

**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<sup>2</sup> of the Gulf Coastal Plain in parts of Alabama, Arkansas, Florida, Illinois, Kentucky, Mississippi, Missouri, Tennessee, Texas, and all of Louisiana (fig. 1). It also includes about 60,000 mi<sup>2</sup> of the Continental Shelf (Grubb, 1984). These regional aquifers, named the Gulf coast aquifer system, 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 system has been divided into 10 water-yielding units based on geologic and hydrologic factors (Weiss and Williamson, 1985; Pettijohn and others, 1986; Hosman and Weiss, 1991; Weiss, 1990).

Permeable zone C is part of the coastal lowlands aquifer system and is composed mostly of lower Pliocene and upper Miocene deposits. These deposits consist of interbedded clay, silt, and sand. Sand content is greater than 60 percent in parts of the outcrop area of Texas, Louisiana, and Mississippi and extends seaward for several tens of miles as isolated lobes. Sand content is also greater than 50 percent in a narrow elongate area extending from southeastern Louisiana into southwestern Mississippi. Sand content generally decreases from outcrop areas toward the downdip limit of the permeable zone and is less than 20 percent throughout a broad area adjacent to the downdip limit of permeable zone C. Permeable zone C has an average thickness of about 2,000 ft, a maximum thickness of about 6,000 ft and generally dips from the outcrop area toward the Gulf of Mexico at about 25 to 45 ft/mi (Weiss, 1990). The relation to overlying and underlying units is shown in figure 3. Ground-water pumping from permeable zone C was about 350 Mgal/d during 1985 (Meeko and others, 1990).

The Gulf Coast RASA is a 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, 1977). 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 (1989).

**Purpose and Scope**

This report describes the water chemistry of permeable zone C (lower Pliocene-upper Miocene 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 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 plotted 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 (1989).

These maps show regional trends in chemical properties. The concentrations of dissolved solids, major ions, pH, and temperature vary with depth within the permeable zone. 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 permeable zone. 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 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 intervals.

The major ion 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-weighted values from geophysical well logs (Pettijohn and others, 1988). The water type was computed from the cations and anions 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 (1986, 1988), Weiss (1987), and Pettijohn and others (1988).

Superimposed on selected maps are locations of geologic structures that are used as points of reference in describing the chemistry of the ground water from east to west. Uplift areas, midpits, and downdips are used as reference areas in describing the chemistry of the ground water from north to south. Uplift areas include the areas adjacent to the updip limit of permeable zone C; midpits refers to areas about midway between the updip limit and the downdip limit of permeable zone C; and downdip refers to areas adjacent to the downdip limit of the data or the downdip limit of permeable zone C. 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)	0.1609	meter per kilometer
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.0438	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 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:

$$T = 1.8(C) + 32$$

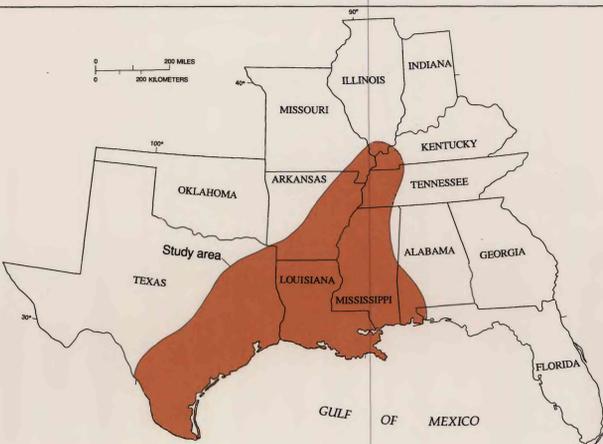


Figure 1.—Location of study area.

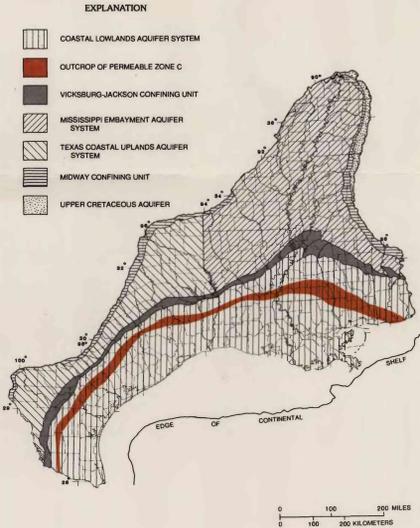


Figure 2.—Generalized outcrop of major aquifer systems and confining units in the Gulf Coast Regional Aquifer-System Analysis study area. Outcrop of permeable zone C (lower Pliocene-upper Miocene deposits) superimposed.

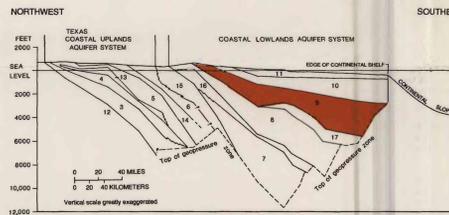


Figure 3.—Diagrammatic geologic section through southwest part of study area.

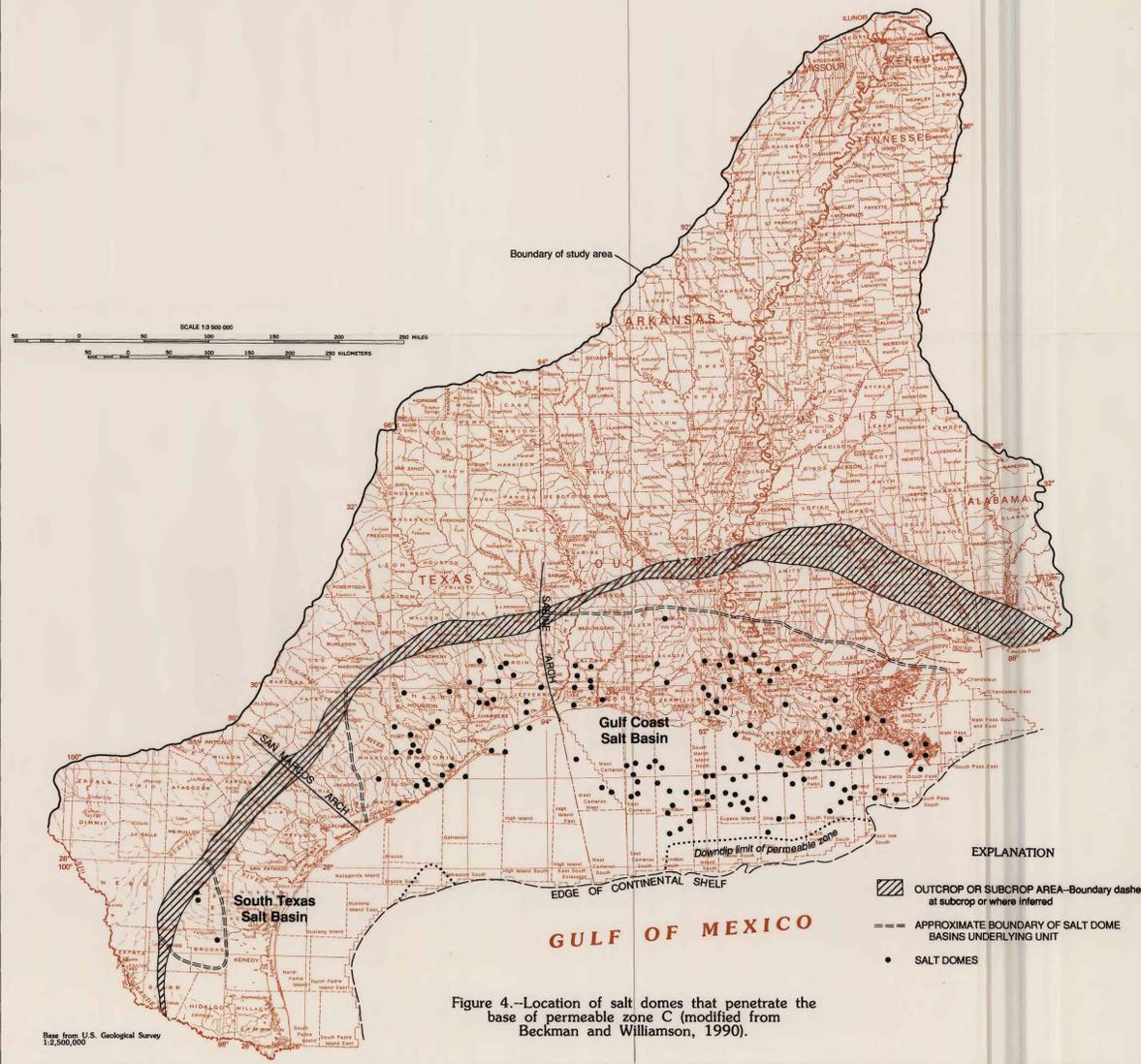


Figure 4.—Location of salt domes that penetrate the base of permeable zone C (modified from Beckman and Williamson, 1990).

