WATER, OIL, AND THE GEOLOGY OF COLLIER, LEE AND HENDRY COUNTIES

Miami Geological Society
The 1980 Fieldtrip Experience
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edited and compiled by

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Acknowledgements

I thank the South Florida Water Management District for its help in this endeavor. In particular, Nietha Long typed the manuscript, and Maureen Miller assisted on graphics.

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ROAD LOG

1980 MGS Fieldtrip Experience

DAY 1

Total Mileage	Mileage from preceding location		Travel guide
0.0	0.0		Depart from the parking area between the Science Bldg. and Otto G. Richter Library at the University of Miami. Turn right on San Amaro Dr. and proceed to Blue Road. Turn left on Blue Road and proceed to Red Road. Turn right on Red Road and proceed to Sylvania Blvd. Turn left on Sylvania and proceed to Tamiami Trail. Turn left on Tamiami Trail (US 41) and head west to Collier-Seminole State Park.
26.9	26.9		Junction with US 27
58.5	31.6		Jetport Training Site
82.7	24.2		Ochopee
87.8	5.1		Junction with SR 29
104.1	16.3	Stop No.1	Collier Seminole State Park. Park by Bay City Walking Dredge. Presentation by Sam Upchurch and Richard Strom. Return to Tamiami Trail and head west
104.7	.6		Junction of Tamiami Trail and SR 92; turn left and proceed to Marco Island
114.7	10		Intersection of South Barfield Dr. and San Marco Road (SR 92 becomes San Marco Rd). Turn left on South Barfield Dr. Dune areas visible.
115.4	.7		Intersection of South Barfield Dr. and Inlet Dr. Turn left on Inlet Dr. Turn left on Watson, then right on Scott, left on Kirk, right on Highland (sometimes Caxambas) Road.
116.7	1.3	Stop No.2	Intersection of Highland and Indian Hill. (Highland may be replaced by Caxambas in places) Calusa Shell mound on NW corner. High sand dune forming Indian Hill. Presentation by John Beriault, Jr. Proceed over Indian Hill to Scott. Make right turn on Scott and proceed back to South Barfield Dr., the same way as in. Drive north on South Barfield.
118.7	2		Intersection of South Barfield Dr. and San Marco Rd. Continue North.
120.8	2.1		Intersection of N. Barfield and North Collier Blvd. Right turn on Collier Blvd. Return to mainland.
128.7	7.9		Junction of SR 951 and US 41. Proceed north on SR 951.
129.1	.4		Turn right on dirt road into rockpit.
129.2	.1	Stop No.3	Marco Island Water Supply rockpit. Presentations by Mark Stewart, Theodore Lizanec, and Paul Jakob. Return to 951, turn right and head north.
137.4	8.2		Intersection of SR 951 and SR 846. Turn right on SR 846 and head towards Corkscrew Swamp Sanctuary.

151.7	14.3	Stop No.4	Corkscrew Swamp Sanctuary. Presentation by Mike Duever.
			LUNCH.
			Return to SR 846 turn right and proceed south to SR 858.
159.0	7.3		Intersection of SR 858 and SR 846. Turn left and drive east on SR 858.
159.7	.7	Stop No.5	Pliocene Reef, James Hill Property. Presentation by Jack Meeder. Return to SR 846, turn left and drive south towards Mule Pen Quarry.
166.6	6.9	Stop No.6	Pliocene Reef. Mule Pen Quarry (Meekins Inc.) on north side of SR 846. Presentation by Jack Meeder. Return to SR 846, head west to Ramada Inn, Vanderbilt Beach.
177.9	11.3	Stop No.7	The beach at the Ramada Inn, Vanderbilt Beach. Presentation by Sandy Nettles.
			DAY 2
177.9	0		Ramada Inn, Vanderbilt Beach. Presentations by Woody Wise, Susan Klinzing and Stan Winn. Proceed east .7 mile to junction of SR 846 and C-901 (Vanderbilt Dr.). Turn left and proceed north on C-901.
182.8	4.9		Intersection of C-901 and SR 865. Turn left on SR 865.
201.9	19.1		Intersection of SR 865 and Kelly Road; sign pointing to Sanibel and Captiva Islands.
202.2	.3		Intersection of Kelly Road and McGregor Blvd. (SR 867). Turn left and head west on SR 867. Proceed to Sanibel Island via Causeway and Lindgren Blvd.
209.8	7.6		Intersection of Lindgren Blvd. and Periwinkle Way. Turn right on to Periwinkle.
212.7	2.9		Intersection of Periwinkle and Tarpon Bay Road. Turn right on Tarpon Bay Rd.
212.9	.2		Intersection Tarpon Bay Rd and Sanibel-Captiva Rd. Turn left on Sanibel-Captiva Road.
215.0	2.1	Stop No.8	Island Water Association (IWA) Reverse Osmosis Plant located on left (south) side of road. Enter by means of dirt road. Tour of facility given by Ian Hynd (IWA). Presentation by Tom Missimer. Return to Sanibel-Captiva Road, turn right, drive east to Sanibel Lighthouse Park. Sanibel-Captiva Road will turn into Palm Ridge Road, then Periwinkle. Follow Periwinkle to Sanibel Lighthouse Park.
221.7	6.7	Stop No.9	Sanibel Lighthouse Park. Bear to left towards fishing pier and head-quarters of J.N. Ding Darling National Wildlife Refuge and park. Shelling excellent! Presentation by Don Moore and Tom Missimer. Return to Periwinkle, then exit from Sanibel Island by turning right and heading north on Lindgren Blvd. Proceed across Causeway and back onto SR 867.
232.4	10.7		Intersection of SR 867 and 865. Continue on SR 867.
239.2	6.8		Intersection of SR 867 and 873 (Colonial Blvd. or 82B). Turn right on Colonial Blvd. and head east.

243.5	4.3		Turn right off (Colonial Blvd (82B) onto unmarked road leading to Harper Bros. quarry operation.
243.8	.3	Stop No.10	Harper Bros. Dolomite Quarry. Presentation by Jack Meeder. Return to Colonial Blvd, turn right and head east; follow signs for Hwy 82B.
246.1	2.3		Follow Hwy 82B as it turns left off Colonial Blvd. If you pass under I-75 you've gone too far.
247.9	1.8		Intersection of SR 82 and 82B. Turn right on SR 82 and head east.
259.2	11.3	Stop No.11	Lee County Spray Irrigation Site. Pull off onto road shoulder. Presentation by Lou Motz and William Bocskocsky. Return to SR 82.
275.2	13.2		Intersection SR 82 and SR 29. Turn left onto SR 29 head north.
278.3	3.1	Stop No.12	Sun Oil Tank Farm - Felda Oil Field. Pumping wells visible in NW-SE trend. Pull into Tank Farm. Presentation by George Winston. Return to SR 29 and head north.
295.5	17.2		Intersection of SR 80 and SR 29 in LaBelle. Turn right and head east on SR 80.
299.5	4.0	Stop No.13	Turn right into Port LaBelle's Water Plant - Wellfield Area. Presentation by Tom Tessier. Return to SR 80 and head west to SR 29.
303.5	4.0		Intersection of SR 80 and SR 29 in LaBelle. Turn left and head south to Tamiami Trail (US 41).
363.5	60.0		Intersection Tamiami Trail and SR 29. Turn left and return to Miami.
451.3	87.8		University of Miami, parking lot between library and science building.

MAP OF FIELD TRIP STOPS

ROLE OF HUMIC SUBSTANCES IN TRANSPORTATION AND DEPOSITION OF CALCIUM

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ABSTRACT

Comparison of calcium activities determined by specific ion electrodes with theoretical activities of calcium calculated from the Davies equation suggests that a significant amount of calcium is in transport in waters of southwest Florida as complexes with organics (humic substances). The Blackwater River, Collier County, Florida, is rich in humic substances derived from cypress swamps, salt marshes, and mangrove swamps. Between 33 and 75 percent of the calcium dissolved in the river is bound to soluble humic substances. The greatest relative amount of complexing is in "fresh" waters where up to 0.19 mg Ca^{+2}/mg organics can be complexed. In brackish and sea water the relative amount decreases owing to competition for bonding sites with other cations. The organometallic complexes are significant in that they may be responsible for up to 75 percent of chemical weathering in aquatic environments and they appear to be a major vector for calcium fixation in the hard parts of marine and estuarine organisms.

INTRODUCTION

The coast of southwestern Florida, including the Ten Thousand Islands, constitutes the most extensive mangrove swamp in North America. This coastal environment forms much of the basis of the food chain for coastal and offshore biota (Lugo and Snedaker, 1973). Mangrove dominated, detrital food systems depend upon production of particulate and soluble humic substances, which are either consumed directly by higher organisms or metabolized by bacteria. Seaward transport of these organics is by tidal flushing and discharge of coastal rivers, such as the Blackwater River at Collier-Seminole State Park, Collier County, Florida.

Manskaya and Drozdova (1968), Saxby (1969), and Jackson and others (1978) have shown that humic substances produced during the partial decay of plant litter are capable of complexing or chemically chelating a variety of cations. Humic substances have poorly defined structures and range in molecular weight from 2,000 to 300,000 (Schnitzer, 1966; Eglington and Murphy, 1969). They are electrically charged and, consequently, solubility and colloidal stability in water are controlled by numerous factors, including pH and ionic strength (salt content) of the solution. The Blackwater River system has from 600 to 10,000 mg/l dissolved organics. At salinities below approximately $20^{0}/oo$ the humic substances are largely dissolved or in a stable suspension. Above this salinity, the organics begin to flocculate owing to an increase in pH and, more important, an increase in salt content. Cations most likely to be complexed with humic substances are those with small ionic radii and charges greater than +1 (Manskaya and Drozdova, 1968). Thus, calcium, magnesium, mercury, cadmium, zinc, iron, and many other cations can be significantly complexed.

In order to test the hypothesis that humic substances are important complexing and transport agents of cations in mangrove swamps, we have undertaken a research program in the Ten Thousand Islands. A number of our samples are from the Blackwater River (Fig. 1). We have sampled water under a wide range in conditions with salinities from 3 to $28^{0}/oo$ and volatile dissolved organic contents from 610 to 10,682 mg/l in the river.

Lowest organic content and salinity can be found near Stop 1, the boat basin in Collier-Seminole State Park. This locality represents the innermost boundary of the mangrove swamp. Inland from this site, where water moves primarily as sheetflow and shallow ground water, the organics are derived from decomposition of vegetable matter in uplands, cypress strands and scattered, small wet pararies. At the transition into mangrove swamps there is commonly a small salt marsh, such as can be seen at this stop. The salt marsh supports a stand of *Juncus*, with scattered *Spartina* and other salt-tolerant plants. Salt marsh is not of major importance in the headwaters of the Blackwater River, but is extensive in drainage systems to the south.

The mangrove fringe averages 11 km in width in the vicinity of the Blackwater River. The inner part of the swamp, which includes all of the Blackwater River shown in Figure 1, consists of thick growths of red mangrove (*Rhizophora*) and black mangrove (*Avicennia*). Small tidal channels allow development of less salt tolerant, mesic plant communities. The outer part of the swamp, which extends from sample station 16 to the open Gulf of Mexico (Fig. 1), is characterized by open bays of near-normal salinities and scattered mangrove islancs. The bays are shallow (mean depths less than 1 m) and contain numerous oyster (Crassostrea) reefs. These reefs are generally linear in nature and are aligned so as to maximize access to detrital food sources.

Sediments in the three major areas of the Blackwater River vary dramatically in composition. The higher areas of the cypress strands and associated pine flatwoods are underlain by fine sands. Wet areas in this environment contain thin peats of fresh water origin (Cohen and Spackman, 1977). The salt marsh areas are generally underlain by thin peats as well. The mangrove swamp is underlain by thicker peats and mucks (Cohen and Spackman, 1977). Near the tidal channels, where terrigenous sediments (silt, fine sand) can enter the swamp, there are mucks with up to 50 percent organic content. Interiors of swamps contain true peats. The beds of rivers, such as the Blackwater, are fine to medium, quartz sand. All carbonate sediments are rapidly destroyed in the swamps by dissolution in the acid, organic-rich water. The bays contain terrigenous fine sand, silt and clay mixed with low-magnesian calcite silt The sediments range from 4 to 76 weight percent carbonate. Much of the carbonate fraction of these sediments is derived from attrition of oyster shells (Williams, in prep.). In addition, Williams has found well developed, unabraded calcite rhombohedra in the sediments of these bays. Our work shows that, if all of the calcium is considered to be unaffected by organic complexing, waters of the bays are over saturated with respect to calcite by almost 20 percent and, thus, calcite crystals could form.

Methods

Samples were taken in the Blackwater River (Fig. 1) on February 25, 1978. Eh, pH, temperature salinity, and "apparent" calcium activity were measured in the field. Samples of water were pumped into sample bottles using a peristaltic pump and the samples were refrigerated on return to the lab. All major anions and cations were measured in the lab according to standard methods.

In order to determine how much calcium is in transport as an organic complex, we designed an experiment to partition total calcium between organically-bound calcium and free or inorganically-complexed ions in solution. The total concentrations of calcium in filtered water samples were determined by atomic absorption spectrophotometry. The "apparent" activities of free Ca^{+2} ions in solution were measured potentiometrically in the field using an Orion specific ion electrode with a 4M KCl salt bridge to a silver chloride electrode.

Using the "apparent" calcium ion activities and the calcium ion activity coefficients calculated from the Davies equation in program WATEQF (Plummer and others, 1976), the concentrations of free and inorganically-complexed calcium ions in solution were calculated. The difference between the calculated and measured calcium concentrations is taken to be "organically-complexed" calcium. Errors introduced into the activity measurements, specifically the liquid junction potential and membrane salting, yield high "apparent" Ca^{+2} activities. Consequently, the values given for "organically-complexed" calcium are minima.

Organic content was determined by filtering the water and evaporating a known volume to dryness at 103° C for 1 hour and at 180° C for 1 hour. This resulted in gravimetric determination of total dissolved solids. Volatile dissolved solids (dissolved organics) were determined by igniting the dissolved solids residue for 30 minutes at 550° C (Jenkins and others, 1973).

Results

Figure 2 shows the distribution of dissolved organics in the Blackwater River on February 25, 1978. Notice that minimum dissolved humic substances are found at the head of the river, where salinities are least. As salinity increases the organic load increases due to contributions from the mangrove swamp. The samples from highest salinities were taken near the mouth of the river (Fig. 1) and contain maximum organics. The abnormally high organic load in the sample at 27‰ salinity (Fig. 2) is undoubtedly due to flocculation. At the time of sampling upper river water with salinities less than 20‰ was a clear, rich brown color and obviously had little or no suspended particulates. As salinity increased above 20‰, however, the water became a turbid, opaque brown. This persisted until station 16, which is very near normal seawater conditions, and indicates that the dissolved organics were flocculating and precipitating in the salt water - fresh water mixing zone. Undoubtedly, filtration of these fragile floccules destroyed some of them and resulted in an abnormally high dissolved organic load reported for the 27‰ salinity sample.

If you compare the pattern of organic content in the water with the partitioning of calcium (Fig. 3), it is apparent that the relative amount of organically-complexed calcium changes as dissolved organic load changes. At low salinities a large proportion (up to 75 percent) of the calcium is bound on organics. As salinity increases the absolute amount of organically-bound calcium does not change drastically, but the relative amount decreases. We feel that there is a competition between calcium and other ions for sites on the organic molecules. At low salinities, there is little competition of ions for complexing sites and the majority of the calcium is easily complexed. As salinity or salt content increases, other ions, which are present in higher concentrations than calcium, begin to compete with calcium for sites. The first evidence of this competition is that the organics flocculate when salt content reaches approximately 20⁰/oo. Second, the amount of free calcium increases. As will be shown below, this could only happen if other ions are blocking complexing in the high organic-content waters of the river mouth.

