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FLORIDA GEOLOGICAL SURVEY

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REPORT OF INVESTIGATIONS

NO. 9

MISCELLANEOUS STUDIES

TALLAHASSEE, FLORIDA

1953

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Florida Geological Survey

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June 20, 1953

MR. CHARLIE BEVIS, *Supervisor*
FLORIDA STATE BOARD OF CONSERVATION
TALLAHASSEE, FLORIDA

SIR:

The Florida Geological Survey, through its cooperation with other state agencies and with the universities of the Nation, is able at moderate cost to have many excellent studies undertaken and reports of the results of these prepared for publication by the Survey.

These studies benefit the State by providing information on our mineral resources and the author of the paper is provided funds for a chosen research problem, the publication of which will make him better known to his associates and may in some cases be used as partial fulfillments of graduate degree requirements.

I am pleased to forward two papers herewith published as Report of Investigations No. 9. One is entitled, "*Dissolved Phosphorus in Florida Waters*," and is written by Dr. Howard T. Odum, Department of Biology, University of Florida. The other paper was prepared by Dr. Alfred G. Fischer while attending Columbia University, New York, and is entitled, "*Petrology of Eocene Limestones in and around the Citrus-Levy County Area, Florida*." These two papers compose the first of our "Miscellaneous studies."

Respectfully submitted,

HERMAN GUNTER, *Director*

CONTENTS

PART I	Dissolved Phosphorus in Florida Waters.	1
PART II	Petrology of Eocene Limestones in the Citrus- Levy County Area, Florida	43

Part I

DISSOLVED PHOSPHORUS IN FLORIDA WATERS

By

HOWARD T. ODUM

Department of Biology
College of Arts and Sciences
University of Florida

January 9, 1953

Report to the Florida Geological Survey

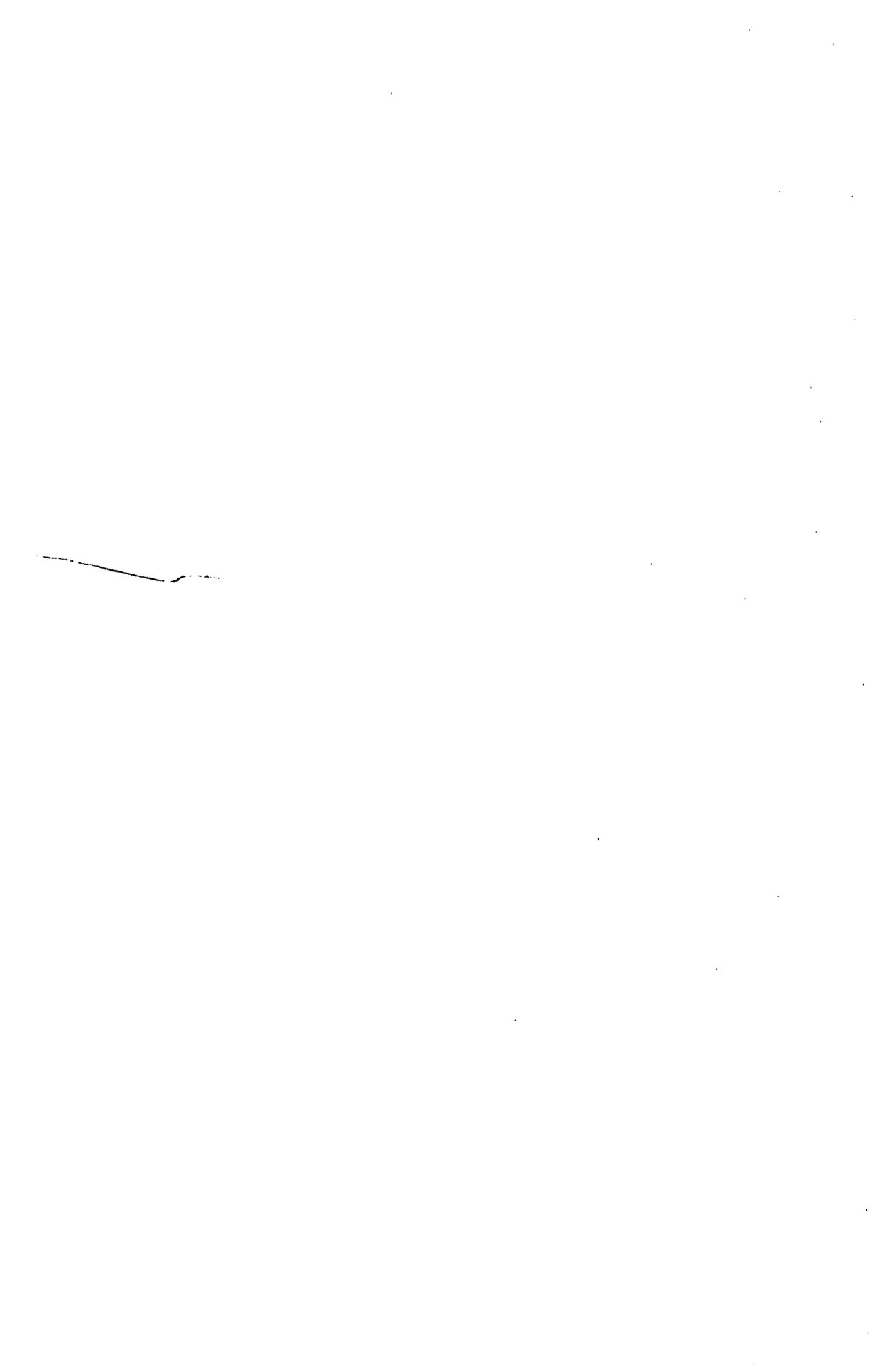


TABLE OF CONTENTS

Abstract	1
Introduction	1
Purpose and scope of investigation	2
Cooperation and acknowledgements	2
Previous investigations	3
Methods	4
Patterns of distribution of dissolved phosphorus	7
Dissolved phosphorus and geological formations	7
Dissolved phosphorus and type of water	9
Dissolved phosphorus in Florida compared with other regions	18
Dissolved phosphorus and the origin of phosphate deposits	18
Dissolved phosphorus and potential fertility	21
Dissolved phosphorus and pollution	23
Dissolved phosphorus and red tide	25
Conclusions	28
References	28
Appendix	30

ILLUSTRATIONS

Figure	Page
1. Surface phosphate-bearing formations	6
2. Dissolved phosphorus in the region of Gainesville, Florida, and the phosphatic Hawthorn formation	7
3. Dissolved phosphorus in Florida waters	8
4. Dissolved phosphorus in Lake Mize, Florida, during summer stratification	9
5. Dissolved phosphorus in the Peace River system	10
6. Dissolved phosphorus in the Devils Millhopper, Alachua County, Florida	11
7. Dissolved phosphorus in the Tampa Bay region, Florida	12
8. Dissolved phosphorus in the rivers and canals of south Florida, during August, 1952	14
9. Dissolved phosphorus in the St. Johns River system	16

TABLES

Table	Page
1. Technique test on known Standard Solutions	5
2. Phosphorus values in Silver Spring Run	5
3. Mean values of phosphorus in types of Florida waters	13
4. Solubility of inorganic phosphorus as a fraction of calcium and acidity	13
5. Regional comparisons of dissolved phosphorus in lakes	15
6. Phosphorus in Florida lakes and streams	17
7. Phosphorus relative to red tide	26

DISSOLVED PHOSPHORUS IN FLORIDA WATERS

by

Howard T. Odum¹

ABSTRACT

A basic survey has been made of the concentrations of dissolved phosphorus in many types of Florida's surface waters. The extensive deposits of phosphate rock in Florida lead to unusually high dissolved phosphorus contents in the streams and lakes which drain these areas. Thus these waters are potentially of high fertility for growth of aquatic organisms. Additional quantities of dissolved phosphorus are being added by sewage and industry in some areas, although little recognition has been made of the possibly large biological effects that relatively small amounts of added phosphorus can have on those areas which are not receiving drainage from phosphate areas. The moderately low phosphorus content of basic springs in contrast to acid surface streams suggests a controlling role of pH in phosphorus solubility in Florida. It seems likely that percolating rainwaters are continually concentrating phosphorus in the layers just beneath the surface as the acid rainwater becomes basic. The natural and artificial phosphates contributed to Florida's surface streams hypothetically seem to be of the magnitude to contribute to red tide phenomena and the rapid growth of water hyacinths in prescribed areas.

INTRODUCTION

Over the surface of the earth as a whole phosphorus is a scarce substance and much in demand as it is an absolutely necessary requirement for Man's civilization and indeed for all life. Without phosphorus no plants can grow and no food production is possible for Man or for fish and wildlife.

Phosphorus is a magic word in Florida because the extensive natural phosphate rock deposits located near the surface have directly and indirectly made many profound changes in the culture of the State. Directly, benefits such as those developing from the phosphate industry and from agricultural advances due to low cost phosphate fertilizer have resulted. Indirectly, as the evidence

¹The writer wishes to acknowledge the able assistance of Mr. Richard Highton, Laboratory assistant.

in this report suggests, sports fishing, commercial fishing, red tide, water hyacinth growth, and pollution are all related to the distribution of phosphorus dissolved in the Florida fresh and marine waters.

Purpose and Scope of Investigation

The purpose of this study has been to analyze representative samples of all kinds of Florida surface waters for dissolved phosphorus and to determine what relationships there are between: dissolved phosphorus and the type of geological rock formations underlying the area; between dissolved phosphorus and the type of body of water; between dissolved phosphorus in Florida and in other regions of the world; between dissolved phosphorus and the processes of formation of phosphate rock; between dissolved phosphorus and the growth of aquatic organisms such as plants and fish; between dissolved phosphorus and the increasing problem of pollution of streams and estuaries; and between dissolved phosphorus and the spectacular red tide.

Cooperation and Acknowledgements

The data and interpretations have resulted from the cooperation between the Department of Biology of the University of Florida in Gainesville and the Florida Geological Survey with the aid of many other persons. The Department of Biology furnished the investigator and laboratory facilities. The Florida Geological Survey furnished the financial support for the assistant Mr. Richard Highton and for supplies. The Office of Naval Research through its support of another project on the productivity of Florida Springs provided considerable aid indirectly since it was possible to collect water samples in the course of this work. Mr. A. O. Patterson, District Engineer, Surface Water Branch, United States Geological Survey, Ocala, Florida, furnished a large series of samples collected by his staff throughout Florida. Mr. Ellis Landquist furnished a series from Peace River. Series of marine samples were received from Mr. William Beck, Florida State Board of Health; Mr. David Karraker, University of Florida; Dr. Harold Humm, and Dr. Nelson Marshall, Oceanographic Institute, Florida State University; Mr. Forrest G. Wood, Marineland; Mr. William Jennings, Florida Game and Fresh-water Fish Commission; Mr. K. Hansen, University of Florida, Dr. Minter Westfall, University of Florida, Dr. J. B. Lackey, Department of Sanitary Engineering, University of

Florida; Mr. Kirk Strawn, University of Texas. The study was much aided by discussions with the above especially as indicated in the text. I am grateful to Dr. A. P. Black, Mr. R. Highton, Dr. J. B. Lackey, and Dr. E. B. Phelps, University of Florida; Dr. G. A. Riley, Bingham Oceanographic Institute, Yale University; and Dr. R. O. Vernon, Florida Geological Survey for comment and criticisms on the manuscript.

Previous Investigations

Over the world as a whole a very large number of studies have established the geochemical behavior of the element and importance of phosphorus to growth on land and in the lakes and ocean. Current knowledge on this may be found in Hutchinson (1952) and Riley (1951).

In Florida although much work has been done on phosphorus in land deposits and its behavior in terrestrial agriculture, relatively little knowledge has been accumulated about the phosphorus in water. Routine analyses of waters have not included phosphorus primarily because in contrast to the usual elements analyzed it is present usually in small quantities, much less than a part per million. However, it is this low concentration that makes the element important. Along with dissolved nitrogen dissolved phosphorus has been shown to be the usual limiting factor to growth in waters in other regions.

Specht (1950) has published a series of analyses of phosphorus dissolved in fresh water of Peace River in a report on phosphorus pollution. Additional analyses of this river have been made by Florida State Board of Health but have not been published.

Some data on the estuarine and marine waters from the Miami area have been published by Miller (1952) and from waters associated with the red tide phenomenon by Ketchum and Keen (1948).

A general survey of the phosphorus over the whole State has been needed in order that the values in special situations could have comparative meaning. The results and principles of general surveys of this sort which have been done in Wisconsin by Juday, Birge, Kemmerer and Robinson (1928) and in marine waters by Redfield, Smith and Ketchum (1937) can not be directly applied to Florida because the State has extensive rock phosphate deposits

and Wisconsin does not. In turn the study of phosphorus behavior in an area where phosphorus minerals occur abundantly can contribute to the general understanding of this critical chemical element the world over.

Methods

Samples were collected in 100 to 400 cc. soft glass bottles with vinylite lined plastic caps. About two-thirds of the samples collected received several drops of chloroform in order to reduce the fixation by adsorption and bacteria of the dissolved phosphorus on the walls of the bottles. Where the quantity of phosphorus present is in concentrations of the magnitude of .020 ppm., the loss to bottle walls has been shown to be appreciable (Harvey, 1948). Phosphorus is present in waters as fine particulate matter, as dissolved organic compounds, and as dissolved inorganic phosphate. Except in a few cases no attempt was made to distinguish between these fractions because the partition of phosphorus changes rapidly due to the action of organisms in the sample bottles. Thus with the delay inherent in the sampling, it was only feasible to make determinations of total phosphorus in most cases. The total phosphorus is of primary interest because in the course of one day the phosphorus in a natural body of water may fluctuate between an inorganic fraction and an organic fraction during phytoplankton plant photosynthesis and decay.

Samples of 100 cubic centimeters were digested with acids over a hot plate to convert all fractions into inorganic phosphorus, a procedure used by Robinson and Kemmerer (1930). When this solution was diluted to 50 cubic centimeters, a blue color developed proportional to the phosphorus content. The intensity of color after five minutes was measured in a Klett Summerson colorimeter. A graph was prepared of the color intensity of known standards that had been treated in the same way as the samples. The concentration of phosphorus in unknown samples was obtained from this graph. With homogeneous materials this method has been reported with an accuracy of reproducibility of 5-10%. For a single series the data in Table 1 and the data for Silver Springs (Table 2) indicate a similar accuracy in these analyses. However for heterogeneous materials and for the lower concentrations it is likely that the errors are considerably greater. Fortunately the types of differences discussed below seem to be much greater than can be accounted for as experimental error by the largest estimate.

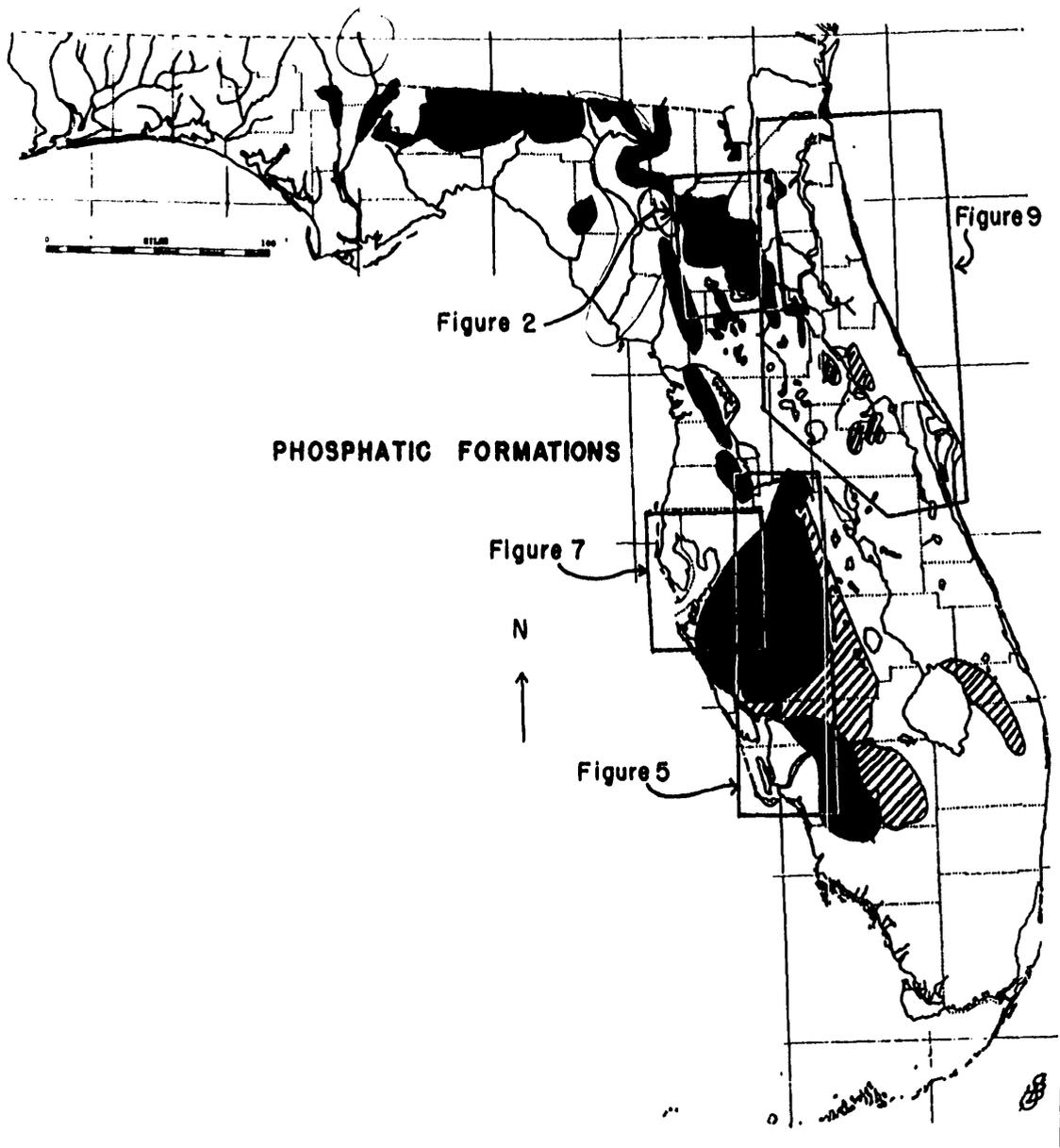


Figure 1.—Surface phosphate-bearing formations. (Position of formations after Cooke, 1945)

In waters that are highly saline the blue color has been shown to be depressed by some interaction with the salts (Robinson and Thomson 1948). This error is usually compensated by analyzing standards to which low phosphorus sea water has been added and deducing a correction usually between 1.1 to 1.35. In this survey a correction of 1.2 was used for saline waters. However for these very varied waters of contrasting qualitative salt compositions and varying salinities, considerable error has necessarily been incorporated by such a procedure. Thus the error is possibly 20% greater for saline than for fresh waters. The analyses include any small quantities of arsenic which may act with phosphorus in this test.

the waters. The correlation seems good in the north central Florida area and in the Bone Valley phosphate mining district in central Florida. Some relatively high values that are not associated with phosphatic geological formations are due to pollution. Some deposits are not crossed by major streams and therefore correlative data are lacking on these. The analyses for Alachua County, figure 2, show the manner in which the dissolved phosphate reflects the geology. In figure 3, lines of equal phosphate concentration have been drawn over the whole State much as one would draw lines of equal height on a topographical map. These are of course approximations but serve to emphasize the superposition of areas of high dissolved phosphate concentration over known phosphate deposits.

Deevey and Bishop (1940) had shown in Connecticut that crys-

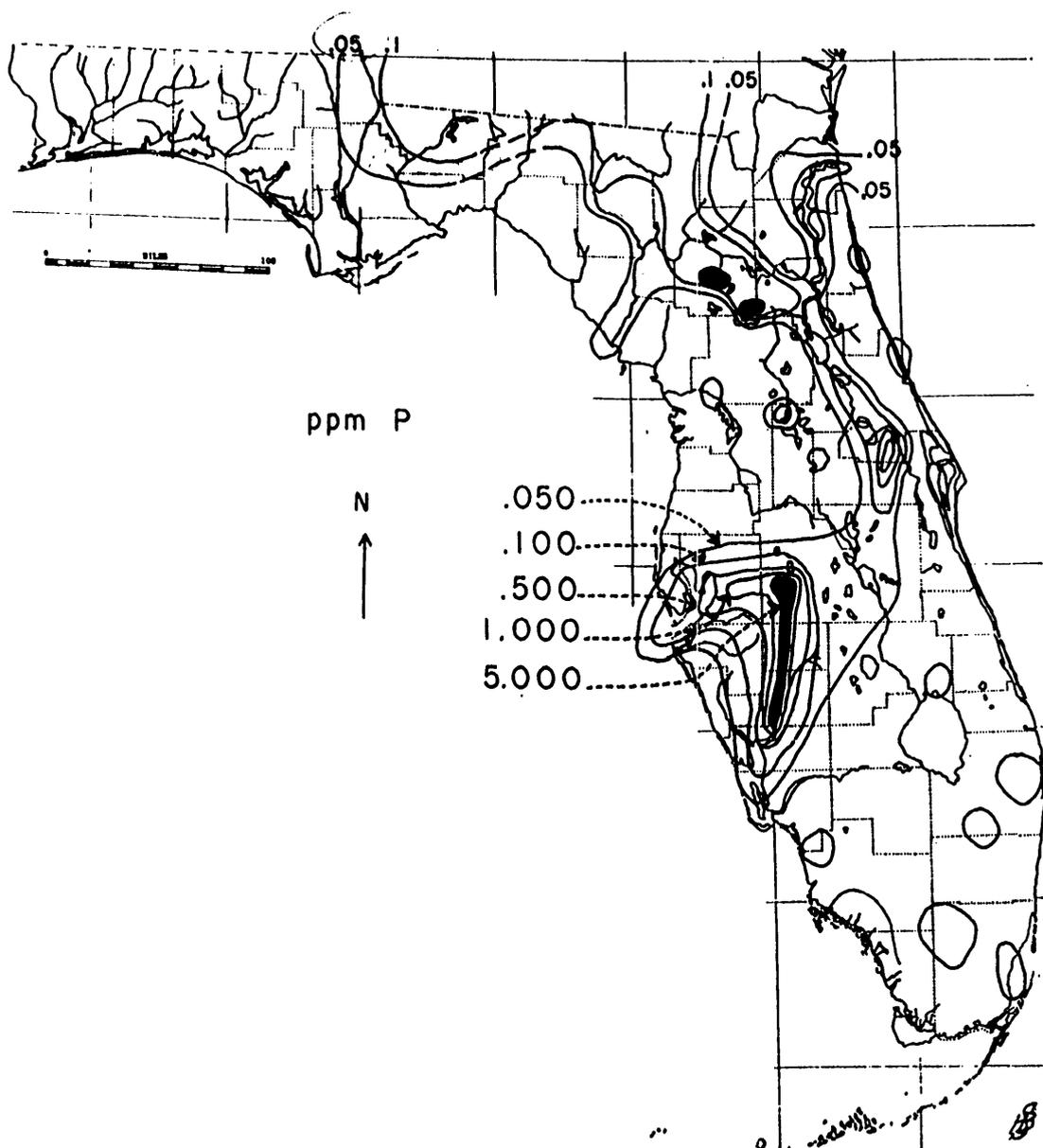


Figure 3.—Dissolved phosphorus in Florida Waters.

