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INTERIM REPORT ON RESULTS OF TEST DRILLING IN THE SAVANNAH AREA, GEORGIA AND SOUTH CAROLINA

By

Stephen M. Herrick and Robert L. Wait

U. S. Geological Survey

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INTERIM REPORT ON RESULTS OF TEST DRILLING IN THE SAVANNAH AREA, GEORGIA AND SOUTH CAROLINA

INTRODUCTION

Purpose and Scope of the Investigation

The purpose of this investigation which is being made in cooperation with the Georgia Department of Mines, Mining and Geology, Chatham County, and the City of Savannah, is to determine whether salt-water encroachment has occurred in the principal limestone aquifer in the Savannah area, and, if so, to delimit the extent of the encrcachment vertically and laterally. The drilling of two test wells, which constitutes the initial part of the investigation, was done in April, May, and June, 1954. This interim report describes the subsurface geology in the Savannah area and reports the results of water samples taken during the test drilling. The investigation is being continued by M. A. Warren and F. B. Hudson of the U. S. Geological Survey, and later results will be given in a subsequent report.

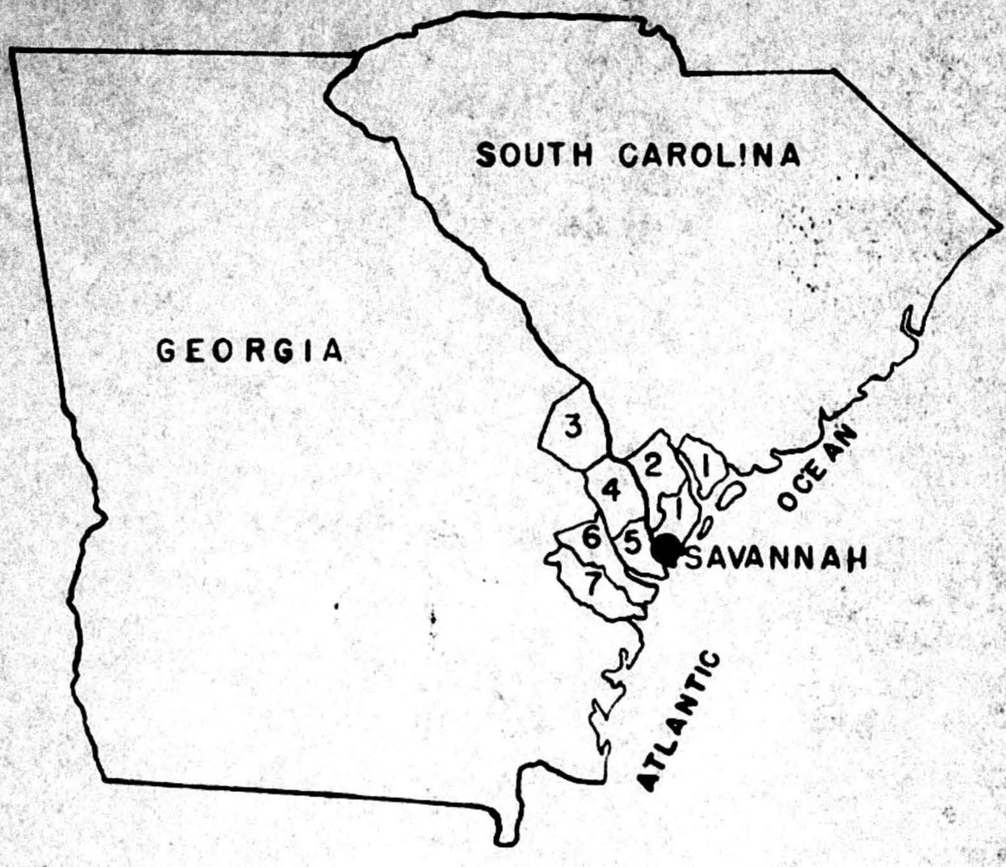
The investigation is being made under the general supervision of A. N. Sayre, Chief, Ground Water Branch, U. S. Geological Survey.

Water samples collected during the drilling of the two test wells were analyzed in the laboratory of the U. S. Geological Survey, Ocala, Fla.

Location of Area

The area covered by this report consists of the Atlantic Coastal region of eastern Georgia and southeastern South Carolina, (fig. 1). Included in this area are five counties in Georgia and two in South

Plate 1



LOCATION OF AREA

COUNTIES

GEORGIA

3. SCREVEN
4. EFFINGHAM
5. CHATHAM
6. BRYAN
7. LIBERTY

SOUTH CAROLINA

1. BEAUFORT
2. JASPER

Carolina. Savannah, in Chatham County, which in 1950 had a population of 119,638, is the largest city in the area and is the center of a large withdrawal of ground water for municipal and industrial purposes.

Previous Investigations

The first report dealing with the artesian waters of the Coastal Plain of Georgia was one by McCallie (1898). A second report by McCallie (1908) described the ground-water resources of the entire state. Stephenson and Veatch (1915) produced what was the most comprehensive report to that year on the ground water of the Coastal Plain of Georgia. In 1938 the U. S. Geological Survey, in cooperation with the Georgia Department of Mines, Mining and Geology, began an investigation of the ground-water resources of Southeastern Georgia. Some of the results of this work were published in 1941 (Stringfield, Warren, and Cooper) and 1944 (Warren). Subsequent to the above reports, water-level measurements on selected wells in this area have been published annually by the U. S. Geological Survey in water-supply papers (Meinzer and Wenzel; Sayre and others). Also, determinations of the chloride content of waters from outpost wells in the area have been compiled from time to time in unpublished, open-file reports (Herrick and LeGrand, 1947; Herrick and Chase 1952).

Acknowledgments

The Geological Survey is indebted to Fred Hack, Vice President of the Hilton Head Co., for the lease of a plot of land upon which to drill test well 2 on Hilton Head Island, S. C. and to Ralston Lattimore of the National Park Service, U. S. Department of the Interior,

for permission to drill test well 1 at the Fort Pulaski National Monument, Chatham County. Thanks are also due Dr. M. L. Taylor, Technical Director of Union Bag and Paper Company, for courtesies extended during the investigation.

GEOLOGY

General

Detailed subsurface studies of the geologic formations in the Savannah area show that this part of Georgia and South Carolina was covered many times by the sea during Late Cretaceous and Tertiary time, which resulted in the deposition of several thousands of feet of alternating beds of clay, sand, and limestone. These sediments are not horizontal but dip approximately 5 feet per mile in a southwesterly direction from Savannah toward Liberty, Long, and McIntosh Counties (McCallie, 1898). The areal distribution and subsurface attitude of these rocks are shown graphically in plates 2 and 3. A large part of the sediments shown on these two plates is a series of limestones, which constitute the principal source for ground water in the area. The thickness of these limestones and their geologic age, lithology, and paleontologic character are described in the following sections.

Need for Test Drilling

The upper 900 feet of sediments noted above includes a section of water-bearing limestones which constitute the principal artesian aquifer of this part of Georgia and South Carolina. Owing to their southwesterly dip the top of these limestones rises in a northeasterly direction from the city of Savannah, coming within 130 feet of the surface of the ground at the site of test well 2, Hilton Head Island, S. C., and to within 100 feet of the surface in the No. 2 U. S. Marine Base test well, Parris Island, S. C. At these two localities, therefore, the impervious cover, which tends to protect the fresh-water-bearing limestones from contamination by sea water, is relatively thin or absent. A map of the original piezometric surface of artesian water indicates that, before large scale withdrawals began, some water discharged from the aquifer as submarine springs northeast of Savannah. Even today a surface boil from a submarine spring may be observed elsewhere for example, 2½ miles east of Crescent Beach off the east coast of Florida (Stringfield and Cooper, 1951). However, as pointed out by Warren (1944), the heavy withdrawal of water in the Savannah area has doubtless reduced the artesian head so as to upset the initial balance of fresh and salt water at the seaward end of these limestone aquifers. Continued increased pumping in Savannah with consequent lowering of the artesian head within the affected aquifer would cause replacement of the fresh water by the heavier salt water, resulting in a steady, though extremely slow, landward encroachment of salt water down the hydraulic gradient in a southwesterly direction toward the center of pumping. Warren indicated that such an encroachment would probably take place in the form of a wedge of salt water moving through the pervious limestones upon a floor of impervious clay that directly underlies the limestone aquifer. In view of the potentialities of salt-water encroachment, two test wells were drilled in 1954 to aid in determining the present position of salt water in the seaward parts of the aquifer. The results of chemical analyses of water from the two wells are described in a later section of this report.

Besides determining the chemical quality of the ground water, a second and equally important objective of this investigation was to determine the geologic age, character, and thickness of the aquifer, and of the confining beds above and below the aquifer. Test wells that completely penetrate the fresh-water-bearing limestones will service the dual purpose of allowing chloride sampling from selected depths and the observation of water-level fluctuations.

Drilling Procedure

The test wells were drilled during the months of April, May, and June, 1954. Test well 1, at Fort Pulaski, on Cockspur Island, Ga., was drilled to a total depth of 745 feet. The test hole, 9-5/8 inches in diameter, was drilled by the rotary method to a depth of 212 feet, then reamed to a diameter of 11-3/4 inches, after which 185 feet of 8-inch casing was cemented in place. From 212 to 745 feet, an eight inch hole was drilled by the cable-tool method. Geologic samples were taken every 10 feet, or at lesser intervals depending upon how frequently the hole was bailed to clean it of cuttings.

Test well 2, Hilton Head Island, S. C., was drilled to a depth of 740 feet by the cable-tool method. The 8-inch casing in this well was driven to a depth of 128 feet, where a hard, sandy limestone was encountered. The casing was not driven further for fear of collapse. In this well also, geologic samples were taken at 10-foot intervals, or whenever the hole was bailed of cuttings.

The following discussion deals with the lithology, paleontology, and stratigraphy of the formations penetrated by the two test wells.

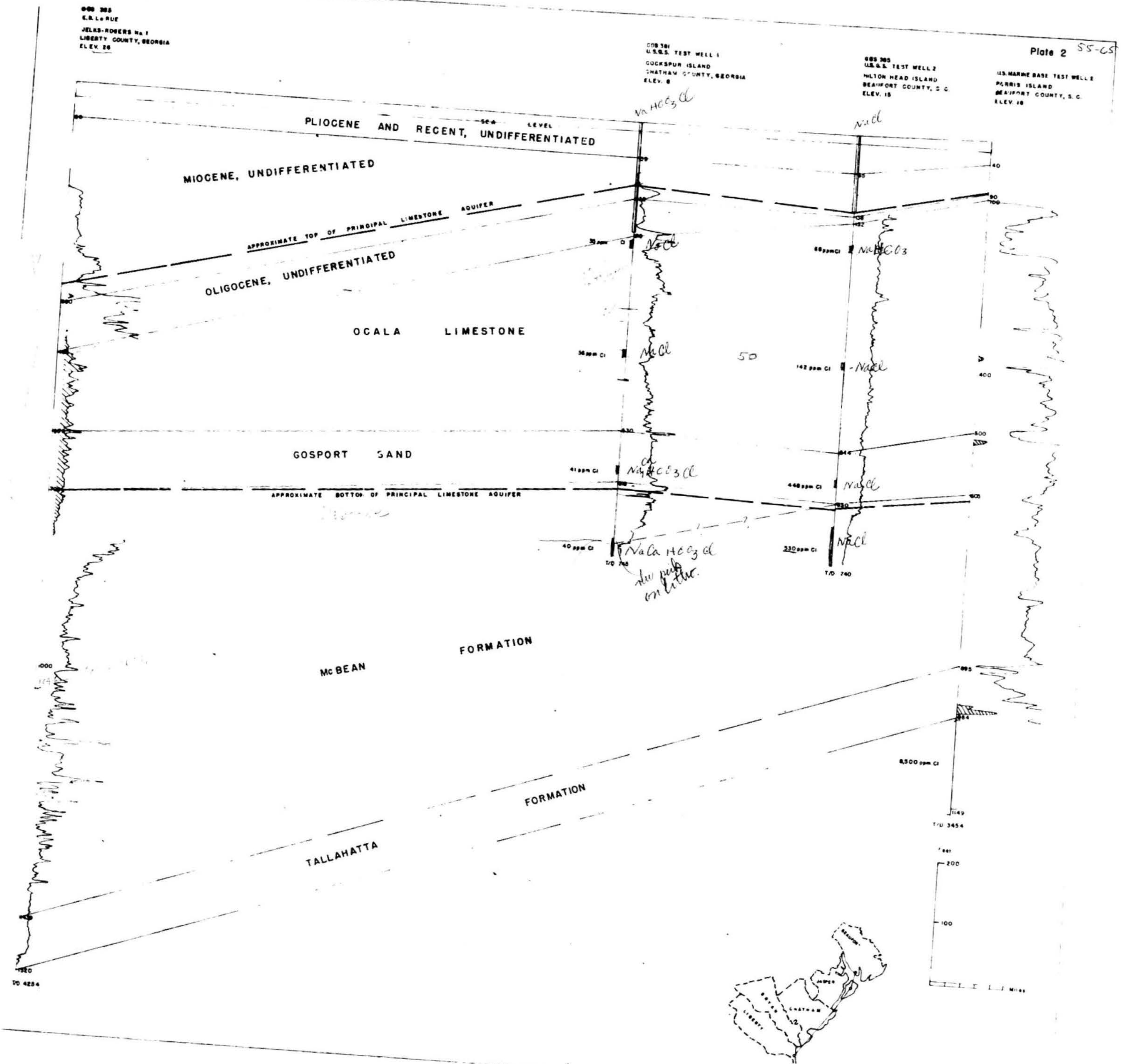
Stratigraphy and Paleontology of Test Wells

A study of the cuttings from approximately 20 wells, mostly in the Savannah area, and including the two test wells, reveals the presence of a considerable thickness of limestones ranging in age from late middle Eocene to early Miocene. The accompanying correlation table (table 1) includes all Tertiary formations, however this study does not include deposits older than early middle Eocene. The following discussion takes up each group of formations, in descending order from top to bottom, and sets forth stratigraphic, paleontologic, and lithologic data as they were determined through a detailed study of samples taken from wells situated in the area, particularly the two test wells.