A traditional manner of determining if complexing takes place is to calculate adsorption isotherms for the metal being complexed and the complexing medium (Riley, 1939). A maximum adsorption capacity can be calculated. In the case of the Blackwater River samples, the adsorption isotherm is not followed and instead an inverse relationship between amount of free calcium and amount adsorbed per unit mass of adsorbant exists. This relationship typically results in either of two cases, (1) saturation with respect to some mineral precipitate or (2) some other cation is more effective at being complexed than the cation of interest. The first case is not likely within the river since only sample 16, which is at the mouth of the river shows saturation with respect to calcite. None of the samples are saturated with respect to aragonite. Magnesium is equally complexed according to other data we have obtained, so dolomite is an unlikely mineral to form.

The second case outlined above seems important. At low salinities up to 0.19 mg Ca/mg organics have been complexed. At higher salinities, the amount bound decreases to a minimum of only 0.02 to 0.04 mg Ca/mg organics. Mean amount of calcium complexed is 0.08 mg Ca/mg organics. If there were no competition for complexing sites, then the amount of calcium complexed per unit mass of organics would follow the isotherm and either continue to increase with increased calcium content (Fig. 3) or remain constant if the complexing maximum has been reached. Since the amount of calcium per unit mass of organics declines with increasing salinity, it can be concluded that other ions are more effective at complexing and calcium is either remaining at that level complexed upstream, before competition, or it is being removed from the complexes and is being replaced by other ions. Figure 3 suggests the former of these possibilities.

CONCLUSIONS

Clearly, there are two important phenomena that are shown by the result of this study. First, chemical weathering of limestones and transport of calcium in low salinity waters are dominated by organic complexing of calcium. If residence times are sufficient for both inorganic and organic equilibria to occur, then the amount of chemical weathering can be prodigious. Studies of the chemistry of calcium in organic-rich fresh waters could elucidate this phenomenon. Simple calculations of inorganic equilibria will be misleading. In fact, it is possible that equilibrium calculations assuming only inorganic complexing will indicate that the water is saturated with respect to a particular mineral when it is not. This is the case with our sample 16, which appears on the basis of total calcium to be over saturated with respect to calcite. In fact, the sample is not over saturated as almost 50 percent of the calcium is tied up in organic complexes and is not directly available to precipitate calcite.

The second important result of this study is the behavior of the organics at the salt-water fresh water interface. As the floccules form, they contain complexed calcium and numerous other cations. These floccules either (1) are redissolved during a later tidal cycle, (2) become part of the organic matrix of the sediment, or (3) are ingested by detritus feeders. The former case will only result in additional transport before one of the latter two cases happens. The second case undoubtedly occurs and results in a high organic content in the sediments of the bays. Diagenesis of bay sediments, including bacterial breakdown of the floccules, may create calcium-rich interstitial waters and hasten formation of authigenic carbonate cements. The third case may be the most significant. Many detritus feeders, such as oysters, are susceptible to trace metal contamination. Ingestion of floccules may serve as a vector for introduction of these trace metals to the food chain. Additionally, it may well be that oysters obtain the calcium required for shell production through ingestion of these floccules.

We are continuing our studies into the technology required to identify organic complexing in water and, in particular, the use of specific ion electrodes for this task. We are also studying the sediments of the shallow bays and rivers of southwest Florida in order to determine the origins of carbonate sediments therein. Finally, a colleague, L.J. Charlesworth, is cooperating with us by examining the origin of reefs and associated sediments.

REFERENCES CITED

Cohen, A.D., and Spackman, W., 1977, Phytogenic organic sediments and sedimentary environments in the Everglades - mangrove complex: Paleontographica, v. 162, p. 71-114.

Eglington, G., and Murphy, M.T.J., 1969, Organic geochemistry: New York, Springer-Verlag, Inc., p. 534-557.
Jackson, K.S., Jonasson, I.R., and Skippen, G.B., 1978, The nature of metals-sediment-water interactions in freshwater bodies, with emphasis on the role of organic matter: Earth-Science Reviews, v. 14, p. 97-146.
Jenkins, D., Snoeyink, V.L., Ferguson, J.F., and Leckie, J.O., 1963, Water chemistry laboratory manual: Assoc. of Environmental Engineering Professors, p. I-1, 1-I-1, 7.
Lugo, A.E., and Snedaker, S.C., 1973, The role of mangrove ecosystems: properties of a mangrove forest in south Florida: Report to U.S. Bur. Sport Fisheries and Wildlife, N.T.I.S. No. PB-231 741, p. 87.
Manskaya, S.M., and Drozdova, T.V., 1968, Geochemistry of Organic substances: New York, Pergamon Press, p. 345.
Plummer, L.N., Jones, B F., and Truesdell, A.H., 1976, WATEQF - A computer program for calculating chemical equilibrium of natural waters: U.S. Geological Survey, Water Resources Invest. 76-13, p. 61.
Riley, G.A., 1939, Limnological studies in Connecticut: Ecological Monographs, v. 9, no. 1, p. 55-94.
Saxby, J.D., 1969, Metal-organic chemistry of the geochemical cycle: Reviews of Pure and Applied Chemistry, v. 19, p. 131-150.
Schnitzer, M., 1971, Metal-organic matter interactions in soils and waters, in Faust, S.J., and Hunter, J.V., eds., Organic compounds in aquatic environments: New York, Marcel Dekker, Inc., p. 297-315.
Williams, M.J., in preparation, Origin of Recent carbonate sediments in the Ten Thousand Islands, Florida (M.S. Thesis): Tampa, University of South Florida.

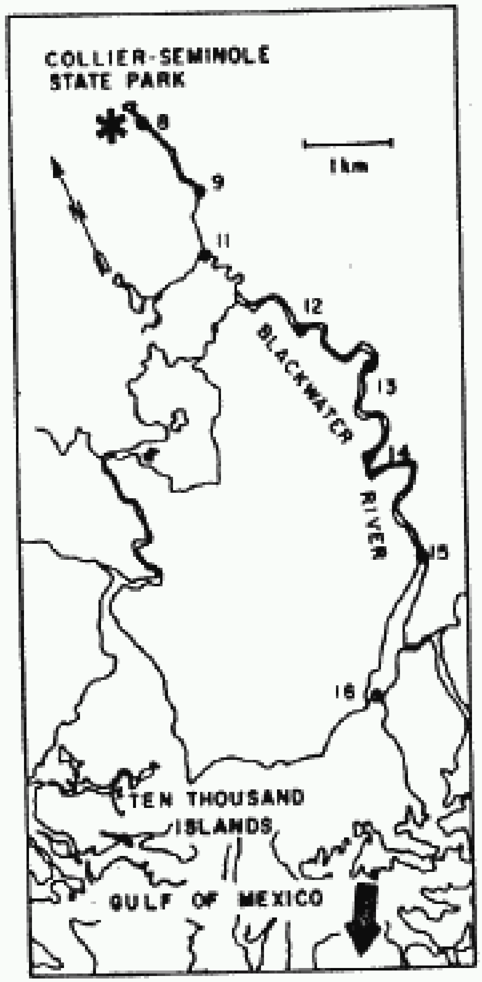

Figure 1. Location map showing sample sites in the Blackwater River. Star is location of Stop 1, Collier-Seminole State Park.

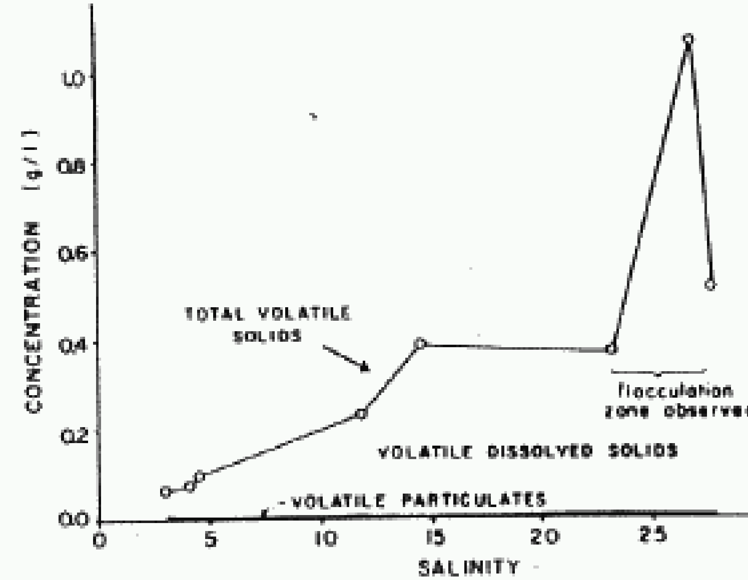

Figure 2. Distribution of volatile solids in Blackwater River.

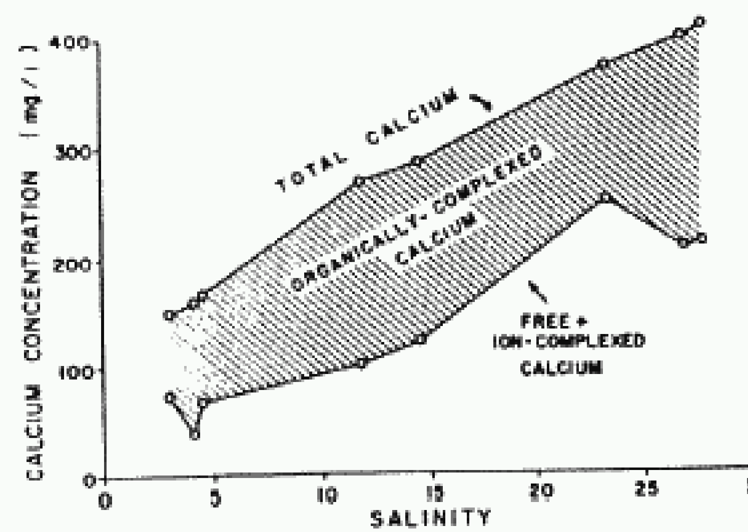

Figure 3. Distribution of total calcium and free plus inorganically - complexed calcium in the Blackwater River. Shaded area represents calcium thought to be organically complexed.

THE NATURAL FEATURES AND PREHISTORY OF MARCO ISLAND, FLORIDA

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INTRODUCTION

Marco Island, the largest of southwest Florida's Ten Thousand Islands is as remarkable in diversity of physical features as in size. The surface area of the island encompasses 2400 hectares (6,000 acres) (Gilliland, 1975) in the form of an irregular land mass extending 7.3 km. on a north-south axis and 8.75 km. on an east-west axis. However, Marco Island is truly noteworthy in a region where all features are less than 7.6 m. (25 foot) elevation (Scholl, 1964) due to its great variance of topographic relief. Land elevation can range from extensive mangrove swamps awash at high tide to 16 m. (50 foot) sand dunes at Caxambas (Cockrell, 1970). Between these extremes, there is also a large, level pineland area in the interior - a feature few other islands in south Florida can display (notable exceptions being Big Pine Key in the Florida Keys and Pine Island near Sanibel).

Marco Island's topographic features can be grouped chronologically into three main physical divisions. Cockrell (1970) surmises "the internal high dune ridges must be the oldest physiographic feature on the island." These dunes and the adjoining pineland areas are likely to be of Pleistocene origin (perhaps dating to Pamlico times), covering a Pliocene-era Tamiami bedrock formation. The Marco Island area has been portrayed on geologic study maps (Davis, 1943; White, 1970) as being situated at a transition zone between underlying Tamiami and Anastasia formations. Evidence suggests since their initial deposition, the dune ridges and interior features of Marco Island have been extensively altered by aeolian sand buildup and possibly a slight amount of aboriginal activity.

Fronting these earlier (Pleistocene) sand dunes and bordering the Gulf of Mexico to the west, is "a dynamic sand beach, shore and lagoon strand" with one or more "low ridged cape(s)"... of an "upland (nature) with well-developed ridge and swale topography (Miller, 1978)." White (1970) describes the coast as "progradational" and mentions "the broad succession of relict beach ridges and barriers" that form as a result of this outward buildup. Further modifications are taking place at the coast as the result of offshore bar deposition and rising sea level (Miller, 1978).

The formation of Marco Island's outer beaches is an ongoing process that began according to some estimates (Miller, 1978) approximately 6,000 years ago. This postulated age corresponds closely with eustatic sea level rise, which has determined rates of coastal sedimentation. Much of this highly organic accretion is linked to the continuing development of the vast mangrove swamps comprising the "drowned" coastline of the Ten Thousand Islands. These massive peat beds receive most of their sediment from biological sources - detrital matter from mangroves and remains of marine organisms (Scholl and others, 1969).

As distinct ecological communities these same topographic features can be discussed in slightly different fashion. The coastal beaches are inhabited by a largely tropical community of littoral plants growing in a medium of finely ground shell with a small percentage of sand. This environment is subject to immediate alteration or disruption by storms and tidal activity which can wash away a section of beach and close or open passes to estuarine areas overnight.

Vegetation

Bordering these backbays and surrounding Marco Island to a varying extent are the mangrove swamps - "mono-forests" consisting largely of red, black, and white mangroves (*Rhizophora mangle* L., *Avincennia nitida* Jacq., and *Laguncularia racemosa* L.) and buttonwood (*Conocarpus erecta* L.), with occasional low understory of saltwort (*Batis maritima* L.) or several other salt-tolerant plants. Despite the apparent floral monotony of this zone, the mangrove swamp system is probably the most intensively productive in terms of biomass of the many environmental regions in south Florida.

Upland and inland on Marco Island from the mangrove zone are saltwater marshes - transition areas containing black rush (*Juncus* sp.) and *Spartina* sp. grasses. Some freshwater marshes existed in a situation still further above sea level, but recent extensive development has eliminated all or most of them. The pinelands, on yet greater elevation, at one time covered a major portion of the flat, sandy terrain in the center of the island. Land height in relation to sea level varied from less than one meter to more than two meters for most of the pinelands. The plant community was predominately carribean slash pine (*Pinus elliottii* var. *densa* Little & Dorman), saw palmetto (*Serenoa repens* (Bartr.) Small), and a variety of herbs and grasses.

Above several meters elevation (above sea level), the pinelands yield to vegetation of the high sand dune ridges which are concentrated in the Barfield Bay/Caxambas Point area and on neighboring Horrs Island. The dune crest averages 6 meters and supports a dense xeric scrub vegetation composed primarily of low oak (Quercus sp.), various thorny plants (ex. Opuntia sp. cactus and Bumelia sp., buckthorn), and scattered saw palmetto. The plant community is similar to that found on certain high sandhills north of Lake Okeechobee, but with the inclusion of several tropical components.

Throughout the xeric scrub of the dune ridge are located scattered patches of tropical hammock which generally coincide with aboriginal sites. These discrete areas are characterized by gumbo-limbo (Bursera simaruba (L.) Sarg.), mastic (Mastichodendron foetidissimum (Jacq.) Cronquist), eugenias (Eugenia sp.), satinleaf (Chrysophyllum oliviforme L.), wild coffee (Psychotria undata J.), tall oaks, and other plants growing on archaeological depositions of thinly mixed black midden soil and shell. In the areas south around Caxambas, these dune hammocks have concentrations of exotic plants introduced during historic times by early white settlers. Century plant (Agave americana L.), Spanish bayonet (Yucca aloifolia L.), periwinkle (Catharanthus roseus (L.) G. Don), miracle leaf, a succulant (Kalanchoe pinnata Pers.), cathedral bells (Kalanchoe grandiflora A. Rich.), bowstring hemp (Sansevieria thyrsiflora Thunb.) and a wide variety of weeds are but a few of the feral introductions.