LAKE MIZE, FLORIDA 26 AUG. 1952

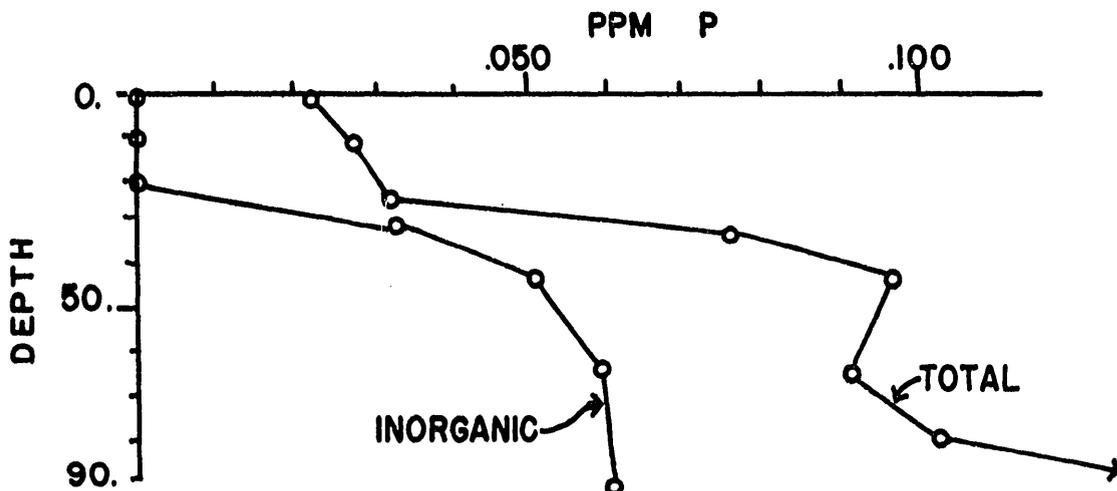


Figure 4.—Dissolved phosphorus in Lake Mize, Florida during summer stratification.

talline rock areas possess slightly lower dissolved phosphate contents than the central lowland sedimentary area. These results confirm in a striking way the general principle of the geologic control of phosphate content of the waters, and it is possible that future prospecting may be facilitated by analyses of dissolved phosphates in stream systems.² It has long been known that dissolved phosphorus is so scarce in the ocean that it is rapidly removed by phytoplankton and lost to the deeper water through sedimentation of organic detritus so that the upper ocean waters are maintained in an impoverished condition receiving a little phosphorus for growth only from turbulent exchange of the element brought up from the deeper waters and in from rivers (Riley, 1951). The analyses of estuarine waters of Florida further document this pattern by showing that Charlotte Harbor and Tampa Bay are one of the richest phosphatic areas and receive more dissolved phosphate from streams than any other estuary in Florida.

Dissolved Phosphorus and the Type of Water

The essential features of the distribution and circulation of phosphorus within streams, lakes, ground waters, and estuaries have been established in other regions (Juday, Birge, Kemmerer, and Robinson 1928; Mortimer 1941-1942; Hutchinson 1941; Newcombe 1940). In general, streams and ground waters have been

²It is amusing to remember the excitement that arose in the laboratory when waters from the Econlochatchee River were found to possess relatively enormous phosphorus concentrations although no phosphate districts were in the drainage. It was learned that a recent shift in the disposition of the Orlando sewage into this river accounted for these values.

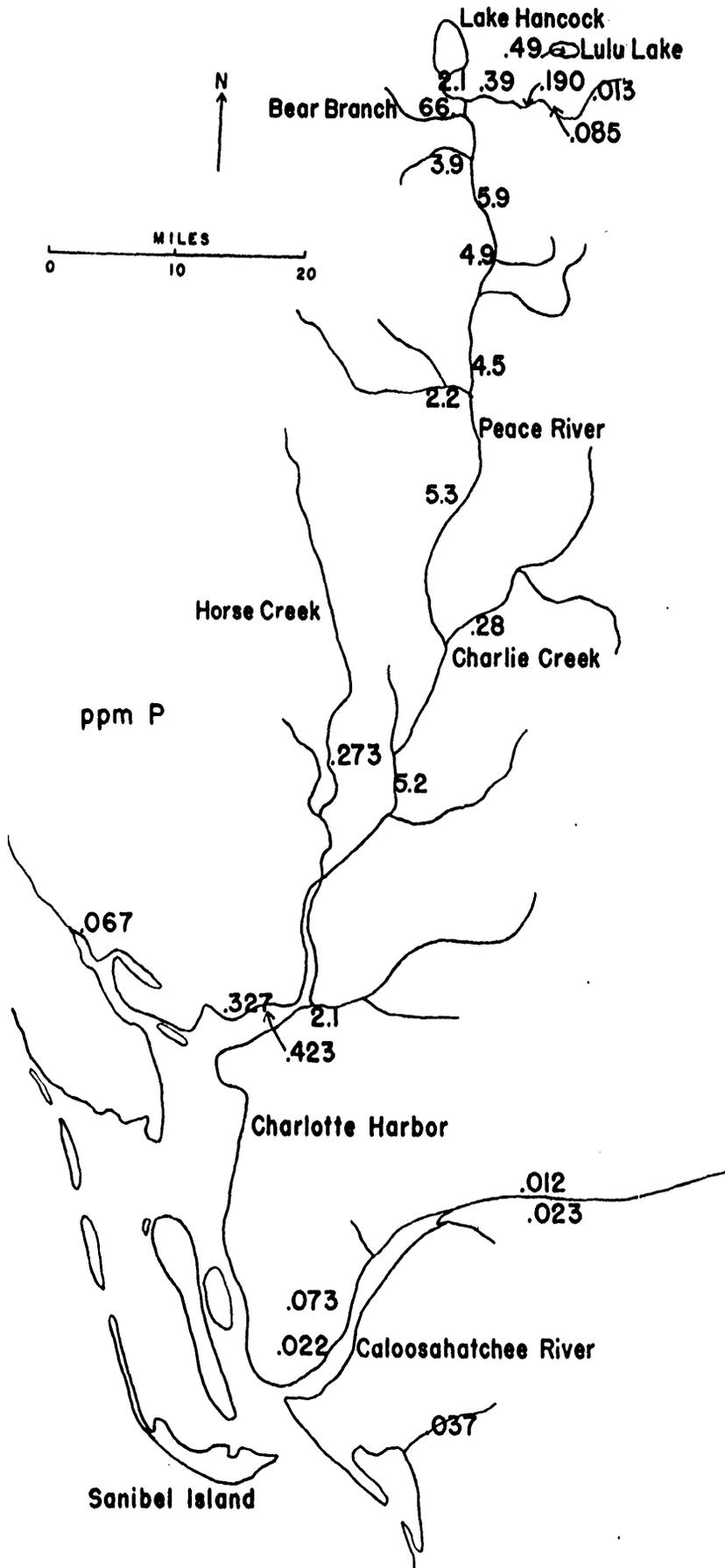


Figure 5.—Dissolved phosphorus in the Peace River system. Data obtained in cooperation with Mr. Ellis Landquist.

found to contain moderate amounts of dissolved phosphorus derived from the rock strata in an inorganic form. In streams with little or no plankton and attached plants the volume of water is large compared to the number of plants that derive phosphorus for growth and thus there is more phosphorus than is needed in plant metabolism. But the situation shifts when these waters flow into lakes where the relatively still waters in the upper levels support microscopic floating plants which take up the phosphorus and convert it into the phosphorus of organic matter. Then the lack of phosphorus often becomes limiting to plant growth. When these tiny single celled plants are eaten by microscopic plankton animals, the phosphorus may be transferred into other organisms and eventually returned to the water as dissolved organic phosphorus or deposited on the bottom as particulate phosphorus. Thus the inorganic phosphorus in shallow lakes and in the upper levels of deeper lakes is small and the organic phosphorus is only a little more. But in the bottom waters of the deeper lakes much larger concentrations of phosphorus are found during the summer stratification. Here the chemically reduced conditions associated with lower oxidation reduction potential and sometimes lower pH and the absence of green plants cause more phosphorus to remain in solution both as dissolved inorganic phosphorus and dissolved organic phosphorus. Thus the processes within the lake remove phosphorus from water as it flows through the lake and deposit it in the lake's lower waters and sediments. It has been shown thus

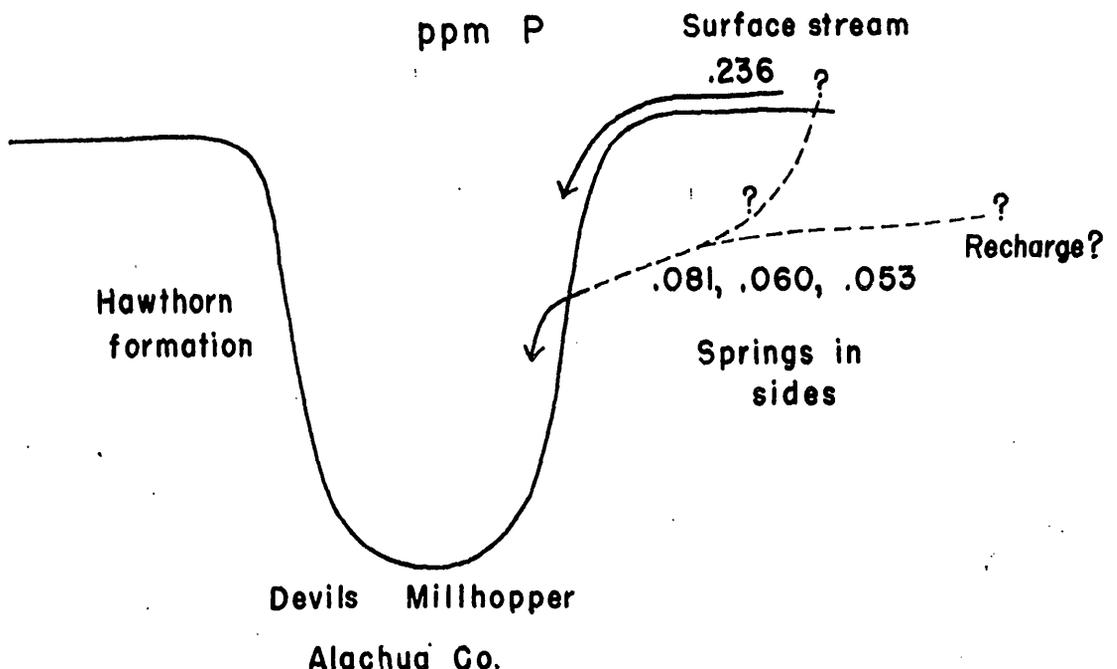


Figure 6.—Dissolved phosphorus in the Devils Millhopper, Alachua Co., Florida.

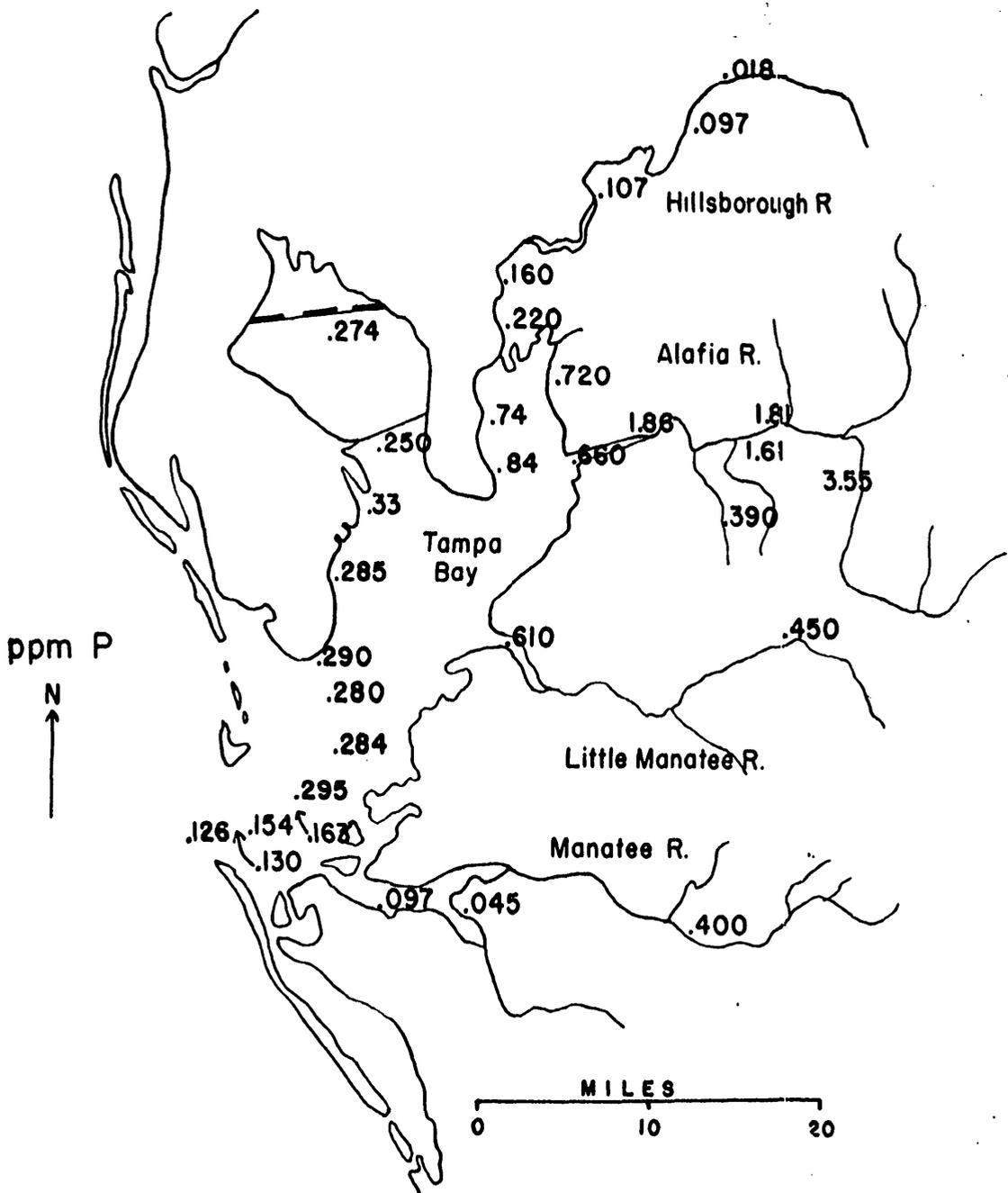


Figure 7.—Dissolved phosphorus in the Tampa Bay region, Florida. Data obtained in cooperation with Dr. Nelson Marshall, Florida State University in the fall, 1952.

that lakes are a phosphorus filter as in River Sussa, Denmark (Berg, 1945). In a similar manner, when phosphorus laden river waters reach the sea the phosphorus is removed and deposited on the bottom of the ocean in the sediments. Estuarine waters are zones of mixing where the phosphorus content is intermediate between rivers and sea.

With the above introductory account of the occurrence and distribution of phosphorus in natural waters, it is interesting to compare data from Florida as summarized in tables 2, 3, 5, 6, 7. It

will be noticed that streams are high and in fact enormously laden with phosphorus in the phosphate districts. The lake waters at the surface have smaller amounts than the streams because of the filtering action of the lakes. Estuarine waters contain more phosphorus than open water, as reported in the literature, but somewhat less than the streams from which the phosphate is derived. In comparison to lakes, streams and estuaries which receive high values in phosphate areas, the spring waters have moderate values irrespective of the area in which they occur. As shown in the Silver Springs analyses the springs have primarily inorganic phosphate, the organic phosphorus having been removed by the soils and rocks of the recharge areas. The spring waters in these limestone areas are basic so that little calcium phosphate is dissolved and very little can be held in solution. Thus pH is critical in regulating the amounts of dissolved phosphate of inorganic form but not that of the organic phosphorus. The solubility of calcium phosphate under a variable pH is represented in Table 4. However, calcium phosphate is found in nature usually in some type of apatite mineral, a complex chemical composition, upon which no such solubility tables are available.

TABLE 3

MEAN VALUES OF PHOSPHORUS IN TYPES OF FLORIDA WATERS

Water Types	ppm Total P	
	Phosphate District	Other
Streams	.876 (18)	.046 (44)
Estuaries	.269 (2)	.044 (21)
Lakes	.290 (8)	.038 (31)
Springs	.061 (5)	.045 (27)

(The number of different bodies of water average in each case is indicated by the figure in parentheses).

TABLE 4

SOLUBILITY OF INORGANIC PHOSPHORUS AS A FUNCTION OF CALCIUM AND ACIDITY. (Based on theoretical data of Green and Holmes (1947) for 68 deg. F.)

Acidity as pH		Calcium ppm					
		.4	4.	12.	20.	40.	80.
6.0	Greater Than 40. ppm						33.
6.5					33.	12.	4.
7.0			8.	10.	4.	1.6	.33
7.5			8.	1.6	.66	.3	.10
8.0			2.3	.33	.16	.066	.026
8.5			27.	.33	.16	.066	.026
							.007

Dissolved phosphorus in ppm

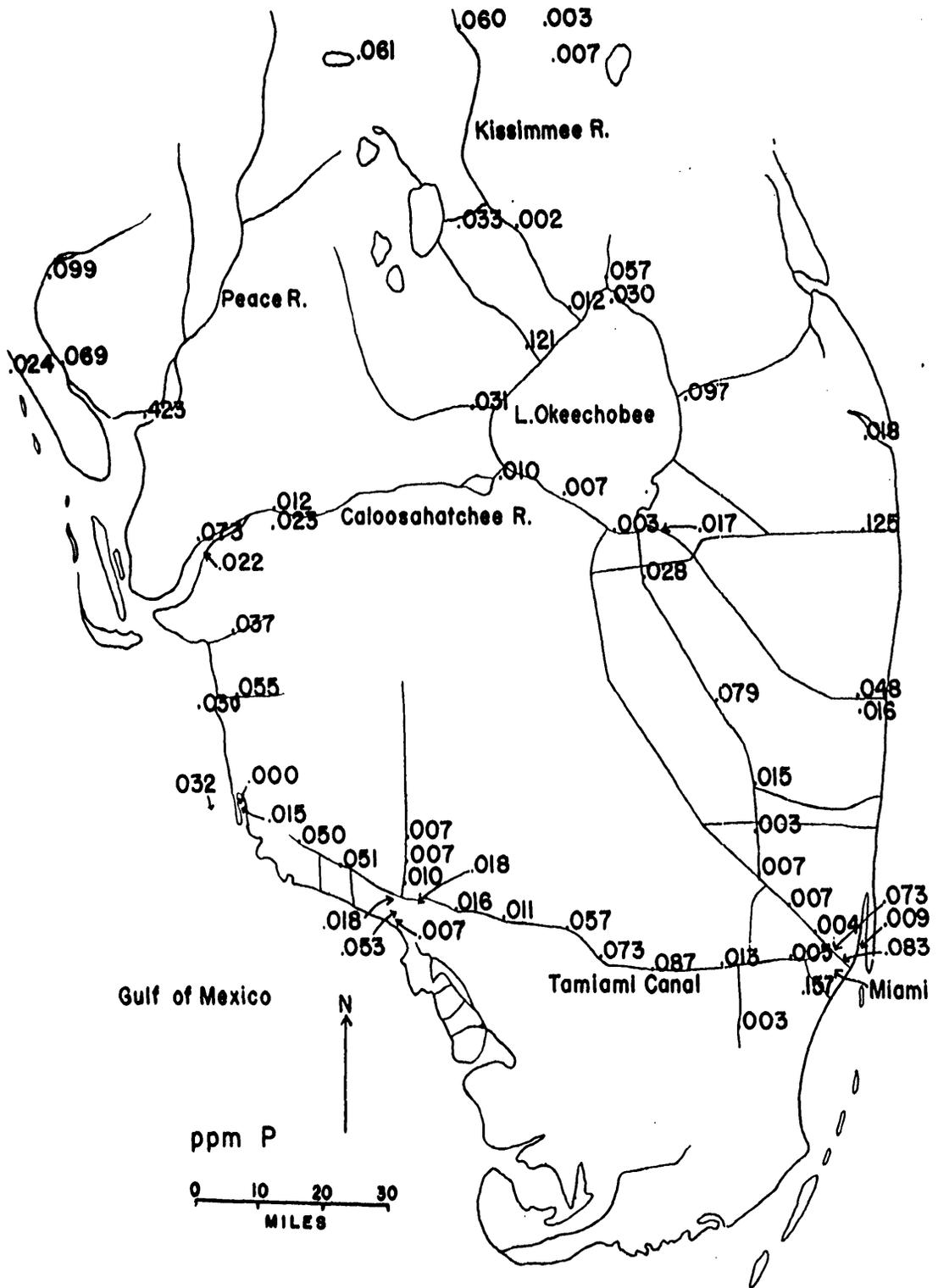


Figure 8.—Dissolved phosphorus in the rivers and canals of south Florida during August 1952.

Among the lakes there are great ranges of phosphate contents just as there are great ranges of conditions such as hardness, carbon dioxide and color. The vertical pattern of phosphorus distribution within Lake Mize, Florida, is similar to that of Lake Mary, Wisconsin, although the values are much higher for these two lakes than for most of the other lakes reported in Wisconsin or elsewhere

(see figure 4 and Juday and Birge, 1931). These lakes are similar in being deep soft seepage lakes with high phosphates possibly due to low pH. Lake Mary, Wisconsin, is very atypical. It is not known whether the stratification of phosphorus in Lake Mize is typical for Florida's relatively few deep lakes.