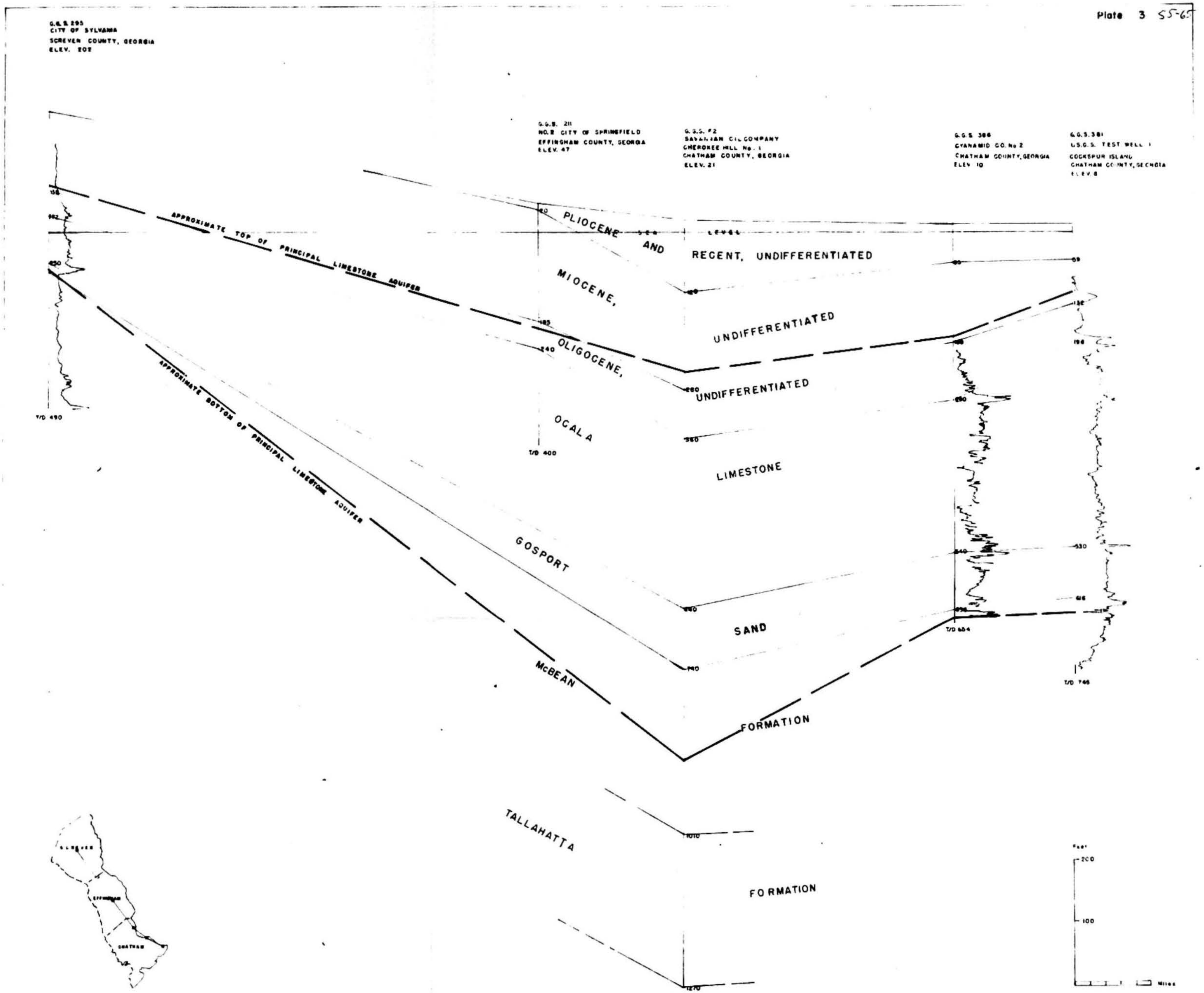
Recent to Pliocene, undifferentiated

Because of lack of diagnostic paleontologic evidence, no attempt has been made to separate Pliocene, Pleistocene or Recent sediments. Lithologically, this undifferentiated unit, in the test wells, consists predominantly of gray to dark-green-silty, micaceous, blocky clays with minor amounts, in the upper 20 to 25 feet, of fine- to medium-grained angular sand. A rather prominent shell bed is present in both test wells at the approximate depth of 30 to 45 feet. Oysters, not identified, appear to make up the bulk of this shell bed. Samples of cuttings

Plate 2



CROSS SECTION AA'



CROSS SECTION BB′

Table 1. - Generalized table of deposits underlying the Savannah area

System	Series	Group	Thickness	Lithology
Quaternary	Recent to Pliocene, undifferentiated.		0-120	Chiefly gray to dark-green silty clay and some fine- to coarse-grained sand and gravel.
Tertiary	Miocene, undifferentiated, (equivalent to Hawthorn and Tampa of Florida).		50-320	Pale to dark-green phosphatic sandy clay; phosphatic sand and phosphatic sandy limestone.
	Oligocene, undifferentiated, (equivalent to Suwannee of Florida).		10-85	Soft chalky fossiliferous limestone, to dense calcitized saccharoidal unfossiliferous limestone.
	Eocene	Jackson group. (Ocala, equivalent to Yazoo of Alabama)	78-400	White to cream much calcitized, recrystallized saccharoidal limestone; sandy, sparsely glauconitic limestone at bottom of section.
		Claiborne group. (Gosport, McBean, Tallahatta; equivalent to Gosport, Lisbon, and Tallahatta of Alabama)	500-800	Dense light-gray sandy, sparsely glauconitic limestone; some bluish clay, dark-brown sandy, cherty, dolomitic limestone and light-gray glauconitic marl.
		Wilcox group. (equivalent to Bashi, Tuscahoma, and Nanafalia of Alabama)	200	Alternating micaceous, lignitic clay, and sand with minor amounts of gray crystalline glauconitic limestone.
	Paleocene	Midway group. (equivalent to Clayton of Alabama)	200	Mostly gray crystalline glauconitic limestone and minor amounts of clay and sand.
Cretaceous	Upper and Lower(?) Cretaceous, undifferentiated		2,000	Alternating green, red, and purple micaceous clay and fine- to coarse-grained sand, with minor amounts of sandy limestone.

from other wells situated on the mainland--in Savannah and northwest of the city--show a predominence of sand in sediments belonging to this unit. However, this is not unusual since the shorelines of the Pliocene and Pleistocene seas must have been situated on the mainland, northwest of Savannah, in Effingham County (Cooke, 1943). A thickness of 60 to 65 feet of sediments is tentatively assigned to this part of the section penetrated by the two test wells.

Miocene, undifferentiated

Cooke (1943) recognized three surface formations as representative of the Miocene series in Georgia, namely Duplin, Hawthorn, and Tampa formations. This classification is followed in this report with two exceptions. First, through lack of paleontologic evidence it was not possible to delineate sediments of Duplin, or upper Miocene age. If these sediments are present the authors have included them in the basal part of the section designated above as Pliocene to Recent, undifferentiated. Second, for similar reasons the geologic age of the limestones occurring at the base of the Miocene in both test wells is not definitely known. However, at the depth, 100-110 feet, in test well 2, poorly preserved Foraminifera belonging to the Genera, *Textularia*, *Quinqueloculina*, and *Discorbis*, were observed. It is thought that these fossils are of lower Miocene, or Tampa age, though their state of preservation was too poor to permit identification to species. Elsewhere in Georgia the fossil, *Archaias floridanus* (Conrad), the only "key" fossil diagnostic of rocks of Tampa age, has been definitely identified in limestones of similar lithologic character and stratigraphic position. In addition to the micro-fossils noted, frequent fragments and molds of macro-shells occur embedded in, and are considered characteristic of, these limestones. Lithologically, these basal limestones are dense, sandy, and coarsely phosphatic. Limestones of Tampa age occur in the interval 112-132 feet in test well 1 and 130-138 feet in test well 2.

Exclusive of the basal limestones, the remainder of the Miocene, i.e., upper and middle Miocene, or Hawthorn formation, consists, lithologically, of pale-green, blocky, sandy, phosphatic, noncalcareous, unfossiliferous clay with interfingerings of dense, dolomitized limestones. The presence of phosphatic pebbles in these clays is regarded as diagnostic of this formation. In the samples from the test wells the phosphatic pebbles are light-brown in color, rounded, and highly polished. Accompanying these phosphatic pellets vertebrate remains of various types--fish teeth, vertebrae(?)--were observed. Wells in other parts of the Coastal Plain of Georgia contain phosphatic pebbles that are similarly rounded but range in color from white, through light gray to jet black. Sediments belonging to the Hawthorn occur in the interval, 59-112 feet in test well 1 and 65-130 feet in test well 2.

In addition to the clays the Hawthorn contains stringers of sandy, somewhat dolomitized, unfossiliferous limestones interbedded with the phosphatic clays. In test well 1 such limestone was observed at the depth, 82-92 feet but was not identified in test well 2. Clays of the

Hawthorn occurred in the interval, 60-112 feet in test well 1 and 65-85 feet in test well 2. Dense, massive, light gray, sandy, phosphatic limestones of probable Tampa age were observed in test well 1 at depth, 112-132 feet and 85-138 feet in test well 2.

Oligocene, undifferentiated

Cooke (1943) regarded most of the outcropping limestones of Oligocene age in Georgia as belonging to the Flint River formation but assigned some, as represented in Brooks, Lowndes, and Thomas counties, to the Suwannee formation. Applin and Applin (1944, p. 1681-1683) did not differentiate between these two divisions except in western Florida and southwestern Georgia. In this report this part of the subsurface section is similarly regarded as "undifferentiated" Oligocene rocks. The following fossils occurring near the top of this series of rocks in both test wells are regarded as characteristic of this group of sediments:

Operculinoides dius (Cole)
Lingulina sp.
Mississippina cf. *monsouri* Howe
Rotalia mexicana Nuttall
Quinqueloculina leonensis E. R. Applin and L. Jordan
Pyrogo monroei Cushman and Todd
Pyrogo sp.
Nonionella hantkeni (Cushman and Applin) Cushman, var. *byramensis* Cushman and Todd
Siphonina advena Cushman
Argyrotheca cf. *wegemanni* Cole

Argyrotheca wegemanni Cole represents a small brachiopod originally described by Cole from the Meson formation of Mexico (1930). Cole (1941) also reported this fossil from the subsurface of Florida and had the following to say about it, "Previously, this species of brachiopod was known only from its type locality. It is therefore, interesting to find it in Florida in association with H. texana which also occurs at the type locality of Argyrotheca wegemanni. It is amazing that more of the foraminifera associated with these two forms in Mexico did not occur in the samples from this well (i.e., 1 J. W. Cory)." It is interesting to note in view of the above the occurrence of Argyrotheca cf. wegemanni Cole in Georgia as well as Rotalia mexicana Nuttall in association with it.

Lithologically, the sediments assigned to this part of the stratigraphic section penetrated by the two test wells consist of soft, cream-colored, somewhat weathered(?), fossiliferous, rather pure limestones. At the base of this series of rocks, however, these limestones become extremely dense, massive, much calcitized, and crystalline in character. Recrystallization has more or less obliterated any fossils that might once have been present in this part of the geologic section.

