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 mi^2 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^2 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 geohydrologic and hydraulic factors (Weiss and Williamson, 1985, Pettijohn and others, 1988, Hosman and Weiss, 1991, Weiss, 1990).

The upper Claiborne aquifer is in sediments of Eocene age and is part of both the Mississippi embayment and the Texas coastal uplands aquifer systems. Relation of the aquifer to overlying and underlying units is shown in figure 3. The Mississippi River Valley alluvial aquifer overlies the upper Claiborne aquifer throughout a 13,000 mi^2 area in the Mississippi embayment, primarily in Arkansas, northeastern Louisiana, Missouri, and west-central Mississippi. The area where the upper Claiborne aquifer is overlain by the Mississippi River Valley alluvial aquifer is combined with the upper Claiborne outcrop area and subsequently referred to as the outcrop-subcrop area. Sand content of the upper Claiborne aquifer is greater than 60 percent in the outcrop area of Texas and extends a few to several ten's of miles toward the coast in isolated lobate patterns. An elongate area where sand percentage exceeds 60 percent is located in southeastern Texas. Several lobes of sand percentage greater than 60 percent extend downdip from outcrop-subcrop areas of northeastern Louisiana, Arkansas, Missouri, Kentucky, Tennessee, and Mississippi. Areas of less than 40 percent sand are common adjacent to the downdip limit of the aquifer (Hosman and Weiss, 1991). The aquifer averages about 500 feet thick and generally dips from the outcrop-subcrop area toward the Gulf of Mexico at about 28 to 96 ft/mi. In the outcrop-subcrop area along the Mississippi River from the northern edge of the outcrop to the southern edge of the subcrop the land-surface slope is about 1.67 ft/mi. Ground-water pumpage from the upper Claiborne aquifer was about 60 Mgal/d during 1985 (Mesko 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 (Bennett, 1979). A summary of progress in 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 the upper Claiborne aquifer. Maps in this 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 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 Storage and Retrieval System (WATSTORE) and data from the Texas Department of Water Resources (Pettijohn, 1988). The data were screened as explained by Pettijohn (1986) and values were posted on maps in each 100-square-mile area where data exist. The 100-square-mile areas are the same as those illustrated by Grubb (1987, p. 115) 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, major ions, pH, and temperature vary with depth within the aquifer. Point values can be smaller or larger than the values shown on the map, 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 constructing 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 is shown in table 1.

The maximum values in table 1 usually are 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 are not enough data of equal magnitude to justify adding additional intervals.

The major ions concentrations 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 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 are shown on the map. More detailed discussions of how the data were analyzed, processed, and mapped are given by Pettijohn (1986, 1988), Weiss (1987), and Pettijohn and others (1988).

Superimposed on selected map are locations of geologic structures that are used as reference points in describing the chemistry of the ground water from east to west. Updip, middip, and downdip are used as reference areas in describing the chemistry of the ground water from north to south. Updip areas include the areas adjacent to the updip limit of the aquifer; middip refers to areas about midway between the updip limit and the downdip limit of the aquifer; and downdip refers to areas adjacent to the downdip limit of the data or the downdip limit of the upper Claiborne aquifer. 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 structures 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 per day (Mgal/d)	0.04381	cubic meters per second
square mile (mi^2)	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 nets 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:

$$°F = 1.8(°C) + 32$$

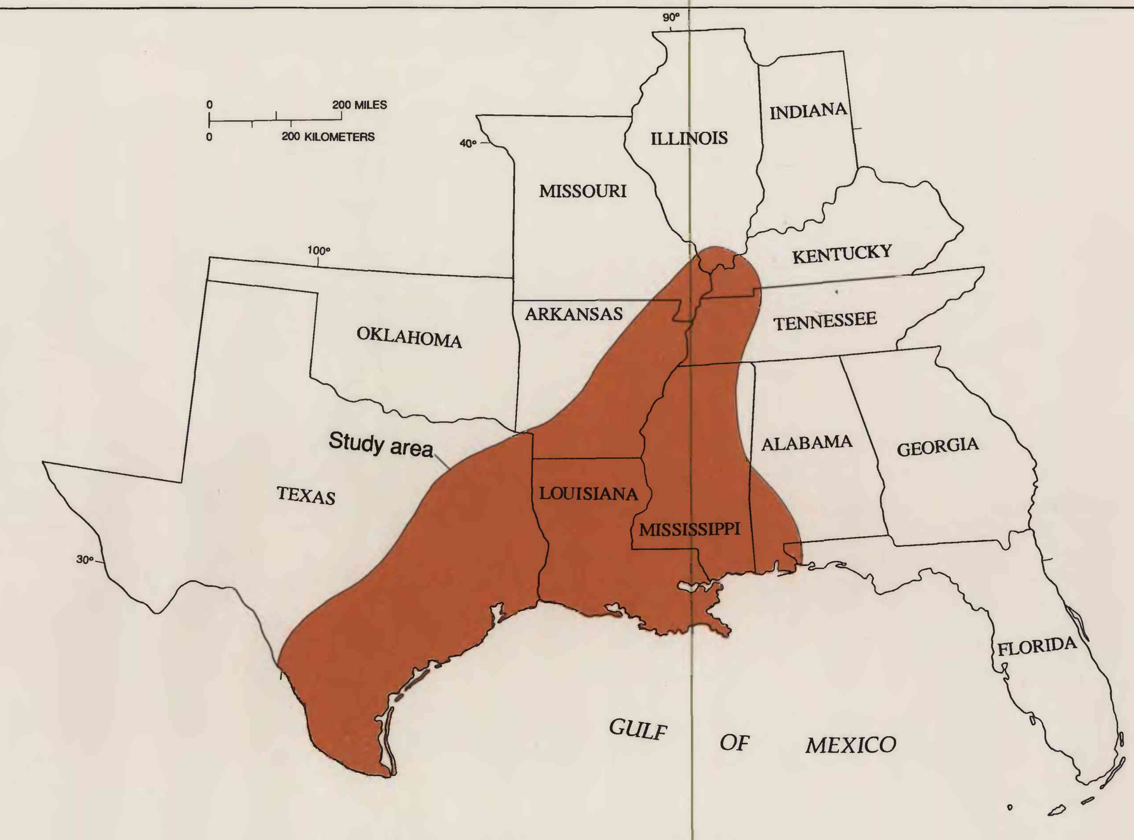

Figure 1.--Location of study area.

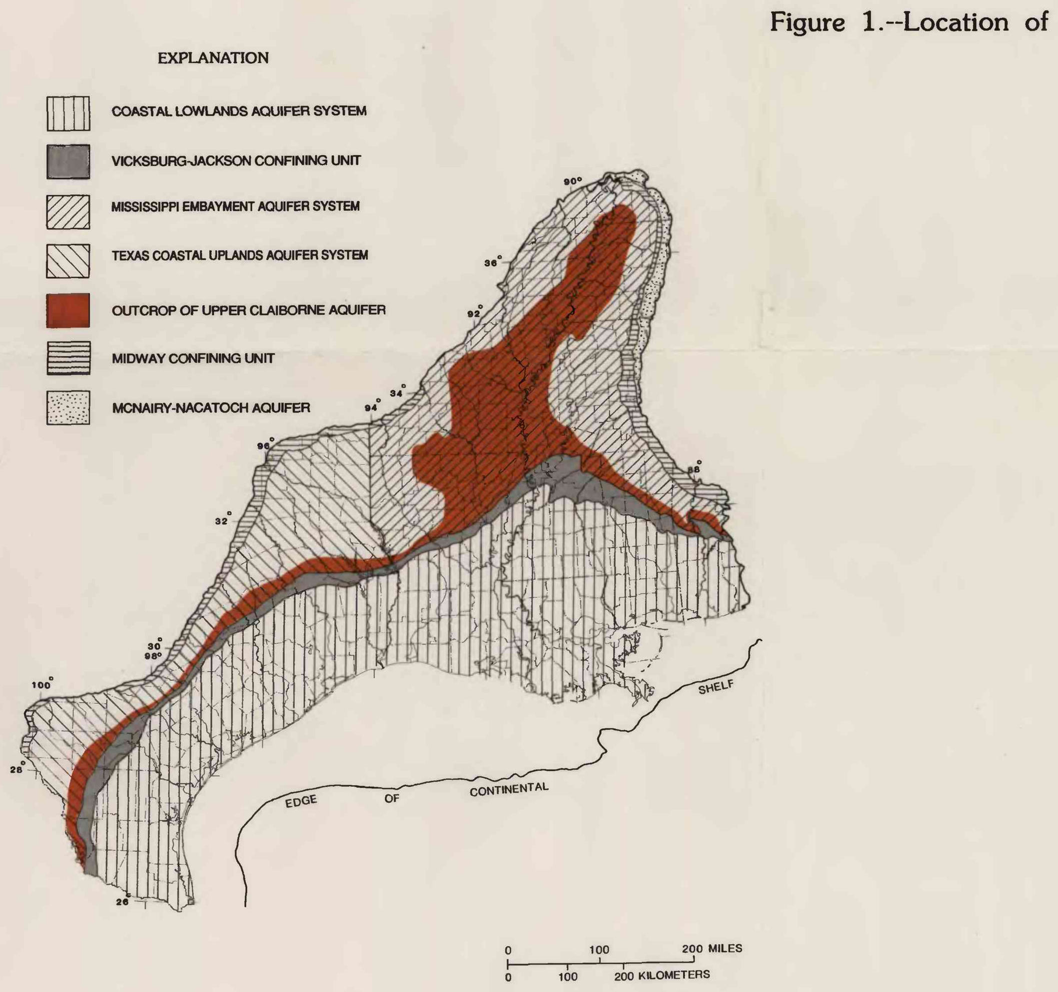

Figure 2.--Generalized outcrop of major aquifer systems and confining units in the Gulf Coast Regional Aquifer-System Analysis study area. Outcrop of the upper Claiborne aquifer superimposed.

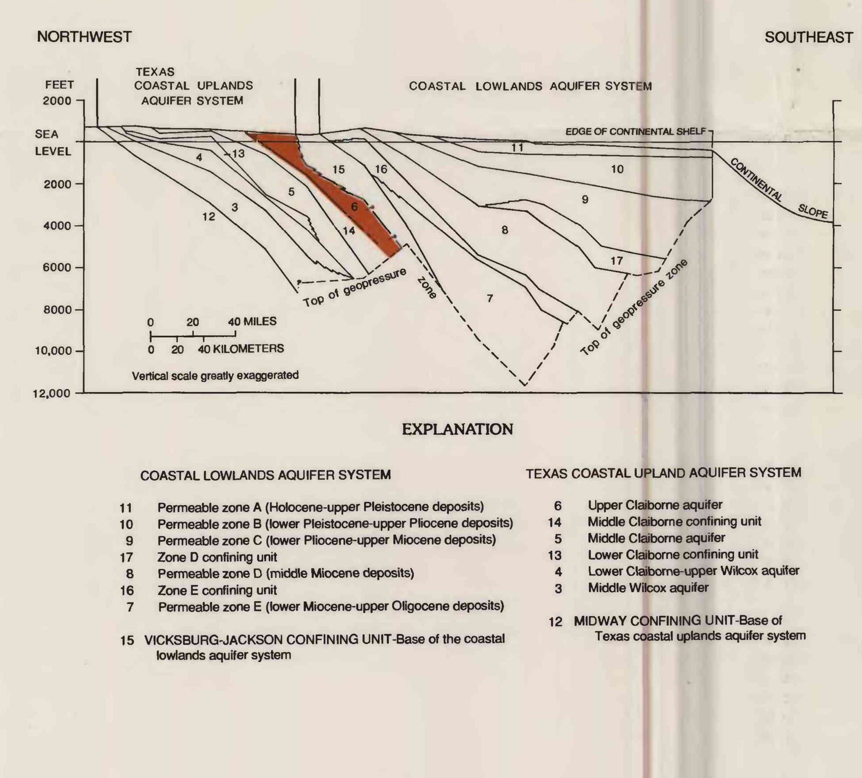

Figure 3.--Diagrammatic geohydrologic section through southwest part of study area.

