PUBLICATION NO. 6

RATE OF SOLUTION OF LIMESTONE IN THE KARST TERRANE OF FLORIDA

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FLORIDA WATER RESOURCES RESEARCH CENTER

UNIVERSITY OF FLORIDA — GAINESVILLE FLA.

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Abstract

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Data are presented and examples cited to explain the rate and pattern of development of the solution features in the karst terrane of Florida. The overall rate of erosion is 1.5 inches per 1,000 years; the rate varies considerably depending upon the quantity and composition of the runoff influx. The early stages of the cycle have developed under artesian conditions with limited entry of surface water. Relatively low primary porosity and permeability have resulted in the circulation and solution being fracture controlled. Subsequent development and channeling of surface runoff into the aquifer results in solution of deep sink holes, extensive caverns and the development of lake basins and prairies. Circulation of the nearly saturated water through the rock from pore to pore away from the solution cavities has resulted in high secondary porosity and permeability. In the open limestone plain under water table conditions solution is concentrated in the upper phreatic zone but not because of shallow lines of flow. With this theoretical model of the development of the porosity, permeability, and cavities in the Floridan aquifer the fracture traces evident on aerial photographs can be used to obtain the quantity and quality of water desired.

Brooks, H. K.
RATE OF SOLUTION OF LIMESTONE IN THE KARST TERRANE OF FLORIDA
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KEYWORDS: aerial photography/ aquifer/ artesian system/ caverns/ cavities/ erosion/ Floridan aquifer/ fracture traces*/ limestone plain/ karst terrane*/ permeability/ porosity/ water quality and water storage/ stream erosion*/ runoff/ sinkholes*/ water table.

PROJECT SUMMARY

Research on the rate of solution of limestone in the karst terrane of Florida was undertaken with the financial support of the Office of Water Resources Research to obtain quantitative data on the rate that mineral matter was being dissolved and removed by ground water. The objective in obtaining this data was to provide basic scientific information on the development of the karst landscape and the solution features in the limestone aquifer system. More data and empirical field observations have been obtained than can be synthesized and reported herein.

Not only has the original objective been achieved, but evidence bearing on the origin and evolution of secondary porosity, permeability and cavity development in the limestone aquifer has been obtained. Much additional information on the changes of climate and sea level have been obtained as a result of examination of the sediments in the lakes, springs, and rivers. This work on the paleo-hydrological conditions is being completed with the financial support of the Graduate School, University of Florida, The Florida State Museum and Silver Springs, Incorporated.

The research procedure has involved chemical studies of the surface and ground water throughout the karst area of northern peninsular Florida. One complete analysis of rain water was obtained. Hydrological information on surface and ground water has been synthesized. This study on the rate of solution was based upon the premise that if the quantity of water circulating through the rock can be determined and the chemical composition before and after analyzed, it is possible to calculate the rate at which rock materials per unit area of land are being removed in solution. These quantitative results have been supported by extensive field observations on the stratigraphy, structure, and landscape. The nature and pattern of the solution features accessible to exploration both above and below the water table were examined.

The results of the study show that the overall rate of solution in the karst terrane of Florida is about 1.5 inches per 1,000 years. In areas of influx of surface streams it was 2.0 inches whereas under open water table conditions, with complete sub-surface runoff, it was 1.2 inches per 1,000 years. In the high land area with few sink holes the rate of solution was determined to be insignificant. This information is significant in interpreting the pattern and history of development in the karst terranes as well as the secondary development of porosity, permeability, and solution cavities in the limestone aquifer. Flow is not concentrated at the water table as has been proposed. The solution that does occur in the upper phreatic zone in the limestone plain, where water table conditions exist, is not due to the shallow lines of flow, but rather because the run-off reacts rapidly with the limestone. In the initial and mature stages of

development of the karst terrane the limestone aquifer was under artesian conditions. This resulted in channeling and localization of solution in sinks, and extensive deep caverns, and in the development of lake basins and prairies.

Several papers will ultimately be submitted for publication based entirely or in part on data obtained in this research. A paper on the rate of solution in the karst terrane of Florida is being prepared which is similar to this completion report, but with tables, graphs, and maps. Additional papers are now in the process of being prepared on the marls in the springs and rivers and on the consolidation of the Neogene clastic sediments.