**SUMMARY AND CONCLUSIONS**

The water chemistry of permeable zone C (lower Pliocene-upper Miocene 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 18 to 3,000 mg/L along the outcrop, 500 to 35,000 mg/L near midpits, and 35,000 to 265,000 mg/L in downdip areas. The increase in concentration of dissolved solids in a downdip direction is attributed to mixing-water interaction and specifically to the dissolution of evaporites comprising salt domes in the deeper parts of the permeable zone. The temperature ranges from 13 degrees Celsius in the outcrop area to 98 degrees Celsius in the Continental Shelf area.

The primary water types in permeable zone C, which are based on the most frequently observed type (mode) in each 100-square-mile area, are calcium and sodium bicarbonate in the outcrop and midpits areas east of the San Marcos arch and sodium chloride in downdip areas and in the area southwest of the San Marcos arch. The pH ranges from 4.8 in the outcrop area east of the Mississippi River to 9.4 in area near midpits in southeastern Louisiana.

The concentrations of major ions generally increase from the outcrop to the downdip limit of the data. The concentration of dissolved calcium ranges from 0.2 mg/L at the outcrop to 26,300 mg/L in the Continental Shelf area. The concentration of dissolved magnesium ranges from 0.1 mg/L in outcrop and midpits areas to 1,420 mg/L in a downdip area east of the San Marcos arch. The concentration of dissolved sodium ranges from 1.9 mg/L in outcrop areas east of the Sabine arch to 100,000 mg/L in the Continental Shelf area. The concentration of dissolved potassium ranges from 0.1 mg/L along the outcrop area east of the Mississippi River to about 995 mg/L in a downdip area of southern Louisiana. The concentration of dissolved bicarbonate ranges from 2 mg/L along the outcrop in south-central Mississippi to 2,000 mg/L in an area near the coastline of southeastern Louisiana. The concentration of dissolved sulfate ranges from 0.2 mg/L in the outcrop area east of the Mississippi River to 2,950 mg/L along the coastline in southern Texas. The concentration of dissolved chloride ranges from 0.5 mg/L in outcrop and midpits areas east of the Mississippi River to 161,000 mg/L in a downdip area east of the Sabine arch. The concentration of silica ranges from 1.5 mg/L in the outcrop area in southern Mississippi to 0.2 mg/L in the outcrop area southeast of the San Marcos arch. However, in most areas of the permeable zone the concentration of silica is near 20 mg/L.

The milliequivalent ratio maps of constituents in water from permeable zone C show areal distributions and any trends in ratios from updip to the downdip limit of the data. The milliequivalent ratio of magnesium to calcium ranges from 0.02 near midpits to 3.8 along the outcrop and the map shows no areal trend. The milliequivalent ratio of magnesium plus calcium to bicarbonate ranges from about 0.01 to 383 and generally decreases from the outcrop to midpits areas and then increases from midpits areas 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 125 and generally decreases from the outcrop to the downdip limit of the data.

The milliequivalent ratio of bicarbonate to sulfate ranges from 0.85 at the coastline in southern Texas to 3.949 in the outcrop area of south-central Louisiana and the map shows no specific trend. The milliequivalent ratio of bicarbonate to chloride (HCO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup>) ranges from less than 0.01 along the downdip limit of the data to 342 in midpits areas of southern Louisiana. The HCO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup> ratio generally increases from the outcrop to midpits and decreases from midpits to the downdip limit of the data in the area east of the Sabine arch.

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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 C (lower Pliocene-upper Miocene 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><sup>-</sup>, bicarbonate; SO<sub>4</sub><sup>-2</sup>, 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	7.3	4.9	9.4	327
Temperature	27.7	13.0	98	476
Dissolved-solids	781	18.0	265,000	465
Calcium	13.0	0.2	26,300	323
Magnesium	3.0	0.1	1,420	320
Sodium	73.2	1.9	100,000	322
Potassium	1.8	0.1	995	240
Bicarbonate	195	2.0	2,000	332
Sulfate	8.2	0.2	2,950	324
Chloride	28.0	0.5	161,000	364
Silica	24.0	1.5	80	269
Ratio Mg:Ca	0.40	<0.02	3.8	320
Ratio Mg:Ca:HCO <sub>3</sub>	0.80	<0.01	353	310
Ratio Mg:Ca:Na+K	0.47	<0.01	12.5	236
Ratio HCO <sub>3</sub> :SO <sub>4</sub>	13.5	0.05	3,940	315
Ratio HCO <sub>3</sub> :Cl	2.4	<0.01	342	332

**PROPERTIES AND CHEMICAL CONSTITUENTS IN GROUND WATER FROM PERMEABLE ZONE C (LOWER PLIOCENE-UPPER MIOCENE DEPOSITS), COASTAL LOWLANDS AQUIFER SYSTEM, SOUTH-CENTRAL UNITED STATES**

by

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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 to the down-dip limit of the permeable zone. The abundance of geophysical well logs (Grubb, 1986, and Wilson and Hosain, 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 is not available. Primary water type and pH generally are not shown offshore because of the absence of data.

**Dissolved-Solids Concentrations**

The concentration of dissolved solids in water from permeable zone C, based on median values of all samples in each 100-square-mile area, ranges from 18 mg/L in the outcrop area to 26,000 mg/L in the down-dip area in southeastern Louisiana (table 1). Concentrations larger than 10,000 mg/L are dehydrated values as described by Pettijohn and others (1988). The trend noted above indicates that the concentration of dissolved solids increases in a down-dip direction. The largest increase, down-dip, 500 to 10,000 mg/L, occurs in about 15 mi east of the Mississippi River (fig. 5).

From the Colorado River eastward to near the western edge of Florida the concentration of dissolved solids in the outcrop and up-dip areas ranges from about 18 to 500 mg/L. An exception is an area west of the Mississippi River where the concentration ranges from 500 to 1,000 mg/L. The concentration increases sharply in a down-dip direction from 500 to 35,000 mg/L near mid-dip and to as much as 26,000 mg/L in a down-dip area in southeastern Louisiana.

The increase in the concentration of dissolved solids in a down-dip direction is attributed to mineral-water interaction and specifically to the dissolution of evaporites comprising salt domes in the deeper part of the permeable zone (fig. 4).

**Temperature**

The temperature of water from permeable zone C, based on combined depth-averaged values and median values of all samples in each 100-square-mile area, ranges from 13 degrees Celsius in the outcrop area in western Mississippi to 98 degrees Celsius in the Continental Shelf area (table 1). Generally where the concentration of dissolved solids is less than 3,000 mg/L, the temperature is generally less than 30 degrees Celsius (fig. 5). In areas where the concentration of dissolved solids increases from 3,000 to as much as 26,000 mg/L, the temperature of the ground water increases from 30 to 98 degrees Celsius. About one-half of the onshore area of permeable zone C contains water with a temperature of less than 30 degrees Celsius.