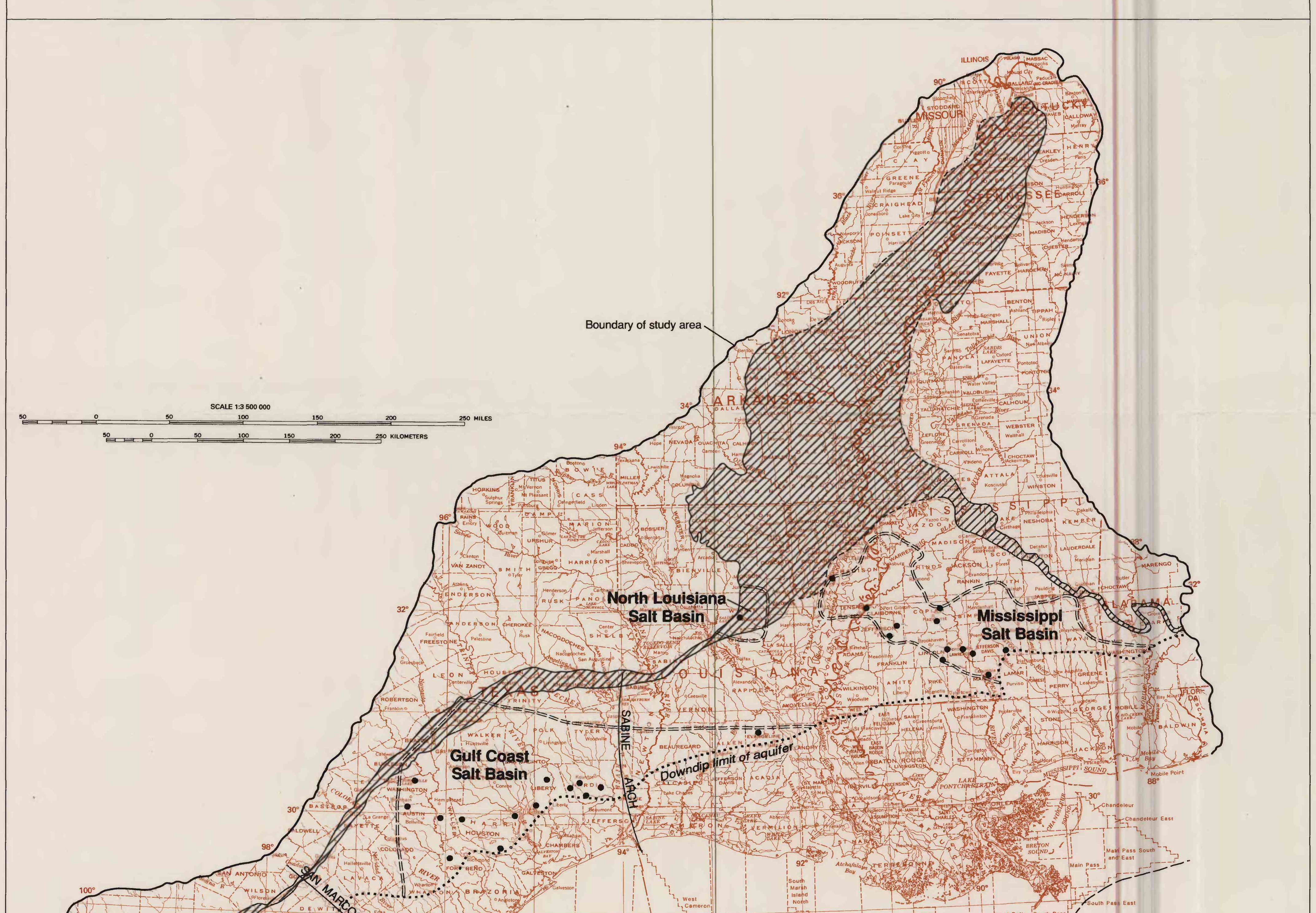

Figure 4.--Location of salt domes that penetrate the base of the upper Claiborne aquifer (modified from Beckman and Williamson, 1990).

SUMMARY AND CONCLUSIONS

The water chemistry of the upper Claiborne aquifer, which is part of the Mississippi embayment aquifer system and the Texas coastal uplands 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 19.0 mg/L in the outcrop-subcrop area to 133,000 mg/L in a downdip areas of Louisiana. The increase in concentration of dissolved solids in a downdip direction is attributed to mineral-water interaction such as dissolution of silicates in outcrop-subcrop areas and dissolution of evaporites comprising salt domes downdip in the deeper parts of the aquifer. The temperature ranges from about 10.5 degrees Celsius in the outcrop-subcrop area to 80 degrees Celsius in a downdip area of southern Louisiana.

The primary water type in the upper Claiborne aquifer, which is based on the most frequently observed type (mode) in each 100-square-mile area, is calcium bicarbonate in northeastern Arkansas, western Tennessee, and western Kentucky. It is sodium bicarbonate in southern Arkansas, eastern Texas, central Louisiana, and central Mississippi. It is sodium chloride in southern Texas and in downdip areas in southeastern Texas. The pH ranges from 4.4 in the outcrop-subcrop area of southern Arkansas to 8.9 in southern Mississippi.

The concentrations of major ions generally increase from the outcrop-subcrop area to the downdip limit of the data. The concentration of dissolved calcium ranges from 0.1 mg/L in the outcrop-subcrop area and an area in southern Mississippi to 4,070 mg/L in a downdip area of southern Texas. The concentration of dissolved magnesium ranges from 0.1 mg/L in the outcrop-subcrop areas to 857 mg/L in a downdip area of southern Texas. The concentration of dissolved sodium ranges from 1.2 mg/L in the outcrop-subcrop in the area of the Mississippi embayment aquifer system to 46,900 mg/L along the downdip limit of the aquifer. The concentration of dissolved potassium ranges from 0.1 to 110 mg/L and generally increases from the outcrop-subcrop area to the downdip limit of the data.

The concentration of dissolved bicarbonate ranges from 4 mg/L in the outcrop-subcrop area to 2,060 mg/L near the downdip limit of the aquifer. The concentration of dissolved sulfate ranges from 0.2 to 1,020 mg/L and generally exhibits a random pattern of large and small concentrations. The concentration of dissolved chloride ranges from 0.2 to 81,200 mg/L and increase from the edge of the outcrop-subcrop area to the downdip limit of the aquifer. The concentration of dissolved silica in water of the upper Claiborne aquifer ranges from 4.4 to 100 mg/L and generally decreases from the outcrop-subcrop area to the downdip limit of the aquifer.

The milliequivalent ratio maps of constituents in water from the upper Claiborne aquifer show areal distribution and any trends in ratios from updip to the downdip limit of data. The milliequivalent ratio of magnesium to calcium ranges from 0.03 to 1.9 with no indicated areal trend. The milliequivalent ratio of magnesium plus calcium to bicarbonate ranges from less than 0.01 to 118 and generally increases from the outcrop-subcrop area to the downdip limit of the data. The milliequivalent ratio of magnesium plus calcium to sodium plus potassium ranges from less than 0.01 to 39.2 and generally decreases from north to south in the northern part of the outcrop-subcrop area and in the area from the outcrop-subcrop to the downdip limit of the data.

The milliequivalent ratio of bicarbonate to sulfate ranges from 0.12 to 2,070. The milliequivalent ratio generally increases from the northern part of the Mississippi embayment aquifer system area to the southern part and from the outcrop-subcrop area to middip. It generally decreases from middip to the downdip limit of the data. The milliequivalent ratio of bicarbonate to chloride ranges from less than 0.01 to 81.3 and generally decreases from the southern edge of the outcrop-subcrop area to the downdip limit of the data.

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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 the upper Claiborne aquifer*

[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_3, bicarbonate; SO_4, 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	7.4	4.4	8.9	325
Temperature	21	10.5	80	424
Dissolved-solids	650	19.0	133,000	393
Calcium	28	0.1	4,070	315
Magnesium	7.0	0.1	857	313
Sodium	107	1.2	46,900	314
Potassium	2.4	0.1	110	207
Bicarbonate	266	4.0	2,060	338
Sulfate	12.0	0.2	1,020	321
Chloride	31	0.2	81,200	369
Silica	21.0	4.4	100	241
Ratio Mg:Ca	0.5	0.03	1.9	313
Ratio MgCa:HCO_3	0.8	<0 01	118	298
Ratio MgCa:NaK	0.9	<0.01	39.2	202
Ratio HCO_3:SO_4	12.9	0.12	2,070	303
Ratio HCO_3:Cl	2.9	<0.01	81.3	337

PROPERTIES AND CHEMICAL CONSTITUENTS IN GROUND WATER FROM THE UPPER CLAIBORNE AQUIFER, GULF COAST REGIONAL AQUIFER SYSTEMS, SOUTH-CENTRAL UNITED STATES

by

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

1993

CHEMICAL AND PHYSICAL PROPERTIES

The areal distributions 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 to the downdip limit of the aquifer. The abundance of geophysical well logs (Grubb, 1986, and Wilson and Hosman, 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. The primary water type and pH generally are not shown in the deeper part of the Mississippi embayment because of a lack of data.

Dissolved-Solids Concentrations

The concentration of dissolved solids in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 19 mg/L in the outcrop-subcrop area to 133,000 mg/L in a downdip area of Louisiana (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 downdip over the shortest distance occurs west of the Mississippi River in east-central Louisiana (fig. 5).

Ground water from the outcrop-subcrop in the area of the Mississippi embayment aquifer system have concentrations of dissolved solids ranging between 0 and 500 mg/L except either side of the Mississippi River in southern Arkansas, northeastern Louisiana, and west-central Mississippi where the concentration ranges between 500 and 10,000 mg/L. The concentration of dissolved solids in the outcrop in the area of the Texas coastal uplands aquifer system ranges from 500 mg/L in eastern Texas to about 10,000 mg/L near the Rio Grande in southern Texas.

The concentration of dissolved solids in ground water increases from 500 to 10,000 mg/L in less than 20 mi in the downdip direction in east-central Louisiana and in less than 50 mi in the downdip direction elsewhere. Concentrations of dissolved solids that exceed 10,000 mg/L occur from about middip to the downdip limit of the aquifer from southwestern Mississippi to the Rio Grande in southern Texas. Concentrations of dissolved solids that exceed 70,000 mg/L occur in downdip areas in southeastern Texas and southern Louisiana. The increase in concentration of dissolved solids from the updip limit to the downdip limit is attributed to mineral-water interaction such as dissolution of silicates in outcrop-subcrop areas and the dissolution of evaporites comprising salt domes downdip in the deeper parts of the aquifer.

Temperature

The temperature of water from the upper Claiborne aquifer, based on combined depth-averaged values and the median values of all samples in each 100-square-mile area, ranges from 10.5 degrees Celsius in the outcrop-subcrop area to 80 degrees Celsius in a downdip area of southern Louisiana (table 1). Generally the temperature increases from 20 degrees Celsius to 30 degrees Celsius where the concentration of dissolved solids increases from 500 to 10,000 mg/L (fig. 5). In areas where the concentration of dissolved solids increases from 10,000 mg/L to more than 70,000 mg/L, the temperature of the ground water increases from 30 degrees to more than 70 degrees Celsius. Ground water in most of the outcrop and subcrop areas have temperatures of less than 30 degrees Celsius.

Primary Water Type

The primary water types in the upper Claiborne aquifer, which are based on the most frequently observed type (mode) in each 100-square-mile area, are calcium bicarbonate, sodium bicarbonate, and sodium chloride (fig. 6). Calcium bicarbonate is the primary water type in northeastern Arkansas, western Tennessee, and western Kentucky. Sodium bicarbonate is the primary water type in southern Arkansas, eastern Texas, central Louisiana, and central Mississippi. Sodium chloride is the primary water type in southern Texas and in downdip areas in southeastern Texas.

pH

The pH of water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 4.4 in the outcrop-subcrop area of southern Arkansas to 8.9 in southern Mississippi (table 1). The pH in most of the outcrop-subcrop area ranges from 7.0 to 8.0 except for a large area in southeastern Arkansas and northwestern Mississippi where the pH exceeds 8.0 (fig. 7). East of the Sabine arch and downdip from the outcrop-subcrop area the pH generally ranges from 7.0 to 8.0 west of the Mississippi River and from 7.0 to more than 8.0 east of the Mississippi River. Between the Sabine arch and the San Marcos arch the pH ranges from 6.0 to 7.0 in southeastern Texas and from 7.0 to 8.0 in other parts of this area. From the San Marcos arch southwestward to the Rio Grande the pH ranges from about 7.0 to more than 8.0 with no specific trend.

CHEMICAL CONSTITUENTS

The areal distributions of eight constituents in ground water are shown on maps and discussed below. The constituents mapped are the major chemical components in ground water from the Gulf Coastal Plain. Lines of equal concentration of constituents generally are absent in an area near the downdip limit of the aquifer in central Louisiana and southern Mississippi due to the absence of data.

Calcium

The concentration of dissolved calcium in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 0.1 mg/L in the outcrop-subcrop area and an area in southern Mississippi to 4,070 mg/L in a downdip area of southern Texas (table 1). In the outcrop-subcrop area, extending from western Kentucky to the Rio Grande, the concentration ranges from less than 10 to more than 500 mg/L but shows no specific trend (fig. 8). Whereas downdip from the southern edge of the outcrop-subcrop area and west of the Sabine arch the concentration generally increases in a downdip direction.

From the Mississippi River eastward to southwestern Alabama the concentration of dissolved calcium in ground water generally ranges from 10 mg/L in downdip areas to 20 mg/L near the outcrop-subcrop area. From the Mississippi River westward to the Sabine arch the concentration generally ranges from 10 to 20 mg/L near the outcrop-subcrop area and from 500 to 1,000 mg/L in the downdip area of southeastern Texas. From the Sabine arch southwestward to the Rio Grande the concentration ranges from 10 to 100 mg/L near the outcrop and from 10 to more than 1,000 mg/L in downdip areas.