Publications that have resulted from this project thus far are:

Brooks, H. K., 1966, Geological history of the Suwannee River: Southeastern Geological Society, Guidebook of the 12th Ann. Field Conference, p. 37-45.

Teleki, P. G., 1966, Differentiation of materials formerly assigned to the Alachua Formation. Unpublished M.S. thesis. University of Florida, 102 p.

INTRODUCTION

Limestone terranes are notable because of the large percentage of runoff transmitted as ground water through the rocks. In large part this hydrological characteristic of karst areas and the underlying limestone or dolomite aquifer system is the result of solution, both cavity and interstitial. Only a small proportion of the transmissibility is due to the primary depositional characteristics of the carbonate rocks, the porosity and permeability, or the results of tectonic activity. This study of the rate and pattern of limestone solution in the karst region of the Suwannee River of Florida was undertaken to provide basic scientific data on an area of active erosion. Quantitative information has been hitherto unavailable.

The study of the rate of solution of rock materials in the Suwannee and Waccasassa River watersheds was based upon the premise that if the water entering and leaving a unit area were balanced and the chemical composition before and after determined, then it would be possible to calculate the rate at which rock materials per unit area of land was being removed in solution.

Meteorological data and the runoff in different portions of the watershed are unbalanced because of differences in percentage of surface and subsurface runoff, but for the total hydrological units, the Suwannee and the Waccasassa, a water balance exists. From runoff and chemical data it has been calculated that the rate of solution is one cubic foot of rock material (largely as $CaCO_3$) per one square foot of land per 8,000 years. In lake basin, prairie, and sink areas where surface waters are channeled locally into the aquifer and where the large volume of surface water first comes in contact with the aquifer, the rate is increased many fold. Localization of solution has resulted in many peculiarities in the karst landscape of Florida.

The overall rate of solution resulting in a degradation of the land is averagely one foot per 8,000 years, or 1.5 inches per 1,000 years. The average rate of terrestrial erosion by all processes in the United States is 2.4 inches per 1,000 years (Judson and Ritter, 1964)[1].

Carbonate deposits in general have low syngenetic porosity and permeability. Epigenetic changes due to compaction, cementation or recrystallization further reduce the capability of the rock to hold and transmit fluids. Limestone aquifers of high transmissibility have developed this characteristic through removal of rock materials by meteoric water circulating through the rock from pore to pore in stratigraphically controlled zones or along fractures.

Development of the solution features of a limestone aquifer is a slow terrestrial process resulting from circulation of runoff through the rocks. The nature and patterns of solution are determined by the lithology of the rock, stratigraphic relationships, structural relationships, climate, and the stage in the geomorphic cycle. Florida is unique in many of these characteristics, thus it is a mistake to indiscriminately apply to Florida the concepts developed in the well known karst terranes of Yugoslavia, Kentucky, Indiana, and Jamaica. The Floridan aquifer in the area of this study is 500 feet thick or more; it is relatively porous and fractures from jointing and faulting are not detectable in fresh exposures. Most significantly, much of the solution occurs under artesian, not water table, conditions.

In this completion report not all of the aspects of research on the Suwannee River watershed will be discussed. The lithology, stratigraphy and structure have been summarized elsewhere (Cooke, 1945; Vernon, 1951; Pirkle, 1956; Brooks, 1966). In a paper on the origin and hydrology of the lake basins of north central peninsular Florida by Pirkle and Brooks (1959) the stages of karst development have been summarized. Recently Brooks (1966) reviewed the geological history of the Ocala Arch and discussed the origin and history of the Suwannee River.

Much quantitative information has been collected in the course of this study that will be published as tables and graphs. At this time only the essential results of the research on the rates and patterns of solution will be presented.

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[1]See reference list attached.

AREA OF STUDY

The Suwannee River watershed of north peninsular Florida and south Georgia (See Figure 1) is an ideal area to study karst development. Different portions of the watershed are stratigraphically distinct and are in different stages of development in the fluviatile and karst geomorphic cycles. The headwaters of all the tributaries originate in upland areas 120 feet or more above sea level. These highlands, the Tifton Uplands and high terraces of Georgia and the Central Highlands of Florida, are directly underlain by sands and clays of Miocene and Pliocene age. The limestone aquifer occurs at a depth of 80 feet or more. The Floridan aquifer in the area of study is predominantly Ocala Limestone of late Eocene age, but in the northern portion of the area the Suwannee Limestone of Oligocene age is present.

