QUALITY OF WATER FROM BEDROCK AQUIFERS

IN THE SOUTH CAROLINA PIEDMONT

by

Glenn G. Patterson and Gary G. Padgett

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QUALITY OF WATER FROM BEDROCK AQUIFERS IN THE SOUTH CAROLINA PIEDMONT

by Glenn G. Patterson* and Gary G. Padgett**

ABSTRACT

The geographic distributions of 12 frequently measured water-quality parameters in ground water from bedrock aquifers in the Piedmont physiographic province of South Carolina are presented in a series of maps. The maps are based on analyses by the South Carolina Department of Health and Environmental Control of water samples collected during the period 1972 to 1982, from 442 public and private wells developed in the bedrock of the Piedmont. In general, alkalinity, hardness, and concentrations of sodium, magnesium, and chloride were higher in the Carolina Slate Belt than they were in the other geologic belts of the Piedmont.

INTRODUCTION

South Carolina includes parts of three physiographic provinces: the Blue Ridge, the Piedmont, and the Atlantic Coastal Plain (fig. 1). In the Piedmont, local aquifers occur in alluvial deposits of sand and gravel; in the weathered saprolite; and in joints, fractures, and fault zones in the crystalline bedrock. The crystalline bedrock aquifer has been labeled the Igneous and Metamorphic Bedrock Aquifer System by the Groundwater Protection Division of the South Carolina Department of Health and Environmental Control as part of its preliminary aquifer designation under the U.S. Environmental Protection Agency's Underground Injection Control Program. These aquifers are important sources of water to hundreds of public and private wells.

The quality of ground water is affected by numerous factors. The mineral content of the aquifer, the solubility of these minerals, the amount of surface area contact between minerals and water, and the duration of the water

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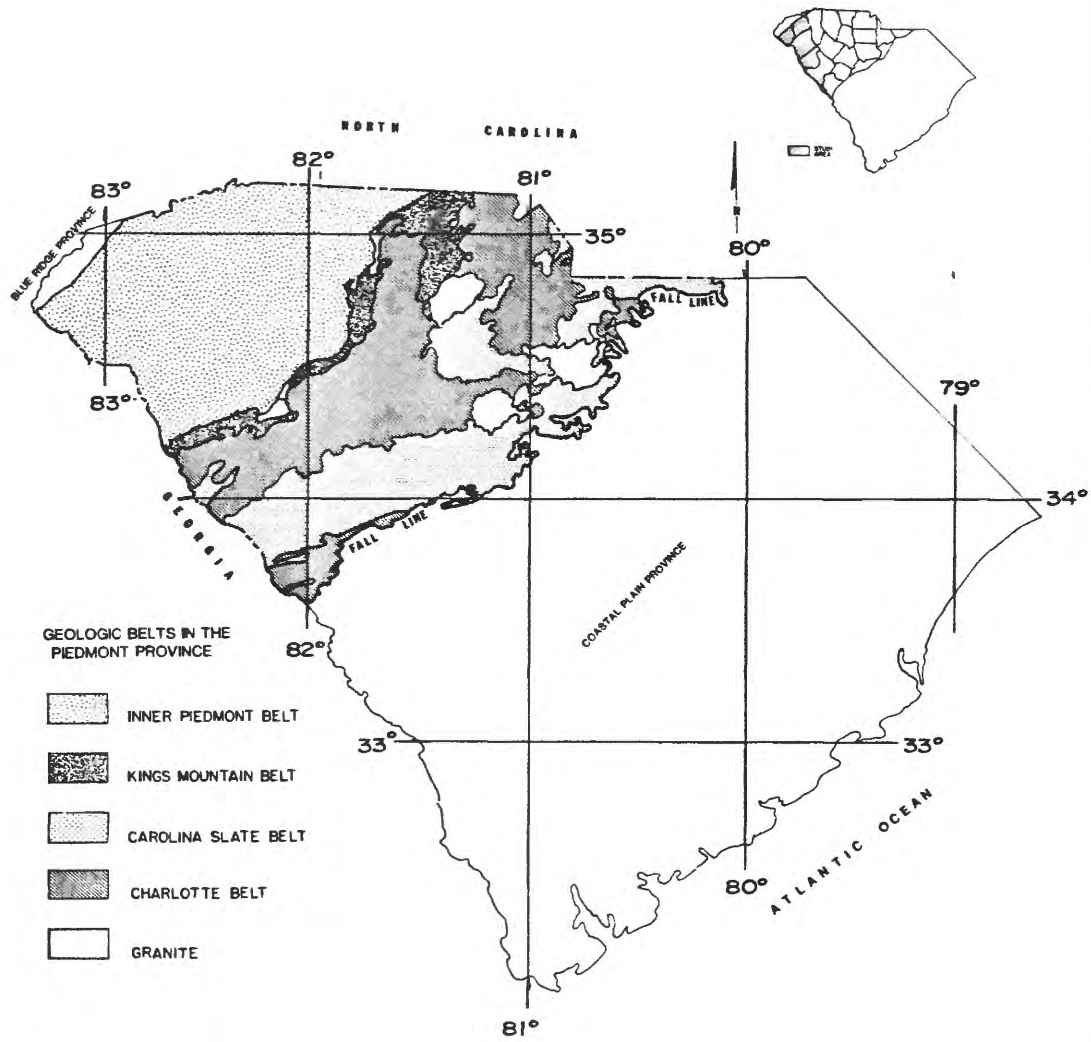

Figure 1.--Generalized geology of the South Carolina Piedmont.

and mineral contact are geology-related factors that affect water-quality. The purpose of this study is to determine the geographic distributions of 12 water-quality parameters in ground water from bedrock aquifers in the Piedmont Province of South Carolina.

Geologic Setting

The Piedmont includes most of the northwestern part of South Carolina (fig. 1). The Piedmont slopes gradually from the Blue Ridge to the Fall Line and is characterized by gently rolling topography.

The rocks of the South Carolina Piedmont were probably deposited during late Precambrian and Paleozoic time (Overstreet and Bell, 1965, p. 1). They were originally composed of shale, graywacke, felsic and mafic tuffaceous shale, tuff, and lava flows that contain thin, interbedded conglomerate, sandstone, limestone, and manganese-rich shale beds (Overstreet and Bell, 1965, p. 9). Following deposition, the Piedmont rocks were modified by folding, regional metamorphism, and igneous intrusion (Overstreet and Bell, 1965, p. 16). Intrusive rocks in the Piedmont include plutons of granite, muscovite pegmatite dikes, bodies of gabbro, norite, syenite, syenite pegmatite, and minette; and diabase dikes (Overstreet and Bell, 1965, p. 15).

The crystalline rocks of the South Carolina Piedmont are commonly grouped into four northeast-trending belts (fig. 1). The belts, which can be traced through neighboring states, are distinguished from each other primarily by differing grades of metamorphism and to a lesser degree by the original composition of the rocks. The Carolina Slate Belt and the Kings Mountain Belt reflect a low grade of metamorphism. The Charlotte Belt and the Inner Piedmont Belt reflect a moderate to high grade of metamorphism. In most of the Piedmont, the bedrock is overlain by saprolite derived from inplace weathering of the rocks. Along streams there are deposits of alluvium.

Methods

The water-quality analyses selected for use in this study were performed by the South Carolina Department of Health and Environmental Control on water samples from 442 wells developed in bedrock aquifers of the South Carolina Piedmont. The samples were collected and analyzed during the period 1972 to 1982. Most samples were drawn from faucets and were therefore subject to changes in water quality caused by passage of water through metal pipes. However, the samples were not subject to water softening or other treatment. The analyses were made for either of two reasons: The well may serve a public water system, in which case periodic water-quality analyses are required; or the well may serve a private water system, and the owner desired water-quality information. Consequently, there may be a bias among the private wells in favor of those having water-quality problems. The wells provided widespread coverage of the Piedmont (fig. 2).

Water-quality records were evaluated and entered into the U.S. Geological Survey's WATSTORE (Water Data Storage and Retrieval) computer file.

