PETROGRAPHIC AND GEOHYDROLOGIC MODEL OF AQUIFER LIMESTONES IN FLORIDA

by

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ABSTRACT

Petrographic analysis of 14 cores penetrating the Inglis and Avon Park Formations (Floridan Aquifer) reveals several distinct lithofacies representing multiple regressive-transgressive cycles, aerial exposure, and diagenesis. Evolution of pore spaces varies with the lithofacies and is a function of primary deposition and diagenetic history. The general tendency has been toward obliteration of primary voids by compaction and calcite and dolomite infilling, but several zones have experienced dissolution enlargement.

There is evidence for penecontemporaneous dolomitization in a supratidal environment, as well as post-depositional dolomitization by Mg-rich groundwater flushing. Various dolomite textures can be used to predict the environment of dolomitization. These textures are: (1). replacement dolomitization of the total sediment so that original fabrics are preserved; (2). dolomitization by aggrading neomorphic processes; and (3). replacement dolomitization of fossils and pellets only.

Other diagenetic processes which have affected these lithofacies include dissolution, recrystallization and inversion, and several phases of calcite cementation. The hydrologic regime and the original texture of the carbonate rock controlled the types of cement present. Scalenohedral crystals have been precipitated from marine waters along the test walls of internal chambers of fossils. Small, equant, blocky crystals have precipitated from meniscus fluid in the vadose zone of groundwater as coatings along internal chamber walls of fossils and at the contacts between grains. Large, rhombohedral crystals have precipitated from fresh water of the phreatic zone as partial and complete infillings of intraparticle and interparticle spaces.

Electrical resistivity measurements proved successful in determining the presence of water-filled, shallow, subsurface dissolution cavities. When augmented with a well-planned drilling program, this geophysical procedure can be used to detect such cavities in a more efficient and inexpensive manner.

The petrographic model presented, provides the framework into which the known geohydrologic and hydrochemical models can be integrated.

INTRODUCTION

Despite the enormous importance of the Tertiary limestones of Florida as one of the world's finest aquifer systems, much confusion still exists as to the accuracy of geologic details. Stratigraphic correlations, recognition of paleoenvironments, identification of lithologic controls on groundwater flow systems, and the evaluation of the influence of the geologic setting on groundwater pollution and volume have not been adequately assessed. A petrographic and geohydrologic model demonstrating the lithologic evolution of the northern Florida platform would help resolve these uncertainties and is of fundamental significance in the spectrum of geologic and hydrologic knowledge.

A specific aspect needed to be determined is the number of different but correlatable microfacies representing the rocks studied. Petrographic examination has revealed microfacies characteristic of paleoenvironments such as shallow shelf or bank, subtidal, intertidal, and supratidal. The transition of those environments established in this study, as well as their migration, have been documented. Likewise, the effects of marine transgressions and regressions, water energy levels, and geomorphic positions have been recognized.

Petrographic controls significant to the functioning of hydrologic systems have been identified and described. Such controls are a manifestation of the character and abundance of the allochemical and orthochemical constituents of the various carbonate rocks. Attention to the nature of these constituents has brought to light the diagenetic changes that have occurred since burial (Randazzo and Saroop, 1976). An attempt has been made to establish a regional pattern of such changes and investigate it's connection with groundwater flow and geochemical processes. Literature on principles of carbonate hydrology (Swinnerton, 1942) and regional studies of Coastal Plain carbonate aquifers (Stringfield and LeGrand, 1966; Stringfield, 1966) have established the framework for this study and the utilization of detailed petrography.

An example of the type of petrographic control considered is the regional and stratigraphic distribution of dolomite ($Ca,Mg\ (CO_3)_2$), Mg/Ca ratios, and strontium content. This study shows that controls such as sea level changes, the original porosity and permeability of the host rock, depth and duration of burial, diagenesis and lithification, and the relationship of the salt water-fresh water interface are of great significance to the occurrence of these parameters in the aquifer.

This project was originally intended to include all of the Tertiary carbonate units of northern Florida. As work progressed, it became apparent that most of the research effort should be concentrated on two of the most important units (Inglis and Avon Park Formations). Since this study represents the first truly definitive investigation of the lithologic characteristics of the Floridan Aquifer, I felt that restricting my efforts to these units in a smaller geographic area (Figure 1) would prove more fruitful and provide the foundation and direction for studying other carbonate units in adjacent areas. However, rocks of this area were compared with subsurface limestone samples from Alabama in an effort to establish gross changes in lithologic character.

METHODS OF STUDY

In this study fourteen cored sections of the Inglis and Avon Park Formations from Citrus and Levy Counties, Florida were examined. Numerous samples were also taken from quarries in the area. Less rigorous sampling was completed in Taylor, Dixie, Gilchrist, Alachua and Marion Counties. More than 500 thin sections were prepared and analyzed to determine the constituents of the rocks, types of cementation and diagenetic changes. The composition of the rocks was determined by point counting with approximately 250-300 counts made on each thin section.

Mineralogy was determined by X-ray diffraction analysis. Where calcite and dolomite were present in the same sample, a thin section of that sample was stained (Friedman, 1959) to determine which constituents of that rock were of calcite and which were of dolomite. Alazarin red-S in a solution of NaOH was used to distinguish dolomite from calcite. The scanning electron microscope was also employed for minute textural studies and the determination of Mg/Ca ratios of selected allochemical constituents. Atomic Adsorption Spectrometry was used for Strontium detection and quantification. The classification used herein is that proposed by Folk (1962). Grain-supported and matrix-supported distinctions have been made and the classification scheme of Dunham (1962) is used where appropriate.

PREVIOUS WORK

The depositional environments of many of the carbonate formations of Florida have been broadly known (Vernon, 1951; Chen, 1965), but only recently has a serious attempt been made to relate modern carbonate shoreline processes to the sedimentologic environments associated with rocks (Randazzo and Saroop, 1976). Several studies

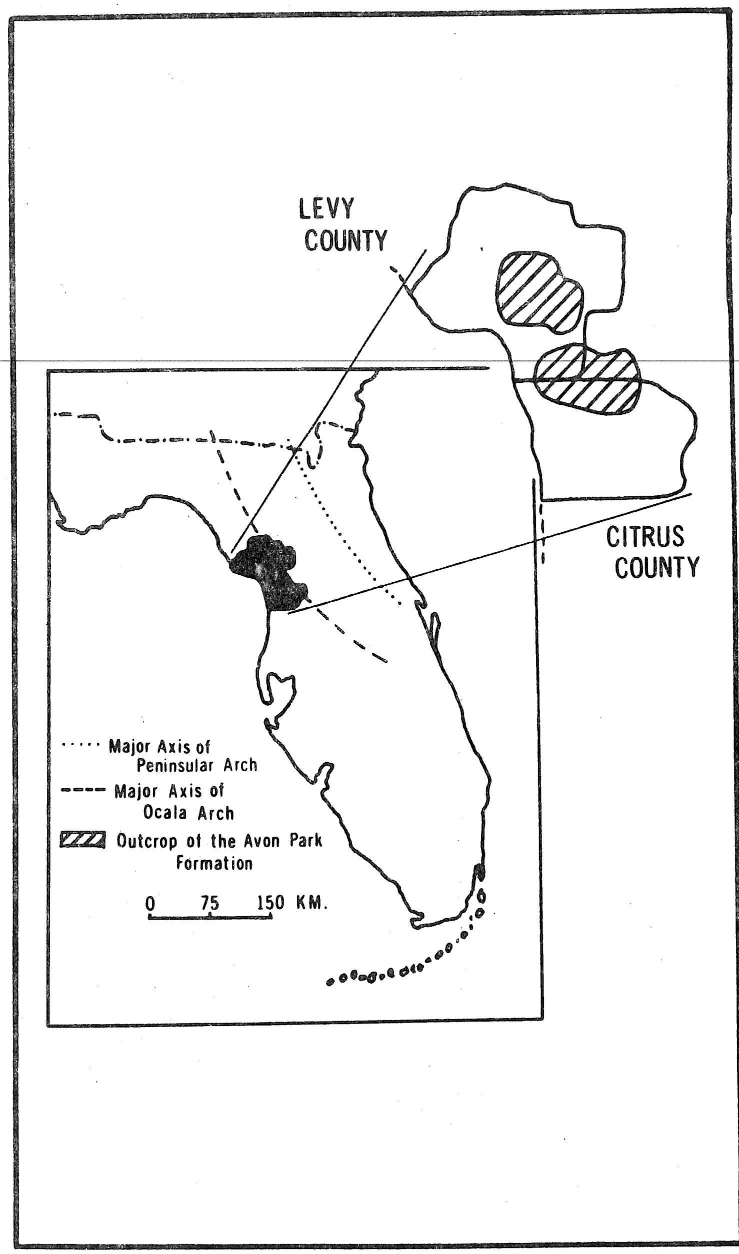

Figure 1. Major structural features of the study area and outcrop pattern of the Avon Park Formation.

have been concerned with the nature of diagenetic alterations, and useful interpretations have been made regarding the environments which brought about the various diagenetic processes (Ginsburg, 1957; Folk, 1965; Land, 1967; Berner, 1971; Folk and Land, 1975; Land et al., 1975).

The oldest exposed rocks in Florida are Late Middle Eocene (Avon Park Formation). These rocks crop out on the crest of the Ocala Arch and are surrounded by rocks of Late Eocene age (Ocala Limestone) which occur on the flanks of the Arch (Figure 1). These Upper Eocene rocks are the principal units composing the Floridan Aquifer.

The Eocene rocks of Florida were first recognized by Dall (Dall and Harris, 1892, p. 103) who proposed the term Ocala Limestone for rocks exposed in the vicinity of Ocala, Florida. He suggested that there were three units in the Eocene of peninsular Florida but considered the upper unit (=Orbitoides limestone) to belong in part to the Vicksburgian Stage (Oligocene).

Cooke (1915) showed that the Ocala Limestone underlies the Mariana (Vicksburg) Limestone and that the Ocala belongs to the Jacksonian Stage. This was supported by Applin and Applin (1944) who made a detailed examination of the regional subsurface stratigraphy of Florida and southern Georgia and discussed the relationship between the clastic facies of panhandle Florida and non-clastic facies of the peninsula. They divided the Eocene into (i). the Oldsmar Limestone; (ii). the Lake City Limestone; (iii). the Avon Park Formation; and (iv). the Ocala Limestone in ascending order. They also informally subdivided the Ocala into an upper and a lower member. Puri (1957) attempted to zone the Ocala by use of microfossils and raised the Ocala to group status by separating it into three formations - Inglis, Williston, and Crystal River. The Eocene formations of Florida are, in reality, biozones which have little lithologic basis for formational status. The rocks studied in this report belong to the Inglis and Avon Park Formations as defined by the fossils contained within them. For the purposes of allowing a reasonable transition in thinking and terminology, I have used these biostratigraphic names in conjunction with the lithofacies that have been established. The Florida Commission on Stratigraphy is encouraging various field investigations which will soon result in a complete reorganization of Florida's stratigraphic names for the Eocene.

DEPOSITIONAL ENVIRONMENTS

The sedimentology and paleoecology of the carbonate rocks investigated have been published by Randazzo and

Saroop (1976). The sequences studied were divided into three distinct lithofacies representing different environments of deposition. A summary of the findings of this aspect of the project is given in Table 1. The major subenvironments and associated communities represented by lithofacies of the Avon Park Formation are presented in Figure 2.

Each lithofacies represents a well-defined environment characterized by well-recognized sedimentologic processes. Lithofacies I was deposited in a shallow basin, part of which was covered by *Thalassia* and a dasyclad alga, *Neomeris*. The *Thalassia* bank must have expanded over parts of the basin as soon as the bottom was stabilized by deposition of sand-sized clasts. The thinly laminated, sapropelic, clayey biomicrite and calcareous clay are interpreted as intertidal (swash zone) deposits on the basis of sedimentary structures, sediment types and position within prograding sequence.

