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FLORIDA GEOLOGICAL SURVEY

Robert O. Vernon, Director

REPORT OF INVESTIGATIONS NO. 29

AQUIFERS AND QUALITY OF GROUND WATER ALONG THE GULF COAST OF WESTERN FLORIDA

By

Jack T. Barraclough and Owen T. Marsh

U. S. Geological Survey

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

in cooperation with the

FLORIDA GEOLOGICAL SURVEY,

ESCAMBIA COUNTY, SANTA ROSA COUNTY,

and the

CITY OF PENSACOLA

TALLAHASSEE

1962

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LETTER OF TRANSMITTAL

Florida Geological Survey

Tallahassee

August 8, 1962

Honorable Farris Bryant, *Chairman*
Florida State Board of Conservation
Tallahassee, Florida

Dear Governor Bryant:

The Division is publishing, as Florida Geological Survey Report of Investigations No. 29, a comprehensive report on the aquifers and quality of ground water along the gulf coast of western Florida, written by Mr. J. T. Barraclough, engineer, and Mr. Owen T. Marsh, geologist, U. S. Geological Survey. This report was prepared in cooperation with this department, Escambia County, Santa Rosa County, and the City of Pensacola.

Three separate aquifers have been identified, each being separated by clay aquicludes. With the definition of the geology in this area, it becomes possible to make some tentative plans for deep well waste disposal, as well as the wise and comprehensive management of the fresh water resources contained in the shallow aquifers.

Respectfully yours,

Robert O. Vernon, *Director and State Geologist*

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February 21, 1962

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AQUIFERS AND QUALITY OF GROUND WATER ALONG THE GULF COAST OF WESTERN FLORIDA

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ABSTRACT

A study of electric logs, well cuttings, and chemical analyses of water from wells in the western Florida Panhandle reveals the relation of the quality of ground water to the geology. Three aquifers separated by clay aquicludes underlie the panhandle west of the Choctawhatchee River: (1) the sand-and-gravel aquifer at the surface, (2) the upper limestone of the Floridan aquifer, and (3) the lower limestone of the Floridan aquifer. The remarkably soft and relatively unmineralized water in the sand-and-gravel aquifer supplies most of the wells in the western half of the area. In the eastern half of the area, where this aquifer is thin, most wells obtain water from the upper limestone of the Floridan aquifer. Electric logs suggest that some fresh water may be present at the top of the lower limestone of the Floridan aquifer in the area north and east of Fort Walton Beach.

Dissolved solids, chloride, and fluoride in water from the upper limestone of the Floridan aquifer increase in a southwesterly direction (downdip) across the area according to a simple, mappable pattern. Hardness of the water decreases downdip as a result of ion exchange by clays in the upper limestone. Areas of usable and unusable water have been delineated on maps.

Two water problems in the Fort Walton Beach area are brought to light by this study: (1) a sharp decline of water levels amounting to as much as 82 feet since 1936, and (2) incipient salt-water intrusion at the Fort Walton Beach Elementary School, induced by the drop in water levels. The magnitude of this decline probably is related to the low permeability of the clay in the upper limestone of the Floridan aquifer.

INTRODUCTION

PURPOSE AND SCOPE

The rapid growth of population in the western part of the Florida Panhandle in recent years has resulted primarily from three factors: (1) The abundance of excellent ground water has attracted more and more industries to the area; (2) two large military bases, the Naval Air Station at Pensacola and Eglin Air Force Base at Niceville, are in the area; and (3) the unsurpassed beaches, numerous waterways, and agreeable climate have been attracting greater numbers of tourists as well as permanent residents.

A key factor in both present and anticipated future growth is the supply of fresh ground water. The present use of ground water in the area probably exceeds 100 million gallons per day. The future development and efficient utilization of the ground-water resources requires a knowledge of both geologic and hydrologic conditions. For example, what water-bearing formations underlie the area? How deep is the fresh water? What is the chemical quality of the water? Is the water level rising, falling, or remaining constant? These are some of the questions that the authors of this report seek to answer.

This paper is a byproduct of an intensive investigation of the water resources of Escambia and Santa Rosa counties being made by the U.S. Geological Survey in cooperation with the Florida Geological Survey, Escambia and Santa Rosa counties, and the city of Pensacola.

LOCATION OF THE AREA

The area discussed in this report (fig. 1) includes about 2,370 square miles in the western part of the Florida Panhandle. It includes the southern half of the following counties: Escambia, Santa Rosa, Okaloosa, and Walton. This area extends about 74 miles along the gulf coast from Perdido Bay (near Pensacola) to the east end of Choctawhatchee Bay, and about 32 miles inland from the Gulf of Mexico, as far north as Crestview and De Funiak Springs.

PREVIOUS WORK

Prior to 1961 relatively little was known about the geology and ground water of westernmost Florida. A few reports contained information of a reconnaissance or strictly local nature. The earliest published report that describes the water resources of this area was by Sellards and Gunter (1912). During the following year, a report on the geology and ground water of the entire State by Matson and Sanford (1913) was published. Jacob and Cooper (1940, unpublished manuscript) made a detailed investigation of ground water in the Pensacola area; their report included a section on geology by Stubbs. Heath and Clark (1951) made a detailed investigation of the potential yield of ground water in the vicinity of Gulf Breeze near Pensacola. Chemical analyses of ground water in the area were prepared by Collins and Howard (1928) and by Black and Brown (1951). Cooke (1945) included in his "Geology of Florida" a reconnaissance of the area in which he described the marine terraces and gave data from wells. The first detailed geologic study of Escambia

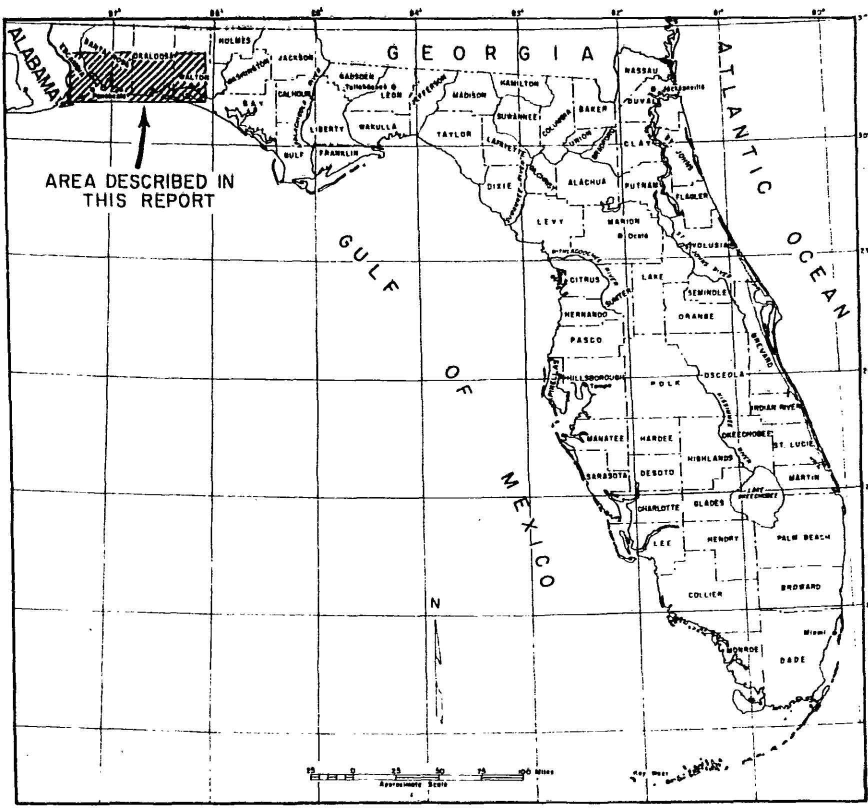

Figure 1. Location of area described in this report.

and Santa Rosa counties was made by Marsh (1962) in connection with a comprehensive investigation of the water resources of the area that is currently being made by the U.S. Geological Survey. An interim report of that investigation (Musgrove, Barraclough, and Marsh, 1961) summarizes the geology and water resources of the western half of the area discussed in the present paper.

ACKNOWLEDGMENTS

The writers would like to express appreciation to M. E. Batz and C. A. Witcher, Jr., of the Chemstrand Corp. for various courtesies extended; to Lehmon Spillers of Pensacola, as well as to Docie Bass and E. L. Thomason of Fort Walton Beach for supplying data on wells; and to Earl Campbell, Okaloosa County sanitarian, A. G. Symons of the Layne-Central Co., and Shelby Sanders of Shelby Sanders and Associates for furnishing chemical analyses of water samples.

GEOLOGY AND HYDROLOGY

GEOLOGIC SETTING

The part of the Florida Panhandle described in this paper lies in the Coastal Plain province and is situated along the north flank of the vast sinking trough known as the gulf coast geosyncline. Long-continued subsidence of this trough has resulted in the deposition of sand, clay, and limestone beds, most of which thicken toward the gulf. These beds dip about 30-35 feet per mile toward the southwest in the area of this report.

Fresh water occurs in parts of three principal aquifers: (1) the sand-and-gravel aquifer, (2) the upper limestone of the Floridan aquifer, and (3) the lower limestone of the Floridan aquifer (fig. 2). East of the Choctawhatchee River the limestone of the Floridan aquifer forms the land surface, which is pock-marked with countless sinkholes. West of the river the limestone slopes uniformly southwestward until at Pensacola it lies more than 1,200 feet below the surface. West of the Choctawhatchee River a westward-thickening wedge of sand and gravel underlies the land surface. Throughout most of the area two thick beds of clay separate the sand-and-gravel aquifer from the upper limestone of the Floridan aquifer. A thinner but more extensive bed of clay divides the Floridan aquifer into an upper limestone and a lower limestone (fig. 3). The lower two clay beds pinch out near the eastern border of the area, bringing the upper and lower limestones of the Floridan aquifer together and causing the sand-and-gravel aquifer to rest directly upon the Floridan aquifer. The uppermost clay bed ends abruptly farther west. The Floridan aquifer is underlain by impermeable clay and shale.