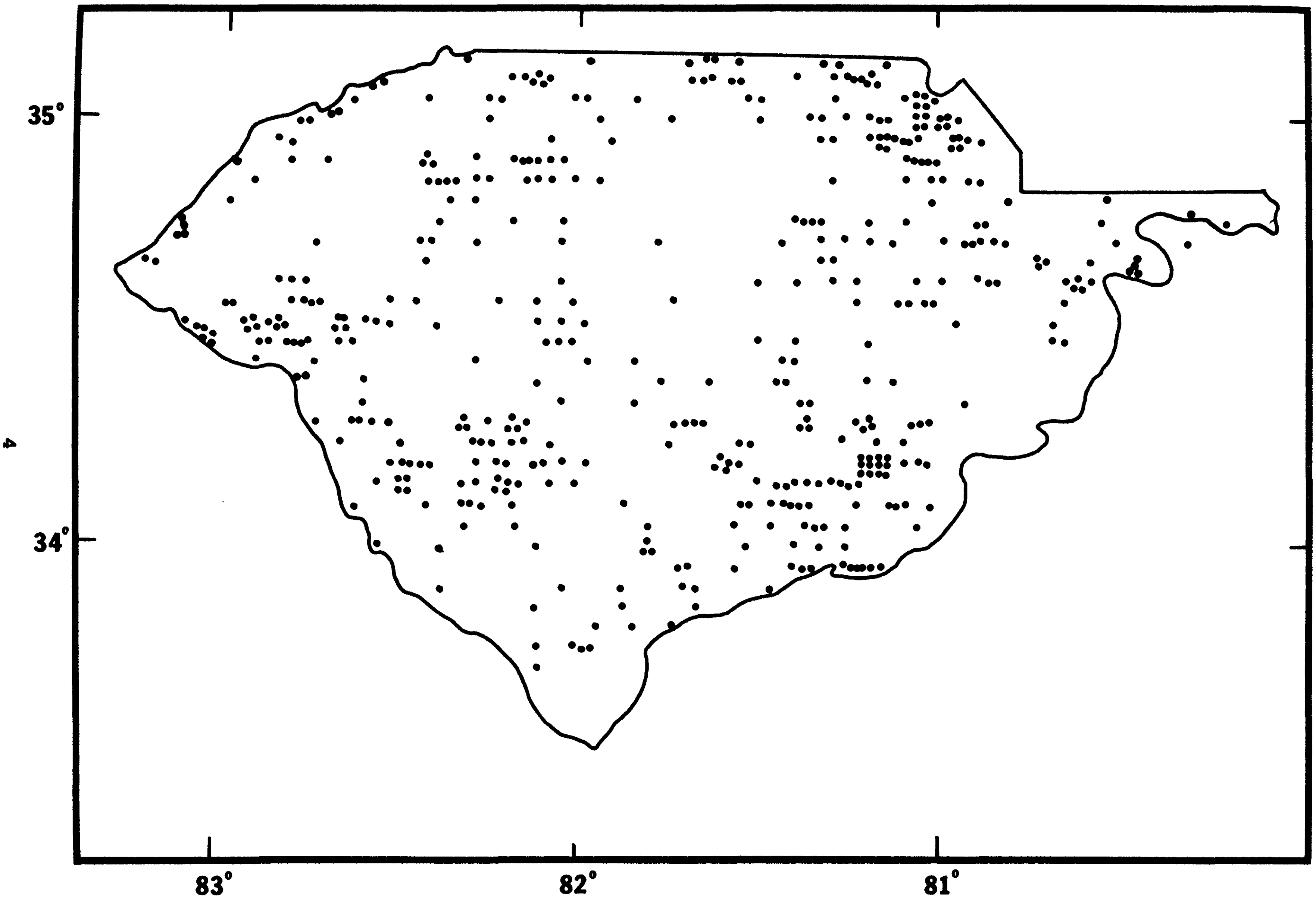

Figure 2.--Locations of wells sampled.

Twelve water-quality parameters were selected for mapping. The parameters selected had sufficient distributions of data points to allow reasonably accurate mapping, and included major chemical constituents and commonly-measured physical properties. The selected parameters were:

pH	Sodium
Total dissolved solids	Potassium
Alkalinity	Chloride
Hardness	Fluoride
Calcium	Nitrite plus nitrate nitrogen
Magnesium	Manganese

For those wells that had been sampled more than once, mean values were computed for each water-quality parameter.

Computer-drawn maps were produced, using WATSTORE programs LPPLOT and QWSYMAP, to describe the distribution of the selected water-quality parameters (U.S. Geological Survey, 1982, sections K and O). Ranges of parameter values for the maps were selected to show generalized areas of low, medium, and high values. Where applicable, drinking water standards were used to select contour intervals (U.S. Environmental Protection Agency, 1977, p. 67, 81; 1979, p. 2). Water-quality maps were compared with the geologic map of the Piedmont of South Carolina (Overstreet and Bell, 1965, plate I) (fig. 1).

MAPPING RESULTS

The results of the computer mapping are presented for each water-quality parameter in figures 3 through 14. Similar results have been reported in reports on ground-water resources of Greenville County (Koch, 1968), Anderson and Oconee Counties (Snipes, 1981), Abbeville County (Snipes and others, 1983), and Spartanburg County (Bloxham and others, 1970).

pH

pH is defined as the negative logarithm of the hydrogen ion activity, in moles per liter. Water with a pH of 7.0 at 25°C is neutral with a hydrogen-ion activity of 10^{-7} moles per liter. For every pH unit below 7.0, the hydrogen activity of the water is ten times greater, and the water is more acidic. For every pH unit above 7.0, the hydrogen activity of the water is ten times less, and the water is more basic. Water is well-buffered if the pH is not greatly changed by the addition of moderate amounts of acid or base. Dissolved carbon dioxide, bicarbonate, and carbonate account for most of the buffering capacity of natural waters (Hem, 1970, p. 92). The pH of water affects the solubility of many substances in water. For example, acidic water is more likely to corrode metal pipes than water that is neutral or basic. The pH of drinking water should be between 6.5 and 8.5 units (U.S. Environmental Protection Agency, 1979, p. 2).

For those wells with more than one determination of a particular parameter, the arithmetic mean of all the values was computed to arrive at a single value for mapping. Because pH is a logarithmic function, it is technically more accurate to compute the log mean of pH values. However, in this study, the greatest error in pH caused by using arithmetic rather than log means is 0.1 standard unit, which is less than the error involved in collecting and analyzing the samples.

The pH of water samples from the bedrock aquifers of the Piedmont ranged from 4.5 to 10.4 units. Of the 401 wells sampled for pH, 74 percent yielded water samples meeting the drinking water standards. Twenty-five percent yielded samples with pH less than 6.5, and one percent yielded samples with pH greater than 8.5. The geographic distribution of pH in water from bedrock aquifers in the Piedmont is shown in figure 3.

Dissolved Solids

Dissolved solids is a measure of the total amount of material that is dissolved in water. If the concentration of dissolved solids in water is high, the water may taste salty, tend to leave scale deposits in boilers, and may be unsuitable for a variety of industrial uses. Water having low concentrations of dissolved solids is generally poorly buffered, likely to have a low pH, and may be corrosive. The U.S. Geological Survey has assigned terms for waters of high dissolved solids as follows (Robinove and others, 1958, p. 3).

	Dissolved solids mg/L
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

The U.S. Environmental Protection Agency has specified that total dissolved solids determined by ignition (evaporation) in drinking water should not exceed 500 mg/L (milligrams per liter) (U.S. Environmental Protection Agency, 1979, p. 2).

Concentrations of dissolved solids in water samples from the bedrock aquifers in the Piedmont ranged from 22 to 1,100 mg/L. Of the 211 wells that were sampled for dissolved solids, about 9 percent yielded water samples with concentrations less than 50 mg/L, and 90 percent yielded samples with concentrations ranging from 50 to 500 mg/L. The geographic distribution of dissolved solids in water from bedrock aquifers in the Piedmont is shown in figure 4.

Alkalinity

Alkalinity is a measure of the capacity of a solution to neutralize acid. Total alkalinity is normally determined by measuring the amount of standard