Rocks of Oligocene age were assigned to the interval, 132 - 196 feet in test well 1 and 138 - 152 feet in test well 2.

64'

→ 14 feet

UPPER EOCENE

Ocala limestone

Beneath the sediments of Oligocene age is a series of fossiliferous limestones here assigned to the Ocala limestone. From surface outcrops Cooke (1943) recognized the Cooper marl and the Barnwell and Ocala formations as the only three subdivisions of the uppermost Eocene in Georgia. In 1952 Cooke and MacNeil decided that the Cooper marl, in South Carolina, on the basis of extremely meager paleontologic evidence, was Oligocene in age and should be removed from the Eocene and regarded as basal Oligocene in South Carolina and adjoining areas (Cooke and MacNeil, 1952). The microfossils as found to occur in surface outcrops of Cooper marl and equivalent subsurface sedimentary rocks in Georgia are here regarded, in spite of the aforementioned report, as decidedly Jackson in age. Until more convincing paleontologic evidence is brought forward, therefore, sediments belonging to this formation will continue to be regarded as uppermost Eocene rather than Oligocene in age. Although the foraminifera characteristic of the Cooper marl are readily recognized in well samples the same cannot be said of the lithologic character of the sediments belonging to this formation. The reason for the latter statement is that the Cooper marl, in its updip occurrences, is clastic in nature and composed of unconsolidated, somewhat sandy, limey marl whereas downdip this material has changed to consolidated limestone that is indistinguishable, lithologically, from the underlying, stratigraphically older, limestones of Ocala age. In conclusion no distinction is made between the Cooper marl and Ocala limestone as found in the subsurface of the area here discussed; both are regarded as upper Eocene in age and are described as a single unit--limestone.

Faunally, as well as lithologically, it is thought that the Ocala can be divided into two units - upper and lower units. Regarding this division of the Ocala it is interesting to note that, in Florida, the Applins (1944), on the basis of paleontologic evidence, divided the Ocala limestone into upper and lower members. However, they were of the opinion that such zoning was not feasible or possible in the subsurface of Georgia. After examining well samples from 20 wells situated in different parts of the area and finding paleontologic evidence of these two units not only in a few instances but in each and every well examined the authors concluded this zoning was possible in the Savannah area. The more commonly occurring foraminifera in these divisions are summarized as follows:

Upper unit	Heterostegina ocalana Cushman Operculinoides ocalanus (Cushman) Gypsina globula (Reuss) Discocyclina nassauensis Cole Discocyclina cf. citrensis Vaughan Gyrodina sp. Planulina cocoaensis Cushman, var. cooperensis Cushman Eponides jacksonensis Cushman and Applin Discorbis assulata Cushman
"Orbitoid Zone" of lower unit	Camerina aff. vanderstoki (Rutten and Vermuth) Camerina jacksonensis Gravell and Hanna Operculinoides mariannensis (Vaughan) Operculinoides barkeri (Vaughan and Cole) Amphistegina pinnarensis Cushman and Bermudez, var. lawsoni E. R. Applin and L. Jordan Discocyclina sp.

Besides the foraminifera, bryozoan and echinoid remains as well as macroshells occur abundantly in certain horizons, particularly in the upper unit. In many samples the limestone appears to be composed almost entirely of bryozoan remains, whereas in others echinoid spines predominate, along with frequent tests of microfossils.

Regarding the lithologic character of the Ocala encountered in the two test wells the upper unit usually appears as a flat-white, somewhat porous, recrystallized limestone. Limestone of the lower unit however, is much denser, more calcitized, crystalline, saccaroidal, and granular in character as compared with that of the upper unit. Glauconite is conspicuous by its absence, generally speaking, in these rocks.

Below the zone of fossils, here called, "Orbitoid Zone," marking the top of the lower unit of the Ocala, the limestones become progressively denser, more calcitized, and unfossiliferous. As was the case in the basal strata of the Oligocene rocks so here calcitization and consequent recrystallization are thought to have destroyed whatever fossils may have originally been present in this part of the section.

In test well 1 the upper unit has been identified in the interval, 196 - 395 feet and 152 - 310 feet in test well 2. In test well 1 the lower unit has been assigned to the interval, 395 - 530 feet, and 310 - 544 feet in test well 2.

MIDDLE EOCENE

Gosport sand

The strata situated between the base of the Ocala limestone and the top of the upper unit of the McBean formation have been assigned to the Gosport sand and are regarded by some authors as early Jackson, or pre-Ocala in age. Regarding the Gosport, Cooke and MacNeil, in 1944, considered these sediments, on the basis of surface exposures, as early Jackson in age (MacNeil and Rainwater, 1944).

This part of the subsurface section is, generally speaking, poor in fossils as compared with other formations included in the section here discussed. However, foraminifera occur in thin clay partings interbedded with the limestones. The "key" foraminifera from the Gosport in the test wells are thought to be Cibicides americanus (Cushman), var. antiquus (Cushman and Applin), Nonion advenum (Cushman), and Cancris sp., all three of which occur commonly in this part of the section. Foraminifera of Gosport age identified by the senior author from an exposure at Danville Bluff, Sumter County, Georgia, are listed below. This fauna agrees very well with that previously listed by Rainwater (Rainwater, 1944, p. 53) from the same locality.

Spiroplectammina mississippiensis (Cushman), var. alabamensis (Cushman)
Textularia adalta Cushman
Textularia dibollensis Cushman and Applin
Guttulina irregularis (d'Orbigny)
Guttulina problema d'Orbigny
Sigmomorphina semitecta (Reuss), var. terquemiana (Fornasini)
Nonion advenum (Cushman)
Reussella eocena (Cushman)
Angulogerina ocalana Cushman
Angulogerina cooperensis Cushman
Discorbis assulata Cushman
Gyroidina soldanii d'Orbingy, var. octocamerata Cushman and G. D. Hanna
Alabamina atlantisae (Cushman)
Cancris sp.
Cibicides lobatulus (Walker and Jacob)
Cibicides danvillensis Howe and Wallace
Cibicides pseudoungerianus (Cushman)
Cibicides americanus (Cushman), var. antiquus (Cushman and Applin)
Cibicides refulgens (Montfort)
Gypsina globula (Reuss)

The occurrence of glauconite-impregnated specimens of Lepidocyclina (Polylepedina) antillea Cushman and Operculinoides sp. at, or near the top of this formation should be noted here. Both these fossils are, of course, middle Eocene in age and their presence at the top of the Gosport poses a problem. After considering available evidence bearing on this problem the conclusion was that these two fossils represent reworked sediments of Claiborne age. Further, it must be pointed out that this phenomenon is not new, having been noted by other workers, notably Cole, (1941, pp. 14-16) in the subsurface of Florida. Regarding this problem Cole decided that these fossils of Claiborne age occurring in beds, in his case, of Oligocene age, represented reworked Claiborne sediments and advanced evidence in support of this view. As occurrences similar to those noted by Cole have frequently been noted by the authors in other wells on the Coastal Plain of Georgia this conclusion appears scientifically sound.

Besides the few foraminifera listed above, this sequence of sedimentary rocks contains, at certain horizons, abundant macro-shells, and bryozoan and echinoid remains. Particularly characteristic of this formation, wherever it has been identified in the subsurface, are the molds and casts of macro-shells, especially molds of gastropods.

Lithologically the Gosport consists predominately of dense, granular, white to light gray sandy, much calcitized and recrystallized, coarsely but sparsely-glauconitic limestone interbedded with thin stringers of fossiliferous pale green clay. At the top of this formation the rocks consist of extremely sandy limestone, almost an indurated sand, or sandstone. Sandy limestone such as the kind here assigned to the Gosport, certainly is, lithologically, quite different from that belonging to the Ocala, moreover it resembles that of the upper unit of the McBean formation more closely than any other type of limestone encountered in the two test wells. Except for the black phosphatic pebbles, this limestone, through its sandy nature, suggests limestone of early Miocene age, i.e., Tampa. Aside from the fossils the following criteria appear to characterize the limestones of the Gosport:

1. Recrystallized, sandy character of the limestone.
2. Presence of coarse, but sparse, grains of glauconite.
3. Presence of numerous molds of large shells, particularly of gastropods.

In test well 1 sediments of Gosport age have been assigned to the interval, 530-616 feet, and 544-630 feet in test well 2.

McBean formation

In the interval, 616-745 feet, in test well 1 and 630-740 feet, in test well 2 it is believed that sediments of middle Eocene, or McBean age were entered. Cooke, (1943, p. 55) and MacNeil, (1944, p. 29) considered the surface exposures of these strata as Claiborne in age and equivalent of both the Tallahatta and Lisbon formations of Alabama and Mississippi. In this report two divisions of the lower part of the middle Eocene, are recognized, i.e. the Tallahatta and McBean formations. Moreover, the McBean formation, as defined here, is divided into upper and lower units on the basis of paleontology and lithology. In this connection both test wells are believed to have terminated in clays of the upper unit. In Georgia the McBean, as a whole, is regarded as equivalent to the Lisbon (in part) and Tallahatta (in part) of Alabama. The Tallahatta, or lowest division of the middle Eocene in Georgia, is regarded as equivalent to the Tallahatta (in part) of Alabama. Comparing the two units of the McBean with supposed equivalents as described by the Applins for Florida, on the basis of paleontologic evidence it would appear that the upper unit of the McBean (in part) in Georgia is the equivalent of the Avon Park limestone in Florida (Applin and Applin, 1944, p. 1686-1695). On similar grounds the lower unit of the McBean (in part) and Tallahatta formations, together, would seem to be the equivalent of the Lake City limestone of Florida. Still farther afield it appears that the upper unit of the McBean of Georgia might be regarded as the stratigraphic equivalent of the Yegua formation of Mississippi while the combined lower unit of the McBean and Tallahatta formations might be regarded as the equivalent of the Cook Mountain of Louisiana and Mississippi..

Study of the foraminifera contained in the bottom samples of both test wells indicates, that both wells ended in sediments of the upper unit of the McBean. In support of this view the following frequency, or abundance chart of the foraminifera occurring in the bottom samples of both test wells is included here.

Abundance Chart of Foraminifera in Test Wells:

(A = Abundant, C = Common, F = Frequent, R = Rare)	Test Well No. 1	Test Well No. 2
Spiroplectammina mississippiensis (Cushman), var. alabamensis (Cushman)	A	A
Textularia adalta Cushman	C	C
Textularia dibollensis Cushman and Applin	F	
Testularia dibollensis Cushman and Applin, var. humblei Cushman and Applin	F	F
Textularia hannai Davis	F	R
Textularia recta Cushman	R	R
Textularia broussardi Howe and Wallace		F
Robulus alato-limbatus (Gumbel)	C	C
Planularia cooperensis Cushman	C	C
Marginulina cocoaensis Cushman	F	F
Dentalina jacksonensis (Cushman and Applin)	C	A
Saracenaria sp.		R

Abundance Chart of Foraminifera in Test Wells continued:

(A = Abundant, C = Common, F = Frequent, R = Rare)	Test Well No. 1	Test Well No. 2
Lagena acuticosta Reuss	R	R
Lagena laevis (Montagu)?		R
Guttulina problema d'Orbigny	C	F
Guttulina spicaeformis (Roemer)	F	R
Globulina gibba d'Orbigny	R	F
Globulina minuta (Roemer)	R	R
Sigmomorphina semitecta (Reuss), var. terquemiana (Fornasina)	F	C
Sigmoidella plummerae Cushman and Ozawa	F	F
Polymorphina advena Cushman, var. nuda Howe and Roberts		R
Nonion inexcavatum (Cushman and Applin)	R	F
Nonion planatum Cushman and Thomas	A	A
Nonionella hantkeni (Cushman and Applin)	R	R
Nonionella hantkeni (Cushman and Applin), var. spissa Cushman	R	R
Guembelina cubensis Palmer	R	R
Bolivinella subpectinata Cushman		R
Buliminella elegantissima (d'Orbigny)	F	C
Buliminella curta Cushman		R
Buliminella robertsi (Howe and Ellis)	R	R
Bulimina elongata d' Orbigny, var. tenera Reuss	R	R
Bolivina jacksonensis Cushman and Applin	F	F
Bolivina jacksonensis var. striatella Cushman and Applin	F	A
Bolivina broussardi Howe and Roberts	C	A
Bolivina cf. taylori Howe		R
Loxostomum cf. claibornense Cushman		R
Reussella eocena (Cushman)	C	A
Reussella subrotundata (Cushman and Thomas)		R
Uvigerina gardnerae Cushman		R
Uvigerina glabrans Cushman	R	
Angulogerina ocalana Cushman	F	A
Angulogerina cooperensis Cushman	C	C
Angulogerina vicksburgensis Cushman	C	A
Spirillina cf. vicksburgensis Cushman		C
Patellina advena Cushman		F
Discorbis hemisphaerica Cushman	F	F
Discorbis alveata Cushman		R
Discorbis assulata Cushman	F	C
Discorbis yeguaensis Weinzierl and Applin	F	F
Valvulineria jacksonensis Cushman	F	F
Gyroidina soldanii d'Orbigny, var. octocamerata Cushman and G. D. Hanna	A	A
Eponides budensis (Hantken), var. planata Cushman	R	R
Eponides jacksonensis (Cushman and Applin)		R