**Primary Water Type**

The primary water types in permeable zone C, which is based on the most frequently observed type (mode) in each 100-square-mile area, are calcium bicarbonate and sodium bicarbonate in outcrop and mid-dip areas east of the San Marcos arch and sodium chloride in the area southwest of the San Marcos arch and in the down-dip area along the coastline (fig. 6). Calcium bicarbonate water is most prevalent between the Sabine arch and the San Marcos arch in the outcrop area. Whereas sodium bicarbonate is most prevalent at mid-dip and in outcrop areas east of the Sabine arch.

**pH**

The pH of water from permeable zone C, based on median values of all samples in each 100-square-mile area, ranges from 4.9 in the outcrop area east of the Mississippi River to 9.4 in areas near mid-dip in southeastern Louisiana (table 1). The trend from the Sabine arch eastward to the western edge of Florida is one of increasing pH from outcrop to mid-dip and one of decreasing pH from mid-dip to the down-dip limit of the data (fig. 7). There appears to be no trend from the Sabine arch southward to the Rio Grande.

From the Mississippi River eastward to the western edge of Florida the pH increases from about 6.0 along the outcrop to about 8.0 at mid-dip and then decreases to about 7.0 at the coastline. From the Mississippi River westward to the Sabine arch the pH increases from about 7.0 along the outcrop to about 8.0 in mid-dip areas and then decreases to 7.0 or less in down-dip areas. From the Sabine arch southward to the Rio Grande the pH ranges from 7.0 to 8.0 with no consistent areal pattern.

**CHEMICAL CONSTITUENTS**

The areal distribution 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 limited to onshore areas of permeable zone C because chemical data generally are not available for the Continental Shelf area.

**Calcium**

The concentration of dissolved calcium in water from permeable zone C, based on median values of all samples in each 100-square-mile area, ranges from 0.2 mg/L at the outcrop to 26,000 mg/L in the Continental Shelf area southeast of the Mississippi coastline (table 1). Concentration generally increases in a down-dip direction in all areas except the area from about 50 mi east of the San Marcos arch southward to the Rio Grande in southern Texas (fig. 8).

From the Sabine arch eastward to the western edge of Florida the concentration of dissolved calcium in permeable zone C is generally 10 mg/L along the outcrop to mid-dip areas. An exception is an area adjacent to the Mississippi River where the concentration is about 50 mg/L in the outcrop. Near mid-dip the concentration increases from 10 to 1,000 mg/L in 20 mi and continues to increase to more than 10,000 mg/L in a down-dip area on the Continental Shelf south of the Mississippi coast. The area down-dip having the greatest concentration of dissolved calcium generally coincides with the deeper part of the permeable zone and with location of salt domes (fig. 4).

From the Sabine arch westward to about 50 mi east of the San Marcos arch the concentration of dissolved calcium ranges from about 10 to 100 mg/L along the outcrop. From the outcrop southward to the down-dip limit of the data the concentration increases to about 1,000 mg/L. From about 50 mi east of the San Marcos arch southward to the Rio Grande the concentration ranges from 50 to 100 mg/L in outcrop, mid-dip, and down-dip areas.

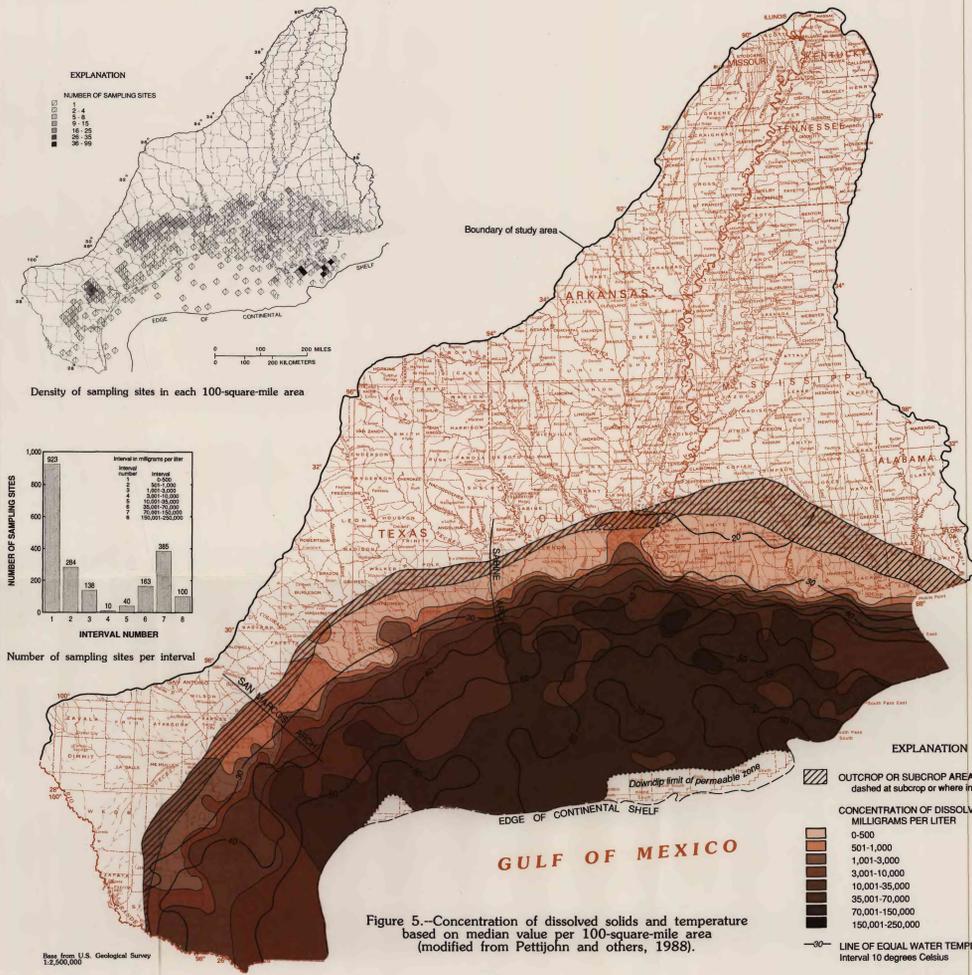


Figure 5.—Concentration of dissolved solids and temperature based on median value per 100-square-mile area (modified from Pettijohn and others, 1988).