The relative importance of lime mud throughout lithofacies I is attributed to high rates of production by calcareous algae. Selective trapping and retention of finer-grained sediments by the angiosperms resulted in much higher percentages of micrite in the rooted biomicrite microfacies (Ic). The marine grasses not only served as a habitat for numerous microscopic organisms, but also played a role in stabilizing the substrate and reducing current velocities at the sediment-water interface.

Lithofacies II was deposited in the supra- to intertidal area. Its close lithologic similarities with Holocene mud-flat deposits are useful in the interpretation of the various subenvironments. This lithofacies is marked by a wide range of features characteristic of the supratidal zone--algal-laminated structures, birdseye vugs, limited number of species of organisms, root casts, mudballs, and intraclasts. Some rocks, such as the dolomitic, thinly laminated biomicrite, are characteristic of higher parts of the mud flat. The dolomitic biosparite, on the other hand, was probably in an area under greater tidal influence, since it contains a wider range of fossils than the other subfacies. An unconformable surface between the Inglis and Avon Park Formations is marked by a paleosol horizon. It represents a relatively small time gap since the clay mineral suite from this horizon shows little or no variation from the rest of the sequence. Several micro-unconformities are found in the Avon Park lithofacies representing local diastems.

Table 1. Summary of lithofacies, sedimentary features and interpreted depositional environments of the Inglis and Avon Park Formations.

		Lithofacies	Lithologic Characteristics	Environmental Interpretation
	d	Pellet-bearing biosparite to biopelsparite	More fossiliferous than underlying horizon; shelly, coquina-like in parts; wide range of fossils.	SHALLOW SUBTIDAL
III	c	Poorly washed pelsparite to biopelsparite	High pellet content; fewer foraminifera and other fossils; fossils generally well preserved.	SHALLOW SUBTIDAL
	b	Biosparite to intrasparite	Wider range of fossils than other subfacies; includes coralline algae, echnoids, and bryozoans.	SHALLOW SUBTIDAL-INTERTIDAL
	a	Poorly washed biosparite to biomicrosparite	Bioclasts fragmented; clay lenses with silt and sand-sized quartz grains; dolorudites.	INTERTIDAL
	f	Paleosol	Highly weathered, clayey and sandy dolomite and microcrystalline crusts.	SUPRATIDAL SUBAERIAL

Table 1. Continued

		Lithofacies	Lithologic Characteristics	Environmental Interpretation
	e	Dolomitized, foraminiferal biomicrite to biopelmicrite	Restricted fossil diversity; abundant micrite, thinly laminated in places.	SUPRATIDAL
II	d	Biosparite to intraclase-bearing biosparite	Abundant sparite and foraminifera with faunal diversity increasing toward the bottom of the subfacies; locally dolomitized;	INTERTIDAL-SHALLOW SUBTIDAL (occurs in northern cores only)
	c	Carbonaceous Montmorillonite	Very fine-grained carbonaceous material; lack of any structures or laminations.	SUPRATIDAL MARSH (occurs in northern cores only)
	b	Algal Dololithite	Algal laminated structures; filaments interlaminated with dolomicrosparite; restricted diversity of fossils.	SUPRATIDAL EPHEMERAL PONDS
	a	Dolomitized to partly dolomitized biosparite and biomicrite	Fauna dominated by foraminifera; biomicrite is grain-supported and biosparite is poorly washed.	SUPRATIDAL-INTERTIDAL

Table 1. Continued

		Lithofacies	Lithologic Characteristics	Environmental Interpretation
	d	Sapropelic, clayey biomicrite	Thinly laminated, sapropelic biomicrite to calcareous clay; few burrows; highly carbonaceous; locally dolomitized.	INTERTIDAL
	c	Foraminiferal and rooted biomicrite	Rhizomes and roots of marine angiosperms in growth position; extensively burrowed in places; abundance of foraminifera; interbedded carbonaceous montmorillonite; partly dolomitized.	INTERTIDAL-SHALLOW SUBTIDAL THALASSIA BANK
I	b	Dolomitized, foraminiferal biomicrite	Abundant micrite; low fossil content and restricted fauna.	SUPRATIDAL (in northern cores only)
	a	Intraclast-bearing biomicrite and biosparite	Biomicrite is grain-supported with intraclasts and pellets occurring in moderate abundance; fauna mainly foraminifera, echinoids, and calcareous algae.	INTERTIDAL-SUBTIDAL

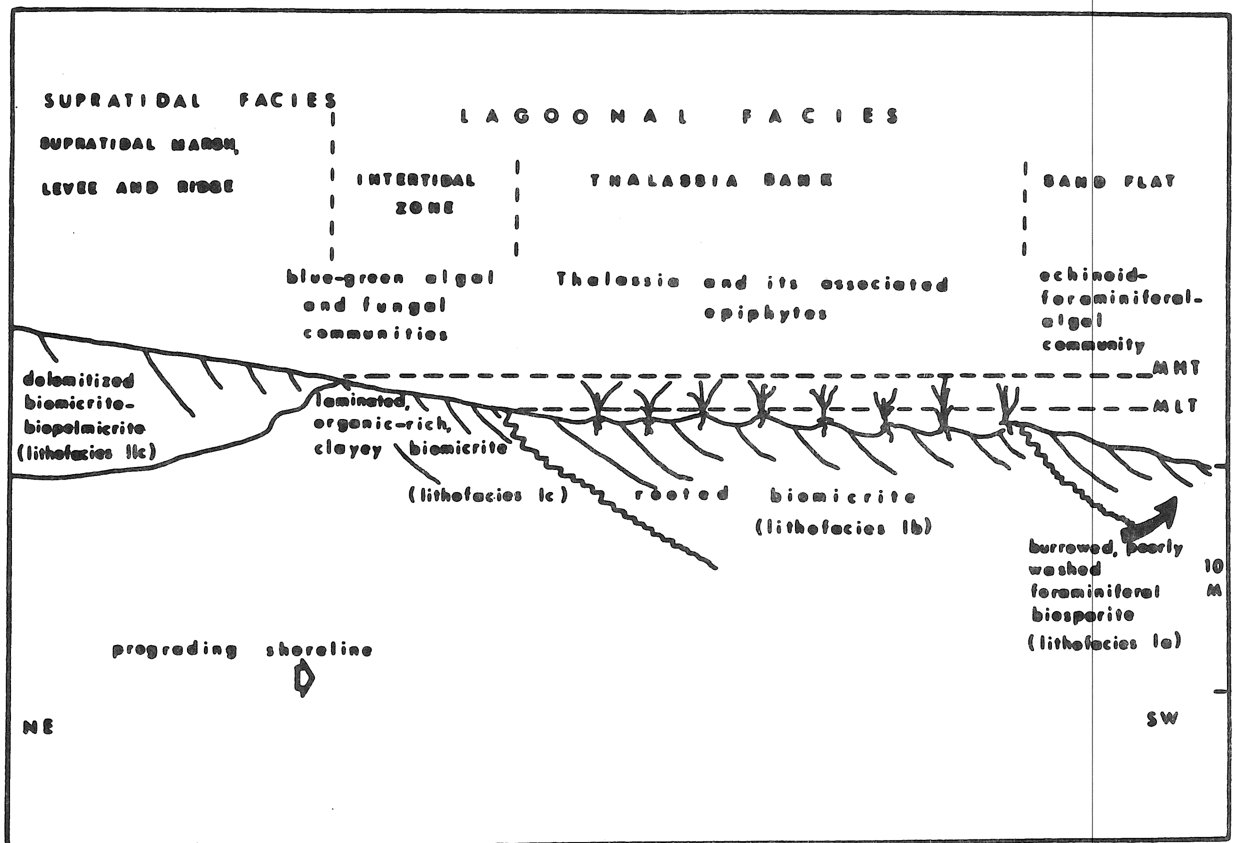

Figure 2. Major subenvironments and associated communities represented by the Avon Park lithofacies.

Lithofacies III is believed to be the shallow water marine counterpart of the supratidal dolostone facies. The skeletal content varies from well-preserved shells to those that have been thoroughly fragmented. Much of the shell debris appears to have been derived from organic activity rather than mechanical destruction, since many whole and unabraded casts of thin-shelled mollusks are found. The abundance of miliolids suggests that shallower-water conditions existed during the deposition of the Inglis than at any other time in the Jacksonian of Florida.

DIAGENESIS

Extensive diagenetic alteration within the rocks studied has destroyed many of the original depositional textures. Diagenesis is here defined as " . . . all those changes that take place in a sediment near the Earth's surface at low temperature and pressure and without crustal movement being directly involved" (Taylor, 1964, p. 417). Table 2 summarizes the prominent diagenetic features found.

Evolution of Pore Spaces

Visible porosity can be helpful in the interpretation of the geological history of carbonate rocks since it reflects in very minute detail the influence of both primary deposition and diagenetic processes. The evolution of pore spaces has been summarized by Choquette and Pray (1970) whose system of nomenclature is used here. These writers stressed the relationship between pore space and fabric elements of carbonate facies and showed that fabric selectivity is usually important in determining" . . . the time of origin of pore in relation to other events . . ." in the diagenetic history of the rock (Choquette and Pray, 1970, p. 211). Textoris et al. (1972), in a study of shallow marine aquifer carbonates of southeastern United States, found that porosity was dominantly fabric-selective and could be related to such factors as packing of allochems, and architecture and original mineralogy of the skeletons.

To assess properly the importance of fabric control in the Inglis and Avon Park Formations, it is necessary to relate the distribution and types of pore spaces to the depositional and diagenetic history of the various facies. Figure 3 shows the wide range in percentages of visible porosity for four of the cores studied. Figure 4 displays the major types of pores found in each lithofacies.

One of the major controls in determining the variations in percentages of pore spaces is the amount of micrite and organic matter in the rock. Biosparites have greater porosity than biomicrites, a reflection of the availability of more original large-sized pore spaces. Most of the

Table 2. Prominent Diagenetic Features Displayed Within the Carbonate Subfacies of the Inglis and Avon Park Formations.

Subfacies	Diagenetic features
IIId	Micritized fossil grains; calcite to calcite aggrading and porphyroid neomorphism.
IIIc	Dissolution of foraminifera; infilling of molds with sparry calcite.
IIIb	Much skeletal fragment and micrite infilling of molds and internal chambers of echinoids and foraminifera.
IIIa	Detrital quartz grains replaced by spar.
IIe	Dissolution of foraminifera; infilling of molds by sparry calcite; dolomitization of the entire rock with preservation of original textures; coalescive neomorphism of dolomite previously developed; gypsum nodules; calcification of gypsum crystals.
IId	Micritized fossil grains; calcite to calcite aggrading neomorphism; dolomitization by porphyroid neomorphism.

Table 2. Continued

Subfacies	Diagenetic Features
IIb	Several cores display dissolution of foraminifer grains and infilling of the resultant molds with sparry calcite; dolomitization has preserved original textures; other cores display micritized foraminifer grains and dolomitization by porphyroid neomorphism.
IIa	Micritized foraminifer grains; dolomitization through porphyroid neomorphism; pyritization of allochems.
Id	One core displays dolomitization by selective replacement of foraminifer grains and pellets; other cores display dissolution of grains and dolomitization by porphyroid neomorphism.
Ic	Micritization of fossils; dolomitization by porphyroid neomorphism; clotted textures suggestive of pelletoidal origin; high degree of recrystallization to distort outlines of pellets.
Ib	Upper part of this subfacies displays dolomitization which has preserved original textures; lower part of this subfacies displays micritization of fossils and dolomitization by porphyroid neomorphism.
Ia	Aggrading calcite to calcite recrystallization.