Abundance Chart of Foraminifera in Test Wells continued:

(A = Abundant, C = Common, F = Frequent, R = Rare)	Test Well No. 1	Test Well No. 2
Siphonina jacksonensis Cushman and Applin	A	A
Siphonina clabornensis Cushman	F	F
Cancris sp.	A	F
Pulvinulinella atlantisae Cushman	F	F
Cassidulina crassa Cushman and Cahill	R	
Cassidulina globosa Hantken	R	
Globigerina sp.	C	C
Anomalina bilateralis Cushman	A	A
Cibicides lobatulas (Walker and Jacob)	C	A
Cibicides americanus (Cushman), var. *antiquus* (Cushman and Applin)	A	A
Cibicides danvillensis Howe and Wallace	A	A
Cibicides westi Howe	R	R
Cibicides choctawensis Cushman and McGlamery		R
Cibicides cocoaensis (Cushman)	A	A
Cibicides refulgens (Montfort)	C	A
Cibicides pseudoungerianus (Cushman)	C	

Lithologically, the upper unit of the McBean is similar to the overlying Gosport sand, that is, it was found to consist predominately of dense, light-gray, sandy, sparsely glauconitic limestones interbedded with minor amounts of green to bluish clay in the form of thin stringers.

Test well 1 penetrated the upper unit of the McBean approximately 129 feet while test well 2 showed about 110 feet of sediments that have been assigned to this part of the middle Eocene.

Owing to the fact that the two test wells were terminated in the upper unit of the McBean, the stratigraphy of the remainder of the middle Eocene has had to be pieced together from a few wells of sufficient depth to penetrate this part of the Tertiary rocks. Below the upper unit therefore, occur sediments that are here assigned to the lower unit of the McBean. Lithologically these strata consist chiefly of finely granular, apparently somewhat loosely cemented, softer limestones interbedded with clays. Locally, particularly in coastal Georgia and southward into Florida, these rocks have been secondarily altered to brown, saccharoidal, sandy, dolomitic, cherty, unfossiliferous limestones. These dolomitic limestones become progressively denser with increased depth partly through an increase in amount of included chert and partly through secondary replacement, or dolomitization. Light-gray to brown chert, in addition to the dolomitic character of these sediments, is considered characteristic of the lower unit of the McBean in areas where dolomitization has taken place. Over the major part of the Coastal Plain, however, exclusive of coastal Georgia noted above, the lower unit consists predominantly of gray, dense, sandy, coarsely but rather abundantly glauconitic limestones interbedded with minor amounts of sand and thin stringers of gray, finely-phospatic clay.

The lower unit of the McBean is believed to have been penetrated at an approximate depth of 740 feet in the No. 1 Cherokee Hill, an oil test situated several miles northwest of Savannah. The newest municipal water well owned and operated by the City of Savannah apparently entered this part of the McBean formation around 800 feet, where coarsely glauconitic limestones occur. At a depth of 890 feet, in this well, this lithology changes to finely granular, loosely cemented, softer limestones, which at 950 feet, change to dense, dark-brown, chert-bearing, dolomitic limestones in which the well terminates at an approximate depth of 1000 feet. In the No. 2 U. S. Marine Base well, Parris Island, S. C., the top of the lower unit was placed at the approximate depth of 605 feet.

Foraminifera considered diagnostic of the lower unit of the McBean include Lepidocyclina (Polylepedina) antillea Cushman, Operculinoides sp., Asterigerina lisbonensis Cushman and Todd and Cibicides westi Howe. On the basis of paleontologic evidence, therefore, the lower unit seems to be more closely related to the Lisbon of Alabama than the overlying upper unit of the McBean. In the Albany area, Dougherty County, where the McBean formation is well represented in its entirety, the two large Foraminifera noted above occur near the top of the lower unit along with Asterigerina lisbonensis Cushman and Todd and other small Foraminifera. In the Savannah area, however, as noted earlier, these two Orbitoids make their first appearance at, or near the top of the rocks here regarded as probable Gosport where they seem to represent the reworked lower unit.

Tallahatta formation

As noted above the Tallahatta formation is here considered equivalent to the Tallahatta of Alabama, Lake City limestone (in part) of Florida, and Cook Mountain formation (in part) of Louisiana and Mississippi. These sediments represent the oldest known middle Eocene, or Claiborne, in Georgia. Moreover, these strata occur only in the subsurface, no surface exposures being known to the authors anywhere in Georgia.

Micro-fossils found to occur in sediments of Tallahatta age are distinctive, numerous, and usually in an excellent state of preservation. Some of the more important Foraminifera identified from this formation include the following:

Robulus alato-limbatus (Gumbel)
Nodosaria cf. globifera (Batsch)
Bolivina broussardi Howe and Roberts
Reussella subrotundata (Cushman and Thomas)
Trifarina wilcoxensis (Cushman and Ponton)
Siphonina claibornensis Cushman
Cibicides pseudoungerianus lisbonensis Bandy
Cibicides blanpiedi Toulmin
Cibicides tallahattensis Bandy

The Tallahatta consists, lithologically, of light-gray, silty, glauconitic, limey clay, or marl carrying scattered hard lime nodules. These marls form a very definite base for the overlying limestones and dolomites of the Jackson group and the upper and middle parts of the Claiborne group, respectively. Sediments belonging to this formation should be capable of being identified and mapped in the subsurface over a region of considerable areal extent. So far, this part of the middle Eocene has been noted in only three deep wells, namely, No. 2 U. S. Marine Base Well, Beaufort County, S. C., No. 1 Cherokee Hill, Chatham County, Ga., and the No. 1 Jelks-Rogers, Liberty County, Ga.

Below the Tallahatta formation lies a series of alternating clays, sands, and some limestones belonging to the Wilcox and Midway groups, respectively. Neither of these groups of sediments constitutes an abundant or readily available source of ground-water supply. Still deeper than the rocks of Wilcox and Midway age are those belonging to the Cretaceous system The latter, for similar reasons, are also not regarded as an economical source of additional ground water in the Savannah area. In conclusion, it seems to be a fact that the chief source of ground water in the Savannah area is confined to a series of limestones described above as being of late middle Eocene to early Miocene age, inclusive. Protection of these economically valuable underground aquifers from overpumping and consequent salt-water encroachment seems to be an obvious necessity.

GROUND WATER

Occurrence

Ground water in the Savannah area occurs under two conditions: Water-table or unconfined, and artesian or confined. Only the artesian or confined water is discussed here.

Artesian water in the Savannah area occurs in limestones ranging in age from late middle Eocene to early Miocene, which are overlain and underlain by impervious clays which effectively confine the water. Rain falling on the earth enters these limestones at the area of outcrop to the north and west and moves slowly through tiny pores and solution channels toward the coastal area of Georgia under the action of gravity (Warren, 1944, p. 18a, fig. 2).

Pumpage

From 1938 to 1944 the U. S. Geological Survey in cooperation with the Georgia Department of Mines, Mining and Geology made an investigation of the ground-water resources of the coastal area of Georgia. It was determined at that time (Warren, 1944, fig. 6,31) that water levels in the Savannah area had been lowered to about 50 feet below sea level and from 70 to 100 feet below the piezometric surface of 1880, which was about 37 feet above land surface.

Pumpage in the Savannah area was estimated by Warren to be about 42 mgd or about 126 acre-feet per day in 1943. Of this total pumpage, approximately 31 mgd was metered, and the remainder, about 11 mgd, was estimated.

The following table gives the average daily metered pumpage for the City of Savannah and Union Bag and Paper Corporation, the two largest water users in the Savannah area for the years 1937 to 1954.

Table 2. - Average daily metered pumpage in the Savannah area.

Year	Million gallons per day	Year	Million gallons per day
1937	19.73	1946	28.28
1938	25.13	1947	27.86
1939	26.34	1948	29.41
1940	26.81	1949	30.55
1941	27.40	1950	28.34
1942	27.98	1951	27.02
1943	31.00	1952	29.34
1944	29.28	1953	31.98
1945	29.68	1954	36.68

In the 18 years reported here metered pumpage has increased from about 20 mgd to nearly 37 mgd. The unmetered pumpage has not been re-estimated, but probably has increased over the 11 mgd estimated of 1943.

Piezometric Surface

Plate 4 is a map of the piezometric surface in the Savannah area for November 1954. This map represents the height in feet to which water would rise with reference to sea level in tightly cased wells

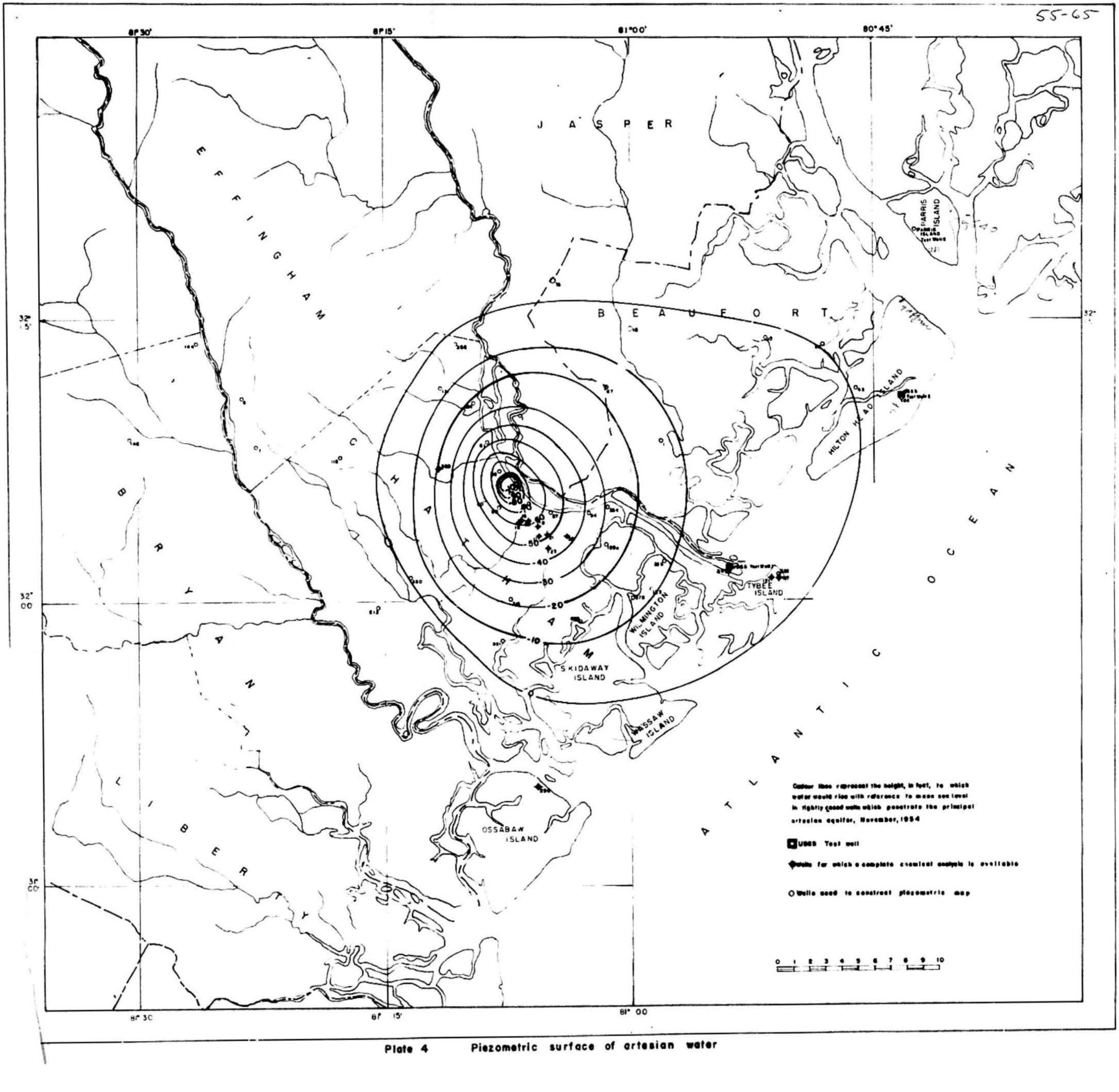


Plate 4 Piezometric surface of artesian water

which penetrate the principal aquifer. Only that portion of the piezometric surface which is at or below sea level is represented on this plate. The cone of depression is deepest about three miles northwest of the City of Savannah. The distance from the deepest part of the cone to the zero contour line is greater to the east than it is to the west. This distance is about eight miles on the west side of Savannah, about 20 miles on the southeast side and, on the northeast side where the cone reaches its maximum extent in the vicinity of Hilton Head, South Carolina, it is about 25 miles. A comparison of this map with that for 1952 shows that the cone has broadened slightly, doubtless as a result of increased pumpage. The cone slopes steeply on the west side and rather gently on the east side.