TABLE 5

REGIONAL COMPARISONS OF DISSOLVED PHOSPHORUS IN LAKES
(Modified from Hutchinson, 1937, 1952)

	Mean	ppm P Range
HUMID CLIMATE; EXTERNAL DRAINAGE:		
N. E. Wisconsin (Birge and Juday)	.023	.008—.140
Connecticut (Deevey)		
Eastern Highland	.011	.004—.021
Western Highland	.013	.007—.031
Central Lowland	.020	.010—.031
Japan (Yoshimura)	.015	.004—.044
Austrian Alps (Ruttner)	.020	.000—.046
Sweden (Lohammar)		
Uplands	.038	.002—.162
South	.026	.004—.092
North	.024	.007—.064
North Germany	.077	.005—.600
Florida		
Phosphate districts	.290	.100—.660
Other districts	.038	.000—.197
Gran Chaco, Paraguay (Carter and Beadle)	-----	.5 —1.5
ARID CLIMATE; INTERNAL DRAINAGE; SALINE LAKES:		
Nevada (Hutchinson)	.90	.05—3.0
Aegean (Stankovic)	-----	.097—.45
Central Africa (Beadle)	-----	.16 —.76
South Africa (Hutchinson, Pickford, Schuurman)	-----	.05—2.0
Indian Tibet (Hutchinson)	-----	.023—.30
Owen's Lake, California	76.	—
Salt Range, Punjab (Hutchinson)	.17	—
Goodenough Lake, British Columbia	208.	—

The data in Table 6 indicate that some of the lowest values are found in waters where attached littoral plants have possibly had a rôle in depleting the waters such as in marshy pools surrounding lakes, pools along roads, and small lakes without appreciable drainage in the sandhills. The action of a lake in filtering phosphorus is illustrated in figure 2.

Data from analyses of water entering Orange Lake from the north and discharging eastward into the Oklawaha River show a marked decrease in phosphorus content. Also in figure 2, the waters entering Newnans Lake, the moderate sized lake just east of Gainesville, show a drop from a phosphorus content of .247 to .117 ppm.

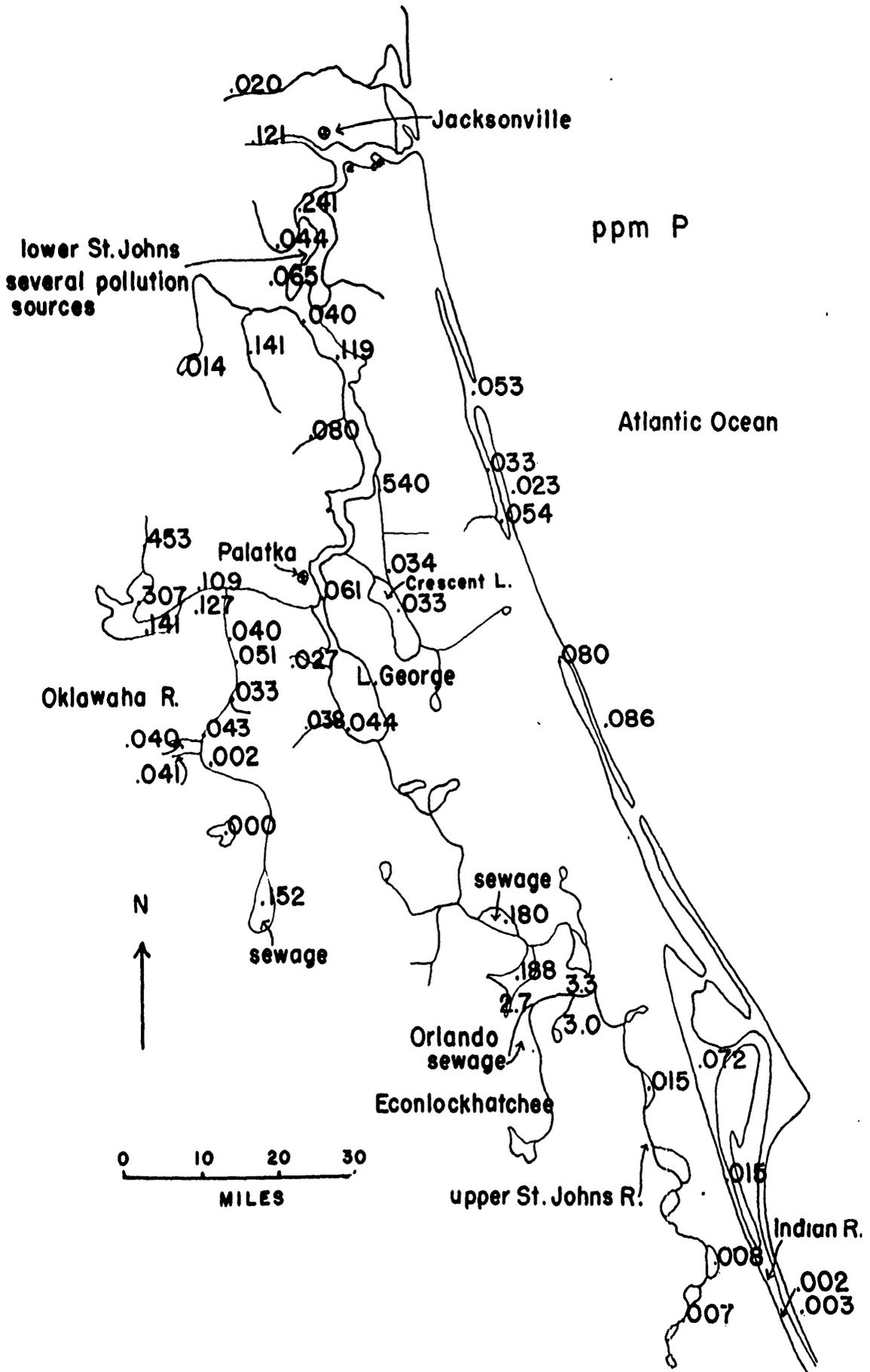


Figure 9.—Dissolved phosphorus in the St. Johns River system.

The general impression that one obtains, that water filled sinks are often fertile, is supported by the analyses of phosphorus. Apparently the water filling the basins are phosphorus laden in contrast to the deeper artesian aquifers as represented by the large springs which have moderate phosphate values.

TABLE 6
PHOSPHORUS IN FLORIDA LAKES AND STREAMS

Standing Waters:	Cases	Mean	ppm P	
			Range	
Grassy, sand bordered lakes	6	.008	.001—	.014
Flatwoods ponds	4	.151	.030—	.43
Sinks	4	.320	.028—	1.01
Lakes with organic mud borders and extensive water hyacinths	5	.298	.100—	.51
Larger lakes receiving sewage (Jessup, Monroe, Griffin, Lulu, Reedy, Tohopekaliga)	6	.185	.042—	.49
Larger lakes not receiving sewage or phosphate district drainage (Geneva, Brooklyn, Kingsley, Eustis, Ola, Weir)	6	.007	.000—	.014
Streams:				
Small streams, not polluted, not draining phosphatic formations	18	.019	.003—	.034
Small, humic watered creeks, draining phosphatic formations, no pollution, generally acid	10	.413	.141—	1.5
Streams not draining phosphate formations but receiving sewage	7	.836	.038—	3.1

The classification of analyses according to the type of water as given in Table 6 suggests some relationship between the percentage of dissolved phosphate and the type of lake water but a general classification of the water types biologically is one outstanding problem not yet completed. In Table 6, it should be noted that the high phosphate contents are found in small acid streams which had relatively short surface courses since falling as rain. The more basic waters which have received ground waters and salts have lower values depending of course on the rocks through which the water passed.

Ohle (1934) found higher values in German dystrophic waters (brown waters) than in clear waters. Similar results noted in Florida are suggested as due to the soft acid nature and to the course of these waters. Also Barbier and Maroger (1950) have shown that colloidal humates increase the amount of calcium phosphate that is dissolved by binding action. Humates are brown mo-

lecular and colloidal breakdown products of the lignin that in natural wood holds the fibers together and in Florida stain many streams brown.

Dissolved Phosphorus in Florida Compared with Other Regions

Since Florida has such large resources of phosphate rock, it is reasonable to expect Florida's waters to contain on the average higher phosphorus concentrations than most other regions of the world. G. E. Hutchinson, in an unpublished manuscript, collected data on dissolved phosphorus in lakes to which averages of Florida data have been added and both are presented as Table 5. This table indicates that Florida has higher dissolved phosphorus concentrations than the rest of the world with humid climate, with the possible exception of those districts elsewhere that indicate major phosphate deposits. Of those analyzed only the salt lakes in arid parts of the world show higher phosphate contents than those of the phosphate districts of Florida. It is interesting that the areas that are most similar to Florida are the sedimentary North Germany area, which resembles Florida in some respects such as elevation and general geological structure, and the Gran Chaco of Paraguay, which has a somewhat similar climate. In contrast, waters in crystalline rock areas are low and the older and more modified sedimentary areas are intermediate in dissolved phosphorus concentrations such as shown for Connecticut and Sweden in Table 5. It is likely that other areas of the world possessing phosphate districts, such as North Africa, Idaho, Esthonia, Egypt, etc., (Johnson, 1952), would similarly possess high dissolved phosphorus.

Dissolved Phosphorus and the Origin of Phosphate Deposits

No wholly satisfactory explanation has become accepted for the origin of Florida's extensive and varied phosphate deposits. The status of knowledge on this is discussed in detail by Vernon (1943, 1951). Apparently a combination of initial deposition of phosphatic minerals, bones and teeth in marine and terrestrial sediments followed by a possible later concentration of these parts of the sediments have produced the existing deposits. Although there is little evidence of phosphate deposition during the Recent, other than at bird and mammal rookeries, following the hypothesis of uniformitarianism we look at contemporary Florida for answer to the processes in past geologic time for there is little evidence

that Florida is geologically much different now than it was in the Tertiary times.

An examination of the data on dissolved phosphate from the present Florida waters suggests two things: First, the marine estuarine deposits now forming off some rivers are forming in the presence of relatively high phosphate concentrations so that these sediments may be expected to contain a proportionately high phosphate content. Miller (1952) has shown for Biscayne Bay in the Miami area that the ratio maintained between dissolved phosphorus and the sedimentary phosphorus is about 1/1000. The high phosphorus contents of the rivers moving into sea water are possibly supersaturated in relation to the high calcium, basic, ocean waters as estimated theoretically by Dietz, Emery, and Shepard (1942). Second, the highest dissolved phosphorus contents have been found where soft acid streams crossed phosphatic formations suggesting that acidity regulates the amount of phosphorus which becomes dissolved.

Since the basic spring waters are moderately low in dissolved phosphorus, even in phosphatic districts, it seems that phosphorus may become dissolved in the surface drainage water but becomes removed again as the ground water passes through deeper strata. This suggests a mechanism by which the deposits already rich in phosphorus now found most abundantly a few feet below the surface have been enriched. First the phosphorus is dissolved and then redeposited as the water becomes more basic on reaching the deeper ground water levels and as the initial carbon dioxide acidity is neutralized with the limestone. Those acid surface waters moving down surface streams to the sea gradually become basic but much of the dissolved phosphorus by this time is converted into the organic phosphorus of plant and animal matter in particulate, colloidal, and dissolved form so that it remains in solution in estuarine waters for some time in spite of high pH. Thus the difference observed between the high phosphorus content of acid surface water and the low phosphorus content of more basic ground waters indicate that phosphorus leached out of one layer can be precipitated in the rocks through which it may pass or that the ground water was relatively free of phosphorus at the recharge area.

That enrichment of phosphorus may occur in existing formations due to the above causes does not imply that the present phosphatic formations are themselves older formations concentrated by leaching. The Alachua formation of Florida (Vernon, 1951) is

typical of those phosphate deposits formed by the fixation of phosphatic acid solutions through reaction with carbonate rocks. Vernon (1951) using detailed stratigraphic data from Citrus and Levy counties, Florida, found that Miocene phosphatic formations (Hawthorn and Duplin marl) were probably laid down in shallow seas adjacent to a land mass upon which the phosphate of the Alachua formation was forming. He feels that the high phosphate content of these formations was derived from a high dissolved phosphate level in the sea and adjacent land at the time of formation.

The solubilities of calcium phosphate in fresh water of varying acidity shown in Table 4, have been modified from Green and Holmes (1947). These solubilities are based on the theoretical equation for the solution of excess tricalcium phosphate under equilibrium conditions, and in the ionic strength of fresh water. Although these assumptions rarely correspond exactly to natural conditions, the important rôle of pH and calcium concentration is demonstrated nevertheless. Acid soft water streams have capacity for taking up very large concentrations of phosphorus mineral matter through which they pass whereas basic hard waters such as in Florida's ground waters, even at equilibrium can hold less than one part per million. The values for the large typical Florida Springs of .020—.123 ppm P with pH ranges mostly between 7.3 and 8.3 with calcium concentrations 30 to 70 ppm are only slightly above those predicted by Table 4.

For salt waters the assumption used in calculating these data do not apply, for solubilities of many substances in saline waters are greater due to the greater ionic strength. The greater ionic strength in part counteracts the effects of high calcium in sea water. However, from similar calculations based on greater ionic strength Dietz, Emery, and Shepard (1942) found that the ocean is possibly saturated with phosphorus. The unusually high phosphorus values reported in Tampa Bay and Charlotte Harbor are of course total values including organic and colloidal fractions. Note that if some source of acidity such as industrial pollution should lower the pH much greater phosphate solubilities are possible and although later neutralized this mechanism would permit the introduction of high phosphate concentrations into organic fractions and into colloidal and soluble form. Bear Branch, which receives wastes from a superphosphate plant near the town of Bartow, was reported by Mr. Ellis Landquist in his biological

study of the Peace River during 1950-51 to possess a pH range from 2.5 to 6. Such acidity accounts for the dissolved phosphate contents up to 177 ppm phosphorus in this branch. Although subsequently diluted by the Peace Creek, the high values of 5 ppm which persisted in the Peace Creek below this point (see figure 5) seem to have been due to this pollution since other streams in the system at the same time had dissolved phosphorus values ranging .5 to 3 ppm.

Some observations made of the dissolved phosphorus in streams in the Devils Millhopper, a large sink near Gainesville, may be interpreted as in agreement with the hypothesis of concentration discussed above. Several small springs issue from the sides of the Millhopper and one stream falls into this sink from the surface. These flows rush down the sides and out through a fissure in the bottom of this 80-foot hole. The sink penetrates the Hawthorn formation which is heavily phosphatic. The data presented as figure 6 indicate that the water which has passed through the ground has a lower phosphate content than the water that flows in over the top of the sink. If surface water does lose its phosphorus upon passing through rock, there should be a concentration of phosphate not far below the soil surface in areas of ground water recharge. Such a concentration has not been determined, but may be present.

Dissolved Phosphorus and Potential Fertility

As indicated in the introduction, all life requires phosphorus as a basic chemical material for its metabolic processes. About two-tenths of one per cent of phosphorus is required to make chromosomes in the cells and to make coenzymes and other energy transforming substances. In most aquatic environments it has been substantiated by many workers (Hutchinson, 1952) that the growth of plants, and the subsequent growth of animals that derive nutrition from these plants, is limited by the amounts of phosphorus and nitrogen available and utilized by the plant. In fresh waters of many tropical areas blue-green algae are abundant and fix nitrogen from the air to help supply the nitrogen requirements, and thus cause phosphorus to be the limiting factor in plant growth. Hutchinson (1937), in discussing lakes in desert regions considered values of phosphorus over .050 as certainly not limiting. There is some evidence that this is true in Florida, for continual blooms of blue-green algae through the long summer have been reported to

me in personal communication by J. C. Dickinson and in the monograph on the St. Johns River by E. L. Pierce (1947). There are of course many other factors affecting the biological productivity of waters and where phosphorus and nitrogen are not so scarce as to limit growth, these other factors will determine the production of protoplasm by the natural community of organisms. For example, trace elements such as copper and cobalt may be limiting.

The phosphorus distribution is not expected to be the same as the distribution of high production but the dissolved phosphorus can be thought of as a measure of potential productivity and fertility. The phrase potential fertility is used in the sense of phosphorus availability. Other things being equal regions of high phosphorus might be proposed as regions of high fertility. This is very important to Florida. The growths of microscopic plants that support fish and other fauna are fundamental to the prosperity of commercial and sports fishing, both of which are very important to Florida's tourist trade. Someone with experience in other regions quickly gains the impression that the waters of the State are fertile and contain much life. Indeed, with a very high annual sunshine average and with its waters carrying considerable phosphorus, one suspects that productivities may be high on a world basis. There are little data as yet to test such a hypothesis, but it can be said that the potential fertility of the State, as measured by the dissolved phosphorus, is very large.

Although a high fertility is generally a good thing from man's point of view in that more life is produced in the lakes, streams and estuarine waters, it is not necessarily so. If the fertility results in the proliferation of some objectionable organism or does not produce the desired type of organism, then either less fertility is needed or some control needs to be exercised over the type of organisms which are permitted to make use of the potential fertility. The clogging of waters by water hyacinths is an example of an undesirable result of high fertility. Another is the overproduction of undesirable fish species in some waters at the expense of species desired for food or sport.

Superficially the distribution of high potential fertility as measured by high concentrations of dissolved phosphorus in figure 3 suggests a possible relationship to the areas of water hyacinth nuisance. Certainly, rapid growths of these plants occur in the St. Johns, Peace and Suwannee river systems and in the lakes of the

phosphate district such as Newnan Lake and Orange Lake in Alachua County. Indeed, this possible correlation should be investigated and comparative growth of hyacinths measured in different waters.

Much work has been done in ponds of other areas to increase the fertility of water by artificial fertilization similar to that done in terrestrial agriculture. However, nothing has been done to work out a method for decreasing the potential fertility of a water should it be deemed advisable. Actually this is a major engineering need since great sums of money are spent each year killing algae blooms in lakes in which clear water is desired rather than rapid production. The approach to the problem of using chemicals is rather a backwards approach for whenever blooms of algae or rafts of hyacinths are killed, the phosphorus within them is released into the water and into the lake muds so that the remaining organisms grow even faster. A much better approach would be one designed to remove the phosphorus. Commercially this might be possible since the dissolved quantities involved are so small, being usually much less than one part per million. As yet, no practical solution seems to be at hand. Perhaps a biological filter is feasible in which phosphorus and plant growth are removed from water running through a lake, with resultant improvement downstream, or perhaps ferrous or aluminum salts could be added to remove the phosphorus as a precipitate.

An understanding of the quality and quantity of the aquatic production under various situations in Florida is needed. A concerted research program should be made to uncover the basic factors and their interactions, which control this natural aquatic agriculture.

It is likely that phosphorus fertilization of the Florida waters which contain more than .050 ppm total phosphorus will not increase biological production because it is probably not limiting at these concentrations.

Dissolved Phosphorus and Pollution

Some types of pollution produce extreme effects on the potential fertility of Florida's waters by adding large amounts of dissolved phosphorus relative to the amounts naturally present. By pollution is here meant the addition of materials to a natural body of water as a result of man's activity so that the conditions of the lake,

stream, or estuary are markedly changed with respect to the quality and quantity of biological growth. By this definition a pollution may not necessarily be bad if the man made changes are not undesirable to the long range welfare of all concerned. However, pollution by changing the natural situation often restricts the variety of organisms and often markedly affects the populations of fish organisms in indirect ways by affecting their plant and animal foods.

In Florida two sources are at present increasing the dissolved phosphorus in Florida waters: Industrial and municipal sewage and the byproducts of the phosphate industry. Phelps and Barry (1950) have summarized sources of pollution in Florida. When sewage is passed through chemical treatment many of its objectionable properties, such as disease organisms and organic matter, are removed, which if dumped directly in streams would use up the dissolved oxygen and kill the organisms. However, the very high content of phosphorus in urine and in the solid materials of raw sewage is not completely removed by sewage treatment plants. By the time the decomposing raw sewage reaches the plant there is already a high concentration of phosphorus in the dissolved inorganic form. Apparently this inorganic fraction passes through the plant without much loss. Raw sewage entering the university sewage plant in Gainesville, April 9, 1953, possessed a dissolved inorganic phosphorus content of 2.1 ppm. The final effluent emerging from the same plant contained 1.9 ppm dissolved inorganic phosphorus. These values in comparison to the natural concentrations in most streams are enormous.

A sample of the phosphorus developed from Lakeland sewage and taken out of Lake Hancock in Saddle Creek and analyzed was 2.0 ppm. and a sample of the Orlando sewage taken in the Econlochhatchee Creek analyzed 3.2 ppm. Standard engineering practice has not recognized these relatively small phosphorus quantities on a weight basis as being a pollution. Considering the possible stimulus to undesirable growths or undesirable species, it is clear that this may at times be harmful although a general increase in fertility is promoted in some fish culture. With the increasing population of Florida and the increased dumping of sewage into Florida's relatively small surface streams, the result of this practice must be studied. It is certainly not possible to say from the available evidence whether the character of Florida's fresh waters and estuaries, which are an important resource, are being markedly

changed and if so whether for the better or worse by these large changes in potential fertility. It is, however, important that the total biological character of the major water types be established before and after such increase in potential fertility to determine if there is a resultant increased hyacinth growth, game fish, or algae blooms in previously clear waters.

The phosphate industry particularly in the Peace and Alafia river systems is discharging phosphate slimes and, in the case of Bear Branch, Bartow, Florida, acid waters high in dissolved phosphorus into a river which must already have had high concentrations because of the underlying rock formations. A high original phosphorus concentration is indicated by the streams in the Peace and Alafia river area which do not receive industrial wastes but have very high values although not as great as the Peace and Alafia proper. It seems likely that the pollution somewhat accentuates the addition of phosphorus. The data in figure 5 support this. Relatively undisturbed Charlie Creek, for example, has a lower phosphorus value than the streams receiving wastes. It is unlikely that at these high levels phosphorus is limiting in the Peace River or that the potential fertility is in any way realized. But the effect on the fertility of Tampa Bay and Charlotte Harbor is probably being increased by the increase in phosphorus going down these rivers. Phosphorus also goes down the Peace River through Lake Hancock from Lakeland sewage. The problem of the possible effects of colloidal and slime phosphorus on river organisms is a separate problem that is being studied by Mr. Ellis Landquist of the University of Florida.

Dissolved Phosphorus and the Red Tide

If there are increasing quantities of phosphate going down some rivers, the question is raised whether this additional fertility is increasing the incidence of the red tide offshore. The so called red tide is a bloom of a microorganism *Gymnodinium brevis* in marine waters which becomes so concentrated that fish are killed in large numbers and are washed up in great quantities on the beaches (Gunter et al, 1948).

Much work has been done to show that similar phenomena occur in many parts of the world at widely timed intervals. Walton Smith (1949) postulated that the occurrence is due to nutrients becoming available, especially phosphorus. Ketchum and

Keen (1948) found unaccountably high total phosphorus concentrations in the 1947 growth off the coast at Sarasota. As yet, however, there is no definite proof that high phosphorus concentrations are required for red tide blooms.