The Suwannee River originates in the Okeefenokee Swamp at an elevation of about 120 feet above sea level. The swamp is in an old Pliocene strath developed by an ancestral Suwannee River that originally flowed northeasterly to the Atlantic Ocean off the Ocala Arch (Brooks, 1966). The main trunk of the river now flows southwesterly in the old strath to near White Springs, Florida where it descends through a series of rapids and then turns abruptly to the northwest. Here it flows in an entrenched meandering valley cut into limestone of Eocene and Oligocene age. This segment of the river borders the northeastern margin of the Ocala Arch and appears to be structurally controlled. After receiving the waters of the Alapaha and Withlacoochee Rivers northeast and north of Ellaville, Florida the Suwannee turns south and meanders in a broad valley across a limestone plain developed upon the Ocala Arch. South of Branford, Florida it receives the waters of the Santa Fe River and then turns to the southwest and flows to the Gulf of Mexico. Enormous quantities of ground water runoff are discharged into the Suwannee River through springs along its course in the limestone terrane. It is this hydrological characteristic of the river that made this study of the amount of mineral transport in solution meaningful.

Periodic samples for chemical analysis were taken at the gaging stations shown in Figure 1. The stations at Pinetta, Statenville, White Springs and High Springs essentially conform to the boundaries of the watershed between the highlands with a high percentage of surface runoff and the limestone plain where surface runoff, for the most part, is nonexistant. Surface water leaving the area of study was last monitored at the gaging station near Wilcox, Florida.

To provide information on the development of the limestone plain west and southwest of Gainesville, Florida samples were analyzed which were taken at the gaging station on the Waccasassa River south of Otter Creek and near Gulf Hammock.

The Suwannee River transports virtually no clastic sediments. Its cummulative detrital load for the last 10,000 years is a portion of the small amount of Recent sand and mud at its mouth. All of the sands in the dunes and islands, from Horseshoe Beach to the Cedar Keys originated in an earlier cycle of erosion. These islands and dunes are

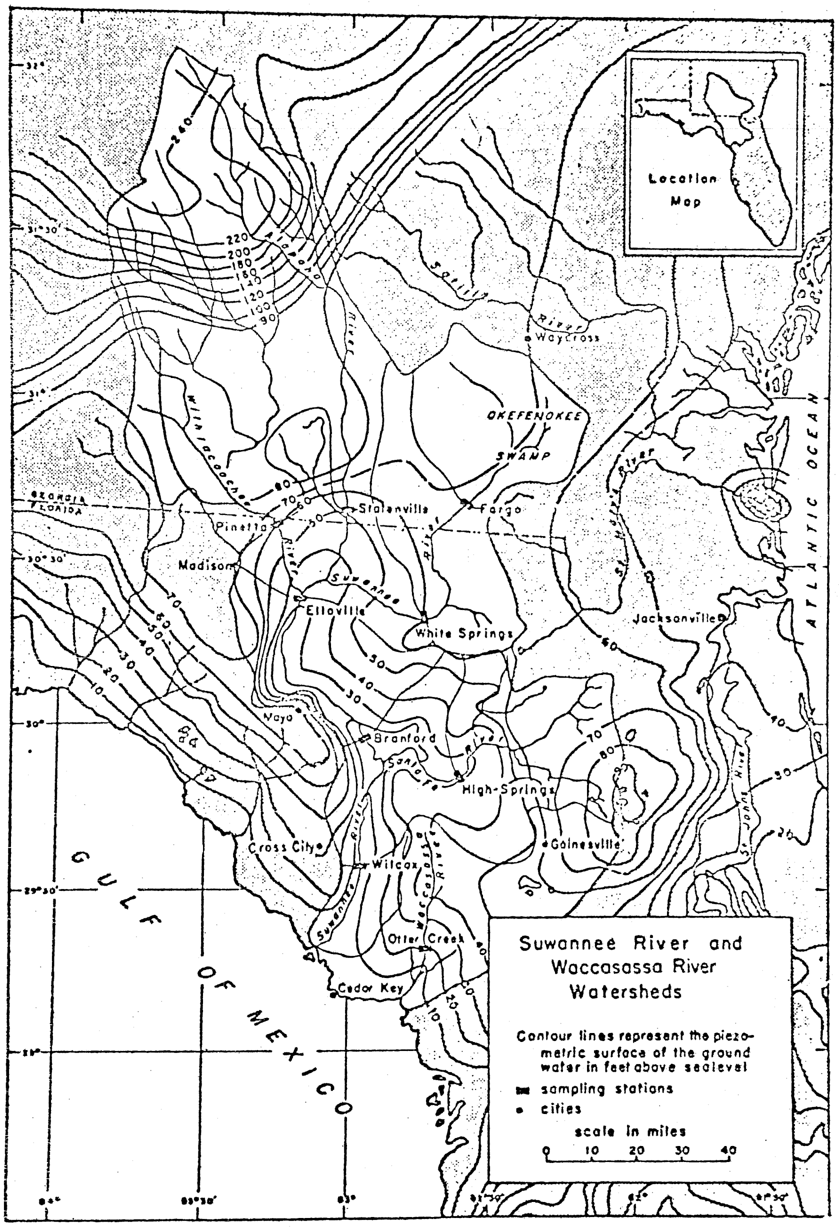
Location Map
OKEFENOKEE
SWAMP
Waycross
Fargo
Statenville
Pinetta
Madison
Ellaville
White Springs
Jacksonville
Mayo
Branford
High Springs
Gainesville
Cross City
Wilcox
Otter Creek
Cedar Key
GULF OF MEXICO
ATLANTIC OCEAN
Suwannee River and
Waccasassa River
Watersheds
Contour lines represent the piezometric surface of the ground water in feet above sealevel
sampling stations
cities
scale in miles
0 10 20 30 40