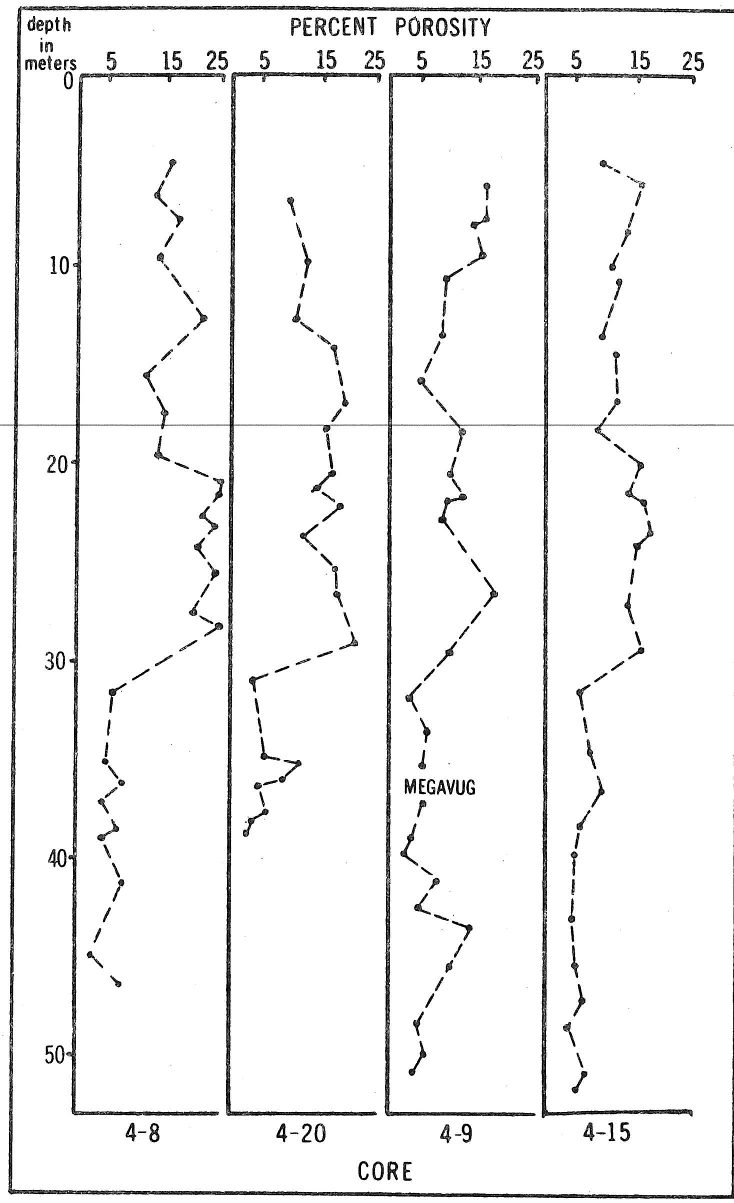

Figure 3. Variations in visible porosity of rocks in four drill cores.

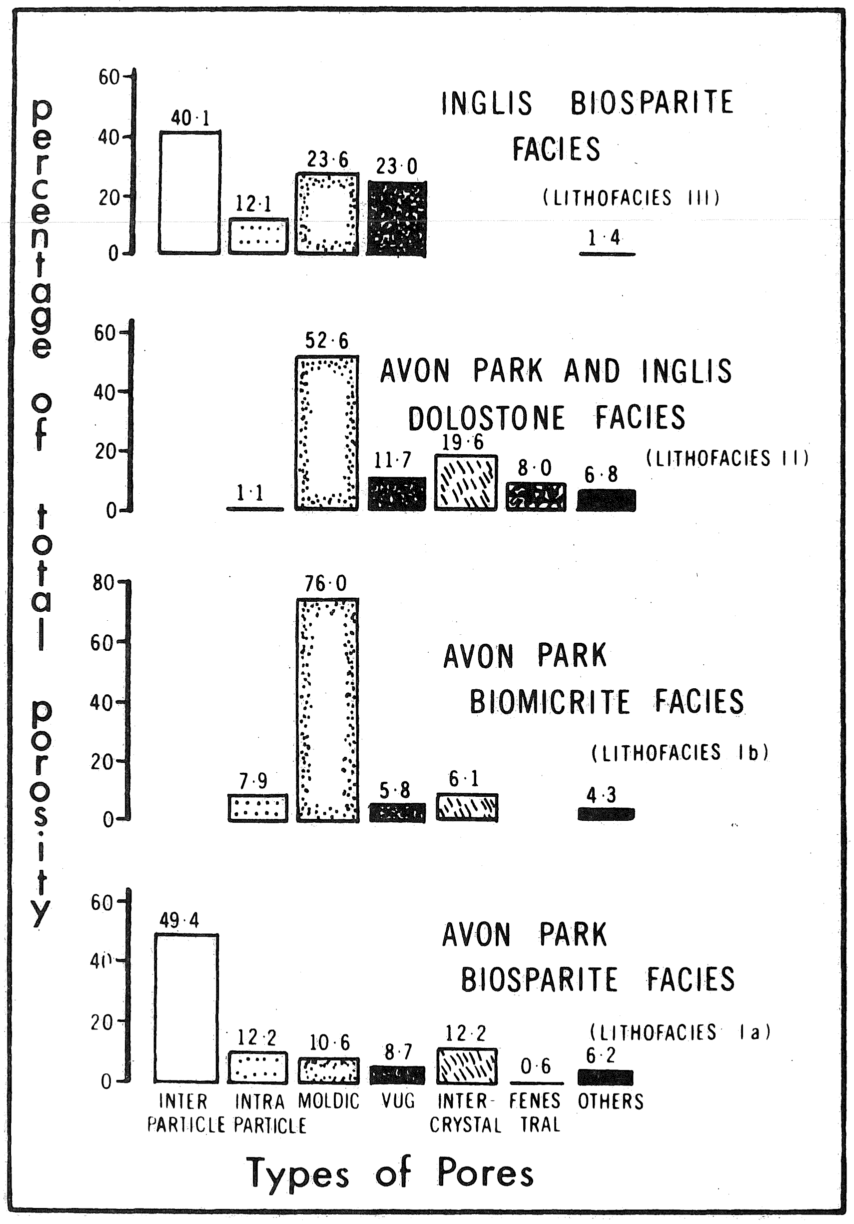

Figure 4. Major types of pores in the Inglis and Avon Park lithofacies.

fossils in the biomicrites are small and are surrounded by a microcrystalline matrix. Intraparticle and moldic pores are hence small, and, except for burrows and voids caused by decaying rootlets, no large pores are apparent. This contrasts with biosparites where interparticle porosity dominates.

A common pore type found in both biosparite and biomicrite is partially filled burrows. These range in size from 0.5 mm to over 2 cm and may be filled with pellets or intraclasts which have simply rolled into the cavities when the structures collapsed. These collapsed structures appear to be centers for localized dolomitization possibly because of greater permeability.

Studies of finer-grained sediments of south Florida made by Ginsburg (1957) showed that substantial losses of original porosity and moisture content occur in the first foot of burial. It was found that factors such as escape of gases and mixing by organisms were more important in reducing porosity than true compaction at this early diagenetic stage. Rapid changes in packing probably contributed to substantial decreases in the percentage of open spaces in biomicrite since collapsed burrows and the pelleted sediment attest to a considerable degree of organic activity.

An important type of moldic pores is that created by the decomposition of organic matter. Locally this may result in substantial increases in porosity since marine grasses, which create these pores, have a complex system of tubes, roots and rhizomes, much of which decay upon oxidation. This results in the formation of an interconnected network of pores, many of which are tubular or elongated and closely resemble the former root pattern. Some are partly filled with sparry cement while others remain as open voids, except when clogged by organic matter. In most cases, however, the voids left by small filaments and rootlets are substantially reduced by dolomitization (Figure 5).

Comparisons between extensively dolomitized and undolomitized rocks of the same lithology reveal substantial differences in porosity. Generally when the cement is dominantly dolosparite there is an increase in meso-intercrystal porosity with the result that total porosity also increases. This indicates that dolosparite does not reduce porosity as effectively as sparry calcite, once a solid framework is available to minimize the effects of subsequent compaction. Similar observations have been made by Murray (1960) and Weyl (1960). On the other hand, further precipitation of pore-filling cement and compaction would be expected to reduce total porosity since many voids are completely infilled by dolosparite.

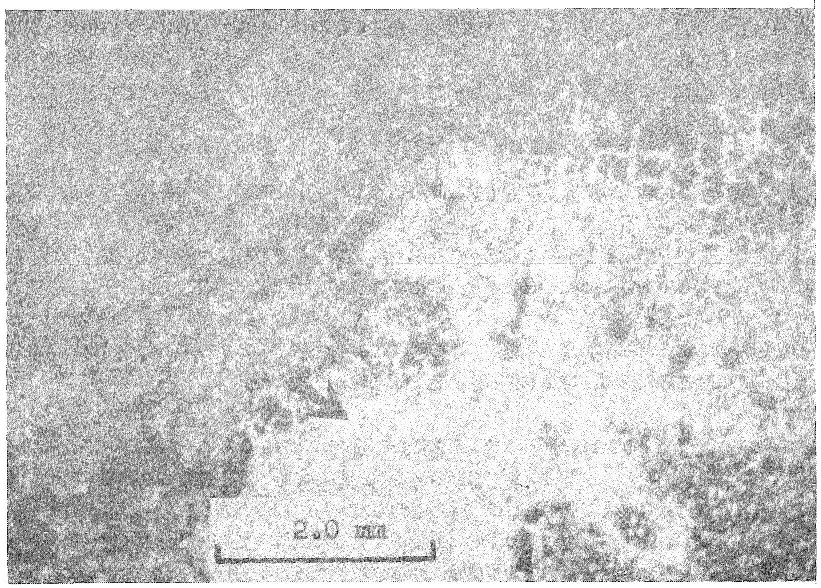

Figure 5. Spar-filled pore caused by decay of rootlets of a marine angiosperm. The sparry area is dolomite (arrow) which is fringed by residual organic matter (dark-colored) and then surrounded by micrite matrix (X-nicols).

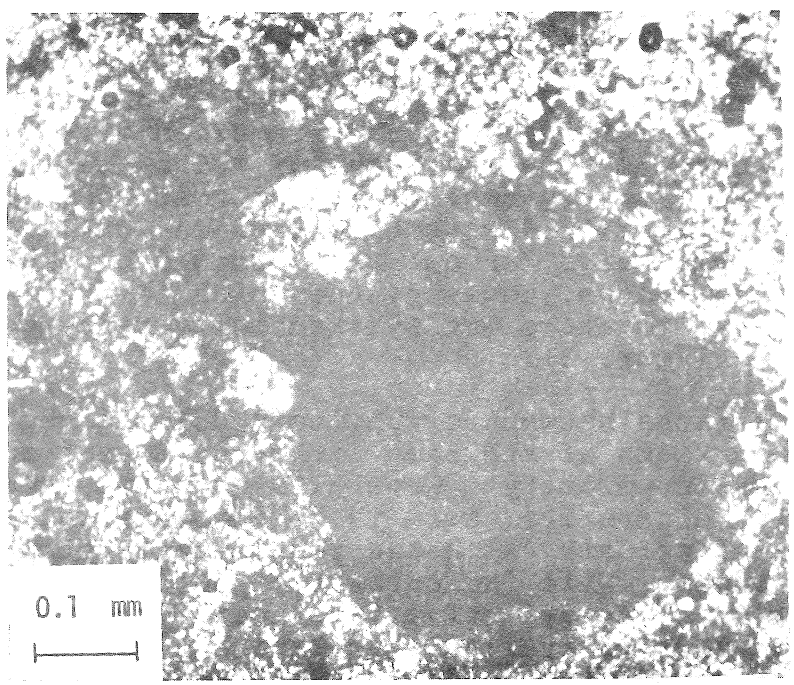

Figure 6. A foraminifer (dark area) which has been completely micritized (X-nicols).

The higher percentage of interparticle pores in biosparite is a reflection of the lack of available interstitial lime mud. Some interparticle pores have been reduced by sparry cement and overgrowths, but this appears to be of local significance. Drusy spar infilling is effective in reducing intraparticle voids and was observed to occur within the thalli of dasycladacean algae and tests of foraminifera and echinoids. Former intraparticle pores show all stages between those that are open and those that are almost completely filled. Most of these are classed as reduced foraminiferal intraparticle micropores.