Slobodkin (1952) has postulated that the relatively frequent red tide occurrence off the lower Florida west coast is a result of rains and northeast winds which carry low salinity waters containing a few of the *Gymnodinium* organisms and nutrients out over the saltier open waters where they develop a bloom and then drift northward and shoreward in the prevailing Gulf drift. The mechanism of this drift was demonstrated by E. L. Pierce (1951). Specht (1950) has shown high phosphorus concentrations entering Charlotte Harbor from the Peace River. From the data in figures 3 and 7 it is suggested that the Peace and Alafia rivers are sources of larger nutrient concentrations than the Caloosahatchee and Okeechobee which have smaller amounts of dissolved phosphorus. The Caloosahatchee river crosses phosphatic formations but is derived largely from phosphorus poor Lake Okeechobee and is not so acid when it crosses phosphorus rocks. A charge of phosphate laden low salinity water might accumulate in Tampa Bay or Charlotte Harbor and then be blown out to sea as a fairly intact mass of water before mixing.

The data in Table 7 suggest that adequate phosphorus is found in these waters in excess of that needed for a red tide bloom. After the initial bloom further fertilization can come from fish that swim

TABLE 7
PHOSPHORUS RELATIVE TO RED TIDE

	Cases	PPM Total Phosphorus Mean	Range
Amber water off Ft. Myers			
July 1947 (Ketchum and Keen, 1947)	5	.335	.152—.630
Nov. 1952 (Marshall and Odum) during late stages of bloom	3	.052	.036—.076
Off Ft. Myers, not at times of Red tide			
Aug. 1947 (Ketchum and Keen, 1947)	5	.029	.019—.038
Dec. 1952 (Lackey and Odum)	4	.016	.008—.024
Estuaries which contribute phosphorus			
Tampa Bay (Marshall and Odum)			
September 27, 28, 1952	15	.318	.125—.840
Charlotte Harbor, June-Dec., 1952	2	.376	.327—.425
Caloosahatchee Estuary			
June, Nov., Dec., 1952	3	.071	.022—.118
Caribbean open water (Ketchum and Keen, 1947)			
Indian River, summer 1952	3	.034	.0003-.015

into the area, die and decompose. The data on samples collected from the recent red tide in 1952 by N. Marshall show that lower concentrations are required at least in these last stages of the bloom than might have been surmised from the values taken by Ketchum and Keen (1948). Perhaps, however, during the last stages, the bloom was being dispersed by mixing although the water was recognizably red at the time. To further test these hypotheses a continuous series of samples must be taken regularly until the initial formation stages of the red tide are covered. Of course adequate phosphorus does not guarantee a bloom for there are other factors, but certainly adequate phosphorus is a prerequisite (Specht, 1950; Smith, 1949; Ketchum and Keen 1948).³

If the phosphate going down the rivers into the coastal areas in large amounts is increasing due to expansion of industry and population, further examinations must be made to determine whether the general fertility of some coastal waters is being increased and whether or not this is following desirable lines or is producing undesirable products. The procurement of adequate fishing statistics may permit some examination of change in this respect.

³(This note was added in press.) Three recent papers and a fresh outburst of red tide in September 1953 at the mouths of Tampa Bay and Charlotte Harbor have further increased interest in red tide phenomena. (Kierstead, H. and L. Slobodkin, 1953. *Journ. of Marine Research*, vol. 12, pp. 141-147; Slobodkin, L., 1953. *Journ. of Marine Research*, vol. 12, pp. 148-155; Chew, F., 1953. *Bull. of Marine Science of the Gulf and Caribbean*, vol. 2, pp. 610-625.) Slobodkin proposes that a lens of brackish water blowing out from shore on the surface provides a means of developing a critical minimum mass for starting a full bloom. He thinks that the nutrient phosphorus could be concentrated by organisms migrating vertically into the surface layer. Thus he thinks that the amount of phosphorus initially present need not be larger than usual. Chew found patches of low salinity water offshore but found that the red tide was not in these but was in slightly higher salinity waters nearby. He interpreted the lower salinity water as derived from rivers and the higher salinity water which was high in phosphorus as derived from offshore. It seems possible that Chew's lower salinity water could have been from the Caloosahatchee and the red tide water could have originated further north in the polluted Tampa Bay estuary and Charlotte Harbor. Slobodkin's idea of critical mass seems more applicable if applied to nutrient containing water from the polluted estuaries. Even if phosphorus is not a limiting nutrient to red-tide blooms, it is likely to be correlated with limiting nutrients from the polluted bays and thus act as a water marker in tracing such water. The repeated localization of the red tide blooms in areas near the mouths of the phosphatic rivers suggests that some causal factor is localized there.

CONCLUSIONS

1. The dissolved phosphorus content of Florida fresh waters is correlated with the underlying phosphatic rock formations of the drainage area.
2. The dissolved phosphorus content of Florida estuarine waters is determined by the proximity of the rivers and the phosphorus content of these rivers.
3. In the phosphatic districts the dissolved phosphorus is highest in the soft acid streams, lower in lakes due to a biological filtering action, and lowest in springs possibly due to a geological precipitating action.
4. The dissolved phosphorus and thus the potential fertility in Florida waters especially in the phosphatic districts is considerably higher than in waters in most other humid regions of the world yet studied.
5. Dissolved phosphorus liberated by sewage and by the phosphate industry is producing a high potential fertility in many waters. There is no definite evidence whether or not this is desirable.
6. The high frequency of the red tide off the mouths of the Peace and Alafia rivers suggests causal relationship between the large quantities of natural and industrial phosphorus passing down these rivers.
7. A program of research is needed to discover what other factors determine how the high potential fertility of Florida's waters is expressed in terms of fish production, water hyacinth growth, and cloudy waters. The natural condition of Florida streams should be studied and recorded as a valid basis for resource use management before further pollution destroys our chance to establish the biological structure of the natural streams.

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APPENDIX

I. Total Phosphorus Analyses of Marine and Estuarine Waters
(Collaboration with others as indicated)

	Total P ppm		
<i>Alligator Harbor Series: (With Nelson Marshall, Harold Humm of Oceanographic Institute, Fla. State Univ.)</i>			
Bald Point, Ochlockonee Bay, Franklin Co., Aug. 21, 1952		.058	
Panacea Bridge, Ochlockonee R., Aug. 21, 1952		.057	
Camp Weed Pier, Alligator Harbor, Aug. 21, 1952		.013	
Marine Lab. pier, Alligator Harbor, Aug. 21, 1952		.040	
Mouth South Creek, Alligator Harbor, Aug. 30, 1952		.028	
Midway South Creek, Alligator Harbor, Aug. 30, 1952		.040	
Mouth North Creek, Alligator Harbor, Aug. 30, 1952		.028	
Midway North Creek, Alligator Harbor, Aug. 30, 1952		.030	
Station No. 208, Alligator Harbor, Aug. 30, 1952		.048	
Station No. 210, Alligator Harbor, Aug. 30, 1952		.019	
Station No. 217, Alligator Harbor, Aug. 30, 1952		.021	
Station No. 213, Alligator Harbor, Aug. 30, 1952		.050	
Peninsula Pt. Channel, Alligator Harbor, Aug. 30, 1952		.018	
<i>Sanibel Island—Tampa Bay series during Red Tide (with Nelson Marshall, Oceanographic Institute, Fla. State Univ.)</i>			
	ppm P (Total)		
	Filtered	Unfiltered	
Plantation Key, Surface, Nov. 19, 1952	.024	.021	
Four miles off Sanibel in Red Water, Nov. 15	---	.043	
Four miles off Sanibel, clear water, surface	.018	.017	
Four miles off Sanibel, Red water, surface, Nov. 16	.041	.076	
Buoy 4B Tampa Bay, Surface, Nov. 15, 1952	.096	.174	
Buoy 4B Tampa Bay, 20 ft., Nov. 15, 1952	.025	.160	
Twelve miles off Sanibel in Red Water, surface, Nov. 16	.018	.036	
End of Naples Pier, Nov. 17, Surface	.021	.024	
Nine miles off Sanibel, surface, Nov. 16	---	.038	
Nine miles off Sanibel, 10 feet deep, Nov. 16	.012	.030	
Sanibel, clear water, surface, Nov. 16	.025	---	
Boca Ciega shore, Nov. 14	.025	.025	
<i>Sanibel Island—Tampa Bay series after Red Tide (With J. B. Lackey, Dept. of Sanitary Engineering, Univ. of Florida)</i>			
Peace R., Punta Gorda, Dec. 3, 1952, Temp. 23 deg. C.		.423	
Estero Lagoon Dec. 2, Temp. 21.5 deg. C.		.030	
Sanibel, Dec. 1, 1952		.025	
Sanibel, Dec. 1, 1952		.032	
Naples Harbor, centrifuged		.032	
Gulf 8 Miles off Naples entire sample		.017	
Naples Harbor, Dec. 2		.015	
Two miles west of the pass, Naples		.008	
Olga Bridge (Caloosahatchee R.), T. 24 deg. C.		.023	
Jones Res. Caloosahatchee, T. 24. deg. C.		.000	
Nokomis Bay, Venice, T. 22 deg. C.		.024	
Myakka R. 22 deg. C., Dec. 3, 1952		.069	
Caloosahatchee R. Ft. Myers Pier, T. 24 deg. C.		.073	
<i>Tampa Bay Series Sept. 27, 1952 (With Nelson Marshall, Oceanographic Institute, Fla. State Univ.)</i>			
	Depth feet	Salinity ppt	Total P ppm
On Ballast Pt. pier 300 yds. out	0	25.2	.74
McDill Field, east coast	0	25.6	.84

	Depth feet	Salinity ppt	Total P ppm
East end of longer bridge of Courtney- Campbell causeway	0	27.3	.274
St. Petersburg-Tampa causeway, west end of Gandy bridge	0	27.7	.250
St. Petersburg, S of Papys Bayou about 54th St.	0	28.4	.33
End of St. Petersburg pier	0	28.9	.285
50 yds. out from Bee line Ferry dock	0	30.0	.290
Buoy 5 off Pinellas Pt. (pH 8.3)	0	30.3	.280
Buoy 1	0	30.6	-----
	10	30.6	.256
Buoy Can 3B	0	29.1	.33
	10	30.0	-----
	20	32.8	.148
Buoy 3A	0	29.4	.284
	10	29.9	-----
	20	32.0	-----
	30	33.0	.136
Buoy 2A	0	-----	.295
Buoy 14	0	-----	.163
Buoy 13	0	-----	.154
Buoy 11 at Harbor mouth	0	33.2	.130
	10	33.0	-----
	20	34.2	-----
	30	34.4	.073
Just outside harbor in Egremont Channel	0	34.0	.126
	10	34.2	-----
	20	34.2	-----
	30	34.0	.096

East Coast Marine Waters:

Indian River, Melbourne, June 23, 1952	.001
Surf, Melbourne Beach, June 23, 1952	.006
Indian River, Cocoa, June 23, 1952	.016
Sound, Bayfront Park, Miami, June 22, 1952	.189
Miami Inlet, June 22, 1952	.083
Tomaka River, July 19, 1952	.096
Matanzas R. Estuary, St. Augustine, July 19, 1952	.053
Moultrie Creek, St. Augustine, Aug. 29, 1952	.255
Indian R. at Indian R. City, July 19, 1952	.086
St. John's Estuary, Jacksonville, Aug. 10, 1952	.289
Surf, Daytona Beach, July 19, 1952	.086

Marineland Series (With Mr. Forrest G. Wood, Marineland)

Fresh Ocean Water—gallery water, Aug. 29, 1952	.023
Marineland Inlet, high tide, Aug. 29, 1952	.033
Gallery water, 2 hrs. after low tide, Sept. 14, 1952	.068
Marineland Inlet, low tide, heavy rain, Sept. 22, 1952	.054

West Coast Florida Marine Waters

Surf, Naples, June 21, 1952	.032
Naples Estuary, June 21, 1952	.000
Everglades, Florida, June 21, 1952	.100
Tampa Bay, along Rt. 541, June 19, 1952	.720
Alafia Estuary on Tampa Bay, June 19, 1952	.660
Manatee River estuary, Rt. 301, June 19, 1952	.097
Sarasota bay, City pier, Sarasota, June 20, 1952	.010
Charlotte Harbor, Punta Gorda, June 20, 1952	.307
Suwannee Estuary, August 6, 1952	.061
Cedar Key main channel, Sept. 18, 1952 (E. L. Pierce)	.011

	Total P ppm	
Cedar Key main channel, July 13, 1952 (E. L. Pierce)	.051	
Bayport Estuary, May 30, 1952, sample 1	.018	
Bayport Estuary, May 30, 1952 sample 2	.010	
Bayport Estuary, May 30, 1952 sample 3	.024	
<i>Chassahowitzka Bay series</i> (With William Jennings, Florida Game and Fresh Water Fish Commission)		
July 22, 1952 aquatic plants listed		
Bay, <i>Chara</i> flats	.014	
Mouth of Chassahowitzka, <i>Chara</i> and <i>Ruppia</i>	.025	
Dog Island, <i>Sago</i> , <i>Ruppia</i>	.032	
Alligator creek, <i>Valisneria</i>	.044	
Porpoise Bay, Mangrove Island, <i>Sago</i>	.018	
<i>Homosassa series</i> July 22, 1952 (With William Jennings, Florida Game and Fresh Water Fish Commission)		
West of town of Homosassa ¼ mile	.030	
North of town, ¼ mile	.040	
Halls river	.023	
Brices Cove west of Homosassa	.067	
II. <i>Inorganic and Total Phosphorus of Spring Waters</i> (With Office of Naval Research) (samples from springs marked by asterisk are aged samples.)		
	Inorganic P ppm	Total P ppm
Silver Springs, July 15, 1952, canal entrance	-----	.045
June 30, 1952, 3 miles down run	.057	.037
June 30, 1952, 5 miles down run	.050	.040
June 30, 1952, in littoral plants	.025	.027
Aug. 16, 1952, boil	.036	-----
Sept. 3, 1952, boil	-----	.061
Warm Salt Springs, Murdock		
June 19, 1952*	-----	.040
June 19, 1952	-----	.050
June 19, 1952	.033	-----
June 19, 1952	.013	-----
June 19, 1952	.053	-----
Alexander Springs, Astor Park		
March 8, 1952*, boil	.067	-----
March 8, 1952	.070	-----
Aug. 14, 1952, boil	.039	.068
Aug. 14, 1952, ½-mile downstream	.045	.061
Salt Springs, Marion County		
Oct. 9, 1951*	.020	-----
Oct. 9, 1951	.018	-----
Oct. 9, 1951	.005	-----
Aug. 7, 1952	-----	.027
Juniper Springs, Marion County		
Aug. 14, 1952	.013	-----
Aug. 14, 1952	.017	-----
Rock Spring, Apopka		
Dec. 27, 1951*	.140	.127
Dec. 27, 1951	.150	.120
Dec. 27, 1951	-----	.127
Sulphur Springs, Tampa		
Dec. 1, 1951*	.007	-----
Dec. 1, 1951	.017	-----
Dec. 1, 1951	.020	-----

	Inorganic P ppm	Total P ppm
Mud Spring, Welaka		
Nov. 1951*	.083	-----
Nov. 1951	.083	-----
Beecher Spring, Welaka		
Nov. 24, 1951*	.145	-----
Nov. 24, 1951*	.137	-----
June 6, 1952	.101	-----
June 6, 1952	.120	-----
Weekiwachee Springs, Hernando County		
Nov. 29, 1951*	.083	-----
Nov. 29, 1951	.073	-----
May 29, 1952	.060	-----
Wacissa Springs, Jefferson County		
August 3, 1952	-----	.033
Ichtucknee Springs, run, Rt. 27, Hildreth		
Aug. 3, 1952	-----	.072
Aug. 12, 1952	-----	.060
Rainbow Springs, Marion County		
Aug. 22, 1952	.053	-----
Wakulla Springs, Wakulla County		
Aug. 12, 1952, boil	-----	.039
Chassahowitzka Springs, Citrus County		
Aug. 23, 1952, boil (with J. H. Davis)	.013	-----
Neck below boil	.013	-----
Boil of 2nd Spring	.013	-----
Down run of 2nd Spring, ½ way	.022	-----
Mouth of second spring	.033	-----
First curve below head springs	.009	-----
Second curve	.013	-----
Boil of third spring	.019	-----
Downstream, ¼-mile	.017	-----
Downstream, 1¼ miles	.015	-----
Downstream, 1¾ miles	.018	-----
Downstream, 3 miles	.019	-----
Downstream, 4 miles	.017	-----
Downstream, 5 miles—estuarine water	.023	-----
Downstream, 6 miles—in Gulf	.023	-----
Su No Wa Springs		
Aug. 10, 1952	.013	-----
Aug. 10, 1952	.022	-----
Devils Millhopper Springs, Alachua County		
Aug. 26, 1952	.060	-----
Aug. 26, 1952	.053	-----
Aug. 26, 1952	.081	-----
Bonita Springs		
June 21, 1952 Hotel	-----	.013
Blue Springs, Orange City		
Undated	-----	.123
Manatee Springs		
Aug. 6, 1952		
Boil	.037	.028
Down run	.023	-----
Down run	.013	-----
Down run	.039	-----
Down run	.048	-----
River sink, Wakulla County		
Feb. 9, 1951	.223	-----
Feb. 9, 1951	.220	-----
Buckhorn Spring, Hillsborough County		
June 18, 1952	.140	-----

	Inorganic P ppm	Total P ppm
Crystal Springs, Pasco County		
June 18, 1952	.020	-----
Lithia Springs, Hillsborough County		
June 19, 1952	.050	-----
June 15, 1952	-----	.067
Silver Glenn Springs, Marion County		
March 22, 1952 Boil	.001	-----
August 14, 1952 Boil	.023	.042
Mouth of Run	.020	.036
Orange Springs, Marion Co., Aug. 7, 1952	-----	.095
Blue Springs, Gilchrist Co., June 9, 1952	.032	-----
Homosassa Springs, Citrus Co., May 29, 1952 Boil	.008	-----
Blue Springs, Marianna, Jackson, Co., Aug. 1, 1952		
Boil	.013	.021
Among plants	.033	-----
Downstream 100 yds.	.065	-----
Glen Julia Springs, Gadsden Co., Aug. 1, 1952		
Boil	.003	.000
Downrun 50 yds.	.011	-----
Mouth of run	.032	-----
Ponce De Leon Spring, Holmes Co., Aug. 2, 1952		
Boil	.009	.027
Start of run	.005	-----
End of run	.015	-----
Morrison Springs, Walton Co., Aug. 2, 1952	-----	.027
Blue Springs, Madison Co., Aug. 1952, (With William Beck of Florida State Board of Health)	-----	.060
Green Cove Springs, Clay Co., Night Series 9-11 p.m. Aug. 10, 1952		
Boil	.005	.006
Pool outlet	.004	.006
Rapids below falls	.005	.005
Middle bridge	.005	.006
Next curve	.005	.012
Last curve	.006	.008
Green Cove Springs Day Series		
July 16, 1952 2-4 p.m. Many people in pool at Sta. B		
Boil	.022	-----
Pool Outlet	.041	-----
Rapids below falls	.041	-----
Middle bridge	.018	-----
Next curve	.008	-----
Last curve	.005	-----

III. Total and Inorganic phosphorus in streams of the Peace River system:
(Station numbers of Florida State Board of Health) (With Ellis Landquist, Univ. of Fla., Dept of Biology)

Six mile creek south of Bartow, Station p-33,		
Aug. 8, 1952	3.86	-----
Peace creek, Ft. Meade, Station p-9, Aug. 7, 1952	4.86	-----
Bear branch, Station p-37, Bartow, pH 3.5		
Aug. 4, 1952	66.	-----
Aug. 4, 1952	96.	-----
March 2, 1952	178.	-----
Bearbranch, Bartow, Station p-35, Aug. 9, 1952	-----	25.3
Peace River, Homeland, Station p-11, Aug. 4, 1952	5.86	-----
Peace River, Bowling Green, Station p-7, Aug. 5, 1952	4.53	-----
Peace creek, Station p-16, Aug. 6, 1952	-----	.39

	Inorganic P ppm	Total P ppm
Arcadia, Station p-4, Aug. 3, 1952	5.3	-----
June 20, 1952	-----	>3.3
Peace River, Zolfo Springs, Station p-5, Aug. 3, 1952	5.3	-----
Aug. 2, 1952	5.1	-----
Peace creek, east of L. Hancock, Station p-55a, Aug. 6, 1952	-----	.186
Paines creek, below Bowling Green, Station p-18, Aug. 8, 1952	-----	.72
Charlie creek, Garderner, Station p-17, Aug. 3, 1952	-----	.83
Shell creek, Rt. 17, Cleveland, Fla. Punta Gorda, June 20, 1952	-----	2.1
Charlotte Harbor, Punta Gorda, June 20, 1952	-----	.273
Horse Creek, Arcadia, June 20, 1952	-----	.273
Peace River, Bartow, March 2, 1952	-----	>3.3
Peace creek, east of Eloise, March 2, 1952	-----	.013
Saddle creek, south of L. Hancock, March 2, 1952 (including much animal plankton)	-----	2.13
Citrus waste, canal, Snively Plant, Polk Co., March 2, 1952	-----	.007
Peace creek, outlet near Alturus, (near station p-55a) Aug. 19, 1952	-----	.085
Phosphate water, clear, Pembroke settling basin	1.00	-----
Lulu lake outlet, Eloise, (receives Winterhaven sewage, flows into Peace Cr. Aug. 15, 1952) (USGS)	-----	.49
<i>Suwannee-Santa Fe River System</i>		
(With William Beck, Florida State Board of Health)		
Carver's camp, river backwater, near mouth, Suwannee River, Aug. 7, 1952	-----	.112
Small creek, tributary of Santa Fe River, Monteocha, Alachua Co., Aug. 31, 1952	-----	.194
Santa Fe River, Rt. 234, Brooker, Bradford Co., Aug. 31, 1952	-----	.180
Creek, tributary of Santa Fe River, Graham, Bradford Co., Aug. 31, 1952	-----	.205
Suwannee River at Fanning Springs, Aug. 6, 1952	-----	.060
Santa Fe River, Camp O'leno Park, Sept. 16, 1952 High water	-----	.163
Aug. 29, 1952	-----	.155
May 27, 1952	-----	.145
Santa Fe River, Rt. 441, Sept. 16, 1952	-----	.121
Santa Fe River, Ft. White, Aug. 11, 1952	-----	.075
Suwannee River, Bell, Aug. 11, 1952	-----	.080
Suwannee River, White Springs, Aug. 12, 1952	-----	.333
Suwannee River, Branford, Aug. 13, 1952	-----	.081
Suwannee River, Ellaville, Aug. 12, 1952	-----	.152
Withlacochee River, Rocky Ford, Brooks Co., Ga., Aug. 1952	-----	.253
Withlacochee River, Rt. 145, Madison Co. Fla., Aug. 1952	-----	.169
Withlacochee River, Pinetta Bridge, Madison Co., Fla., Aug. 1952	-----	.083
Withlacochee River, Blue Springs Bridge, Madison Co., Fla., Aug., 1952	-----	.193
Withlacochee River, junction with Suwannee, Aug. 1952	-----	.101