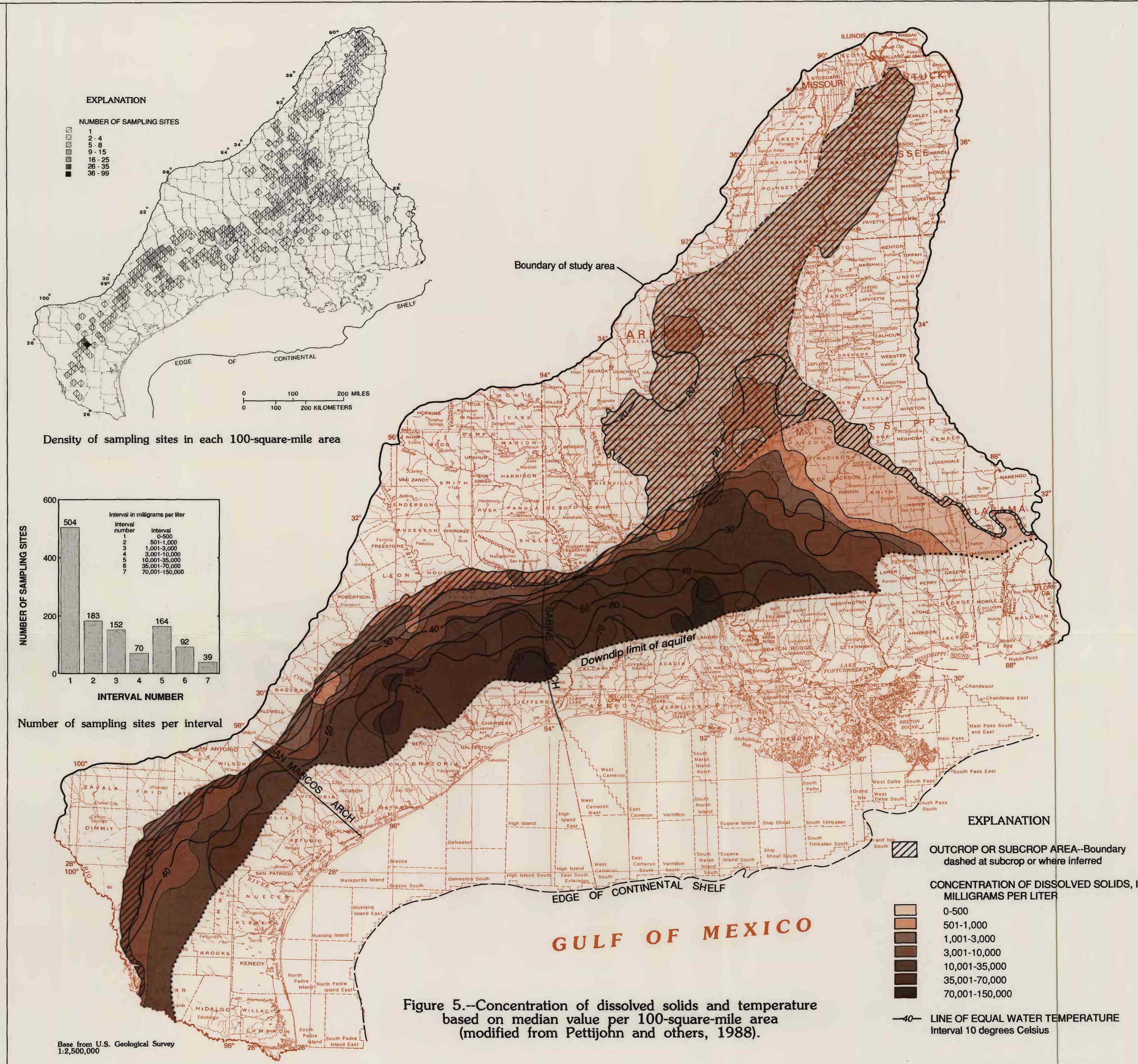

Figure 5.--Concentration of dissolved solids and temperature based on median value per 100-square-mile area (modified from Pettijohn and others, 1988).

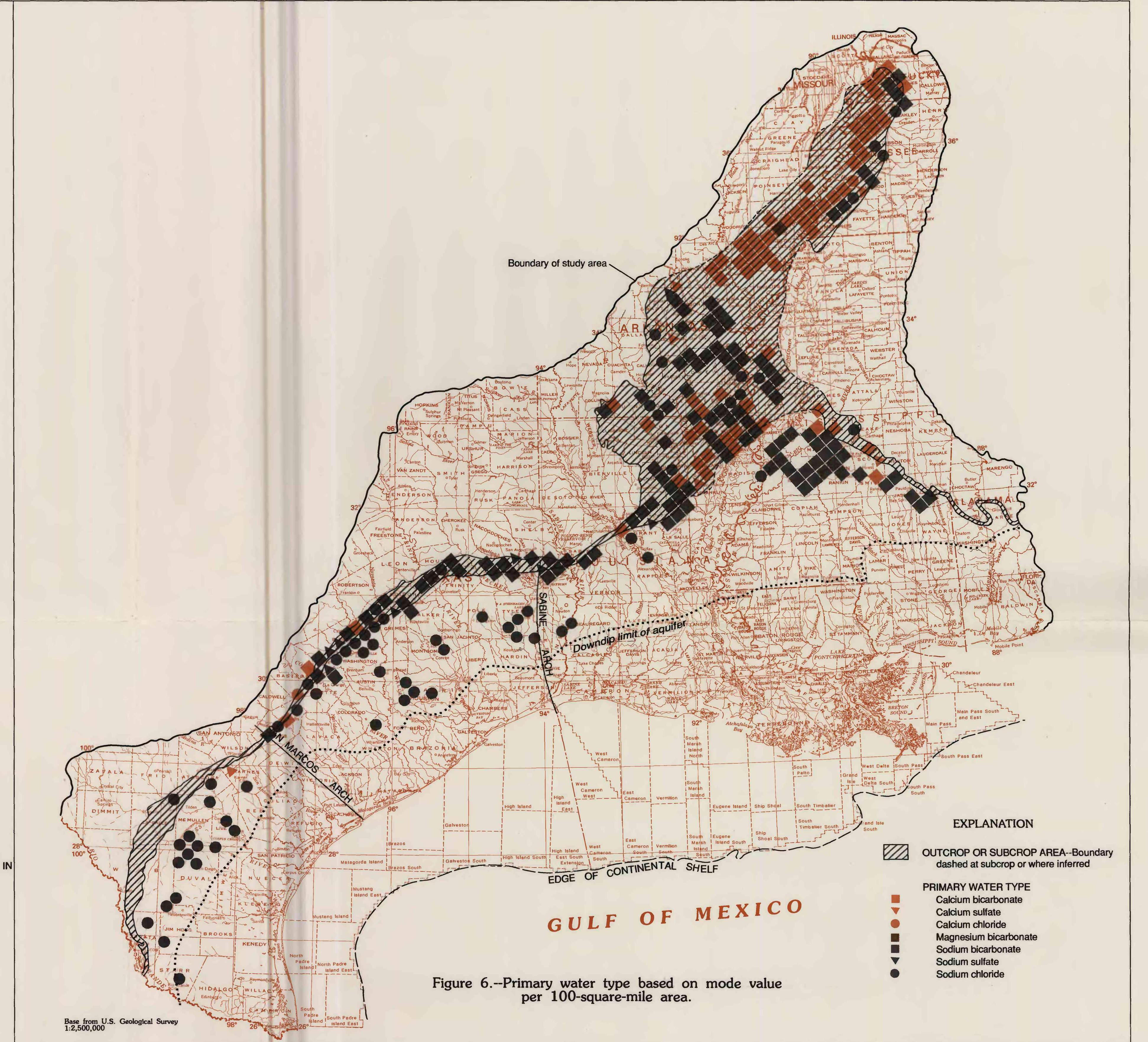

Figure 6.--Primary water type based on mode value per 100-square-mile area.

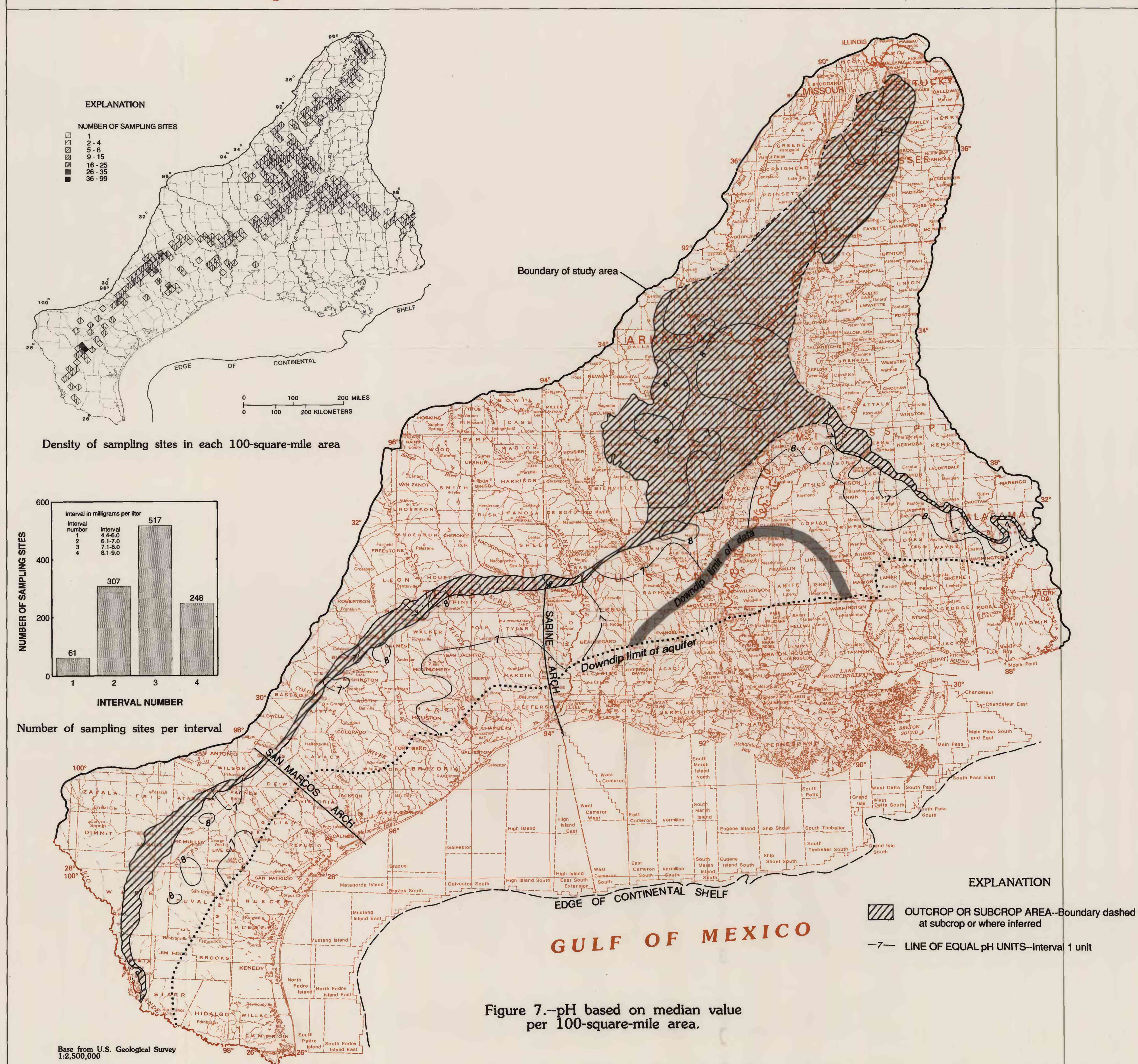

Figure 7.--pH based on median value per 100-square-mile area.

