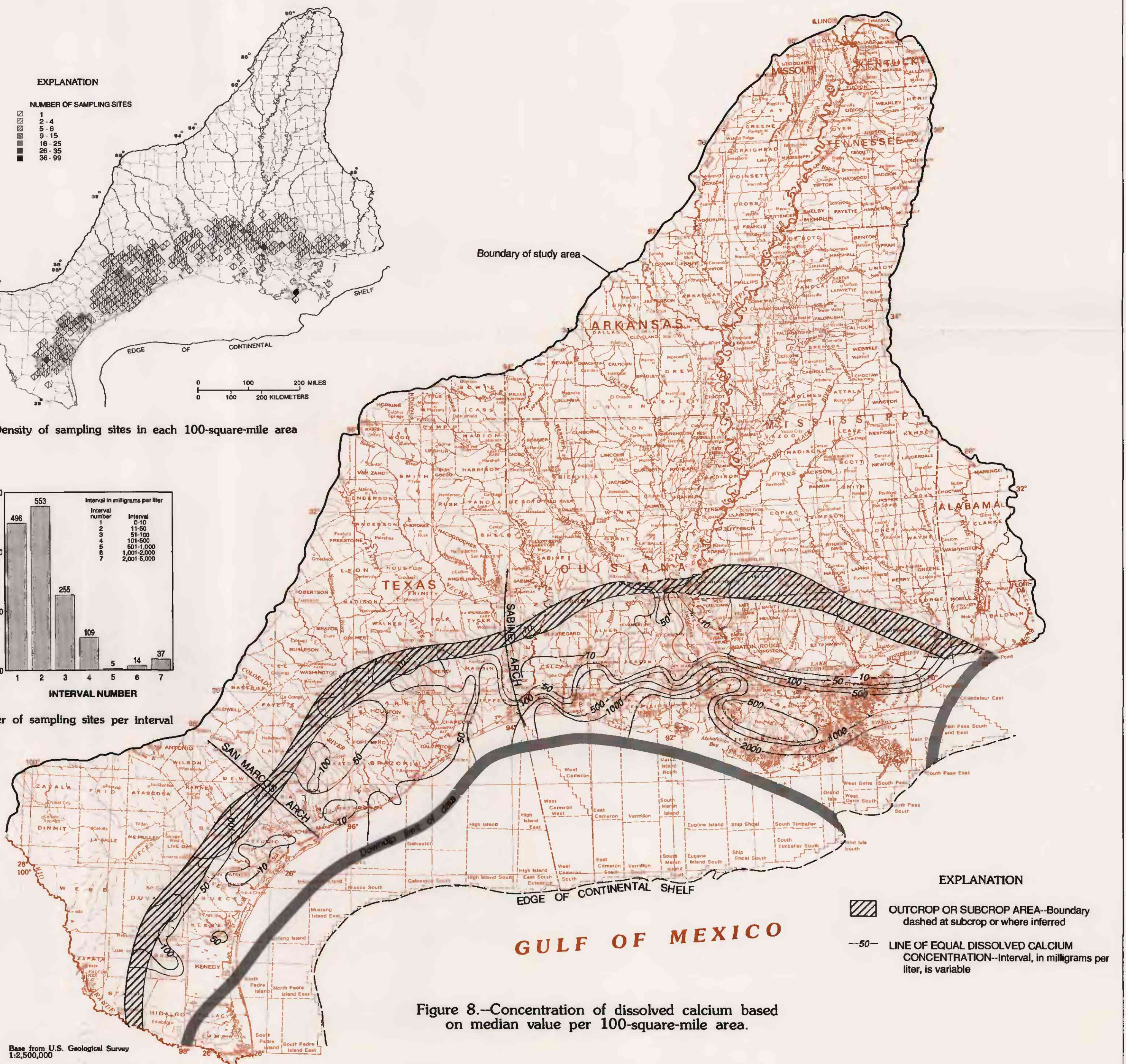
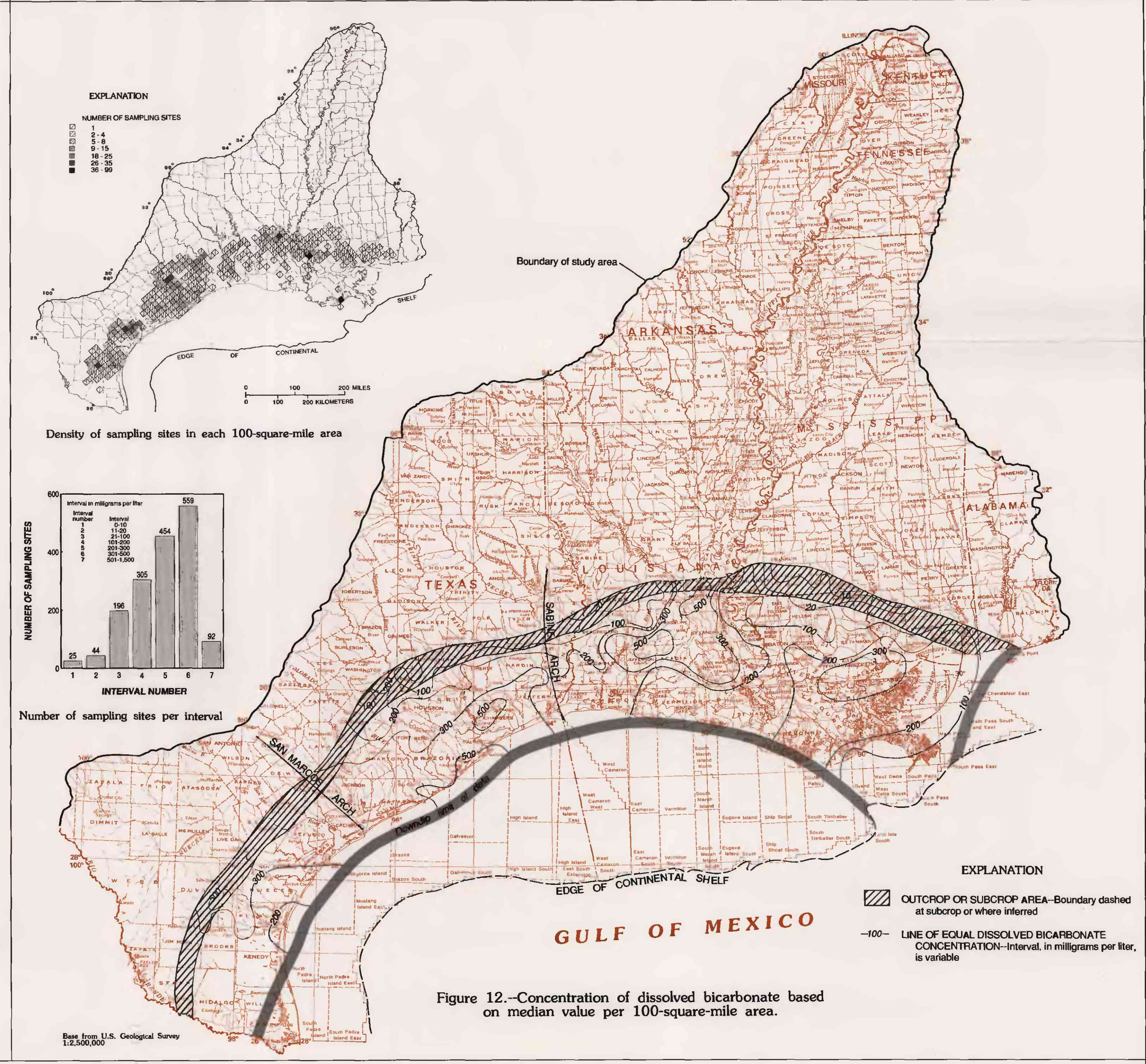