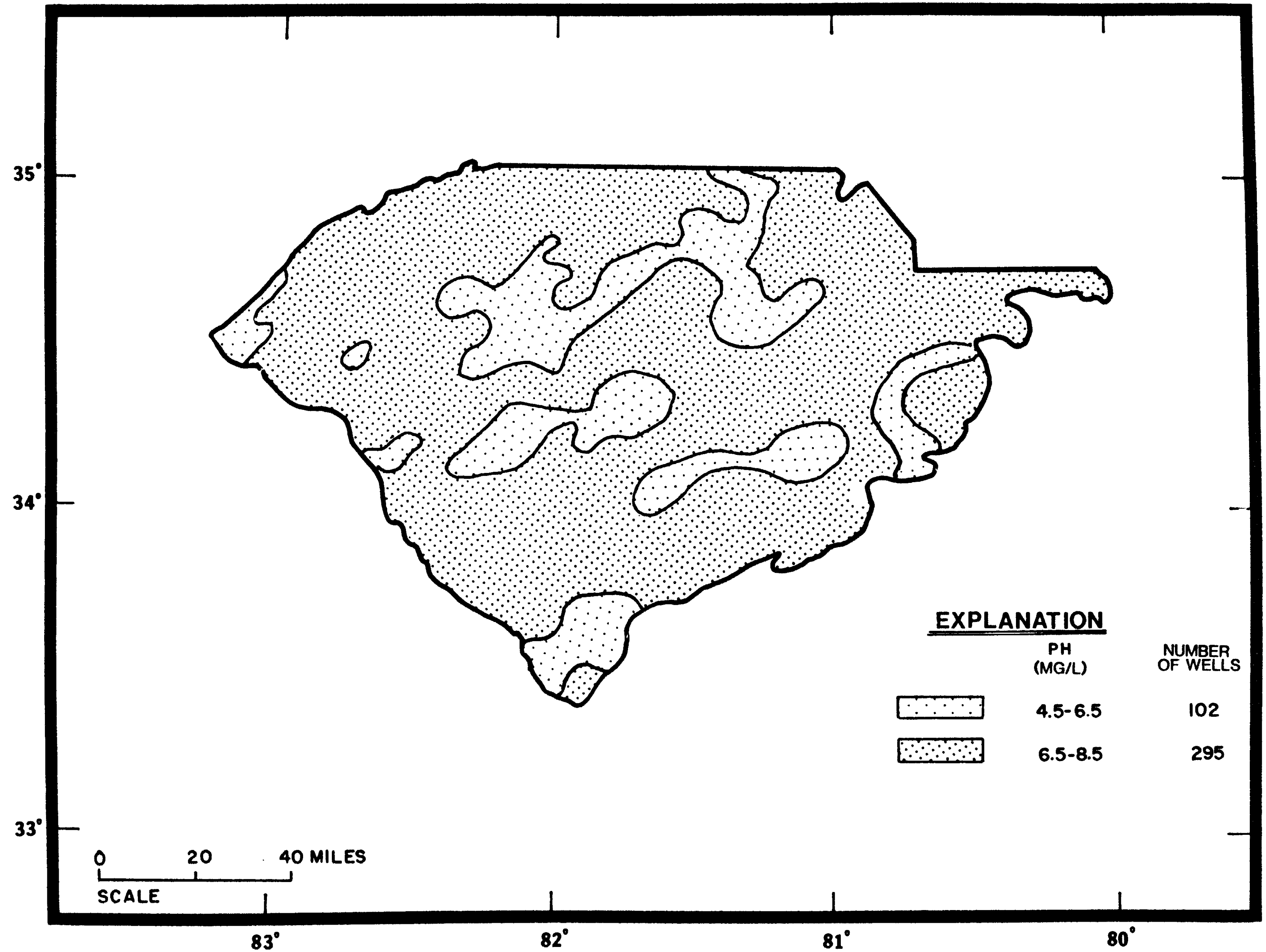

Figure 3.--pH of water from bedrock aquifers in the South Carolina Piedmont.

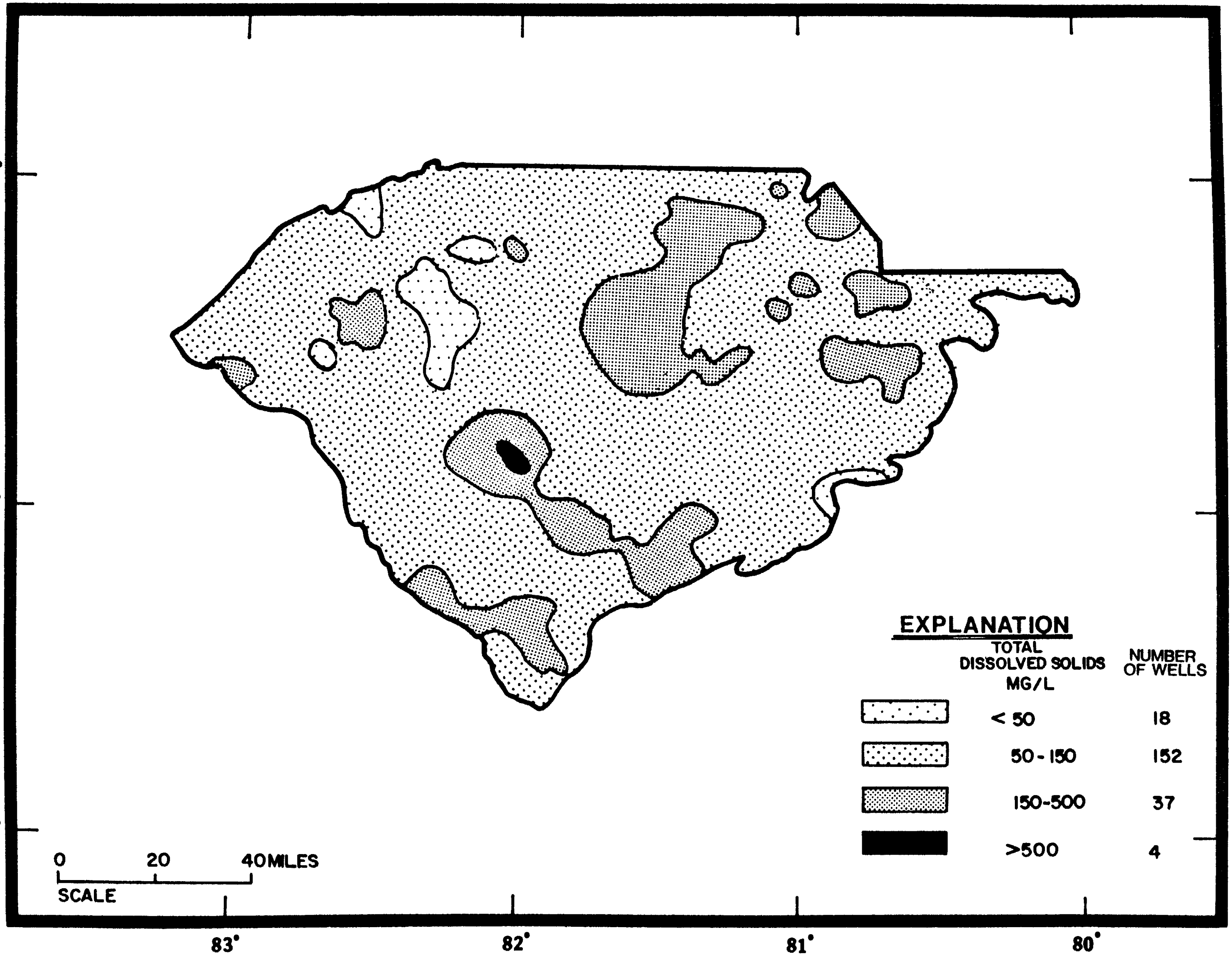

Figure 4.--Dissolved solids in water from bedrock aquifers in the South Carolina Piedmont.

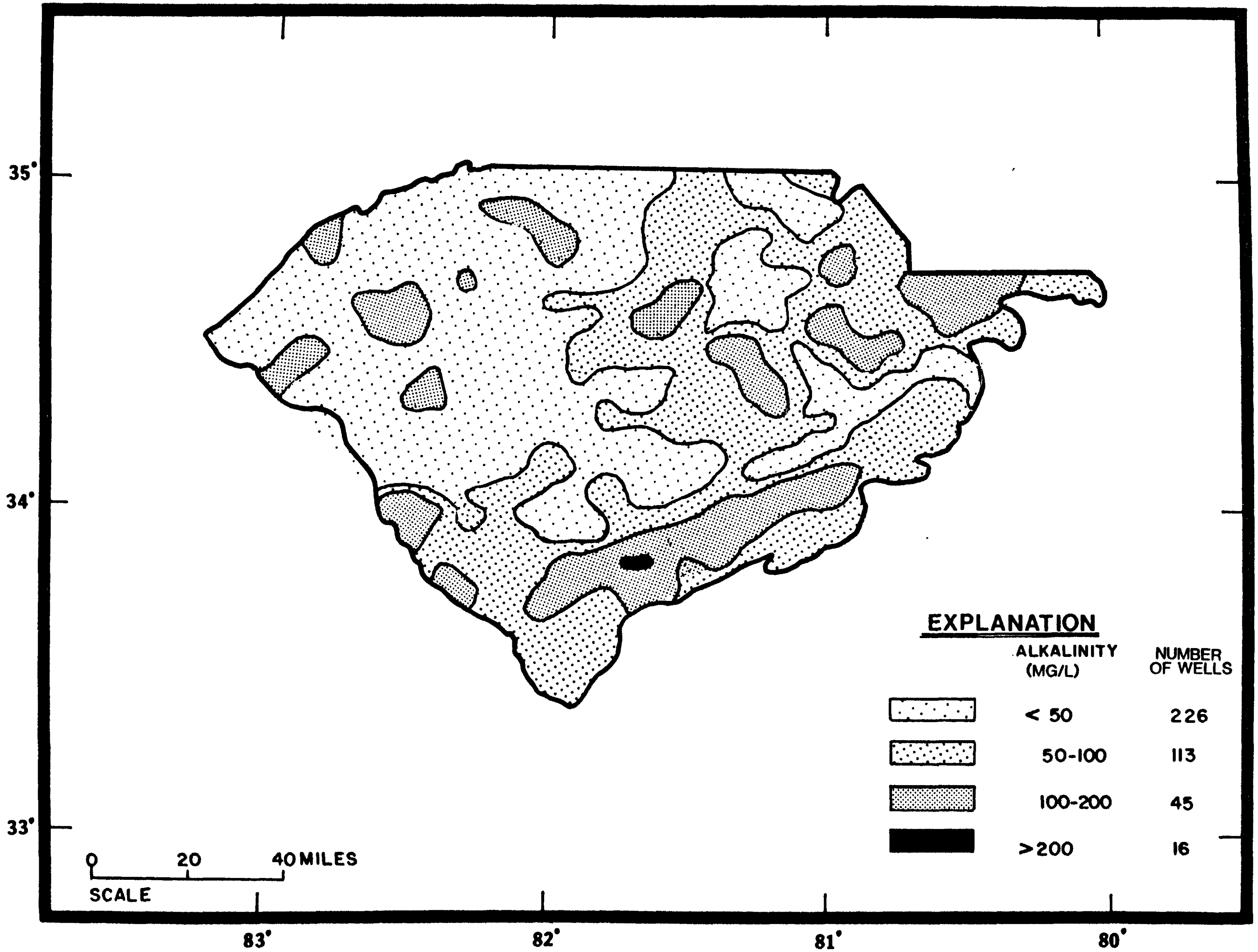

Figure 5.--Alkalinity of water from bedrock aquifers in the South Carolina Piedmont.

acid required to lower the pH of a given volume of water to a specified end-point value, usually 4.5. Most of the alkalinity in natural water is produced by dissolved carbonate and bicarbonate ions. Alkalinity is reported in terms of milligrams per liter of calcium carbonate, even though both carbonate and bicarbonate are involved. Alkalinity governs the response of water to efforts to lower its pH. No standards have been set for alkalinity of drinking water.