HYDROLOGIC PRINCIPLES

Part of the rain that falls on the land surface runs off into lakes and streams; part returns to the atmosphere by evaporation, either directly or through the leaves of plants *(evapotranspiration);* and part seeps into the ground to become *ground water*. A simple analogy would be to compare the ground with a pail of sand. If you sprinkle water on the sand (in imitation of rain) until the water rises nearly to the top of the sand, you have a rough example of ground water that occurs under water-table conditions. But to bring the analogy closer to reality, the pail must have a few holes in the sides and bottom so that the water is continually leaking out. Unless you keep sprinkling water on the sand, the water level—called the *water table*—will drop steadily lower and lower. Similarly, ground water keeps leaking away through seeps and springs into streams, lakes, and oceans. This subterranean water supply must be replenished periodically by rainfall (and snowmelt in northern areas) if the water table is to remain near a given level. The quantity of rainfall

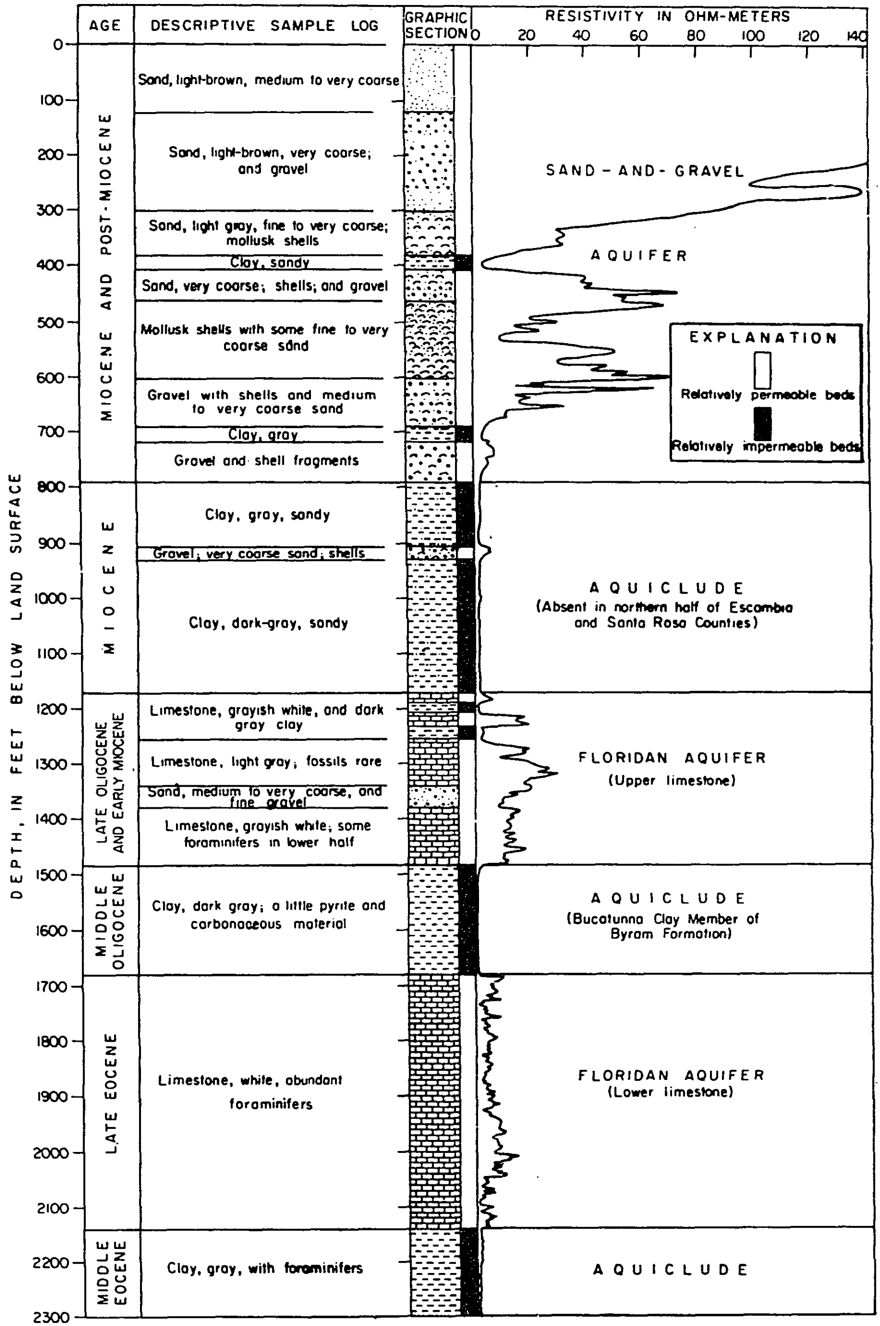

Figure 2. Aquifers and aquicludes along the gulf coast of western Florida as shown in representative test well near Pensacola.

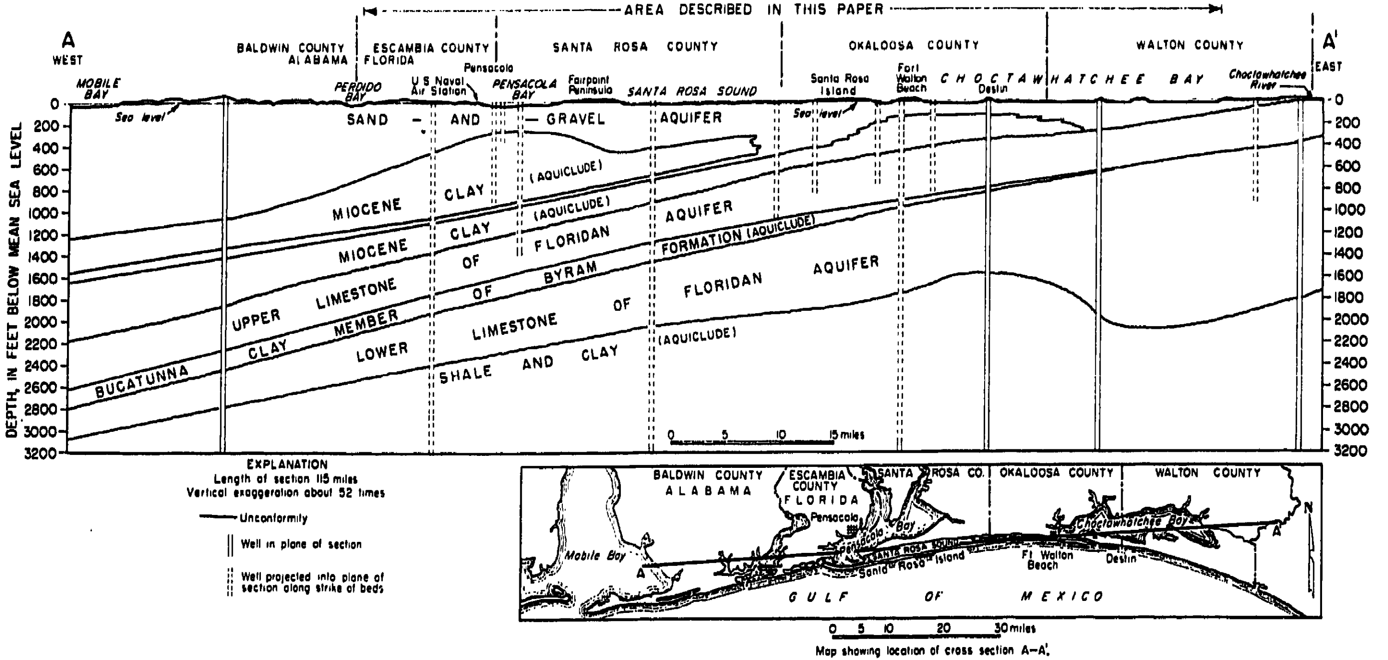

Figure 3. Geologic cross section A-A' along the gulf coast of western Florida.

varies from month to month and year to year in an unpredictable manner, although the average for a given period may be fairly constant. In times of above-average rainfall the water table rises, and in times of below-average rainfall the water table declines. Figure 4 shows this relationship.

The type of ground water just described is called *nonartesian*. Commonly, however, the water is confined in a permeable bed of sand or limestone, for example, that is sandwiched between relatively impermeable beds, such as clay. Such confined water is under artesian pressure. Ground water is termed *artesian* if it is confined under enough pressure to make it rise in a well above the top of the permeable bed that contains the water. It is not necessary that the water rise to or above the land surface to be classified as artesian. A rough demonstration of water under artesian pressure can be made with a 3-foot piece of garden hose filled with water. If you hold your thumb over one end and raise the other end, you can feel the pressure against your thumb. But if someone were to cut a small hole into the upper surface of the hose near its middle, a jet of water would shoot upward, just as water rises in a well drilled through a confining bed of clay into a water-bearing bed of sand or limestone. The height to which water will rise in an artesian well is called the *artesian pressure head.*

An *aquifer* is a formation (such as a thick layer of sand or limestone), a part of a formation, or a group of interconnected formations that are permeable enough to transmit usable quantities of water. An *aquiclude* is a bed (such as clay or shale) that is too impermeable to transmit water in usable quantities. Areas where aquifers are replenished are called *recharge areas,* and areas where aquifers lose water are called *discharge areas.*

AQUIFERS

SAND-AND-GRAVEL AQUIFER

The wedge-shaped deposit of sand and gravel that underlies the land surface west of the Choctawhatchee River is known as the sand-and-gravel aquifer (Musgrove, Barraclough, and Marsh, 1961). The aquifer is exposed from Escambia County, Alabama, on the north to the Gulf of Mexico on the south, and from the Choctawhatchee River on the east at least to Mobile Bay on the west. Although the aquifer generally thickens downdip to the west and southwest from its thin outcrop along the Choctawhatchee River, considerable variations in thickness occur throughout the area, as indicated in figure 3: 150 feet at Fort Walton Beach, 500 feet at the Santa Rosa-Okaloosa County line, 300 feet in downtown Pensacola, 700 feet at Perdido Bay, and 1,200 feet at Mobile Bay. The aquifer overlies thick layers of relatively impermeable clay everywhere in the area except the eastern part, where it rests upon the upper limestone of the Floridan aquifer.