The final major ecological community can be found on the major undisturbed shell mounds on Marco Island and the surrounding region. On Marco Island, these sites are located either at the base of the dune ridges or in mangrove swamps, but always near navigable water. These artificial shell structures, often of several meters height, support more of the above-named tropical and exotic vegetation, much of it thorny and adapted to the dry, nearly desert-like conditions prevalent on these sites in the winter months. A study of the plant communities found on 21 random sites of this type extending from Cape Sable north to Mound Key in Lee County catalogued at least 201 species found on one or more locales. Of these, as many as 20-35 plant species can be commonly found growing on most unaltered shell mounds exceeding .5 hectare (about one acre) extent (Craighead, 1977).

Archaeological Periods

Marco Island has undergone various name changes during historic times. In the earlier archaeological literature, it is frequently referred to as "Key Marco," but this designation tends to apply only to the site worked by Frank Hamilton Cushing in 1896 on the north end of the island (an area today known as Old Marco Village).

Besides the Key Marco Site, Marco Island contains two other large shell mounds and many smaller ones of varying degrees of importance. The Goodland Point Site, surface-collected by John M. Goggin in the late 1940's, lies to the east. Caxambas Point with its lofty dune formation and neighboring shell mound is situated on the south end of the island.

Cushing (1896), Clarence Moore (1905), Ales Hrdlicka (early 1920's), Matthew Stirling (1930's), Goggin (1930's to 1950's), and other archaeologists have over the years made sporatic investigations at Marco Island. However, beginning in 1967, the Florida Department of Archives and History began a comprehensive survey and series of test excavations. The principal investigators (Morrell and Cockrell) discovered "a previously unsuspected cultural stage dating from ca. 500 to ca. 3,000 B.C...." (Widmer, 1974) which includes "...a new verified southern distribution for fiber-tempered ceramics... and the existence of the Late Archaic tradition in the Calusa sub-area" (Cockrell, 1970).

As a result of these conclusions derived from this survey and earlier archaeological work, two basic chronological divisions or stages have been formulated to explain the prehistoric (pre-Contact) aboriginal habitation of Marco Island - the (earlier) Archaic Stage and the (later) Formative Stage (further divided into three "Glades" periods).

The Archaic Stage in southwestern Florida has been tentatively dated back to 6,000 years B.P. The characteristic site types on Marco Island have been depicted as small camping areas on the high dune ridges which contain fiber-tempered pottery (Widmer, 1974).

During the Archaic Stage, Indians in Southern Florida "were semi-sedentary, basing their economy on hunting, fishing and gathering. They depended equally on terrestrial and marine resources." (Widmer, 1974). There was "no specialization of subsistence technology to exploit the rich marine environment to the fullest extent" (Cockrell, 1970). The early Archaic Period possessed no ceramics but the latter part of the tradition saw the introduction of fiber-tempered ceramics - the oldest pottery type in the New World. At Site 8Cr 112 on Marco Island, one sherd was C-14 dated by association with charcoal at ca. 3150 B.C., one of the oldest dates yet obtained for fiber-tempered pottery in North America. John M. Goggin classified fiber-tempered sherds in the Florida area into the "Orange Series" which includes Orange Plain, Orange Incised, and Tick Island Incised (Cockrell, 1970).

In addition to the above creamics, Archaic sites on Marco Island display limestone-tempered Perico Island Plain and Incised wares and a chalky, temperless pottery similar to St. Johns Plain. Two other artifactual traits for the Archaic stage seem to entail the use of shell tools with modified columellae and chipped stone stemmed projectile points for atlatls or spear throwers (Widmer, 1974).

The demarcation point (often referred to as the Transitional Period) between the earlier Archaic and the later Formative Stages is, as in most broad temporal divisions, not precise. By 800-500 B.C., cultural traditions had generally undergone a change in the south Florida area to an era marked by "ceramics, distinct in sand-tempered paste, and incised and/or ticked decorative motifs..." (Cockrell, 1970).

In addition to changes in pottery, the Formative Stage was marked by "the exploitation of the food resources of the tropical coastal waters, with secondary dependence on game and some use of wild plant food" (Goggin, 1949). This change in food-gathering patterns led to a shift in habitation from the small sand dune campsites to larger, more established settlements - villages of dwellings, possibly supported on piles, in lowland areas on or near navigable water. The resulting byproduct of this more efficient and specialized mode of environmental exploitation are the extensive shell mounds, often of 4 hectares (10 acres) extent or greater.

The new emphasis and dependence on marine resources during the Formative saw the development of "a very diversified shell tool industry" (Widmer, 1974) which utilized whole or partial lightning whelks (Busycon contrarium) and horse conchs (Pleuroploca gigantea) to create hafted and unhafted picks, hammers, gouges, and dippers. Clam (Mercenaria mercenaria) shells were sectioned and notched to produce a distinctive artifact which may have functioned as a net weight.

John M. Goggin, as the pioneer interpreter of south Florida archaeology, divided the Formative Stage into three (Glades) periods: Glades I, 500 B.C - 500 A.D.; Glades II, 500 A.D. - 1300 A.D.; Glades III (Climax), 1300 A.D. - 1600 A.D. or European Contact.

Glades I is subdivided into two parts, the first (Ia) saw the use of undecorated sand-tempered plain ceramics; the latter (Ib) encompassed the introduction of the earliest decorated ceramic styles of the Formative (Fort Drum Incised and Punctate). Glades II saw the introduction of additional decorative (incised) ceramic motifs (Gordon Pass Incised, Sanibel Island Incised).

Glades III has also been delineated in the main by changes in pottery type-styles. St. John's Check-Stamp, an "imported" pottery from northern Florida becomes abundant at the beginning of this period and serves as a general time marker. This last Glades period is further subdivided (Glades IIIa, IIIb, IIIc) on the basis of localized ceramic changes. Surfside Incised (Glades IIa); Glades Tooled, with its "pie crust-crimped" rim (Glades IIIb); and finally, Contact times (Glades IIIc) with the occurrence of Spanish Olive Jar pottery and other European trade goods - these are but a part of the artifactual evolution denoting cultural changes during the last 300 years of south Florida's prehistory.

The Glades III period (at last during its earlier portions) is considered the "climax" culturally of the Formative Stage. The extensive shell midden village complexes were in full development by this time and exhibited construction features such as canals, ramps, mounds, and platforms (Miller, 1978). Glades III is also the time (ca. 1300 A.D.) to which Cushing's famous Key Marco finds have been assigned (Widmer, 1974). This remarkable assemblage of carved wooden masks, ceremonial paraphernalia, tools, and weapons was recovered from a muck-filled "court" on the southwest corner of the Key Marco shell midden in 1896. This discovery still ranks as one of the most significant in terms of preserved wooden materials made in southeastern North America. Stylistic elements and motifs of the Key Marco artifacts link them tenuously with a broader regional cultural phenomena termed the "Southeastern Ceremonial Complex" - manifestations of a widespread and formalized "state-religion" practiced in varying forms throughout the Southeast.

Caxambas Point

Of the three major shell midden sites on Marco Island, only Caxambas Point retains even a trace of its former appearance in the face of intensive development. Cockrell, in his investigations indicated aboriginal shell deposits at the site may be as deep as 9 meters (30 feet) (Cockrell, 1970).

The name "Caxambas" is as striking as the place itself and is apparently of quite early origin. D. Graham Copeland, an early South Florida historian, contacted one linguist who felt the name may have originally been "Cajimbas" and stated, "this is probably a Calusa name and cannot be translated" (Copeland, 1947). Another source believed the word to be "Casimba", Spanish for "bailing bucket", denoting the obtaining of fresh water by the early explorers from shallow wells that tapped a layer of fresh water overlying salt on several areas of Marco Island. One obscure newspaper article recounted this presumed activity in the following manner:

> "The name Caximba was pronounced Kahamba in 1830 and is interpreted by some as 'the place of many wells', for the Spanish ships got their fresh water there by digging shallow wells on the beach a few paces back from the salt water. The word is also interpreted by some as 'the torch' in ancient Spanish, possibly due to Indians' fires showing from the hill tops" (Watson, 1927).

Whatever the derivation of the name, Caxambas has had as equally varied and eventful a history as its prehistory. Copeland felt that certain alleged references in the diary of the pilot of Ponce de Leon to "sand hills" may have referred to the first recorded European sighting of the hills of Caxamba: However, one of the earliest verifiable references to the specific area of Caxambas was made in John Lee Williams' Territory of Florida (1837) which stated:

"Isle Roman (Marco Island) is separated from the main by the Caximba (Caxambas Pass). It is about thirty miles southeast of Carlos (Caloosahatchee River). It is near fifteen miles from north to south and ten to twelve from east to west. The north end is cut up with creeks and lagoons, but contains some extensive hammocks and old Indian fields (shell mounds?). Three or four good plantations are under cultivation. That occupied by John Durant, a native of Savannah, lies about a mile from the western coast, the white oyster clifts of which are seen halfway through the Caximba. Corn, peas, and mellons are the principal productions. The interior of the island is pine barren. The south point of the island is the Cape Acies, or Punta Longa of the Spanish charts, and the Cape Roman of the British; it terminates in dangerous shoals which extend fifteen miles into the Gulf" (Williams, 1837).

The idyllic conditions detailed above were disrupted by the hostilities of the Seminole Wars when white settlement became unsafe in South Florida. Except for passing military expeditions, there was little white presence in the area until the late 1860's when the next "permanent" settlers made their home on Marco Island to hunt, fish, and farm vegetable crops for the northern winter market via Key West. Caxambas Point during the early part of the twentieth century became the site of the Burnham (Clam) Packing Company which flourished until about 1945. Ironically, this clam harvesting activity notably increased the size of the prehistoric shell midden upon which it was situated.

The small commercial fishing community at Caxambas was relocated to Goodland Point in 1949 to make way for an abortive land development. Conditions remained essentially static until the early 1960's when the Marco Island Development Corporation began extensive alterations at Caxambas and elsewhere on Marco Island resulting in homesites, roads and canals (Cockrell, 1970). Despite these modern changes, Caxambas still clings to a small remnant of the topography that made it worthy of interest during the 6,000 years of its interaction with humanity.

REFERENCES CITED

Beriault, J.G., Feb. 24, 1980, Notes taken at Site 8Cr 110, Marco Island, Florida (taped notes).

Cockrell, W.A., 1970, Glades I and pre-Glades settlement on Marco Island (M.A. thesis): Tallahassee, Florida State University, 104 p.

Copeland, D.G., 1947, Data relative to Florida (manuscript), 1170 p.

Craighead, F.C., Sr., 1977, List compiled of plants growing on or near twenty one random indian sites and test areas in Southwest Florida (manuscript), 12 p.

Gilliland, M.S., 1975, The material culture of Key Marco, Florida: Gainesville, University Presses of Florida, 266 p.

Goggin, J.M., 1949, Cultural traditions in Florida prehistory: The Florida Indian and His Neighbors, John W. Griffin, ed., p. 13-44.

Miller, J.J., and Fryman, M.L., 1978, An Archeological and historical survey of the Collier Bay Tract, Marco Island, Florida: Tallahassee, Cultural Resource Management, Inc., 23 p.

Scholl, D.W., 1964, Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: Marine Geology, Part I, v. 1, no. 4, p. 344-366.

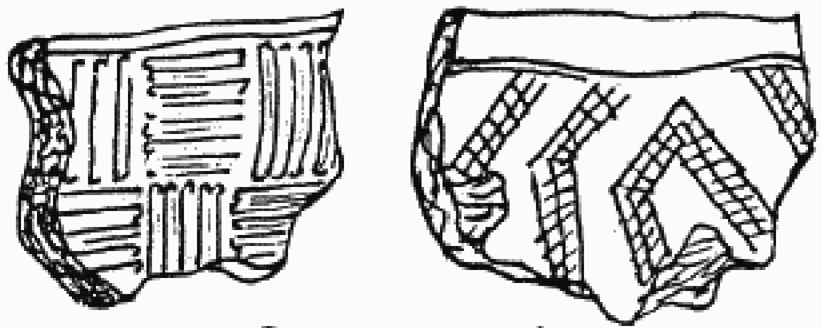
Scholl, D.W., Craighead, F.C., Sr., and Stuiver, M., 1969, Florida submergence curve revised: its relation to coastal sedimentation rates: Science, v. 163, p. 562-564.

Watson, R.C. Jan. 20, 1927, History of the Ten Thousand Islands of Florida: American Eagle (Estero, Florida) - as cited in Copeland's Data Relative to Florida.

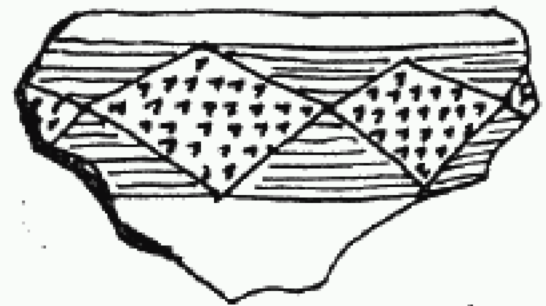
White, W.A., 1970, The geomorphology of the Florida Peninsula: Florida Bureau of Geology, Bulletin no. 51, 164 p.

Widmer, R.J., 1974, A survey and assessment of archaeological resources on Marco Island, Collier County, Florida: State of Florida Division of Archives, History and Records Management, Miscellaneous Project Reports Series, no. 19, 56 p.

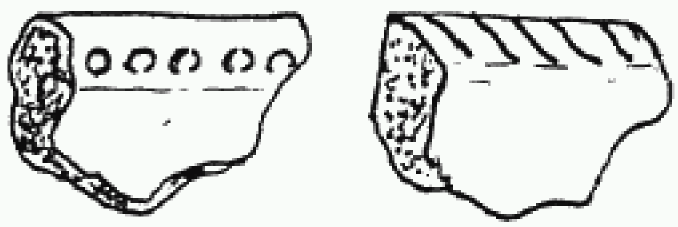
Williams, J.L., 1962, (1837 repr.), The territory of Florida: Gainesville, University Presses of Florida, 304 p.