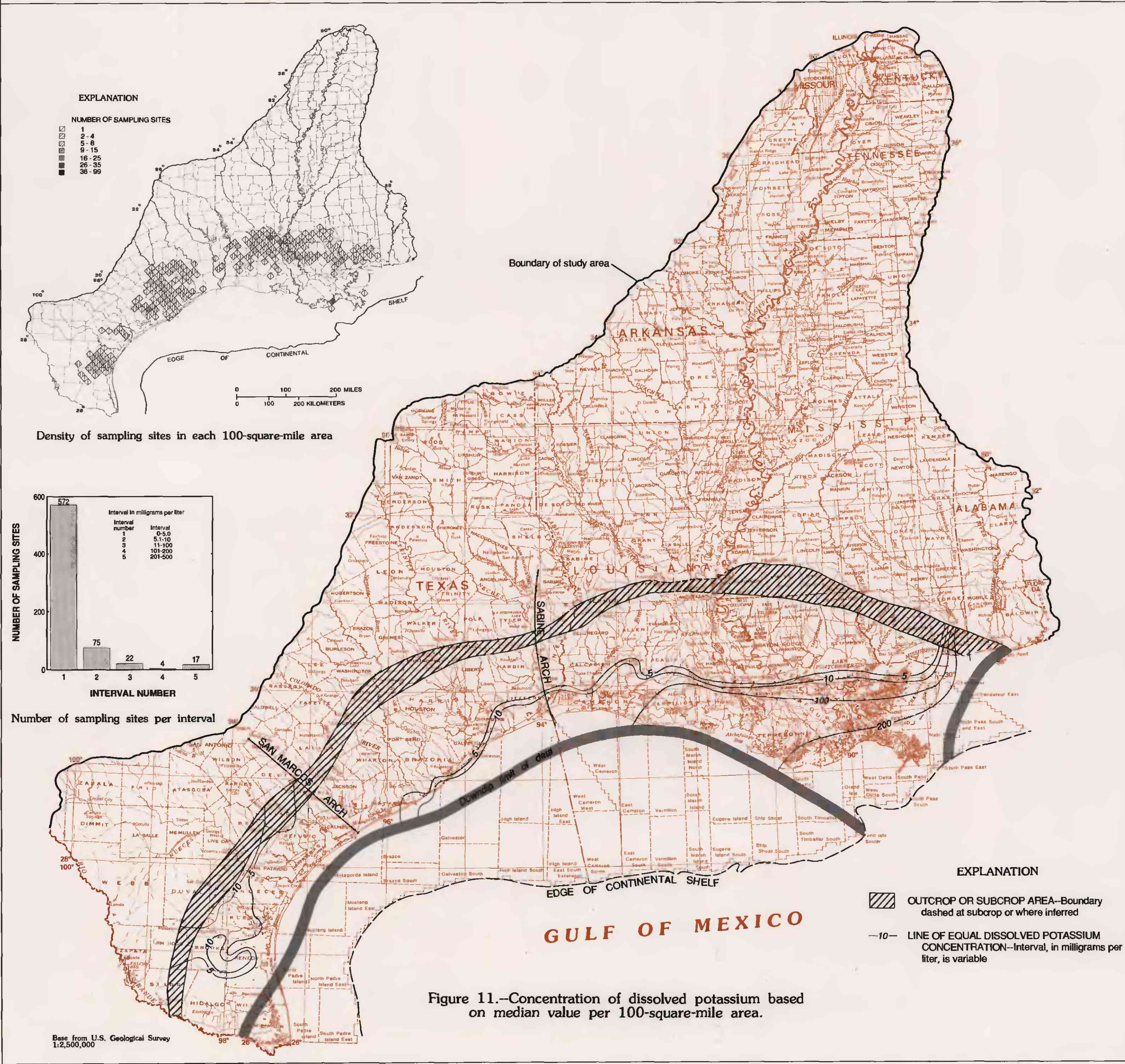