The sand-and-gravel aquifer consists predominantly of white to reddish brown quartz sand ranging from very fine to very coarse and in places mixed with granules and small pebbles of quartz and chert. Lenses and stringers of gravel and clay occur throughout the aquifer. The clay lenses range from a few inches to several tens of feet in thickness and may extend from a few feet to several miles in length. Impermeable layers of hardpan also are found within the sand-and-gravel aquifer. This dense, rusty brown material—referred to simply as "rock" by local drillers—is formed through cementation of sand by iron oxides precipitated from ground water. It occurs extensively throughout western Florida and southern Alabama and ranges in thickness from a fraction of an inch to 3 or 4 feet. Little is known about the lateral extent of these layers, but probably no layer extends for more than a few thousand yards.

Fossils, including snails, clams, and microscopic animals, indicate that the lower part of the sand-and-gravel aquifer is of Late Miocene Age (roughly 10-15 million years old); the upper part is much younger.

The sand-and-gravel aquifer contains ground water under both artesian and water-table conditions. Where the water is confined by clay or hardpan, it is under artesian pressure. Where the water is not confined by impermeable layers, it is under water-table conditions.

Changes of the water level within the sand-and-gravel aquifer are the result of both natural and artificial causes. The principal natural cause is variation in the amount of rainfall which affects recharge of the aquifer. Manmade causes include intensive pumping and the erection of structures, such as dams or canals, which alter the natural pattern of drainage or infiltration. Figure 4 compares variations in the annual rainfall at Pensacola with changes of the artesian pressure head in a well drilled into the upper limestone of the Floridan aquifer, as well as with changes of the water level in a well drilled into the sand-and-gravel aquifer. The hydrograph for the latter well (Santa Rosa 10) shows water-level changes from 1947 to 1960 in an area where this aquifer is virtually unaffected by pumping. The graph shows close correlation of ground-water levels with rainfall. The high water levels from 1947 to 1949 reflect a very wet period, the lowered levels from 1950 to 1955 indicate a relatively dry period, and the rise of the water table from 1956 to 1960 reflects the increase in rainfall during that period. The 1959-60 water level is about the same as it was in 1948. The maximum change observed during the period of record was 13 feet, the highest water level at 56 feet above sea level in 1949 and the lowest water level at 43 feet above sea level in 1955.

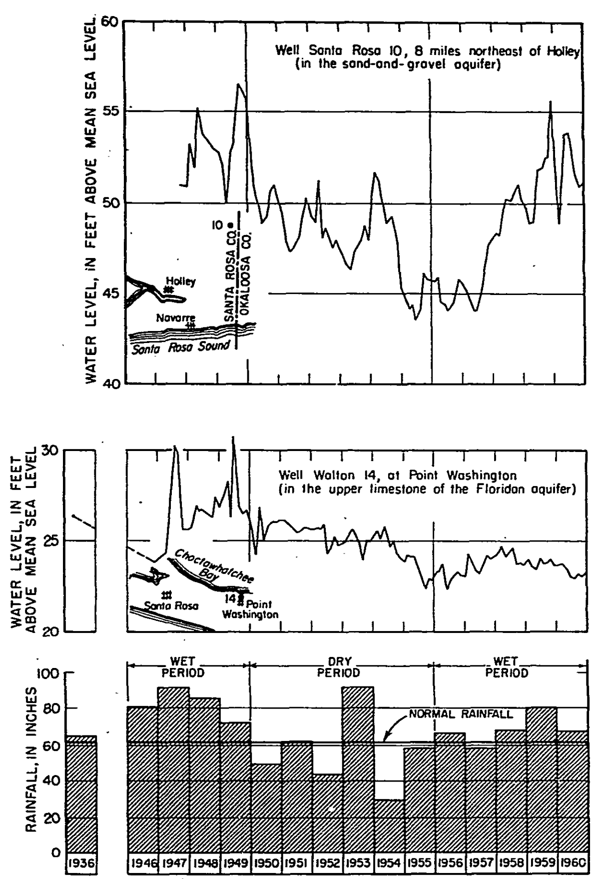

Figure 4. Water levels in a well in the sand-and-gravel aquifer and a well in the Floridan aquifer compared with rainfall at Pensacola.

Wells in the sand-and-gravel aquifer furnish almost all the ground water used in Escambia and Santa Rosa counties, as well as a substantial part of the smaller supplies in Okaloosa County. The temperature of water from the aquifer increases with depth from about 68°F near the ground surface to about 74°F at about 400 feet below the land surface. The aquifer becomes less important in the eastern half of the area because larger quantities of fresh water are obtainable from the upper limestone of the Floridan aquifer at moderate depths.

FLORIDAN AQUIFER

In peninsular Florida the limestone formations that range in age from Eocene to Miocene are collectively referred to as the Floridan aquifer. Athough it is much thinner than in central Florida, this aquifer also underlies the entire Florida Panhandle and southwestern Alabama at least as far as Mobile Bay.

East of the Choctawhatchee River the Floridan aquifer forms the land surface, which is dotted with sinkholes. West of the river the top of the aquifer slopes uniformly southwestward (fig. 5) until at the eastern shore of Mobile Bay it lies about 2,100 feet below the land surface. Thus, the top of the Floridan aquifer has an average apparent dip (along section A-A′, fig. 3) of about 20 feet per mile from east to west.

Within the area of this report the Bucatunna Clay Member of the Byram Formation separates the Floridan aquifer into an "upper limestone" and a "lower limestone." The Bucatunna thins to the east and finally pinches out a few miles east of Destin. The maximum thickness of the Floridan aquifer within the area, including both the upper and the lower limestones, is about 1,900 feet in southern Walton County.

Upper limestone. Along section A-A′ (fig. 3) between the Choctawhatchee River and Mobile Bay the upper limestone ranges from 350 to 450 feet in thickness. The upper limestone thins northward from the Gulf of Mexico (fig. 6). This thinning is much more rapid in the eastern part of the area than in the western. The thinnest known section of the upper limestone (45 feet) is in southern Okaloosa County, north of Niceville: the thickest known section (455 feet) is near the mouth of Perdido Bay.

The upper limestone is composed of light gray to brown dolomitic limestone and some dolomite which has a distinctive "spongy-looking" texture and contains abundant shell fragments of clams, snails, and microscopic animals. In much of the area the upper limestone contains layers of green and brown clay. In some wells this limestone section must be screened and gravel packed, or the clay beds cased off, to prevent the water that is withdrawn from becoming turbid.

The upper limestone of the Floridan aquifer is recharged directly by rain where the limestone lies at or near the surface of the ground, or indirectly by percolation from the sand-and-gravel aquifer. The Floridan aquifer discharges water continuously by seepage into the gulf, by upward leakage, and by pumping or flowing from wells.

The water in the Floridan aquifer within the area of study is under artesian pressure. Changes in the artesian pressure head are dependent upon variations in rainfall and the quantity of water withdrawn by wells. Pumping from the upper limestone has the greatest effect on the artesian pressure in the central part of the area.

Figure 4 shows the artesian pressure head in a well drilled into the upper limestone of the Floridan aquifer at Point Washington, near the east end of Choctawhatchee Bay. Although the well is in an area where

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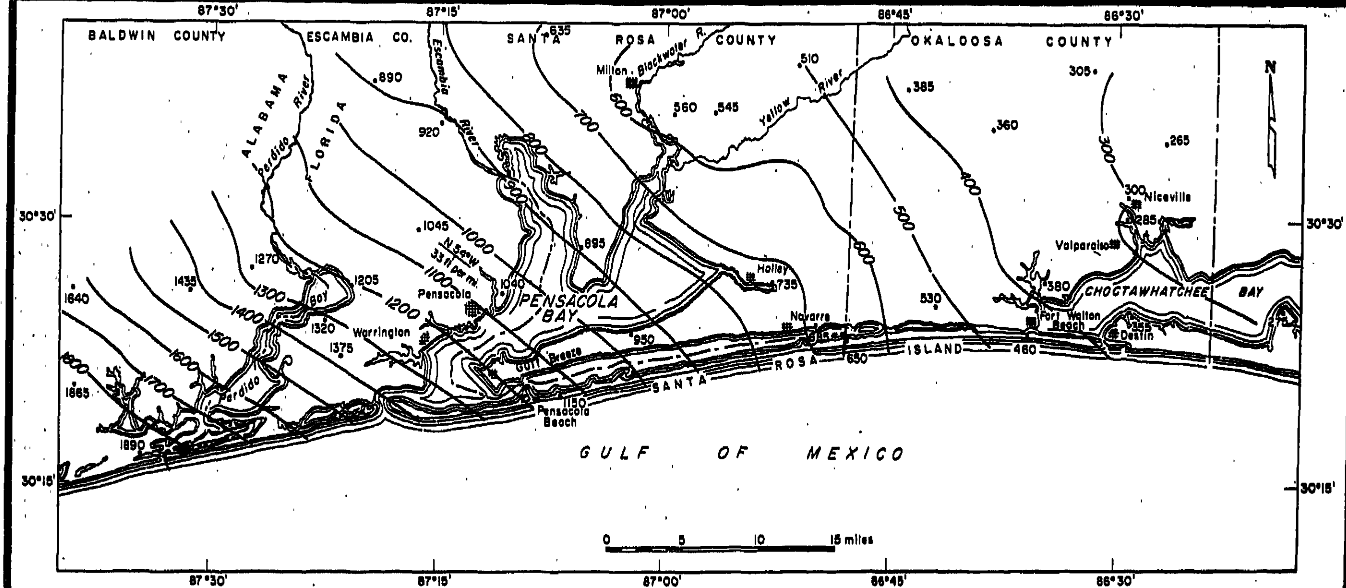

EXPLANATION

.360
Well
Number indicates altitude of top of limestone of the Floridan aquifer in feet below mean sea level

——500——
Contour of top of Upper limestone of the Floridan aquifer, in feet below mean sea level
Contour interval, 100 feet

Base taken from Army Map Service topographic quadrangle 1:250,000

Figure 5. Western Florida gulf coast showing structure contours on top of the upper limestone of the Floridan aquifer.