Relation between Salt Water and Fresh Water

The general relation between fresh water and salt water along sea-coasts was first stated by Badon Ghyben. This principle as stated by Brown (1925, p. 16), is as follows:

> "Let H equal total thickness of fresh water,
> h equal depth of fresh water below sea level,
> t equal height of fresh water above sea level,
> Then H equals h + t.
> But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Therefore if g is the specific gravity of sea water, and that of fresh water is taken as 1,
>
> $$H = h + t = hg, \text{ whence } h = \frac{t}{g - 1}$$
>
> In any case g - 1 will be the difference in specific gravity between fresh and salt water."

The specific gravity of sea water in the Atlantic Ocean is very nearly 1.025 and that of fresh water is 1.000. Under these conditions salt water would be displaced by fresh water to a depth of 40 feet below sea level for each foot of head the fresh water is above sea level. This relationship applies strictly only if the two fluids are in static balance.

Intensive pumping in coastal areas inevitably gives rise to the possibility of the movement of salty water into the fresh-water bearing aquifer, owing to a reduction in fresh-water head within the aquifer.

Such salt-water encroachment could occur by leakage through the confining bed, where it is thin, or by leakage directly into the aquifer where the confining bed is absent, or by movement into the aquifer from the area of the submarine outcrop. It is believed the salt water would move inland as a wedge shaped body, the lower part of the wedge preceding the upper part.

Test-Well Sites

The sites for the two test wells were chosen on the basis of the fresh-water-salt-water relation as described by Badon Ghyben, and the shape of the piezometric surface as determined by Warren in 1943, as well as the known presence of salty water in the aquifer at Parris Island.

Test well 1 is about one-half mile west of old Ft. Pulaski, a pre-Civil war fortification, on the eastern end of Cockspur Island, in the Savannah River, and about 20 miles southeast of Savannah, in Chatham County, Georgia. A 10-foot square plot of land was leased by the U. S. Geological Survey from the National Park Service for a period of ten years, this lease renewable at the end of that time, thus insuring the permanency of the well.

Test well 2 is about 22 miles northeast of the City of Savannah at Hilton Head Island, in Beaufort County, South Carolina. A plot of land was leased from the Hilton Head Company for "as long as the well shall be needed," also insuring the permanency of this well. Thus both wells have been located as close as practicable to the ocean, the most likely source of salt-water contamination, and to the submarine outcrop.

QUALITY OF WATER

General

As water moves through the ground from the area of recharge to the wells by which it is removed, it is affected by the mineral constituents of the rocks through which it passes. Some of the minerals are more easily dissolved by water than others, and consequently are taken into solution by the water, thereby helping to characterize the waters which come from different rock types.

In the Savannah area the principal water-bearing beds are limestones ranging in age from middle Eocene to early Miocene. Waters from these limestones contain some of the dissolved minerals which constitute the limestone. The principal minerals found in limestone are the carbonates of calcium, magnesium and sodium. Waters from limestones may range from soft to very hard, depending upon the amount of calcium and magnesium carbonate, the principal hardness-forming constitutuents, that is contained in them. Analyses of water taken from 12 wells in this area, ranging in depth from 174 feet to 700 feet show a range of hardness of from 100 parts per million to 152 ppm. Accordingly these (Warren, 1944, p. 138, 139) are classed as moderately hard to hard water.

Previous investigations (Herrick and LeGrand, 1947, Herrick and Chase, 1952) have shown that in wells ranging in depths from 76 feet to 1010 feet, the chloride content of the waters ranges from 3 ppm to 87 ppm, and varies as much as 66 ppm in the same well. Warren, (1944, p. 127) obtained water with a chloride content of 2475 ppm from the Savannah Oil Company, Cherokee Hill No. 1, which was drilled northwest of the City of Savannah near the municipal airport in 1920. This well was drilled to a total depth ~~of~~ 2130 feet, and the sample was collected from water which flowed from between an 8-inch casing ~~which extended~~ extending to a depth of 2126 feet, and a 10-inch casing which extended (extending) to a depth of 1630 feet. Thus the water may be presumed to have come from the interval between 1630 and 2160 feet. The water is thought to be connate, however, and is probably from sedimentary rocks of Cretaceous age which lie below the limestones and are separated from them by the clays of the McBean formation as well as the sediments of the lower Eocene and Paleocene series.

Water samples obtained from a test well drilled in 1939 for the Navy Department at the U. S. Marine Barracks, Parris Island, S. C. contained 8500 ppm chloride from the interval 990-1149, 925 ppm chloride from the interval 1850-1900 and 435 ppm chloride from the interval 1850-2500. A sample taken from the interval 2600-2811 feet contained only 82 ppm chloride, but contained 1320 ppm bicarbonate, 7 ppm fluoride, 69 ppm carbonate, and 1 ppm sulfate, which composition is similar to that of waters found in other places in the Coastal Plain areas of Virginia, North Carolina, and South Carolina.

Water Sampling Procedure

In order to determine the variation in water quality with depth, and to determine the quality of water in various stratigraphic zones, four water samples were taken from each test well during drilling, approximately every 200 feet, by means of a rubber packer and a portable centrifugal pump. The packer was placed on a 4-inch pipe, with a 12-foot length of 4-inch pipe below the packer. The upper 8 feet of this 12-foot length of pipe was slotted and the bottom 4 feet was left blank in order that cuttings which could not be bailed from the hole would not interfere with water moving into the 4-inch pipe. Additional 4-inch pipe was screwed onto this assembly until it extended to land surface. When the assembly was allowed to rest on the bottom of the hole, the weight of the pipe caused the packer to expand against the sides of the hole and form a seal which shut off all water above the packer. Thus, when water was pumped from the 4-inch pipe, only the water between the packer and the bottom of the hole was withdrawn, assuming the packer formed a tight seal in each setting. The volume of the 4-inch pipe was calculated and the pump was allowed to run for approximately an hour beyond the time necessary to evacuate the original volume of water from the pipe. On the basis of changes in quality of water as shown by the chemical analyses, it is concluded that in general, the packer did form an effective seal and that the samples are representative of water from those zones which were tested.

The pump was allowed to run at full capacity when the water level in the 4-inch pipe did not fall below the intake hose while pumping at that rate. Pumping rates varied from 60 gpm to 0.75 gpm. Table 3 shows the rates of pumping for various tests, depths at which water samples were taken and water level measurements inside the 4-inch pipe, and the 8-inch casing. All measurements are in feet below the top of the well casing.

Table 3. - Depth at which water samples were collected.

Test Well 1

Packer test	Depth	Depth to water below casing		Pumping rate	Temp. °F.
		4" pipe	8" casing	gpm	
1	203-215	14.10 ft.	13.60 ft.	60	73
2	390-402	14.53	13.56	60	73
3	589-601	14.34	13.74	50	73½
4	712-745	18.00	13.67	15	74
Composite	185-745	---	---	150	73

Test Well 2

Packer test	Depth	Depth to water below casing		Pumping rate	Temp. °F.
		4" pipe	8" casing	gpm	
1	188-200	---	13.70 ft.	55	69
2	388-400	23.67	14.48	5	70½
3	588-600	22.64	14.20	6	--
4	668-740	29.25	13.77	0.75	85
Composite	128-740	---	---	--	--

When each test well was completed a fifth water sample was taken from the well. At test well 1 the mud pump was used to obtain the water sample, being allowed to pump at the rate of 150 gpm for 8 hours, at the end of which time the sample was collected. At test well 2, the centrifugal pump was used to obtain the water sample. Here the pump was allowed to run for approximately 6 hours before the sample was collected. These samples are listed as "composite sample" in the table of analyses. At test well 1 the sample consists of a mixture of waters from the limestone of Oligocene age, Ocala limestone, Gosport sand, and the McBean formation. At test well 2, the sample was a mixture of waters from limestone of the early Miocene age, the limestone of Oligocene age, Ocala limestone, Gosport sand and McBean formation. Both the temperature of the water and the chemical analyses of the composite sample indicate that the composite samples came chiefly from the upper portion of the test well.

Results of Analyses

Table 4 gives the results of the the analyses of the water samples obtained during the drilling of the two test wells. All values are given in parts per million (ppm) except color, pH (hydrogen-ion concentration) and specific conductance.

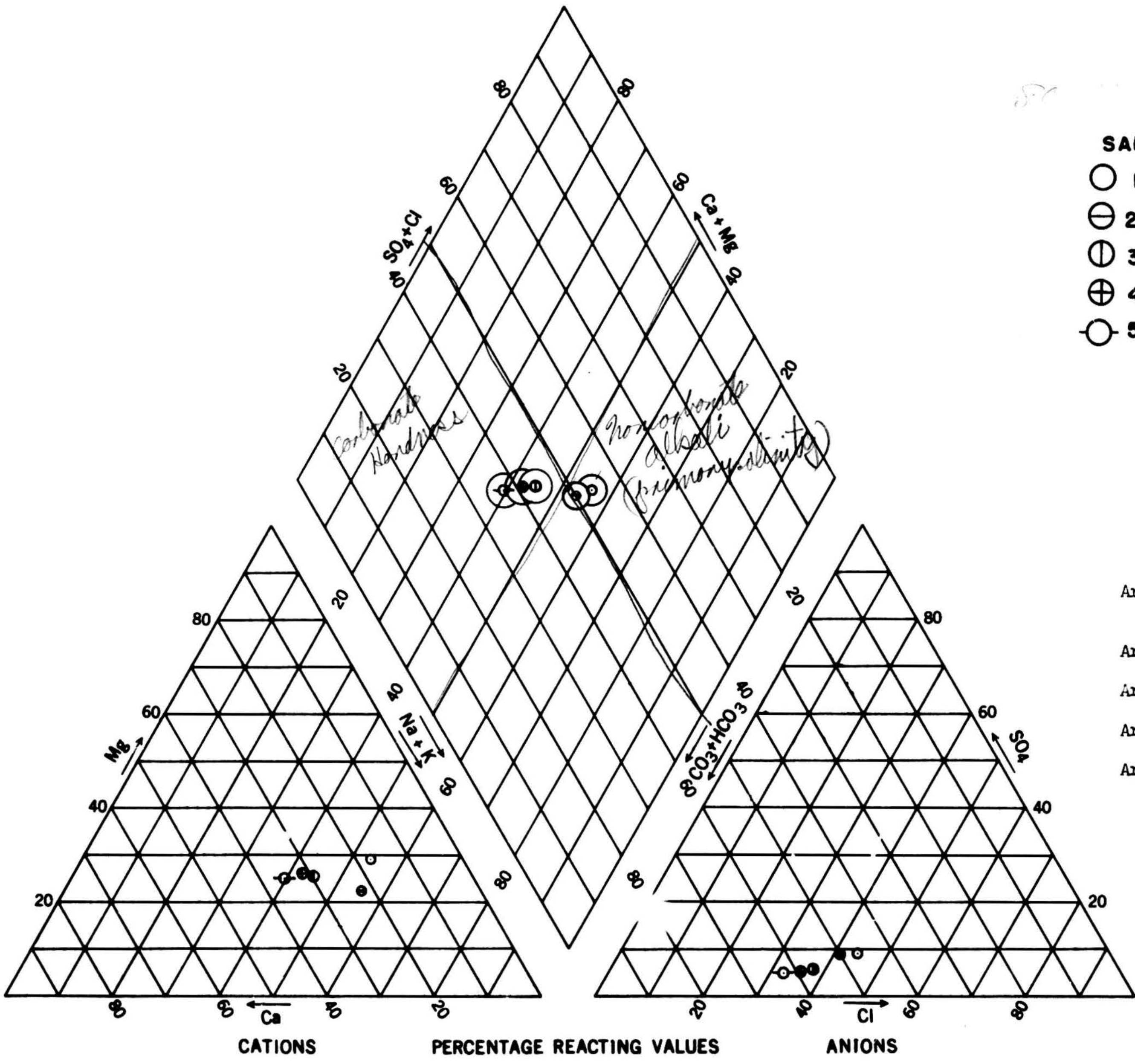
The samples from test well 1 were low in dissolved solids, the dissolved solids ranging from 162 ppm in sample 1 to 209 ppm in sample 4. The total hardness ranges from 52 ppm in sample 1 to 94 ppm in sample 5, and is carbonate or temporary hardness. The chloride content ranges from 33 ppm in sample 1 to 41 ppm in sample 3. The chloride content, hardness and dissolved solids all increase with depth.