Alkalinity in water samples from bedrock aquifers in the Piedmont ranged from 3.0 to 360 mg/L as $CaCO_3$. Of the 403 wells sampled for alkalinity, 84 percent yielded water samples with less than 100 mg/L as $CaCO_3$. The geographic distribution of alkalinity in water from bedrock aquifers in the Piedmont is shown in figure 5. In general, ground water in the Carolina Slate Belt has a higher alkalinity, and ground water in the Inner Piedmont Belt has a lower alkalinity, compared with ground water in the other geologic belts.

Hardness

Hardness of water is a measure of the concentration of cations that form insoluble complexes with soap. Hydrogen ion and all polyvalent metals can contribute to hardness, but nearly all hardness in natural waters is due to calcium and magnesium. Hardness is reported in terms of milligrams per liter as calcium carbonate, even though both calcium and magnesium are involved. Hardness affects the soap-consuming quality of water. Hard water tends to leave crusty deposits of scale when it is heated or evaporated. Hardness in drinking water does not appear to be detrimental to health, and it may be slightly beneficial (Hem, 1970). Federal drinking-water standards classify water according to hardness, but do not set a hardness limit:

0 - 50 mg/L	soft
51 - 100 mg/L	moderately hard
101 - 200 mg/L	hard
over 200 mg/L	very hard

(U.S. Environmental Protection Agency, 1977)

Hardness in water samples from bedrock aquifers in the Piedmont ranged from 1.4 to 700 mg/L. Of the 390 wells sampled for hardness, 67 percent yielded soft water, 15 percent yielded medium-hard water, 12 percent yielded hard water, and 6 percent yielded very hard water. The geographic distribution of hardness in water from bedrock aquifers in the Piedmont is shown in figure 6. In general, ground water in the Carolina Slate Belt is harder, and ground water in the Inner Piedmont Belt is softer, compared with ground water in the other geologic belts.

Calcium

Calcium is a major dissolved constituent in natural water. Calcium interacts chemically with a variety of other ions, including carbonate, and contributes to hardness in the water. No standards have been set for calcium in drinking water.

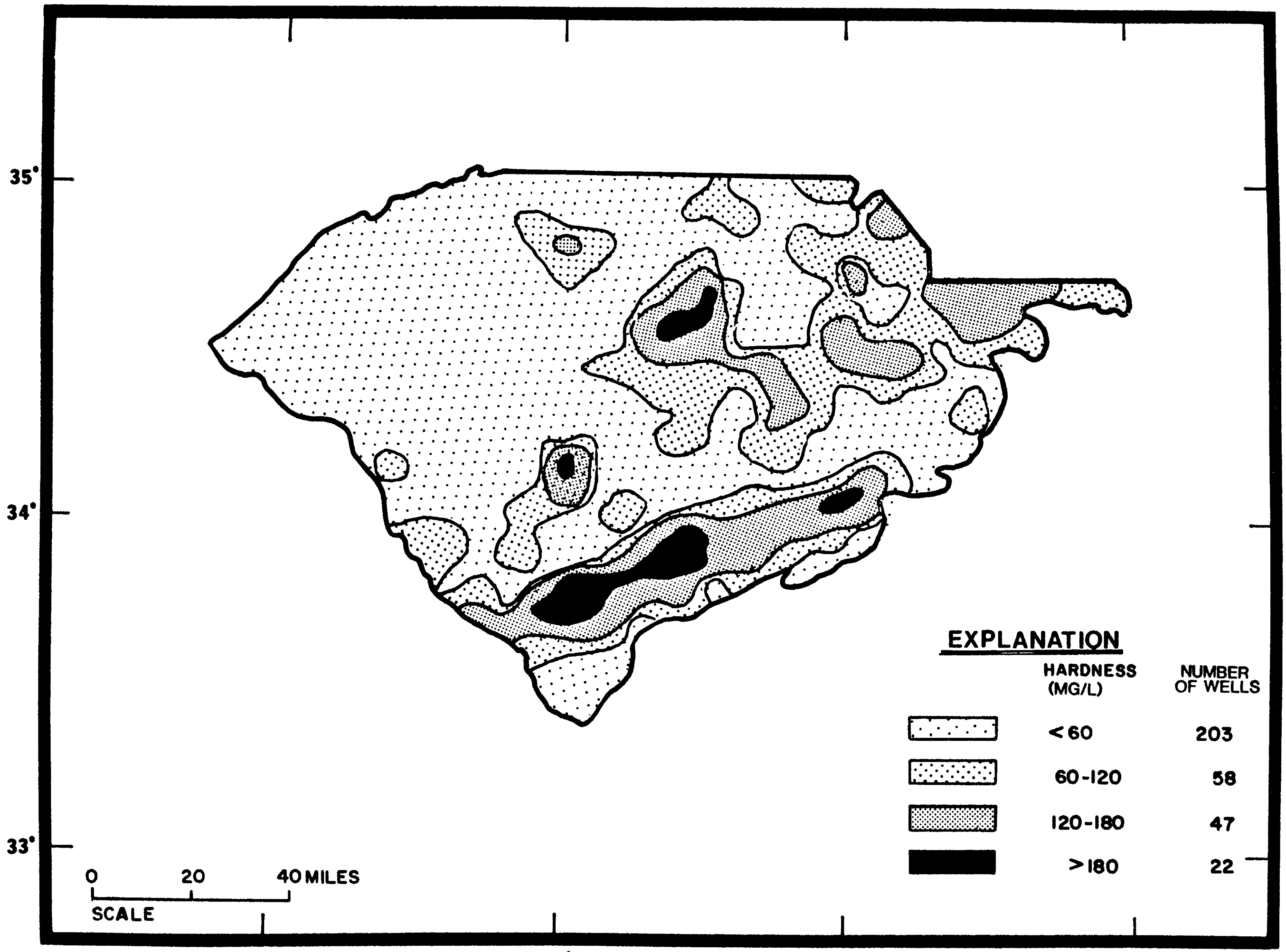

Figure 6.--Hardness of water from bedrock aquifers in the South Carolina Piedmont.

Concentrations of calcium in water from bedrock aquifers in the Piedmont ranged from 0.7 to 310 mg/L. Of the 260 wells sampled for calcium, 52 percent yielded water samples with concentrations less than 10 mg/L, 45 percent yielded samples with concentrations between 10 and 100 mg/L, and 3 percent yielded samples with concentrations greater than 100 mg/L. The geographic distribution of calcium in water from bedrock aquifers in the Piedmont is shown in figure 7.

Magnesium

Magnesium is usually not as abundant as calcium in water, but it behaves somewhat similarly, especially in contributing to hardness. No standards have been set for magnesium in drinking water.

Concentrations of magnesium in water from bedrock aquifers in the Piedmont ranged from 0.04 to 115 mg/L. Of the 225 wells sampled for magnesium, 80 percent yielded water samples with concentrations less than 5 mg/L, 20 percent yielded samples with concentrations between 5 and 50 mg/L, and 1 well yielded a sample with a concentration of 115 mg/L. The geographic distribution of magnesium in water from bedrock aquifers in the Piedmont is shown in figure 8. In general, concentrations of magnesium tend to be higher in ground water in the Carolina Slate Belt, and lower in ground water in the Inner Piedmont Belt, compared to ground water in the other geologic belts.

Sodium

Sodium is the most abundant alkali metal. It is readily dissolved in water and not easily precipitated. When dissolved calcium and magnesium are replaced by sodium and potassium through cation exchange, hard water becomes soft. Soft water requires less soap for lather than hard water and does not tend to leave hard scale deposits on evaporation. High sodium concentrations in irrigation water can be detrimental to soil structure. Sodium is an essential nutrient, but high sodium concentrations in drinking water can be unhealthy, especially for people with hypertension. However, no standards have been set for sodium in drinking water.

Concentrations of sodium in water samples from bedrock aquifers in the Piedmont ranged from 2 to 110 mg/L. Of the 169 wells for which sodium was determined, 60 percent yielded water samples with concentrations less than 10 mg/L, 39 percent yielded samples with concentrations between 10 and 100 mg/L, and 1 percent (1 well) yielded a sample with a concentration of 110 mg/L. The geographic distribution of sodium in water from bedrock aquifers in the Piedmont is shown in figure 9. In general, concentrations of sodium tend to be higher in ground water in the Carolina Slate Belt, and lower in ground water in the Inner Piedmont Belt, compared to ground water in the other geologic belts.