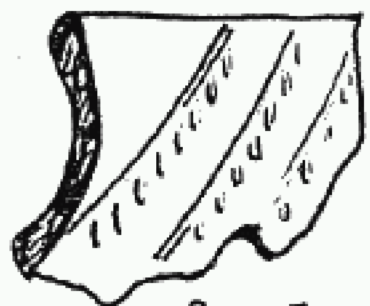
Orange series



Perico Island

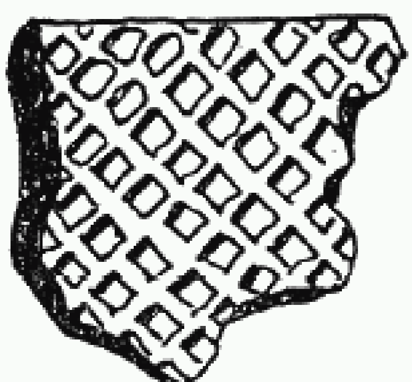


Fort Drum

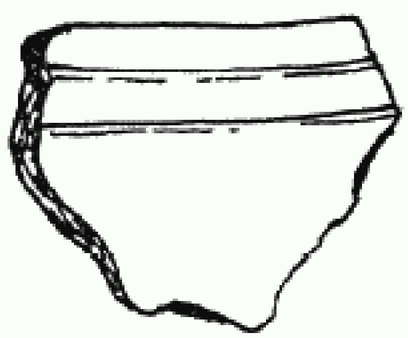


Gordon Pass Incised

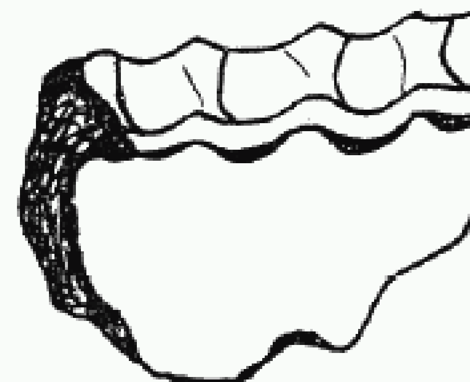
Sanibel Island



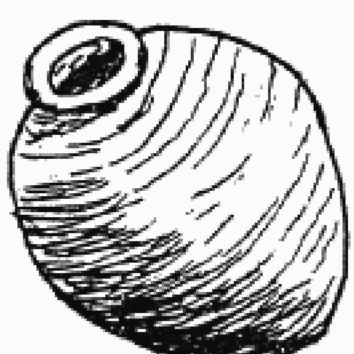
St. Johns Check Stamp



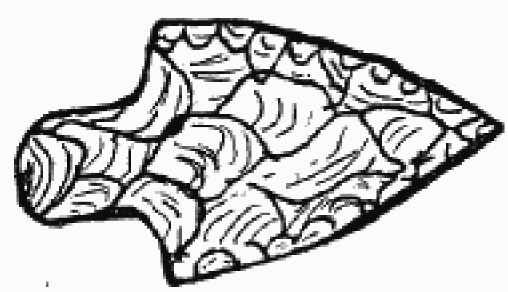
Surfside Incised



Glades Tooled



Spanish Olive Jar (45 cm. tall)



Archaic Stemmed Point

APPLICATION OF ELECTRICAL RESISTIVITY METHODS TO GROUND WATER RESOURCE INVESTIGATIONS IN COASTAL COLLIER COUNTY, FLORIDA

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ABSTRACT

A surface DC resistivity investigation was conducted in order to assess the potential of resistivity methods for determining water quality and lithology in coastal zones. Ninety-four vertical electric soundings were completed and interpreted using an automatic, digital computer inversion technique. The salt water interface is approximated by the depth at which bulk resistivities are 20 ohm-meters or less. The interface exhibits a steep seaward margin with a narrow zone of diffusion. Inland the interface is less distinct, and water quality variations are correlated more closely with near-surface lithology than water table elevation. The conclusions are that resistivity methods are effective in determining water quality and lithology to depths of 200-250 ft., that the seaward margin of the salt water interface fits the expected hydro dynamic model, but that inland water quality variation is strongly influenced by lithology and flow system vigor.

INTRODUCTION

This report presents the results of a study of the use of surface electrical resistivity methods for ground water resource investigations in coastal areas of south Florida. The geophysical survey was conducted by members of the Geology Department of the University of South Florida, in cooperation with the South Florida Water Management District. Major funding was provided by the SFWMD.

This investigation of the application of surface electrical resistivity to ground water investigations had two objectives. The first was to attempt to locate the fresh water/salt water interface at the coastal and lower margins of the aquifer. The second was to determine the usefulness of surface resistivity for mapping lithologic and water quality variations within the landward, fresh water portions of the aquifer.

The site chosen for the study was western Collier County, just south of Naples, Florida. The study area covers 24 square miles, six miles long by four miles wide. Its long axis parallels Highway 41, running SE from a point one mile NW of the Highway 41 and Highway 951 junction. A total of ninety-four resistivity soundings were completed during the winter and spring of 1979 (Figure 1). The resistivity data were interpreted using the INVRSE program of Zohdy (1974). The output from INVRSE is a geoelectric solution for layer thicknesses and resistivities at a sounding site. The data were contoured and printed using the SYMAP program (Harvard Computer Graphics Laboratory).

RESULTS

Depth to the salt water/fresh water interface

In order to estimate the depth to the salt water/fresh water interface it was necessary to decide which bulk resistivity values represented geologic units saturated with salt water. The vertical electrical sounding solutions show a steep decrease in resistivity values between resistivities of 20 to 10 ohm-meters, suggesting a transition between relatively fresh and highly saline waters. Also comparisons of VES solutions with well log data indicate that the geologic units in the upper 200 ft of the section have bulk resistivities greater than 20 ohm-m. The VES solutions for sites near the coast where water quality data show the interface is very close to the surface all show bulk resistivities of less than 10 ohm-m. The water quality in units with bulk resistivities less than 10 ohm-m is very poor, with TDS values well in excess of 1000 mg/l. For this reason the 20 ohm-m surface was chosen as the salt water interface as it is probably the best indicator of the thickness of fresh or slightly brackish waters.

As bulk resistivity also varies with porosity and lithology, higher in the section brackish pore waters could result in higher bulk resistivities than would be observed lower in the geologic section with the same pore water resistivity. This is due to the higher formation resistivities of the limestones of the upper part of the section as compared with the lower formation resistivities of the sandstones of the lower section. The fresh water/brackish water interface is probably between 15-25 ohm-m below 90-100 ft., and perhaps as high as 30 ohm-m in the upper limestones above 40-50 ft. BLS.

Figure 2 is a contour map of the depth below land surface of the 20 ohm-m resistivity interface.

Below this depth units have bulk resistivities less than 20 ohm-m and are assumed to be saturated with salt water. The contour pattern reveals two different configurations of the interface. One configuration is the classic, steep, salt water interface expected at the seaward border of an unconfined aquifer. This portion of the interface is roughly parallel with Highway 41, with its center about one mile southwest of the highway. The interface is relatively steep, descending from the surface to a depth of over 100 ft. in 0.3 to 0.5 miles. The average slope is 2-3.5°, and the shape is well represented by a plane or very shallow, concave upward parabola.

The steep, seaward portion of the interface shows several significant deviations from the general NW-SE trend. One deviation is a zone of high resistivity which extends seaward two miles SSE of Belle Meade. This seaward extension of the interface is associated with a hammock which has a maximum elevation of 2-3 ft. above the surrounding marshes, which apparently is high enough to maintain a fresh water lens.

There are two significant landward re-entrants. One is about 3 miles SSE of Belle Meade. South of 41 it trends NNE, and appears to bend NNW just north of 41. The cause of this re-entrant cannot be determined from the resistivity data, but the NNE and NNW trends suggest that it may be natural or pumping induced salt water intrusion along a set of complementary joints or fracture traces with roughly NE and NW strikes. The second is the NE trending pattern just north of the Henderson Creek bridge on Highway 41. The inland end of this re-entrant has a closed 100 ft. depth contour. The eastern end has a SE trending lobe which points toward the other landward re-entrant, again suggesting that the interface configuration may be influenced by prominent joints or fracture traces in the more competent units of the aquifer.

Landward from the steep portion of the interface the depth to the 20 ohm-m interface is an irregular surface, with relief of over 100 ft. Areas with depths in excess of 150 ft. to resistivities less than 20 ohm-m have a general NW-SE trend, roughly parallel to the coast. However these areas are not laterally continuous, either parallel to the coast or inland. There is a well-defined zone of shallow depths to low resistivities in the NE portion of the study area. This zone is connected by a low saddle or divide with the landward re-entrant near Henderson Creek bridge. There are two linear zones with deep depths to salt water, roughly parallel to and just north of 41. Maximum depths to resistivities of 20 ohm-m or less are 250-300 ft.

Variation of resistivity with depth

Several resistivity cross-sections were completed in order to study the variation of bulk resistivity with depth below land surface. Figure 3 is a cross-section roughly perpendicular to the NW-SE interface trend. The location of the section is shown on Figure 1.

This section perpendicular to the main salt water/fresh water interface shows the same pattern of resistivity variation as noted in the discussion of the map of depths to a resistivity of 20 ohm-m or less (Fig. 2). The steep, parabolic resistivity gradient on the southern or seaward margin of the section represents the classic salt water interface configuration. However, in the central and northern sections of the profile vertical variations of resistivity have a more complex pattern and do not have a well-defined relationship or continuity with the interface along the seaward margin or with water table elevations.

The reasons for this more complex pattern of resistivity in an inland direction cannot be determined from resistivity data alone. Three possible explanations are:

1. Variations in porosity and permeability could lead to the existence of zones with very low ground water flow rates, preventing the flushing by fresher waters of relict sea water which intruded the aquifer during the Sangamon or earlier transgressions.
2. Lower resistivity zones could be areas where discharge from the Floridan aquifer is entering the shallow aquifer system. Floridan waters in this part of Collier County commonly have a total dissolved solids content in excess of 1000 mg/l. Discharging Floridan waters could be distinguished from relict sea water by measuring the $SO_4^{=}/Cl^{-}$ ratios, as Floridan waters would have a higher ratio than would be expected for waters resulting from the dilution of sea water.
3. Variations in porosities can cause significant changes in resistivity, even if fluid resistivities remain constant. At the seaward margin of the aquifer a sharp interface caused by an active flow system over shadows resistivity changes due to porosity or lithology variations. However in inland areas the less active, predominantly horizontal flow systems would have a broader zone of diffusion between fresh and salt waters, and resistivity variations due to porosity changes would have a greater effect.

Geoelectric Stratigraphy

The geoelectric stratigraphy is characterized by a general simplicity or consistency of pattern over much of the study area. However, although a general geoelectric stratigraphy can be proposed, local variations are large and significant. Figure 4 is a general geoelectric section averaged from all of the VES data. The indicated resistivities represent the average values for that depth for all soundings. Resistivities of less than 10 ohm-meters were not used in the averages, as these resistivities are assumed to represent saturation with salt water and not a variation in lithology or porosity.

Geoelectric layer 1 is characterized by the highest resistivities in the section. Although the average resistivity is 65 ohm-meters, resistivities of 100-140 ohm-meters are not uncommon. This layer extends downward to a depth of 15'-18'. The assumed lithology is quartz sand with some areas or stringers of very well cemented limestone. Outcrops of this limestone near the Highway 41/951 junction were so indurated that it was not possible to drive steel electrodes into them.

Geoelectric layer 2 is characterized by decreasing resistivities, varying from 60-65 ohm-meters at the top of the unit to 30-40 ohm-meters at the lower boundary. At the top of this layer a consistent and very distinctive 'kick' is noted on the VES field curves. This 'kick' is interpreted to be a very well-cemented, hard, low porosity limestone or series of limestone stringers at a depth of 15'-40'. The lower part of GEL 2 exhibits decreasing resistivities with increasing depth. This is attributed to increasing amounts of quartz and loose shell in a moderately to poorly cemented limestone. GEL 2 extends from 18'-60'.

Geoelectric layer 3 extends from 60' to 100', and has a resistivity of 36 ohm-meters. This layer is assumed to be poorly cemented, quartz and shell hash rich limestone. The lower part of this layer is marked by an abrupt transition to GEL 4, in contrast to the more gradual transition between GEL 2 and GEL 3.

Geoelectric layer 4 extends from 90-100' to the salt water interface. The lower boundary of GEL 4 varies widely locally, but at most VES sites where it is distinguished it is less than 160'-180' below land surface. GEL 4 has a consistent resistivity of 25-28 ohm-meters, and represents very loosely cemented, very porous quartz sandstones.

Geoelectric layer 5 represents all resistivities less than 10 ohm-meters. As explained earlier, these low resistivities are assumed to represent varying lithologies saturated with salt water. This interface can and does occur anywhere in the section. Once the interface is reached on a sounding curve all other geoelectric layers are masked by the presence of a highly conductive pore fluid. All five geoelectric layers are present only when GEL 5 is at depths greater than 125'-150'.

High resistivity near-surface zones

Figure 5 is a SYMAP produced contour map of the depth to the base of a layer with a resistivity of greater than 75 ohm-meters. If this map is compared to the map of depth to a resistivity of less than 20 ohm-meters (Figure 2), it can be seen that those areas with high resistivities (greater than 75 ohm-m) to depths of 10'-15' or more correspond to those areas with the greatest depths to the assumed salt water interface.

A possible explanation for the correspondence of these two maps is that areas with high near-surface resistivities represent areas with competent, well-cemented, and highly permeable 'reef' limestones. These competent limestones would have a low primary porosity, but would develop good secondary solution porosity and permeabilities along joints. The results would be more active ground water flow systems in the competent, high resistivity limestones due to greater recharge volumes. These more active flow systems would increase the fresh water discharge at the salt water interface, leading to greater depths to salt water.

CONCLUSIONS

The salt water interface can be located to depths of 200-300 feet using low-power surface DC resistivity surveys. The accuracy of the interface determination is best where the slope of the interface is steep. Here the transition zone is narrow, the water quality and hence resistivity gradients steep, and the inherent ambiguity between porosity and water quality variations is less significant. Inland from this steep portion the interface is found deeper in the flow system where flow rates are lower, the transition zone is much wider, and water quality variations are probably more closely correlated with lithology than with a theoretical, hydrodynamic salt-fresh water balance in a homogeneous aquifer. In inland areas water quality is determined by the hydraulic characteristics of the section, especially the upper 50-75 feet, and not simply by water table elevation. It is suggested that high near-surface resistivities are associated with more active flow systems, and deeper depths to poor quality waters. Figure 7 illustrates these concepts.

REFERENCES CITED

Laboratory for Computer Graphics and Spatial Analysis, 1975, SYMAP User's reference manual, fifth edition: Harvard College, Cambridge, MA.

Zohdy, A.A.R., 1974, Auto-interpret VES with MDZ and convolution. U.S. Geological Survey, Denver.

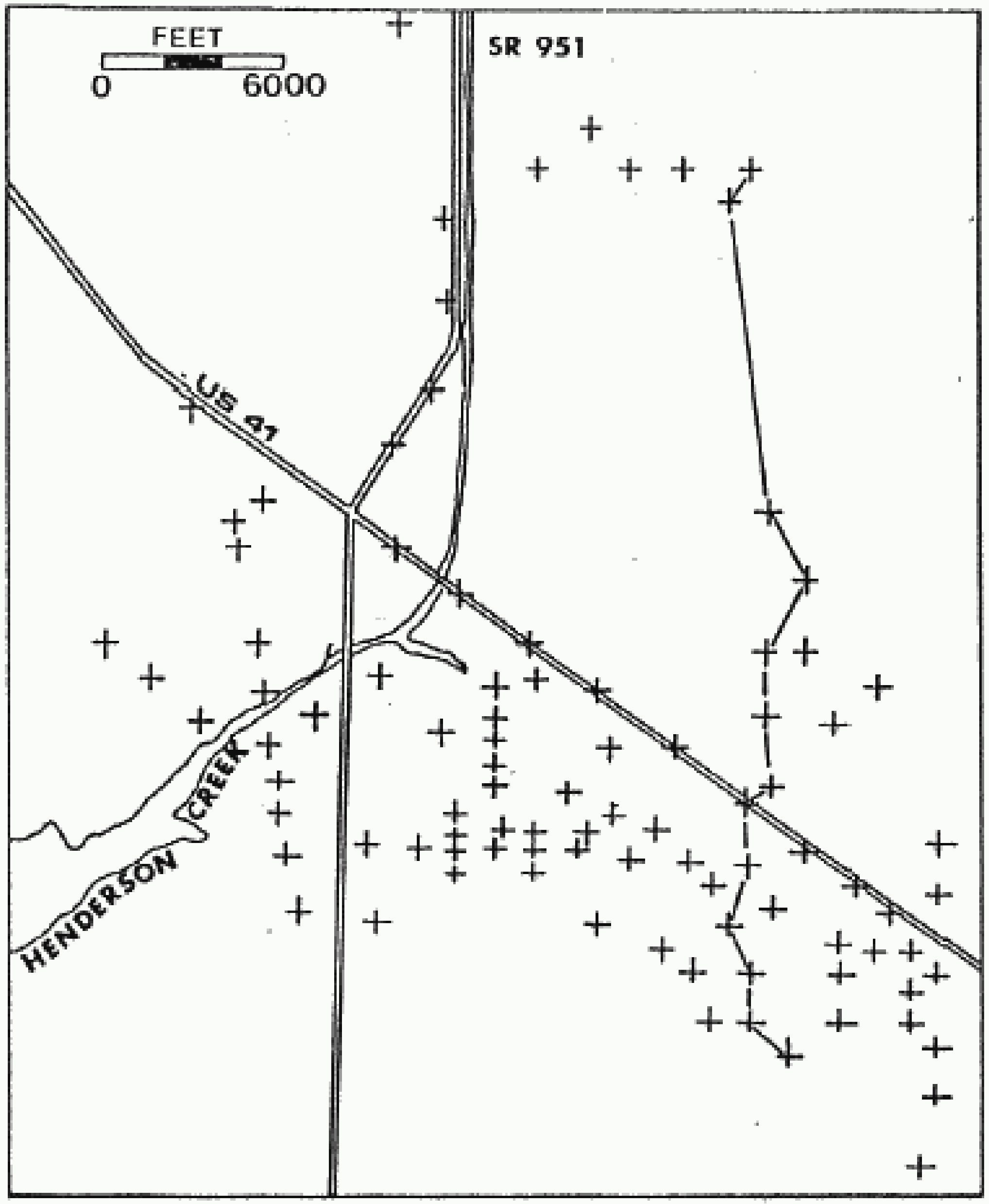

Figure 1. Vertical Electric Sounding Sites And Location of Geoelectric Cross-Section.