In test well 2, the dissolved solids range from 327 ppm in sample 1 to 1360 ppm in sample 4. The hardness ranges from 109 ppm in sample 1 to 243 ppm in sample 4, and in samples 2, 3, and 4 consisted partly of the noncarbonate or permanent type. Chloride content ranges from 66 ppm in sample 1 to 530 ppm in sample 4. The total iron content is above the recommended limit, as set by the U. S. Public Health Service,

Table 4. - Chemical Analyses of Samples from Test Wells 1 and 2

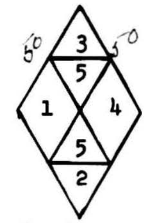
Well No.	Depth in Feet	Date of Collection	Temp. °F	Dissolved Solids	Silica SiO_2	Iron Fe	Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO_3	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Fluoride F	Nitrate NO_3	Hardness as $CaCO_3$	Specific Conductance Micromhos at 25°C
				Parts per million														
Test Well 1																		
Sample 1	203-215	5-11-54	73	162	37	a).01 b).30	8.0	7.8	26	2.9	14	42	9.8	33	.4	.0	52	236
2	390-402	5-13-54	73	169	34	a).02 b).--	10	6.0	27	2.7	13	41	10	36	.4	.0	50	243
3	589-601	5-17-54	73½	204	37	a).08 b).15	18	9.3	29	2.9	0	107	8.5	41	.4	.2	83	314
4	712-745	5-20-54	74	209	38	a).09 b).40	20	10	29	2.8	0	116	7.8	40	.4	.1	91	329
5	Composite	5-21-54	73	205	39	a).00 b).45	22	9.6	27	2.4	0	122	8.2	36	.4	.1	94	320
Test Well 2																		
Sample 1	188-200	6-1-54	69	327	33	a).18 b).33	24	12	56	3.2	0	145	30	66	.6	.0	109	490
2	388-400	6-3-54	70½	468	24	a).08 b).41	26	26	84	8.0	0	165	34	142	.7	.0	172	789
3	588-600	6-5-54	--	1,180	29	a).38 b)1.2	26	33	330	18	0	185	128	484	1.2	.5	200	2,080
4	688-740	6-9-54	85	1,360	26	a).01 b)8.8	38	36	375	18	0	180	207	530	1.2	.0	243	2,340
5	Composite	6-9-54	--	353	33	a).10 b).31	25	13	68	3.9	0	150	35	82	6	.0	116	578

a) In solution
b) Total Iron



VARIATION IN QUALITY OF WATER, TEST WELL I

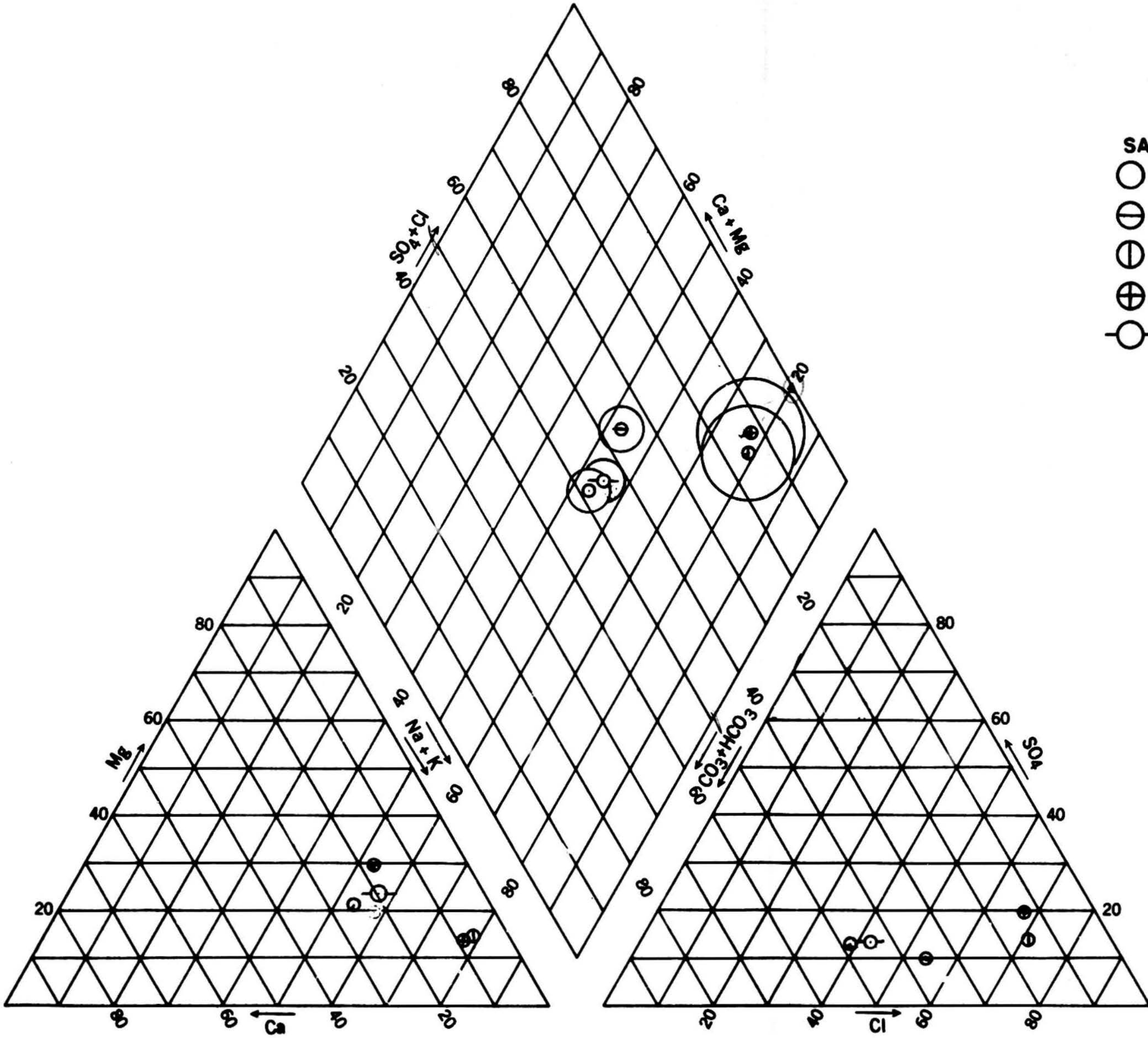
SAMPLE	DATE	DISSOLVED SOLIDS (ppm)	DEPTH
○ 1	May 11, 1954	162	203-215
⊖ 2	May 13, 1954	169	390-402
⦶ 3	May 17, 1954	204	589-601
⊕ 4	May 20, 1954	209	712-745
-○- 5	May 21, 1954	205	185-745



Key Diagram

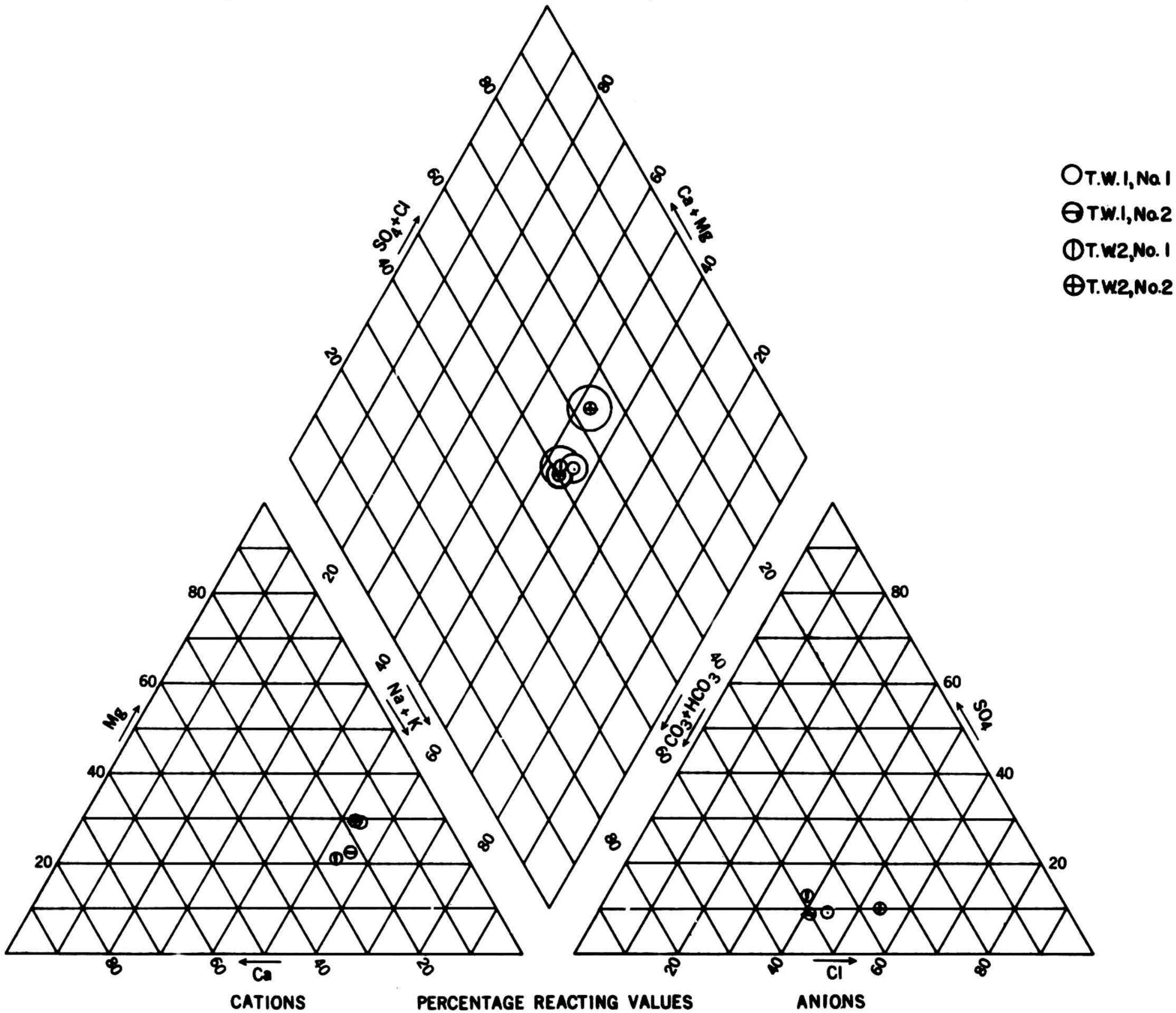
Area 1: Carbonate hardness (secondary alkalinity) exceeds 50 percent of all the dissolved solids in terms of chemical equivalents.
Area 2: Carbonate alkali (primary alkalinity) exceeds 50 percent.
Area 3: Noncarbonate hardness (secondary alkalinity) exceeds 50 percent.
Area 4: Noncarbonate alkali (primary salinity) exceeds 50 percent.
Area 5: No one of the preceding four characteristics is as much as 50 percent.

fig 31b



SAMPLE	DATE	DISSOLVED SOLIDS (ppm)	DEPTH
1	June 1, 1954	327	188-200
2	June 3, 1954	468	388-400
3	June 5, 1954	1,180	588-600
4	June 9, 1954	1,360	668-740
5	June 9, 1954	353	129-740