Porosity in the dolomitized lithofacies (II) is complex and polygenetic. Although the original texture of the rock was probably similar to the undolomitized facies, porosities are greater. The dominant types of pores within the sequence are moldic and intercrystal, but substantial variations occur from subfacies to subfacies.

The most common pore type, and the type most often found in the dolomitized lithofacies IIa, is molluscan-forminiferal mesomold. Most of these molds were probably created by leaching of original skeletal materials which were more resistant to dolomitization. This is evidenced by corroded relics of fossil fragments which are still preserved as calcite.

Although both moldic and intercrystal pores are found in the algal dololithite (lithofacies IIb), there are also numerous planar mesopores which occur between algal filaments. These fenestral pores are sometimes filled with gypsum, but most often with clear, subhedral to euhedral dolosparite crystals which, following Bathurst's observation (1958), are larger towards the center. Incompletely filled pores are recognized by their multigranular margins. These fenestral bodies are common in the inter- to supratidal zones (Shinn, 1969) and are often associated with allochems rimmed with micrite envelopes.

Grain Diagenesis

One of the more important aspects of diagenesis is the destruction of fossil grains. There are many steps which these grains go through and many processes which operate upon them between the death of the contributing organism and their eventual destruction.

Calcitization and Early Recrystallization - Within the rocks studied, virtually all of the fossil grains are presently low-Mg calcite. Originally these fossil grains were aragonite and high-Mg calcite, and commonly the original structure of the fossils has been altered.

Calcitization is here defined as any process whereby material is altered in composition so that it becomes low-Mg calcite. The mechanisms of the processes are discussed in detail by Land (1967), Bathurst (1971), and Lippman (1973).

A definite order of recrystallization is recognizable. Mollusks, composed predominantly of aragonite, seem to undergo the most intense recrystallization and are represented by mosaics of pseudospar. Porcellaneous foraminifer tests (originally high-Mg calcite) are usually recrystallized to microspar, and in some cases, these slightly recrystallized tests are both surrounded and infilled by sparite showing no evidence of having been recrystallized. If these tests are indeed recrystallized during the periods when inversion of aragonite is occurring, then perhaps the non-recrystallized porcellaneous tests represent those that had not yet changed from high-Mg calcite to low-Mg calcite at the time when aragonite inversion was occurring. Nowhere within the rocks studied have the tests of the hyaline foraminifera undergone this early process of recrystallization. Likewise the zooecia of bryozoans have not recrystallized. Thus, there is a definite order in degree of recrystallization, increasing from the hyaline foraminifera and bryozoans to the porcellaneous foraminifera and mollusks. This order of recrystallization is consistent with that found by Banner and Wood (1964) and is apparently related to both the mineralogy and arrangement of crystals within the test. Grain boundaries are still distinct at the conclusion of these early processes.

Micrite Envelopes - In many carbonate rocks micrite envelopes around fossil grains are abundant. These envelopes are thought to be caused by the infilling with lime mud of the tubes vacated by boring blue-green algae (Bathurst, 1971). Micrite envelopes are common only in the uppermost lithofacies III and in the supratidal biomicrite subfacies (IIe and Id). They are well developed and the testament to the previous existence of mollusks and foraminifera which have been dissolved.

Micritization - The term micritization is used to describe the process of alteration of fossil grains to homogeneous patches of randomly oriented micrite or microspar crystals where neither chambers nor test walls are recognizable. The size and outer boundaries of these patches of micrite are roughly identical to that of the original fossil grains. All gradations of alteration exist between this textural end product and fossil grains where only a small portion of chamber and adjacent test wall are altered to a homogeneous area of micrite (Figures 6-8). Particularly susceptible to this alteration are the foraminifer grains.

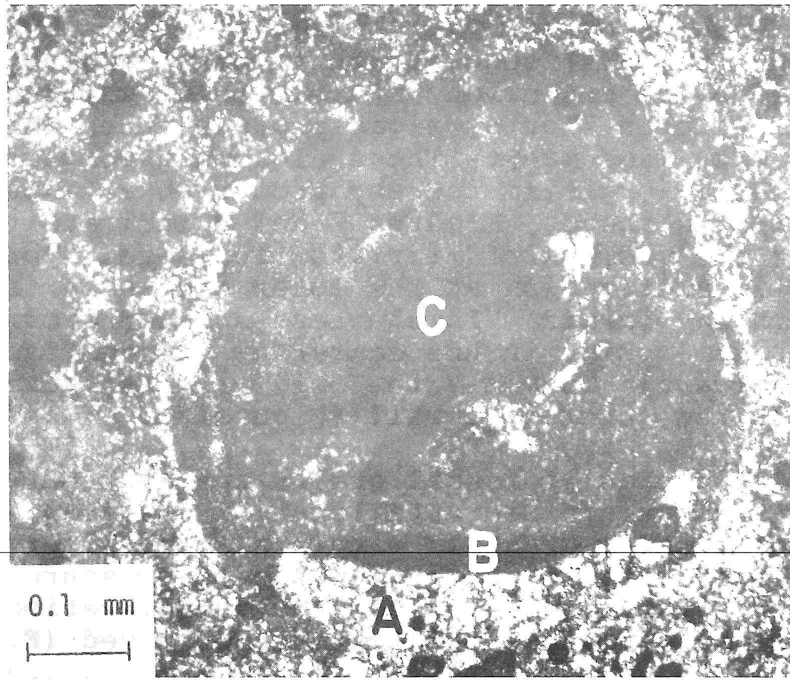

Figure 7. A foraminifer which has undergone a moderate degree of micritization. At (C) is the micritized area. At (B) are remnants of the test wall. (A) shows recrystallized, void-filling spar in the outer chambers of the test (X-nichols).

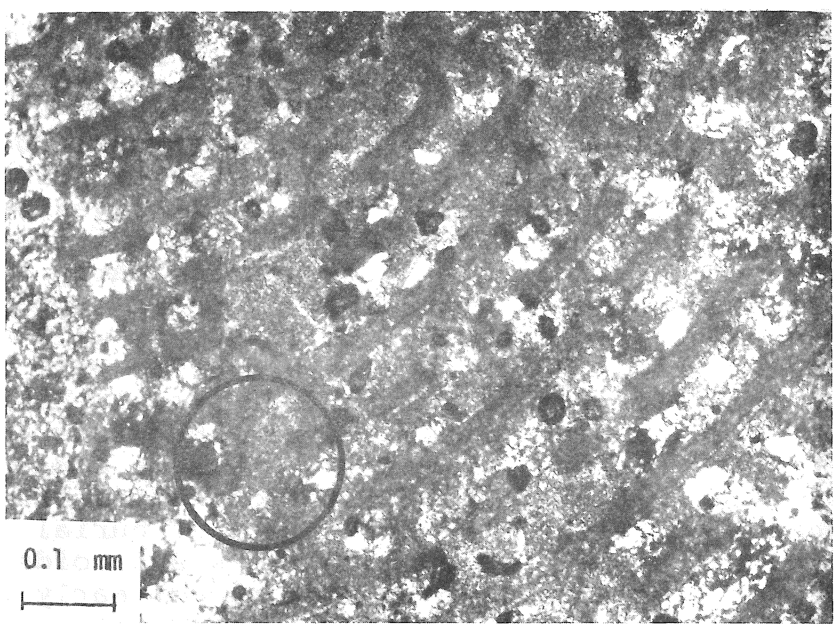

Figure 8. This section of Coskinolina floridana displays an early stage of micritization (circled area). A section of the test wall and adjacent chamber space is now occupied by slightly recrystallized micrite (X-nicols).

Bathurst (1971) suggests that fossil grains may become micritized by an extension of the process which creates micrite envelopes (boring algae produce tubes which become infilled with lime mud). These algae may completely bore the test of an organism thereby producing a texture like that described above. Figures 7 and 8 indicate that this cannot be the process of micritization here. Boring algae would begin destruction at the outer edge of a test and work their way inward. In the test studied micritization begins at some point in the center of the test and progresses outward. Commonly the only original structure remaining is the outer test wall (Figure 7).

Micritization of fossil grains can also be brought about through strain recrystallization (Wardlaw, 1962). Growing pseudospar crystals within a foraminifer test could undergo strain recrystallization due to pressure exerted by a resistant test wall; later recrystallization of the test wall could produce the textures observed (Figure 9).

The acid condition during organic decomposition which causes partial or complete dissolution of an organism's calcareous test could account for micritization. At some point, bacteria begin to attack the decaying matter and $CaCO_3$ is precipitated (Wolf, 1965; Berner, 1971). Inside the test, circulation and addition of fresh water would be restricted, and local alteration in the chemistry of the chamber-filling fluid could occur without disruption by fluid outside the test. Bacterial micritization probably occurs either shortly before, during or shortly after deposition (Figures 6-8).

Matrix Diagenesis

Aggrading neomorphism of the microcrystalline calcite has resulted in the formation of a mosaic of irregular, highly interlocking crystals in the biomicrites of the Avon Park Formation. Zankl (1969) has pointed out that a significant feature of lime muds which undergo early lithification is the absence of compaction. This is supported by my observations. Thin-shelled mollusks, as well as the dasycladacean alga, *Neomeris* sp., are quite well preserved and show little effect of compaction. Fecal pellets within the biomicrite have a clotted texture and grade imperceptibly into the surrounding matrix. This is considered to be due to the initial loss of interpore water from both muds and pellets within the first foot of burial (Ginsburg, 1957). Numerous well preserved burrows and voids created by plant rootlets attest to some degree of early lithification. Aggrading neomorphism of the biomicrite must have occurred within the supratidal or subtidal environments since it is truncated by several discontinuous micro-unconformities and overlain by facies which are considered to have been deposited in the supratidal zone (Figure 10).

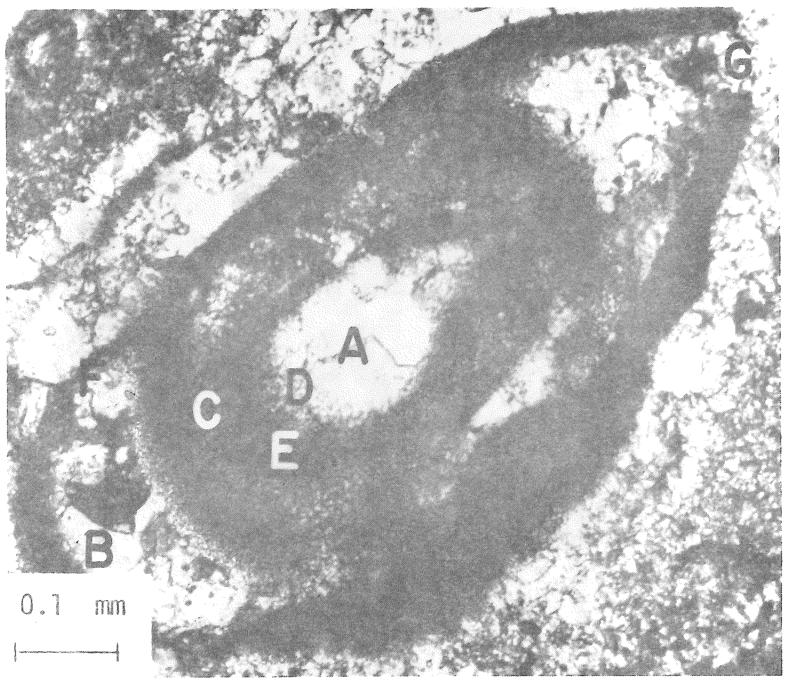

Figure 9. Foraminifer whose chamber has been infilled by sparry calcite cement which has undergone aggrading neomorphism (A and B). At (C) and (D) are microspar crystals resulting from strain recrystallization of pseudospar crystals due to pressure exerted between the test wall (E) and the growing pseudospar. At (F) and (G) pseudospar has incorporated material from the test wall, thus destroying sections of it (X-nicols).