Figure 1

paleodunes that presently are partially drowned by marine water. They originated before the post-glacial rise of sea level.

CLIMATE

For this report the meteorological records of the recording stations at Lake City, Cross City, and Gainesville were used. The climate is warm temperate with a mean annual temperature of 69° F. The rainfall in the area fluctuates about a mean of 51.8 inches per year (Butson, 1962). The calculated rate of evapo-transpiration is 39.7 inches which compares with the 40 inches reported for Jacksonville. Thus, the mean annual precipitation available for runoff is essentially one foot.

RATE OF SOLUTION

Final calculation of the rate of limestone solution cannot be made at this time due to the inaccessibility of stream flow data from the U.S. Geological Survey. Therefore only preliminary results are summarized herein. Tables, graphs and basic calculations will be included in the paper prepared for publication.

A water balance does exist in the Suwannee River drainage area as a whole. Gaging stations at the margin of the highlands show a deficiency of water because stream flow is largely surface and perched water runoff. It is also true that the divides between the surface and subsurface areas of drainage do not always completely coincide. However, when all the segments of the watershed are integrated, there is remarkable agreement between the amount of water being discharged at Wilcox and the amount of runoff calculated from meteorological data.

Two hundred and five tons of mineral matter per square mile of watershed per year is transported in the water of the Suwannee River at Wilcox. This is equivalent to degradation of the landscape by 1.5 inches per 1,000 years.

To check the above rate of erosion, calculations were made in a strip one mile wide directly down the slope of the peizometric surface in the area of subsurface drainage west of Gainesville. Data used for these calculations were determined from the analysis of 66 selected wells, typical surface water, and rain water. These data have been compiled as maps and tables and will be submitted for publication separately.

In the sinks and prairies south and west of Gainesville, where surface water runoff from relatively large areas enters the ground, the rate of solution is 262 tons per square mile per year. At the points of entry it is probably many times this amount. In the limestone plain where solution is due to direct infiltration of the excess of one foot of precipitation over evapo-transpiration, the rate of solution is about 172 tons per square mile per year. These rates agree remarkably well with the overall rate calculated for the Suwannee River. They indicate that the most active karst development is in the areas of influx of surface runoff.

In the flatwoods of the Central Highlands very little water infiltrates downward to the aquifer. The rate of solution here is insignificant except in the vicinity of the few open collapsed sinkholes which have developed. The sinks, largely incipient, and ponds that do exist in the flatlands are the net result of downward percolation and solution. There is substantial removal of rock materials by solution in the limestone plain due solely to downward and lateral movement of excess precipitation, but here the water movement is not being channeled.