VARIATION IN QUALITY OF WATER, TEST WELL 2



QUALITY OF WATER IN OCALA LIMESTONE

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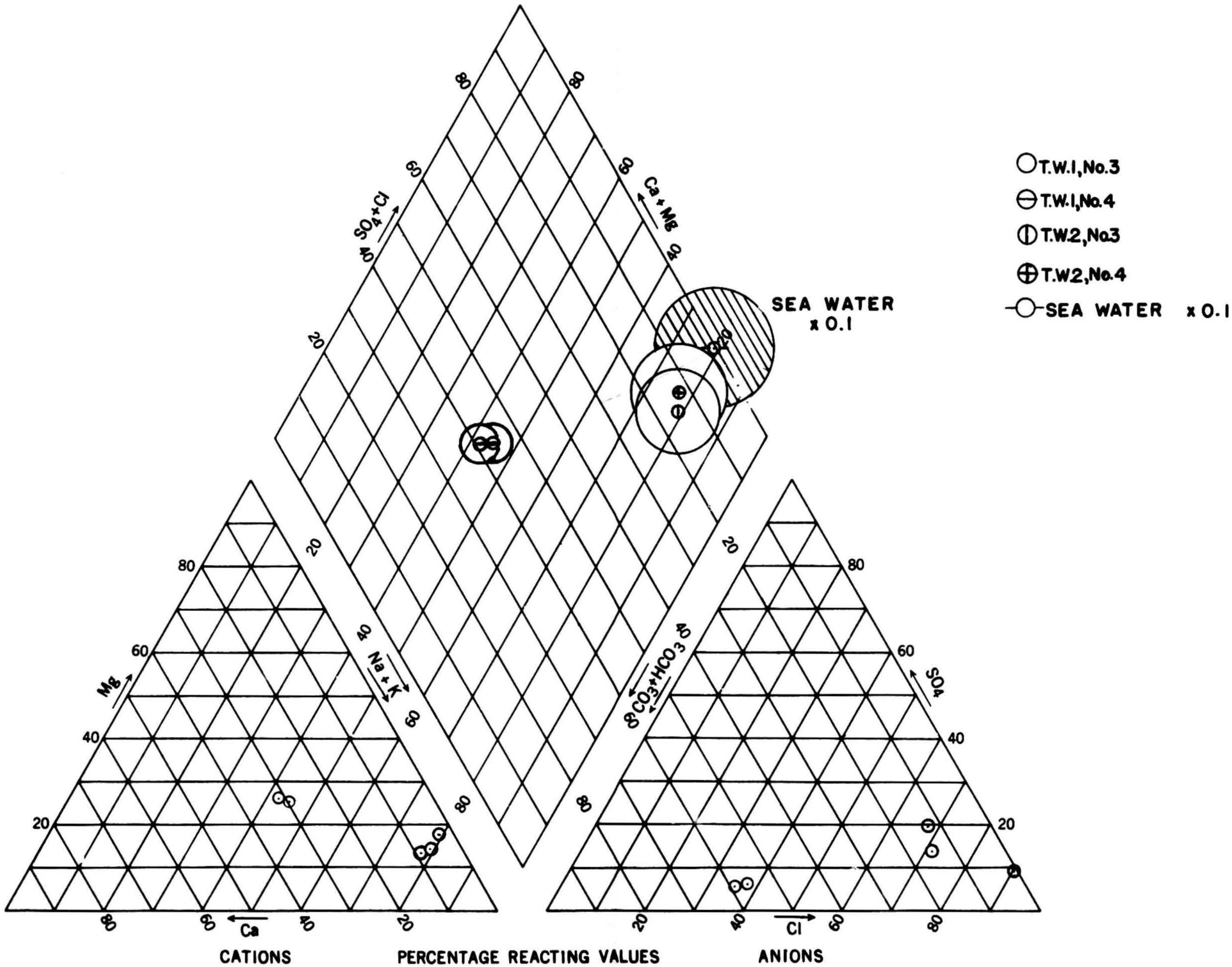


VARIATION IN QUALITY OF WATER IN GOSPORT SAND, McBEAN CLAY

p. 31 e

in samples 3 and 4. Percent sodium is 70 in sample 4, making this water injurious to some types of crops. Dissolved solids, hardness, chloride and percent sodium increase with depth at this location.

Plates 5 and 6 show the results of these analyses plotted according to percent reacting value as described by Piper (1944, p. 916). Accordingly the water falls into five classes according to the percentage, by weight, of each of the six major constituents (See plate 5 for key). These plates show the variation in the quality of water with depth at each of the test wells.

At test well 1, (Plate 5), the analyses of samples 1 and 2 plot as waters of the saline type, while those of samples 3, 4, and 5 plot as waters of the carbonate hardness type. Among the cations, the percentage of calcium is increased in each successively lower sample, while the percentage of sodium decreases, producing a harder water with increasing depth. There is a corresponding change in the anions with depth, the percentage of chloride decreasing and that of bicarbonate increasing.

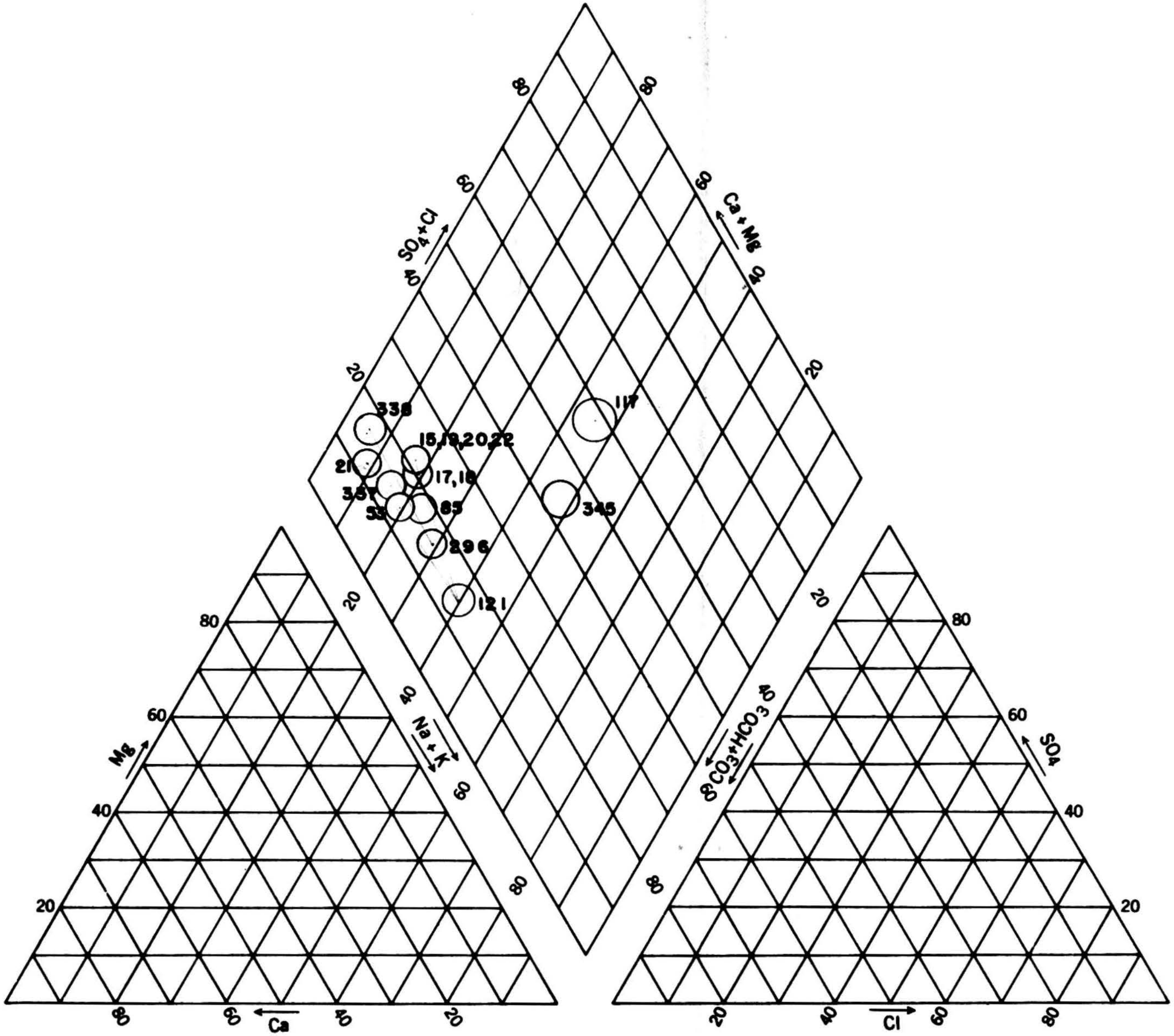
At test well 2, (Plate 6) the analyses of all samples plot as waters of the saline type, salinity increasing with depth. Among the cations, there is a slight decrease in the percentage of magnesium and calcium, and a rather marked increase in the percentage of sodium. The decrease of calcium and magnesium and increase of sodium could represent base-exchange softening of the natural ground waters as they pass through the area. Base exchange could occur as the waters come in contact with glauconite, or certain types of clays, both of which are known to be present here, the magnesium and calcium in the water being replaced by the sodium from the clay or glauconite. The anions show a slight increase in percentage of sulphate, a marked decrease in percentage of bicarbonate, and a marked increase in the percentage of chloride present.

Plates 7 and 8 show a comparison of waters from corresponding zones in the two test wells. Samples 1 and 2 (Plate 7) from both of the test wells are from the Ocala limestone. All four samples plot as primary saline waters. Sample 2, test well 2, is higher in chloride than any samples previously collected from that formation.

Samples 3 and 4 (Plate 8) from both of the test wells are from the Gosport and McBean formations. At test well 1 the waters are of the carbonate hardness type, low in dissolved solids and chloride. At test well 2, samples 3 and 4 are of the saline type and are high in hardness, dissolved solids and chloride. Samples 3 and 4, test well 2, are approaching by percent reacting value, or relative amount of each constituent, the composition of sea water. However they do not appear to be a simple mixture of sea water and fresh water of the type encountered in test well 1, samples 3 and 4.

Areal Variation of Chemical Character of Water

In order to determine the chemical character of water throughout this area, as well as to determine any change in the chemical character of the water as it moves coastward toward the area of submarine outcrop where it is discharged into the ocean by submarine springs, a comparison of the analyses in Chatham county, reported by Warren, and those obtained



AREAL VARIATION IN QUALITY OF WATER

during the test drilling is presented. Table 5 shows the wells for which an analysis is available, depth of well, amount of casing, and probable producing horizons. Analyses for these wells are found in Appendix A.

Table 5. - Depth and producing horizons of wells for which an analysis is available, Savannah, Georgia.

Chatham County No.	Depth to which cased	Depth of well	Rocks from which water was obtained: Miocene	Oligocene	Ocala limestone	Gosport and McBean formations
15	180	500 ±		x	x	
17	206	500		x	x	
18	220	700	x	x	x	x
19	225	603		x	x	x
20	250	525		x	x	
21	250	550		x	x	
22	245	587		x	x	x
85	256	696		x	x	x
117	125	602	x	x	x	x
121	85 ±	174	x	x		
296	---	367	x(?)	x	x	
338	269	681		x	x	x
345	352	535			x	x

Wells 15, 17-22, and 85 are Savannah municipal water wells and are located within the City of Savannah. Wells 117 and 121 are on Tybee Island, which is seaward from test well 1, and well 296 is southwest of test well 1 on Ossabow Island.

Plate 9 shows the distribution of water types throughout the area. Again it is to be noted that these samples are mixtures of waters and do not necessarily present a true picture of the chloride content of the lowest beds penetrated by well.

From this figure it can be seen that the water from the city wells is characterized by carbonate hardness, the chemical properties being dominated by alkaline earths and weak acids, as is water from wells 337 and 338, which are at the Savannah municipal air field northeast of the city. Water from well 345, which is on Cockspur Island near test well 1, has a chloride content of 48 ppm and is more saline than the city wells or the air field wells. Well 117 has water of the primary salinity type, and is located furthest seaward of any of the wells for which analyses are available. The chloride content of water from this well is 52 ppm, and is higher than that of sample 4 from test well 1, in both parts per million and percent reacting value. Well 296, although located seaward from test well 1, well 345 and well 117, yielded water having only 4 ppm chloride. Thus it appears that in the vicinity of the Savannah River, the chloride content of water from the aquifer is slightly higher than in any of the inland area, or in the area along the coast to the south.

SUMMARY

Geologic data from twenty wells, including two 740-foot test wells, indicate that approximately 500 feet of limestones, capable of yielding copious ground-water supplies, occur beneath the Savannah area. These rocks slope upward in a northeasterly direction from the City of Savannah, coming within 100 feet of land surface at Parris Island, South Carolina, approximately 30 miles northeast of Savannah. The materials overlying the water-bearing limestones consist predominantly of clay which, according to available information seems adequate in preventing a downward percolation of salt water. The limestones, themselves, differ locally in hardness and amount of secondary alteration, changing at depth to rather dense, dolomitic rocks.