Potassium

Potassium is generally not as abundant as sodium and, unlike sodium, is prone to leave solution and become reincorporated in solid weathering

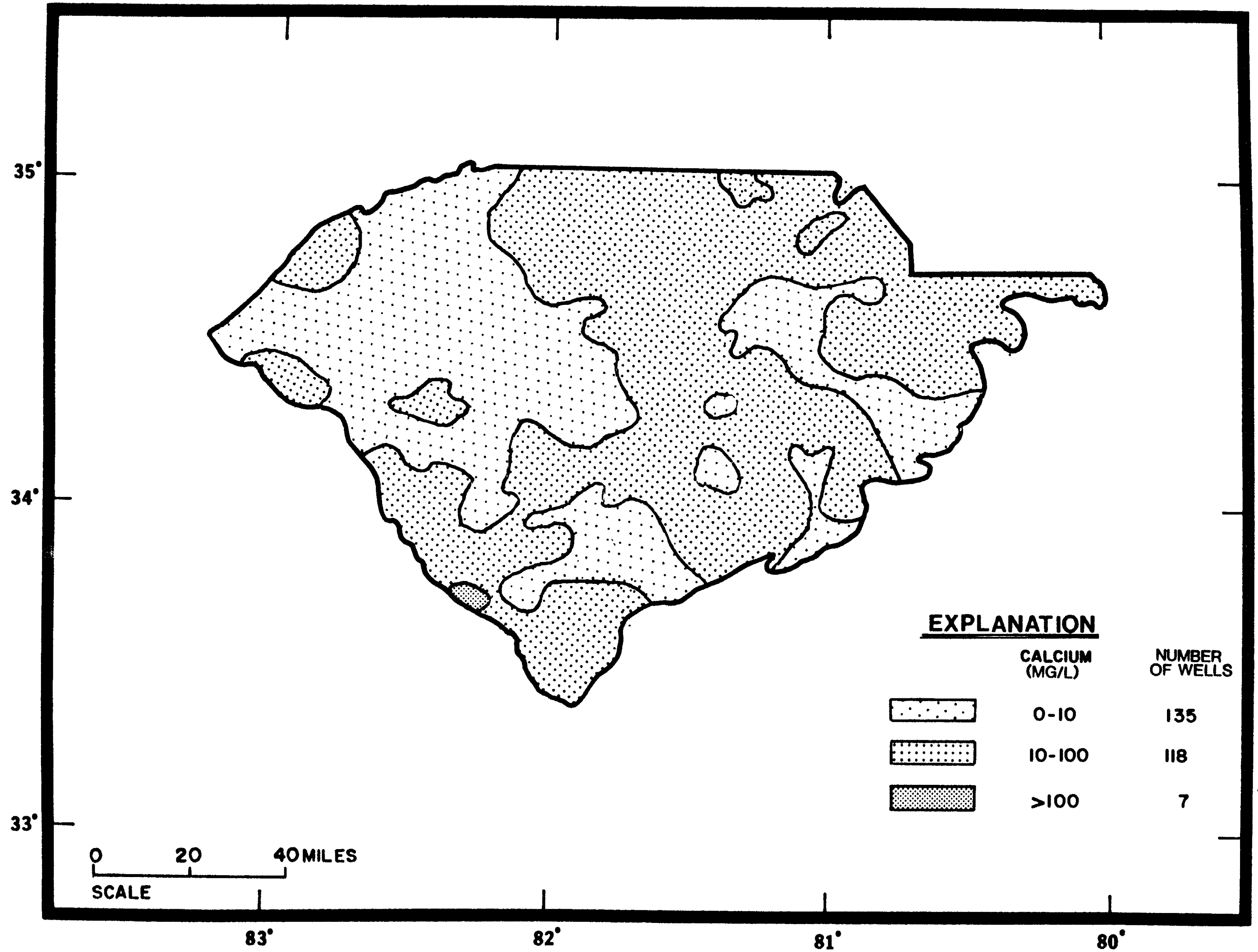

Figure 7.--Calcium in water from bedrock aquifers in the South Carolina Piedmont.

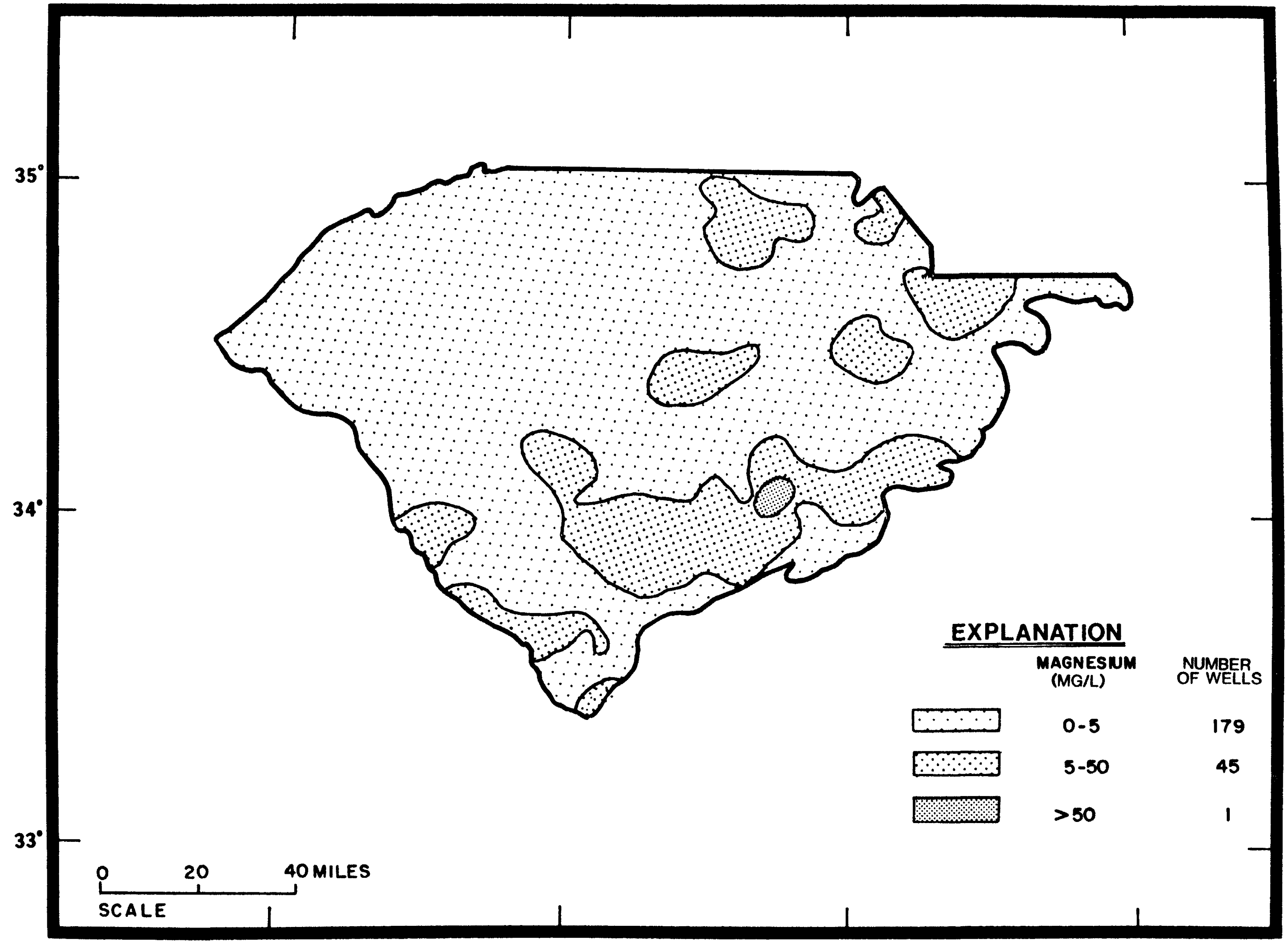

Figure 8.--Magnesium in water from bedrock aquifers in the South Carolina Piedmont.