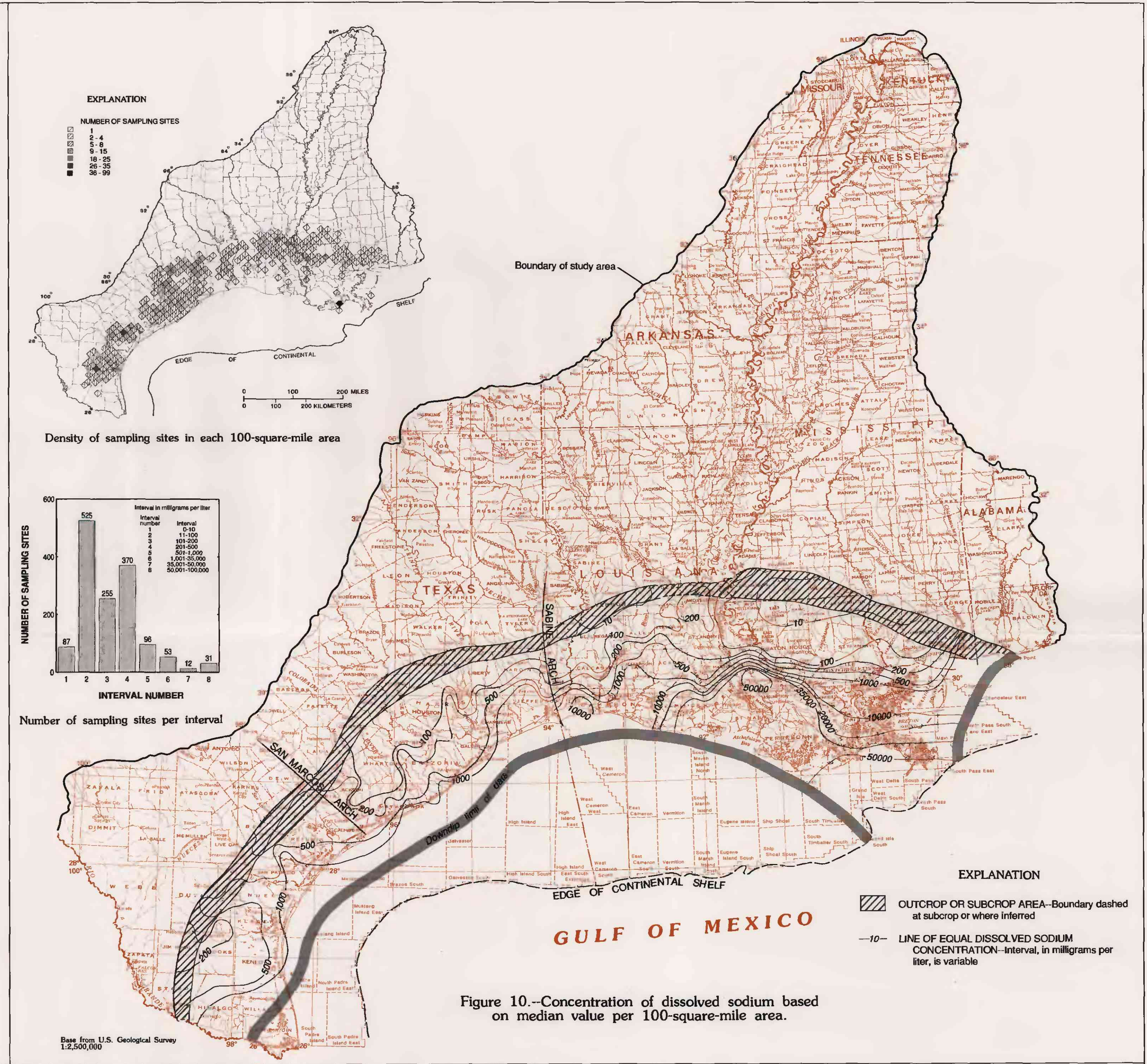
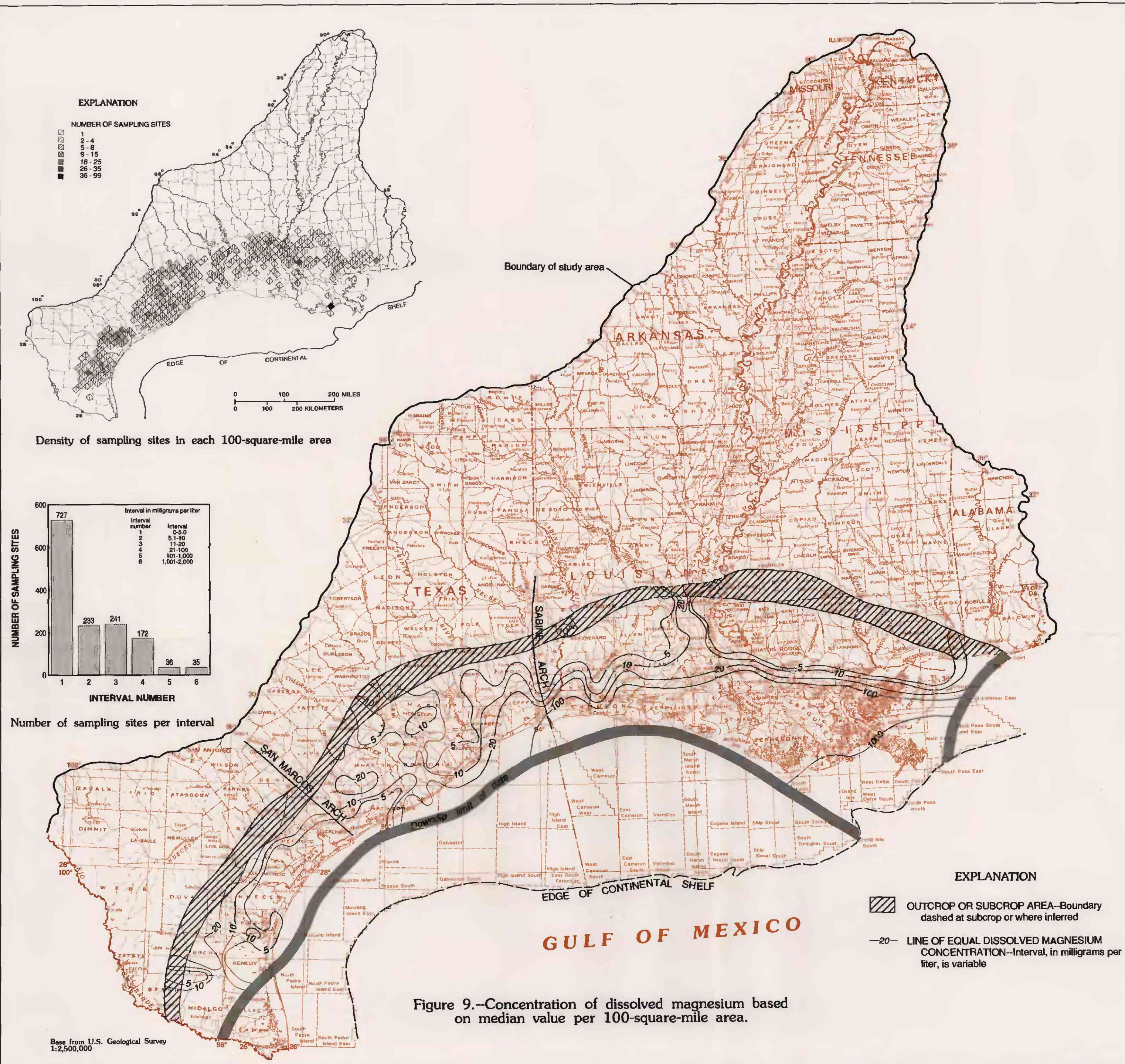