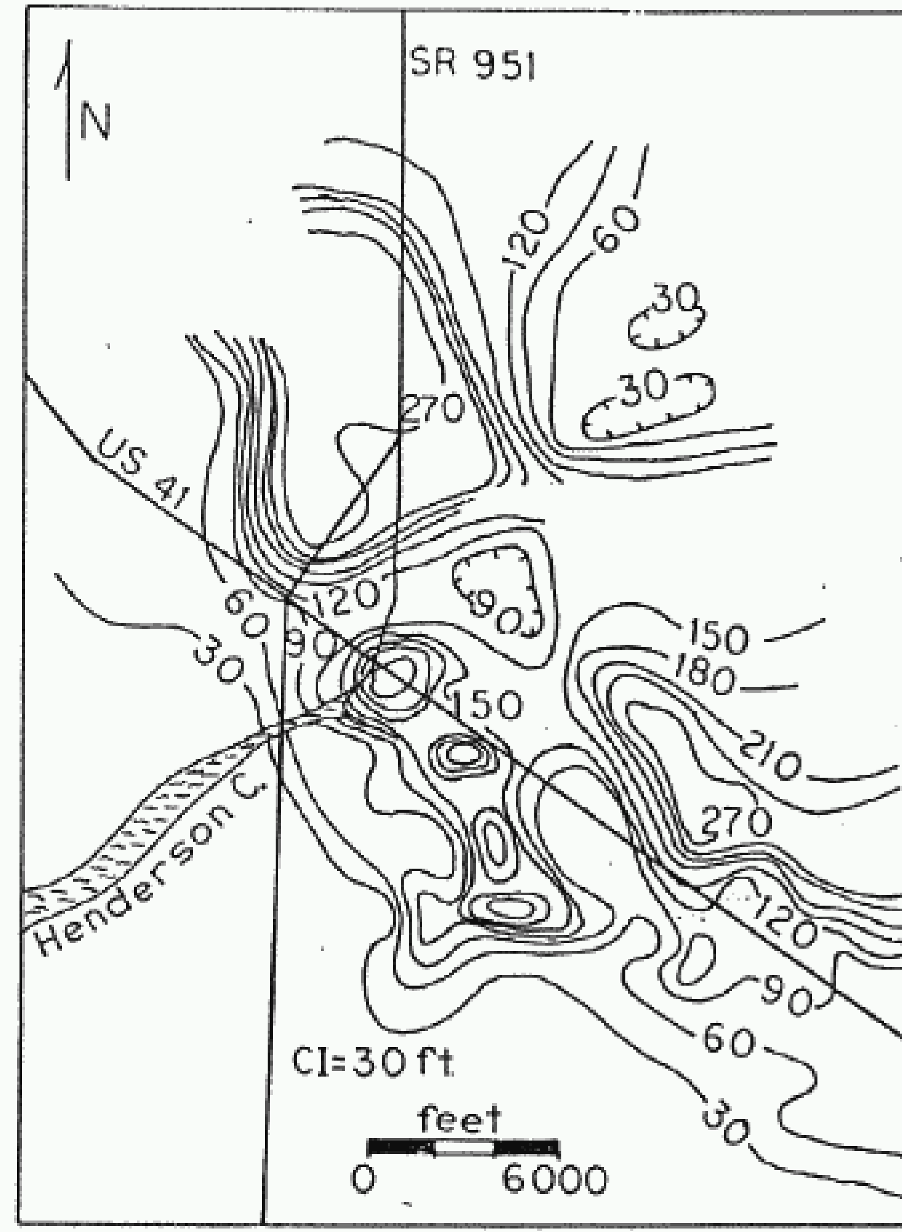

Figure 2. Depth (In Feet) To A Resistivity Of 20 ohm-m Or Less.

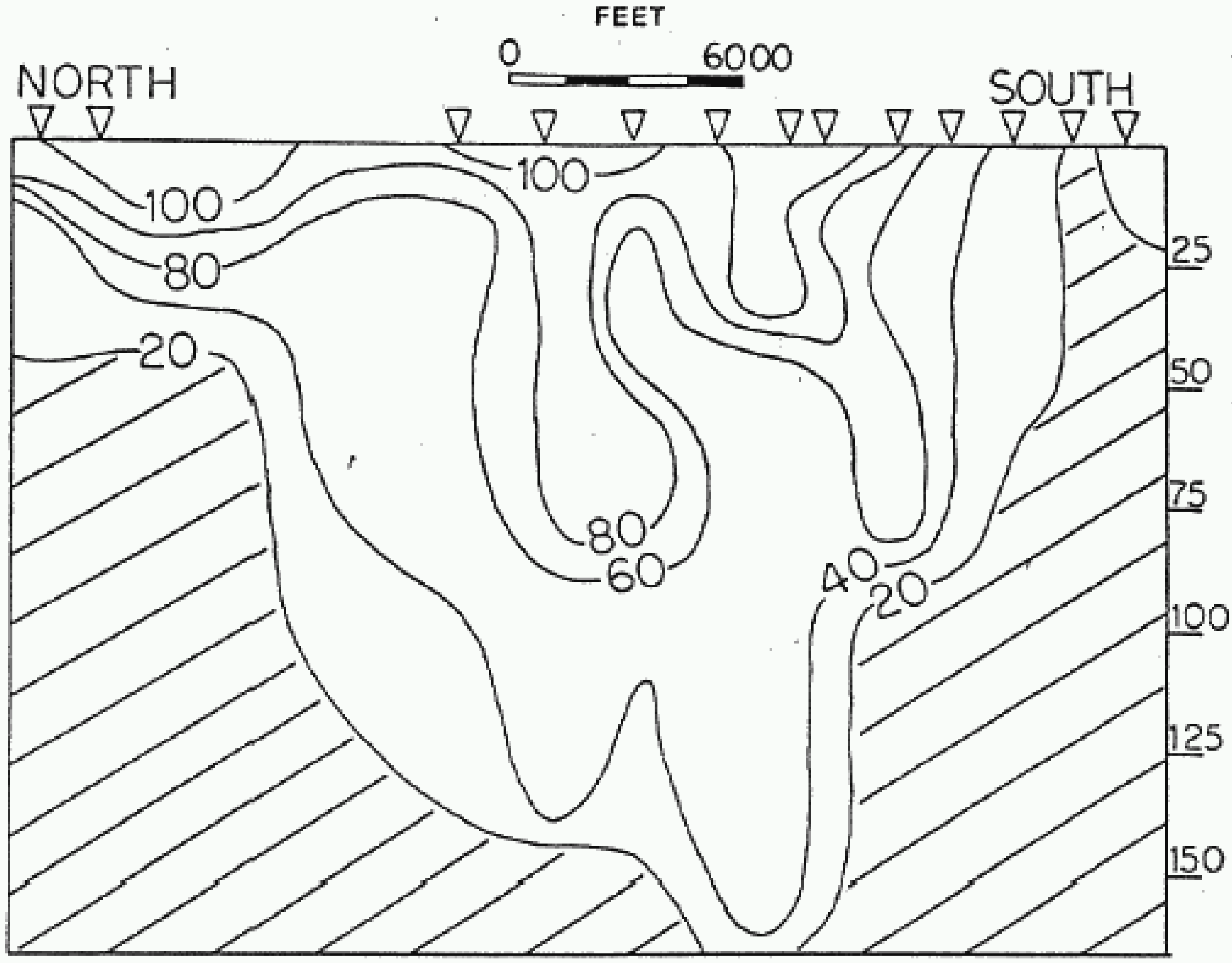

Figure 3. North-South Geoelectric Cross-Section About 3 Miles SE of SR 951 (Units Are ohm-m).

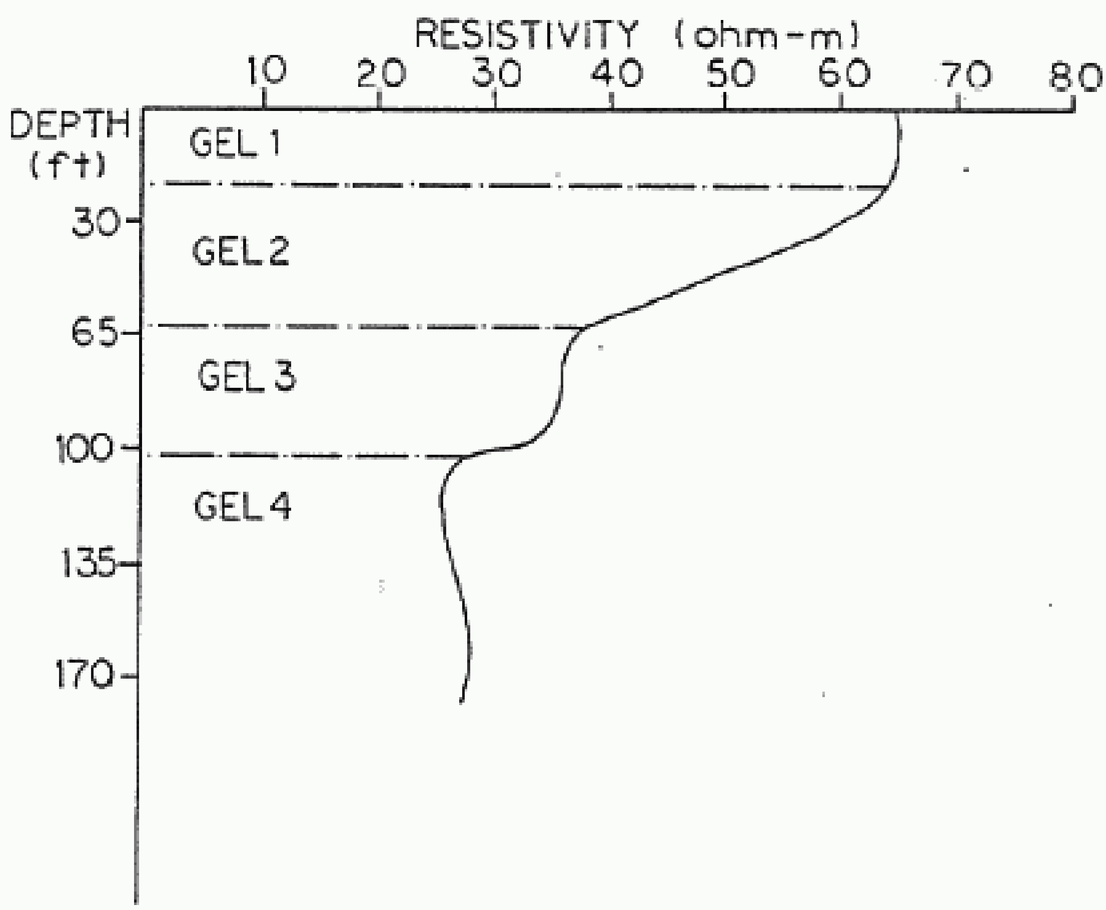

Figure 4. General Geoelectric Section For Study Area.

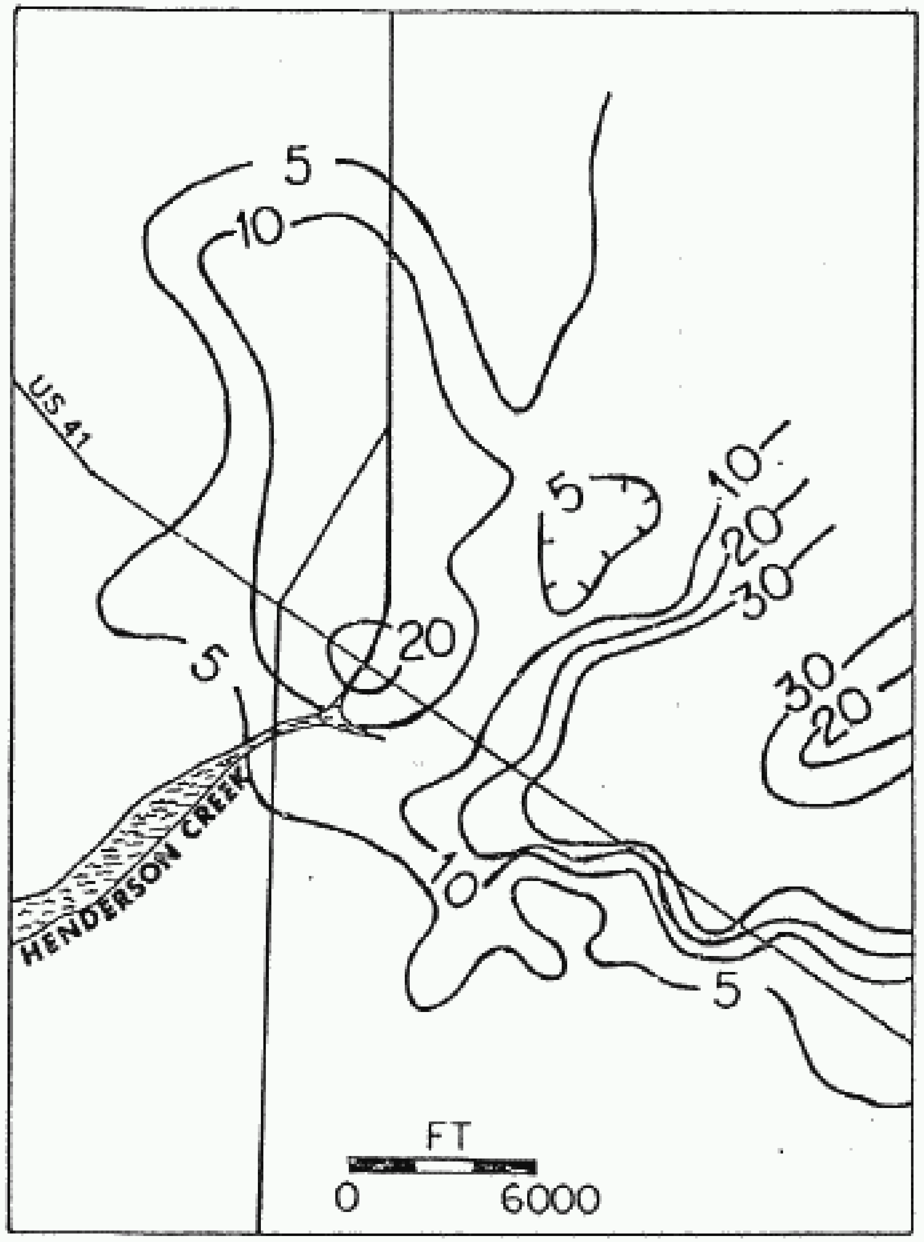

Figure 5. Depth (In Feet) To A Layer Of 75 ohm-m Or Less.