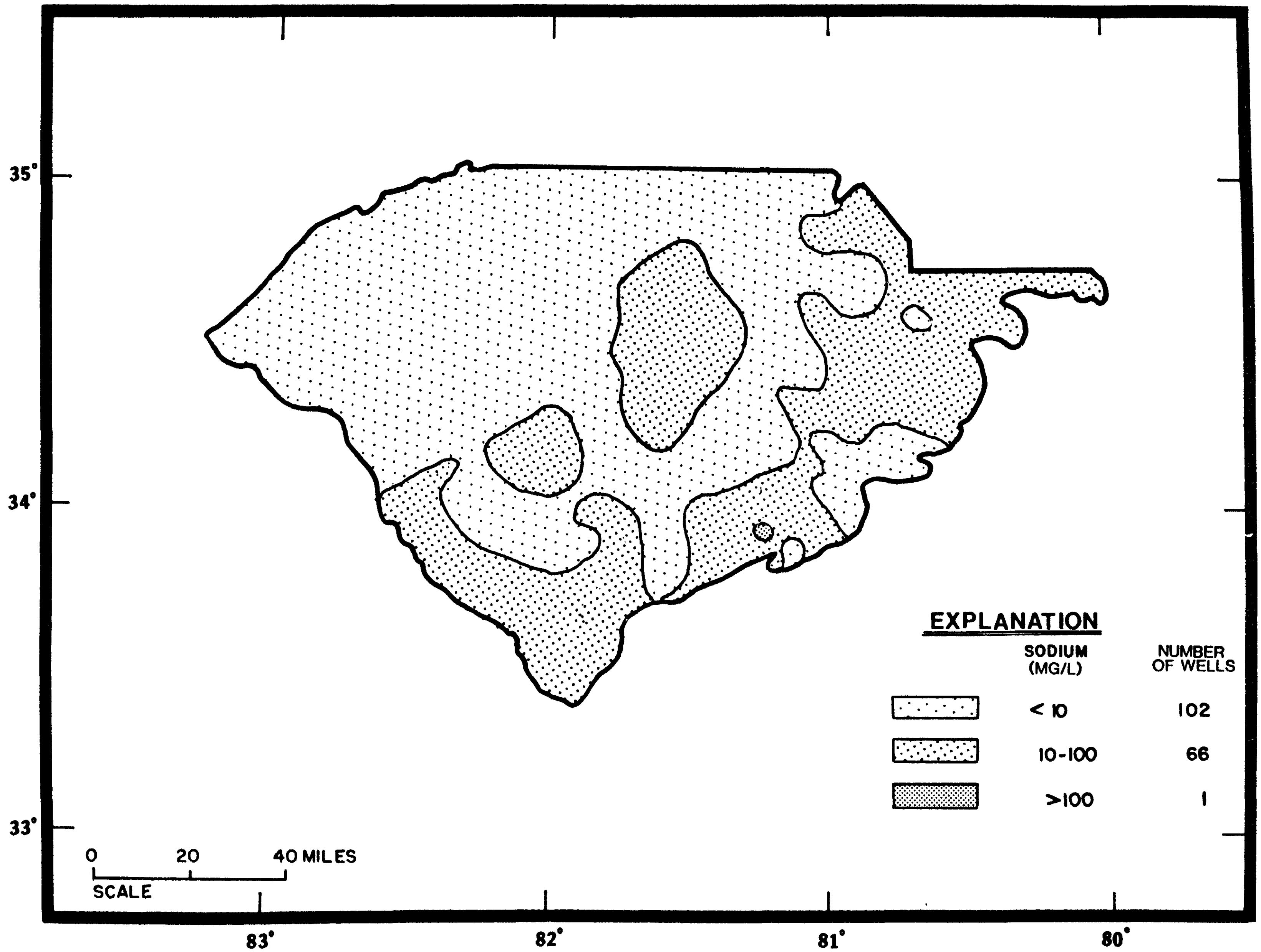

Figure 9.--Sodium in water from bedrock aquifers in the South Carolina Piedmont.

products. Potassium, like sodium, is an essential nutrient. Although high concentrations of potassium in drinking water may have some adverse health effects, no standards have been set.

Concentrations of potassium in water samples from bedrock aquifers in the Piedmont ranged from 0.09 to 6.3 mg/L. Of the 195 wells sampled for potassium, 49 percent yielded water samples with concentrations less than 2 mg/L, 46 percent yielded samples with concentrations between 2 and 4 mg/L, 5 percent yielded samples with concentrations between 4 and 6 mg/L, and 1 well yielded a sample with a concentration of 6.3 mg/L. The geographic distribution of potassium in water from the bedrock aquifers in the Piedmont is shown in figure 10.

Chloride

Chloride, the anionic form of chlorine, is the most abundant halogen found in natural water. It is readily soluble, and interacts very little with other substances. Of the major constituents of natural water, chloride is the least abundant in the various rock types (Hem, 1970, p. 171). A significant source of chloride in natural water appears to be residual seawater incorporated into sedimentary rocks (Hem, 1970, p. 171). Other sources include rainfall and human activity (Gambell and Fisher, 1966, p. K9; Fisher, 1968, p. M4). High concentrations of chloride impart a salty taste to water. Concentrations of chloride in drinking water should not exceed 250 mg/L (U.S. Environmental Protection Agency, 1979, p. 2).

Concentrations of chloride in water samples from bedrock aquifers in the Piedmont ranged from 0.5 to 420 mg/L. Of the 389 wells sampled for chloride, 89 percent yielded water samples with concentrations less than 25 mg/L chloride, 10 percent yielded samples with concentrations between 25 and 250 mg/L, and 1 percent yielded samples with concentrations greater than 250 mg/L. The geographic distribution of chloride in water from bedrock aquifers in the Piedmont is shown in figure 11. In general, concentrations of chloride are markedly higher in ground water in the Carolina Slate Belt, and lower in ground water in the Inner Piedmont Belt than elsewhere in the Piedmont.

Fluoride

Fluoride is the anionic form of fluorine, another halogen. Unlike chloride, fluoride is abundant in rocks. However, the fluoride-bearing rocks are relatively insoluble, and fluoride concentrations are generally low in natural water. Fluoride is essential to healthy teeth. When the concentration in drinking water is less than 0.7 mg/L, fluoride is often artificially added. However, high concentrations can cause fluorosis, or mottling, of teeth. Drinking water standards for fluoride are dependent on temperature to account for children drinking more water on hot days. For the range of mean annual daily maximum air temperatures found in the South Carolina Piedmont (70.7° to 79.2°F or 21.5° to 26.2°C), the optimum fluoride concentration is 0.8 mg/L, and the recommended upper limit is 1.6 mg/L (U.S. Environmental Protection Agency, 1977, p. 67).

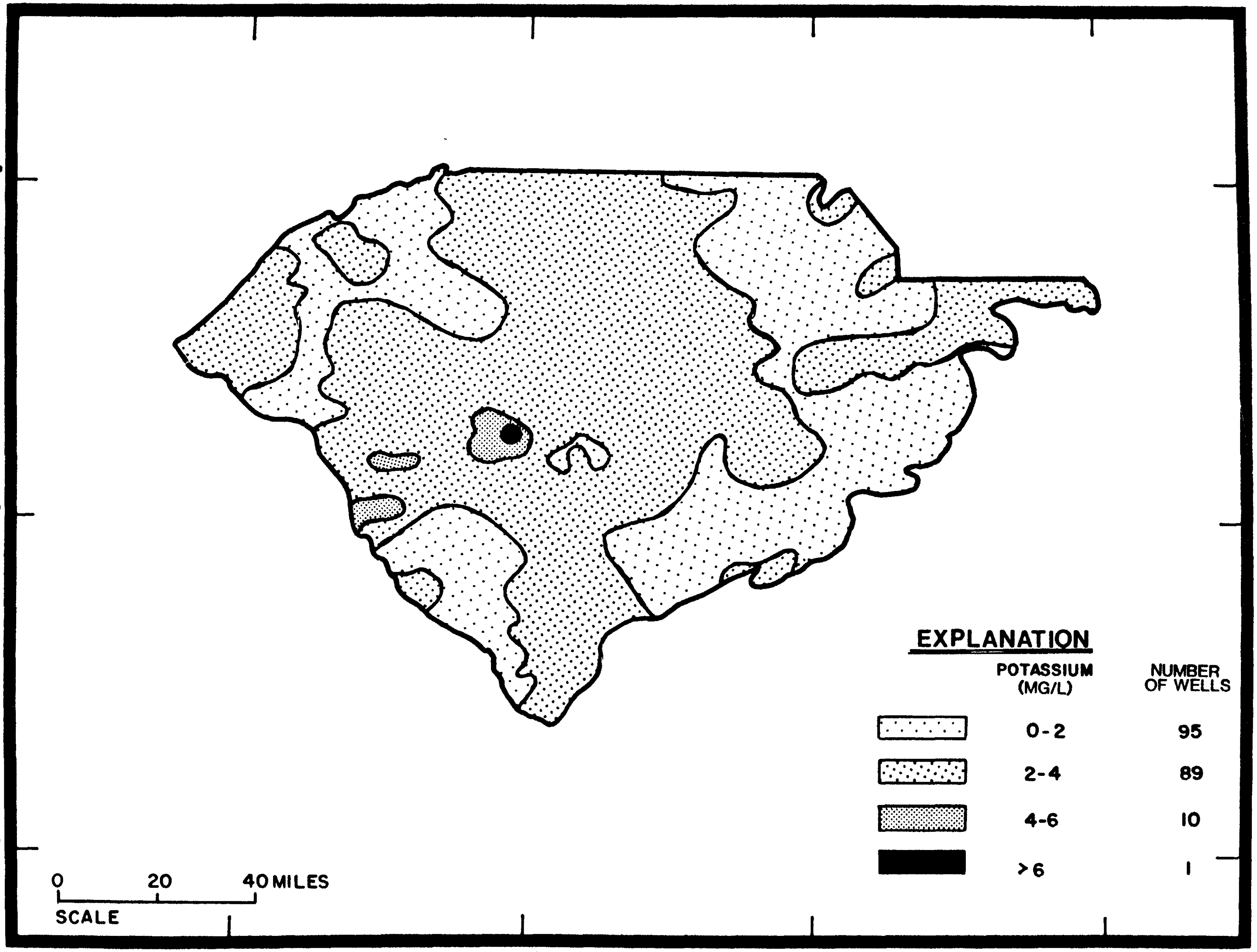

Figure 10.--Potassium in water from bedrock aquifers in the South Carolina Piedmont.