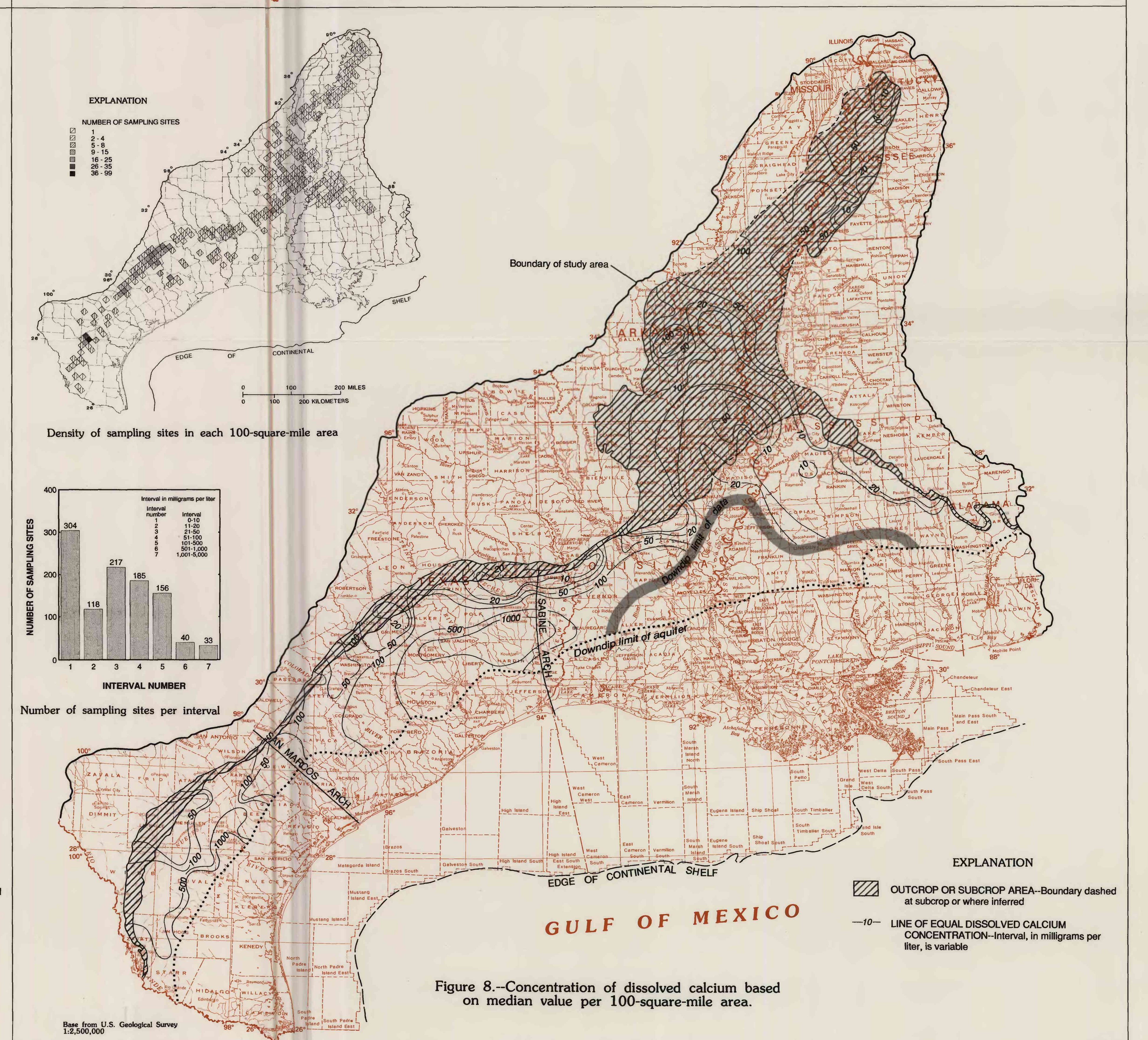

Figure 8.--Concentration of dissolved calcium based on median value per 100-square-mile area.

SCALE 1:3 500 000

50 0 50 100 150 200 250 MILES

50 0 50 100 150 200 250 KILOMETERS

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Magnesium

The concentration of dissolved magnesium in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 0.1 mg/L in the outcrop-subcrop area to 857 mg/L in a downdip area in southern Texas (table 1). The concentration in the outcrop-subcrop area tends to increase from east to west in the area of the Mississippi embayment aquifer system (fig. 9). Whereas downdip from the outcrop-subcrop area and extending from the Mississippi River southwestward across the Texas coastal uplands to the Rio Grande the concentration generally increases from north to south in the aquifer.

In the area of the Mississippi embayment aquifer system the concentration of dissolved magnesium in the outcrop-subcrop area that is east of the Mississippi River is about 10 mg/L. Whereas west of the Mississippi River the concentration ranges from 10 to 20 mg/L. From the Mississippi River westward to about midway between the Sabine arch and the San Marcos arch the concentration increases in a southerly direction from about 10 mg/L at the outcrop to more than 200 mg/L in downdip areas. From about midway between the Sabine arch and the San Marcos arch southwestward to the Rio Grande the concentration increases from a range of 10 to 20 mg/L along the outcrop to a range of 100 to more than 200 mg/L along the downdip limit of the aquifer.

Sodium

The concentration of dissolved sodium in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 1.2 mg/L in the outcrop-subcrop in the area of the Mississippi embayment aquifer system to 46,900 mg/L along the downdip limit of the aquifer (table 1). The areal trend is one of increasing concentration from the outcrop-subcrop area to the downdip limit of the aquifer (fig. 10).

The concentration of dissolved sodium in water from the outcrop-subcrop area of the Mississippi embayment aquifer system generally ranges from 10 mg/L in the northern part of the embayment to 100 mg/L in the southern part. From the Sabine arch southwestward the concentration in the outcrop-subcrop area generally increases from 100 mg/L at the arch to 5,000 mg/L at the Rio Grande in southern Texas.

The concentration of dissolved sodium in water from the area between the outcrop-subcrop areas and the downdip limit of the aquifer generally ranges from 100 mg/L at the outcrop-subcrop to about 20,000 mg/L in some of the downdip areas. For example east of the Mississippi River the concentration increases from about 100 mg/L near the outcrop-subcrop area to about 500 mg/L at the downdip limit of data. In an area extending westward from the Mississippi River to about midway between the Sabine arch and the San Marcos arch the sodium concentration increase from about 1,000 mg/L near the outcrop to more than 20,000 mg/L at the downdip limit of the aquifer. From about midway between the Sabine arch and the San Marcos arch southwestward to the San Marcos arch the concentration increases from about 500 mg/L near the outcrop to more than 10,000 mg/L at the downdip limit of the aquifer. In the area from the San Marcos arch southwestward to the Rio Grande the concentration increases from about 100 mg/L near the outcrop to about 20,000 mg/L at the downdip limit of the aquifer. Part of the area showing large increases in concentration of dissolved sodium are coincident with the deeper part of the aquifer and with the location of salt domes (fig. 4).

Potassium

The concentration of dissolved potassium in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 0.1 to 110 mg/L (table 1). There appears to be no trends in concentration in the outcrop-subcrop area (fig. 11). However from the southern edge of the outcrop-subcrop area to the downdip limit of data the concentration appears to be increasing.

The concentration of dissolved potassium in water from the outcrop-subcrop area is generally less than 5 mg/L. Exceptions are small areas in south-central Arkansas, northwestern Mississippi and southwestern Tennessee, and from Washington County, Texas, to the San Marcos arch where the concentration exceeds 10 mg/L. Concentration increases in a southerly direction from less than 5 to greater than 5 mg/L in the area from the outcrop-subcrop area to the downdip limit of the data. An exception is the area from Washington County, Texas, to the San Marcos arch where the concentration increases from less than 5 mg/L to more than 10 mg/L.

Bicarbonate

The concentration of dissolved bicarbonate in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 4 mg/L in the outcrop-subcrop area to 2,060 mg/L near the middip area of the aquifer (table 1). The concentration generally increases in a downdip direction from the outcrop-subcrop area to the downdip limit of the aquifer (fig. 12).

The concentration of dissolved bicarbonate in water from the outcrop-subcrop area ranges from 100 to 500 mg/L in most of the area. Exceptions are areas along both the east and west boundary of the aquifer in the area of the Mississippi embayment aquifer system where the concentration is less than 100 mg/L. Also there are two areas adjoining the Mississippi River where concentration exceeds 500 mg/L. From the outcrop-subcrop area southward to the downdip limit of the data the concentration generally increases from 100 to 500 mg/L in the area east of the Mississippi River except for a localized area adjoining the Mississippi River where it exceeds 1,000 mg/L. In the area from the Mississippi River southwestward to the San Marcos arch the concentration generally increases from 500 mg/L at the outcrop to 2,000 mg/L at the downdip limit of the aquifer. In the area from the San Marcos arch southwestward to the Rio Grande the concentration ranges from less than 500 mg/L to more than 2,000 mg/L with no areal trend in concentration indicated in this area.

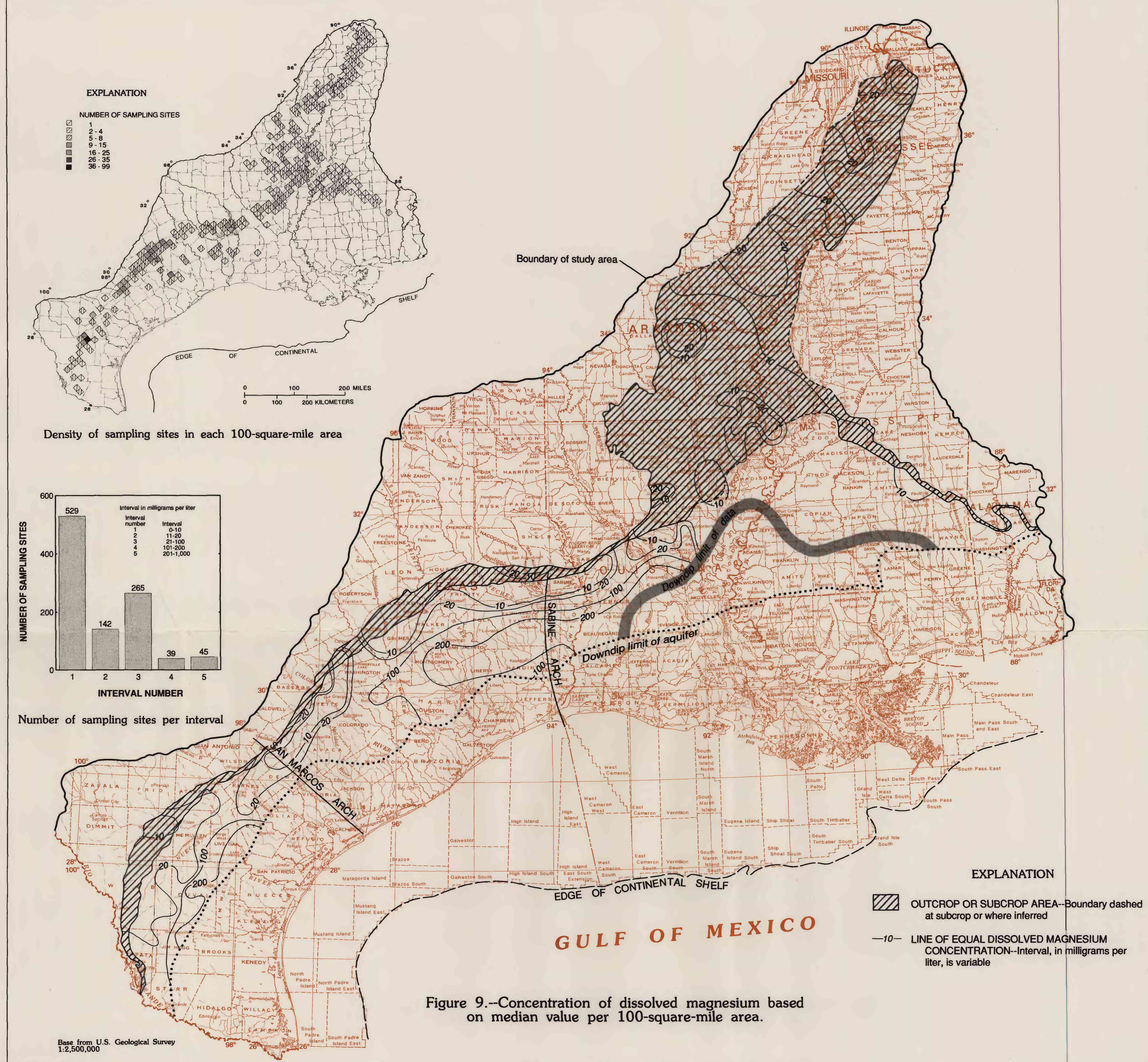

Figure 9.--Concentration of dissolved magnesium based on median value per 100-square-mile area.

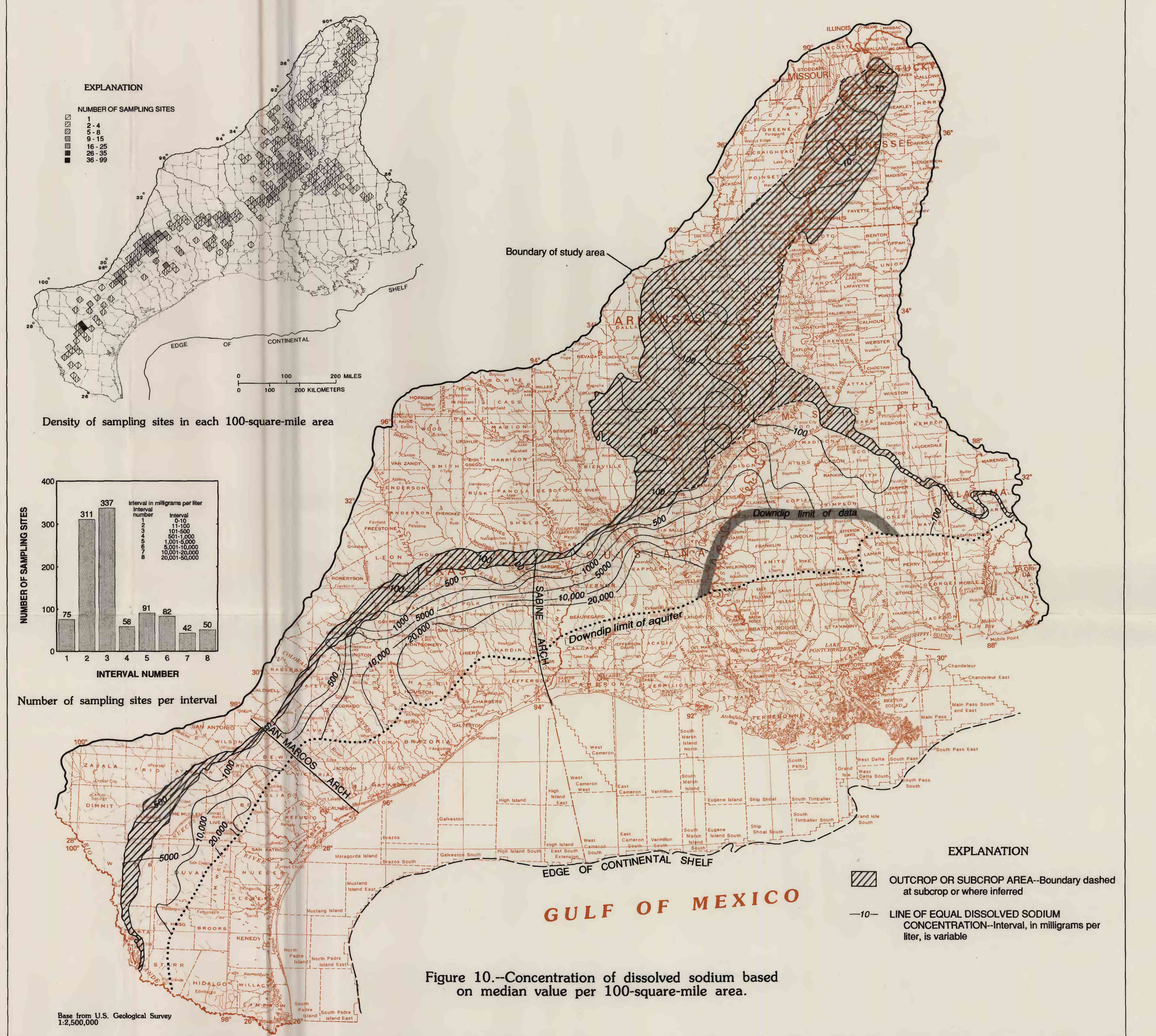

Figure 10.--Concentration of dissolved sodium based on median value per 100-square-mile area.