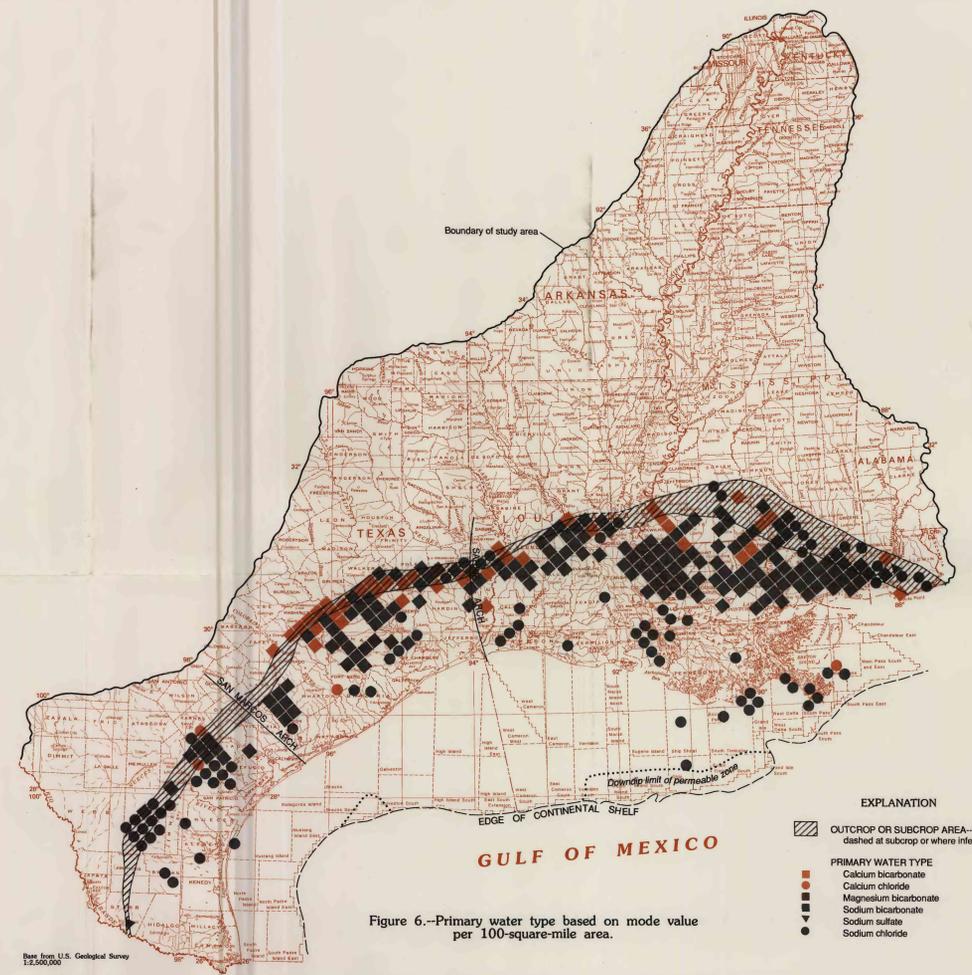


Figure 6.—Primary water type based on mode value per 100-square-mile area.

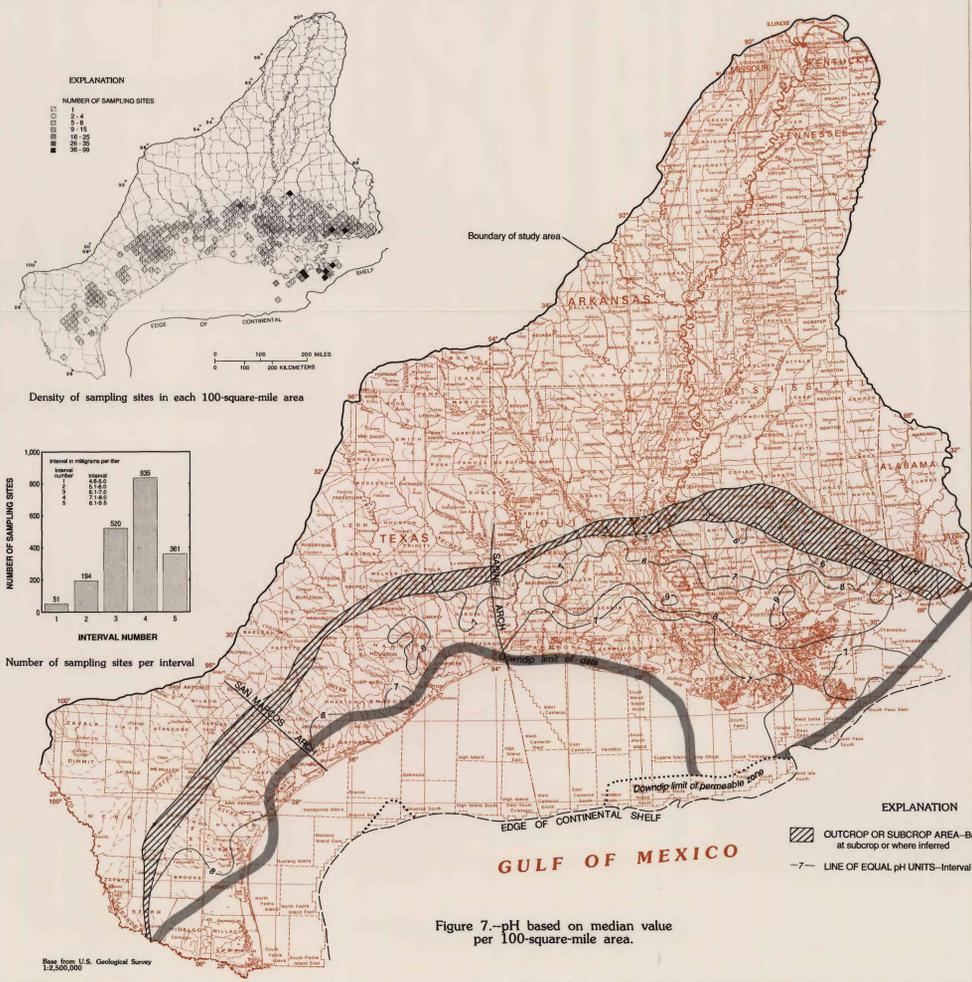


Figure 7.—pH based on median value per 100-square-mile area.