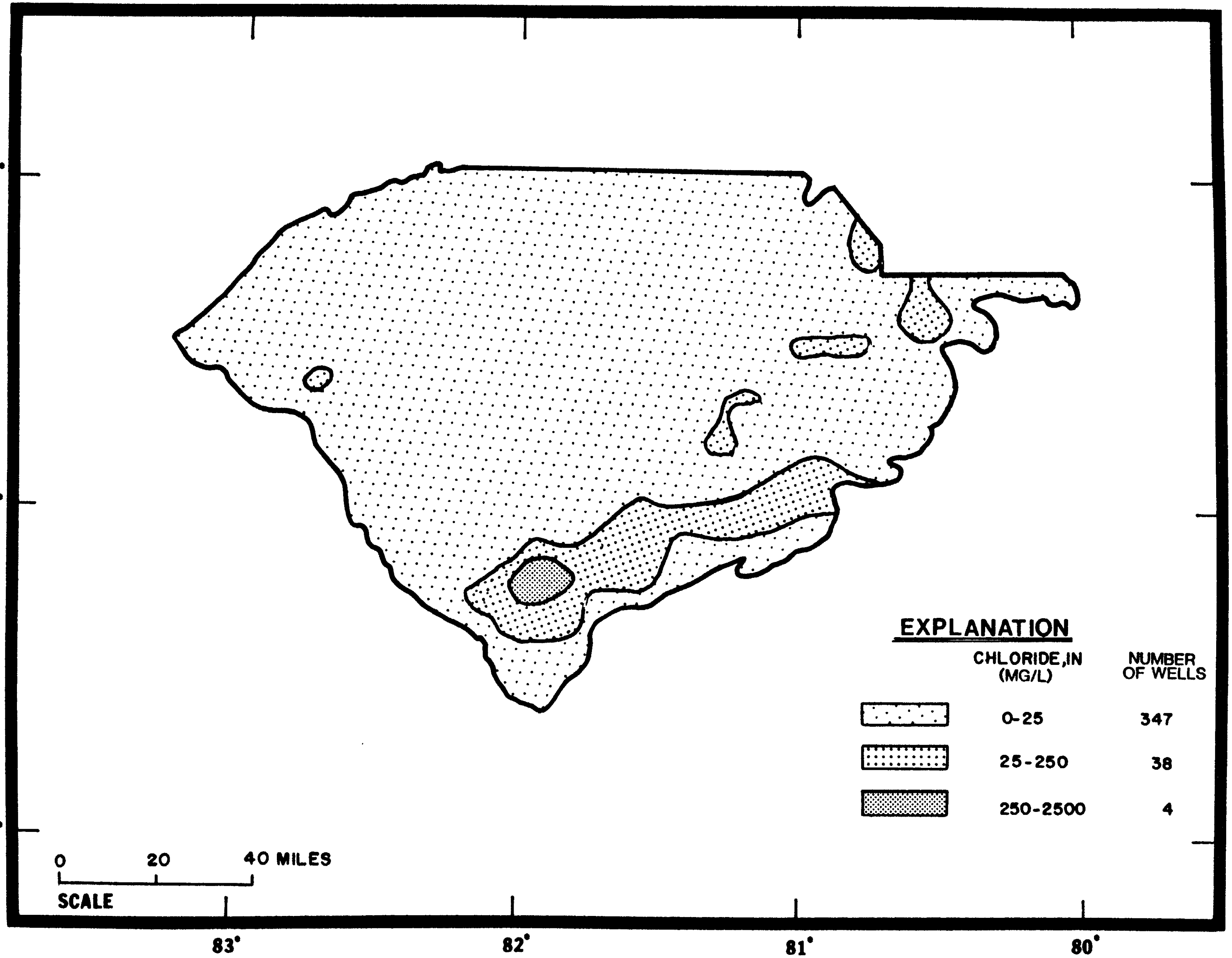

Figure 11.--Chloride in water from bedrock aquifers in the South Carolina Piedmont.

Concentrations of fluoride in water samples from bedrock aquifers in the Piedmont ranged from 0.09 to 2.19 mg/L. Of the 155 wells sampled for fluoride, 91 percent yielded water samples with concentrations less than 0.8 mg/L, 6 percent yielded samples with concentrations between 0.8 and 1.6 mg/L, and 3 percent yielded samples with concentrations greater than 1.6 mg/L. The geographic distribution of fluoride in water from bedrock aquifers in the Piedmont is shown in figure 12.

Nitrite and Nitrate Nitrogen

Nitrite and nitrate nitrogen are oxidized, anionic forms of nitrogen that are readily soluble. Nitrite is seldom abundant in water because it is rapidly converted to nitrate by bacteria. Nitrogen is not abundant in rocks, but exists in organic and inorganic forms in soil and water. Much of the nitrate in natural water is derived from human activity such as fertilizer application and sewage disposal. Nitrate is an important plant nutrient. When sufficient quantities of other nutrients are available in lakes and estuaries, high concentrations of nitrate can contribute to unsightly algal blooms. In human infants, drinking water with high concentrations of nitrate can cause a condition known as methemoglobinemia or blue babies. Standards for drinking water specify that the concentration of nitrite nitrogen should not exceed 1 mg/L, and the concentration of nitrate nitrogen should not exceed 10 mg/L (U.S. Environmental Protection Agency, 1977, p. 5, 81).

Concentrations of nitrite plus nitrate, as nitrogen, in water samples from bedrock aquifers in the Piedmont ranged from 0.01 to 150 mg/L. Of the 84 wells sampled, 56 percent yielded water samples with concentrations less than 1 mg/L, 38 percent yielded samples with concentrations between 1 and 10 mg/L, and 6 percent yielded samples with concentrations greater than 10 mg/L. The 84 wells do not comprise a well-distributed sample over the entire Piedmont, but are concentrated in an area around Columbia. The geographic distribution of nitrite plus nitrate concentrations in water from bedrock aquifers in the vicinity of Columbia is shown in figure 13.

Manganese

The distribution of manganese is included in the report because of its abundance in excess of secondary drinking water standards. Manganese is readily soluble under reducing conditions such as may be found underground. In oxidizing conditions, such as the open air, dissolved manganese tends to form a dark-colored precipitate. Some manganese in the samples may have been derived from metal pipes. Standards for manganese in drinking water recommend a maximum of 0.05 mg/L (U.S. Environmental Protection Agency, 1979, p. 2).

Concentrations of manganese in water samples from bedrock aquifers in the Piedmont ranged from 0 to 2,400 mg/L. Of the 151 wells that were sampled for manganese, 11 percent yielded water samples with concentrations less than 0.005 mg/L, 24 percent yielded samples with concentrations between 0.005 and 0.05 mg/L, and 65 percent yielded samples with concentrations greater than 0.05 mg/L. The geographic distribution of manganese in water from bedrock aquifers in the Piedmont is shown in figure 14.

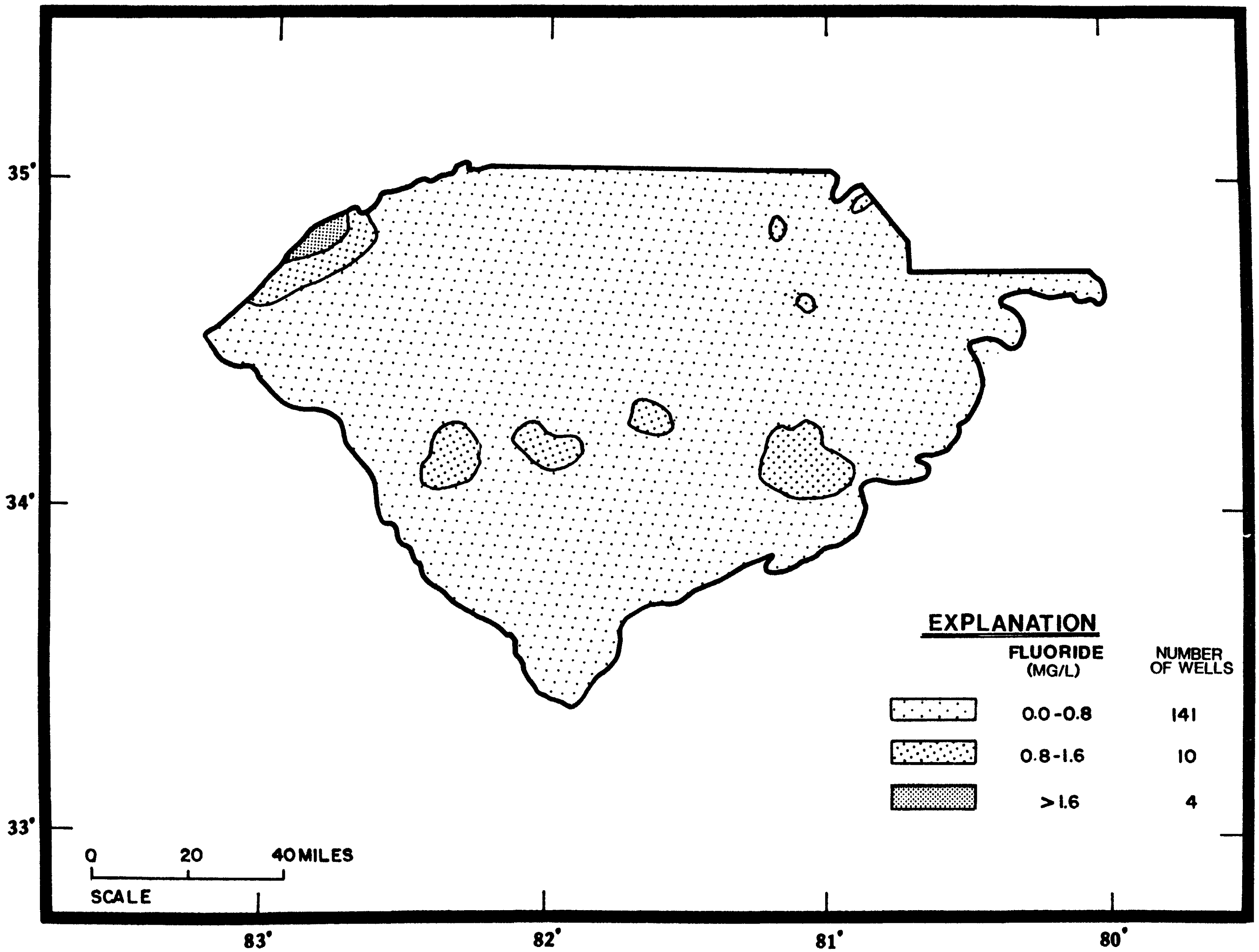

Figure 12.--Fluoride in water from bedrock aquifers in the South Carolina Piedmont.