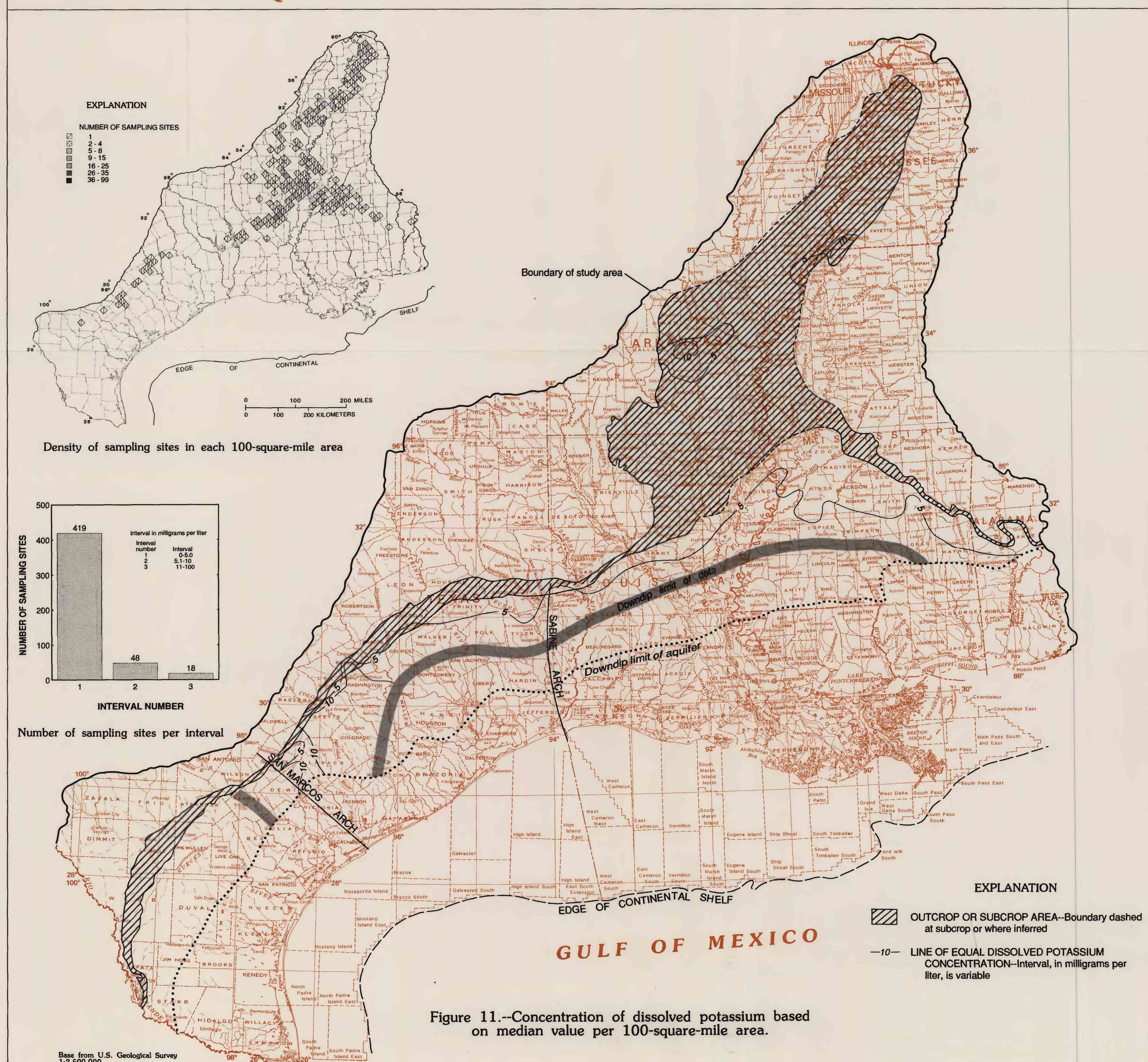

Figure 11.--Concentration of dissolved potassium based on median value per 100-square-mile area.

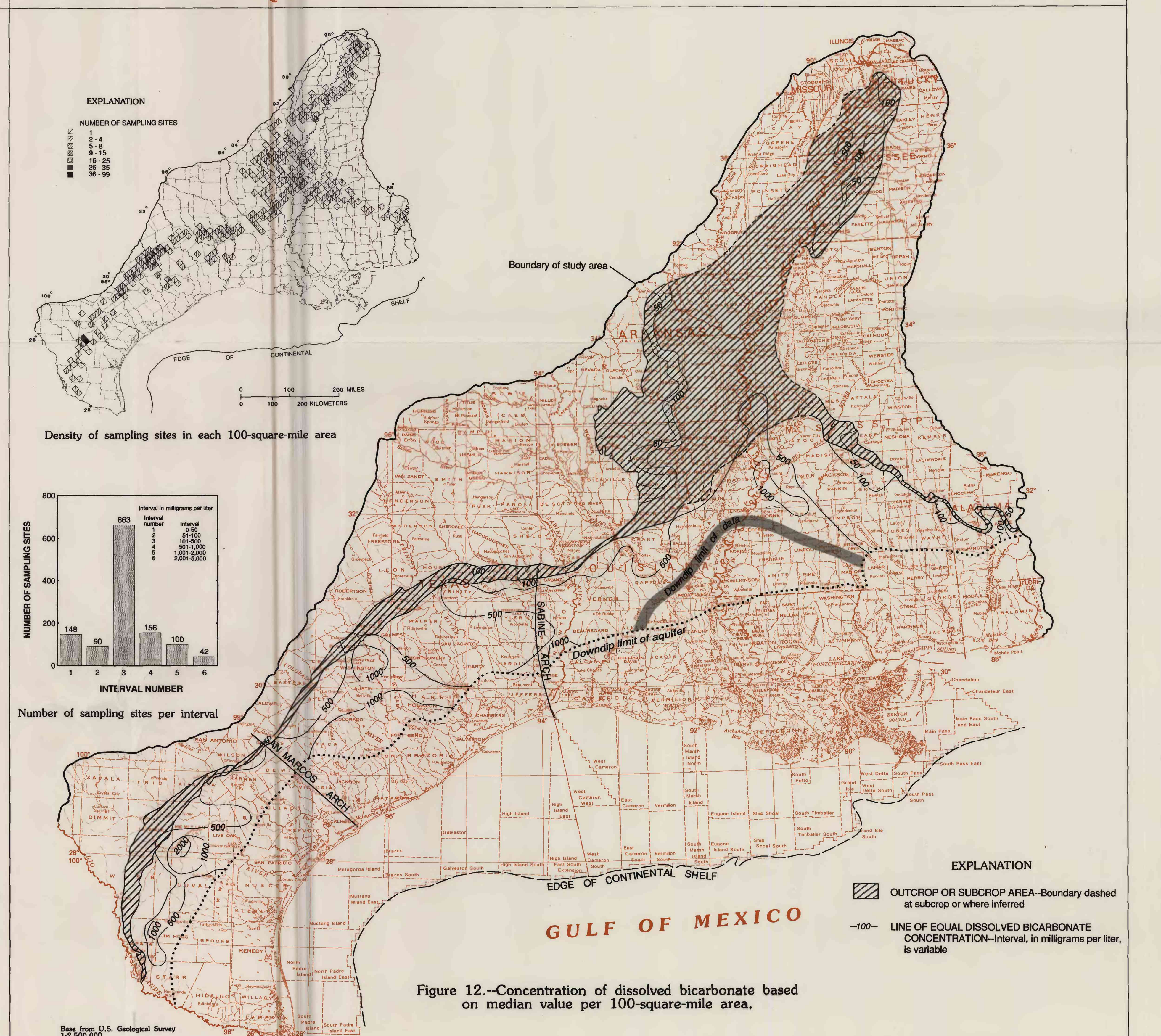

Figure 12.--Concentration of dissolved bicarbonate based on median value per 100-square-mile area.

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Sulfate

The concentration of dissolved sulfate in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 0.2 to 1,020 mg/L (table 1). There appears to be a pattern of minimum concentration in the middip area from the Sabine arch westward to the Rio Grande (fig. 13). Elsewhere dissolved sulfate exhibits a random pattern of large and small concentrations with no apparent trend.

The concentration of dissolved sulfate in water from the outcrop-subcrop area generally ranges from 5 mg/L in both the northern part and the southern part of the area of the Mississippi embayment aquifer system to 200 mg/L in Cleveland County, Arkansas, and several areas along the outcrop from Sabine County, Texas, to Atascosa County, Texas. East of the Mississippi River and between the outcrop-subcrop area and the downdip limit of the data the concentration generally ranges from 5 to 20 mg/L. From the Mississippi River westward to the San Marcos arch the concentration from the outcrop-subcrop area to downdip limits generally ranges from 5 to 200 mg/L with the smaller concentration occurring near middip. From the San Marcos arch southwestward to the Rio Grande the concentration from outcrop to downdip generally ranges from 10 to 200 mg/L with the smaller concentration also occurring near middip.

Chloride

The concentration of dissolved chloride in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 0.2 to 81,200 mg/L (table 1). The concentration in the outcrop-subcrop in the area of the Mississippi embayment aquifer system shows no trend from north to south (fig. 14). However there is a general increase in concentration from east to west in the area that extends from the embayment southwestward to the Rio Grande. Also in this area the concentration of dissolved chloride increases from the outcrop-subcrop area to the downdip limit of the aquifer with the largest increase generally occurring between the downdip edge of the outcrop-subcrop area and middip.

The concentration of dissolved chloride in water from the outcrop-subcrop area generally ranges from 10 mg/L in the northern part of the Mississippi embayment aquifer system area to 100 mg/L in the southern part. Also in the southern part are three small areas where the concentration is larger than 100 mg/L. The concentration along the outcrop-subcrop area increases in a southwestward direction from about 10 mg/L at the southern end of the Mississippi embayment aquifer system to more than 1,000 mg/L near the Rio Grande in southern Texas. East of the Mississippi River and between the southern edge of the outcrop-subcrop area and the downdip limit of the data the concentration increases from about 10 to about 1,000 mg/L. In the area from the Mississippi River westward to the San Marcos arch the concentration increases from about 100 mg/L near the outcrop-subcrop area to 10,000 mg/L at middip. This increase in concentration occurs within a distance of 50 mi in a downdip direction. From the San Marcos arch southwestward to the Rio Grande the concentration increases from about 1,000 mg/L at the outcrop to 10,000 mg/L at middip. Part of the area having a large concentration of chloride generally is coincident with the deeper part of the aquifer and with the location of salt domes (fig. 4).

Silica

The concentration of dissolved silica in water from the upper Claiborne aquifer, based on median values of all samples in each 100-square-mile area, ranges from 4.4 to 100 mg/L (table 1). There appears to be no areal trend in silica concentration in the outcrop-subcrop area (fig. 15). However from the outcrop-subcrop area southward to the downdip limit of the aquifer the concentration appears to decrease.

The concentration of dissolved silica in water from the outcrop-subcrop area ranges from about 10 to 20 mg/L. East of the Sabine arch the concentration decreases from about 20 mg/L at the southern edge of the outcrop-subcrop area to about 10 mg/L at middip. In the area from the Sabine arch southwestward to the San Marcos arch the concentration decreases from about 50 mg/L near the outcrop edge to less than 20 mg/L at the downdip limit of the aquifer. From the San Marcos arch southwestward to near the Rio Grande the concentration ranges between 10 and 20 mg/L along most of the outcrop area and between 20 and 50 mg/L in downdip areas.