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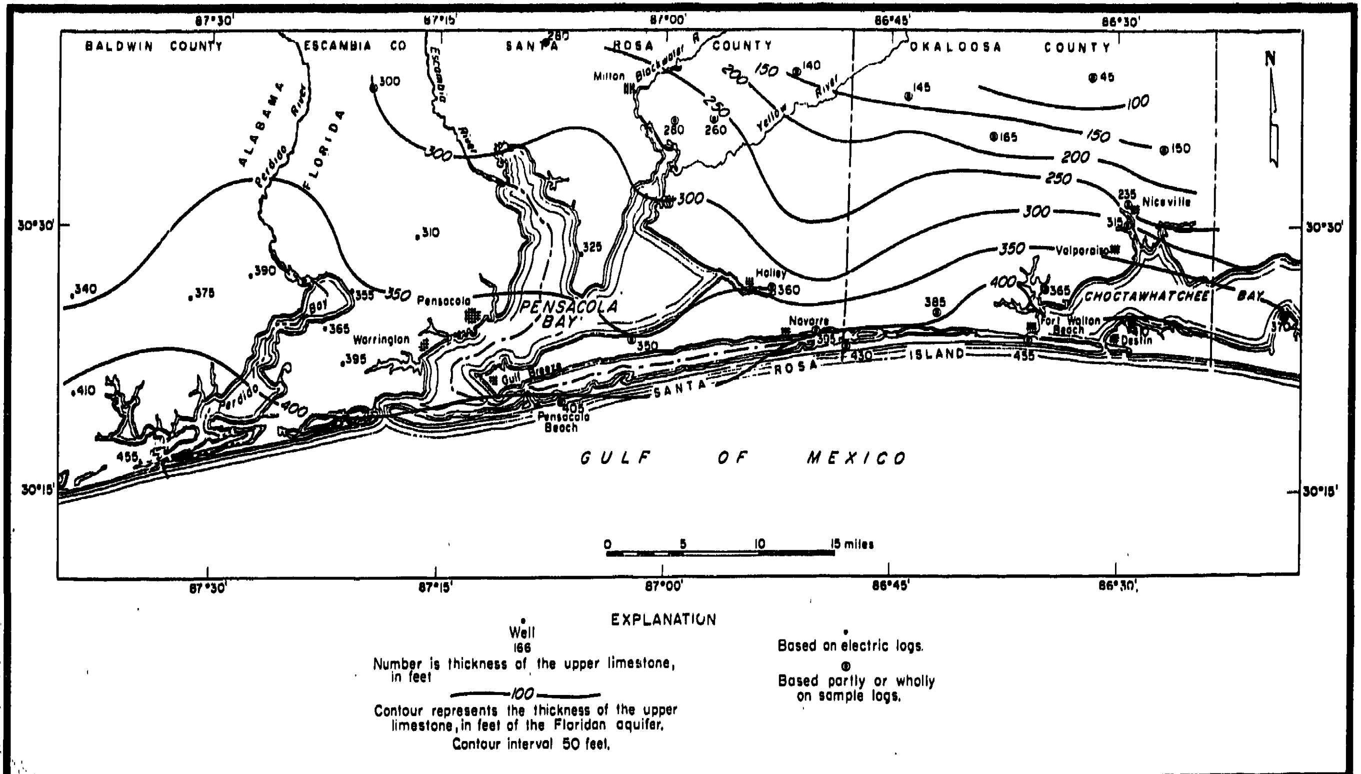


Base taken from Army Map Service topographic quadrangle 1:250,000

Figure 6. Western Florida gulf coast showing thickness of the upper limestone of the Floridan aquifer.

very little water is pumped from the aquifer, the head has dropped about 3 feet since 1948. This lowering may be the result of heavy pumping from the upper limestone elsewhere in the area. From 1946 to 1949 the artesian pressure rose, from 1949 to 1956 it declined slightly, and from 1956 to 1960 it rose slightly. These trends reflect periods of abundant or deficient rainfall.

Formerly, artesian wells in low areas in the Fort Walton Beach area would flow but they no longer flow because of the considerable decline in the artesian pressure head. This decline doubtless has been caused by increased use of water, especially by Eglin Air Force Base, the city of Fort Walton Beach, and other nearby water users. In 1936, the artesian pressure head in wells tapping the upper limestone at Fort Walton Beach averaged about 56 feet above sea level. By 1960, however, the average artesian pressure head had declined to about 18 feet below sea level. This means that the average net decline of the artesian pressure head in the upper limestone at Fort Walton Beach has been about 74 feet since 1936.

Figure 7 illustrates part of this striking decline. The top graph shows that the artesian pressure head in a well that is 17 miles northwest of Fort Walton Beach has declined about 16 feet since 1948. The hydrograph shows very little correlation with rainfall. The gradual decrease of the artesian pressure may be attributed mainly to pumping. The middle graph shows the decline of the artesian pressure in a well that is 7 miles north of Fort Walton Beach. During the period of record the average decline was about 30 feet. The bottom graph represents the most striking decline of artesian pressure in the area, in a well (Okaloosa 3) at the Fort Walton Beach Elementary School. This decline was 95 feet between 1936 and 1957. The artesian pressure head recovered about 13 feet from August 1957 to December 1960. It should be noted, however, that this recovery was a result of above-average rainfall from 1958 to 1960. If rainfall returns to or below average and present pumping continues, the downward trend of the artesian pressure head may be expected to continue. In 1951 the well stopped flowing and since then has flowed only intermittently for short periods. The artesian pressure head dropped below sea level in 1954 and has remained below this level most of the time since then. Low points on the hydrograph of Okaloosa 3 generally reflect the increased use of water during the summer for watering lawns and other purposes.

Figure 8 is a contour map of the area showing the net decline of artesian pressure in wells tapping the upper limestone, from January 1948 to September 1960. The map is based on an analysis of the hydrographs of wells in the area. It shows that the greatest decline, about 56

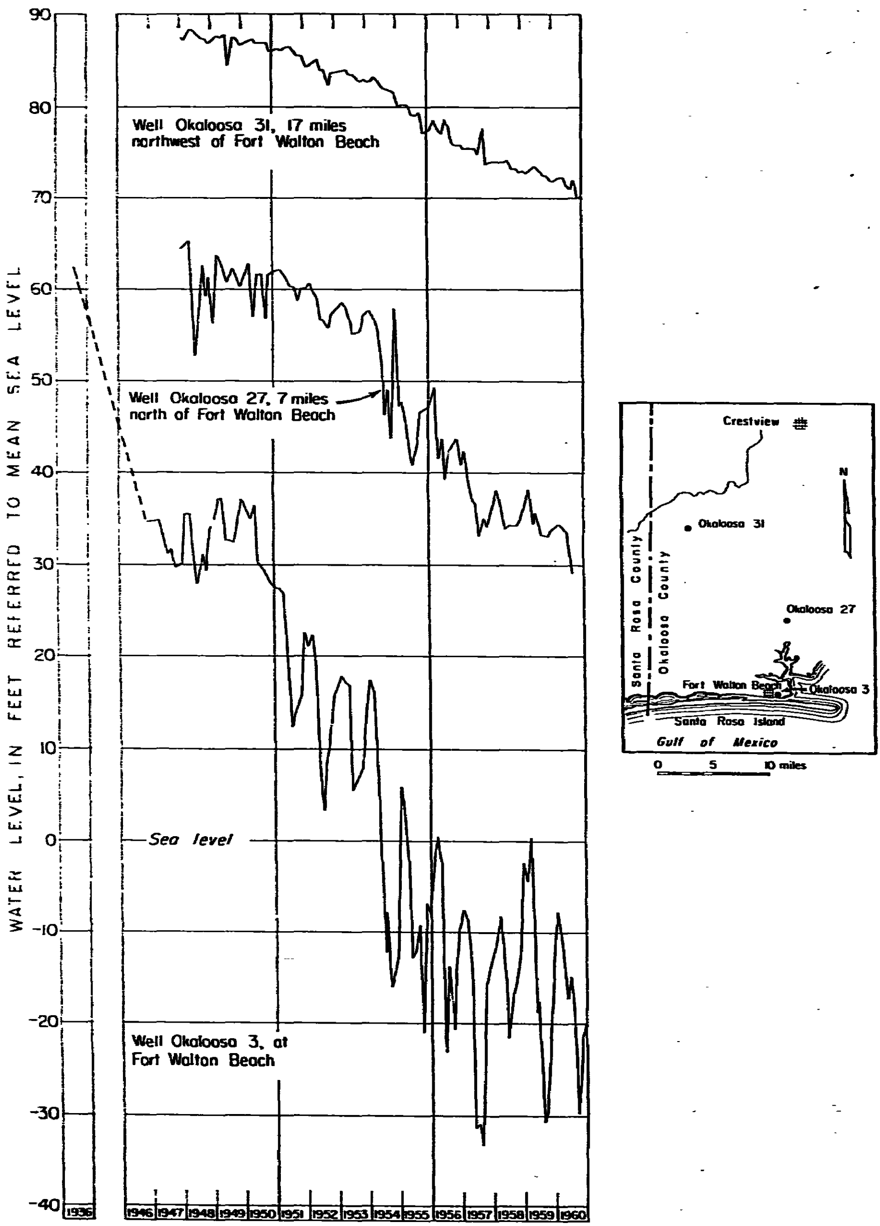
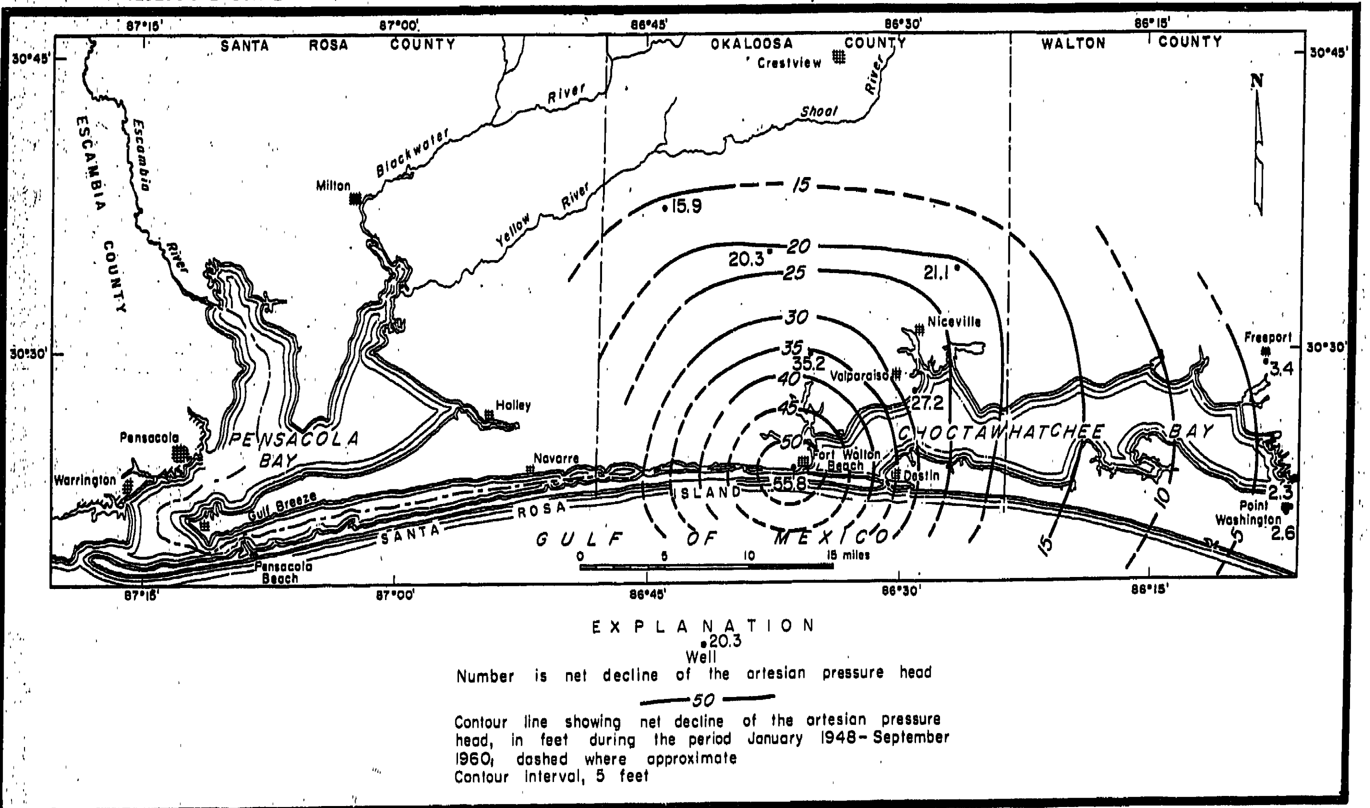