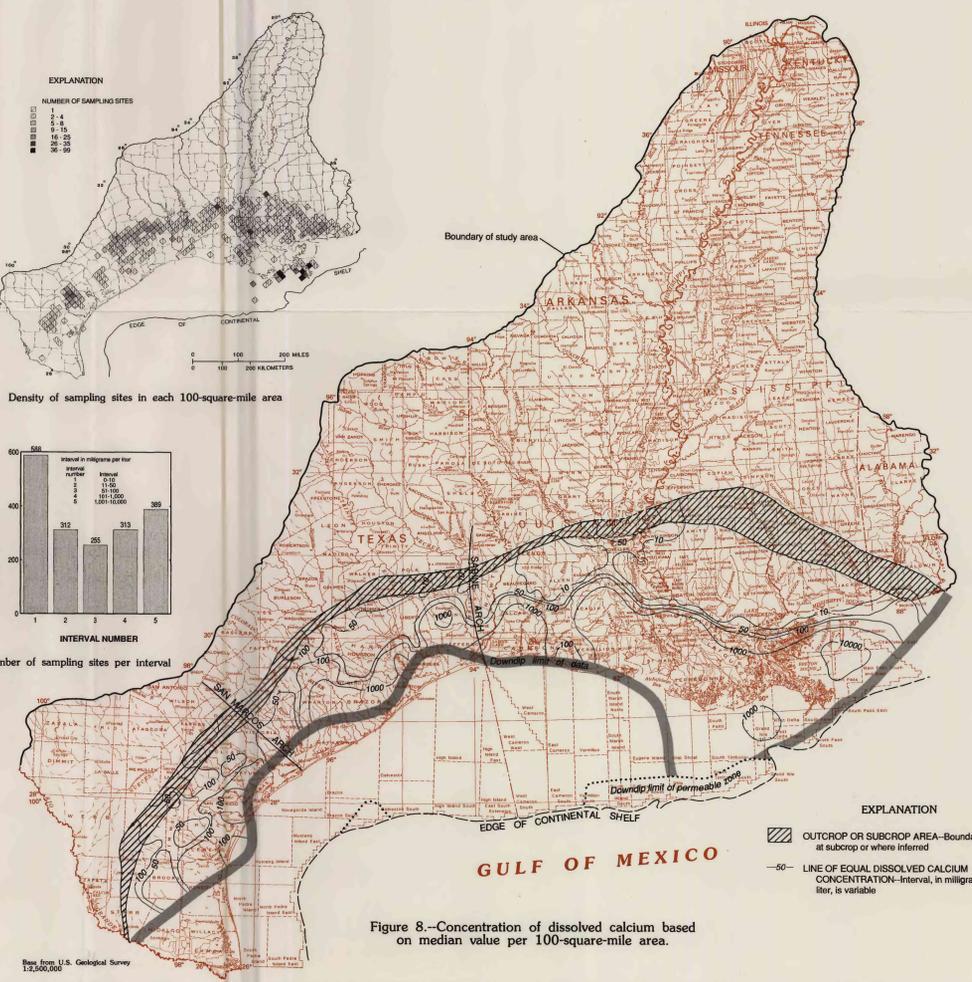
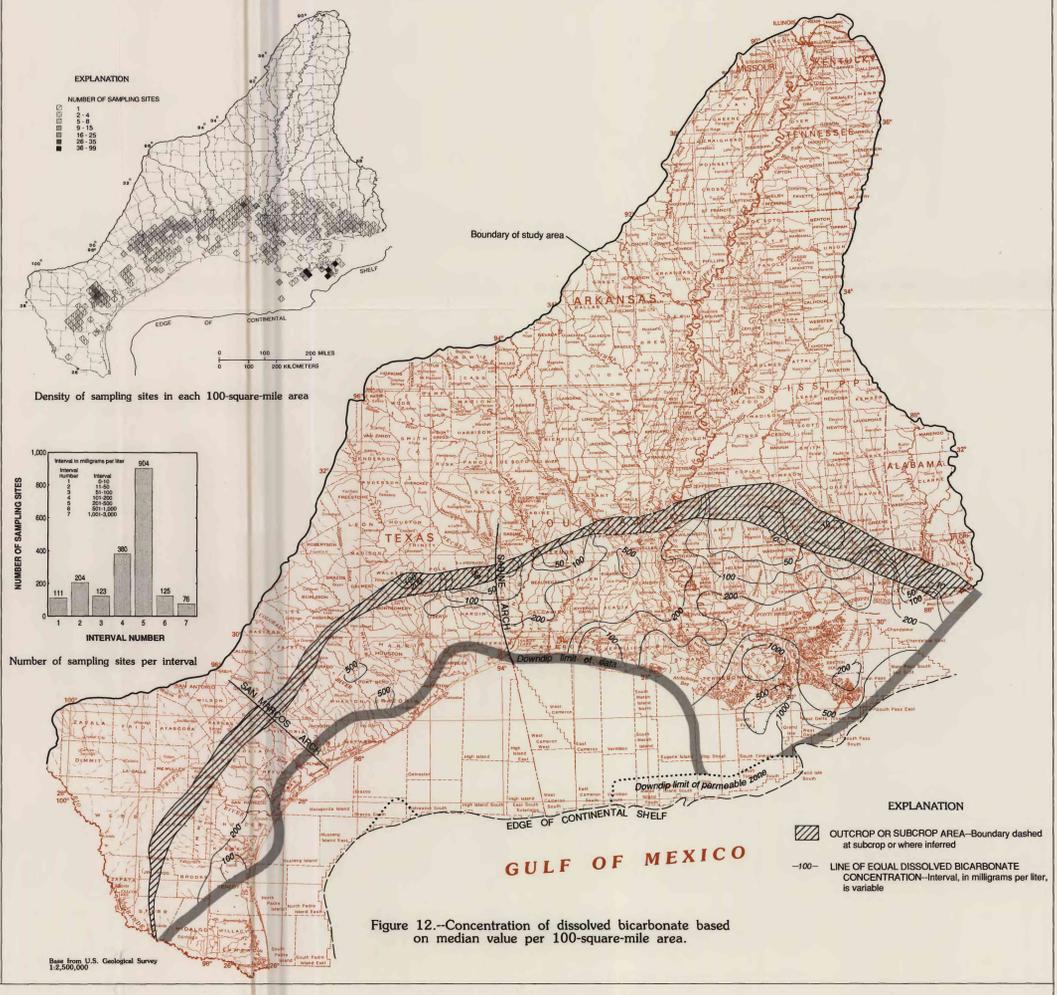
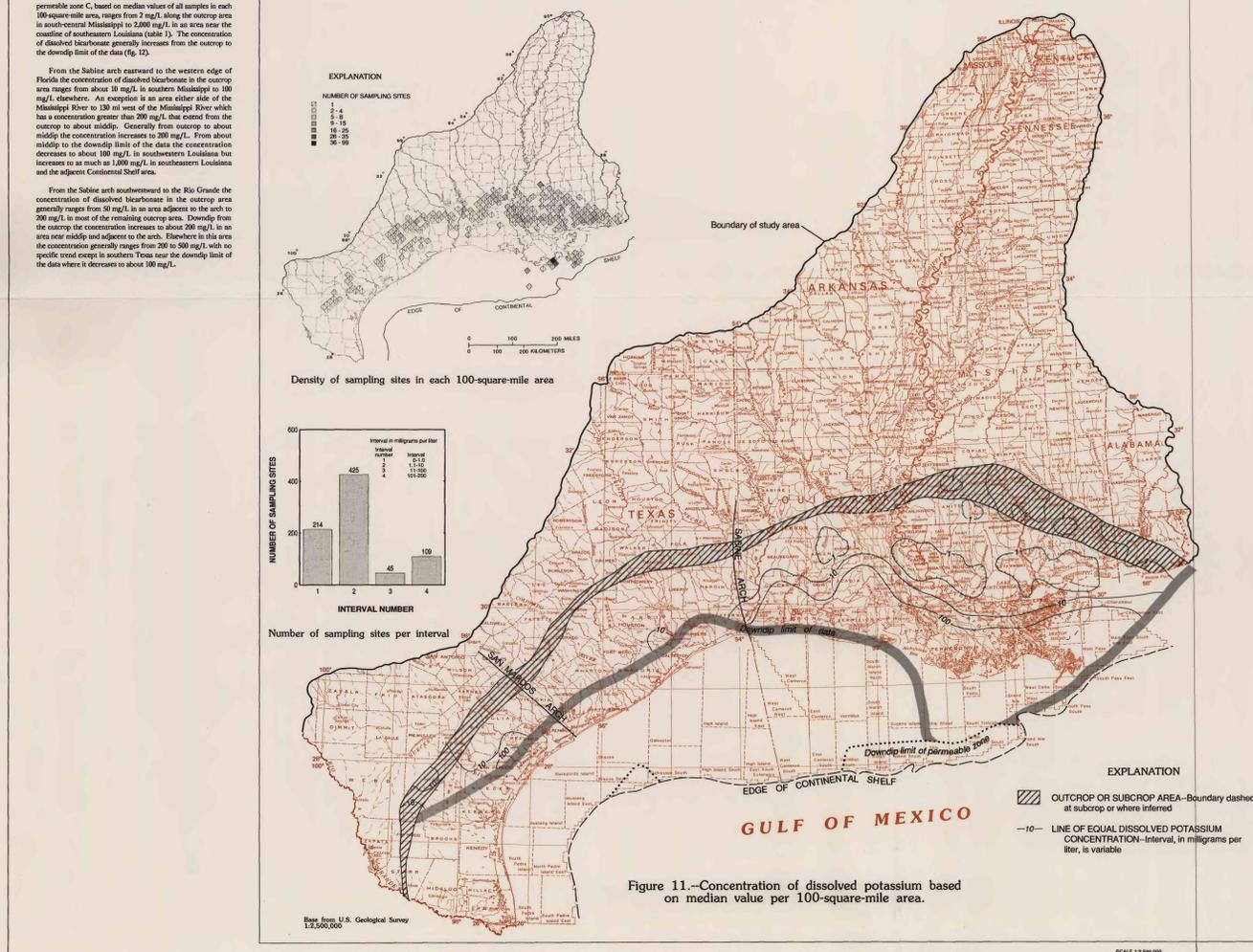
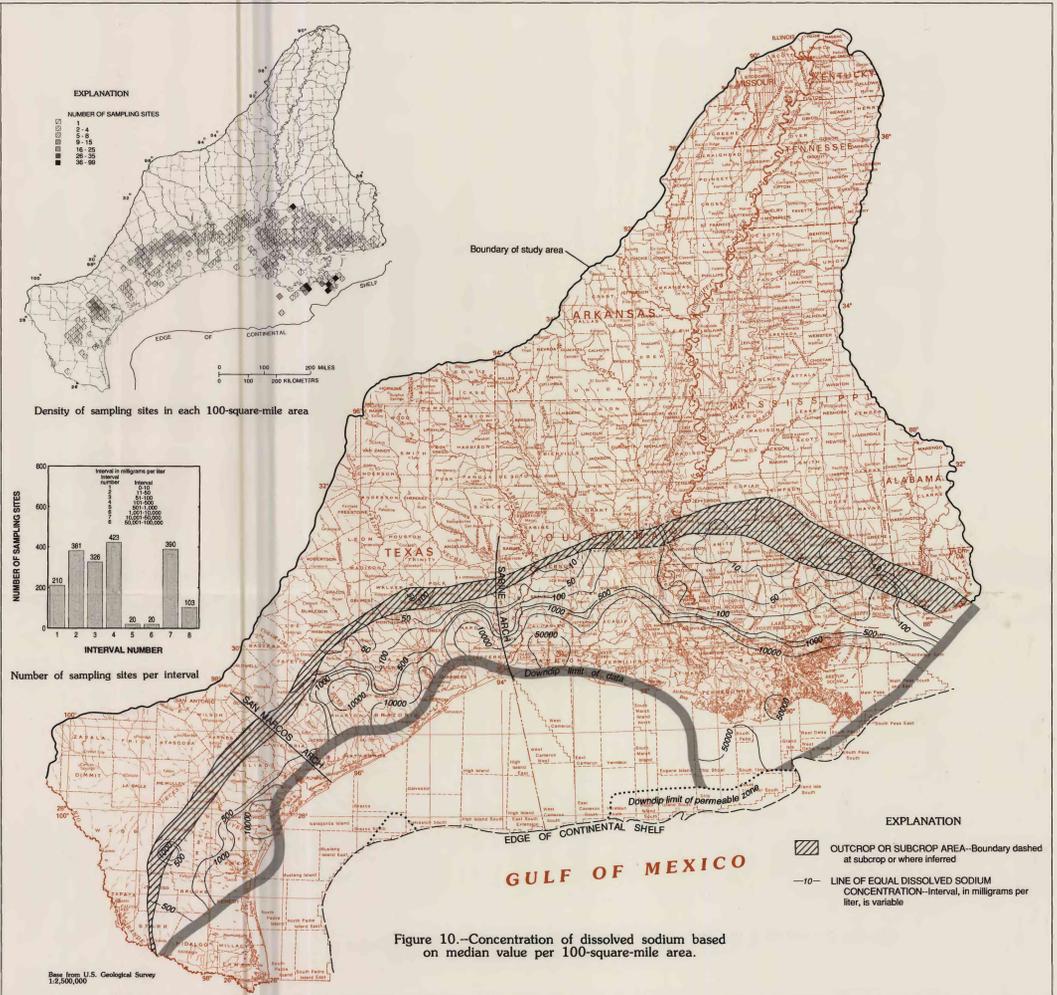
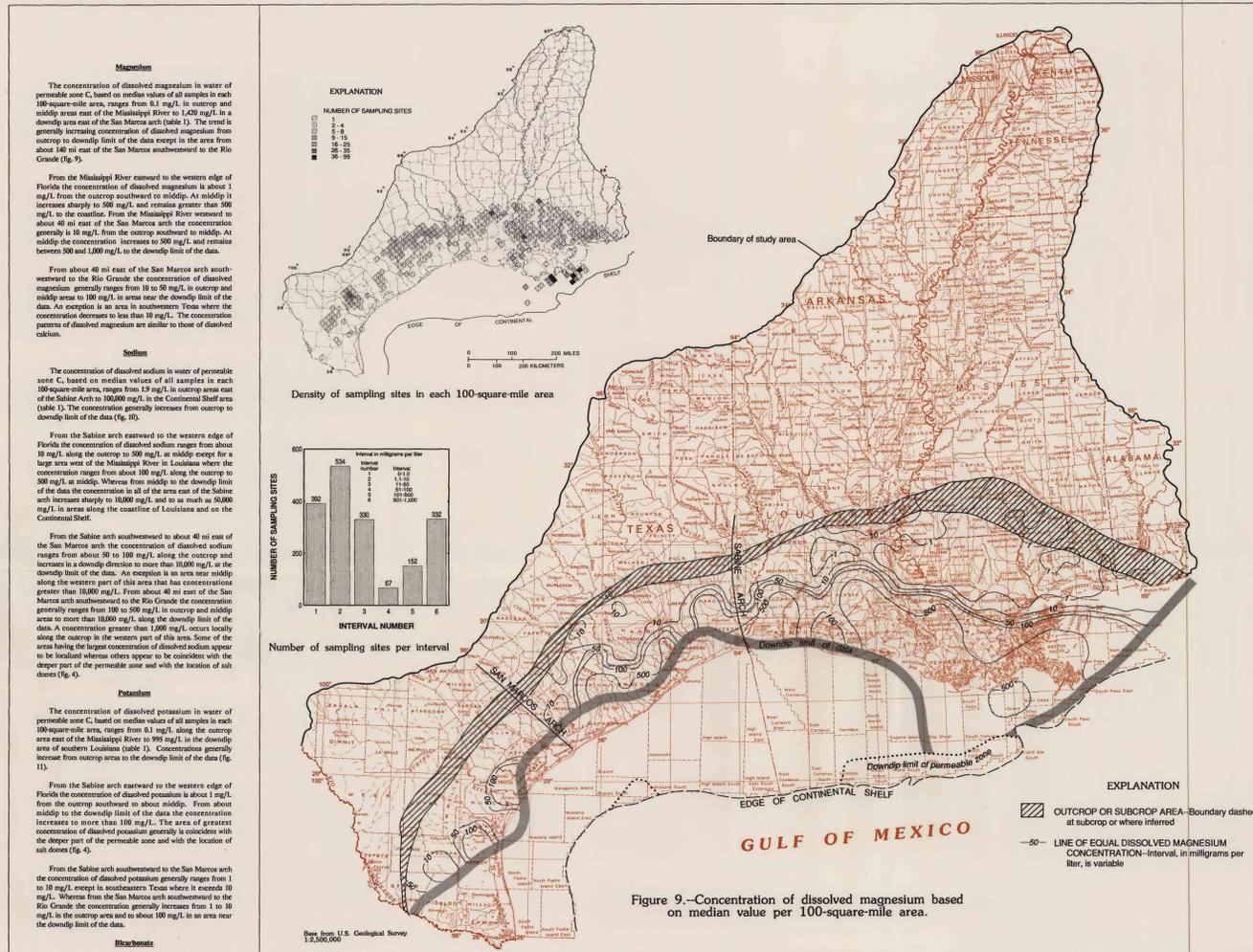