	Inorganic P ppm	Total P ppm
<i>Streams Draining into sinks, Alachua Co.</i>		
Hatchet creek, Montecoha Rd. 2.3 miles north of Waldo Gainesville road, Aug. 31, 1952	-----	.027
Hatchet creek, Rt. 24, July 17, 1952	-----	.184
Aug. 26, 1952 low water	-----	.125
Alachua sink, north edge of Paynes Prairie receives Prairie creek, Sept. 11, 1952	-----	1.0
Hatchet Creek, Rt. 26, Sept. 9, 1952	-----	.247
Camp's Canal, near Rochelle,	-----	.065
Hogtown Creek, Univ. Ave., Gainesville, Aug. 26, 1952	-----	1.4
Hogtown Creek, west branch, 16th Ave. Gainesville, Aug. 26, 1952	-----	>2.0
Hogtown Creek, east branch, 16th Ave., Gainesville, Aug. 26, 1952	-----	>1.0
Hogtown sink, receives Hogtown creek, Sept. 2, 1952	-----	>2.0
Prairie Creek, Rt. 20, east of Gainesville, Aug. 31, 1952	-----	.114
Stream draining Hammock, Southwest of Paynes Prairie, Sept. 11, 1952	-----	.087
<i>Alafia River system</i>		
Alafia estuary, June 19, 1952	-----	.660
Fishhawk creek, June 19, 1952	-----	.390
Alafia River		
Above Lithia Springs, June 19, 1952	-----	1.81
at Lithia Springs, June 19, 1952	-----	2.37
Alafia River, Riverview, June 19, 1952	-----	1.36
South branch of Alafia, Pinecrest, June 19, 1952	-----	>3.33
Alafia River, Bloomingdale-Lithia Rd., June 19, 1952	-----	1.25
<i>Smaller West Coast Rivers (draining Phosphate districts)</i>		
Manatee River estuary, Rt. 301, June 19, 1952	-----	.097
Rt. 675, June 19, 1952	-----	.450
Hillsborough River, Univ. of Tampa bridge, June 18, 1952	-----	.220
Sulphur Springs, Tampa, June 18, 1952	-----	.160
Myrtle's Fish Camp, June 18, 1952	-----	.107
Hillsborough River State Park, June 18, 1952	-----	.097
Rt. 39, June 18, 1952	-----	.018
Drainage canal near Hillsborough River June 18, 1952	-----	.057
Braden River, tidal estuary, June 19, 1952	-----	.054
Myakka River		
West of Murdock, Rt. 41, June 20, 1952	-----	.067
At State Park June 20, 1952	-----	.059
Little Manatee River		
Rt. 674, June 19, 1952	-----	.400
Rt. 301, June 19, 1952	-----	.587
Anclote River, Elfers, Aug. 7, 1952	-----	.014
Brooker Creek, Mt. Odess, Aug. 9, 1952	-----	.011
Withlacoochee River		
Dunnellon, May 29, 1952	-----	.063
Rt. 33, March 2, 1952	-----	.028
Lake, Southshore, May 29, 1952	-----	.045
Fenholloway River, Aug. 3, 1952	-----	.013
Perry, July 30, 1952	-----	.070
Palatlahaha Creek, Okahumpa, Sept. 11, 1952	-----	.017

	Inorganic P ppm	Total P ppm
<i>Canals and Rivers of South Florida</i> (See figure 8) (with William Jennings, Florida Game and Fresh Water Fish Commission)		
Tamiami Canal, Ochopee, June 21, 1952	-----	.018
West of Ochopee, 10 miles, June 21, 1952	-----	.051
East of Ochopee, 7.5 miles, June 21, 1952	-----	.016
East of Ochopee, 18 miles, June 21, 1952	-----	.011
East of Ochopee, 30 miles, June 21, 1952	-----	.057
East of Dade County line, 2 miles, June 21, 1952	-----	.073
East of Ochopee, 40 miles, June 21, 1952	-----	.087
Collier-Seminole State Park, June 21, 1952	-----	.050
At Rt. 27	-----	.013
At Coral Gables canal, June 22, 1952	-----	.006
Coral Gables Canal, pool, Univ. of Miami Service Center, June 22, 1952	-----	.157
Miami Canal		
At 26th Street, Miami, June 22, 1952	-----	.073
At 37th St., Miami, June 22, 1952	-----	.007
Eighteen miles north of Miami, June 22, 1952	-----	.007
Rt. 29 canal running north from Everglades, Fla. estuarine for first 6 miles, June 21, 1952		
At Everglades	-----	.100
North of Everglades, 1 mile	-----	.008
North of Everglades, 2 miles	-----	.063
North of Everglades, 4 miles	-----	.018
North of Everglades, 6 miles	-----	.010
North of Everglades, 9 miles	-----	.007
North of Everglades, 12 miles	-----	.007
Hillsboro Canal		
Deerfield, June 17, 1952	-----	.016
Belle Glade, June 22, 1952	-----	.017
Deerfield Beach, Aug. 22, 1952	-----	.048
St. Lucie Canal, Port Mayaca, June 18, 1952	-----	.097
South New River Canal, Rt. 27, June 22, 1952	-----	.003
North New River Canal		
Rt. 27, June 22, 1952	-----	.015
North of Miami, 45 miles, June 22, 1952	-----	.079
At Bolles Canal, Okeelanta, June 22, 1952	-----	.028
Lake Okeechobee		
Bean City, south dike canal, June 22, 1952	-----	.003
Clewiston, June 22, 1952	-----	.007
Near mouth of Taylor Creek, north shore, June 22, 1952	-----	.030
Caloosahatchee River		
Moorehaven, June 22, 1952	-----	.010
Olga, June 20, 1952	-----	.012
Olga, Dec. 2, 1952 (J. B. Lackey)	-----	.023
Ft. Myers, June 20, 1952	-----	.022
Ft. Myers, Dec. 2, 1952 (J. B. Lackey)	-----	.073
West Palm Beach Canal, West Palm Beach, Aug. 22, 1952	-----	.125
Fisheating Creek, Rt. 78, June 22, 1952	-----	.031
Indian Prairie Canal, Rt. 78, June 22, 1952	-----	.121
Kissimmee River		
Rt. 78, June 22, 1952	-----	.012
Below Kissimmee, Aug. 19, 1952	-----	.060
Ft. Bassinger, June 16, 1952	-----	.002
Taylor Creek, mouth at Lake Okeechobee, June 22, 1952	-----	.057
Imperial River, Bonita Springs, June 20, 1952	-----	.055
Estero River, Rt. 41, Estero, June 21, 1952	-----	.037
Josephine Creek, De Soto City, Aug. 19, 1952	-----	.043

	Inorganic P ppm	Total P ppm
Small Creek, Rt. 441, Osceola-Okeechobee County Line, June 23, 1952	-----	.007
Small Creek, Rt. 441, 6 miles north of Yehaw Junction, June 23, 1952	-----	.003
<i>Streams of West and Northeast Florida</i>		
<i>Apalachicola River</i>		
Chattahoochee, Aug. 26, 1952 (USGS)	-----	.200
Chattahoochee, Aug. 3, 1952	-----	.041
Perdido River, Barrineau Park, Aug. 23, 1952 (USGS)	-----	.021
Escambia River, Century, Aug. 23, 1952 (USGS)	-----	.033
Chipola River, Altha, Aug. 11, 1952	-----	.025
Aug. 1, 1952	-----	.030
Coldwater Creek, Milton, Aug. 24, 1952 (USGS)	-----	.005
Ochlockonee River, Bloxham, Aug. 11, 1952 (USGS)	-----	.687
Aug. 1, 1952	-----	.072
Choctawhatchee River, Caryville, Aug. 2, 1952	-----	.033
Aug. 26, 1952 (USGS)	-----	.047
St. Mary's River, Macclenny, Sept. 16, 1952 (USGS)	-----	.033
Nassau River, Rt. 1, Aug. 10, 1952	-----	.020
<i>Oklawaha River System</i>		
Above Silver River, Aug. 9, 1952	.003	.041
Rt. 40, Aug. 1952	-----	.043
Eureka, Aug. 7, 1952	-----	.040
Eureka, 1952	-----	.051
Moss Bluff, Aug. 18, 1952	-----	.027
Orange Springs, Aug. 20, 1952	-----	.050
Lake Griffin (headwater of Oklawaha, receives sewage), June 23, 1952	-----	.152
Orange Lake Outlet, Citra, July 22, 1952	-----	.141
Lochloosa Lake outlet, Lochloosa, July 22, 1942	-----	
Lochloosa Creek, Grove Park,	-----	.453
Orange Creek, Aug. 20, 1952	-----	.127
Creek near Mud lake, Aug. 7, 1952	-----	.033
Haines Creek, Lisbon, Aug. 18, 1952	-----	.027
<i>St. John's River System (see figure 9)</i>		
Lake George, at Silver Glen Springs, Aug. 14, 1952	-----	.044
St. John's River, Green Cove Springs, July 16, 1952	-----	.119
Doctor's Lake, Rt. 17, Aug. 9, 1952	-----	.065
Ortega River, Rt. 21, Aug. 9, 1952	-----	.044
Black creek, Rt. 17, Aug. 9, 1952	-----	.040
Trout creek, Dinsmore, Rt. 1, Aug. 19, 1952	-----	.121
St. Johns River, Crows Bluff, Volusia Co., (K. Strawn) Sept. 3, 1952	-----	.117
St. Johns River, Rt. 192, June 23, 1952	-----	.007
St. Johns River, Rt. 50, June 23, 1952	-----	.015
St. Johns River (Palatka), July 19, 1952	.015	.061
Econlockhatchee River, Rt. 419, Oviedo, June 23, 1952	3.1	-----
Chulota (USGS), July 29, 1952	-----	2.67

	Inorganic P ppm	Total P ppm
Lake Jessup, June 23, 1952	-----	.188
Lake Monroe, Sanford, June 23, 1952	-----	.180
Wekiva River, Rt. 46, June 23, 1952	-----	.088
Creek, north shore of Crescent Lake, Andalusia, July 19, 1952	-----	.034
Lake Washington, marshes, August, (W. Jennings)	-----	.008
Creek, Hastings, Rt. 207, July 14, 1952	-----	.540
Crescent Lake, Andalusia, July 19, 1952	-----	.033
Clarke creek, south of Green Cove Springs, Aug. 9, 1952	-----	.080
IV. <i>Lakes, ponds, sinks</i> (Some data on lakes in appendix sections on Oklawaha and St. Johns rivers)		
<i>Sinks</i>		
Green sink, Univ. of Fla., Gainesville, Aug. 31, 1952	1.01	-----
Dairy sink, Univ. of Fla., Gainesville, Aug. 31, 1952	-----	.129
Sink, Administration Building, Univ. of Fla., Gainesville, Aug. 31, 1952	-----	.120
<i>Lakes</i>		
Lake Alice, Gainesville, (fertilized surrounding fields, Heron rookery) July 16, 1952 (D. Karraker)	.550	.660
July 16, 1952 (D. Karraker)	.530	.631
Lake Santa Fe, July 13, 1952	.015	.044
Lake Geneva, Keystone Heights, July 16, 1952	-----	.013
Brooklyn Lake, Keystone Heights, July 16, 1952	-----	.005
Kingsley Lake, July 16, 1952	-----	.015
Hampton Lake, Bradford Co., Aug. 31, 1952	-----	.025
Newnan's Lake, Gainesville, Aug. 31, 1952	-----	.119
West edge	-----	.117
Outlet	-----	.081
May 16, 1952	-----	.506
Lake Kanapaha, Gainesville, Aug. 31, 1952	-----	.055
East Tohopekaliga Lake outlet, St. Cloud, Aug. 21, 1952 (USGS)	-----	.042
Tohopekaliga Lake Outlet, St. Cloud, Aug. 21, 1952 (USGS)	-----	.067
Lake Rochelle, town of Lake Alfred, March 2, 1952	-----	.000
Johnson Lake, Clay Co., June, 1952 (M. Westfall)	-----	.000
Pebble Lake, Putnam Co., June, 1952 (M. Westfall)	-----	.027
Lake Ola, Mt. Dora, June 20, 1952 (W. Jennings)	-----	.002
Spring Lake, Winterhaven, Fla., March 2, 1952	-----	.027
Lake Dora, Mt. Dora, June 20, 1952 (W. Jennings)	-----	.000
Lake Weir, Oklawaha, June 20, 1952 (W. Jennings)	-----	.007
Lake Okeechobee, Clewiston, June 22, 1952	-----	.030
North shore, June 22, 1952	-----	.233
Bivin's Arms, Gainesville, July 11, 1952	.070	.100
Unfiltered	-----	.008
Filtered	-----	.000
Lake Eustis, Tavares, June 23, 1952	-----	.061
Clubhouse Lake, 7 miles east of Keystone Heights, June 15, 1952 (H. Hansen)	-----	.033
Reedy Lake, outlet, Frostproof, Aug. 19, 1952 (USGS)	-----	
Istokpoga Lake, outlet canal, Cornwell, Aug. 19, 1952 (USGS)	-----	

	Inorganic P ppm	Total P ppm
Red Water Lake, 6 miles southeast of Hawthorne, Sept. 10, 1952 (H. Hansen)	-----	.197
Johnson Lake, 4 miles north of Gainesville, Sept. 8, 1952	-----	.039
Hanna Lake, outlet, Lutz, Aug. 8, 1952 (USGS)	-----	.061
Hutchins Lake, outlet, Lutz, Aug. 8, 1952 (USGS)	-----	.016
Lake Wauberg, Gainesville, July 6, 1952	-----	.087
July 25, 1952	-----	.091
June 27, 1952	-----	.127
Lake Winnemisset, DeLand, Aug. 29, 1952	-----	.024

Small Ponds, Pools, Marshes

Flatwoods pond, roadside ditch connection, Alachua Co., 4.2 miles north of Rt. 24 on Monteocha road, Aug. 31, 1952	-----	.072
Pool, marshy margins of Lake Kerr, north shore, Marion Co., Aug. 7, 1952	-----	.000
Swampy tributary in Suwannee floodplain, Carver's camp, 10 miles south of Oldtown, Aug. 6, 1952	-----	.112
Pond in Hammock, Duckweed covered, Rt. 329, 4 miles south of Rt. 235, 3 miles east of La Crosse, Alachua Co., Aug. 31, 1952	-----	.190
Flatwoods pond, Rt. 301, 1 mile north of Orange Heights, Alachua Co., Aug. 31, 1952	-----	.030
Boat basin, near mouth of Silver Springs, Creek, sluggish meander in cypress swamp, Rt. 52, San Antonio, June 18, 1952	-----	.035
Pond, sandy dunes, maidencane, in scrub area, Rt. 19, north of Weekiwachee Springs, Hernando Co., May 30, 1952	-----	.004
Pond, sand dunes, maidencane, in scrub area, Rt. 19, Weekiwachee Springs, Hernando Co., May 30, 1952	-----	.001
Pond, sand dunes, maidencane, in scrub area, Rt. 19, north of Weekiwachee Springs, Hernando Co., May 30, 1952	-----	.004
Marsh water, seepage from Fowlers Prarie, Rt. 20, Putnam Co., June 9, 1952	-----	.008
Flatwoods pond, ¼-½ mile south of Devils Millhopper, Alachua Co., Sept. 11, 1952	-----	.260
Edgar Clay Pits, Edgar, Putnam Co., 25 miles east of Gainesville, Sept. 10, 1952	-----	.070
Pond, 7/10 miles south of Wachoota, Alachua Co., Sept. 11, 1952	-----	.027
Slough between Kanapaha Prarie and Levy Lake, Alachua Co., Sept. 11, 1952	-----	1.0
Pond, hyacinth filled, along road, 12.2 miles south of Wachoota, Alachua Co., Sept. 11, 1952	-----	.017
Flatwoods pond, along road, 11.3 miles south of Wachoota, Alachua Co., Sept. 11, 1952	-----	.077
Watermelon pond, Archer, July 30, 1952	-----	.433
Pond, watershed, just north of Watermelon Pond, Archer, July 30, 1952	-----	.044
Cummer Limestone Co. Quarry, Ocala, Aug. 18, 1952	-----	.136
Tsala Apcpka Lake, pond-like coves, Rt. 200, June 18, 1952	-----	.353
Tsala Apopka Lake, small stream draining margins, Rt. 200, June 18, 1952	-----	.013
Pond, Marion Co., 1½ miles east of Rt. 42 and Rt. 450, Aug. 30, 1952	-----	.027
	-----	.121

Part II

**PETROLOGY OF EOCENE LIMESTONES IN AND
AROUND THE CITRUS-LEVY COUNTY AREA, FLORIDA**

By

Alfred George Fischer

University of Kansas, Lawrence, Kansas

May 21, 1949

Report to the Florida Geological Survey

TABLE OF CONTENTS

	Page
The Nature of the Problem	43
Location of samples	43
Acknowledgments	43
Methods of Study	45
Examination under binocular microscope	45
Insoluble residues	46
Thin-sections	48
Data Obtained	48
Data derived from microscopic study of hand specimens	48
True limestones	48
Composition	48
Non-carbonate constituents	52
Porosity	52
Sedimentary structure	53
Color	53
Changes on weathering	53
Dolomitic limestones	53
Dolomite rocks	54
Composition and texture	54
Porosity	55
Sedimentary structure	56
Color	56
Compaction phenomena	57
Data derived from insoluble residues	57
Allogenic minerals	57
Clastic quartz	57
Heavy minerals	58
Clay minerals	58
Authigenic minerals	58
Pyrite	59
"Glauconite"	59
Secondary silica	60
Limonite	61
Carbonaceous matter	61
Distribution of lithologies and insoluble residues	62
Avon Park limestone	62
Moody's Branch formation (Inglis member)	63
Ocala limestone (restricted) and Williston member of Moody's Branch formation	64
Interpretation	65
Significance of data in correlation	65
Rock origin	65
Massive limestone	65
Laminated limestone	66
Dolomite rocks	66
Bibliography	69

ILLUSTRATIONS

Figure	Page
1. Index map	44
2. Eocene facies changes from Dixie County to Pasco County	46
3. Thin section of limestone	47
4. Thin section of limestone	49
5. Thin section of limestone	50
6. Thin section of dolomitic limestone	50
7. Thin section of foraminiferal limestone	51
8. Thin section of massive dolomite rock	52
9. Thin section of dolomite rock	54
10. Polished section of laminated dolomite rock	55
11. Thin section of laminated dolomite rock	56
12. Deformed internal mold of echinoid	57
13. "Glauconite"	60
14. Authigenic silica	61
15. Areal distribution of carbonate rocks	62

TABLES

Table	Page
1. Location of surface samples	45
2. Occurrence frequency of minerals in subsurface samples	59
3. Occurrence frequency of minerals in surface samples	59
4. Occurrence frequency of minerals in Avon Park limestone	63
5. Occurrence frequency of minerals in the Inglis member, Moodys Branch formation	63
6. Occurrence frequency of minerals in Ocala limestone (restricted) and Williston member of Moodys Branch formation	64

PETROLOGY OF EOCENE LIMESTONES IN THE CITRUS- LEVY COUNTY AREA

Alfred by

George Fischer

THE NATURE OF THE PROBLEM

The Eocene sediments of the Florida peninsula consist of relatively pure carbonate rocks composed largely of the minerals calcite and dolomite. As part of a study of the stratigraphy of Citrus and Levy counties (see Vernon, 1947, 1951) the Florida Geological Survey sponsored a research project on the petrology of the Eocene limestones which are there exposed. The aim of this project was twofold, namely to provide data which might supplement faunal studies in developing a detailed stratigraphic zonation, and to clarify questions of rock origin, dealing with the original deposition of the rocks and with the changes subsequently wrought in them.

In order to gain regional perspective and to test the application of petrographic methods to these rocks over considerable distances, the study was not restricted to the Citrus-Levy County area, but was extended into Dixie County to the northwest, and into Hernando and Pasco counties to the south (Fig. 1). The section studied includes the upper portion of the Avon Park limestone, the Inglis member of the Moodys Branch formation, and the Ocala limestone (restricted) (Fig. 2), with which were included beds now classified as the Williston member of the Moodys Branch formation.

Location of Samples

Of the 299 samples studied, 32 subsurface cores are from Dixie County, 87 cores and 118 surface samples from Levy County, and 62 cores from the Hernando-Pasco County area. The majority of the subsurface samples are from core borings on file at the Florida Geological Survey office. The locations of core holes are shown in Table 1.