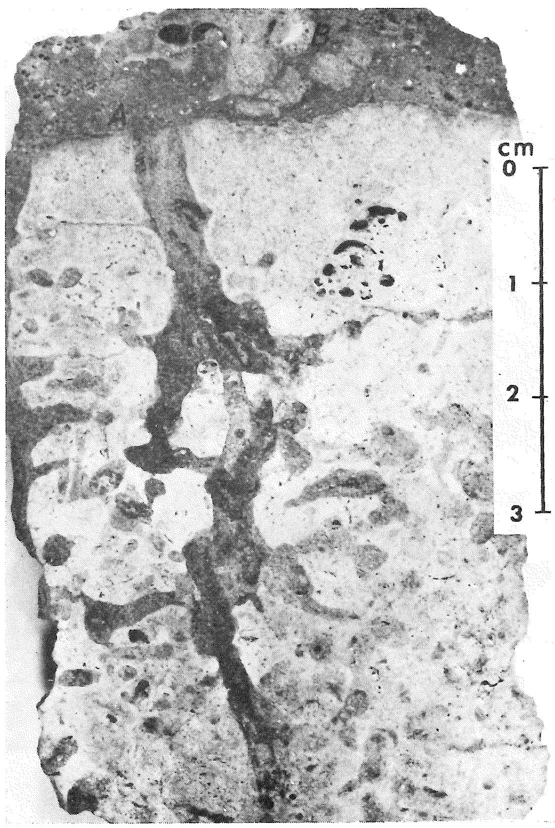

Figure 10. Knife-edge contact between biomicrite (lighter-colored) and overlying dolostone crust (lithofacies IIa). The dolostone forms an irregular, rind-like layer at (A) and has filled vugs and small cavities, some of which have been created by decay of rootlets. Note partly dolomitized clasts at (B) (etched slab).

Cementation

The morphology of carbonate cements is dependent upon a number of variables including: chemistry of interstitial fluids, pore geometry, original mineralogy of the crystals, rate of precipitation, and microbial activities. Cements from marine or mixed marine-fresh water environments are either high-Mg calcite or aragonite. With subaerial exposure these are replaced by low-Mg calcite or dissolved (Friedman, 1964; Purdy, 1968; Gavish and Friedman, 1969). The morphology of these crystals have been summarized by Taylor and Illing (1969), Land (1970) and Milliman (1974).

Although micritic or cryptocrystalline cements have been described from Holocene deposits (Purdy, 1968; Shinn, 1969; Moore, 1973), they have not often been reported from ancient rocks (but see Inden, 1972). One slide showed some indication of micritic cementation, but the gross textural relationship with later cements could not be determined. This horizon probably represents a bored surface and is similar to those found in submarine hardgrounds (Moore, 1973). A second type of micrite cement appears to be related to stabilized microenvironments such as the shelter voids of pelecypods. Micritic cements have been attributed to the binding action of various micro-organisms (fungi, algae and bacteria) which also tend to concentrate iron (Osborn, 1960). This may account for the presence of pyrite near the edges of the grains.

Another useful feature in distinguishing early cements are alternating micritic and acicular cements (Shinn, 1969). The micrite cements represent intervals during which the acicular crystals appear to be up to ten microns in length and generally bladed.

A closely related type of cement encountered consists of short, equant-bladed crystals, some of which are terminated by pointed crystal faces and project radially into existing pore spaces (Figure 11). These crystals completely fringe the grains and are generally about 10 microns in length although those that are obtusely pointed may reach up to 20 microns in length. These are similar to "onion skin", isopachous cements that have been described by Land (1970) from the marine phreatic zone. Dunham (1971) suggests that such block-shaped crystals at grain contacts are due to precipitation of these crystals from meniscus fluid in the vadose zone of a subaerial environment. These cements within the Avon Park Formation appear to round off the sharp corners of interparticle voids. This would be expected if they were precipitated from meniscus fluid.

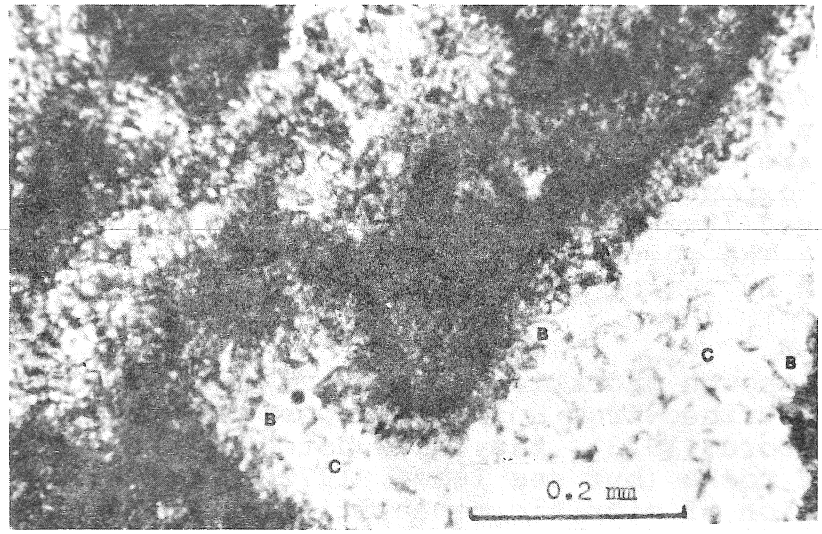

Figure 11. Finely crystalline, equant cement (A) fringing a former cavity with larger, bladed spar (B) which is obtusely pointed toward coarsest spar (C).

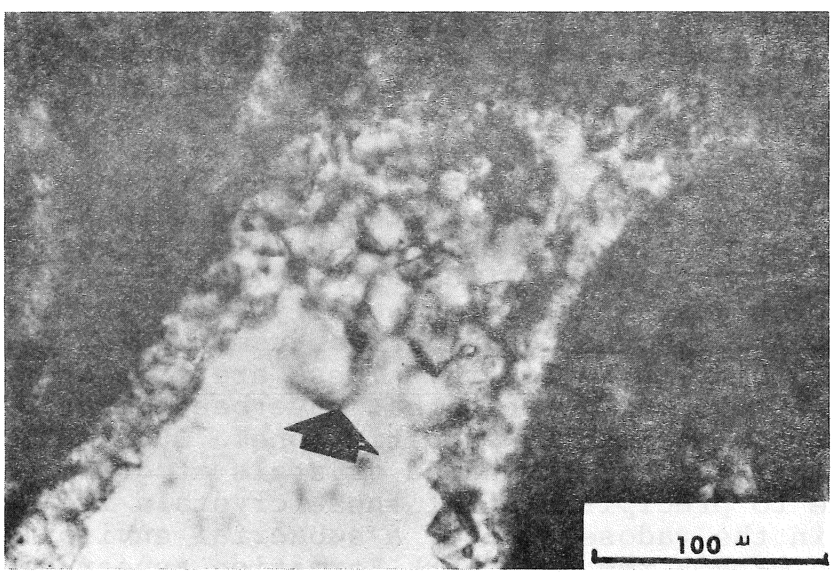

Figure 12. This type of equigranular, pore-filling cement (arrow) is initiated at grain contacts. It may have been precipitated from capillary-held water (lithofacies III).

One difficulty in using the morphology of crystals as a key to their origin is that, with the possible exceptions of micritic and "microstalactitic" cements (Taylor and Illing, 1969), a single type may form in several environments. Thorstenson et al. (1972, p. 165), for example, have reported growing "isopachous" cements experimentally under vadose conditions.

Use of geochemical criteria may be helpful in determining the depositional environment of the various types of cement. Evamy (1969) has stressed that ferrous iron is not available to enter the calcite lattice in the oxidizing zone above the water table. Ferroan-calcite may precipitate from interstitial waters below the water table. Although the first generation cements that were examined did not contain ferroan-calcite, this is regarded as a useful but not infallible criterion in recognition of subsea or vadose cements since: (1). the ferrous iron content within the calcite lattice might be too low to be detected by staining; and (2). the groundwaters might have been deficient in iron. Variations in the amounts of ferrous iron in the calcite lattice is also dependent upon " . . . temperature, confining pressure and other variables" (Evamy, 1969, p. 792).

The concentration of strontium in carbonate rocks analyzed was considerably lower than what should be expected in marine calcites (Kinsman, 1969). The more coarsely crystalline spar is usually associated with the low strontium concentrations. This indicates that much of the coarse cement formed or reequilibrated in the presence of fresh waters. Land et al. (1975) stated that the largest crystals should form nearest a groundwater recharge area where the "cleanest" solutions occur.

Pittman (1974) has pointed out that interparticle cement that can be derived from the dissolution of aragonite and precipitation of calcite is approximately equal to 8 percent of the rock volume. The growth of second generation spar must largely depend upon another source of calcite. One such source may be neomorphic replacement of nearby allochems through solution-reprecipitation on a microscale (Friedman, 1964). Intergrain cements may form optically continuous crystals which are from 0.5 to 2 mm in size. These appear to act as a front for nucleation. Remnant allochems are often included within the crystal and are easily recognized by their turbid appearance and ghost outline. In some instances these crystals grade into first generation cements, but sometimes there is a sharp grain-cement contact. The final pore-filling cement is generally coarse but equant. Detrital quartz grains also show evidence of replacement by pore-filling spar.

First generation cements, on the other hand, show wide variations in sizes and shapes. Most form short, bladed crystals which vary from a few to twenty-five microns in size (Figure 11). Later crystals which develop at grain contacts are larger in size and often develop interference boundaries.

Fibrous cements do not surround grains completely, but individual crystals may be associated with fine-grained, loosely packed, blocky crystals. Some allochems are fringed by a closely packed 1-2 crystal thick rim which projects radially into existing pore spaces. Rim crystals are equigranular and scalenohedral in shape and about 15-25 microns in size (Figure 11). These are fringed by rhombic, equigranular crystals which are initiated at grain contact and not obviously in contact with allochems. Similar crystals have been figured by Land (1970) from the vadose zone and Moore (1973) from the shallow marine environment. The similarity in size of the types of cements is probably a reflection of precipitation under related conditions.

Dolomitization

The different textures of dolomitization and constituents of a limestone which are dolomitized are the result of time, place, and manner in which the constant chemical mechanism of alteration to dolomite is brought about. These differences lead to three principal textures of dolomitization recognized in the study: (1). dolomitization by total replacement; (2). dolomitization involving aggrading porphyroid and coalescive neomorphism; and (3). dolomitization by selective replacement.

Subfacies Ib, IIb, and IIe display original textures that have been preserved by total dolomitization (Figure 13). Original dissolution of allochems, creation of molds, infilling of sparry calcite and calcitization of micrite envelopes, and a mud matrix can all be recognized. The entire rock may have been dolomitized at once, or there may have been several stages of dolomitization.

The most widespread form of aggrading neomorphism of dolomite is porphyroid neomorphism which is characterized by discrete euhedral rhombs of dolomite scattered throughout the rock (Figure 14). This texture is equivalent to that described by Folk and Land (1975) for "limpid" dolomite. The spatial density and size of these dolomite rhombs are directly related to how far the dolomitization process has gone. If a process of random dissolution of certain dolomite crystals and enlargement of other dolomite crystals continued over time, coalescive neomorphism of dolomite could proceed.

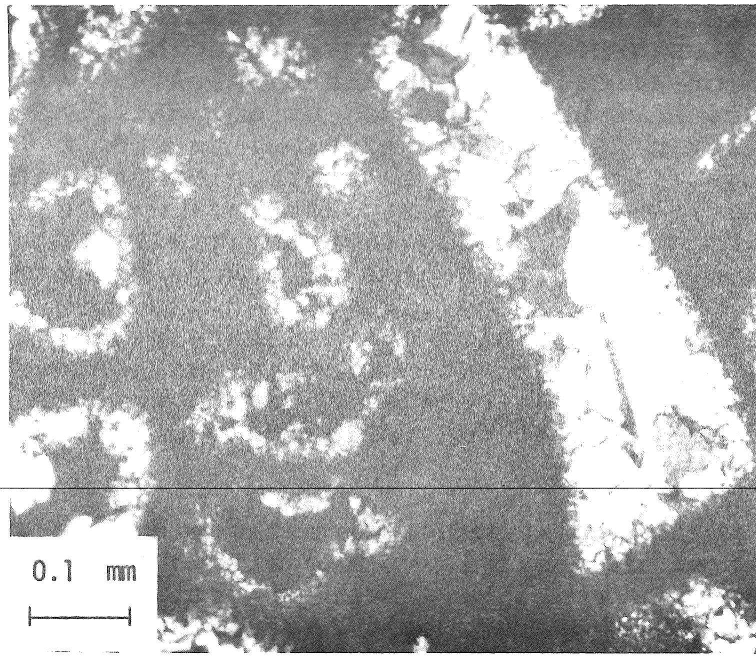

Figure 13. Dolomitization by total replacement. The foraminifer tests and pelecypod valves were dissolved and later infilled by sparry calcite cement. After infilling, the entire rock was dolomitized, preserving original rock textures (X-nicols).