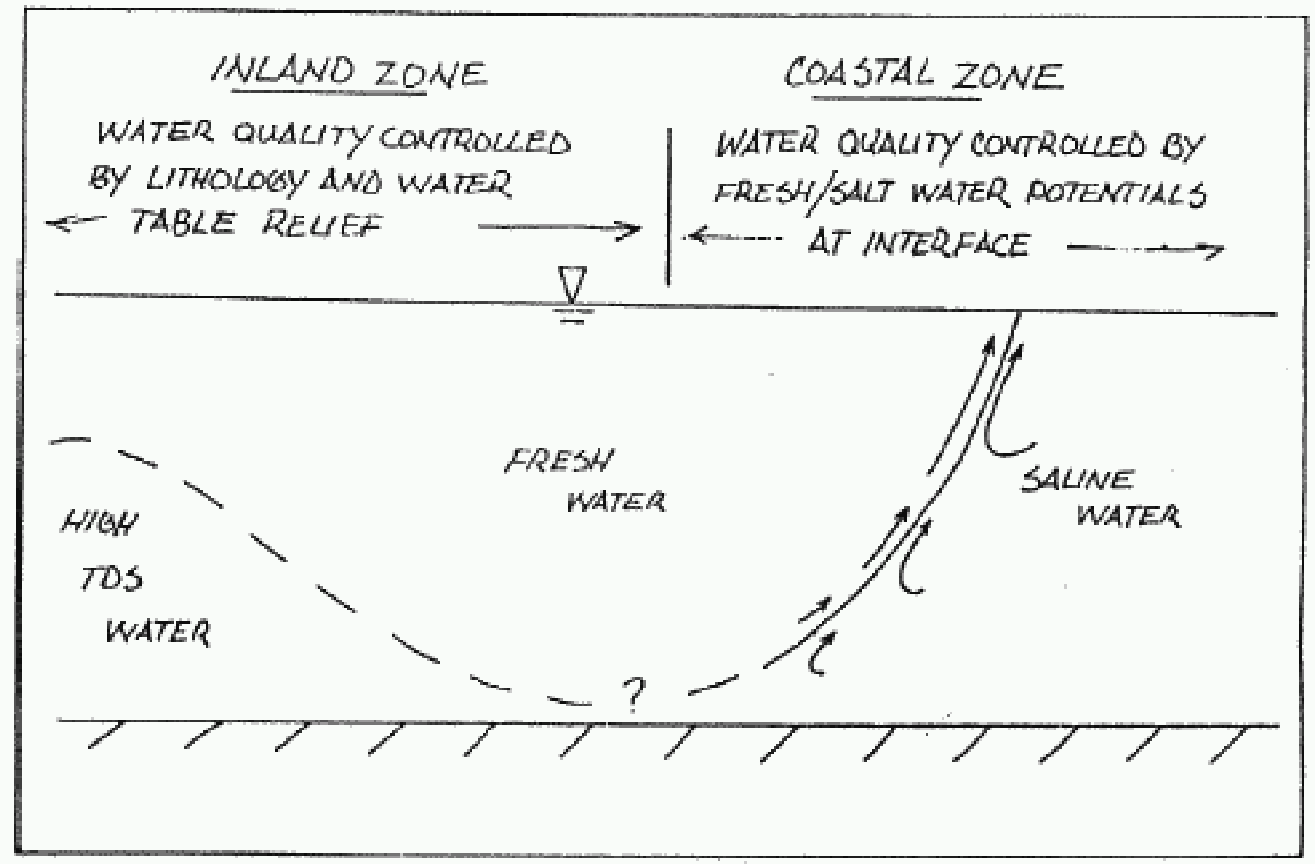

Figure 6. Summary Of Factors Controlling Water Quality In Southern Collier County.

SOME ASPECTS OF THE HYDROGEOLOGY OF COASTAL COLLIER COUNTY, FLORIDA

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INTRODUCTION

The area southeast of Naples, Florida, and northwest of Collier Seminole State Park, is rapidly being developed for both agricultural and residential uses. The increasing demand on the groundwater resource of this area prompted this study, the objective of which is to define the hydrogeologic regimen of the shallow aquifer with emphasis on the salt water intrusion hazard, as a step toward an assessment of groundwater availability.

The methods used in the study are exploratory drilling (mud rotary) to the base of the aquifer, geophysical logging of the boreholes, sampling for water quality determination, and ultimately, monitoring for both water quality and water levels.

With the completion of fourteen boreholes and associated geophysical logs, the study is approximately eighty percent complete at this writing. The following discussion takes focus on three selected wells as exemplary, hydrogeologically and in the techniques applied, of the entire study area.

GEOLOGY OF THE SHALLOW AQUIFER

The study area (Figure 1) encompasses about forty square miles southeast of Naples, bordering U.S. Route 41. About 3 miles to the north, the geology of the shallow strata described by Missimer (Missimer and Associates, 1978) includes the Pamlico Sand Formation (±10 feet thick), underlain successively by the Fort Thompson - Caloosahatchee Marl formations (undifferentiated, ±20 feet thick), and the Tamiami Formation (at least 200 feet thick). The upper part of the Tamiami Formation is subdivided into the Ochopee Limestone member (±130 feet thick), the Buckingham Limestone member and the Cape Coral Clay member (both members vary in thickness from a few feet to greater than 25 feet). This scheme is generally consistent with findings in the study area.

Figure 2 shows the lithologic log of well No. 14, the tentative stratigraphic designations and a demonstration of one mode of inter-borehole correlation - the neutron log. Lateral changes in rock character as shown in section A-A' are moderate (increasing intensity of the neutron log response indicates a lesser presence of the hydrogen atom, therefore a lesser porosity). Gamma log correlations conform well to those of the neutron log. Generally strata lie parallel and dip slightly to the southwest along this section; however, a slight rise in stratigraphic height is noted from well No. 14 to No. 15.

The Fort Thompson - Caloosahatchee Marl formations, which underlie the surficial, silica sands of the Pamlico formation, consist primarily of a hard, sandy, shelly, and in places, marly, limestone. Near the bottom of this zone, large cavities are frequently encountered. Above about 80 feet, the Ochopee Limestone consists of abundant shell fragments in a soft, calcareous, micritic matrix, with numerous vugs and in places, cavities up to 2 feet in height. Below lies a soft limey sandstone, containing shell fragments and some silt. Generally, this sandstone continues to the bottom of the aquifer at an average depth of 165 feet.

The confining zone at the bottom of the aquifer (the Buckingham Limestone and/or the Cape Coral Clay) consists predominantly of carbonate mud and varies arealy with depth and in thickness. Although several wells on the periphery of the study area penetrate an artesian aquifer, containing brackish water at depths of about 240 feet, no artesian pressures were detected in project wells after having penetrated thin strata (several feet) of carbonate mud to depths of 220 feet.

HYDROLOGIC CHARACTERISTICS OF THE SHALLOW AQUIFER

Evidence from the well cuttings, caliper logs, electric logs, neutron logs, temperature logs, and flowmeter logs indicates that the upper 60 feet of strata are highly permeable. The caliper log correlation along section A-A' (Figure 3) shows extensive cavities between the bottom of the casing and about 40 feet. A short-term aquifer test at well No. 11 indicates a transmissivity of about 300,000 gallons per day per foot (40,000 feet^2 per day). A flowmeter log taken during the test showed that about 95 percent of the water contribution came from the zone between the bottom of the casing at 12 feet and a depth of 60 feet. Although it is not quantifiable at present due to the lack of a leveling survey, an overwhelming portion of the groundwater flow in the shallow aquifer is concluded to occur in this zone.

Unlike the area to the north, evidence in the study area of a confining layer in the Ft. Thompson - Caloosahatchee Marl is inconclusive at present. Until such evidence develops, the aquifer is considered to be unconfined.

THE SOURCE OF BRACKISH WATER AND THE POSITION OF THE FRESH/BRACKISH INTERFACE

The bottom half of the water table aquifer (to a depth of about 165 feet in this part of Collier County), generally contains highly mineralized water. Near the coast, this brackish water is appropriately attributed to contact with the Gulf. Inland, however, the brackish water may be attributed to at lease two possible sources including: (1) seawater, resulting from past innundations, and (2) upward leakance of brackish water from deeper aquifers.

In mapping the depth to the fresh/brackish stratification interface (defined here as the depth in the aquifer where the chloride content equals 250 mg/l) within this aquifer, several methods were used. Because the lithology of the aquifer is rather uniform and has a fairly consistent resistivity in the vertical direction, the major changes in borehole resistivity measurements are attributed to changes in water quality. Following the completion of drilling, resistivity logs were used to tentatively determine the depth to the interface and the optimal depth to set monitoring-well intakes. On seven wells, the boreholes were flushed of drilling mud and developed using compressed air, by placing a rigid air line down the well at predetermined depths, working from top to bottom, in such a way as to derive a representative water sample at each depth of development. Figure 4 shows the results of this sampling and analysis, and the degree of relationship between the bulk resistivity response and the quality of water derived from air line development.

Based on a significant number of chemical analyses, a linear correlation between chloride content and water conductivity was established, and can be written: Chloride (in mg/l) = 0.31 conductivity (in u mhos/cm) - 215. Water having a chloride content of 250 mg/l would therefore have a conductivity of 1500 u mhos/cm. Comparing groundwater conductivities with borehole resitivities, a conductivity of 1500 u mhos/cm was found to correlate with a bulk resistivity of about 30 ohm-meters on a fairly consistent basis, as shown in Figure 4.

These relationships were used to incorporate a large number of existing wells with the project wells, in an overall scheme to determine the approximate depth to the fresh/brackish water interface. Most of the existing wells sampled, however, were of insufficient depth to actually detect the interface, but did provide a check on the project-well determinations.

Figure 5 shows an inter-borehole correlation along section A-A' of six-foot lateral logs (resistivity). Apparent on this figure is the landward dip of the interface slope, as defined by the 30 ohm-meter resistivity value. This slope relates mainly to the coastal source of salt water. It is principally such determinations from resistivity logs and to a lesser extent, air-line sampling and private well sampling, that were used to compile the depth to interface map (Figure 1).

The brackish water that lies at the bottom of the shallow aquifer inland from the coast, in the study area and most of western Collier County, is an important consideration in wellfield siting and management. The origin of this brackish water, yet to be definitely determined, is believed to be upward leakance from the underlying brackish-water artesian aquifer for the following reasons: (1) the high flushing potential of the upper part of the aquifer and its presumed ability to minimize deep infiltration during and after seawater innundation, and (2) the uneven areal distribution of the brackish water and the areally variable competence of the confining layer at the bottom of the shallow aquifer. Further testing is necessary to verify this conclusion.

Upon completion of well drilling, logging and development-sampling, permanent casing and screens were set at depths just above the fresh/brackish water interface, for the purpose of long-term monitoring of water quality and water levels. Several of the boreholes were fitted with two, side-by-side well casings and screens at different depths. The purpose of these was to afford advance warning of the movement of the interface in the vertical direction, and to better define the actual position of the interface.

SUMMARY

Through the use of exploratory drilling, geophysical logging, short-term pumping tests, borehole water sampling taken during well development, and sampling of private wells, a tentative model of the shallow aquifer south of Naples has been developed. The geologic strata were found to be of uniform thickness with a slight dip towards the southwest. The limestones within at least 60 feet of the land surface are highly permeable, while the underlying limey sandstone is less permeable. The dominant groundwater flux occurs within 60 feet of the land surface in this unconfined aquifer. The depth to the fresh/brackish water interface appears to be unrelated to the vertical permeability distribution within the shallow aquifer; it is related to the coastal source of salt water in the usual wedge-shaped manner; and, it is variable inland. The source of inland brackish water at the aquifer bottom is apparently the underlying artesian aquifer, which leaks upward through a semi-persistent confining zone.

REFERENCES CITED

Missimer and Associates, Inc., 1978, Hydrology and Water Management: The Glades Development, Consultant's Report.

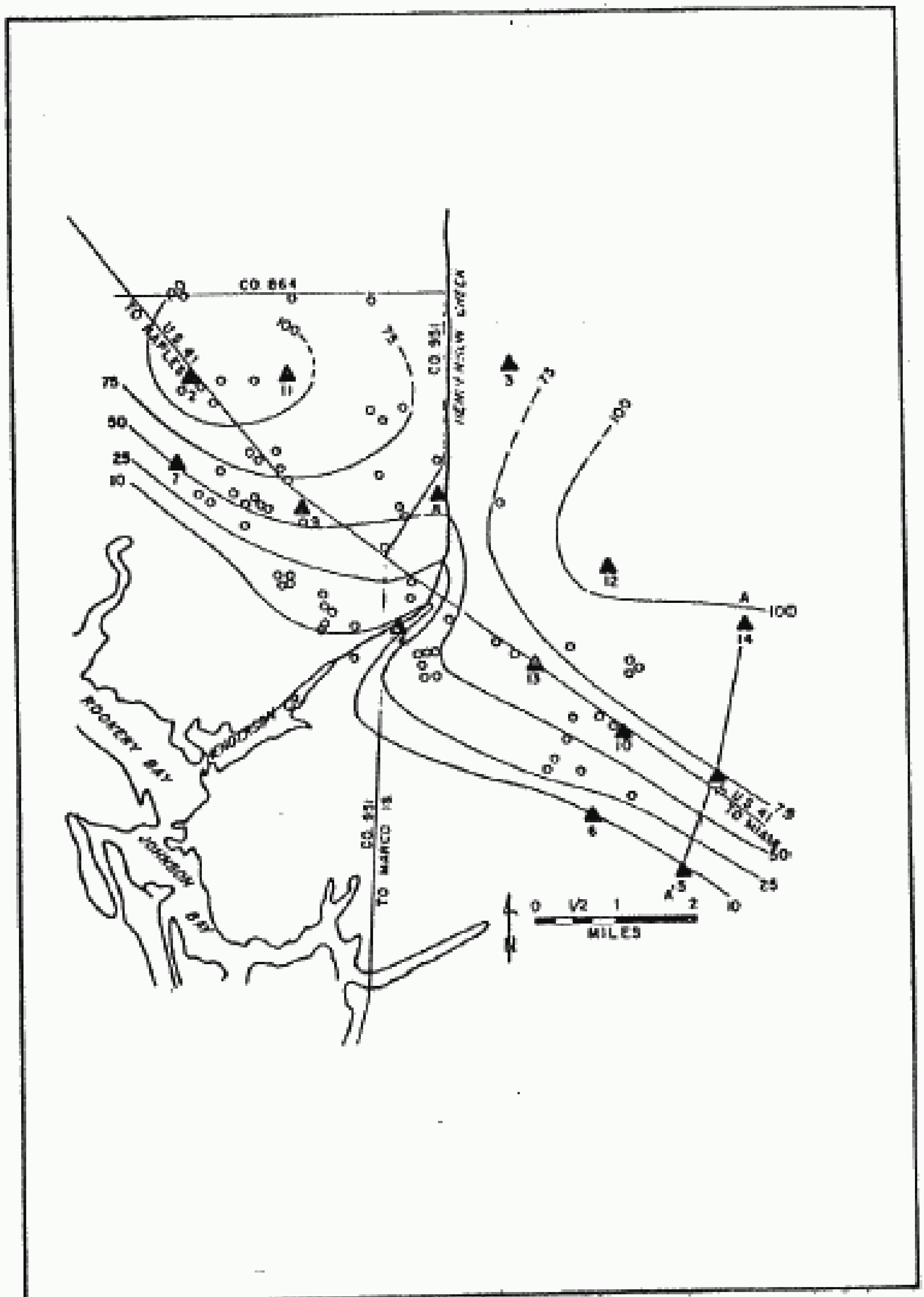

Figure 1. Map of study area showing contours of the depth in feet below land surface to a chloride concentration of 250 mg/l in the groundwaters of the Ochopee Limestone aquifer. Numbered triangles locate project wells. Circles locate existing private wells sampled during the study.