Figure 8.—Concentration of dissolved calcium based on median value per 100-square-mile area.

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**Magnesium plus Calcium to Bicarbonate**

The areal distribution of the milliequivalent ratio of magnesium plus calcium to bicarbonate ( $Mg+Ca/HCO_3$ ) in water of permeable zone C ranges from less than 0.51 in the midship area between the Sabine arch and southeastern Mississippi to 253 in a downcrop area of southeastern Louisiana (table 1). The  $Mg+Ca/HCO_3$  ratio generally decreases from the outcrop to midship areas and then increases from midship to the downcrop limit of the data (fig. 17).

From the Sabine arch eastward to the western edge of Florida the  $Mg+Ca/HCO_3$  ratio ranges from about 0.5 to 1 in the outcrop area, 0.1 to 0.5 in the midship area, and 0.5 to about 10 in downcrop areas. From the Sabine arch southward to the San Marcos arch this ratio ranges from 0.5 to 1 in both the outcrop and midship areas and increases to about 10 in downcrop areas. From the San Marcos arch southward to the Rio Grande the  $Mg+Ca/HCO_3$  ratio ranges from about 1 in the outcrop area to 10 in areas downcrop from the outcrop.

**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 of permeable zone C ranges from less than 0.81 in midship areas of southern Louisiana to 12.5 in an area near the coastline of Alabama (table 1). The  $Mg+Ca/Na+K$  ratio generally decreases from the outcrop to the downcrop limit except in the midship area across Louisiana where the ratio is smaller than at the downcrop limit of the data (fig. 18).