Figure 8.—Concentration of dissolved calcium based on median value per 100-square-mile area.

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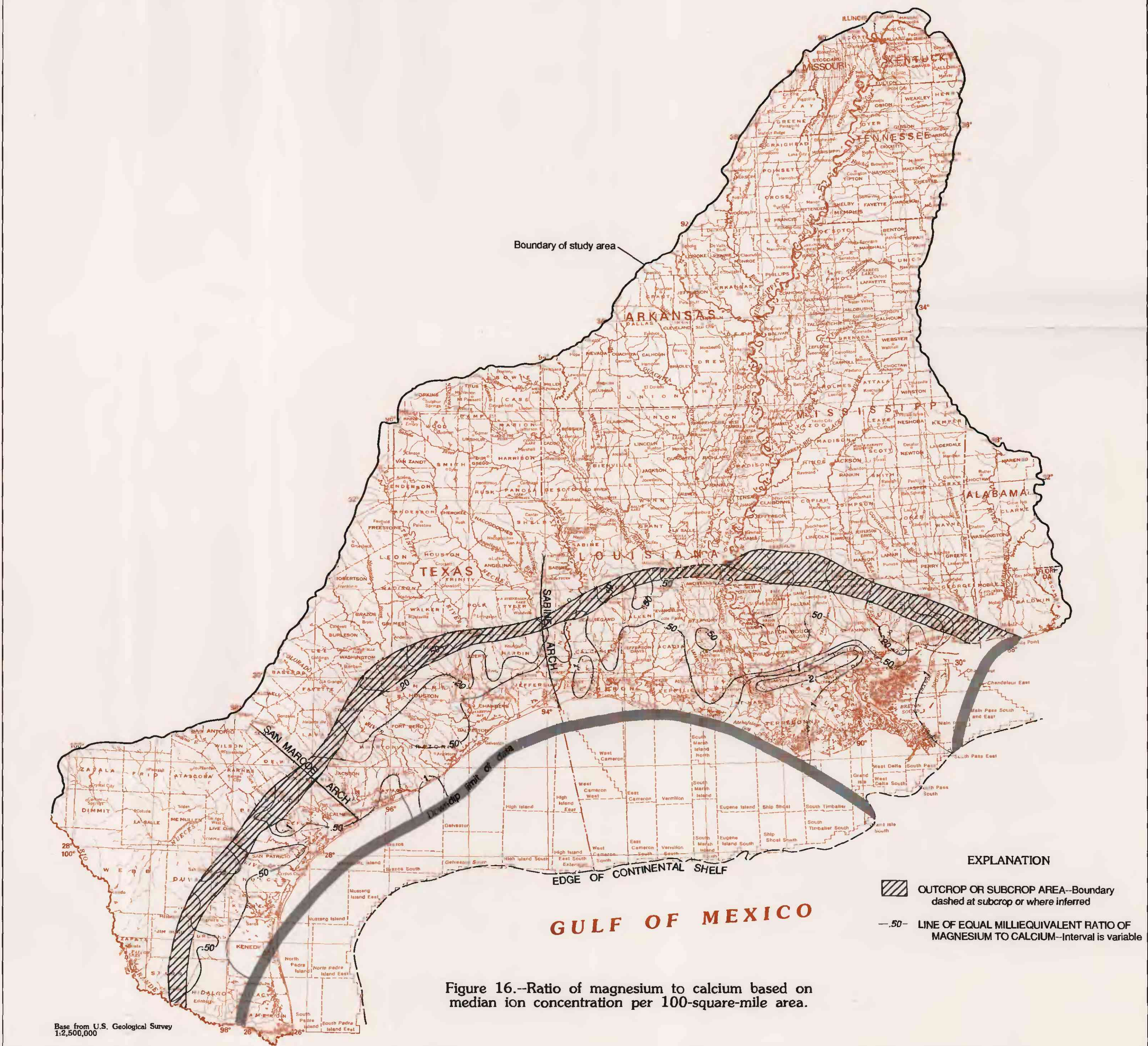
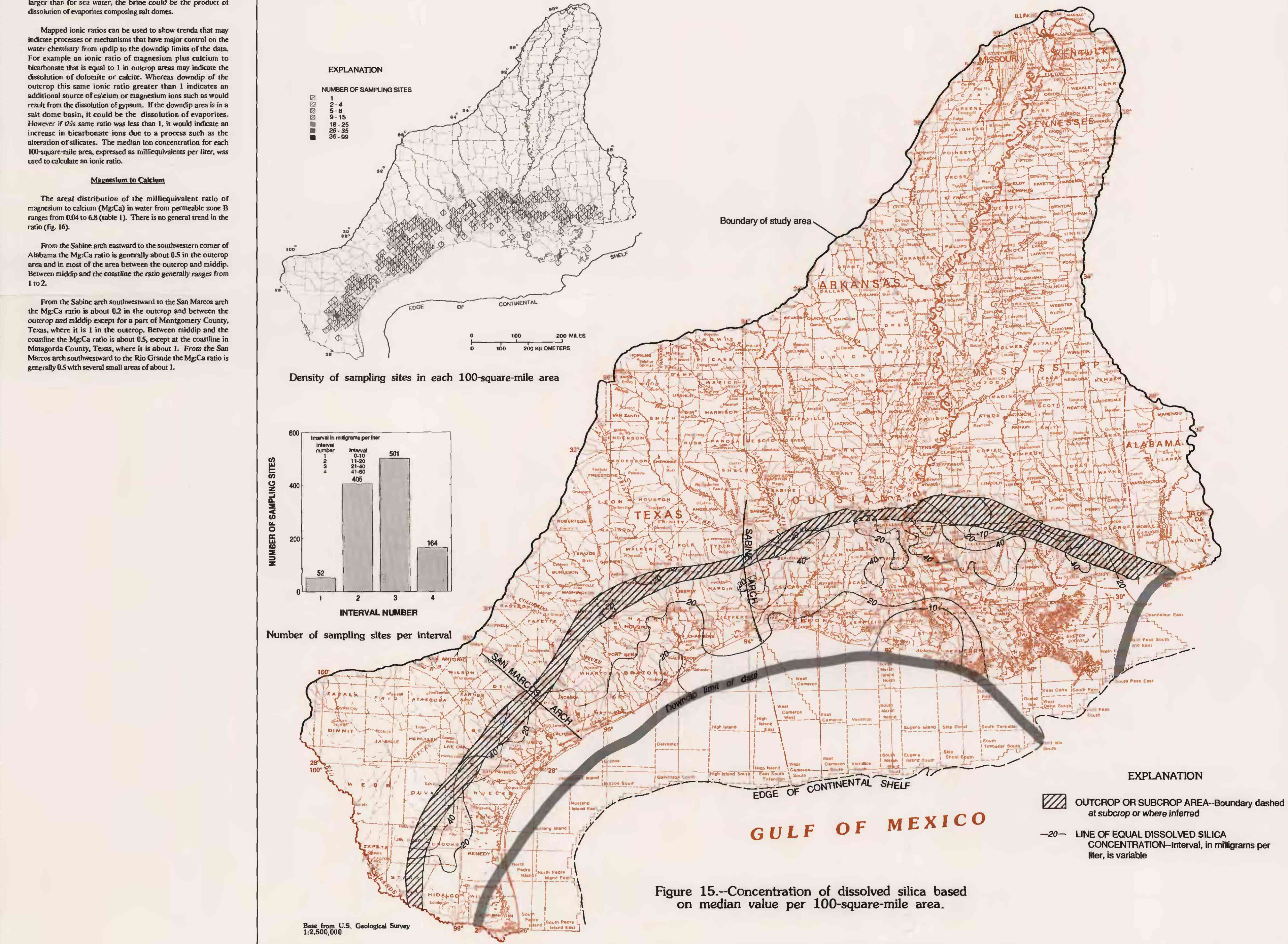
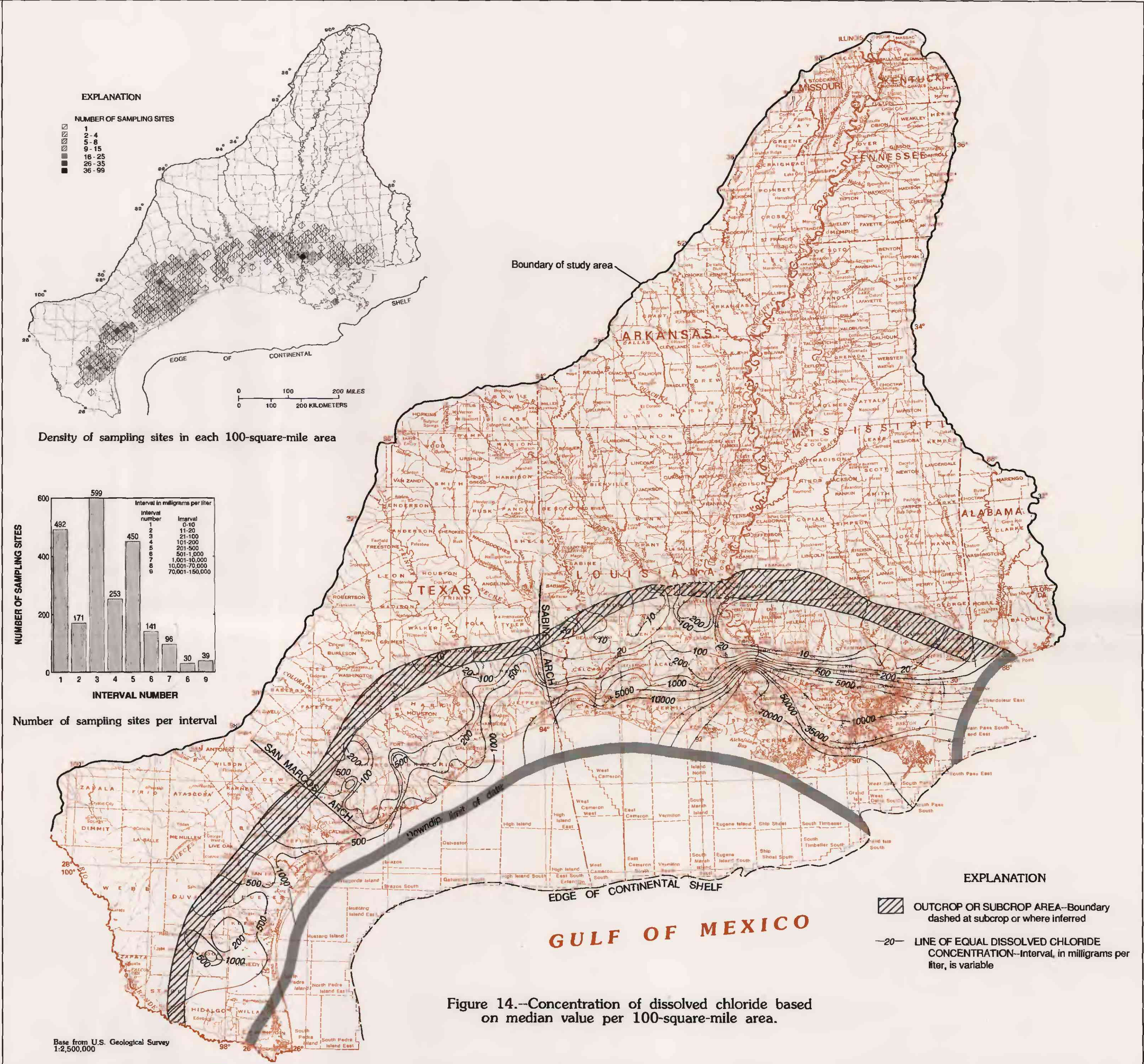
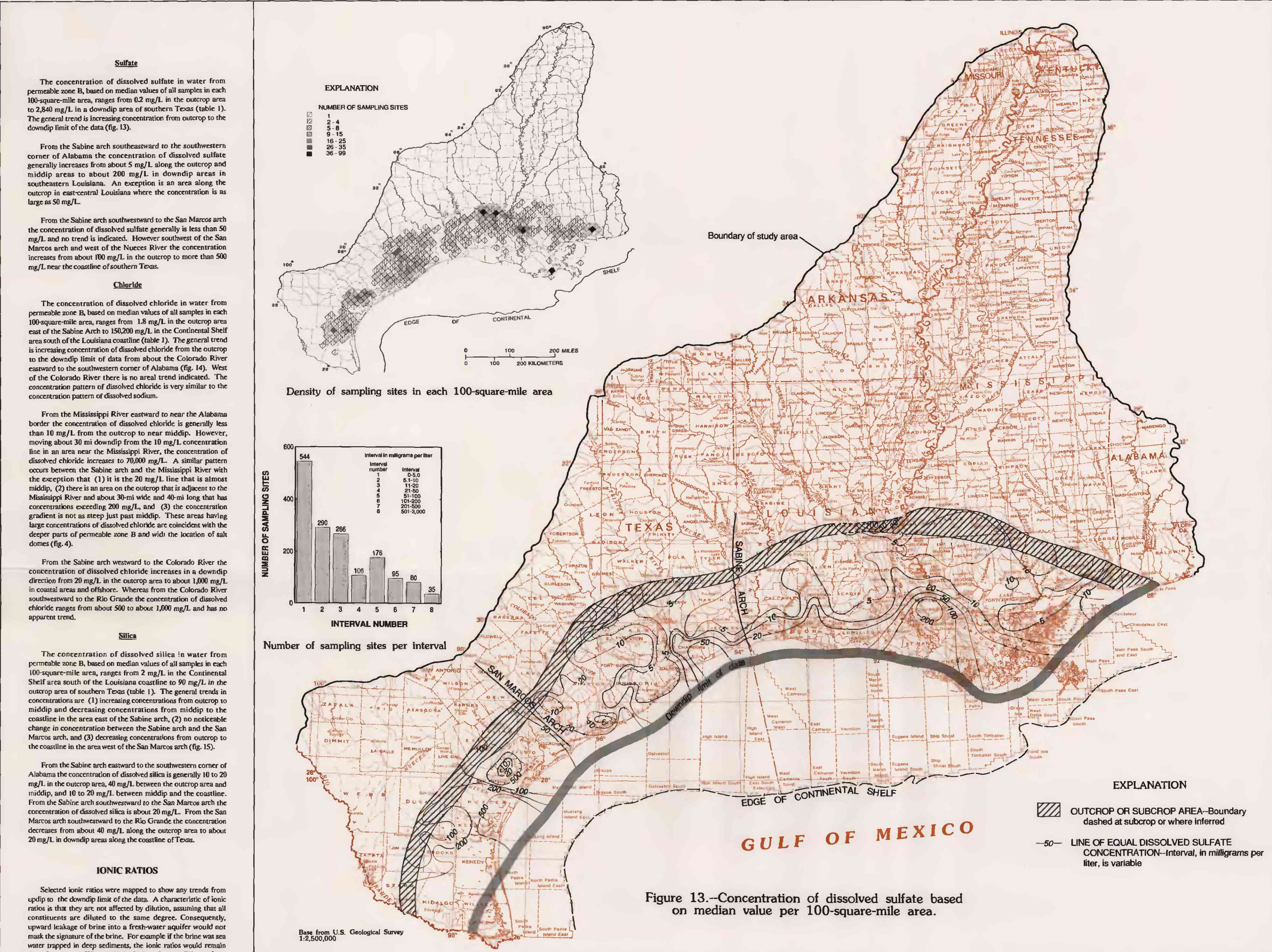