Figure 7. Hydrographs of three wells tapping the upper limestone of the Floridan aquifer, showing decline of artesian pressure head in southern Okaloosa County.



Base taken from Army Map Service topographic quadrangle 1:250,000

Figure 8. Western Florida gulf coast showing net decline of artesian pressure head in wells tapping the upper limestone of Floridan aquifer, January 1948 to September 1960.

feet, was at Fort Walton Beach, and the smallest decline, about 2 feet, was at Point Washington, near the east end of Choctawhatchee Bay. It is interesting to note that the water level in a well drilled into the sand-and-gravel aquifer 8 miles northeast of Holley and located well within the cone of depression of water in the upper limestone of the Floridan aquifer (fig. 4) had a net rise of 1.3 feet during this same period.

Little is known about the water-transmitting and water-storing abilities of the upper limestone. Well-yield figures indicate that the aquifer transmits water readily in some places and reluctantly in others. In some localities large quantities of clay have been found and probably the clay fills some voids in the limestone. This clay may have been deposited in the voids during later advances of the sea, after solution cavities had been formed. Electric logs and well samples also indicate that fairly continuous beds of clay are present in the upper limestone.

The drawdown in the Fort Walton Beach area (fig. 8) appears to be much greater than would be expected from the amount of pumping in the area. The presence of the clay in the upper limestone provides a reasonable explanation. This clay would reduce both the permeability and the effective porosity of the aquifer, and would result in unusually large drawdowns. In addition, the erratic occurrence of clay-filled voids would explain the great variation observed in the yield of otherwise similar wells.

The temperature of water from the upper limestone of the Floridan aquifer ranges from about 70°F in the eastern part of the area to as high as 95°F near Pensacola.

Lower limestone. The lower limestone of the Floridan aquifer is much more variable in thickness than the upper limestone. From its maximum thickness of about 1,500 feet in southern Walton County, it thins abruptly to about 700 feet just west of Destin. The limestone continues to thin to the west, although at a much more uniform rate, until at Mobile Bay it is less than 300 feet thick. The limestone also thins southward, toward the gulf, from about 1,000 feet in northern Santa Rosa County to about 450 feet in central Escambia County. Thus, unlike most geologic formations along the gulf coast, this limestone thins rather than thickens downdip. The lower limestone is white to grayish cream and is rather soft and chalky. It consists mainly of microscopic animals, corals, sand dollars, clams, and many other types of shells. Thick, lens-shaped masses of hard, light gray shale and siltstone, as well as a small amount of gray clay, are irregularly distributed in the lower half of the limestone.

AQUICLUDES

In most of the area the aquifers are separated by relatively impermeable formations (aquicludes) which greatly retard the upward and downward movement of ground water.

MIOCENE CLAY

Two thick masses of clay (Marsh, 1962) separated by a thin bed of sand lie between the sand-and-gravel aquifer and the Floridan aquifer over most of the area. Along section A-A′ (fig. 3) the upper clay thickens from about 300 feet at Mobile Bay to about 670 feet at Pensacola. East of Pensacola the clay thins, and just west of the Santa Rosa-Okaloosa County line it terminates rather abruptly by interfingering with the sand-and-gravel aquifer. The lower clay thins from about 500 feet at Mobile Bay to 150 feet at the Santa Rosa-Okaloosa County line. East of this point it thickens again to about 300 feet at Fort Walton Beach and then thins and finally pinches out in southwestern Walton County. Both the upper and lower clays appear to interfinger with the sand-and-gravel aquifer about 20 miles north of Pensacola. The sand bed between the two clays thickens from about 30 feet at Pensacola to about 90 feet at Mobile Bay and about 130 feet just northwest of upper Perdido Bay. A flowing well in Warrington obtains water from this bed of sand.

Fossil clams, snails, and shells of microscopic animals date these thick clays as late Miocene in age (10 to 15 million years old). The clay is gray to dark gray and contains much silt, very fine to coarse sand, and a little gravel.

BUCATUNNA CLAY MEMBER

Throughout most of the area the upper and lower limestones of the Floridan aquifer are separated by the Bucatunna Clay Member of the Byram Formation (Marsh, 1962). This clay bed differs from the Miocene clays discussed above in being much thinner, more uniform in thickness, and more regionally extensive. The Bucatunna underlies most of westernmost Florida and parts of Alabama, Mississippi, and Louisiana. Within the area discussed in this report the Bucatunna attains a maximum thickness of 215 feet just north of Escambia Bay. It thins northward and eastward, pinching out in southern Walton County, 17 miles west of the Choctawhatchee River.

The Bucatunna consists of soft gray silty to sandy clay containing a variety of fossils. The clay rests unconformably upon the eroded surface of the lower limestone of the Floridan aquifer and is overlain conformably by the flat, even base of the upper limestone, with which it interfingers locally.

MIDDLE EOCENE CLAY AND SHALE

In the western part of the Florida Panhandle the limestones of the Floridan aquifer are underlain by gray clay and shale of Middle Eocene Age (roughly 50 million years old). The top of this formation dips generally southwestward and undulates broadly. Eastward along the coast from Mobile Bay the top of the formation is relatively flat, except in southern Walton County where it plunges abruptly downward.

CHEMICAL QUALITY OF GROUND WATER

Ground water contains various amounts of substances dissolved from the air, soil, or rocks, as well as mineral matter introduced from bodies of surface water such as streams and oceans. For example, salt water may enter the aquifer from the sea. The amount of such substances dissolved by ground water depends on the climate, type of soil or rock, and other factors. The chemical content of ground water differs considerably from one aquifer to another and even from place to place within a given aquifer. Ground water along the gulf coast of western Florida is of several types: Some is so free of dissolved substances that it can be used even in automobile batteries in place of distilled water; some, although mineralized to a moderate degree, can be made entirely satisfactory for most uses by simple treatment; and some is so highly mineralized that it cannot be made suitable for ordinary use by any practical treatment.

DEFINITIONS AND GENERAL DISCUSSION

The standard unit for reporting the concentration of various mineral constituents in ground water is *part per million* (ppm), which means that if a sample of water is reported to contain one part per million of iron, a million pounds of such water would contain one pound of iron.

The term *total dissolved solids* indicates approximately the total quantity of mineral matter in solution. The U.S. Public Health Service (1946) recommends that the concentration of dissolved solids in a drinking-water supply should not exceed 500 ppm, although water with 1,000 ppm is acceptable where nothing better is available. Water with more than 1,000 ppm of dissolved solids usually contains enough of some constituents to produce a noticeable taste or to make the water unsuitable for many domestic and industrial uses.

Hardness of water is caused principally by compounds of calcium and magnesium. Hardness of water is generally recognized by the amount of soap required to produce lather. Many U.S. Geological Survey reports have classified water ranging in hardness from 0 to 60 ppm as soft, from 61 to 120 ppm as moderately hard, from 121 to 200 ppm as hard, and more than 200 ppm as very hard.