Stratigraphically, the water-bearing limestones were found to range in age from lower Miocene (Tampa limestone) to middle Eocene (McBean formation). Both test wells were terminated in clay of unknown thickness and horizontal extent. Indicative of the geologic age of these bottom clays are the included foraminifera which were identified as the late McBean in age. The fact that the faunal association found in the bottom samples of both test wells is practically identical with that which was described from the type locality of the McBean formation (Cushman and Herrick, 1945 pp. 55-73), as well as that described from sediments of known McBean age at Danville Bluff, Sumter County, Georgia (Rainwater, 1944, p. 53), supports this conclusion. Moverover, the stratigraphic position of these clays is in favor of this conclusion--such clays underlie the younger strata of proven (see listed Foraminifera of Ocala limestone in text) Jackson (upper Eocene) age. Accordingly, both test wells penetrated completely the principal limestone aquifer and proved the existence of overlying and underlying clays. The underlying confining bed prevents upward movement of saline waters from the formations that underlie the aquifer. Likewise the upper confining bed prevents downward movement of saline water, except where the bed may be thin or absent.

The logs of three other deep wells in the area indicate that dolomitic limestones of early McBean age occur beneath clays of the upper unit of the McBean and that clays of Tallahatta age underlie the McBean. (See X-Sections A-A' and B-B').

The water samples taken at both test wells reveal changes in the chemical character of ground water with depth. At test well 1, the water from the Ocala limestone is of the saline type, and the water from the McBean and Gosport formations is of the carbonate hardness type. At test well 2, the samples indicate waters of the saline type are present in both the Ocala limestone and the McBean and Gosport formations The saline waters contrast greatly with the carbonate waters from the inland area in the vicinity of the city well field.

The sharp increase in chloride in test well 2 may be due to incomplete flushing of salt water present in the beds as a result of the last marine invasion of the area. The chemical composition of this water is not the same as that of a simple mixture of fresh artesian water and sea water. Indications are that the salty water invaded the aquifer by natural processes in the geologic past. It is evident from the chloride content of the water samples from the Parris Island test well and the Cherokee Hill oil test that saline waters underlie the fresh water-bearing limestones in the Savannah area and under certain circumstances, may be considered a potential source of contamination. Any wells drilled into these deeper saline-water-bearing rocks, and left unplugged may allow the saline water to move upward through the hole and into the fresh-water-bearing limestones.

The fact that relatively salty water was found in the aquifer in test well 2 does not, in itself, indicate that salt water is advancing. Therefore, sampling should be continued over a period of time to observe whether there is any significant increase in salinity.

Although the fact that only fresh water was found in test well 1 gives no assurance that salt water is not moving inland from the direction of Cockspur Island, it does show that if salt water is advancing it has not yet reached the well.

An answer to the question of whether salt water is now moving toward Savannah must remain partly conjectural until such time as the program of long-term sampling from outpost wells, together with other data, has provided positive information. Inferences can be drawn, however, from what has already been learned regarding the position of the piezometric surface, the geology, the presence of salty water in the aquifer, and from a consideration of the mechanics governing salt-water encroachment. These factors give reason to believe that salt water is advancing, but at an exceedingly slow rate. Judging from what little is known now, the salt water is advancing so very slowly that its arrival in Savannah may take several decades. Lest caution be waived, however, we must recognize that each increase in the withdrawal of artesian water in the Savannah area will accelerate the rate of advance. This preliminary estimate of the situation is based on scanty information and may have to be revised--perhaps toward a more pessimistic plan--as more information is obtained and further studies are made.

Residual Problems and Continuing Investigation

Additional test drilling is needed on the north end of Hilton Head Island, on Daufuskie Island, and on Wassaw Island or Ossabow Island to determine the presence or absence of the clay of the McBean formation which underlies the main aquifer in other parts of the area. Additional test drilling would also reveal the geologic and hydrologic characteristics of the aquifer as well as provide a means of obtaining water samples from the lower portion of the limestone. At present there are no deep wells which penetrate the lower portion of the aquifer in these areas, and consequently no water samples are available from the lower portion of the aquifer. Sampling from the lower portion of the aquifer is critical to the problem of early detection of salt-water encroachment. Such a system of outpost wells would allow periodic chloride sampling to be done and to enable detection of salt-water intrusion at the earliest stages. Preventive measures instituted on the basis of data which can be obtained only through such outpost wells will provide the most effective means of safeguarding the water supply of the Savannah area.

Further, it seems advisable that the current investigation of determining the relation of pumpage, and subsequent loss of hydraulic head in the formation, to salt-water encroachment--the crux of the problem--be continued beyond the initial period of one year so that substantiating data may be gathered, interpreted, and presented in a report.

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Appendix A

Chemical Analyses of Water, Savannah, Georgia Area

	Well 15		Well 17	
	Parts per million	Equivalents per million	Parts per million	Equivalents per million
Silica (SiO_2)	53	--	53	--
Iron (Fe)	.01	--	.0	--
Calcium (Ca)	26	1.298	27	1.348
Magnesium (Mg)	9.7	.798	10	.822
Sodium (Na)	9.5	.413	11	.478
Potassium (K)	1.4	.036	1.4	.036
Carbonate (CO_3)	3.0	--	3.9	--
Bicarbonate (HCO_3)	137	2.246	145	2.377
Sulfate (SO_4)	6.9	.144	6.3	.131
Chloride (Cl)	5.0	.141	5.2	.147
Fluoride (F)	0.0	.000	0.0	.000
Nitrate (NO_3)	0.0	.000	.06	.001
Dissolved solids	173	--	181	--
Total hardness as $CaCO_3$	105	--	108	--
Specific conductance (Micromhos at 25°C.)				
pH				
Temperature (°F.)	73	--	73	--
Date of collection	Feb. 9, 1938		Feb. 9, 1938	
Depth to which cased	180		206	
Depth of well (feet)	500		520	

Chemical Analyses of Water, Savannah, Georgia Area

	Well 18		Well 19	
	Parts per million	Equiva-lents per million	Parts per million	Equiva-lents per million
Silica (SiO_2)	52	--	53	--
Iron (Fe)	.01	--	.01	--
Calcium (Ca)	27	1.348	26	1.298
Magnesium (Mg)	9.1	.748	10	.822
Sodium (Na)	10	.435	10	.435
Potassium (K)	1.1	.028	1.4	.036
Carbonate (CO_3)	3.9	--	2.0	--
Bicarbonate (HCO_3)	137	2.246	138	2.262
Sulfate (SO_4)	7.1	.148	6.8	.142
Chloride (Cl)	5.5	.155	5.8	.164
Fluoride (F)	.0	.000	.0	.000
Nitrate (NO_3)	.0	.000	.0	.000
Dissolved solids	174	--	176	--
Total hardness as $CaCO_3$	105	--	106	--
Specific conductance (Micromhos at 25°C.)				
pH				
Temperature (°F.)	71	--	73	--
Date of collection	Feb. 9, 1938		Feb. 9, 1938	
Depth to which cased	220		255	
Depth of well (feet)	540		603	

Appendix A - continued

Chemical Analyses of Water, Savannah, Georgia Area

	Well 20		Well 21	
	Parts per million	Equivalents per million	Parts per million	Equivalents per million
Silica (SiO_2)	54	--	56	--
Iron (Fe)	.01	--	.04	--
Calcium (Ca)	27	1.348	30	1.497
Magnesium (Mg)	11	.905	11	.905
Sodium (Na)	10	.435	4.3	.187
Potassium (K)	1.2	.031	2.0	.051
Carbonate (CO_3)	4.9	--	--	--
Bicarbonate (HCO_3)	135	2.377	139	2.278
Sulfate (SO_4)	6.4	.133	7.2	.150
Chloride (Cl)	6.0	.169	6.0	.169
Fluoride (F)	.0	.000	.0	.000
Nitrate (NO_3)	.0	.000	.0	.000
Dissolved solids	182	--	180	--
Total hardness as $CaCO_3$	113	--	113	--
Specific conductance (Micromhos at 25°C.)				
pH				
Temperature (°F.)	67	--	72	--
Date of collection	Feb. 9, 1938		Feb. 9, 1938	
Depth to which cased	250		250	
Depth of well (feet)	525		550	

Appendix A - continued

Chemical Analyses of Water, Savannah, Georgia Area

	Well 22		Well 85	
	Parts per million	Equiva-lents per million	Parts per million	Equiva-lents per million
Silica (SiO_2)	55	--	50	--
Iron (Fe)	.01	--	.01	--
Calcium (Ca)	27	1.348	25	1.248
Magnesium (Mg)	11	.905	9.2	.757
Sodium (Na)	9.4	.409	13	.565
Potassium (K)	1.4	.036	2.0	.051
Carbonate (CO_3)	5.9	--	0.0	--
Bicarbonate (HCO_3)	134	2.393	135	2.213
Sulfate (SO_4)	6.7	.140	10	.208
Chloride (Cl)	5.5	.155	8.5	.240
Fluoride (F)	.0	.000	.4	.021
Nitrate (NO_3)	.0	.000	.0	.000
Dissolved solids	183	--	179	--
Total hardness as $CaCO_3$	113	--	100	--
Specific conductance (Micromhos at 25°C.)				
pH				
Temperature (°F.)	72	--	73	--
Date of collection	Feb. 9, 1938		Jan. 29, 1941	
Depth to which cased	245		256	
Depth of well (feet)	595		696	

Appendix A - continued

Chemical Analyses of Water, Savannah, Georgia Area

	Well 117		Well 121	
	Parts per million	Equivalents per million	Parts per million	Equivalents per million
Silica (SiO_2)	40	--	45	--
Iron (Fe)	.02	--	.04	--
Calcium (Ca)	28	1.397	22	1.098
Magnesium (Mg)	20	1.645	11	.905
Sodium (Na)	56	2.435	15	.652
Potassium (K)	4.2	.107	2.6	.665
Carbonate (CO_3)	0.0	--	4.9	.163
Bicarbonate (HCO_3)	145	2.377	128	2.098
Sulfate (SO_4)	85	1.770	7.8	.162
Chloride (Cl)	52	1.466	6.6	.186
Fluoride (F)	.6	.032	.5	.026
Nitrate (NO_3)	.25	.004	.10	.002
Dissolved solids	347	--	170	--
Total hardness as $CaCO_3$	152	--	100	--
Specific conductance (Micromhos at 25°C.)				
pH				
Temperature (°F.)	72	--	70	--
Date of collection	Feb. 1, 1941		May 25, 1941	
Depth to which cased	125		85 ±	
Depth of well (feet)	602		174	

Appendix A - continued

Chemical Analyses of Water, Savannah, Georgia Area

	Well 296		Well 337	
	Parts per million	Equivalents per million	Parts per million	Equivalents per million
Silica (SiO_2)	35	--	56	--
Iron (Fe)	.04	--	.03	--
Calcium (Ca)	21	1.048	29	1.447
Magnesium (Mg)	12	.987	8.6	.707
Sodium (Na)	17	.739	8.6	.374
Potassium (K)	3.4	.087		
Carbonate (CO_3)	.0	--	.0	--
Bicarbonate (HCO_3)	141	2.311	132	2.173
Sulfate (SO_4)	17	.354	9.1	.189
Chloride (Cl)	4.0	.113	5.6	.158
Fluoride (F)	.7	.037	.3	.016
Nitrate (NO_3)	.05	.001	.0	--
Dissolved solids	169	--	179	--
Total hardness as $CaCO_3$	102	--	108	--
Specific conductance (Micromhos at 25°C.)				
pH	--	--	7.9	--
Temperature (°F.)	74	--	68	--
Date of collection	June 9, 1941		Dec. 7, 1942	
Depth to which cased	---		272	
Depth of well (feet)	367		652	

Appendix A - continued

Chemical Analyses of Water, Savannah, Georgia Area

	Well 338		Well 345	
	Parts per million	Equivalents per million	Parts per million	Equivalents per million
Silica (SiO_2)	56	--	40	--
Iron (Fe)	.03	--	.01	--
Calcium (Ca)	33	1.647	18	.898
Magnesium (Mg)	9.0	.740	16	1.316
Sodium (Na)	3.3	.143	48	2.086
Potassium (K)				
Carbonate (CO_3)	.0	--	.0	--
Bicarbonate (HCO_3)	142	2.327	149	2.442
Sulfate (SO_4)	7.6	.158	23	.479
Chloride (Cl)	1.0	.282	48	1.354
Fluoride (F)	.3	.016	.8	.042
Nitrate (NO_3)	.0	--	.0	--
Dissolved solids	192	--	260	--
Total hardness as $CaCO_3$	119	--	111	--
Specific conductance (Micromhos at 25°C.)				
pH	7.7	--	7.6	--
Temperature (°F.)	68		--	
Date of collection	Feb. 2, 1943		July 22, 1943	
Depth to which cased	269		352	
Depth of well (feet)	681		535	