From the Sabine arch eastward to the western edge of Florida the  $Mg+Ca/Na+K$  ratio ranges from 1 to 5 along the outcrop, from 0.50 to 1 from outcrop to midship, 0.10 to 0.50 across the midship area, and is about 0.10 in downcrop areas. From the Sabine arch southward to the Rio Grande the  $Mg+Ca/Na+K$  ratio ranges from 1 to 2 along the outcrop, 0.5 to 1 from outcrop to midship, and 0.10 to 0.50 from midship to the downcrop limit of the data.

**Bicarbonate to Sulfate**

The areal distribution of the milliequivalent ratio of bicarbonate to sulfate ( $HCO_3/SO_4$ ) in water of permeable zone C ranges from 0.65 at the coastline in southern Texas to 3.90 in the outcrop area of south-central Louisiana (table 1). The  $HCO_3/SO_4$  ratio appears to have no specific trend but varies randomly across permeable zone C (fig. 19).

From the Sabine arch eastward to the western edge of Florida, the  $HCO_3/SO_4$  ratio ranges from 10 to 100 along the outcrop, from 5 to about 20 at midship, and from 10 to 20 along the downcrop limit of the data. From the Sabine arch westward to the San Marcos arch the  $HCO_3/SO_4$  ratio ranges from about 10 to about 20 in the outcrop area, from 5 to 20 at midship, and is about 100 near the downcrop limit of the data. From the San Marcos arch southward to the Rio Grande the  $HCO_3/SO_4$  ratio ranges from 0.10 to 10 along the outcrop, from 1 to 20 at midship, and 0.10 to 20 along the downcrop limit of the data.

**Bicarbonate to Chloride**

The areal distribution of the milliequivalent ratio of bicarbonate to chloride ( $HCO_3/Cl$ ) in water of permeable zone C ranges from less than 0.81 along the downcrop limit of the data in southern Louisiana to 342 in the midship area of southern Louisiana (table 1). The  $HCO_3/Cl$  ratio generally increases from the outcrop to midship and decreases from midship to downcrop in the area from the Sabine arch eastward to the western edge of Florida (fig. 20). From the Sabine arch southward to the Rio Grande the ratio generally decreases from outcrop to downcrop limit of the data.

From the Sabine arch eastward to the western edge of Florida, the  $HCO_3/Cl$  ratio ranges from 0.50 to 10 in the outcrop area, from 2 to 20 in the midship area, and 0.05 to 0.10 in the downcrop area. From the Sabine arch southward to the San Marcos arch this ratio ranges from 1 to 5 in the outcrop area, from 0.50 to 2 in the midship area, and from 0.10 to about 5 along the downcrop limit of the data. From the San Marcos arch southward to the Rio Grande the  $HCO_3/Cl$  ratio ranges from 0.10 to about 2 in the outcrop area, from 0.50 to 1 in the midship area, and from 0.05 to about 0.50 in the downcrop area.

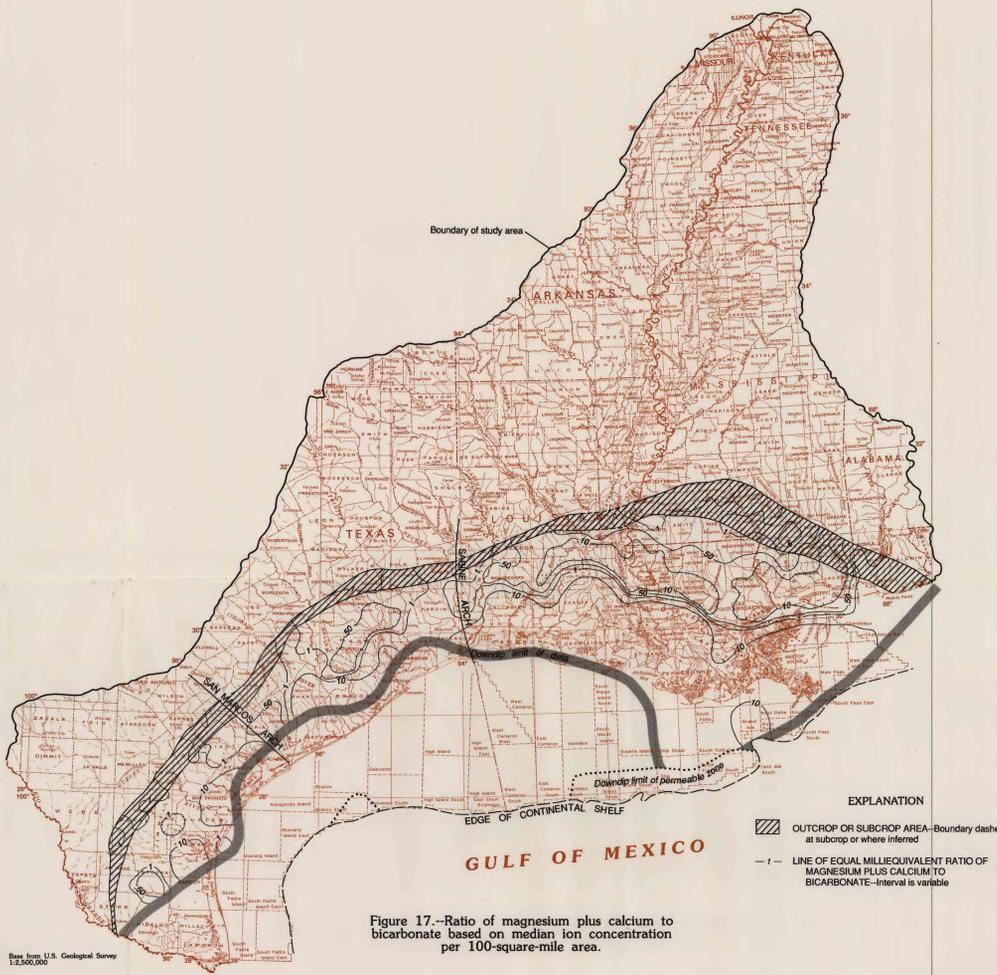


Figure 17.--Ratio of magnesium plus calcium to bicarbonate based on median ion concentration per 100-square-mile area.