The *chloride* content of ground water is a good indication of the extent to which it has been contaminated by sea water, for about 90 percent of the dissolved-solids content of sea water consists of chloride salts. Ground water with a chloride content of less than 30 ppm generally has not been contaminated by water from present or ancient seas. Chloride salts do not usually affect the potability of water except when present in quantities sufficient to cause a salty taste. The U.S. Public Health Service recommends 250 ppm of chloride as the upper limit for public drinking water supplies. Water with a chloride content of 500 ppm tastes salty to most people. Water with a chloride content of more than about 800 ppm may cause damage to plants, shrubs, and irrigated crops. In addition, a high-chloride content makes the water more corrosive.

The *fluoride* content of water used for drinking has aroused considerable public interest in recent years. Evidence indicates that the presence of about 1.0 ppm of fluoride in drinking water decreases the occurrence of dental caries (tooth decay) when the water is habitually consumed by children during the period of formation of their teeth. For this reason, fluoride is added to many public water supplies. Drinking water containing more than 1.5 ppm of fluoride may cause dental fluorosis (mottled enamel) in children's teeth. The U.S. Public Health Service (1946) specifies 1.5 ppm of fluoride as the maximum concentration allowable for water that is to be used for drinking.

Iron is dissolved by ground water and surface water (streams, lakes, and oceans) from nearly all rocks and soils and from iron pipes. A concentration of more than about 0.3 ppm of iron in water is objectionable as it stains porcelain, plumbing fixtures, and clothing; it imparts an undesirable taste to the water; and upon oxidation it forms a reddish brown sediment. Excess iron usually can be removed from water by aeration and filtration, but some water supplies require the addition of hydrated lime or soda ash. Along the gulf coast of western Florida, the concentration of iron in the ground water varies considerably from place to place and from one depth to another.

Hydrogen sulfide gas is present in ground water in some areas and gives the water a distinctive taste and odor. Water containing it are usually called "sulfur water." This gas, which is probably caused by the reduction of sulfates, can be removed by aerating the water, by chlorination, or by allowing it to stand in an open container.

Carbon dioxide in water from the sand-and-gravel aquifer causes the water to be acidic and therefore corrosive. Most industries and municipalities in the western part of the Florida Panhandle treat the water from this aquifer to reduce its corrosiveness in order to protect water pipes, water heaters, and other metallic objects with which the water comes into contact.

WATER IN THE SAND-AND-GRAVEL AQUIFER

Water in the sand-and-gravel aquifer is not only abundant but also extraordinarily soft and relatively unmineralized. The availability of a water supply of such excellent quality is the prime reason that major industries, such as the Chemstrand Corp. and St. Regis Paper Co., have chosen to locate in this part of the State. The Columbia National Corp. extracts zirconium from minerals mined at Starke, Florida, and transports the ore 345 miles to its processing plant in Santa Rosa County in order to utilize ground water in the area.

Dissolved solids. The dissolved-solids content of water from the sand-and-gravel aquifer in this area generally is extremely low, ranging from 15 to 40 ppm. However, water from this aquifer in some localities may contain as much as 300 ppm of dissolved solids.

Hardness. Water from the sand-and-gravel aquifer is exceptionally soft, generally containing 4 to 30 ppm of calcium and magnesium carbonates. In places, water from deeper parts of this aquifer may be considerably harder, containing as much as 150 ppm of these carbonates.

Chloride. The chloride content of water from the sand-and-gravel aquifer generally ranges from 2 to 30 ppm except where salty water has not been completely flushed from the aquifer or where lateral encroachment from salt-water bodies has occurred.

Fluoride. The water from the sand-and-gravel aquifer usually contains less than 0.2 ppm fluoride.

Iron. The iron content of water from the sand-and-gravel aquifer ranges from 0.06 to 4.9 ppm, although it is usually less than 0.25 ppm.

Dissolved gases. Water from the sand-and-gravel aquifer contains enough carbon dioxide to make the water acidic. Some water from this aquifer contains hydrogen sulfide in solution.

WATER IN THE FLORIDAN AQUIFER

The upper limestone of the Floridan aquifer is of more economic importance to the area than the lower limestone as a source of fresh water, for both present and future use. Few, if any, wells in the area obtain water from the lower limestone, whereas the upper limestone is the principal aquifer for wells in the eastern part of the area.

UPPER LIMESTONE OF THE FLORIDAN AQUIFER

Water in the upper limestone of the Floridan aquifer is suitable for most uses in the eastern two-thirds of the area. However, increasing concentrations of dissolved solids, chloride, and fluoride in the western third of the area makes the water unsuitable for most purposes.

Dissolved solids. In the western part of the Florida Panhandle, the dissolved-solids content of water from the upper limestone ranges from 92 ppm at De Funiak Springs to 3,960 ppm at Pensacola Beach. As shown in figure 9, dissolved-solids content increases in a southwesterly direction across the area. In the region between De Funiak Springs, Crestview, Holley, Fort Walton Beach, and Freeport, water from the upper limestone contains less than 500 ppm of dissolved solids. The dissolved-solids content increases toward Point Washington and in a small area in Fort Walton Beach, as well as southward and westward from Holley. At Pensacola, Gulf Breeze, and Pensacola Beach, the dissolved-solids content of water from the upper limestone exceeds 1,000 ppm (fig. 9).

Hardness. Figure 10 shows that the hardness of water from the upper limestone ranges from 24 to 146 ppm across the area. The hardest water occurs in the area between Crestview and Destin (including Niceville and Valparaiso) and around Point Washington. Moderately hard water (hardness range from 60-120 ppm) from the upper limestone is found at Pensacola, Gulf Breeze, Crestview, De Funiak Springs, and Freeport. Soft water (hardness range 0-60 ppm) is found at Fort Walton Beach, Destin, Navarre, and Holley.

The dissolved-solids content of the water from the upper limestone increases in a southwesterly direction within the area (fig. 9). It would be reasonable to expect the water to become increasingly harder in this direction also, for the hardness of ground water in limestone usually increases as the dissolved-solids content increases. This actually happens in the area between De Funiak Springs and Niceville and around Point Washington. However, from Niceville to Fort Walton Beach the hardness decreases rather abruptly; and at Pensacola and Pensacola Beach, where the water is highly mineralized, it is only moderately hard.

A possible explanation for this decrease of hardness may be natural softening of the water by ion exchange between the water and clay minerals, as considerable clay occurs in the upper limestone of the Floridan aquifer. Glauconite, an ion-exchange mineral commonly found in marine sediments, also has been noted in many well cuttings from this area. Carlston (1942, p. 16) suggests that the increase in bicarbonate content of water from northern Alabama is caused by carbon dioxide reacting with calcium and magnesium carbonates in the sediments. The calcium and magnesium ions that were taken into solution by this reaction are exchanged for sodium ions on glauconite and on clay minerals. Such a process would explain the softening of the water and the increase in sodium and bicarbonate ion contents.

A less important process that may tend to reduce the hardness of the water is indirectly a result of the dip of the upper limestone. In general, where the top of the upper limestone is more than 400 feet below sea level, the water in it is softer than farther updip. The temperature of the ground water down to a depth of about 50 feet is usually about the same as the average annual temperature of the air, which at Pensacola is about 68°F. Below a depth of 50 feet the temperature of ground water increases steadily downward for a considerable distance. In the western Florida Panhandle the temperature of ground water increases about 1°F for each 50 to 80 feet of depth. Thus, the temperature of water in the upper limestone of the Floridan aquifer increases in a southwesterly direction as the aquifer gets deeper. In the areas where the water is relatively soft, its temperature is at least 75°F. As water becomes warmer the amount of carbon dioxide gas that it can hold in solution decreases. The less carbon dioxide in the water, the smaller the amount of calcium and magnesium carbonate that can remain in solution. Therefore, as the temperature of the water increases, these carbonates tend to precipitate out of solution, leaving the water softer.

Chloride. The chloride content of water from the upper limestone of the Floridan aquifer ranges from 2 to more than 2,000 ppm. Figure 11 shows how the chloride content varies in the area. The chloride concentration is very low between Crestview, De Funiak Springs, and Niceville, and increases in a southwesterly direction. The 250-ppm contour crosses Fairpoint Peninsula west of Navarre and crosses Santa Rosa Island near the Santa Rosa-Okaloosa County line. Except in a small area at Fort Walton Beach and another south of Point Washington, the chloride content of water east of this contour meets the U.S. Public Health Service recommended standards for a public supply. West of the 250-ppm contour much of the water from the upper limestone is too salty for a public supply.

This study revealed evidence of incipient salt-water encroachment in the upper limestone of the Floridan aquifer in a small area at Fort Walton Beach. During 1948, the chloride content of water from the well at the Fort Walton Beach Elementary School was determined at three different times to be 70, 68, and 72 ppm. On October 7, 1960, the