Figure 2 summarizes the physiographic and hydrologic conditions discussed above.

GEOMORPHOLOGY

In the northwestern portion of peninsular Florida in the area of this study two physiographic divisions are recognized, the Central Highlands and a Limestone Plain (Cooke, 1945). The portion of the Central Highlands discussed herein is a poorly dissected plain that lies between 120 and 180 feet elevation, MSL. There are a few open sinkholes. Mostly the solution features are incipient sinks in the form of small circular cypress ponds. The reason for this is that an aquifuge tens of feet thick, the "Hawthorne Formation", (including both Miocene and Pliocene sands and clays) overlies the Floridan aquifer. At the western margin of the highlands there may be a relatively abrupt erosional scarp but in most places there is a belt four to ten miles wide that is maturely dissected by sinkholes and collapsed cavern development. The hills are capped by outliers of the insoluble rock material of the aquifuge of the high flatlands to the east. The limestone plain is a subdued erosional feature with only a few remnant outliers. Its inner portion has an elevation of between 90 and 100 feet, MSL. In the Suwannee River valley and the coastal areas the plain generally dips one foot per mile.

The portion of the limestone plain above 90 feet appears to be a karst peneplain graded to a base level, the sea, during an early Pleistocene interglacial interval of long duration. The level of the plain has been lowered somewhat through subsequent solution but extensive sink and cavern development has not occurred in the rejuvenated cycles. Large lake basins and prairies are developing in the area of the limestone plain adjacent to the highlands. The present base level of erosion of these basins appears to be the water table (Pirkle and Brooks, 1959).

A study of aerial photographs reveals that the texture of the

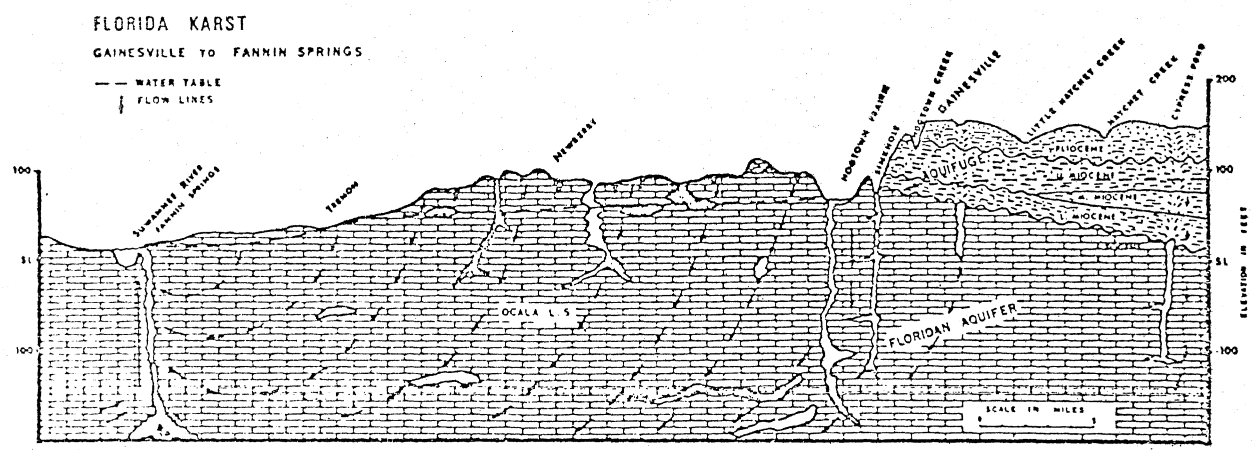
FLORIDA KARST
GAINESVILLE TO FANNIN SPRINGS
WATER TABLE
FLOW LINES
SUWANNEE RIVER
FANNIN SPRINGS
NEWBERRY
HOGTOWN PRAIRIE
SINKHOLE
HOGTOWN CREEK
GAINESVILLE
LITTLE HATCHET CREEK
HATCHET CREEK
CYPRESS POND
PLIOCENE
AQUIFUGE
U. MIOCENE
M. MIOCENE
L. MIOCENE
OCALA L.S.
FLORIDAN AQUIFER
SCALE IN MILES
0
1
200
100
SL
-100
ELEVATION IN FEET