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1993



**Magnesium plus Calcium to Bicarbonate**

The areal distribution of the milliequivalent ratio of magnesium plus calcium to bicarbonate ( $Mg+Ca/HCO_3$ ) in water from permeable zone B ranges from less than 0.01 at midship in Louisiana to 1.08 in an area south of the Louisiana coastline (table 1). East of the Sabine arch the  $Mg+Ca/HCO_3$  ratio generally decreases from outcrop to midship and then increases from midship to the downdip limit of the data. South of the Sabine arch no trend is apparent.

From the Sabine arch eastward to the southwestern corner of Alabama the  $Mg+Ca/HCO_3$  ratio decreases from about 1 in the outcrop area to as low as 0.05 between the outcrop and midship. From midship to the downdip limit of data the ratio increases to 0.05 over short distances downdip reaching values of 1.00 at the coastline in southeastern Louisiana. From the Sabine arch southward to the Rio Grande the  $Mg+Ca/HCO_3$  ratio generally decreases from about 1 at the outcrop to 0.5 at midship. Further downdip this ratio decreases to about 0.2 and then increases to 0.5 and 1 near the downdip limit of the data.

**Magnesium plus Calcium to Sodium plus Potassium**

The areal distribution of the milliequivalent ratio of magnesium plus calcium to sodium plus potassium ( $Mg+Ca/Na+K$ ) in water from permeable zone B ranges from less than 0.01 in midship and outcrop areas to 6.1 in outcrop areas (table 1). The ratio generally decreases from outcrop to the downdip limit of the data (fig. 18).

From the Sabine arch eastward to the southwestern corner of Alabama the  $Mg+Ca/Na+K$  ratio decreases from about 1 along the outcrop to 0.1 at midship and remains at this value to the downdip limit of data in Louisiana. An exception is an area around Baton Rouge, Louisiana, where it decreases to 0.05 at midship. From the Sabine arch southward to the San Marcos arch the  $Mg+Ca/Na+K$  ratio increases from 1 at the outcrop to 2 between the outcrop and midship. From midship to the coastline the ratio decreases to 0.1. From the San Marcos arch southward to the Rio Grande the  $Mg+Ca/Na+K$  ratio decreases from 1 in the outcrop area to about 0.05 downdip along the coastline.

**Bicarbonate to Sulfate**

The areal distribution of the milliequivalent ratio of bicarbonate to sulfate ( $HCO_3/SO_4$ ) in water from permeable zone B ranges from 0.02 in southern Texas to 1.00 in south-central Louisiana (table 1). The trend is generally increasing values from updip to downdip except in southern Texas where the values decrease from updip to downdip (fig. 19).

From the Mississippi River eastward to the southwestern corner of Alabama the  $HCO_3/SO_4$  ratio ranges from 0.5 to 1.0 in the outcrop area to as much as 2.00 at midship in the area of New Orleans, Louisiana. From the Mississippi River westward to the Sabine arch the  $HCO_3/SO_4$  ratio along the outcrop ranges from 0.5 adjacent to the arch to 2.00 adjacent to the Mississippi River. Values of 2.00 occur from the outcrop southward to midship and into much of the midship area in south-central Louisiana.

From the Sabine arch southward to the San Marcos arch the  $HCO_3/SO_4$  ratio ranges from 1.0 along the outcrop to 2.00 downdip near the coastline in Brazoria and Galveston Counties, Texas. Ratios of 1.00 occur in three areas ranging from small to large and located between the outcrop and midship. From the San Marcos arch southward to the Rio Grande the  $HCO_3/SO_4$  ratio ranges from 2 to 5 in the outcrop area and decrease to 0.5 to 1 at the downdip limit of data except for a small area near the common border of San Patricio and Refugio Counties, Texas, where it increases to more than 5.0.

**Bicarbonate to Chloride**

The areal distribution of the milliequivalent ratio of bicarbonate to chloride ( $HCO_3/Cl$ ) in water from permeable zone B ranges from less than 0.01 in a downdip area near the coastline in Louisiana to 4.2 in the midship area in south-central Louisiana (table 1). The  $HCO_3/Cl$  ratio generally increases from the outcrop to the area between the outcrop and midship, and then decreases continually to the downdip limit of the data (fig. 20). An exception is the area west of the San Marcos arch where there is no trend in the ratio.

From the Sabine arch eastward to the southwestern corner of Alabama the  $HCO_3/Cl$  ratio increases from about 1 in the outcrop to about 10 at midship and then decreases in the downdip direction to 0.1 at the coastline. From the Sabine arch southward to the San Marcos arch the ratio increases from about 1 at the outcrop to about 2 at midship and then decreases to about 0.5 at the downdip limit of data. From the San Marcos arch southward to the Rio Grande the  $HCO_3/Cl$  ratio ranges from 0.5 to 1.