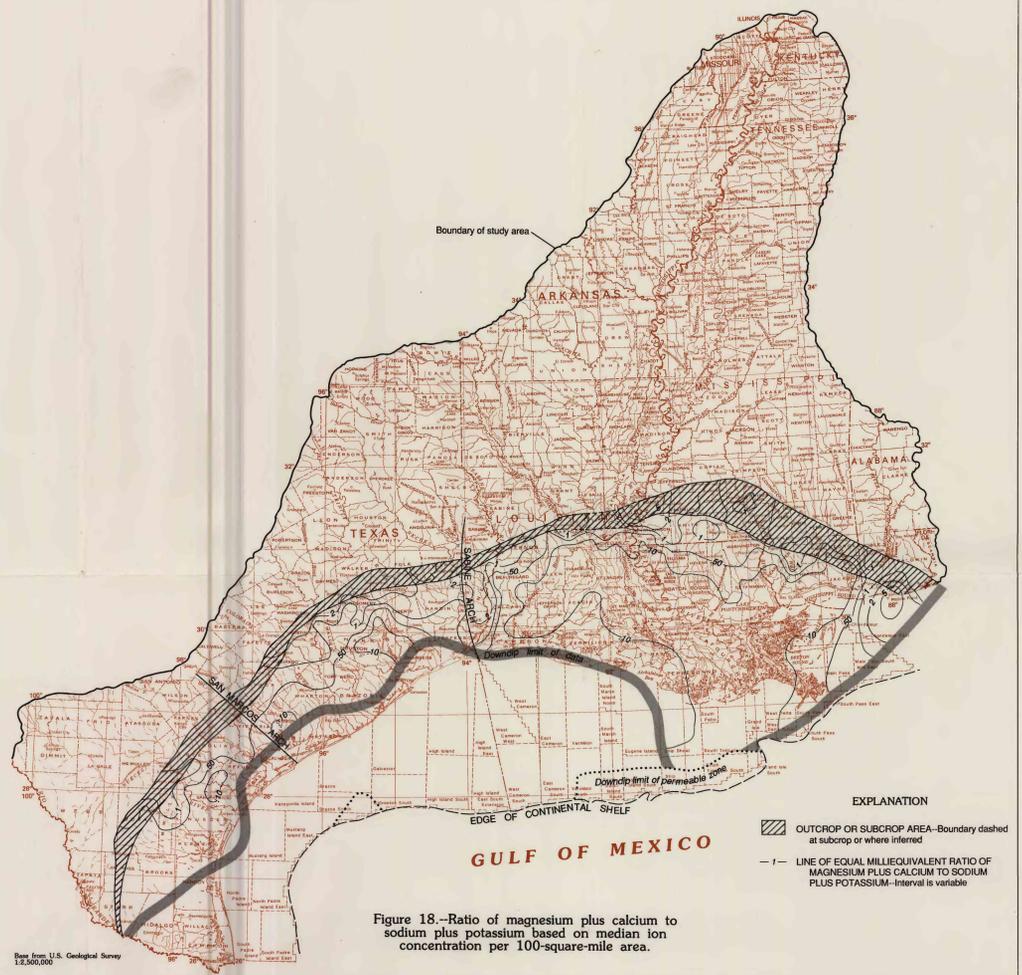


Figure 18.--Ratio of magnesium plus calcium to sodium plus potassium based on median ion concentration per 100-square-mile area.

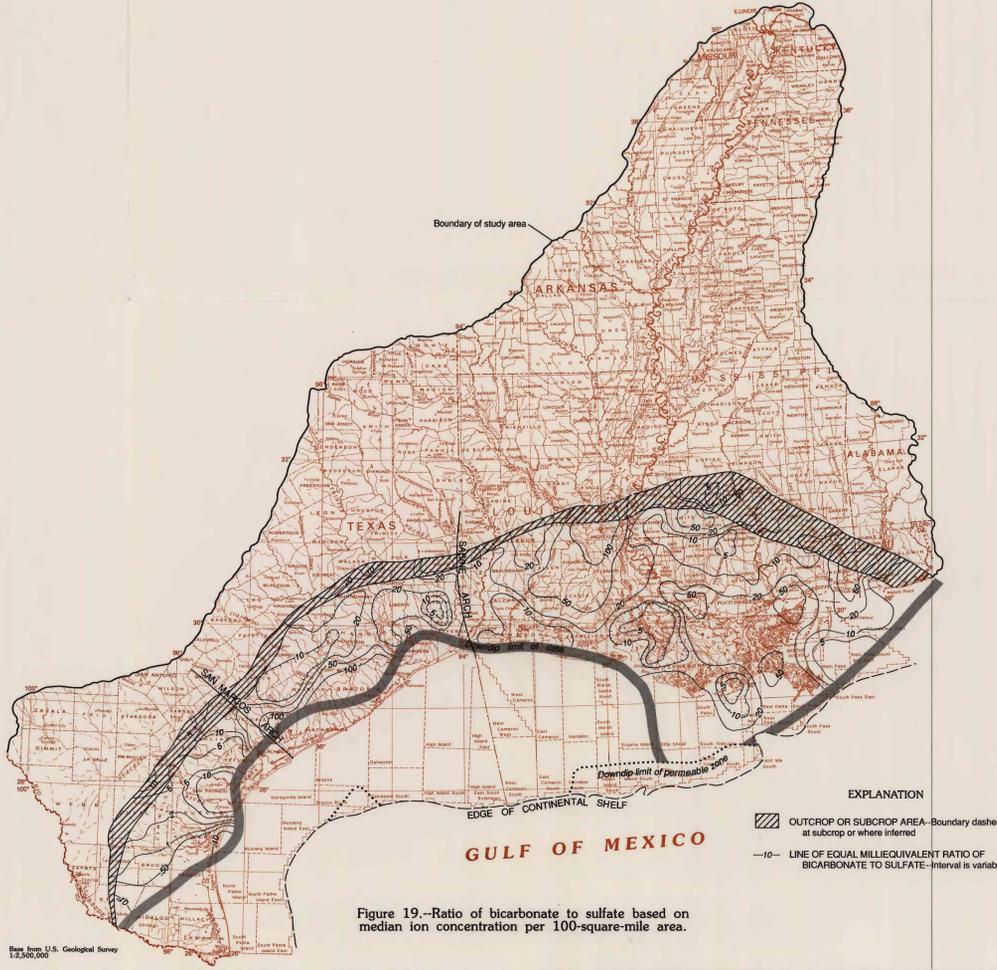


Figure 19.--Ratio of bicarbonate to sulfate based on median ion concentration per 100-square-mile area.

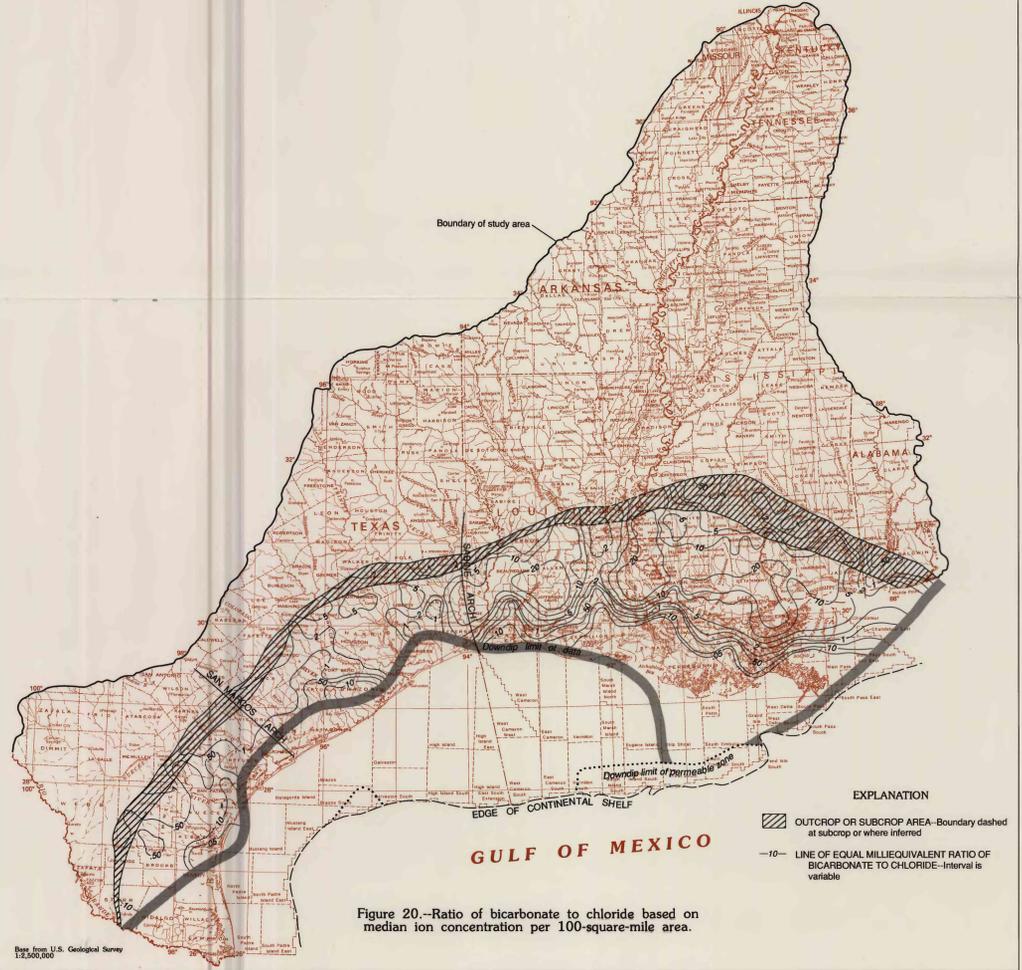


Figure 20.--Ratio of bicarbonate to chloride based on median ion concentration per 100-square-mile area.

SCALE 1:2,500,000  
100 MILES  
0 100 200 300 400 500 600 700 800 900 1000

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

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1993