Figure 2

land is dominated by sinkholes, lakes and cypress ponds which have a distinct lineation. The fabric of the landscape has a distinct northeast-southwest and northwest-shoutheast trend. Maps of the caverns in peninsular Florida in the files of the Florida Speological Society in Gainesville also show the chambers of the caverns to be similarly oriented. This preferential orientation prevails in spite of the fact that the limestone is not the typical dense impervious rock typical of fracture controlled karst features. The Floridan aquifer, for the most part, is only partially lithified. It has a relatively high permeability, and fracture systems cannot be detected in the fresh rock in quarries except where solution features have developed. However, there can be no doubt that a fracture system is controlling the pattern of karst development.

The limestone plain has been referred to by many (Cooke, 1945; MacNeil, 1950; Brodkorb, 1959) as a plain of marine planation. Pirkle and Brooks, (1959) have shown that the plain developed as the ultimate stage in a karst cycle of erosion just as the present water table is serving as the base level for the solution in Orange Lake, Payne's Prairie and Hogtown Prairie.

The limestone terrane on the Ocala Arch has had a long history of karst development. This is proven by the many sink holes and cavern fillings containing the remains of terrestrial land vertebrates of Late Oligocene-Lower Miocene age, Middle Miocene age, Early and Middle Pliocene age, and Pleistocene age (Patton, 1967; Webb, 1967). Pirkle (1956) and more recently Brooks (1966) have interpreted the stratigraphic and tectonic history of the Ocala Arch. There are buried limestone hills in the area south and eastward from Crystal River to Brooksville. The sediment covering this earlier karst landscape appears to be Upper Miocene in age (Teleki, 1966). It is possible that some portions of the Arch were covered by a late Pliocene stand of sea level that rose to 120 to 140 feet higher than present sea level, but as yet marine deposits to prove this have not been found. The axis of the Arch was probably undergoing active karst development during most of Pliocene time, but the erosional plain at 90 to 100 feet elevation is obviously post-Pliocene.

A spring throat filling of marls and freshwater snail shells was encountered in the quarrying operations at Haile, north of Newberry. Mixed with the spring fauna were a few Chione cancellata, a typical Pleistocene marine clam. Evidence from elsewhere (Brooks, 1966 and Conklin, 1966) indicates that the 90 foot stand of sea level to which the karst plain is graded is first interglacial Pleistocene: Aftonian.

PATTERNS OF SOLUTION

Sinkhole and cavern development in Florida conforms to the fracture system within the limestone, incipient and inconspicuous as these fractures may be. There is more to the pattern of development than this. There is the problem of the depth at which active solution occurs and the influence of geographic variations due to stratigraphic, physiographic and hydrologic conditions. There is also the added complication of distinguishing the relic karst features from paleohydrological conditions.

The area of this study can be separated into three basic categories: (1) a limestone plain of nearly complete direct sub-surface runoff, (2) a highland area in which an aquifuge overlies the limestone artesian system resulting in considerable surface runoff, and (3) an area between the two in which a large volume of surface runoff from the highlands is discharged onto the limestone in sinks, lake basins, and prairies. As proved in this research, the rate of erosion in the limestone plain is 172 tons per square mile per year; whereas the rate in the lake-sink area is at least 262 tons per square mile per year. In the highland area underlain by the aquifuge, the amount of rock material removed in solution is relatively insignificant.

Many sinkholes and caverns in Florida extend to considerable depth. It is common for water well drills to intersect chambers at 300 or more feet below present sea level. Much evidence has been presented from work on other limestone terranes (Davis, 1930, Bretz, 1942) confirming that the most active solution occurs at or near the water table. Stringfield and LeGrand (1966) have attributed the deep solution features in Florida to more active circulation of the ground water during lower Pleistocene stands of sea level. They conclude that "The rough zonation of cavities is thought to be related to lower positions of Pleistocene sea level and to corresponding lower positions of water level in the limestone," and not to stratigraphic control.