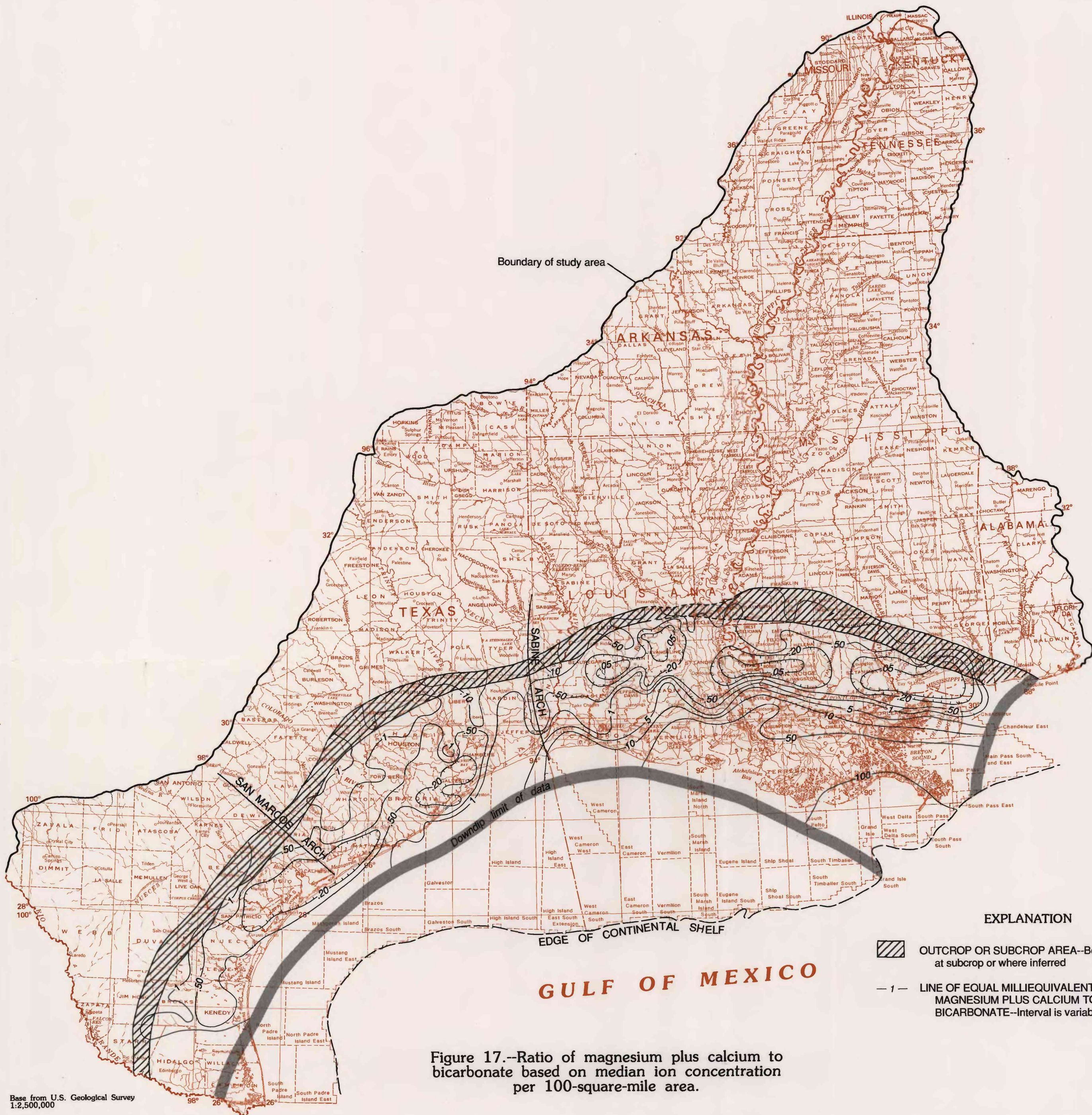


Figure 17.—Ratio of magnesium plus calcium to bicarbonate based on median ion concentration per 100-square-mile area.

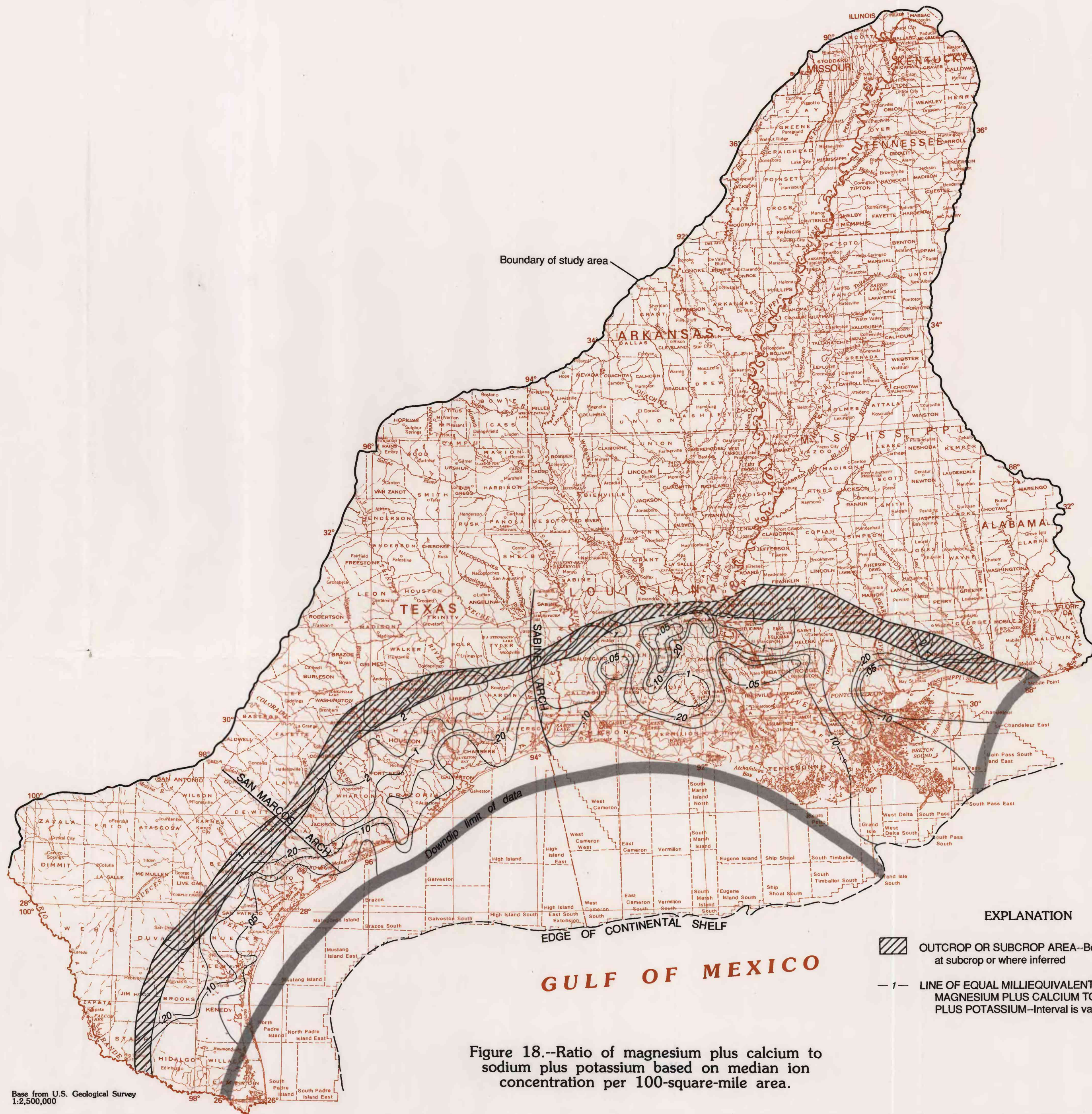


Figure 18.—Ratio of magnesium plus calcium to sodium plus potassium based on median ion concentration per 100-square-mile area.