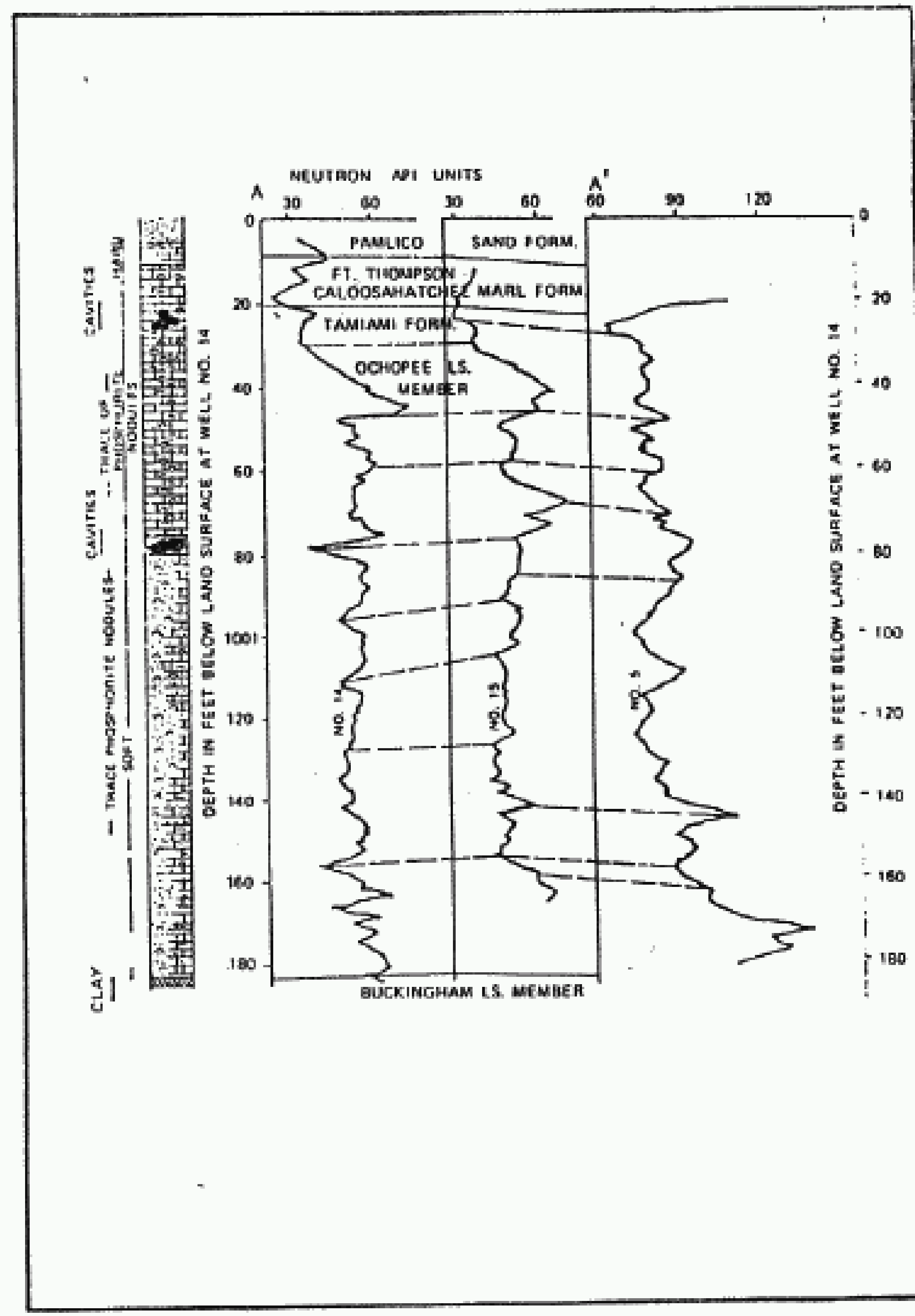

Figure 2. Cross section A-A' showing inter-borehole stratigraphic correlations of neutron logs and the lithologic log of well No. 14.

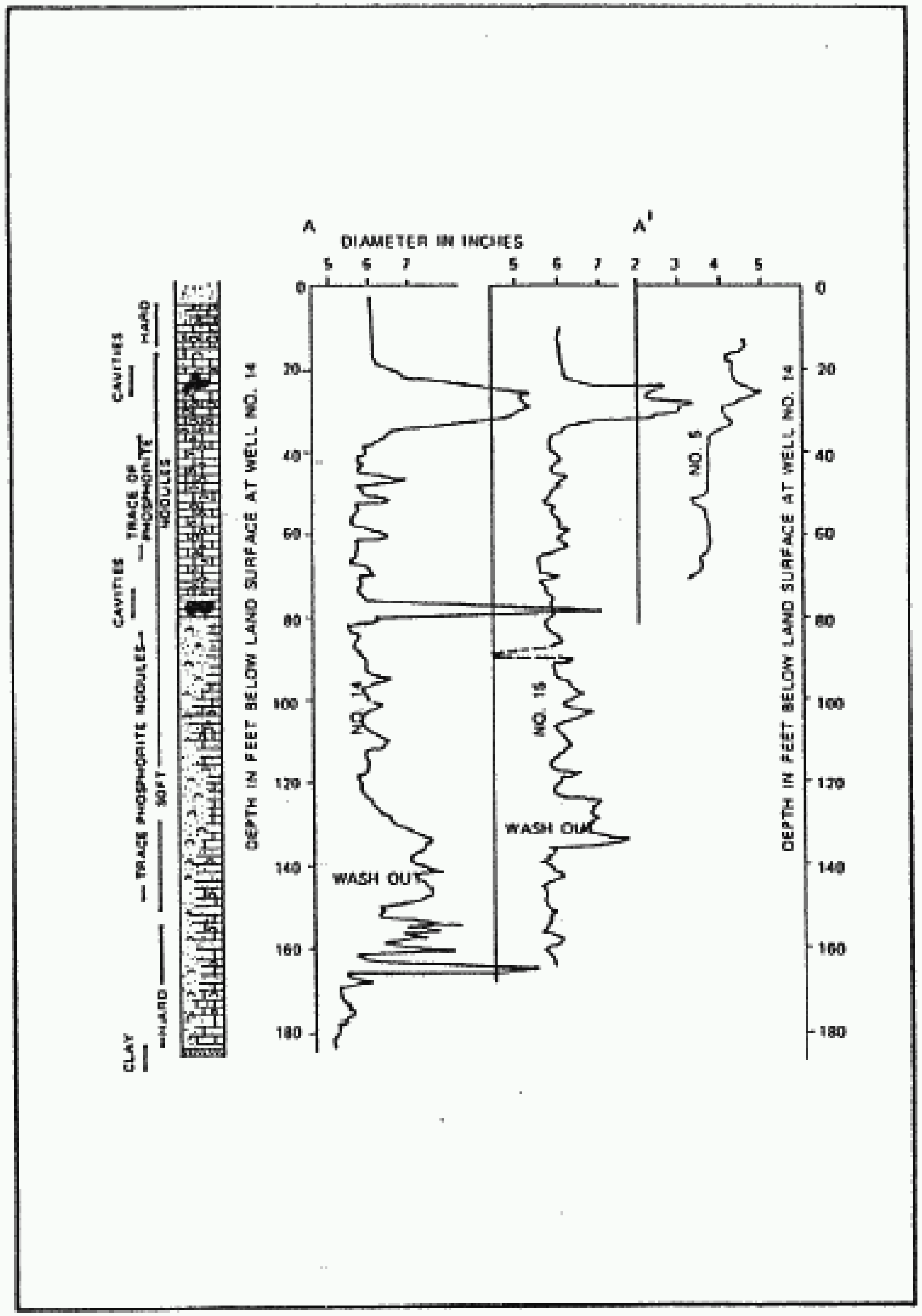

Figure 3. Cross section A-A' showing inter-borehole correlations of caliper logs and the lithologic log of well No. 14.

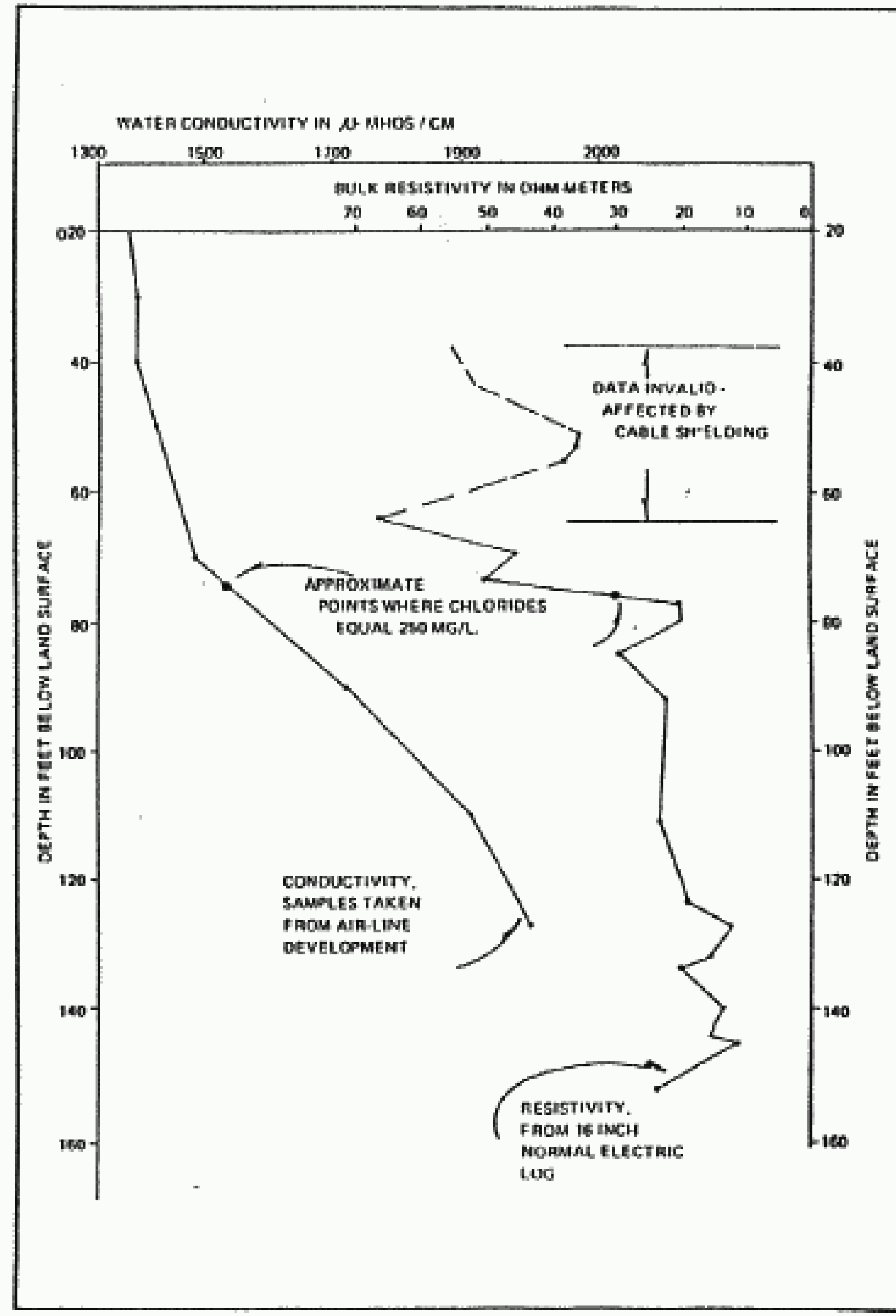

Figure 4. Graphic comparison of two down-hole methods of determining the approximate depth to a chloride concentration of 250 mg/l, at well No. 8.

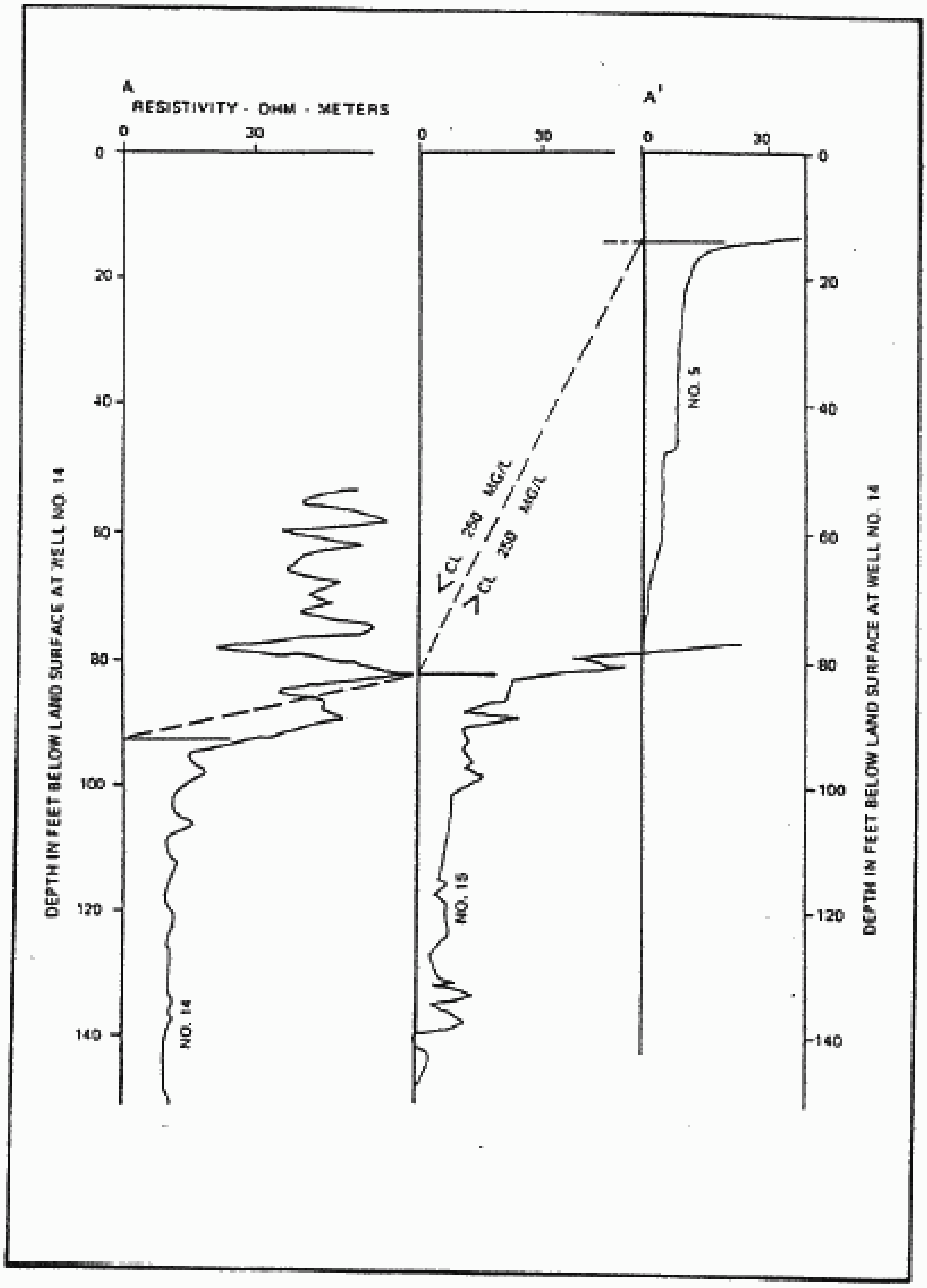

Figure 5. Cross section A-A' showing inter-borehole correlations of six-foot lateral logs and the depth to a chloride concentration of 250 mg/l as defined by the 30 ohm-meter response on the lateral log.