Sea-level has been 350 feet or more lower during continental glacial stages. It is also true that the sinks, springs, and underwater caverns, i.e., Wakulla, Hornsby and Silver Springs, provide evidence of being dry to levels of 160 feet or more below the present sea level. White (1958) believed that changes in sea level would have little or no effect upon the water table or the piezametric surface. As he reasoned the lowering would merely extend the land seaward at essentially the same slope as the present land area. This is true for the shallower portions of the limestone terrane extending into the Gulf of Mexico. However, there is no doubt that the lakes, prairies, sinks, and springs of peninsular Florida were dry during continental glacial stages.

Large quantities of water flow through the Floridan aquifer. In an artesian system the water may be channeled downward or upward several hundred feet. Jordan (1950) has argued that this is the cause of the deeper cavities in the limestone terrane of Florida; however, he neglects to mention that deep cavities also exist in the limestone plain where water table conditions prevail.

Ground water from some wells 800 feet or more into the Floridan aquifer are not completely saturated with calcium carbonate (Back, 1963). This chemical evidence proves that deep circulation and solution are occurring at the present time.

Water samples from sixty-six selected wells representative of the different stratigraphic, geomorphic, and hydrological conditions were analyzed to provide chemical data relative to the rate and pattern of rock solution. pH readings were taken on the fresh sample in the field with a Beckman model N2 meter. This data has been prepared in map form and will be published.

From the study of the composition and pH of the ground water in the Floridan aquifer it became apparent that chemical equilibrium was approached very quickly by reaction with the limestone. For example, in wells in fracture zones where large amounts of acid surface waters (pH 4.4 - 5.6) were flowing directly into the limestone aquifer, it was rare to find water that had a pH of less than 7.2 and total dissolved solids of less than 100 ppm. The majority of the well water samples had a pH of 7.6 and 150 to 180 ppm of total dissolved solids, most of which was as $CaCO_3$. In the areas where the largest amounts of surface water were infiltrating the aquifer, it was not uncommon to find total dissolved solids from 250 to over 320 ppm. This super concentration must be due to the increased reactivity of the organic acids in the surface waters with the limestone.

Shallow wells in the limestone plain typically have 150 to 180 ppm of total dissolved solids. Even the water being discharged into the Suwannee River from the aquifer has only 190 to 230 ppm of total dissolved solids (Ferguson, Lingham, Love, and Vernon, 1947). Much of this spring water must travel great distances through the limestone; some as much as 40 to 45 miles and to depths of 400 feet or more.

Davis (1930), Bretz (1942), and Stringfield and LeGrand (1966) have concluded that limestone solution is concentrated in the upper portion of the phreatic zone. Rhodes and Sinacori (1941) have argued that in a homogenous aquifer, the initial flow occurs at both great and shallow depths but that solution and increased flow becomes more pronounced in the upper zone because of the shorter flow lines. Progressive increase in flow in the upper phreatic zone is believed to produce master conduits and cause eventual diminution of flow and solution at depth. This argument appears to be valid for many karst terranes, but in Florida it is complicated by the fact that the early solution history is under artesian conditions. It also does not appear to apply to the open limestone plain where water table conditions exist. In the large areas being drained by sub-surface runoff, flow of water 300 to 400 feet vertically is of no significance in the many miles the water percolated from its point of entry to its point of discharge.

In the Pliocene-Pleistocene-Recent history of karst development in north peninsular Florida the limestone originally was completely overlain by 80 feet or more of sands and clays acting as an aquifuge. In the early stages of development of the landscape and the aquifer, sub-surface runoff was channeled through sink holes that breached the impermeable clays.

The orientation of the solution features proves that the initial circulation of water through the rock was controlled by a fracture system.

The high permeability of the Ocala limestone and the Floridan aquifer, in general, can be proved to be largely a secondary feature as the result of selective solution of the fine-rock matrix, particularly the aragonite. A definite mineralogical distinction has been achieved between the two $CaCO_3$ minerals calcite and aragonite. Only calcite fossil and mineral particles have prevailed in rock subjected to circulation of meteoric water.

Solution of the limestone is largely localized where runoff first comes in contact with the limestone. The amount of solution is largely dependent upon the quantity of water entering the aquifer. At points where runoff from large areas is channeled underground through sinks, lakes, and prairies the rate of solution may be rapid.