Acknowledgments

The work was carried out partly at the offices of the Florida Geological Survey, partly at the Department of Geology, Columbia

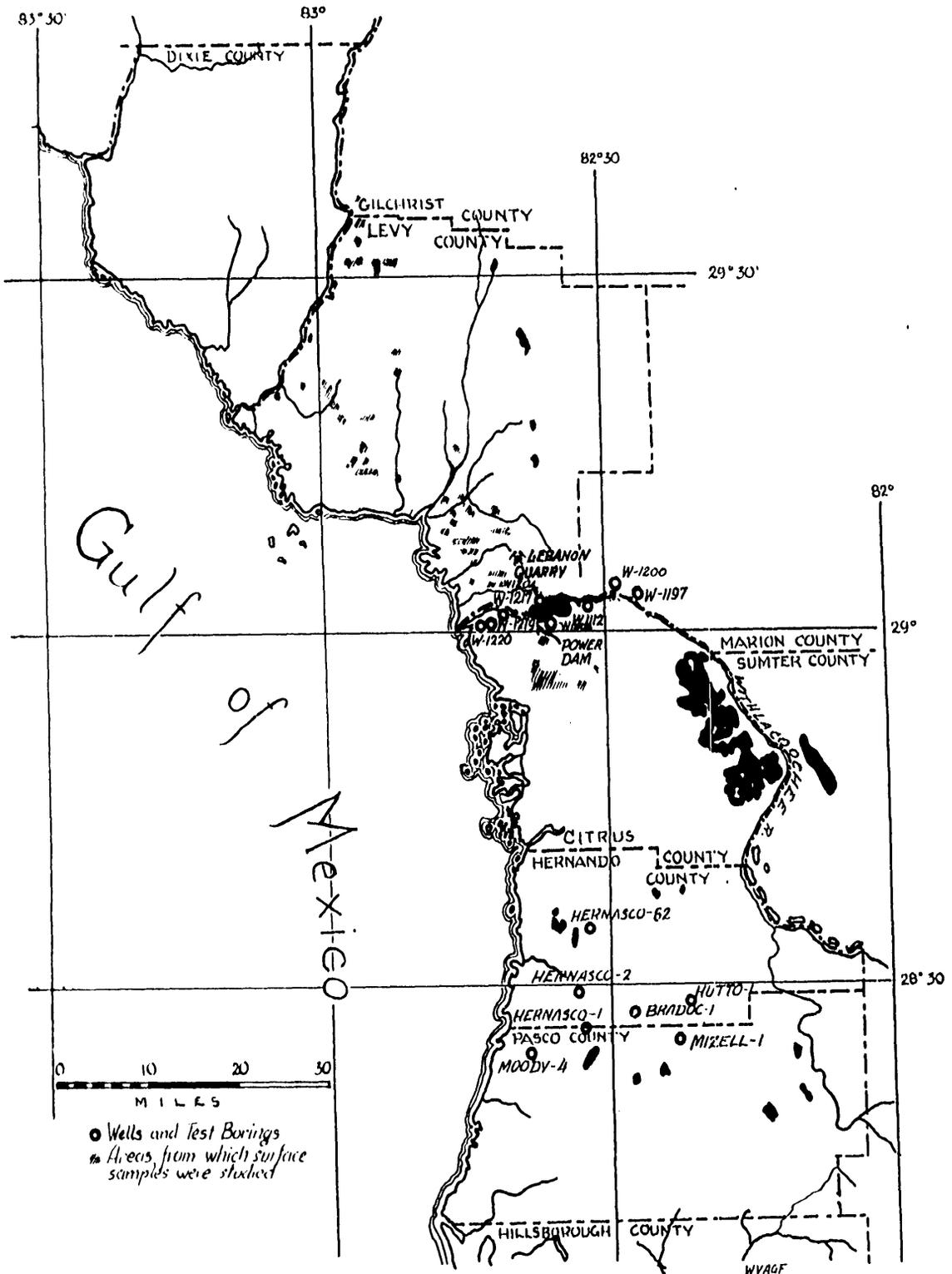


Figure 1.—Index map, showing location of wells and surface exposures studied in Levy, Citrus, Marion, Hernando, and Pasco Counties.

University, and partly at the Department of Geology and Geography of the University of Rochester. The samples from the Hernando-Pasco County area were made available by the Ohio Oil Company.

The study was supervised by Professor Marshall Kay, to whom the writer is deeply grateful for stimulation, help and advice. Spe-

TABLE 1.

LOCATION OF SUB-SURFACE SAMPLES

A. Levy-Citrus County area

Fla. Geol. Survey No.		Location
W-1112	(natural "well")	Sec. 6, T. 17 S., R. 18 E.
W-1197		Sec. 36, T. 17 S., R. 18 E.
W-1200	United States Army	Sec. 34, T. 16 S., R. 18 E.
W-1203	Engineers test borings	Sec. 4, T. 17 S., R. 17 E.
W-1204	for Trans-Florida	Sec. 5, T. 17 S., R. 17 E.
W-1217	Barge Canal	Sec. 10, T. 17 S., R. 16 E.
W-1219		Sec. 17, T. 17 S., R. 16 E.
W-1220		Sec. 18, T. 17 S., R. 16 E.

B. Hernando-Pasco County area

Fla. Geol. Survey No.		Location
W-1538	Ohio Oil Co. Mizell No. 1	NW $\frac{1}{4}$ Sec. 11, T.24S., R.19E.
W-1539	Ohio Oil Co. Moody No. 4	SW $\frac{1}{4}$ Sec. 18, T.24S., R.17E.
W-1540	Ohio Oil Co. Bradac No. 1	SW $\frac{1}{4}$ Sec. 25, T.23S., R.18E.
W-1541	Ohio Oil Co. Hernasco No. 62	SE cor. Sec. 18, T.22S., R.18E.
W-1542	Ohio Oil Co. Hernasco No. 2D	SW cor. Sec. 13, T.23S., R.17E.
W-1543	Ohio Oil Co. Hernasco No. 2A	SW cor. Sec. 13, T.23S., R.17E.
W-1544	Ohio Oil Co. Hutto No. 1	NE $\frac{1}{4}$ Sec. 24, T.24S., R.19E.
W-1545	Ohio Oil Co. Hernasco No. 1	NW cor. Sec. 6, T.24S., R.18E.

cial thanks are due to Dr. Herman Gunter and Dr. Robert O. Vernon of the Florida Geological Survey for their help during the study and in the preparation of the report; to Professor Paul Kerr and his staff for aid in the mineral identification, and to Professor Harold Alling for help in the analysis of thin-sections, in the interpretation of data, and in the preparation of the manuscript. Among the various geologists from whom the writer has received aid are Dr. W. H. Twenhofel, Mr. and Mrs. Paul L. Applin, Mr. David B. Ericson, Dr. C. Wythe Cooke, Mr. Joseph Banks, Dr. Louise Jordan, Mr. H. Glen Walter, Dr. Hans Naegeli, and Mr. J. Clarence Simpson (deceased March 29, 1952). To all of these he expresses sincere thanks.

METHODS OF STUDY

Each sample was described under the binocular microscope and analyzed for insoluble residues. In addition, some samples were studied in thin-section.

Examination under Binocular Microscope

Examination at magnifications of 15 to 30 diameters served to place the rock into one of the major categories of rock types represented—as being composed of calcite, dolomite, or a mixture

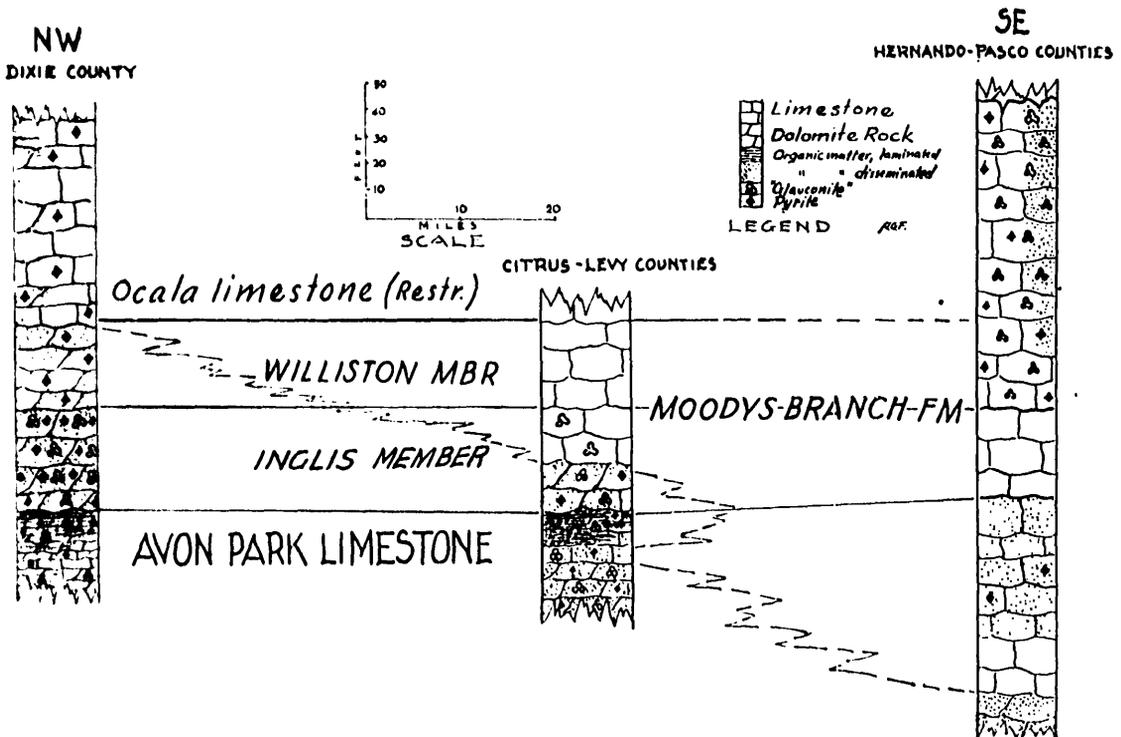


Figure 2.—Eocene facies changes from Dixie County to Pasco County.

thereof, and as being laminated or massive. Notes were made on color, texture, fossil content, and the presence of notable amounts of non-carbonate material. Confirmatory tests for calcite and dolomite were made with dilute hydrochloric acid, and in a few cases with Lemberg's silver nitrate-potassium chromate staining method (Krumbein and Pettijohn, 1930).

Insoluble Residues

From cores and hand-specimens, samples of 20 to 30 grams were prepared for insoluble residue study. In the case of cores, a separate sample was prepared for each lithologic unit, and in cases of uniform lithology a sample was prepared for every five feet wherever possible. An attempt was made to obtain a composite sample of several chips from various parts of the interval sampled.

The sample was weighed to an accuracy of one gram, and was then digested with dilute hydrochloric acid in a 600 or 1000 cc beaker. After digestion the relative amount and color of the fine, flocculant material (*slimes*) was noted. Slimes and solution were then decanted. The remaining *coarse residue* (silt and sand grades) was repeatedly washed, and dried on a watchglass. The residue was weighed to an accuracy of 0.01 gram, and the weight expressed as percentage of the original rock sample. Volumetric methods which have proved useful in insoluble residue studies elsewhere

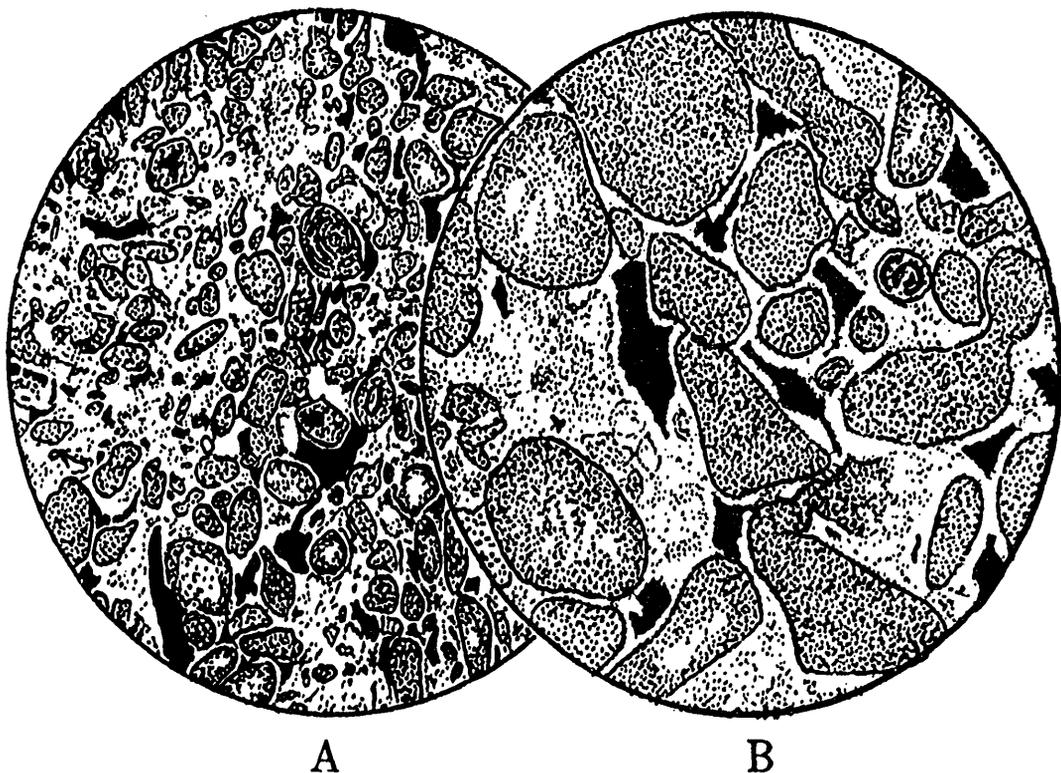


Figure 3.—Thin-section of limestone. Microcoquina of altered small Foraminifera and unidentified skeletal material (strongly stippled), bound together by chalky paste (lightly stippled), recrystallized paste (clear), and secondary calcite (clear areas surrounding pore space). Interstitial pore space shown photograph in black. A- x 13, B- x 42. Inglis member Moodys Branch formation, W-1544, 327-332 feet, Hernando County.

were not feasible, since despite the large samples used, the amount of residue was commonly microscopic, and since in numerous samples the bulk of the residue consisted of lacy or spongy masses of silica, which occupy a volumetric prominence far out of proportion to their comparative weight.

The residue was studied under the binocular microscope, at magnifications of 30 to 60 diameters. The various constituents were identified and the quantity of each constituent in terms of the entire residue was estimated by eye. In these estimates allowance was made for differences in specific gravity, so that the resulting figures could be converted into percent by weight of the original rock sample. This method is admittedly crude, but most of the constituents are present in such minute quantities (0.001 to 0.1 per cent of the rock) that small errors in estimation are not likely to change the overall aspect.

Finally the residues were filed in standard foraminiferal dry-mount slides, and in special cases grains were mounted in Canada balsam for study under the petrographic microscope.

Thin-sections

Thin-sections were prepared by the writer for representative rock-types. In order to facilitate pore-space studies, most of the rock slices were impregnated, prior to sectioning, with *bioplastic*, a synthetic polyester resin, stained with methylene orange. The thin-sections were studied under the petrographic microscope, and were quantitatively analyzed according to the Delesse-Rosiwal method, by the use of a Wentworth stage.

DATA OBTAINED*Data derived from microscopic study of hand-specimens and thin sections*

Examination of the rocks under the binocular microscope, and in thin-section under the petrographic microscope, yielded numerous data on composition. The carbonate rocks studied are complex in makeup, and are consequently subject to much variation. However, three major classes may be recognized on the basis of mineral composition: rocks composed mainly of (1) calcite (here called *limestone*), (2) calcite and dolomite (*dolomitic limestone*), and (3) dolomite (*dolomite rock*). The great bulk of rocks studied are limestones (1), and dolomite rocks (3).

Within these major classes the chief variables seen under the microscope are structure (presence or absence of lamination), texture, porosity, color, fossil content, and the amount of carbonaceous matter and other "impurities."

TRUE LIMESTONES*Composition.*

The limestones are largely composed of three calcareous constituents, *skeletal material*, *paste*, and *secondary calcite*. These occur in varying proportions.

Skeletal material. Most of the limestones studied are coquinas, or "shell sands," in the sense that they appear to be composed largely of skeletal material in the form of calcite shells, tests, and ossicles, or fragments thereof. Actually there is also generally considerable (but less apparent) paste and secondary calcite, which fills the shells and cements the skeletal material. A few samples

contained less than five per cent skeletal matter, whereas most contained between 40 and 70 per cent. It is the nature of these fossil remains which determines the texture and to some extent the porosity of the rock.

In most of the rocks studied, the greater part of the skeletal matter (up to 56 per cent of total rock volume) is of foraminiferal origin. Small

Foraminifera, especially miliolids, are most common (Figs. 3, 4, and 5), but in some cases large Foraminifera (*Amphistegina*, valvulinids, orbitoids, or camerinids) predominate (Fig. 7). In some beds echinoid remains, especially those of *Periarchus*, are quantitatively important. Skeletal elements of many other groups of organisms occur in minor quantities, generally not exceeding ten per cent of any one rock. Thus remains of red algae and green (for the most

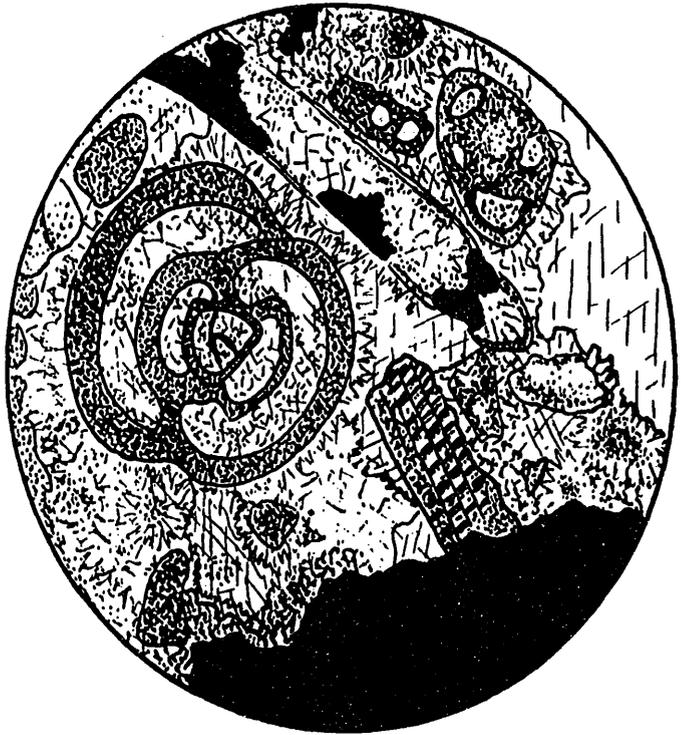


Figure 4.—Thin-section of limestone. Large miliolid Foraminifera, an echinoid fragment with typical grid-structure, and other shell fragments in matrix of medium to coarsely crystalline calcite. Porosity shown in black. X 42. Inglis member Moodys Branch formation (well bottomed in Inglis), so far as samples show.

part of the genus *Dasycladus*) algae are encountered (Fig. 5), bryozoa are widely distributed, barnacle plates and the claws of the ghost-shrimp *Callianassa* characterize certain beds, starfish ossicles are locally common, and certain pelecypods and gastropods that had shells of calcite rather than aragonite are minor rock-forming constituents. In many cases the present composition of the rock in terms of skeletal material is not a true reflection of the composition of the original sediment, as aragonitic skeletal matter, including most of the pelecypod and gastropod shells as well as the occasional remains of corals, has been removed by solution, leaving only molds. If these be taken into account, the Mollusca in some beds rivalled the Foraminifera as agents of sedimentation.

In most rocks the calcitic remains have undergone considerable

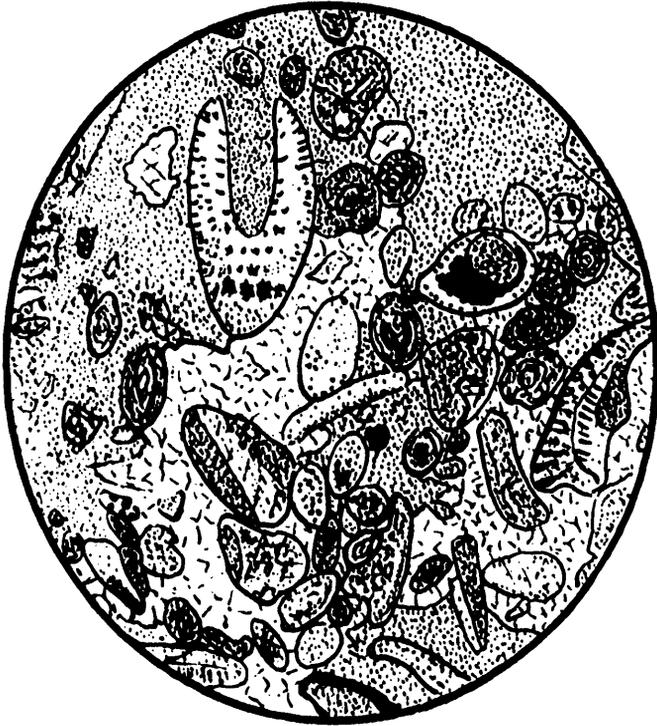


Figure 5.—Thin-section of limestone. Miliolid Foraminifera, a dasycladacean alga, and other skeletal remains embedded in dense paste; former pore-spaces filled with coarsely crystalline secondary calcite. Porosity shown in black. x8. Lower part, Inglis member Moodys Branch formation. Taken from boulders in borrow pits south of Gulf Hammock, Levy County.

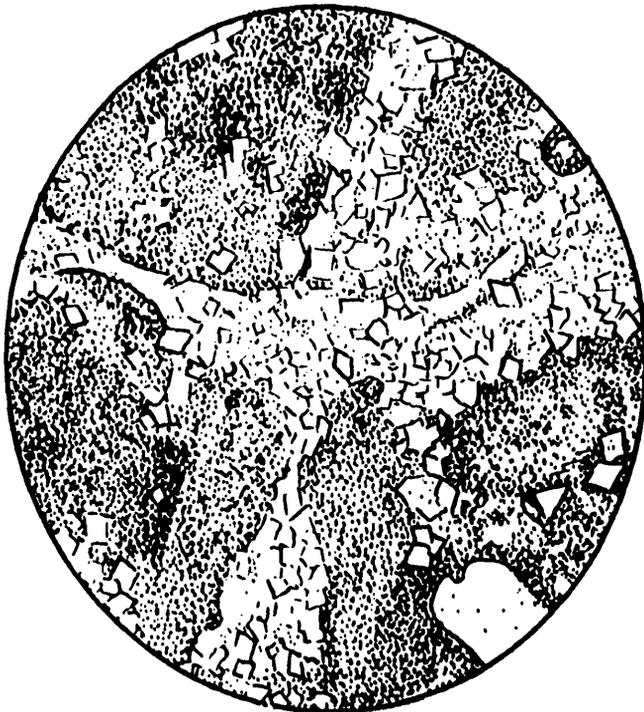


Figure 6.—Thin-section of dolomitic limestone. Chalky shell fragments (light stippling) grade into paste (heavy stippling). Clear rhombs of dolomite appear to be replacing paste and possibly filling some former voids. X 42. Ocala limestone, western Dixie County.

alteration, in some cases so much as to render them unidentifiable. The degree of alteration depends chiefly upon the composition of the original particles. Miliolids and other small Foraminifera have lost the "chitinous" organic matter, and therewith the coherence, of their tests; the latter have become chalky, and may remain distinct from the embedding matrix or may blend with it (Figs. 3, 5). Bryozoa and large Foraminifera appear to be more resistant to alteration (Fig. 7) but commonly are also soft and chalky. The calcitic remains of mollusks, algae, and echinoderms generally show little alteration, retaining their original internal structure.