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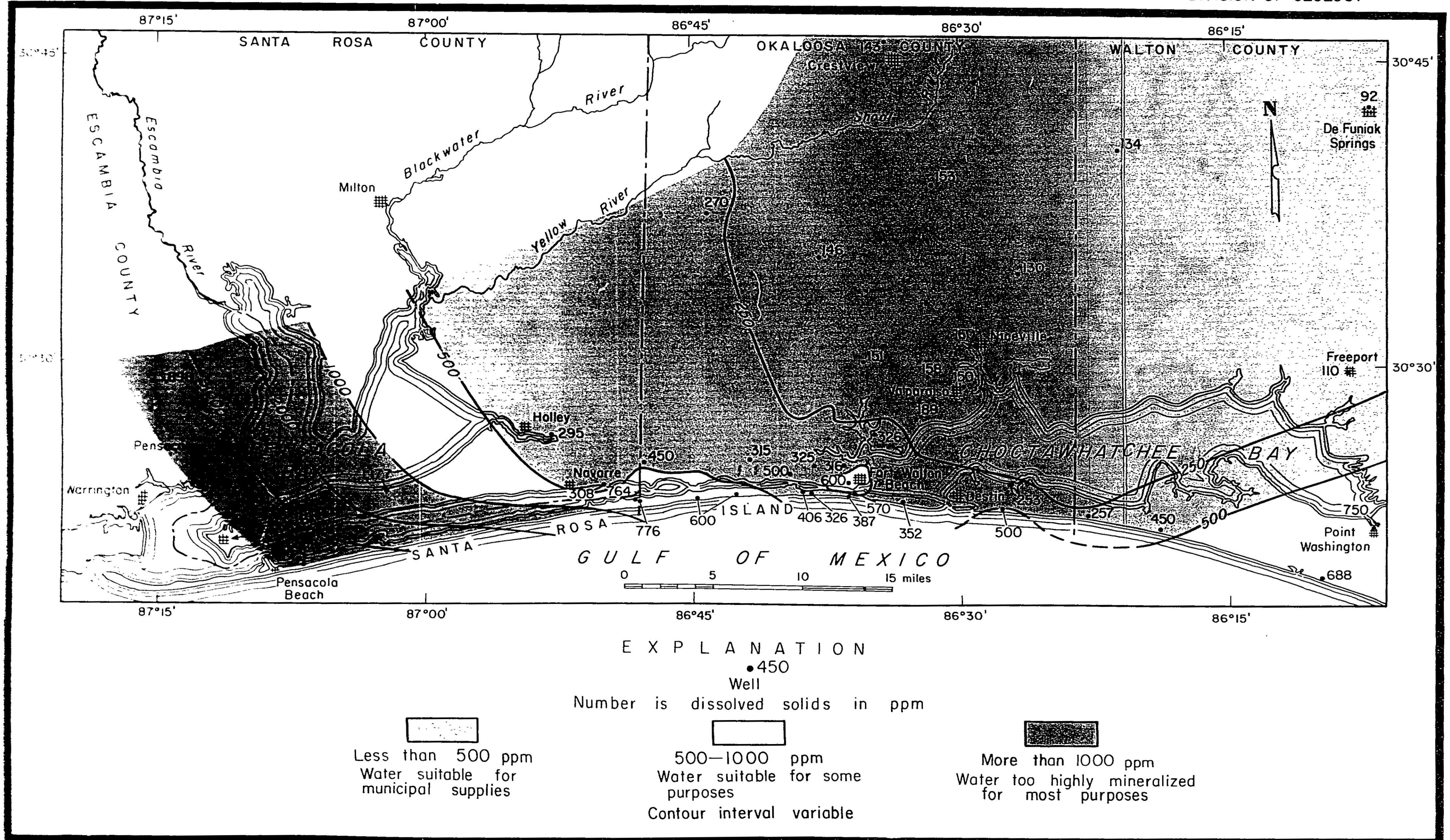

Base taken from Army Map
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Figure 9. Western Florida gulf coast showing the dissolved-solids content of water from the upper limestone of the Floridan aquifer.

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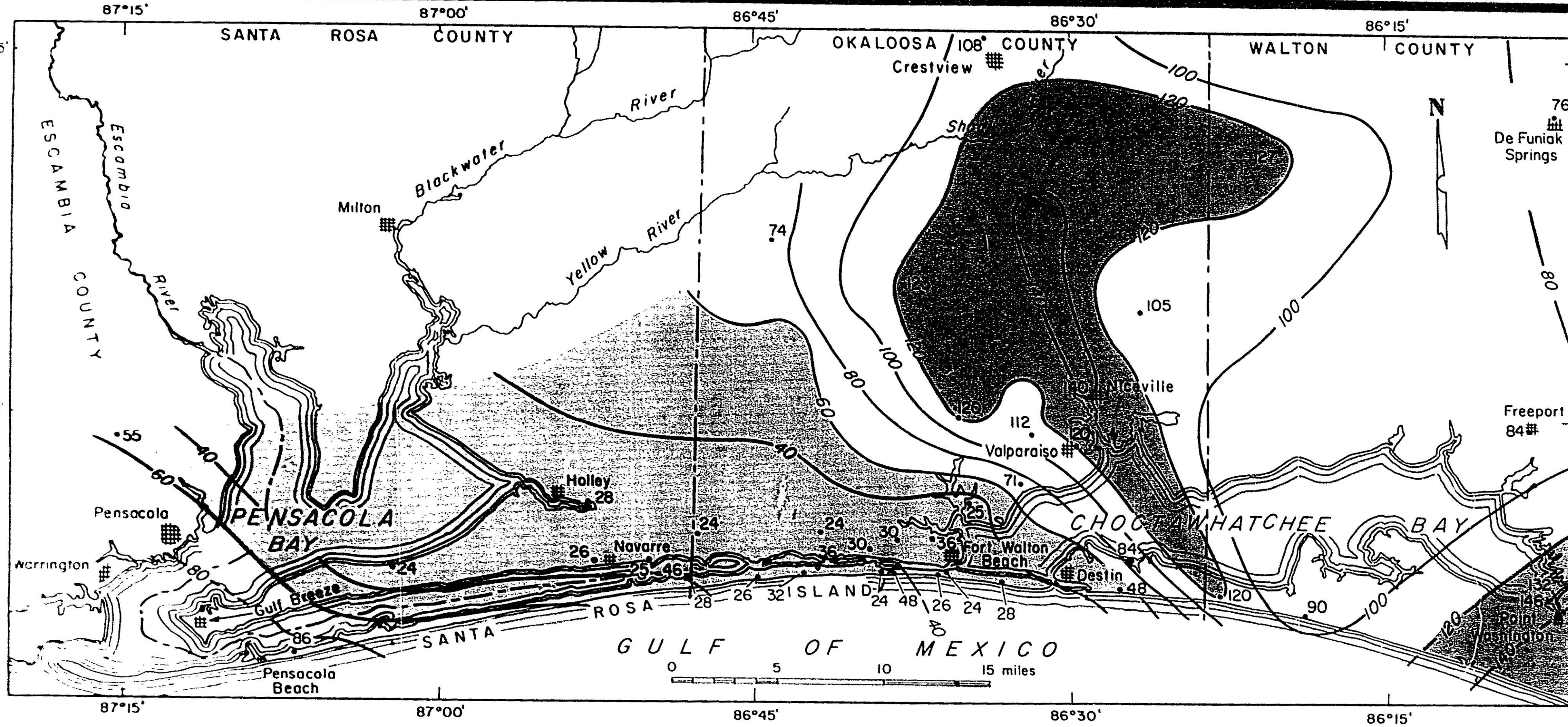


EXPLANATION

•24
Well
Number is hardness in ppm

0-60 ppm Soft	61-120 ppm Moderately hard	121-200 ppm Hard

Hardness expressed as $CaCo_3$
Contour interval, 20 ppm

Base taken from Army Map Service topographic Map 1:250,000

Figure 10. Western Florida gulf coast showing hardness of water from the upper limestone of the Floridan aquifer.

chloride content was 262 ppm, and about 2 weeks later it was 290 ppm. This is an increase of more than 200 ppm in the last 12 years. Salt-water encroachment may be a result of the drastic lowering of the water level in this well (fig. 7). Before much water was withdrawn from the upper limestone, the artesian pressure head in the upper limestone probably was about the same as in the lower limestone. Extensive pumping of water from the upper limestone has doubtless reduced the artesian pressure head considerably below that in the lower limestone. This difference in head would cause the water in the lower limestone to move upward, under the higher artesian pressure. Salt water from the lower limestone probably is moving upward through about 60 feet of the Bucatunna Clay Member (fig. 3) into the upper limestone. This upward encroachment may have been facilitated by the presence of old wells that penetrated the Bucatunna Clay Member and were later plugged or partially plugged. Salt water may have moved upward through part of the borehole.

As the water level in the upper limestone at Fort Walton Beach is below sea level most of the time, salt water from the Gulf of Mexico or Choctawhatchee Bay would have the potential head to percolate downward to this limestone. However, the possibility that this has happened seems remote, because a bed of clay about 300 feet thick overlies the limestone and would greatly retard the movement of water from above into the aquifer. In contrast, the clay bed below the upper limestone is relatively thin and, moreover, is perforated by open-hole sections of several old wells; this situation, coupled with the fact that water in the lower limestone has a higher head than water in the upper limestone, makes intrusion of salt water from below much more likely. Furthermore, no appreciable increase in the chloride content has been noted in water from wells closer to the gulf or the bay than the high-chloride well at the elementary school.

The implications of the data collected at the school well in Fort Walton Beach warrant continued measurement of the water level and the initiation of a periodic sampling program to keep a check on the chloride content. In addition, the chloride content of water from nearby wells, especially the city wells, should be checked periodically to determine any significant change in the salinity of the water.

Fluoride. The fluoride content of water from the upper limestone of the Floridan aquifer ranges from 0.0 ppm in the vicinity of Niceville to 6.5 ppm at Pensacola Beach. Figure 12 indicates that the fluoride content of water from this aquifer increases in a southwesterly direction across the area. Patterns on the map indicate areas in which the fluoride content of the water (from 0.5 to 1.5 ppm) would reduce tooth decay among children drinking the water (Black and Brown, 1951, p. 15). An area of beneficial fluoride content lies between Destin and Holley, and another south of Point Washington. An area in which the fluoride content (more than 1.5 ppm) of water from the upper limestone is so high that it might cause mottling of children's teeth also is shown on figure 12 (Black and Brown, 1951, p. 15). This area includes Fairpoint Peninsula west of Navarre and the western part of Santa Rosa Island. It is interesting to note that the fluoride content of water from a test well at Pensacola Beach (6.5 ppm) was almost twice as high as that from any other well in Florida known to the writers (excluding ground water contaminated by industrial wastes). In the area between Niceville, Crestview, and De Funiak Springs the fluoride content of water from the upper limestone is less than 0.5 ppm and probably would have little or no effect on children's teeth (Dean, 1943, p. 1173).