With the aid of SCUBA gear the author has explored every accessible sinkhole, spring and underwater cavern in Florida. In the sinkholes the lateral chambers are joint controlled. They rapidly narrow and close away from the central chamber. The springs have a similar pattern and appear to be converted sinkholes that have changed functions due to changing hydrological conditions. The springs are certainly not the result of solution by the mineral-charged water they are now discharging. In this respect Jordan (1950) was wrong, but he was correct in attributing much of the deep cavity solution to channeling of water in an artesian system.

There are some chambers and cavities in the karst terrane of Florida that do extend for several miles. For example, the Santa Fe River northeast of High Springs enters a sinkhole and emerges three miles farther down the valley through another vertical passage, probably a former sinkhole. The general area of the Santa Fe River near High Springs is riddled with extensive underwater caverns. There are vast chambers that have never been completely explored in the Hornsby Sink-Springs cavern complex that extend downward over 200 feet.

All of the known extensive underground caverns in Florida have a relationship to present or former surface drainage systems. South and west of Gainesville is an extensive fracture zone known to be riddled with caverns (Brooks, 1966). There are two surface streams that originate from surface runoff in the high flatlands that discharge into sinkholes in this zone. They are Prairie Creek (from Hatchet Creek and Newnan's Lake) that discharges into the Floridan aquifer south of Gainesville in Payne's Prairie at Alachua Sink, and Hogtown Creek that discharges into the Floridan aquifer west of Gainesville in Hogtown Prairie and Sink. No doubt the deep sinkholes and extensive cavern systems that have developed are the result of such channeled and localized flow of large volumes of acid surface water into the aquifer system. From Gainesville it is over twenty miles to the point of nearest discharge from the aquifer. There is no evidence of an integrated system of solution caverns. Thus it is concluded that as the ground water approaches saturation it leaves the cavities that have been dissolved and flows through the integranular pores in the limestone.

Solution may take place just below the water table as Davis (1930) and Bretz (1942) have postulated. Observations in caverns and deep quarries in the limestone plain of northwestern peninsular Florida show a pattern of chambers, both incipient and developed, in relationship to the present and past stands of the water table.

Solution is occurring in the limestone plain away from the points of entry of surface streams into the sinkholes, lakes, and prairies. West of Gainesville and throughout much of the limestone plain of the Suwannee River watershed all of the runoff is as ground water. This water that is infiltrating directly into the ground is dissolving limestone to the amount of 170 to 220 ppm of total dissolved solids as it flows through the rock, resulting in an erosional rate of 172 tons of rock material per square mile per year. No doubt the runoff water obtains its mineral load very quickly. It may be this instead of the subsequent lines of flow that determines the development of solution features in the upper phreatic zone under water table conditions.

APPLICATION IN DEVELOPING WATER RESOURCES

It has often been assumed that the high yield characteristics of the Floridan limestone aquifer were due to a high primary porosity and permeability (Palmer, 1965). In the area of outcrop the rocks do, for the most part, have a high porosity and permeability, especially the Ocala Limestone. Porosity ranges from 20 to 55 per cent and permeability from 0.02 to 1.55 darcies on representative specimens. Most wells produce directly from the rock and not from joint controlled cavities so typical of other limestone terranes (Lattman and Parizek, 1962).

In the early history of circulation in the area of recharge, solution is controlled by fracture systems. This can be due only to a relatively low original transmissibility of the carbonate rock. As the landscape and underlying hydrological system has evolved, circulation of meteoric water directly through the rock from pore to pore away from the fracture zones has resulted in a high secondary porosity and permeability. It is now recognized that in areas of artesian conditions and incipient karst development in Florida, higher yield wells and well fields can be developed only in fracture zones. In the areas of more mature karst landscape with extensive cavern development these zones should be avoided because of the poorer quality of water due to color and pollution (from the surface water) and higher mineral content, especially calcium and iron. In these areas and in the open karst plain under water table conditions the aquifer system has developed a high secondary porosity and permeability and copious yield can be obtained directly from the rock.

Lattman and Parizek (1962) have called attention to the relationship between fracture traces and the occurrence of ground water in carbonate rocks. These traces can readily be detected on aerial photographs. It is recommended that more use be made of this valuable tool to obtain the quality and quantity of ground water desired in developing the water resources of the Floridan aquifer.

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