IONIC RATIOS

Selected ionic ratios were mapped to show any trends from updip to the downdip limit of the data. A characteristic of ionic ratios is that they are not affected by dilution, assuming that all constituents are diluted to the same degree. Consequently, upward leakage of brine into a fresh water aquifer would not mask the signature of the brine. For example, if the brine was sea water trapped in deep sediments, the ionic ratio would remain that of sea water. Whereas if the ionic ratio is different from sea water and the concentrations of sodium and chloride are larger than for sea water the brine could be the product of dissolution of evaporites composing salt domes.

Mapped ionic ratios can be used to show trends that may indicate processes or mechanisms that have major control on the water chemistry from updip to the downdip limit of the data. For example an ionic ratio of magnesium plus calcium to bicarbonate that is equal to 1 in outcrop areas indicates the dissolution of dolomite or calcite. Whereas downdip of the outcrop this same ionic ratio greater than 1 indicates an additional source of calcium or magnesium ions such as would result from the dissolution of gypsum or if the downdip area is in a salt dome basin it could be dissolution of evaporites. However if this same ratio was less than 1 it would indicate an increase in bicarbonate ions which could be due to a process such as the alteration of silicates. The median concentration for each 100-square-mile area, expressed as milliequivalents per liter, was used to calculate an ionic ratio.

Magnesium to Calcium

The areal distribution of the milliequivalent ratio of magnesium to calcium (Mg:Ca) in water from the upper Claiborne aquifer shows that the ratio ranges from 0.03 to 1.9 (table 1). The mapped data show no apparent areal trend but rather random variations in the Mg:Ca ratio across the aquifer area (fig. 16). Most of the mapped data show that the ratio is near 0.5.

The Mg:Ca ratio in the outcrop-subcrop area generally ranges from 0.2 to 0.8. Most of the areas with ratios near 0.2 and 0.8 are small whereas the area with a ratio near 0.5 extends over most of the outcrop-subcrop area. From the southern edge of the outcrop-subcrop area southward to the downdip limit of the data in the area east of the Sabine arch the Mg:Ca ratio generally is near 0.5 with several small areas near 0.2 or 0.8. From the Sabine arch southwestward to the Rio Grande the Mg:Ca ratio ranges from 0.2 to 0.8 with no specific pattern to the change in the ratio.

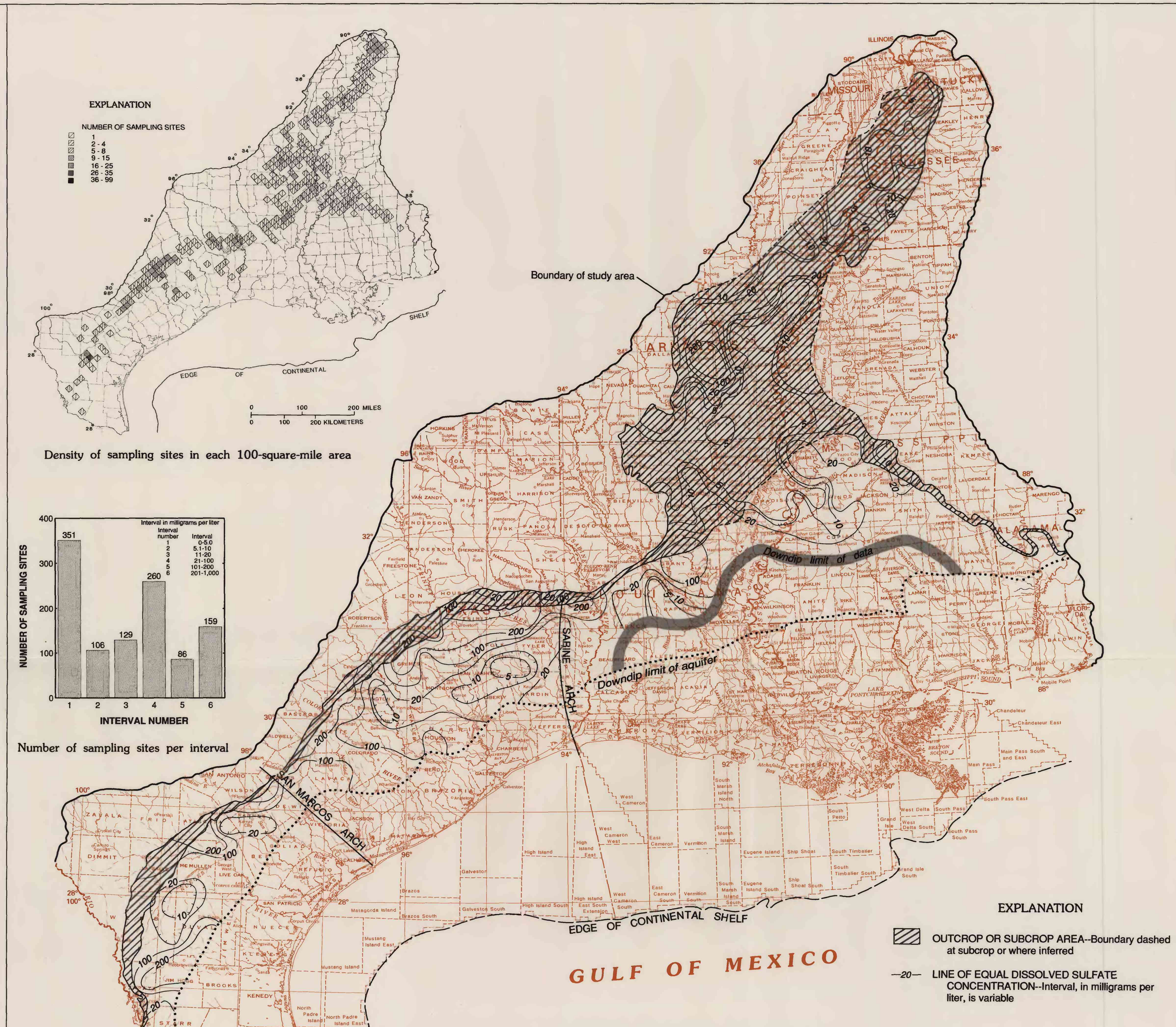

Figure 13.--Concentration of dissolved sulfate based on median value per 100-square-mile area.

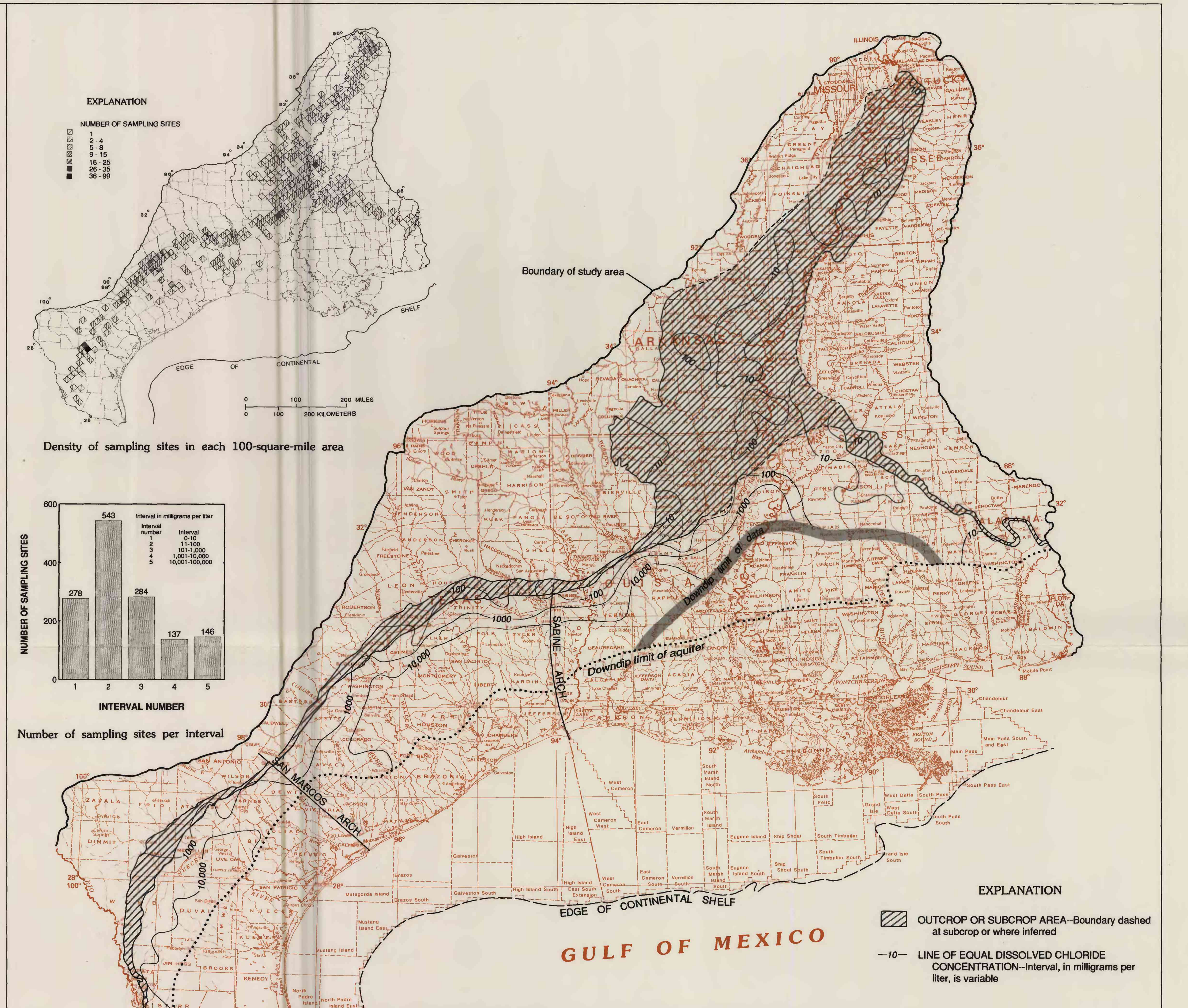

Figure 14.--Concentration of dissolved chloride based on median value per 100-square-mile area.

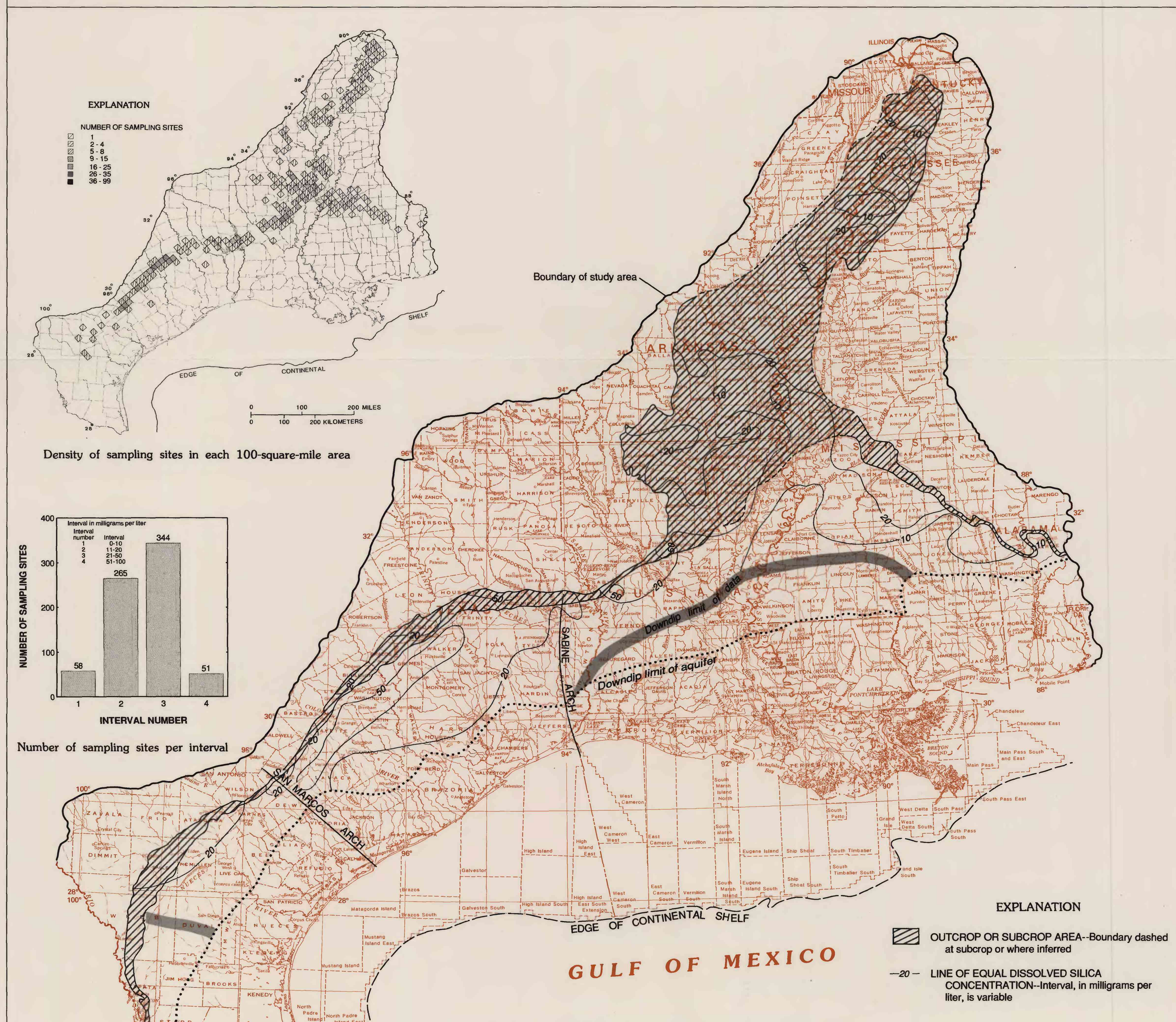

Figure 15.--Concentration of dissolved silica based on median value per 100-square-mile area.