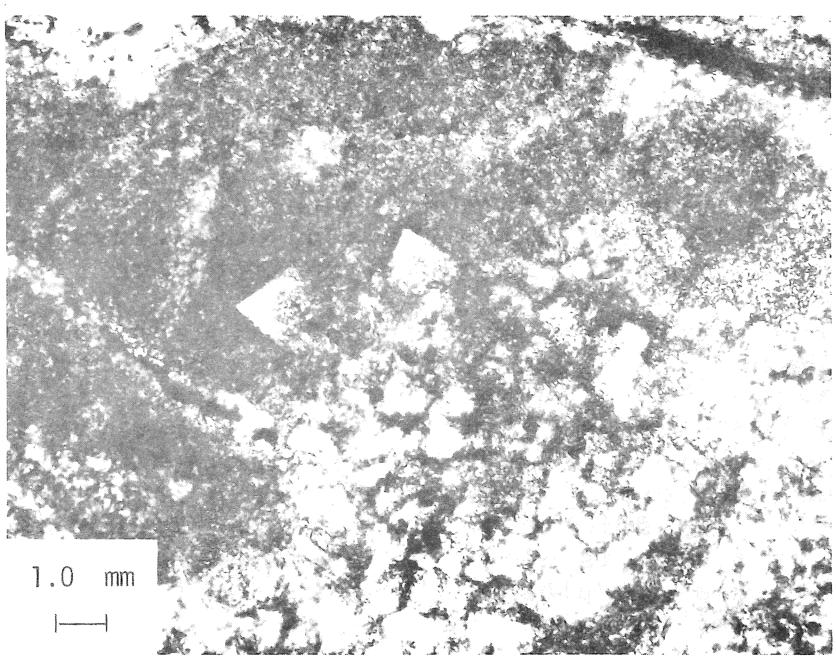

Figure 14. Dolomitization through porphyroid neomorphism at a very early stage of development. Only a few, incompletely formed, dolomite rhombs are present (X-nicols).

Within subfacies Id selective replacement by dolomite occurs. This subfacies is represented by a partially dolomitized biopelmicrite where the bioclasts, pellets, and intraclasts have been replaced by dolomite and where the micrite matrix is undergoing dolomitization by porphyroid neomorphism. The mineral alteration of the matrix from high-Mg to low-Mg calcite may have rendered it less susceptible to dolomitization than the grains which had not yet undergone mineralogic changes of any kind (Land, 1967).

Model for Dolomitization - The relation between dolomite texture and its interpreted chemical environment of formation and the relation between dolomite texture and its place of occurrence lead to the following model for dolomitization.

The total replacement dolomites are interpreted to be the result of interstitial brine with a high Mg/Ca ratio. These sediments would have been subjected to subaerial exposure, and fresh water could have flushed them, bringing about changes in the original chemical environment and causing the instability of original mineralogies and subsequent calcitization and growth of void-filling calcite. Periodic inundation by sea water followed by evaporation would cause the precipitation of $CaSO_4$, enriching the Mg/Ca ratio (Kinsman, 1969). Folk and Land (1975) suggest that water of high Mg/Ca ratio would need to be diluted by fresh water for dolomitization to proceed. Such dilution would not substantially alter the Mg/Ca ratio but is necessary to reduce the inhibiting effect of salinity on dolomitization.

The close association of the total replacement dolomites with supratidal sediments, the high Mg/Ca ratios interpreted to cause replacement dolomitization, and the presence of evaporite minerals in such dolomites imply that subfacies Ib, IIb and IIc were dolomitized by downward-seeping, Mg-rich brines created in a sabkha environment.

The role of the microflora of this environment may also have had some significance in the process of magnesium concentration in sediments (Friedman et al., 1973). Gebelein and Hoffman (1971) have shown that the blue-green algae can create microenvironments where Mg-rich organic complexes can form. These organic-rich layers could form sites for later dolomitization. In the Inglis and Avon Park Formations gypsum is often concentrated beneath algal laminations either as nodules or filling fenestral pores. This may be related to selective uptake of Mg^{+2} ions by the algae or, alternatively, selective mineral preservation due to protection by algal sheaths from flushing by meteoric waters.

Although tidal flooding and evaporative concentration may lead to formation of dolomite during the dry season, percolation of fresh water during heavy rainfall results in considerable dilution of interstitial waters. A freshwater wedge may sometimes extend considerable distances offshore (Figure 15). Although flushing by rain water can take gypsum into solution, it plays a more important role in dissolving unreplaced aragonite and calcite. In areas where meteoric waters are ponded, such as supratidal marshes, dissolution of skeletal remains often results in considerable moldic porosity, an essential part of the dolomitization process (Murray, 1960).

As the brine sank deeper into the sediments, it's high Mg/Ca ratio was reduced by removal of Mg^{+2} ions used in dolomitizing the sediments through which it passed, and it's salinity was lowered by the intermixing with subterranean fresh water. Thus, as a downward-seeping brine penetrated to lower depths, the dolomite texture would progress from replacement dolomites near the surface, to aggrading neomorphic dolomites with depth as the Mg/Ca ratio dropped below 2/1 (Folk and Land, 1975) and, finally, to no dolomitization when the Mg/Ca ratio dropped below 1/1.

The interstitial solutions causing dolomite coalescive neomorphism (Figure 16) would, as in calcite to calcite coalescive neomorphism, be originally contained in primary pore spaces or secondary dissolution vugs. As the growing dolomite crystals press close to one another, the water would become trapped as thin films at intercrystalline boundaries creating closed chemical systems. Influences of outside solutions would be very slow and fluctuation of the closed-system solution, between being rich and depleted in magnesium, could proceed undisturbed.

Fresh-water continental runoff or rain water often dilute the saline water in a sabkha environment. This would not appreciably affect the Mg/Ca ratio. It was earlier suggested that the Mg/Ca ratio would have been very high in the original dolomitizing brine. As such, it is doubtful that the sabkha water could have brought about the dolomite coalescive neomorphism. Coalescive neomorphism of the dolomite would probably not have occurred in the fresh subterranean water as here the Mg/Ca ratio would not be likely to ever be as high as the 1/1 ratio necessary for dolomitization (Hanshaw et al., 1971, p. 721). A major environment in which coalescive neomorphism of the dolomite could proceed would be the zone of mixing between the fresh water and brine in the subterranean environment (Land et al., 1975; Folk and Land, 1975). Here the Mg/Ca ratio could be between 2/1 and 1/1, and the proper saturation levels for Mg^{+2} ions could be achieved.

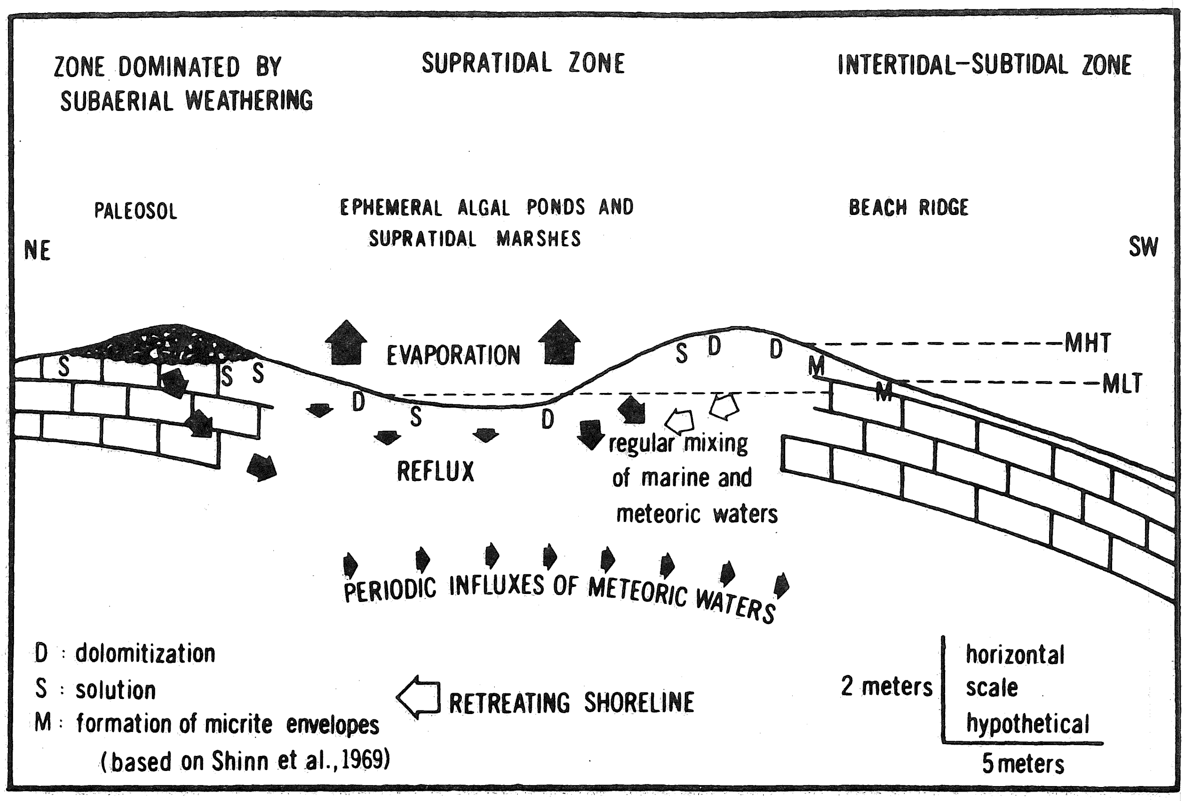

Figure 15. Conceptual model for early dolomitization of the Inglis and Avon Park lithofacies.

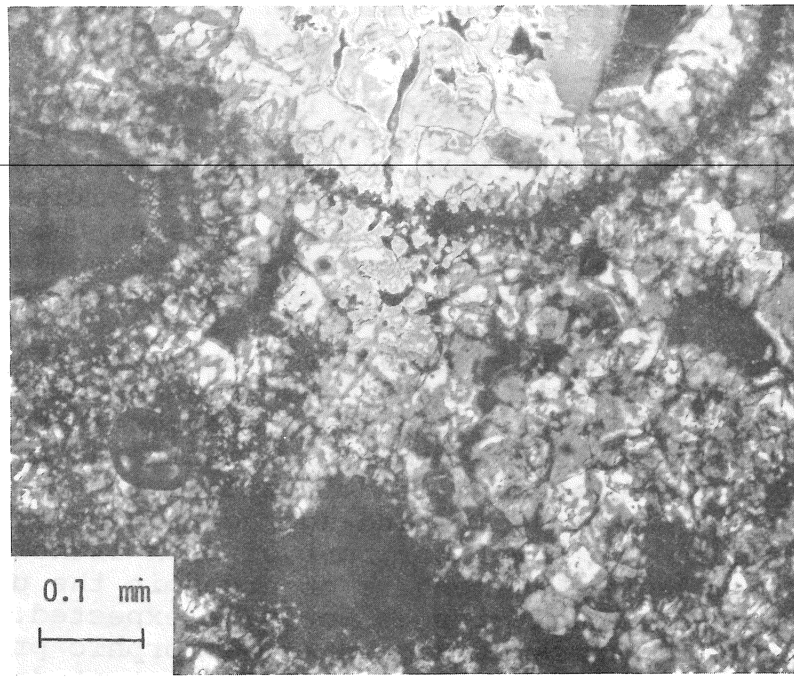

Figure 16. Dolomitization through aggrading coalescive neomorphism.