Paste. Extremely fine-grained calcite, termed calcite paste, commonly makes up 20 to 50 per cent of the rock, but is less conspicuous than the skeletal material. It is generally chalky (Fig. 3), but in a few cases it is firmly consolidated (Fig. 5). While much

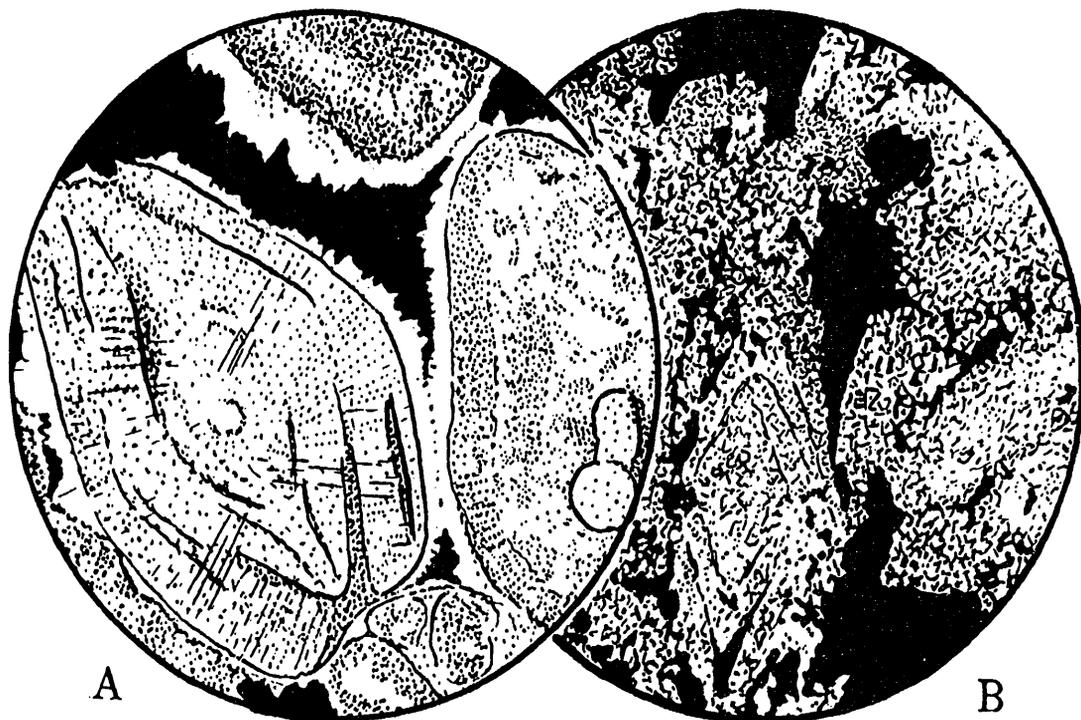


Figure 7.—A. Thin section of foraminiferal (camerininid and orbitoid) limestone, showing interstitial pore-space (black) and cementation of fossils by secondary calcite (clear). x 42. From the Ocala limestone of western Dixie County (subsurface).

B. Thin section of dolomite rock formed by replacement of foraminiferal limestone. Note crudely preserved in lower center of field. Interstitial pore space appears to have been maintained. x 13. From the Ocala limestone of western Dixie County (subsurface).

of this material is of primary origin many thin-sections show a gradation from recognizable, clearly bounded fossil shells through shells with indistinct borders into paste with phantom fossils, indicating that at least some of the paste is derived from the diagenetic break-down of skeletal material.

Secondary calcite. In rocks composed largely of skeletal matter, with open spaces between the fossils, a thin crust of calcite crystals commonly covers and cements the fossil particles (Figs. 3, 7). In some cases cavities in the rock are partly or completely filled with secondary calcite. Thus in the case of the limestone boulders of the Moodys Branch formation found south of Gulf Hammock, the molds left by aragonitic shells have been filled with coarsely crystalline calcite, producing casts of the originals.

In many cases the calcite paste grades into more coarsely crystalline material which is evidently the result of recrystallization, and in one bed (Fig. 4) the paste appears to have completely gone over into translucent, buff, coarsely crystalline calcite.

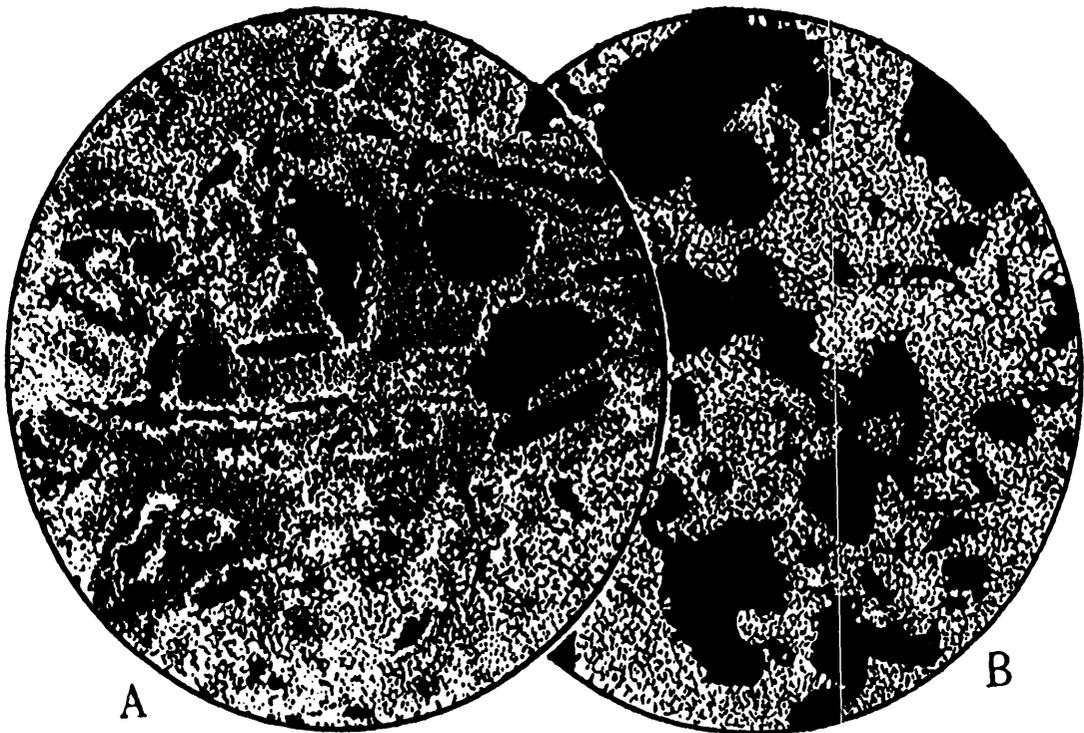


Figure 8.—Thin sections of massive dolomite rock.

A. Finely crystalline dolomite (stippled), and crude fossil molds lined with medium-crystalline dolomite. Pore-space shown in black. X 42. From a bed 5-6 feet above base of the Inglis member Moodys Branch formation, at the power dam on the Withlacoochee River, Levy County. See Vernon (1951, p. 129)

B. Medium crystalline minutely vugular dolomite rock. X 42. Sample taken two feet below the other one (A).

Non-carbonate constituents.

Many of the samples contain such small quantities of non-carbonate matter that it is not apparent under the binocular microscope and not identifiable in thin-section. Other samples are mottled with small quantities of pyrite, and many surface samples show a limonite stain. Some of the rocks contain appreciable quantities of carbonaceous matter (up to 12.4 per cent), and one of them contains 3.7 per cent clay.

Porosity.

The two main types of visible pore-space are interstitial pores between the constituent skeletal particles of coquina limestones, and secondary cavities formed by the solution of aragonitic shell-matter. In addition, there is intergranular pore-space, which is too fine to be visible in thin-section. Visible porosity measured in ten thin-sections ranges from 0 to 13 per cent, and values of 5 to 13 per cent are representative of the rock-types most commonly encountered.

Sedimentary structure.

With the exception of a single, finely laminated bed, the rocks are characterized by a conspicuous lack of sedimentary structures. There are few well-defined bedding planes, but a rude type of massive stratification is produced by vertical changes in composition and cementation. The above mentioned exception is a bed in the Avon Park limestone, exposed at the base of the Lebanon quarry, and consists chiefly of calcite paste which is laminated with thin layers of carbonaceous matter.

Color.

Most of the unweathered limestones are white to cream colored. Some show a bluish-gray mottling due to pyrite. A few limestones from the Avon Park are buff colored, probably because of finely divided organic matter.

Changes on weathering.

Weathering generally causes "case hardening" of the rocks by deposition of mineral matter at exposed surfaces. Some of the limestones are partly replaced by silica, to form after continued weathering and leaching a dull white, porous, friable mass of fine grained quartz, containing crude molds and pseudomorphs of the original calcite constituents. Weathering also commonly stains the rock with limonite.

DOLOMITIC LIMESTONES

Limestone composed of a mixture of dolomite and calcite grains are less common than nearly pure limestones or dolomite rocks, and the examples found have come from zones of vertical or horizontal transition from one rock type to the other. Thus, a fifteen-foot sequence of cores from the Avon Park limestone of Dixie County shows a white miliolid limestone at the base that is overlain by similar rock containing scattered buff dolomite rhombs in the chalky paste between the miliolids. Above this a buff, finely crystalline, friable dolomite rock which retains abundant white miliolids of chalky calcite, grades upward into similar dolomite rock from which the miliolid calcite has been removed, leaving a large amount of cellular pore space.

Another dolomitic limestone shows the calcite paste and some

of the chalky skeletal elements to be invaded and largely replaced by dolomite rhombs (Fig. 6).

DOLomite ROCKS

Composition and texture.

The dolomite rocks consist chiefly of fine (about 0.01 mm.) to medium grained (about 0.1 mm), buff colored, anhedral to rhombic crystals of dolomite. In some rocks these crystals are interlocked

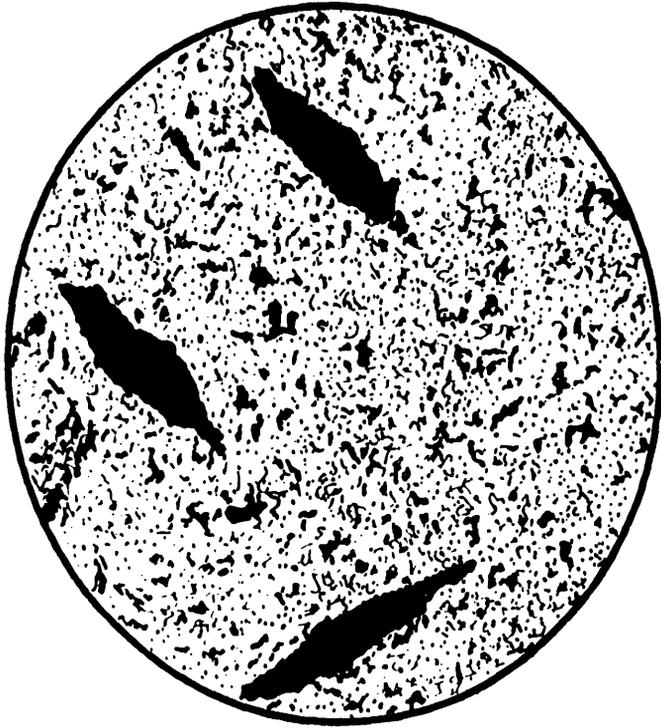


Figure 9.—Thin section of dolomite rock derived from a limestone which contained abundant camerinids. Pore-space shown in black. Dolomitization has produced a rock of tightly innerlocking, medium grained dolomite crystals with irregular intercrystalline pore-spaces, and has obliterated the character of the parent sediment except for the camerinids, which are preserved as cavities (external molds). x8. From the Ocala limestone of western Dixie County (subsurface).

to produce a very hard sedimentary "marble." In many of the finer grained rocks the crystals are merely in loose contact, and the rock is friable.

In addition to texture determined by the size of the component crystals, most of the dolomite rocks exhibit texture which is inherited from the parent sediment. This inherited texture may be positive or negative. The positive inherited texture is shown in Fig. 7-B, a case in which skeletal constituents (larger Foraminifera) have been replaced by dolomite, and the inter-

stices have remained open. The negative inherited texture is more common; in this, paste and pore-space of the original sediment have become converted to dolomite, and former skeletal material is represented by pore space (Figs. 8-9). In some cases dolomitization leaves little or no pore space, and inherited texture is obscure, represented by phantom outlines of skeletal elements which may be observed only in thin-section.

Under the binocular microscope and in thin-section many of

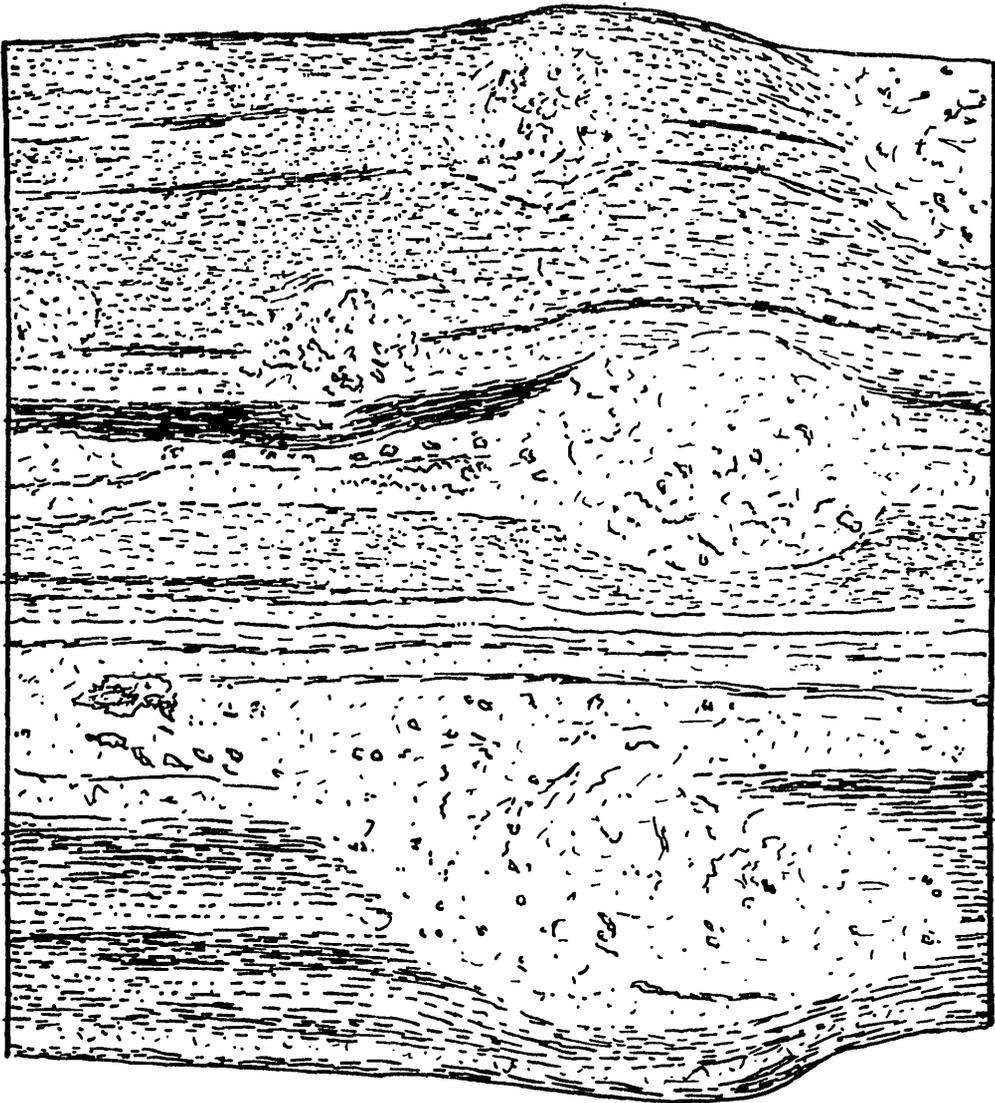


Figure 10.—Polished section of a specimen of laminated dolomite rock. Note interbedding with thin beds of “massive” types, from which burrows extend downward. X 1.6. From the Avon Park limestone at the Lebanon Quarry, Levy County, see Vernon (1951, pp. 108-110) for section.

the dolomite rocks show little in the way of impurities except for very finely divided material which clouds the sections and is commonly concentrated at crystal boundaries. Some rocks are speckled gray or black with pyrite, and others are speckled gray with minute quantities of “glaucanite.” These minerals are discussed below, under the heading of insoluble residues. Carbonaceous matter is present in small quantities in virtually all of the dolomite rocks and is sufficiently abundant in some to be apparent in hand-specimens and thin-sections. It occurs in amorphous form, or as fossil twigs and leaves of land plants.

Porosity.

In ten samples analyzed in thin-section, visible porosity ranged from 2 to 39 per cent. Porosity occurs as original interstitial

porosity inherited from the parent limestone, as fossil mold porosity, and as intercrystalline porosity (the latter commonly not visible in

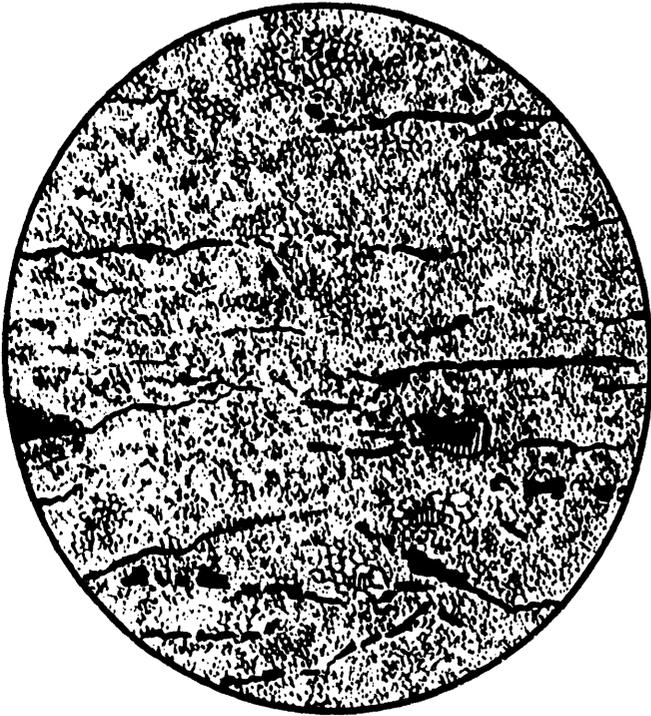


Figure 11.—Thin section of laminated dolomite rock. Note fine texture with scattered patches of medium-crystalline dolomite (cavity fillings?). Organic laminae shown in black, pore-space by parallel lines. x 100. Sample from Avon Park limestone at the Lebanon quarry, Levy County, for section see Vernon (1951, pp. 108-110).

thin-section). Fossil mold porosity is even more common in the dolomite rocks than it is in the limestones as not only aragonitic skeletal remains but also those originally composed of calcite are most commonly represented as molds in the dolomite rocks.

Sedimentary structure.

Like the limestones, the dolomite rocks occur in two facies: the massive and the laminated. The latter is not a rarity like its calcareous equivalent but occurs widely in the Avon Park limestone

(Figs. 10-11). The lamination is produced by the alternation of thin beds of dolomite crystals and carbonaceous material. The carbonate layers are from 1 to 10 or more millimeters thick, largely composed of finely crystalline dolomite (the crystals being generally less than 0.01 mm. in diameter), but containing patches of somewhat coarser crystals. The carbonaceous material occurs as discontinuous laminae which may be as closely spaced as twelve in one millimeter. Commonly these laminated beds of fine dolomite are interstratified with thin beds of medium crystalline dolomite (crystals generally ranging from 0.015 to 0.04 mm. in diameter). These medium-grained beds are devoid of organic lamination, and show much fossil porosity. They correspond to the usual massive type of dolomite rock of the type illustrated in Figure 8.

Color.

The dolomite rocks studied are universally buff to brown. Some show additional gray mottling due to pyrite, "glauconite," or both,

and many are speckled or laminated with black carbonaceous matter.

Compaction phenomena.

Whereas the limestones examined show no evidence of compaction after deposition, shells and echinoid tests in some (but not all) of the dolomite rocks are flattened parallel to the bedding. Thus abundant molds of *Cassidulus* (Fig. 12) occurring in a bed of unconsolidated, fine grained dolomite rock (Vernon, 1951, pp. 129-30, bed 4) show compaction of up to 30 per cent. The molds are marked by jagged fractures which follow the sutures of echinoid tests, indicating that the tests were collapsed as compaction occurred. The tests subsequently were removed by solution.

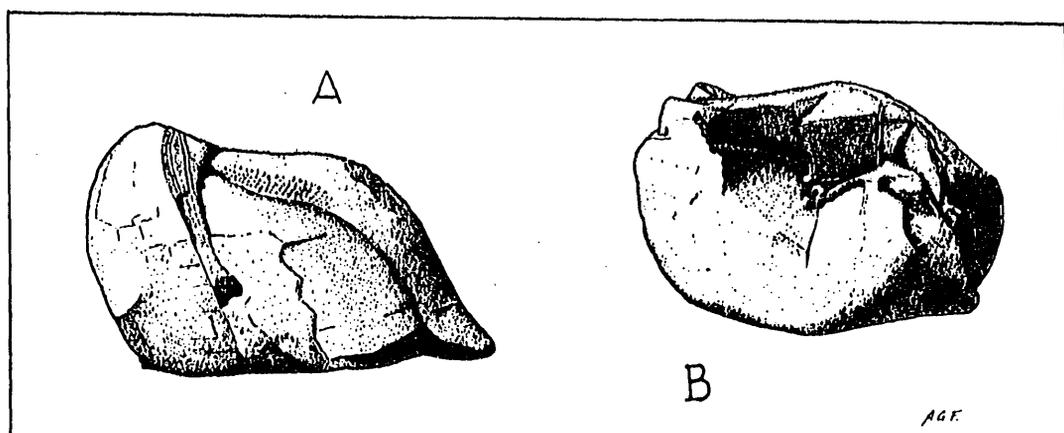


Figure 12.—Deformed internal molds of echinoids (*Cassidulus*) from dolomite rock of the Inglis member, Moodys Branch formation, at the power dam on the Withlacoochee River, Bed 4 of Locality L-138, Vernon (1951, p. 129).

Data Derived from Insoluble Residues

By dissolving and removing the carbonate portion of the rock, constituents that make up only a fraction of a per cent of the rock, and that are rarely seen in the rock itself, may be concentrated and made available for study. These constituents may be separated into three groups: (1) mineral grains derived from pre-existing rocks, generally brought from afar, termed *allogenic*; (2) minerals precipitated in place from solution, termed *authigenic*; and (3) organic (carbonaceous) material.

ALLOGENIC MINERALS

Clastic quartz.

Quartz sand and silt comprise the greater part of most residues.

Sand. Sand grains that lie free in the cavities of cores and surface samples represent contamination of the Eocene limestones from later Tertiary and Quaternary sources. Pleistocene sands lie directly on the limestone over most of the area studied, and are slowly being removed from the surface by sifting into solution channels and other pore spaces of the underlying rock. In the process of coring, some sand may have been pumped into the cores with the drilling fluid, and some sand also may have been introduced by later handling of the cores. No sand grains were seen to be firmly embedded in the rocks, hence none are believed to be original constituents of the sediments.

Silt. Some silt is probably derived from the same sources as the sand, and represents contamination. Thin-sections and analyses of tight, uncontaminated rocks indicate that there are also small quantities (fractions of one per cent) of quartz silt which are original constituents of the sediments.