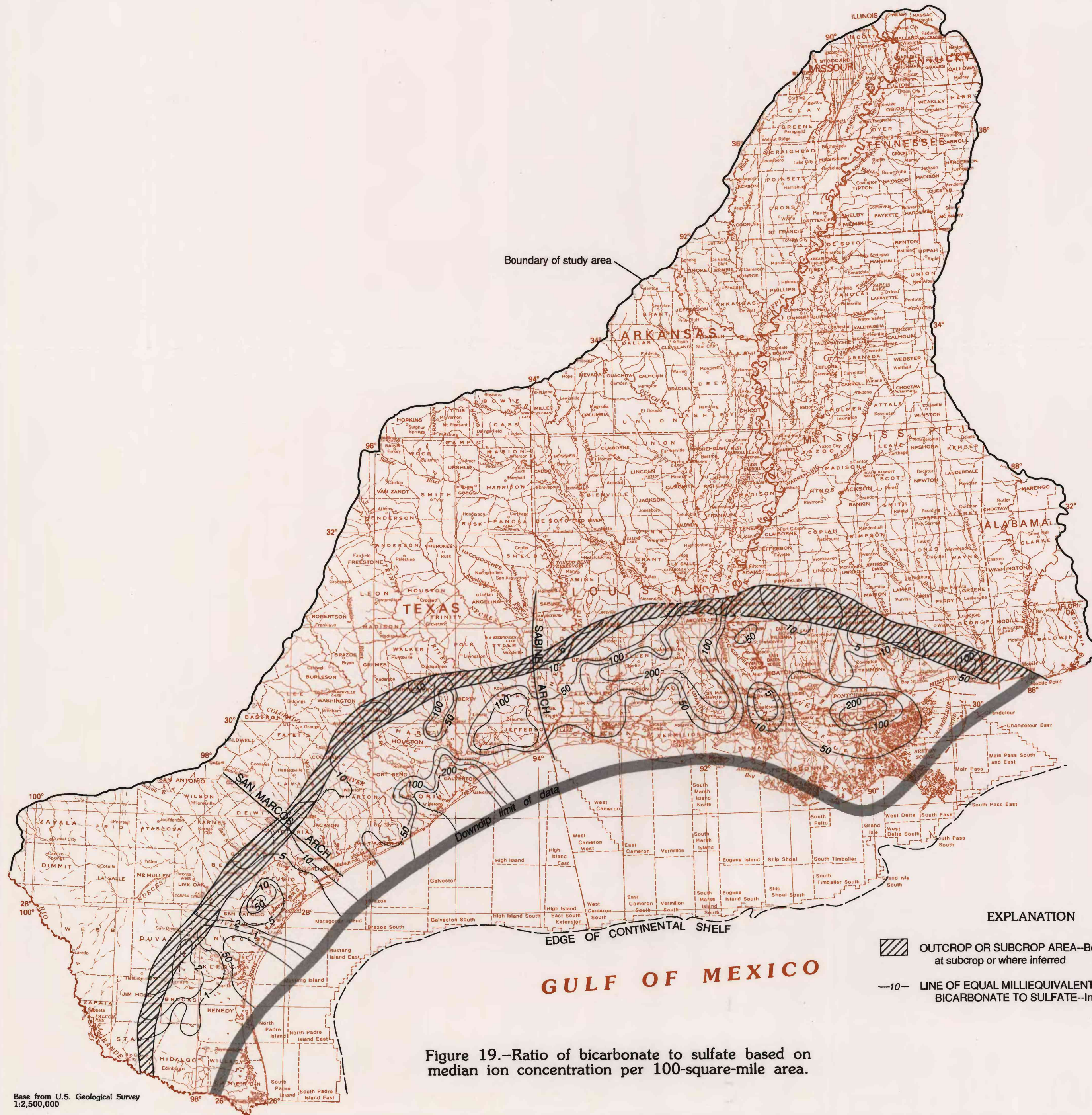


Figure 19.—Ratio of bicarbonate to sulfate based on median ion concentration per 100-square-mile area.

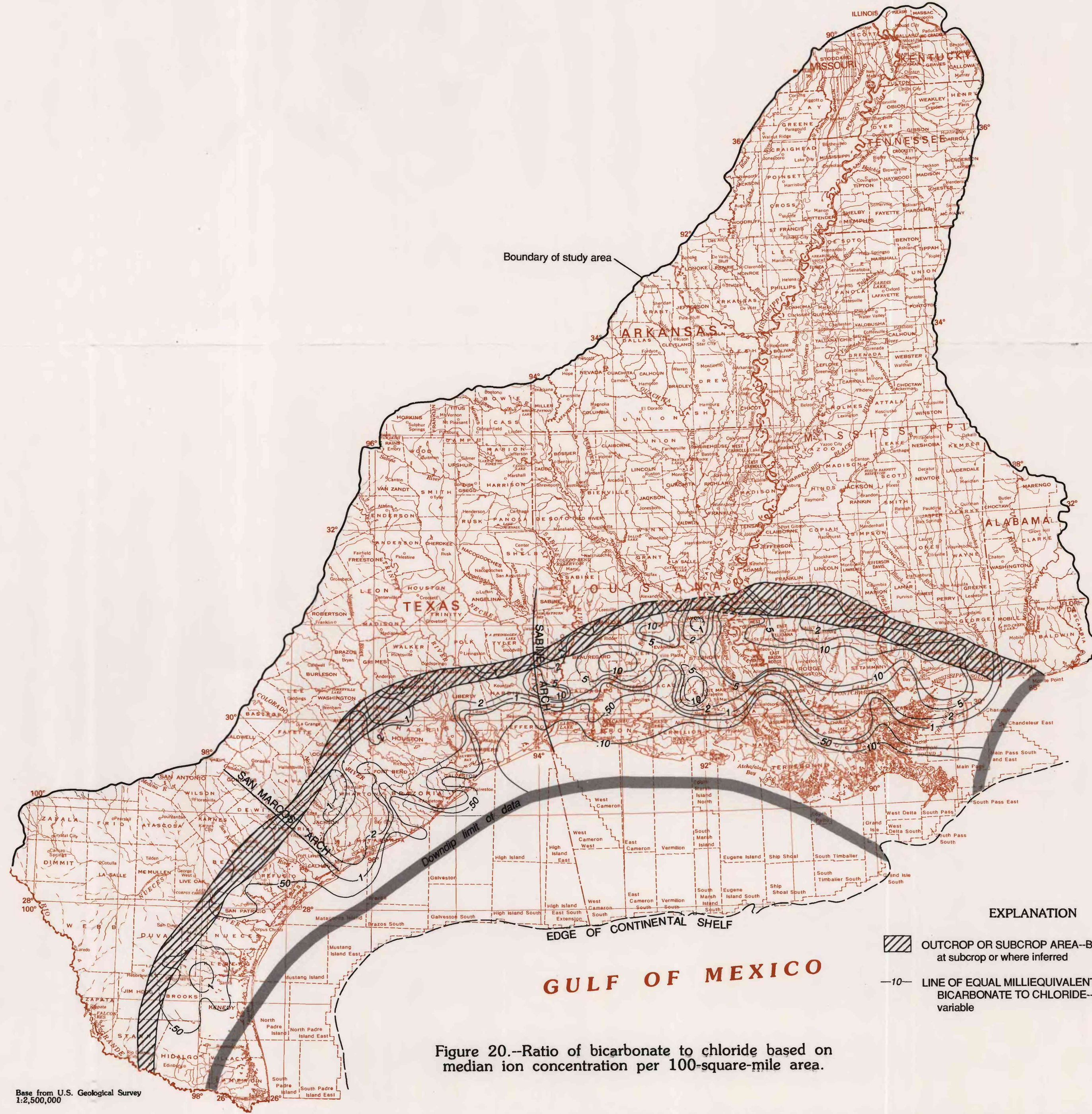


Figure 20.—Ratio of bicarbonate to chloride based on median ion concentration per 100-square-mile area.

PROPERTIES AND CHEMICAL CONSTITUENTS IN GROUND WATER FROM PERMEABLE ZONE B (LOWER PLEISTOCENE-UPPER PLOICENE DEPOSITS), COASTAL LOWLANDS AQUIFER SYSTEM, SOUTH-CENTRAL UNITED STATES

by  
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