As with coalescive neomorphism of dolomite, the interstitial water which brings about porphyroid neomorphism of dolomite would need to be saturated with respect to magnesium at a level very near the equilibrium value. Further, the Mg/Ca ratio would need to be between 2/1 and 1/1. Such water, would be present at the zone of intermixing between fresh water and brine in the subterranean environment. Another possible way to derive water which has the proper attributes to bring about porphyroid dolomitization is by the removal of Mg^{+2} from Mg-rich brine and simultaneous fresh water dilution to create the proper saturation level with respect to magnesium.

Magnesium-rich water created in a sabkha environment could, as it sinks into progressively deeper sediments, cause dolomitization of these sediments, thereby losing Mg^{+2} ions. As the brine sinks, fresher groundwater could intermix with it and cause dilution. Thus as the brine sinks lower and lower, conditions could become favorable for the aggrading neomorphism of newly dolomitized sediments.

If this were the only operative mechanism of dolomitization, one would expect to find the sequence of dolomite textures described above. Since lithofacies I and II were deposited by transgressive-regressive marine sequences, one should find replacement dolomitization in the upper portions of each lithofacies and aggrading neomorphic dolomite textures in the lower portions of each lithofacies. Dolomitization by replacement is observed in the upper portions of each lithofacies as would be expected. However, dolomitization textures of aggrading neomorphic processes are often observed below sections which are not dolomitized. While the above method explains the replacement dolomites of the upper portions of each lithofacies, it does not explain all of the dolomite found within the lithofacies.

When a sea transgresses an area, sea water will intrude the pores of the sediments of that area so that a lens-shaped interface is created between the intermixing salt water and the subterranean fresh water which was present before intrusion and is now being pushed landward (Figure 17). Along this interface is created a zone of mixing between the two bodies of water. Within this zone of intermixing, salinity and Mg/Ca ratios may come within the necessary limits to bring about dolomitization by aggrading neomorphic processes (Land et al., 1975). The cyclical recurrence of transgressive-regressive stratigraphic sequences implies that intruded sea water could have flushed the rocks of the various lithofacies several times. This mechanism is interpreted to have caused extensive dolomitization within the rocks studied (Figure 17).

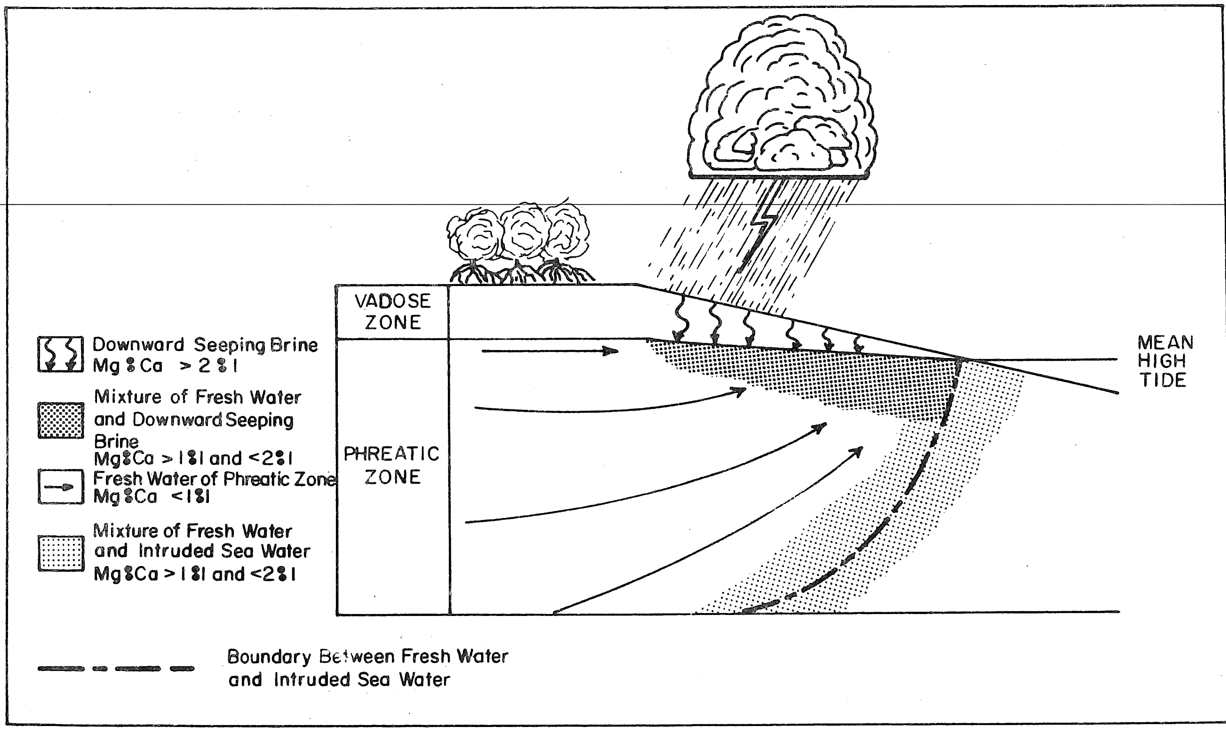

Figure 17. Conceptual model of groundwater flow patterns and their associated Mg/Ca ratios which bring about dolomitization (groundwater flow patterns based on Hubbert, 1940, p. 925).

Various roles have been assigned to clay minerals in dolomitization. They have been described as nucleation sites and catalysts (Kahle, 1965), as an aid in increasing the permeability of sediments and hence enhancing the flow of percolating brines (Murray and Lucia, 1967), and as part of the reaction itself (Zen, 1959). According to Zen (1959), the change from calcite to dolomite may be accompanied by a conversion of montmorillonite to kaolinite. However, no variation in clay mineralogy was observed between the dolomitized and undolomitized facies of the Inglis and Avon Park Formations. Other catalysts, such as detrital dolomite (Lindholm, 1969) and various organic compounds (Kitano et al., 1969), are difficult to evaluate, but were probably important in the environment of deposition.

From the above considerations it would seem that there are many factors which could either retard or enhance the formation of dolomite. Although the basic controls are fairly well known, their relative importance is still far from established. A conceptual model for dolomitization must hence treat the system as a dynamic feature where changes in the Mg/Ca relationship are a function of a wide range of variables.

RELATION OF HYDROLOGY TO LITHOFACIES

The cores studied are in the vicinity of many of the most popular and important springs in Florida. Daily flows from several of these springs, as reported by Ferguson et al. (1947), are: Rock Bluff Springs - 27 mgd*; Poe Springs - 45 mgd; Wekiva Springs - 47 mgd; Manatee Springs - 108 mgd; Homosassa Springs - 120 mgd; Rainbow Springs - 452 mgd; and Silver Springs - 500 mgd. Discharge from these springs involves the stratigraphic units studied, as well as several above and below them, constituting the Floridan Aquifer.

Cherry et al. (1970) described the general hydrology of the western part of the study area covered in this report. They concluded that there were four major permeability zones of highwater production: (1). upper limestone of the Hawthorne and Tampa Formations (Miocene age); (2). lower part of the Suwannee Limestone (Oligocene age); (3). the Avon Park limestone below the top 100 feet of this formation (Eocene age); and (4). the upper part of the Lake City Limestone (Eocene age). Transmissivities of the aquifer from different parts of their study area were computed to be 5-15 mgd per foot. A coefficient of storage from 0.002 to 0.007 was computed from the southern Middle Gulf area. Well yields from Avon Park Formation wells were from 500-1,000 gallons per minute in the Withlacoochee and Waccasassa river areas

* mgd = millions of gallons per day

(Anonymous, 1966). The numbers cited above are an impressive indication of the abundance of water and storage capacity of the Floridan Aquifer.

Parker (1975a) described the Ocala Group of carbonate rocks as varying in their permeabilities and cavernous nature within the Southwest Florida Water Management District (SWFWMD). The potentiometric surface of the Floridan Aquifer in the Southwest Florida Water Management District gently slopes away from the Green Swamp high and toward the Gulf coast. This is well illustrated on Parker's (1975a, figure 7) potentiometric surface map of the Floridan Aquifer.

From the various hydrologic studies cited above, as well as those by Stringfield (1966), Back and Hanshaw (1971), Stewart et al. (1971), Sinclair (1974), and Parker (1975b), much hydrologic data involving well yields, potentiometric surfaces, aquifer tests, computation of transmissivity and storage coefficients and spring discharges are available on a general scale. Local variations are numerous but these hydrologic data can be used as a general indication of hydrologic conditions.

The lithofacies representing the stratigraphic units studied are probably best described, in a broad, general sense, as aquicludes within the Floridan Aquifer. Locally, however, hydrologic properties of the lithofacies display much variation and can represent important transmissivity zones. The dolomitized and grain-supported lithofacies appear to be the most permeable zones (Figures 3 and 4). The nature and degrees of dolomitization can affect porosity so that substantial variations are recognizable. Ancient and modern interactions of marine and fresh waters with the carbonate rocks have produced substantial changes in rock textures and mineralogies (see diagenesis section). Dissolution appears to have been particularly instrumental in contributing to these changes. Groundwater dissolution is usually greatest in a thin zone just below the water table and which fluctuates with changes in sea level (Stringfield and LeGrand, 1966). The great extent of sea level changes during the Pleistocene has caused vertical changes and migration of zones of maximum dissolution.

Salt-water encroachment, through Man's activities, is being experienced along present day coastal areas of western Florida (Parker, 1975b). This study has shown former, natural salt-water encroachments to have occurred repeatedly with dramatic effects on the texture and mineralogy of the carbonate aquifer. Present day water chemistry is in part, also controlled by the aquifer rock composition and texture and the degree of it's dissolution. The high-sulfide content of some of the deeper aquifer waters can be directly attributed to the dissolution of gypsum ($CaSO_4$) originally present in the rocks. This study has discerned the origin and distribution of the gypsum and it's former presence in the rocks closer to the surface. Future diagenetic changes will involve the processes of dissolution, calcitization and cementation, recrystallization, and dolomitization. Such changes will affect fluid mobility and alter the currently recognized zones of permeability and impermeability.

DETECTION OF SUBSURFACE DISSOLUTION CAVITIES

Introduction

The cavernous nature of the limestones in the Floridan Aquifer accounts for the high transmissivity zones present. Detection of these large dissolution cavities by drilling is limited to the drill site area and is very expensive. An offshoot of this project evolved as a consequence of the concern in the ability to recognize and define subsurface dissolution cavities more cheaply and efficiently. The importance attributed to the detection of near surface (0-50 feet) dissolution cavities is due, in part, to problems they pose for the planning of major construction projects, housing developments, nuclear power plants, and groundwater flowage. This report presents the results of a limited test to determine the feasibility of subsurface dissolution cavity detections with electrical resistivity measurements. The goal was to correlate resistivity anomalies indicative of dissolution cavities with known voids detected by a shallow drilling program. Formal publication of this supplemental investigation can be found in Smith and Randazzo (1975).

Resistivity methods have traditionally been regarded to be of limited value for geophysical exploration, having applications only for unique situations. Heiland (1940) and Jakosky (1950) have comprehensively summarized the theory and practical uses of electrical exploration whereas Van Nostrand and Cook (1966) have exhaustively treated the concepts of interpretation of data. Bristow (1966) presented a new technique for the detection of subsurface cavities which involved placing one of four electrodes at a distance of effective infinity. Phillips and Standing (1969) discussed a more complicated, but essentially similar process for the electrical detection of caves. A recent report (Bates, 1973) summarizes all geophysical methods for the detection of subsurface cavities and regards electrical resistivity measurements as most promising. Bates presented results of research designed to test and improve the Bristow Method.