Heavy Minerals.

Ilmenite, zircon, garnet, and other "heavy minerals" accompany the quartz sand and silt in variable proportions. As in the case of the quartz, the majority of these grains represent contamination from younger, overlying sediments, though it is likely that among the silt-sized particles there are some which represent original constituents of the Eocene rocks.

Clay Minerals.

All of the rocks studied contain insoluble matter in the size-range of clay; some of this probably consists of true clay minerals. In most cases this material comprises less than one per cent of the rock, though the laminated limestone bed and the clayey limestone bed of the Avon Park limestone in the Lebanon quarry (see Vernon, 1951, pp. 108-109) yielded 7.4 and 3.7 per cent of incombustible clay-size material respectively. Occasional flakes of clay in the coarse residues are due to contamination from Miocene and Pliocene (?) sediments that probably covered the entire area, and that have been removed except for thin remnants.

AUTHIGENIC MINERALS

In addition to the authigenic grains of calcite and dolomite that compose the bulk of the rocks studied, and that have been discussed above, minor quantities of other authigenic minerals are found

in the insoluble residues. The authigenic minerals may be divided into those formed before burial, called *syngenetic*, and those formed after burial, called *epigenetic*. Both types are represented.

Pyrite.

Forty-nine per cent of the subsurface samples and three per cent of the surface samples studied contained pyrite. This is generally finely crystalline, and may occur either in scattered crystals or in spongy aggregates of greenish gray or dull brassy appearance. Small euhedra of pyrite are commonly seen in pellets of "glauconite." While most of the pyrite aggregates are irregular, some represent internal molds of Foraminifera, especially of miliolids. As little as 0.01 per cent pyrite may impart a gray mottling to the rock. The discrepancy in the occurrence frequency of pyrite in surface and subsurface samples (tables 2-3) is due to the alteration of pyrite to limonite in the oxidizing environment at the surface.

TABLE 2.

OCCURRENCE FREQUENCY OF PYRITE, "GLAUCONITE," AND CARBONACEOUS MATTER IN SUBSURFACE SAMPLES
(Figures indicate the percentage of limestone and dolomite rock samples in which the constituent was found.)

	Limestones (113 samples)	Dolomite rocks (70 samples)
Pyrite	38	70
"Glauconite"	22	41
Carbonaceous matter	62	97
None of these three constituents	29	0

TABLE 3

OCCURRENCE FREQUENCY OF PYRITE, "GLAUCONITE," AND CARBONACEOUS MATTER IN SURFACE SAMPLES

	Limestones	Dolomite rocks
Pyrite	2	4
"Glauconite"	26	42
Carbonaceous matter	4	88
None of these constituents	70	8

"Glauconite."

Among the most conspicuous elements of the coarse residues, though rarely present in amounts exceeding a fraction of one per cent, is a soft, slightly translucent, clay-like substance. Many of the grains are internal molds of foraminiferal tests (Fig. 13), and



Figure 13.—“Glauconite,” internal molds of foraminiferal chambers, $\times 30$. Moodys Branch formation, Dixie County.

some have been observed in the interior of echinoids (*Peronella*). The color varies from sea-green and grass green to white and brown; intermediate shades of olive green and olive gray are most common. The occurrence of this mineral or group of minerals suggests glauconite, as does the green color of some samples. The optical properties could not be studied in detail because of the extremely small size of the crystal units which compose the grains. Some of the grains appeared optically isotropic (perhaps because of crypto-crystalline structure) whereas others showed some birefringence. The refractive indices of the grains diverged in some cases widely from those reported for glauconite. The latter shows a variation of n_{α} from 1.590 to 1.612, of n_{β} from 1.609 to 1.643 and of n_{γ} from 1.610 to 1.644. The highest indices observed in the insoluble residues were 1.590, and the pale grains showed indices below that of balsam (1.537). Thus both true glauconite and the “glauconite” of the residues studied show a wide range in refractive index, but the range of the latter lies entirely below that of the former. That this discrepancy may be partly due to changes caused by the hydrochloric acid used in the preparation of the residues is attested by the fact that “glauconite” grains which were not treated with acid (seen in thin-sections of the rocks) all showed indices higher than that of balsam (1.537).

Attempts to obtain an x-ray diffraction pattern failed, the pattern showing only pyrite and quartz which were also present in the sample. Not enough material could be obtained to run either a thermal diffraction analysis or a chemical analysis. Although the material has not been positively identified as glauconite, its affinities to that mineral have not been disproved. In general habit it resembles glauconite more than any other mineral described, and is therefore here referred to as “glauconite.” Its occurrence frequency is shown on tables 2 and 3.

Secondary Silica.

Secondary silica is widely distributed in the coarse residues, and is occasionally seen in thin-sections. It takes the form of white spongy, lacy masses (Fig. 14) consisting of variable proportions of chalcedony and quartz. In some cases the quartz predominates and forms more massive subhedral drusy aggregates while in other

cases miliolids, echinoid fragments and other rock constituents have been crudely replaced. The distribution of authigenic silica does not appear to be correlated with either stratigraphic horizons or the occurrence of other residues.

Limonite.

In the subsurface, limonite is absent, or present in very small quantities. Most of the samples that contained little or no carbonaceous matter yielded slimes colored various shades of ochreous yellow and orange brown, by traces of limonite. Many of the rocks on the surface are stained with larger quantities of this material, derived from the weathering of pyrite or introduced from overlying deposits.



Figure 14.—Authigenic silica, x 10. Avon Park limestone, W-1197, 135.1-144.3 feet. Marion County.

CARBONACEOUS MATTER.

Some of the samples examined contain large quantities of carbonaceous matter, up to 12.4 per cent of the entire rock (laminated limestone from the Lebanon Quarry). Insoluble residues show the presence of small quantities of organic (carbonaceous) matter in many rocks in which it is not apparent in hand specimen or thin-section. Virtually all of the dolomite rocks and half of the limestones studied contained some carbonaceous material, of which the following types were recognized:

(1) Very finely divided matter, which slowly settles out of suspension, has a greasy feel, and is highly adhesive. (2) Shreds or irregular filamentous aggregates, visible at magnifications above 100 diameters. (3) Massive brown consolidated aggregates in which no structure is visible. (4) Plant tissues in various stages of preservation, some showing cellular structure: fragments of leaves and stems of land plants and sea weeds. (5) Pollen grains of various types. (6) Tiny, clear, spheroidal bodies that are insoluble in alcohol, ether, or butyl acetate, and take a deep brownish red stain when treated with iodine in a medium of hydrochloric acid. (7) Organic matter from the tests of invertebrate animals, such as chitinous linings of foraminiferal tests (obtained in acetic acid preparations from the laminated limestone of the Lebanon quarry).

Distribution of lithologies and insoluble residues

The distribution of limestones and dolomite rock is essentially independent of the formation boundaries drawn on faunal and minor lithologic changes (Figs. 2-15). Other characters of the carbonates

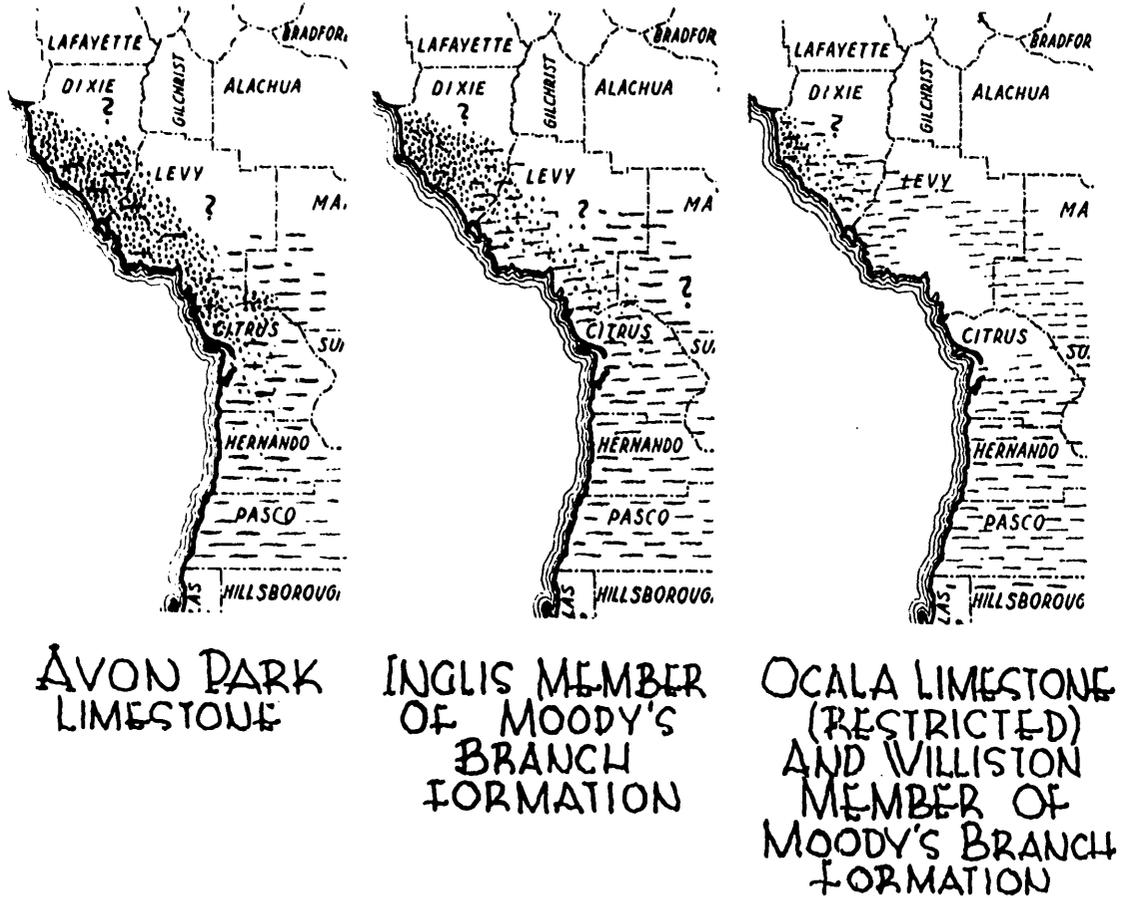


Figure 15.—The areal distribution of limestone and dolomite rocks of the three stratigraphic units. Dashed areas are limestone, stippled areas, dolomite rock. Due to scarcity of available geologic sections the boundaries of the facies are conjectural.

such as lamination and faunal composition appear to be more nearly related to time lines. The distribution of allogenic minerals could not be determined because of excessive contamination from younger beds. Authigenic insoluble residues and organic matter are more closely correlated with the type of carbonate (calcite or dolomite) than with position in the stratigraphic column.

AVON PARK LIMESTONE

The upper portion of the Avon Park limestone is represented by dolomite rock with some interbedded limestone in Dixie, Levy, and Citrus counties, and by limestone in the Pasco-Hernando County area. The rocks are partly massive, partly laminated. The laminated facies occurs near the top of the formation in Dixie, Levy and

Citrus counties but has not been recognized in the Moodys Branch formation or the Ocala limestone. The distribution of authigenic constituents is shown in Table 4.

TABLE 4
OCCURRENCE FREQUENCY OF RESIDUES IN AVON PARK
LIMESTONE
(For explanation, see Table 2, p. 59)

	Percentage of limestones (27 samples)	Percentage of dolomite rocks (36 samples)
Pyrite	59	83
"Glauconite"	22	42
Carbonaceous matter	89	95
None of these constituents	0	0

Organic matter is more widespread and occurs in greater quantities in the Avon Park limestone than in either the Moodys Branch formation or the Ocala limestone, and is present not only in disseminated form, but also as fossil leaves and twigs. The massive limestones of the Avon Park contain abundant miliolids, some of which reach larger size than those of the overlying formations. Among the larger Foraminifera, valvulinids are prominent.

INGLIS MEMBER OF MOODYS BRANCH FORMATION

In western Dixie County the Inglis member of the Moodys Branch formation is entirely represented by gray, mottled ("glauconitic" and pyritic), slightly carbonaceous, hard dolomite rock. In central and eastern Dixie County the upper portion is a massive miliolid limestone. Over much of Levy County the lithology is limestone, with traces of "glauconite," the lower portion containing abundant crab claws, mollusk molds and echinoids, whereas the upper is a miliolid coquina. Along the Citrus-Levy County

TABLE 5
OCCURRENCE FREQUENCY OF RESIDUES IN THE INGLIS
MEMBER, MOODYS BRANCH FORMATION
(For explanation, see Table 2, p. 59)

	Percentage of limestones (42 samples)	Percentage of dolomite rocks (23 samples)
Pyrite	19	52
"Glauconite"	17	61
Carbonaceous matter	40	100
None of these three constituents	47	0

border, the basal portion of the Inglis member grades into massive, fine grained, poorly consolidated dolomite rock containing pyrite and "glauconite." In the Hernando-Pasco County area the Inglis member is present as a pure, fairly hard, mollusk-bearing miliolid limestone. The only large Foraminifera which reach local prominence as rock builders are comparatively small valvulinids.

OCALA LIMESTONE AND WILLISTON MEMBER OF MOODYS
BRANCH FORMATION

At the time the analyses were made the rocks now classified as the Williston member of the Moodys Branch formation were considered to be basal Ocala limestone by the writer. Samples from these beds are therefore grouped with samples of the Ocala limestone, which they resemble lithologically more than they resemble the underlying Inglis member.

The Ocala limestone and Williston member of the Moodys Branch formation are represented by true limestones in the entire area except in western Dixie County. Here the Williston member passes into carbonaceous beds of dolomite rock, and the Ocala limestones are interbedded with similar rocks. The limestones are massive, and tend to be more chalky than the limestones of the Inglis member of the Moodys Branch formation. Many of them are composed largely of altered small Foraminifera (including miliolids) and shell fragments. Much of the Ocala limestone contains abundant large Foraminifera (camerinites and orbitoids), or mollusk remains. In the Pasco-Hernando County area the Ocala limestone becomes slightly "glauconitic" and slightly carbonaceous. The distribution of authigenic residues is summarized in Table 6.

TABLE 6

OCCURRENCE FREQUENCY OF RESIDUES IN THE OCALA
LIMESTONE AND WILLISTON MEMBER OF THE MOODYS
BRANCH FORMATION

(For explanation, see Table 2, p. 59)

	Percentage of limestones (44 samples)	Percentage of dolomite rocks (11 samples)
Pyrite	39	64
"Glauconite"	34	0
Carbonaceous matter	43	100
None of these three constituents	41	0

INTERPRETATION

It was hoped that the data obtained would furnish new means of correlation, and would shed new light on the origin of the rocks and thereby on the conditions which existed in the region at the time when the rocks were deposited.

Significance of data in correlation

No widespread zones of distinctive minerals were discovered. Allogenic minerals could not be used because of excessive contamination from younger beds. Organic matter, pyrite, and "glauconite" show great differences in vertical distribution in different parts of the area (Figs. 2-15). In some cases the occurrence of these constituents appears to be closely related to the occurrence of dolomite, which was found to cut across the formation boundaries established largely on faunal differences. Yet, the following generalizations can be made: (1) Throughout the area, the top of the Avon Park formation is characterized by more carbonaceous matter than is present in the overlying beds. (2) Over large parts of Dixie County, the dolomite rocks of the Inglis member, Moodys Branch formation are distinctively mottled gray by pyrite, and may be differentiated on that basis from the overlying dolomite rocks of the Ocala limestone. (3) In Levy and Dixie counties the Ocala limestone is largely devoid of "glauconite," which is present in the underlying rocks. This situation is reversed in the Hernando-Pasco County area (Fig. 2). Zones established on the presence or abundance of carbonaceous matter, pyrite, or glauconite may be found useful for detailed subsurface work in limited areas, especially in thoroughly dolomitized sections. On a regional scale correlation of these beds on the basis of mineral content does not appear to be feasible.

ROCK ORIGIN

Limestones and dolomite rocks are each represented by a massive and by a laminated facies. Textures, fossils, and pore-space configuration indicate that most of these rocks were derived from two types of parent sediment: massive calcitic and aragonitic "shell sands," and lime mud laminated with organic matter. Both of these sediments find modern counterparts in the sediments being deposited in the region of the Florida Keys.

Massive limestones.

The massive limestones are diagenetic alteration products of

calcitic and aragonitic shell sands, containing variable amounts of fine, chalky calcareous paste. Carbonaceous matter was present in some cases, absent in others. The abundance of miliolids and of large Foraminifera such as camerinids, orbitoids, and large valvulinids, as well as the sporadic occurrence of calcareous algae indicate deposition in warm waters, within the zone of light (maximum depth 200 meters). Lack of stratification may be accounted for by uniform sedimentation and by mixing of the sediment by burrowing organisms; one of the latter, the ghost shrimp *Callianassa*, has left abundant remains in part of the limestone of the Inglis member, Moodys Branch formation. The abundant entonic fauna and the general scarcity of carbonaceous matter indicate deposition on well-aerated bottoms.

The original sediment underwent considerable change. In some cases "glauconite" formed in the empty chambers of foraminiferal tests, while pyrite crystallized in or between the tests. The aragonite, present mainly as the chief constituent of most molluscan shells, was in all cases removed in solution, leaving shell molds. Calcite, on the other hand was precipitated from solution to form secondary incrustations upon the original grains of the sediment, thus cementing the loose sediment into rock. The less stable shells disintegrated to chalk and in many cases blended with the paste. In other cases the paste recrystallized, to grade into the secondary calcite.

Laminated limestone.

The single example of the laminated limestone facies, from the Avon Park limestone of the Lebanon Quarry (Vernon, 1951, p. 109, bed 2), is a virtually unaltered sediment of unconsolidated calcareous mud with laminations of carbonaceous matter. Small Foraminifera are present, but form only a small percentage of the sediment. They are so well preserved that treatment with acetic acid yields the chitinous chamber-linings of entire tests. The large amount of organic matter, including what appear to be branches of land plants, suggests deposition in shallow water, protected from waves and currents. The writer has observed sediments of this type around mangrove islands in Florida Bay.

Dolomite rocks.

The occurrence of the textural features of the limestones in most of the dolomite rocks is strong indication that the latter are largely a result of secondary dolomitization of limestone sediments.

In this process, rhombs of dolomite appear to form in the calcite paste which lies between the shell fragments, foraminiferal tests and other skeletal constituents. Various stages of this process are exhibited by samples of dolomitic limestones, ranging from limestones with scattered dolomite rhombs in the paste to those in which all of the paste has been dolomitized, and only the fossils remain as calcite. Dolomitization may proceed beyond this, to replace the fossils, and to fill the pore-space with dolomite crystals; this results in a tight, hard rock of interlocking dolomite crystals, of the type found in the deposits of the Moodys Branch formation and the Ocala limestone of Dixie County. In most of the dolomite rocks studied, dolomitization has gone only to partial completion, and has been followed by solution of the remaining calcite, resulting in a rock riddled by the molds of formerly calcareous fossils. In some cases this removal of calcite has led to compaction of the rock, as shown by up to 30 per cent flattening of enclosed fossils (Fig. 12). Alteration of the rock may proceed by the deposition of dolomite on the walls of cavities. The dolomite rhombs thus formed tend to be larger and clearer than those which replace the paste. They convert the fossil molds and other cavities into microscopic geodes, and may fill them entirely.

All of the dolomite rocks studied may be explained in this manner, as penecontemporaneous or epigenetic alteration products of calcitic and aragonitic sediments. However, the question arises as to whether some may not equally well be accounted for by other processes. It is conceivable that some of the fine-grained, friable dolomite rock showing little or no inherited texture was formed as a primary chemical precipitate, or as a clastic sediment derived from the physical breakdown of older dolomites possibly exposed on nearby islands. If the sediment had accumulated as a dolomite silt, either of chemical or clastic origin, then the rocks might be expected to show some of the following features:

- (1) Primary sedimentary structures such as bedding, ripple marks, and cross-lamination.
- (2) Valvulinid and other foraminiferal tests of dolomite. Agglutinating organisms would have built their tests of dolomite, picked up from the bottom.

Well defined bedding is shown only by the platy facies of these rocks, laminated with organic matter. The absence of other sedimentary structures suggests that these fine-grained friable dolomite rocks are probably not of clastic origin. The fact that arenaceous

Foraminifera such as the various valvulinids (*Eodictyoconus*, *Coskinolina*, *Dictyoconus*, *Discorinopsis* and others) are found preserved as molds only is taken as definite evidence that they built their tests of calcite rather than dolomite, and that the bottom sediment was chiefly composed of calcite.

Furthermore, it seems unwise, at the present state of our knowledge, to postulate a large-scale precipitation of primary dolomite on the sea floor, in the absence of evidence (1) from the modern ocean bottom (where such occurrences have not been observed), (2) from the chemical laboratory (where dolomite has not yet been formed under conditions approaching those of the ocean bottom).

It therefore seems most reasonable to conclude that the dolomite rocks studied are the result of secondary (possibly penecontemporaneous) alteration of normal calcite and aragonite sediments, the massive dolomites having been derived from the massive limestones, the laminated dolomites from the laminated limestones.

The *when*, *how*, and *why* of dolomitization remain among the most perplexing problems in sedimentation. A theoretical approach to the problem will not yield conclusive evidence until the true solubility constants of dolomite have been determined and until chemists are able to predict solubility relationships in such complex solutions as sea water and connate waters. Thus the study of dolomitization is at present limited largely to an empirical approach. The data furnished by microscopic study of the rocks and the insoluble residues were scanned for possible correlation of any features with dolomitization, which might yield clues as to the environment in which dolomitization occurred. Such correlation was found in the occurrence of carbonaceous matter. Out of a total of 70 subsurface samples of dolomite rock, 68 (97 per cent) yielded carbonaceous matter in the insoluble residues. Of the remaining two, one contained pyrite (indicative of the presence of reducing substances, presumably organic matter, in the original sediment). The distribution of these samples may be compared on Tables 2, 3, 4, 5, and 6. Only 88 per cent of the dolomite rock samples from surface exposures yielded carbonaceous matter; this is believed to be due to surface oxidation of organic matter, and to the difficulty of recognizing small quantities of carbonaceous matter in slimes discolored by limonite. Among limestones from the subsurface 62 per cent contained carbonaceous matter, among surface limestones only 4 per cent (Tables 2 and 3).

In summary, carbonaceous matter is present in virtually all dolomite rocks but only in part of the limestones. This suggests that the presence of carbonaceous matter may have been necessary for dolomitization to take place. It seems likely that bacterial decomposition products such as carbon dioxide, hydrogen sulfide, or ammonia, may have played a decisive rôle in the chemical changes within the original sediments, which led to the transmutation of calcitic and aragonitic shell sands and muds into dolomite rock.

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