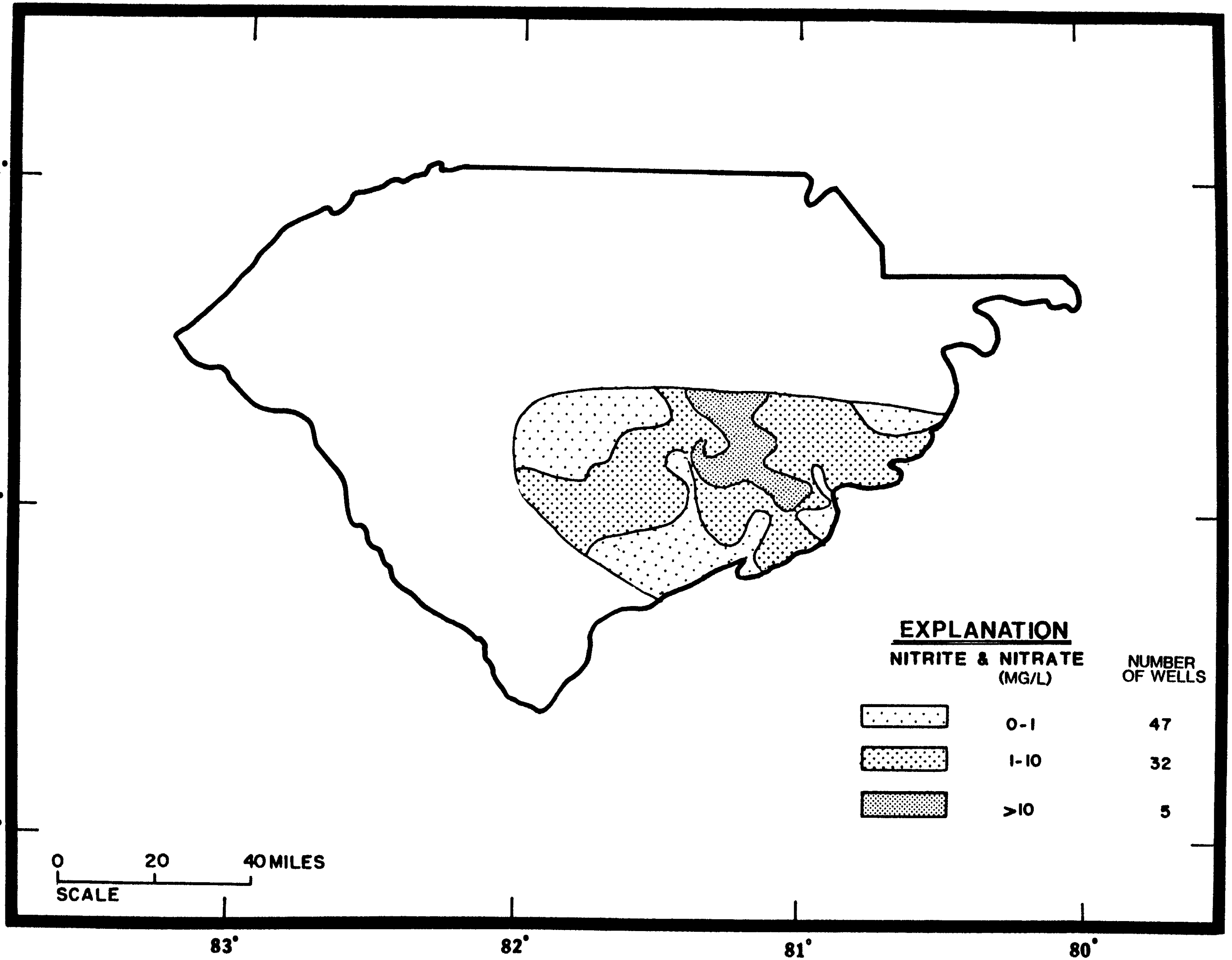

Figure 13.--Nitrite plus nitrate in water from bedrock aquifers in the South Carolina Piedmont.

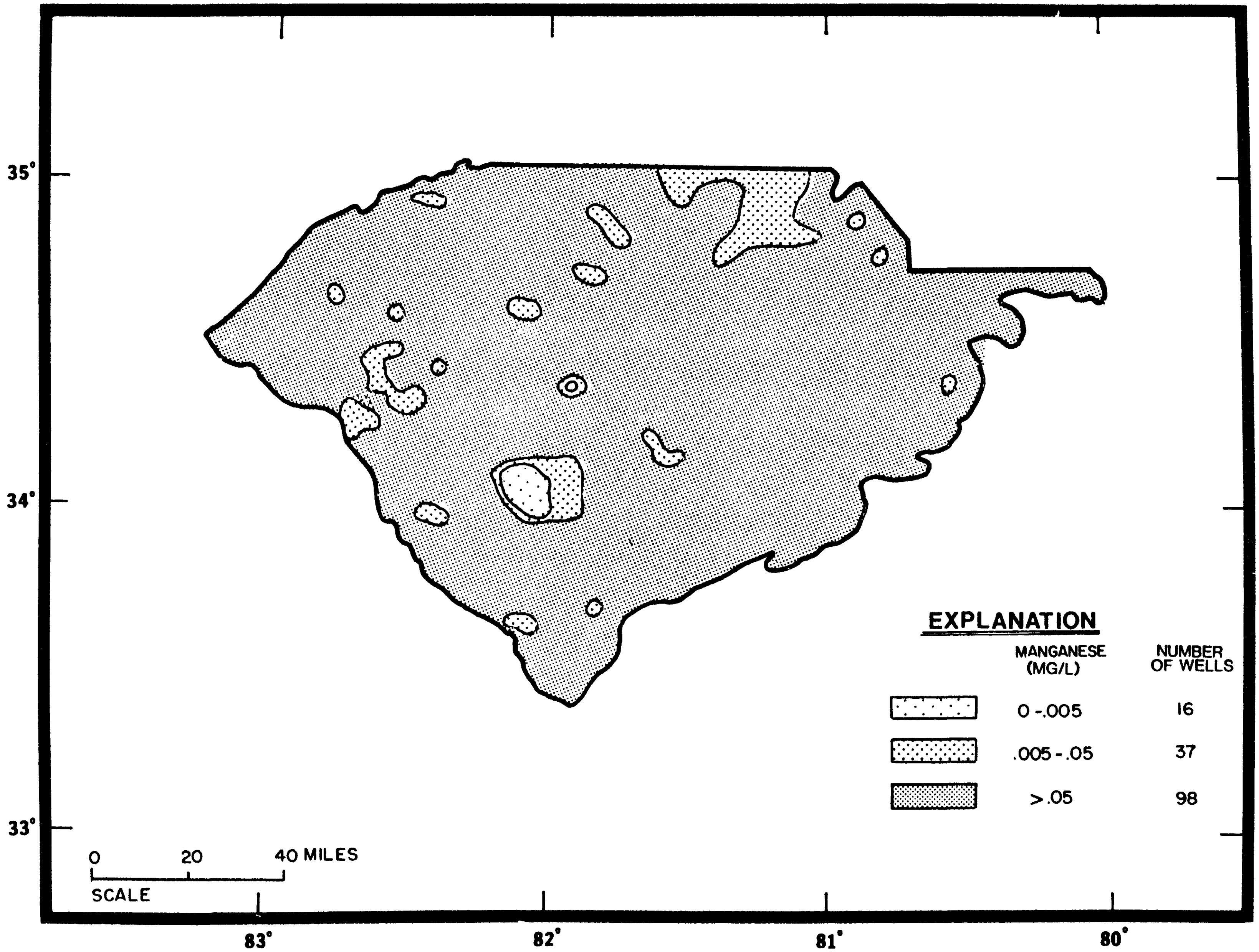

Figure 14.--Manganese in water from bedrock aquifers in the South Carolina Piedmont.

SUMMARY AND CONCLUSIONS

The geographic distributions of selected water-quality parameters in ground water from bedrock aquifers of the South Carolina Piedmont are presented in a series of computer-generated maps. Alkalinity, hardness, and concentrations of sodium, magnesium, and chloride generally are higher in ground water in the Carolina Slate Belt than in the ground water in the other geologic belts of the Piedmont, and lower in the Inner Piedmont belt. The other parameters studied had no discernable correlation with rock type.

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