Measurements of electrical resistivity were made during April, 1974, in Citrus County, about 3 miles west of Homosassa Springs, Florida. The area represented a portion of a large (one square mile) tract of land that had been cleared of brush and small trees, leveled with a maximum of three feet of fill, and surveyed for commercial development. The general elevation is approximately 8 feet above sea level and the water table was between 3 and 5 feet below the surface at the time of the survey. The Inglis Formation is exposed at the surface and, except for the thin overburden of fill and numerous subsurface, water-filled cavities, should appear electrically as a homogeneous medium.

The area was first investigated for subsurface cavities by means of 38 drill holes (DH) located on a grid pattern having an equal spacing of 300 feet. Two of these holes were cored to a depth of 65 feet. The resistivity surveys were conducted about wash boring DH 23 (75 feet deep) in order to verify the detection ability for a large dissolution cavity known to exist between 38 and 45 feet. This wash boring encountered moderately hard Inglis limestone at a depth of three feet below the drilling surface. Resistances offered to drilling by the subsurface rocks varied with depth and only soft limestone occurred directly below the cavity for six feet. The very hard rock below a depth of 58 feet was probably dolostone.

Wash boring DH 34 (25 feet deep) was selected for a resistivity survey in order to test the detection ability for a shallow cavity which occurred between 15 and 19 feet. Rock encountered in wash boring DH 34 was generally softer than that in DH 23. Drill hole DH 33 was included in this resistivity survey because of its proximity to DH 34 and to document the actual rock types present.

Groundwater dissolution has been discussed in other sections of this report. Porosity and permeability trends develop along original faunal distributions and are dependent on aragonite, low-Mg calcite, and high-Mg calcite ratios in shells and skeletons. The abundant moldic porosity found in this area suggests such an origin (Textoris et al., 1972). The larger dissolution cavities encountered may represent an enlargement of moldic pores to the extent of creating nonfabric selective vugs, which eventually merge into a substantial cavity. The role of joint solution could not be documented in this study area.

Resistivity Measurements

The basic procedure of the resistivity method is to measure at the surface the potential gradient associated with a known current flowing into the earth. Anomalies in electrical conductivity at depth appear as variations of the potential drop. The recorded variable is an apparent resistivity and reflects an averaging effect of electrical resistance through all material penetrated.

All measurements were made with a Keck Earth Resistivity meter model VB-63, which permitted manual control of current flow direction and provided for accurate nulling of self potentials. Due to the reconnaissance nature of the investigation, the Wenner configuration of four equally spaced electrodes was used exclusively. Both sounding and profiling data were collected, with several electrode arrays arranged perpendicularly about bore hole sites.

Table 3 lists sounding data for various east-west and north-south electrode spacing centered on drill holes DH 23 and DH 34. Values recorded during repetitive measurements are also given. In all cases, the value ρ is the product of resistance in ohms and "A" is electrode spacing in feet.

Table 3. Sounding data for east-west and north-south oriented resistivity measurements over drill holes DH 23 and DH 34. "A" is electrode spacing in feet and ρ is apparent resistivity in ohms-feet. Asterisk (*) indicates low confidence value due to self potential uncertainties.

	DH 23		DH 34	
A	E-W	N-S	E-W	N-S
5			61, 70	58, 58
10	29, 28	36, 46	33, 35	37, 40
15			38, 38	39, 48
20	46*, 34	50, 80	28, 28	32, 36
25			22, 24	22, 25
30	57, 48	54, 64	33, 38	12, 28
40	40, 40	64, 104	26	27
50	36, 36	40*, 50		
60	38*, 30	37, 51		
70	19	56*		

Profiling measurements, those with a constant electrode spacing but with array centers moved throughout a perpendicularly arranged grid pattern, were made about drill holes

DH 23, DH 33, and DH 34. Measurements were made on north-south and east-west axes with the electrode array centered on, but perpendicular to, the axis. Table 4 lists the results. Based on drilling results and sounding data, an electrode spacing of 40 feet was selected for DH 23 and a spacing of 25 feet was used for DH 33 and DH 34. Accordingly, the profiling results, while representing a cumulative or apparent resistivity, can demonstrate anomalies in resistance, i.e. dissolution cavities, that are present throughout a certain thickness or at a particular depth. Graphs of the profiling data can be found in Smith and Randazzo (1975).

Discussion

Mooney (1954) has discussed the problem of depth determination at length and Parasnis (1962) has presented a summary of work relating the fraction of current reaching depths related to electrode spacings. In general, estimates of the effective depth of penetration vary from A/4 to 2A, where A equals electrode spacing. In view of the high water table and overall low values of resistivity recorded in this survey, the effective depth has been assumed to equal electrode spacing.

The sounding results for DH 23 (Table 3) demonstrate an initial general increase in resistivity with electrode spacing, and therefore depth, for arrays oriented both north-south and east-west. The apparent resistivity peaks at approximately 30-40 feet, then drops sharply, suggesting the presence below that depth of a low resistance solution cavity. This is corroborated by the coring results indicating a void between the depths of 38 and 45 feet. The resistivity high overlying the solution cavity cannot be correlated to a more resistant zone, but a general pattern of low resistance bounded by sharp high resistance has been theorized by Cook and Van Nostrand (1954) for filled sinks. The general trends of these data can best be visualized by plotting, on log-log scales, apparent resistivity versus electrode spacing (Figure 2 of Smith and Randazzo, 1975).

Sounding data for DH 34 (Table 3) show an initial decrease of apparent resistivity, followed by a slight increase, and then a decrease from about 15 to 25 feet depth. The higher values (at A = 5 feet) probably represent a strong influence from the undersaturated fill material an effect that is considerably dampened with electrode spacings of 10 feet or greater. Interpretation of the data indicates a possible dissolution cavity between 15 and 25 feet depth. The actual void is between 15 and 19 feet as discovered by drilling. Figure 2 of Smith and Randazzo (1975) again illustrates the general trends of these data.

Table 4. Apparent resistivity data (profiling) along east-west and north-south axes over drill holes DH 23 (A = 40 feet), DH 33 (A = 25 feet), and DH 34 (A = 25 feet). Values are in ohms-feet. Asterisked * value is of low confidence.

Hole	Distance of Array center from hole (feet)	E-W Arrays		N-S Arrays	
		N	S	E	W
DH 23	0	40	40	64	64
	15	152	44	84	48
	30	132	60	88	132
	45	60	72	140	92
	60	280	100	60	128
DH 33	0	53	53	80	80
	25	53	46	75	112
	50	9	135	120	150
	75	10	93	122	40
	100	13		14	35
	125	10		48	10
	150	15		25	22
	175	10		20	70
	200	11			20
	225	17			27
	250	19			18
	275	33			34
	300	43			
DH 34	0	22	22	22	22
	25	30	68	26	78
	50	54	60		55
	75	88	18	75	43
	100	53	46	22	165
	125	31	22		27
	150	22	16*		18
	175	23	30		
	200	21			
	225	31			
	250	22			

It seems apparent that simple resistivity measurements requiring uncomplicated interpretation and modest expense, can be used to survey the type of featureless, essentially homogeneous karst terrain that is characteristic of north and central Florida. The potential of this method as a preliminary tool in efficiently planning limited drilling programs for the detection of shallow solution-filled voids appears significant.

SUMMARY

Two of the most important stratigraphic carbonate units of the Floridan Aquifer are the Inglis and Avon Park Formations. These formations were deposited in a shallow marine environment and represent a complex history of deposition and diagenesis. Three principal lithofacies are recognizable (Table 1). These are: (I). a biomicrite-poorly washed biosparite; (II). a dolomitized facies; and (III). pellet- and intraclast-bearing biosparite-biomicrosparite. Each lithology represents a well-defined environment characterized by distinct sedimentologic processes.

Porosity in these rocks is largely fabric controlled (Figures 3 and 4) and is a function of both primary deposition and diagenetic history. Biosparites and dolomitized sections generally have greater porosity than biomicrites. The most common type of visible porosity in the biosparites is interparticle. Moldic pores are most abundant in the dolostone and biomicrite assemblages. The general tendency has been towards the obliteration of primary, and even secondary, porosity through a variety of sequences including compaction, infilling, calcitization, and dolomitization.

The varied forms of diagenesis include those that affected the grains solely, caused the precipitation and alteration of chemical cements, and affected all rocks indiscriminately. Micritization of grains is brought about by bacterial action or strain-induced physical-chemical processes. Dissolution of grains is the result of the chemical instability of high-Mg calcite and aragonite, which originally composed the grains, after the introduction of these grains to water of a different chemical composition from that of sea water.

Three different chemical cements are recognized. Scalenohedral crystals have been precipitated from marine water along the test walls of internal chambers of fossil tests. Small, equant, blocky crystals have been precipitated from meniscus fluid in the vadose zone of groundwater as coatings between grains. Large rhombohedral crystals have been precipitated from fresh water of the phreatic zone of groundwater as partial and complete fillings of intraparticle and interparticle spaces.

Aggrading neomorphism of calcite to calcite is common and is interpreted to take place in relatively fresh water. The process appears to be solely coalescive neomorphism.

Rock types of aggrading neomorphism can involve dolomite. Coalescive neomorphism of dolomite is restricted to rocks which have been extensively dolomitized at some stage prior to the commencement of the coalescive neomorphism. Porphyroid neomorphism of dolomite occurs simultaneously with initial dolomitization and appears to originate solely in micrite.

Three distinct textures of dolomitization are present and are the result of varying chemical environments and original mineralogy of the sediment. These textures are: (1). replacement dolomitization of the total sediment so that textures present prior to dolomitization are preserved; (2). dolomitization by aggrading neomorphism; and (3). replacement dolomitization of fossil grains and pellets only.

Dolomitization that is commonly observed to have taken place in such a way as to preserve original textures is interpreted to be the result of interstitial water with a Mg/Ca ratio greater than 2/1. Such water may develop by evaporation of sea water in a sabkha-type environment by the precipitation of gypsum and subsequent removal of Ca^{+2} ions, thus creating a highly concentrated, magnesium-rich solution. As this solution sinks downward through the sediments, dolomitization occurs. For aggrading neomorphism of dolomite to occur, the Mg/Ca ratio must be between 2/1 and 1/1. The creation of interstitial water with this specific range of Mg/Ca concentrations may occur upon the removal of Mg^{+2} ions from downward-seeping, dolomitizing brines created in a sabkha environment, or the result of intermixing of subterranean fresh water and salt water derived from either groundwater sources or upon sea water encroachment. Selective replacement of fossils and pellets by dolomite is attributed to mineralogic alteration of the matrix that rendered it less susceptable to dolomitization than the grains which did not undergo the same changes.

Hydrologic data demonstrate the abundance of water and storage capacity of the Floridan Aquifer, as well as it's cavernous nature. Petrographic controls significant to the functioning of the hydrologic system of the region include the lithofacies present and their diagenetic history. Dolomitized and grain-supported biosparites are more important as zones of transmissivity. The nature and degree of dolomitization, calcitization, and dissolution are of fundamental importance in bringing about the substantial changes in rock texture and mineralogies. Ancient and modern salt-water encroachments have also affected rock properties which influence groundwater flow and chemistry.

Attempts to determine the presence of water-filled, shallow, subsurface dissolution cavities, by means of electrical resistivity measurements, were successful. Values from profiling and sounding measurements employing the Wenner electrode arrangement in Citrus County, Florida, were interpreted as indications of dissolution cavities at a depth of 38 feet at one site and 20 feet at another. A shallow drilling program at the sites encountered dissolution voids at these depths, substantiating the effectiveness of the method. The electrical resistivity measurements method demonstrates a valuable auxiliary tool for the planning of drilling programs to detect subsurface cavities.

The petrographic model presented here provides the framework into which the known geohydrologic and hydrochemical models can be integrated. This study has determined those petrographic controls significant to the functioning of hydrologic systems. By determining the lithologic factors affecting groundwater flow, understanding their development, and recognizing their distribution, the geohydrologic model of this region has been substantially improved. This model will be useful in exploring for or developing better groundwater supplies in an effective and systematic manner. It will aid in predicting and mapping the distribution of liquid wastes and other polluting effluents entering the aquifer system because of the information it provides to the regional flow patterns.

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