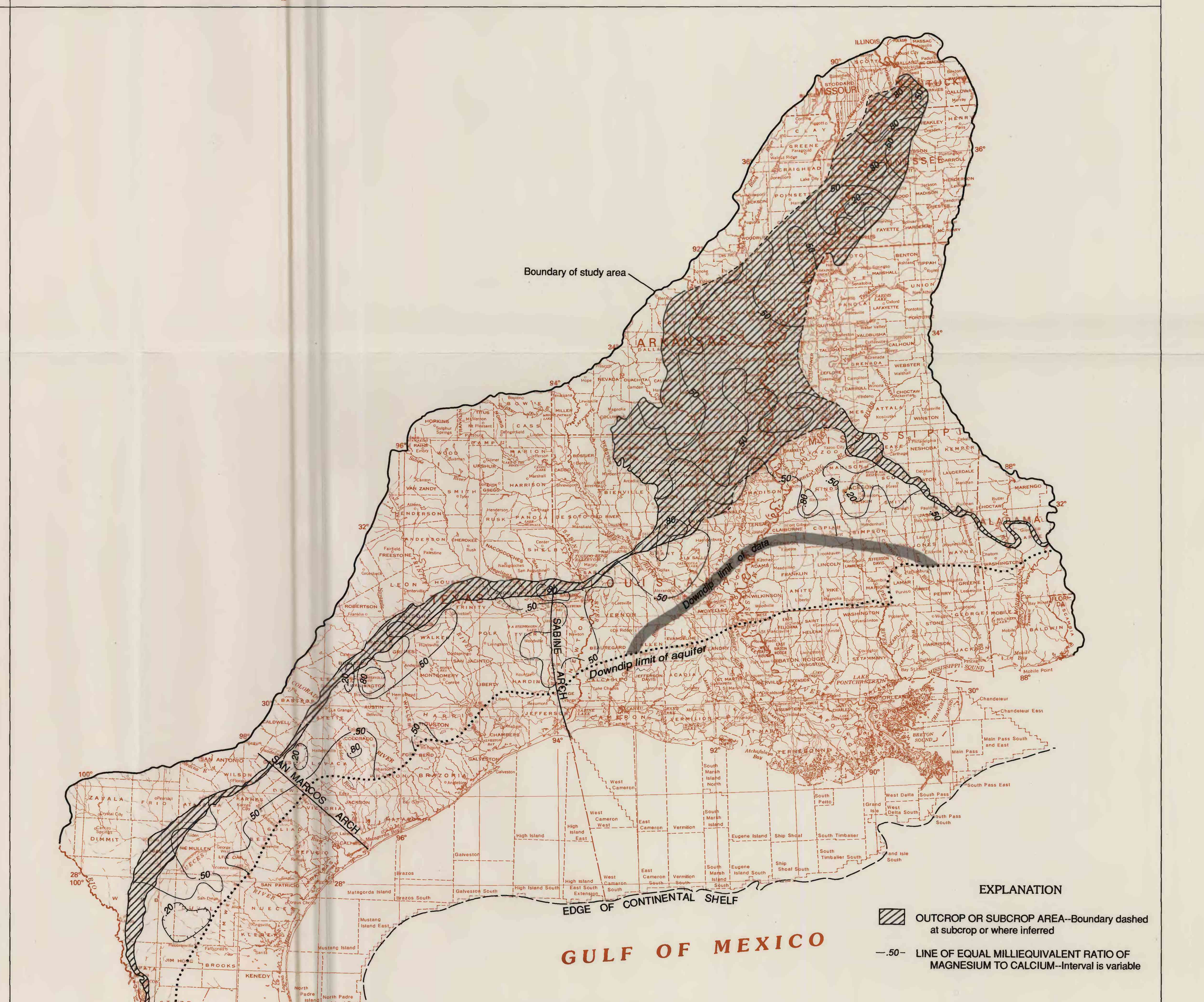

Figure 16.--Ratio of magnesium to calcium based on median ion concentration per 100-square-mile area.

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Magnesium plus Calcium to Bicarbonate

The areal distribution of the milliequivalent ratio of magnesium plus calcium to bicarbonate ($MgCa:HCO_3$) in water from the upper Claiborne aquifer shows that the ratio ranges from less than 0.01 to 118 (table 1). There appears to be a decrease in the $MgCa:HCO_3$ ratio from both the east and west boundary of the outcrop-subcrop area to the Mississippi River (fig. 17). Whereas from the southern edge of the outcrop-subcrop area southward to the downdip limit of the data the $MgCa:HCO_3$ ratio generally increases.

The mapped data in the outcrop-subcrop area show that the $MgCa:HCO_3$ ratio generally ranges from 0.1 to 2 with the smallest ratio occurring near the confluence of the Arkansas and Mississippi Rivers in the southern part of the Mississippi embayment aquifer system area. The $MgCa:HCO_3$ ratio in the area east of the Mississippi River and from the edge of the outcrop-subcrop area southward to the downdip limit of the data ranges from 0.1 to 1. The absence of larger ratios east of the Mississippi River could be due to the lack of data in downdip areas. In the area from the Mississippi River westward to about midway between the Sabine arch and the San Marcos arch, the $MgCa:HCO_3$ ratio increases from about 1 near the outcrop-subcrop area to 20 at middip. From middip to downdip the $MgCa:HCO_3$ ratio decreases to about 10. In the area from about midway between the Sabine arch and the San Marcos arch southwestward to the San Marcos arch the $MgCa:HCO_3$ ratio ranges from 0.1 to 2. In the area from the San Marcos arch southwestward to the Rio Grande, the $MgCa:HCO_3$ ratio generally increases in a downdip direction from about 1 at the outcrop to 20 at the downdip limit of the aquifer.

Magnesium plus Calcium to Sodium plus Potassium

The areal distribution of the milliequivalent ratio of magnesium plus calcium to sodium plus potassium (MgCa:NaK) in water from the upper Claiborne aquifer shows that the ratio ranges from less than 0.01 to 39.2 (table 1). However, most of the aquifer area has MgCa:NaK ratios ranging between 0.1 and 2 (fig. 18). The MgCa:NaK ratio generally decreases from the northern part of the outcrop-subcrop in the area of the Mississippi embayment aquifer system to the confluence of the Arkansas and Mississippi Rivers and then generally increases to the southern limit of the outcrop-subcrop area. The MgCa:NaK ratio decreases from the southern limit of the outcrop-subcrop area to the downdip limit of the data which is near middip because of the absence of data along the downdip part of the aquifer.

The mapped data in the outcrop-subcrop in the area of the Mississippi embayment aquifer system show that the ratio generally ranges from 0.1 in the southern part to 10 in the northern part. Whereas in the outcrop-subcrop area extending from the Mississippi embayment southwestward to near the San Marcos arch, the MgCa:NaK ratio ranges from about 0.1 to about 2. In the area that extends from southwestern Alabama southwestward to near the San Marcos arch and from the outcrop-subcrop area southward to the downdip limit of the data, the MgCa:NaK ratio generally ranges from 0.1 to 2. However most of this area has ratios of less than 1.

Bicarbonate to Sulfate

The areal distribution of the milliequivalent ratio of bicarbonate to sulfate ($HCO_3:SO_4$) in water from the upper Claiborne aquifer shows that the ratio ranges from 0.12 to 2,070 (table 1). The $HCO_3:SO_4$ ratio in the outcrop-subcrop in the area of the Mississippi embayment aquifer system appears to increase from the aquifer boundary toward the Mississippi River and from the northern part of the embayment to the southern part (fig. 19). From the outcrop-subcrop area southward the $HCO_3:SO_4$ ratio generally increases from outcrop-subcrop to middip and decreases from middip to downdip. An exception is an area in southern Mississippi where the trend is reversed.

The mapped data in the outcrop-subcrop area show that the $HCO_3:SO_4$ ratio generally increases from 10 along the aquifer boundary in the area of the Mississippi embayment aquifer system to 50 along the Mississippi River in the northern part of the embayment area to more than 100 in the southern part. In the area from the southern edge of the outcrop-subcrop to the downdip limit of the data in southeastern Mississippi, the $HCO_3:SO_4$ ratio decreases from about 50 to 5 and than increases to 10 near the downdip limit of the data. However, in southwestern Mississippi the $HCO_3:SO_4$ ratio ranges from 50 to 100 from the outcrop-subcrop to the downdip limit of the data. In the area from the Mississippi River westward to the Sabine arch the $HCO_3:SO_4$ ratio generally ranges from 5 to 100 and increase in a downdip direction. From the Sabine arch southwestward to the Rio Grande the $HCO_3:SO_4$ ratio generally increases from 5 at the outcrop to 100 at middip and then decreases to about 50 in downdip areas.

Bicarbonate to Chloride

The areal distribution of the milliequivalent ratio of bicarbonate to chloride $HCO_3:Cl$ in water from the upper Claiborne aquifer shows that the ratio ranges from less than 0.01 to 81.3 (table 1). In the outcrop-subcrop area of the Mississippi embayment the $HCO_3:Cl$ ratio varies tenfold but shows no areal trend or pattern (fig. 20). Whereas from the southern edge of the outcrop-subcrop area to the downdip limit of the data the $HCO_3:Cl$ ratio appears to decrease.

The mapped data in the outcrop-subcrop area show the $HCO_3:Cl$ ratio generally ranges from 1 in the southwestern part of the Mississippi embayment aquifer system area to 10 in an area that extends from the northern end of the embayment to the southern edge of the outcrop-subcrop area. From the southern edge of the outcrop-subcrop area to the downdip limit of the data the $HCO_3:Cl$ ratio ranges from about 5 along the outcrop-subcrop area to 10 near both the Mississippi River and the downdip limit of the data in the area east of the Mississippi River. In the area west of the Mississippi River to the Sabine arch the $HCO_3:Cl$ ratio generally decreases from 5 near the outcrop-subcrop area to 0.1 in the downdip area. From the Sabine arch westward to the San Marcos arch the $HCO_3:Cl$ ratio decreases from about 1 near the outcrop to about 0.1 in middip and downdip areas. From the San Marcos arch southwestward to the Rio Grande the $HCO_3:Cl$ ratio ranges between 0.01 and 0.1 in downdip areas and between 0.1 and 1 in updip areas.

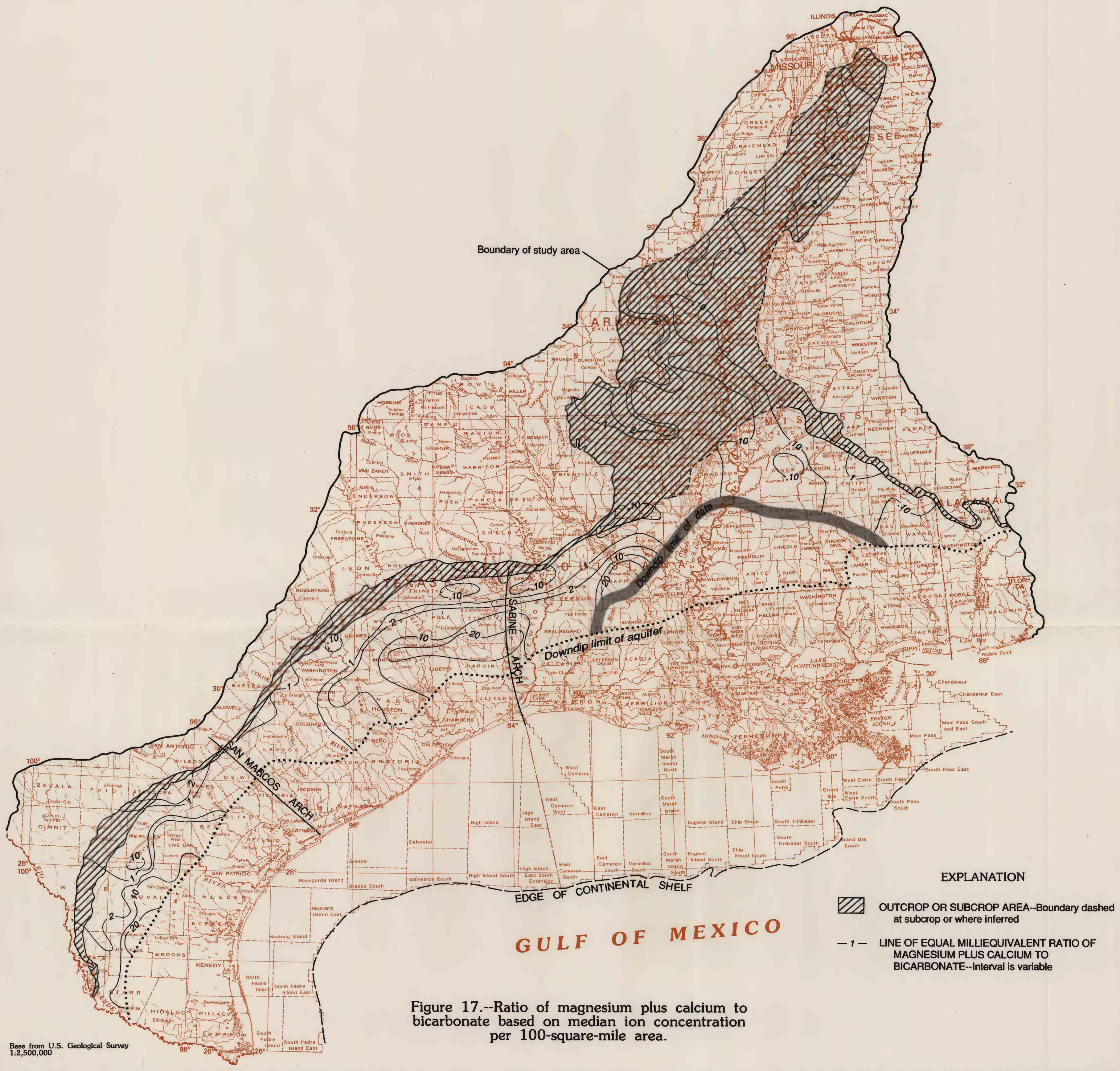

Figure 17.--Ratio of magnesium plus calcium to bicarbonate based on median ion concentration per 100-square-mile area.