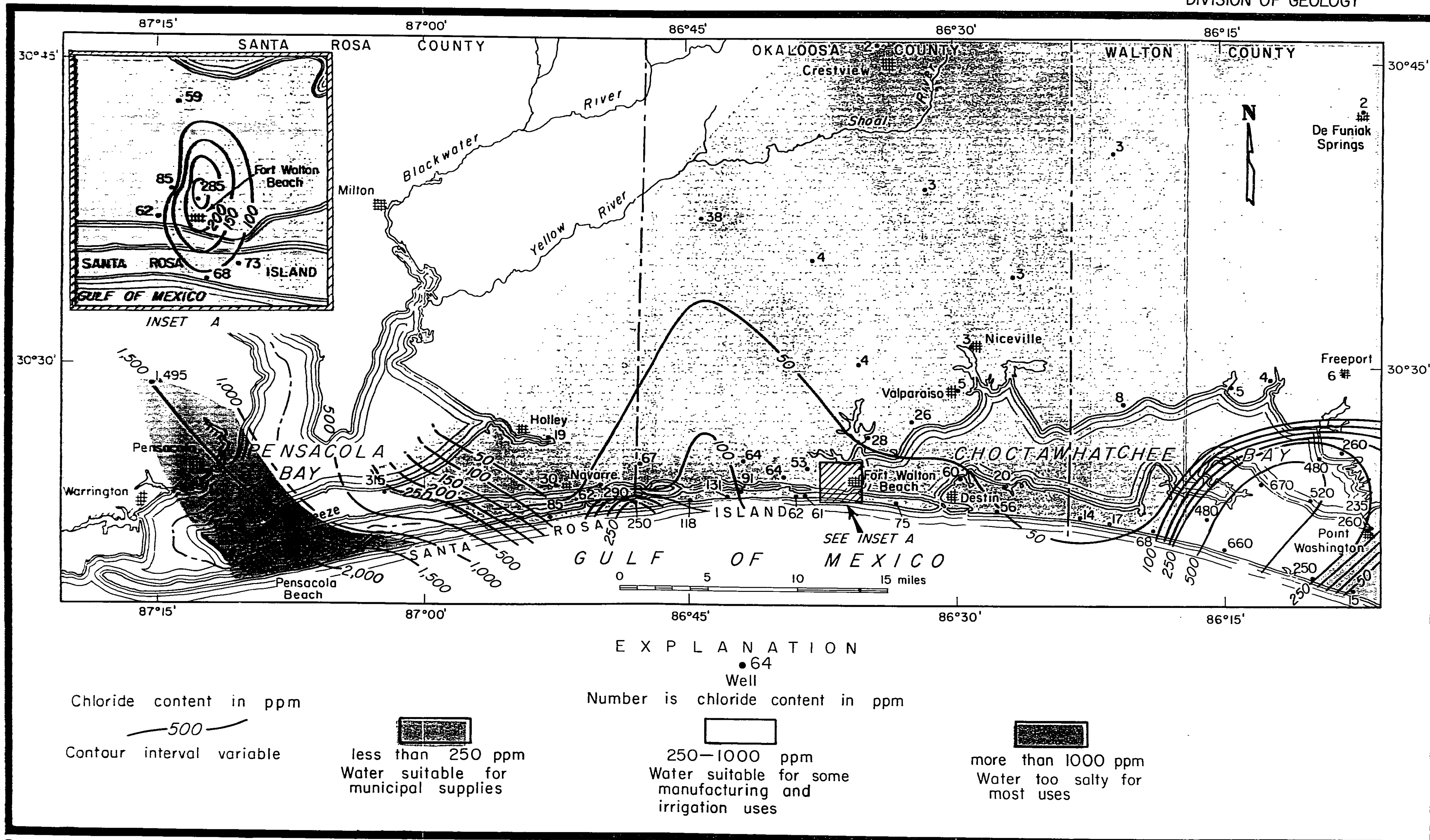
There are several possible sources of this fluoride. Certain minerals common in marine sediments contain fluoride. Among these are glauconite, phosphate, and muscovite, which have been noted in well samples in West Florida. The mica (muscovite) is especially abundant. According to Hem (1959, p. 112), "Cederstrom (1945) attributes fluoride in ground waters of the Virginia coastal plain to solution of micas which contain fluoride." Another possible source, mentioned by LaMoreaux (1948, p. 32-34) is sea water that has not been completely flushed from the aquifer. Fluoride is a normal, although minor, constituent of sea water. In West Florida, the fluoride content of water from the upper limestone generally increases with increasing depth of the aquifer. LaMoreaux noted a similar correlation in certain marine sands of southern Alabama. He also observed a relation between high-fluoride content of ground water and marine glauconitic sands. Some of the fluoride may be derived from the clay beds located within the aquifer.

Iron. The concentration of iron in water from the upper limestone of the Floridan aquifer ranges from 0.0 to 5.0 ppm.

Dissolved gases. Most waters from the Floridan aquifer within the study area contain hydrogen sulfide gas in solution.

LOWER LIMESTONE OF THE FLORIDAN AQUIFER

Unfortunately, no water samples could be obtained from the lower limestone of the Floridan aquifer. However, electric-log resistivities indicate that most of the water in this limestone is salty. The upper part of the lower limestone possibly contains fresh water north and east of Fort Walton Beach (updip), but until samples of the water can be analyzed, this possibility can be only speculative.



Base taken from Army Map Service topographic 1:250,000

Figure 11. Western Florida gulf coast showing chloride content of water from the upper limestone of the Floridan aquifer.

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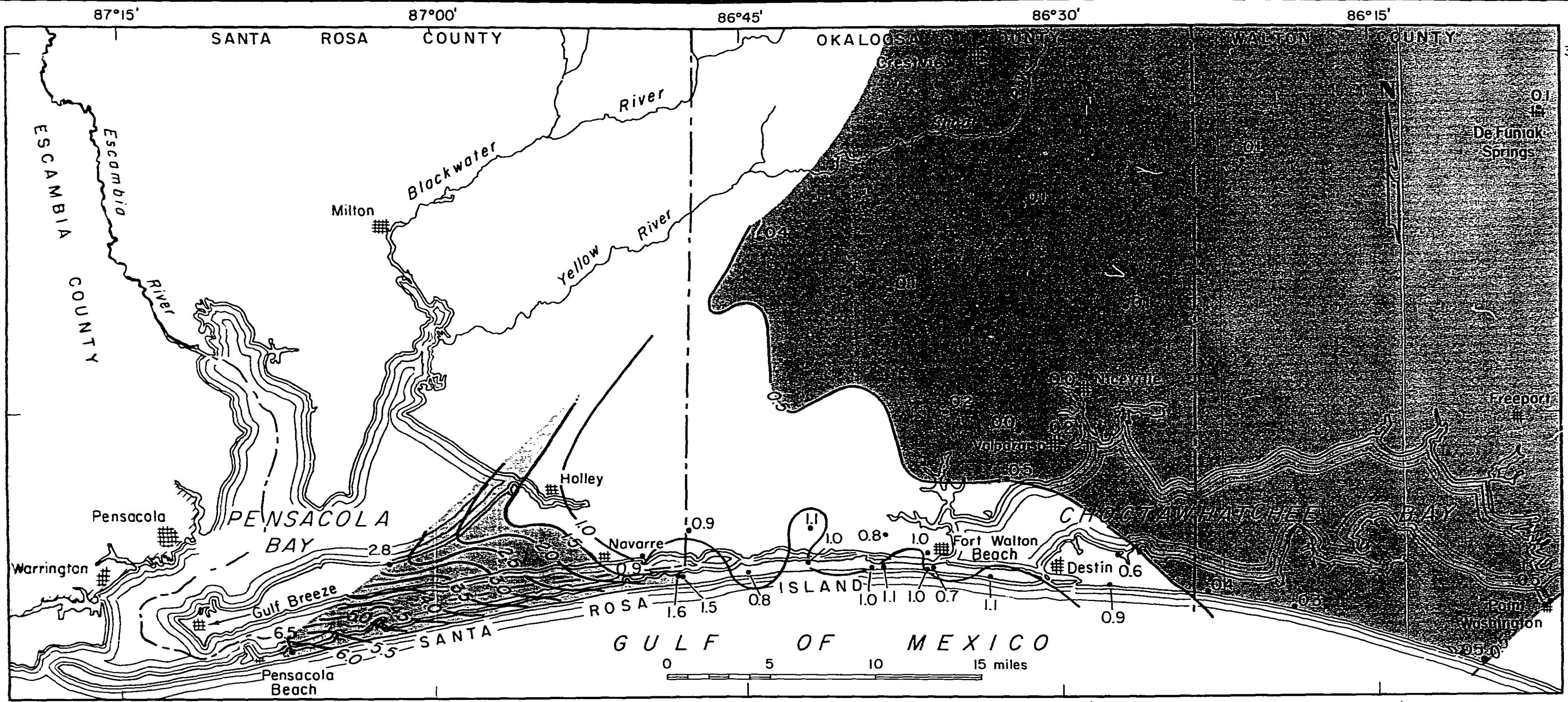

EXPLANATION

Less than 0.5 ppm
Fluoride content too low to have any appreciable effect on children's teeth

0.5 to 1.5 ppm
Fluoride content beneficial to children's teeth

More than 1.5 ppm
Fluoride content injurious to children's teeth

Contour interval, 0.5 ppm

Base taken from Army Map Service topographic Map 1:250,000

Figure 12. Western Florida gulf coast showing fluoride content of water from the upper limestone of the Floridan aquifer.

SUMMARY AND CONCLUSIONS

Three aquifers separated by clay aquicludes underlie the area discussed in this paper. The sand-and-gravel aquifer at the surface contains soft, relatively unmineralized water and supplies most of the wells in the western half of the area. The deeper lying upper limestone of the Floridan aquifer contains water that is more mineralized and supplies most of the wells in the eastern half of the area. Most of the lower limestone of the Floridan aquifer is too salty for use.

Maps showing hardness, dissolved solids, chloride, and fluoride in water from the upper limestone indicate that this water is suitable for most uses in the eastern two-thirds of the area. The concentrations of the mineral constituents increase in a southwesterly direction, making the water unsuitable for most purposes in the western third of the area. The hardest water occurs in the eastern part of the area and the water becomes softer in a southwesterly direction.

A decline in head in the upper limestone at Fort Walton Beach has amounted to about 82 feet since 1936. Apparently, this caused salt water from the lower limestone to move upward through the Bucatunna Clay Member into the upper limestone. Clay in the upper limestone of the Floridan aquifer has played a significant role in the producton of large drawdowns by decreasing both the permeability and the effective porosity of the aquifer. It has also effectively softened the water in the aquifer by ion exchange.

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