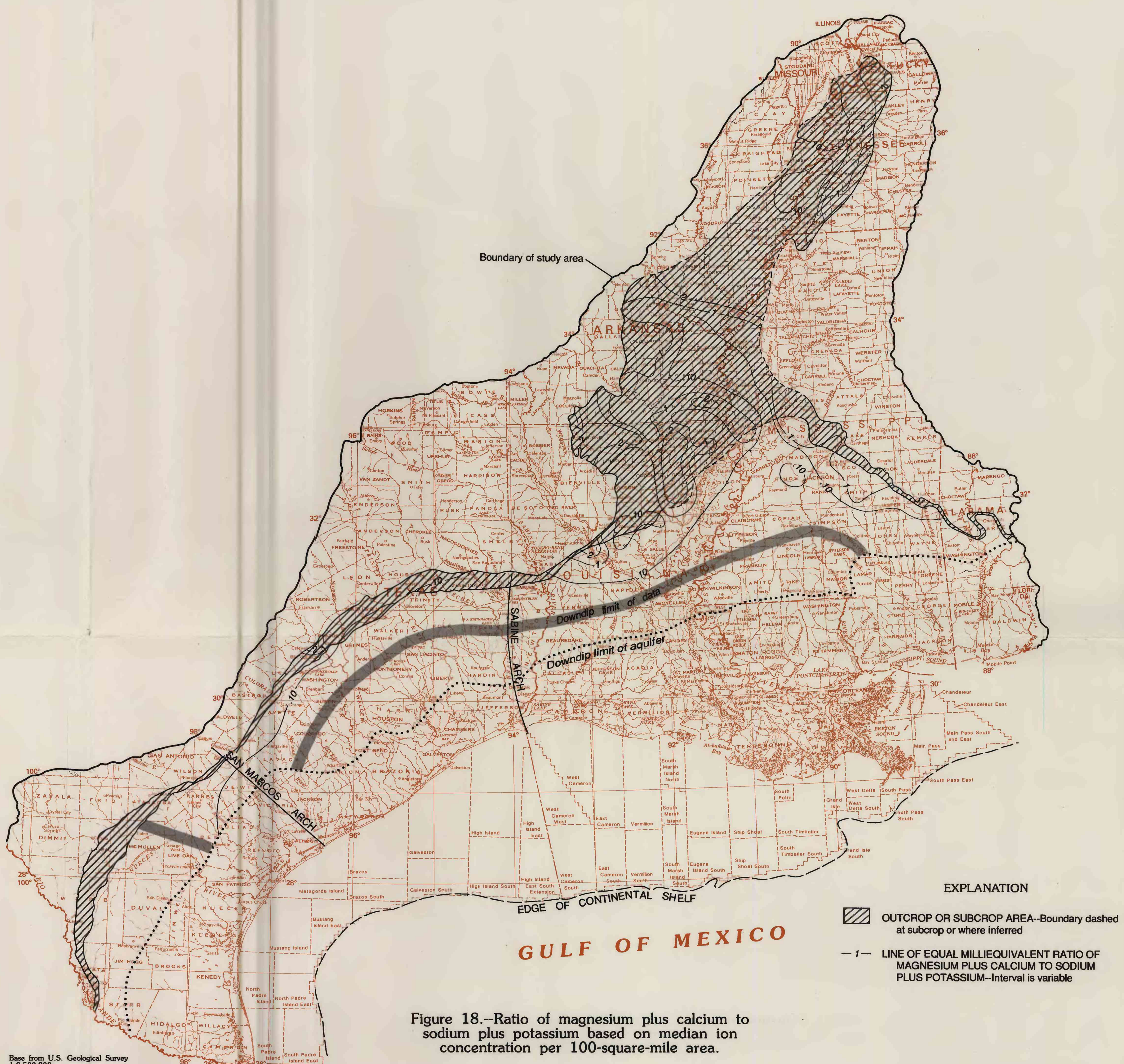

Figure 18.--Ratio of magnesium plus calcium to sodium plus potassium based on median ion concentration per 100-square-mile area.

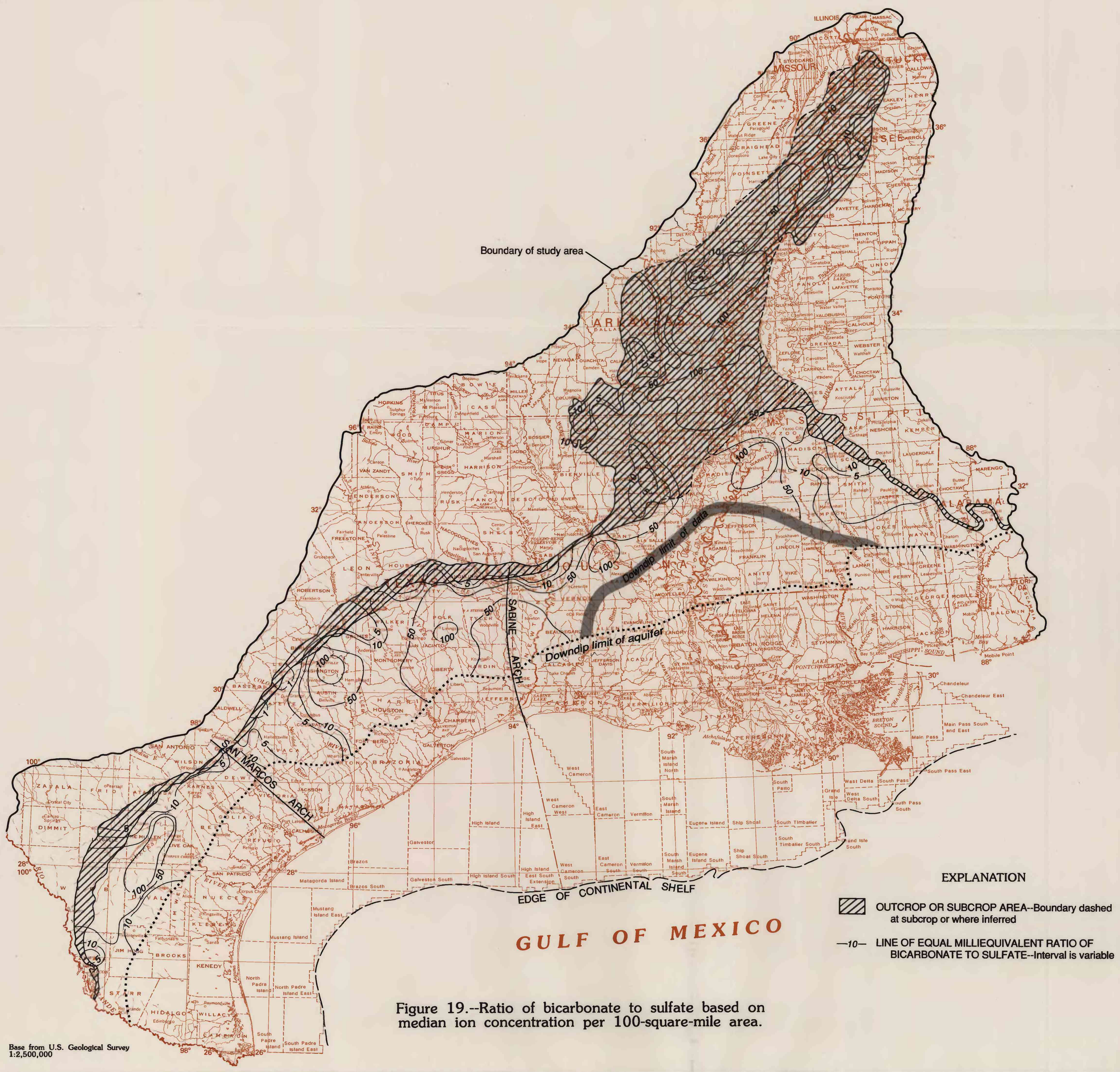

Figure 19.--Ratio of bicarbonate to sulfate based on median ion concentration per 100-square-mile area.

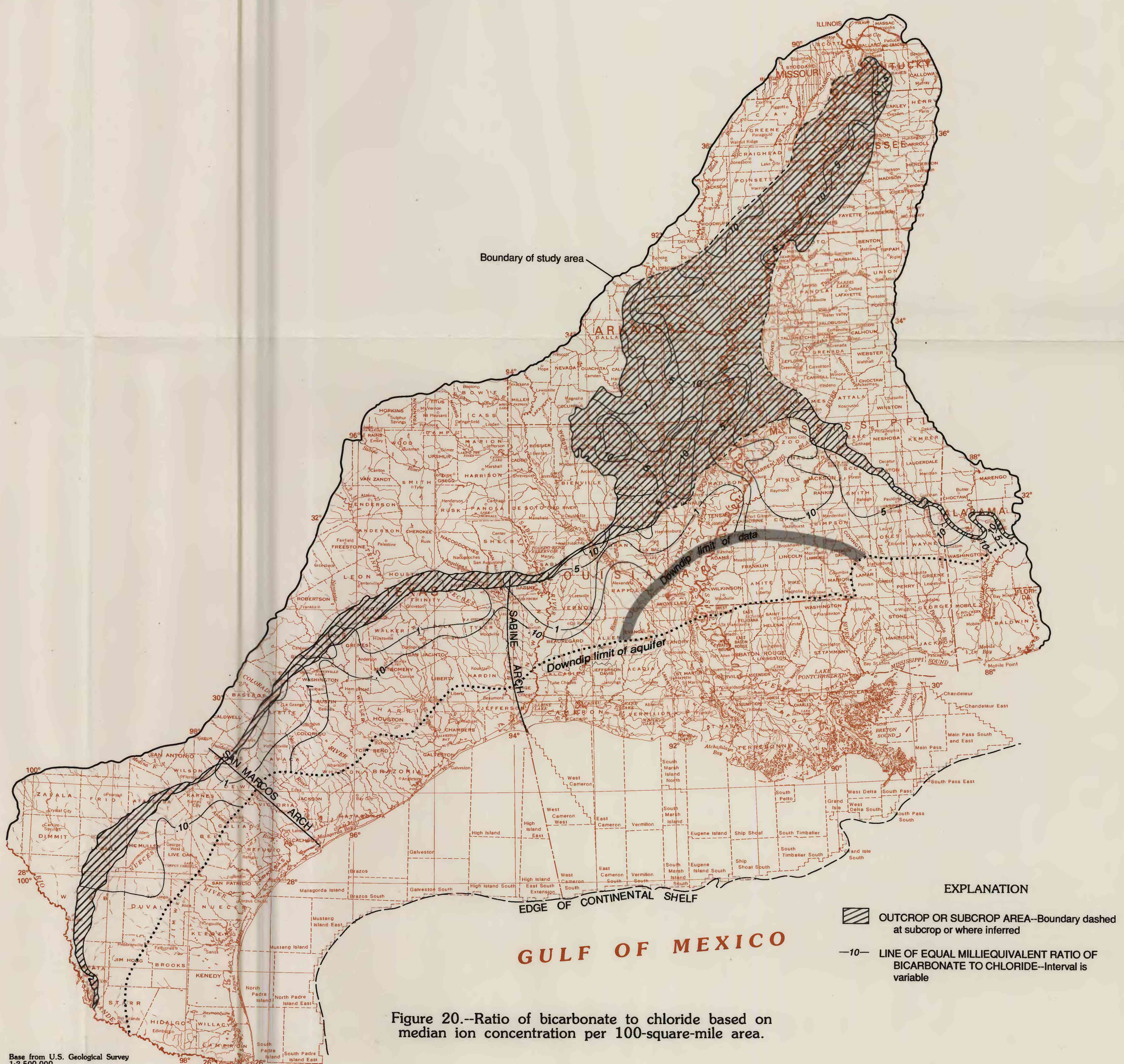

Figure 20.--Ratio of bicarbonate to chloride based on median ion concentration per 100-square-mile area.

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