NEW INFORMATION ON PLIOCENE REEF LIMESTONES AND ASSOCIATED FACIES IN COLLIER AND LEE COUNTIES, FLORIDA

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ABSTRACT

Initial results obtained from a rock coring program in progress show that coral reef and associated facies are to be included in the Tamiami Formation. Six distinct fossil assemblages (biofacies) are recognized within the Tamiami Formation. Each biofacies is often found in several distinct lithologies based upon petrographic inspection. Variation in lithofacies is often the result of post-depositional processes on original depositional texture. These processes and their resultant patterns must be understood before accurate detailed stratigraphic studies can be completed.

Termination of the Middle Pliocene coral growth is associated with a regression that resulted in a long period (approx. 2.5 my) of non-deposition or erosion with the exception of local lenses of freshwater calcitic muds. Water depth during deposition of the entire Tamiami Formation was between 5 to 35m based upon the presence of shallow water hermatypic corals. A pioneer reef community of Porites colonized unconsolidated shell beds containing abundant solitary hermatypic corals. Reef characteristics suggest closer affinities to Tertiary rather than Holocene reefs.

INTRODUCTION

Research in the Pliocene reef trend in Southwest Florida began in 1975 and reached a plateau last year (Meeder, 1979). Prior work was completed on surface outcrops and quarry and canal spoil. This year Harold R. Wanless and myself began a rock coring program which will consist of approximately 20 holes when completed; the majority of holes are located along two transects (Figure 1). Initial results from the first four cores are reported herein.

The major purpose of this paper is to make workers aware that the Tamiami Formation includes a reef and that the Tamiami is a very complex assemblage of lithologies which vary laterally and vertically. The nomenclatural problems associated with the Tamiami will not be addressed and interested readers are referred to an excellent review and proposed revision (Hunter, 1978).

Additional information on the regressive-transgressive history, water depth, and reef characteristics are also presented.

BIOFACIES

Several distinct biofacies have been recognized within the Collier and Lee counties strata that have been characteristically placed in the Tamiami Formation (after Hunter, 1978). Evidence from surface and subsurface geology suggest that at least 3 additional biofacies (coral reef, coral rubble, and oyster bioherm) should be included in the Tamiami Formation (Table 1, left column).

LITHOFACIES

Lithological descriptions in this paper are based on Dunham (1962). Dunham's method was chosen for its easy application and its stress on depositional texture. Briefly, mudstone, wackestone, and packstone contain mud whereas grainstone and boundstone generally do not. Boundstone occurs when original components were bound together during deposition. Grainstones lack mud and are grain supported. Packstones are essentially muds with enough grains included to be grain supported. Wackestone differs from mudstones by the presence of more than 10% grains. Modifiers added in front of the main sediment class are standard and refer to special characteristics (i.e., argillaceous molluscan packstone is a grain supported lime mud containing a minor amount of mineral clay and abundant mollusks).

Major lithofacies are summarized in Table 1, right column.

PATTERNS

Initial patterns from observations on 4 cores and from previous fieldwork are tentative pending completion of the coring program. Surface rock (cap rock) which may be as much as 2m thick is essentially useless in this study because it has undergone repetitive dissolution and recrystallization. With the above limitations in mind several general patterns have been recognized:

1) Oyster rich wacke-packstones become more recrystallized and more dolomitized to the north.

2) Oyster boundstones have only been found in the northern portion of the study area and apparently grade southward into higher diversity molluscan pack-grainstones. They appear to be found both in the fore and back reef areas.

3) Cores 1 and 2 along the southern transect (approx. 1.7km apart) miss the reef core but penetrate marginal reef accumulations. Molluscan packstone and grainstone appear to be opposite one another and alternate.

4) Mudstone tend to have moldic porosity whereas grainstones usually exhibit vuggy porosity.

5) The molluscan pack-grainstones below the reef and associated coral facies are somewhat recrystallized, partially cemented, voids may be spar filled, and incompletely dolomitized.

DISCUSSION

Biofacies patterns tend to vary less than lithofacies. This is probably a response to variations in sediment regime and sediment influx during deposition. These variations may be local or more regional. Original depositional textures are often modified by cementation processes, dissolution and recrystallization, porosity development, and dolomitization which are probably responses to interstitial water chemistry. These processes although apparent are not properly understood at present. Detailed diagenetic patterns are also yet to be determined.

Core 1 at 870-920cm exhibits what may be a laminated subaerial exposure surface at the base of the reef sequence. This "laminated crust" correlates to the oyster-vermetid pack-wackestone in core 2 at 825-915cm. This faunal change (molluscan pack-grainstone above and below it) may support the interpretation of this crust as a subaerial exposure surface. However, this crust may be a cavity filling; detailed petrographic analysis will determine the interpretation. If it is a subaerial exposure surface considerably more relief must have existed at the time of reef construction. Coral reef debris located between 1215 and 1335cm in core 2 may suggest that more relief was present if it is contemporaneous with the onset of reef development at 870cm in core 1.

Both cores 1 and 2 exhibit a coral community succession from a soft bottom community dominated by solitary coral species (Antillia, Placocyathus, and Scolymia) to a ramose Porites community which is followed by a higher diversity reef community of ramose and massive forms such as Stylophora, Acropora, and Montastrea. Corals generally found in water depths of less than 30m are common throughout cores 1 and 2 (Manicina, Stylophora, and Acropora).

Cores 3 and 4 show no major changes in fauna from the surface to 1350 and 925cm respectively. The greenish-gray clays (1250-1300cm) at the base of core 4 are interpreted initially as lagoon deposits which become more calcareous and more open marine upwards (925-1025cm).

The problematical subaerial laminated crust in core 1 is the only possible evidence at present suggesting anything but a slow steady transgression until reef growth termination by an initial rapid regression at the end of the Middle Pliocene. If the subaerial horizon is properly interpreted the transgression may have been reversed briefly at a stand approximately 420cm below present sea level. The final regression was rapid but initially resulted in a drop of approximately 3m where it remained long enough for siltation of portions of the reef lower than the reef crest which was exposed. This assumes that the reef crest was near shoaling during development. Although this is quite likely the reef crest during development may have been submerged beneath as much as 10m of water which requires adjustment of the above figure by as much as 10m.

The reef appears more closely related to Tertiary reefs than Holocene reefs on the following basis: 1) presence of abundant diverse hermatypic solitary corals, 2) the reef developed on soft bottom, 3) forereef slope minimal, and 4) the total accumulation of reef material is thin. Frost (1972) recognizes these criteria as characteristic of Tertiary reefs. The reef is obviously a bank reef, not having developed on the shelf break. The reef presently occupies the west coast of Florida, however, if sea level were raised enough to inundate south Florida the reef trend is then found in the approximate center of the Florida Platform.

REFERENCES CITED

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, in Ham, W.E., ed., Classification of carbonate rocks-a symposium: AAPG Memoir 1, p. 108-121.

Frost, S., 1972, Evolution of Cenozoic Caribbean coral faunas: VI Conferencia Geologica del Caribe-Margarita, Venezuela Memorias, p. 461-464.

Hunter, M.E., 1978, What is the Caloosahatchee Marl?: Southeastern Geological Society Publ. 20, p. 61-88.
Meeder, J.F., 1979, The Pliocene Fossil Reef of Southwest Florida: Miami Geological Society 1979 Field Trip Guidebook, 18 p.

ACKNOWLEDGEMENTS

This study has been funded in part by a Naples Shell Club Scholarship, the Miami Geological Society, and the National Science Foundation Grant #EAR 79-21790.

TABLE 1
Common biofacies in the Tamiami Formation and their common corresponding lithofacies.

BIOFACIES	LITHOFACIES
1. Oyster bioherm (almost monospecific assemblage)	a. Calcitic wacke-packstone b. Dolomitic wacke-packstone c. Vuggy boundstone
2. Oyster-Pecten (low diversity molluscan fauna with rare solitary coral)	a. Unconsolidated argillaceous wacke-packstone b. Consolidated argillaceous wacke-packstone c. Argillaceous molluscan mudstone
3. Stylophora rubble (coral fragments lacking growth orientation in molluscan-rich assemblage containing abundant lithoclasts)	a. Moldic lithoclastic pack-grainstone b. Lithoclastic pack-grainstone c. Lithoclastic wacke-packstone
4. Reef core (ramose and massive corals in growth position with coralline algae)	a. Moldic boundstone b. Recrystallized boundstone c. Lithified pack-grainstone (corals often aragonitic)
5. Encope tamiamiensis (vermetid and turritella rich)	a. Moldic arenaceous molluscan pack-grainstone b. Arenaceous molluscan packstone
6. Manicina areolata (high diversity shell beds, solitary corals)	a. Moldic molluscan pack-grainstone b. Molluscan wacke-packstone c. Molluscan pack-grainstone

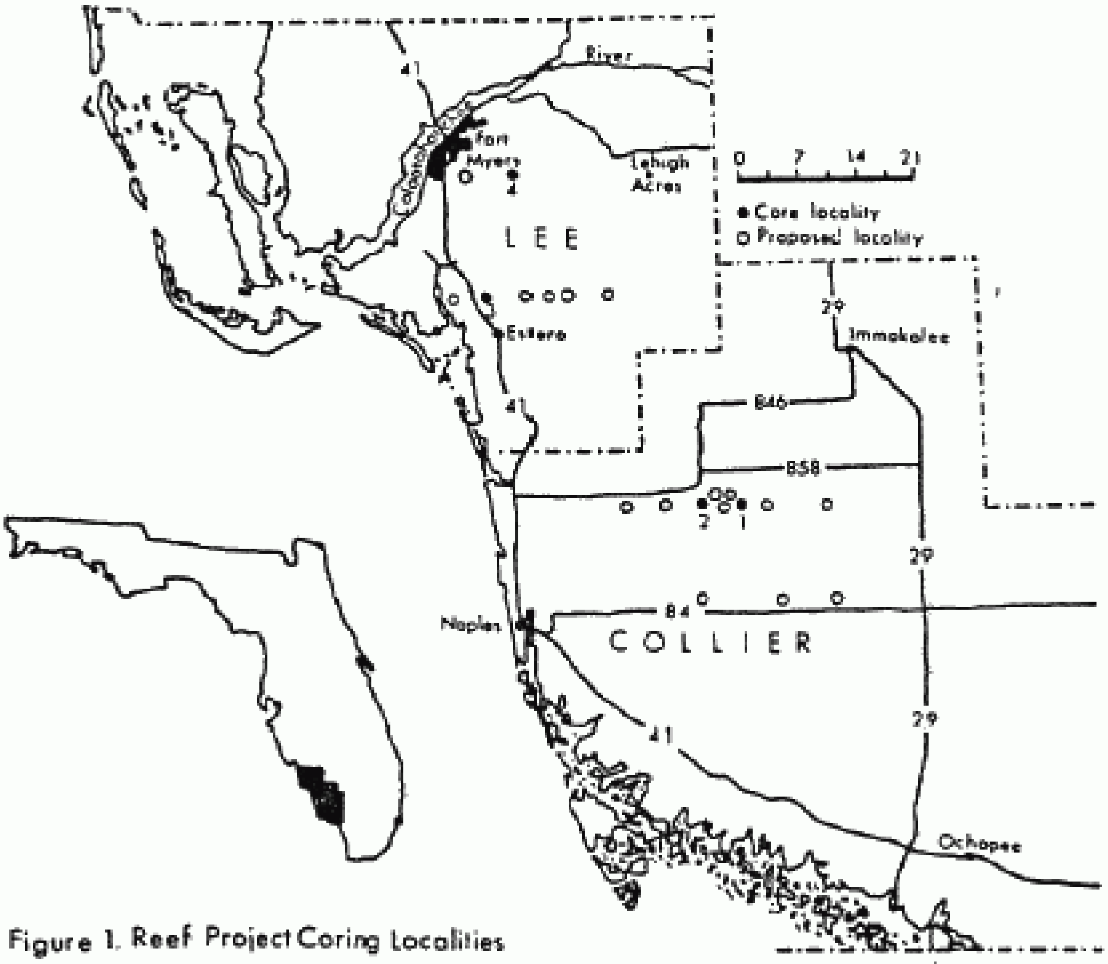

Figure 1. Reef Project Coring Localities

WATER RESOURCE EVALUATION OF WESTERN COLLIER COUNTY - 1980 UPDATE

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INTRODUCTION

The Regional Water Resources Study - Basin Program No. 2201 was conducted between November 1977 and April 1980. Field investigations through test wells, pumping test, water quality sampling and analysis and flow monitoring were carried out. Atmospheric monitoring consisted of rainfall, evaporation, wind speed and temperature measurements. In addition, literature pertaining to the area geology, ground and surface water occurrence and quality, soils, topography, climate and water resource management was reviewed.

Analysis of the data collected and results of investigations are summarized as follows:

HYDROGEOLOGY

The Naples study area is almost flat with a slight slope from the east boundary to the coast. It is broken by a low coastal ridge. The Gordon River Basin lies immediately east and drains into the Bay of Naples (Figure 1). These major topographic features lie parallel to the coastline. Underlying a thin veneer of siliceous sand is a sequence of limestone and fine silty sand. The upper 100 feet of the section is composed of 3 limestone units (Units 2, 3 & 4) (Figure 2). These units thicken in reef type structures in the extreme south and northeast parts of the study area and along the northwest coast.

Units 2 and 3 comprise the surficial water table aquifers. They are very permeable and transmit water at high rates under unconfined conditions. Representative transmissivities and storage coefficients are 500,000 gpd/ft and 0.3. This aquifer unit contains potable water throughout the study area. Lateral permeability is generally much higher than vertical and both vary over the area in response to lithologic variations. Unit 4, the lower silty limestone unit is less permeable having representative transmissivity and storage coefficient values of 170,000 gpd/ft and 1.4×10^{-2}. This unit contains nonpotable water below 60 feet in the central part of the study area. Below Unit 4 silty sand units (Units 5 and 5B) are dominant with thin interbedded limestone layers (Units 5A and 6). Permeability is decreased considerably in these units. The interbeded limestone units are under semi-confined conditions and contain nonpotable water over the study area except along the northwest coast and in the extreme northeastern part of the study area where they contain potable water. At about 180 feet of depth a silt and clay bed (Unit 7) (Hawthorn Formation) of reported considerable thickness is encountered. This unit is reported to have very low permeability and acts as a confining bed for underlying artesian aquifers. Individual units are generally flat lying with a slight southwest regional dip of the top of the basal Hawthorn Formation. The lower silty sand units thicken toward the coast in response to the regional dip.

GROUNDWATER QUALITY

Potable groundwater extends from the water table to about 60 feet in depth over much of the study area. Where the coastal ridge has been intersected by the Gordon River and nearby bodies of saline surface waters, it is considerably less thick or nonexistent. Salt water intrusion has occurred along most of the surface drainageways and along the coast to varying degrees as a result of reduced surface and groundwater discharge and increasing groundwater withdrawals. Greater thicknesses occur under and to the east of the highest section of the coastal ridge in the northeast and south central sections of the study area (Figure 3). Under the coastal ridge and to the northeast the thickness exceeds 180 feet. Relatively low concentrations of chloride in the upper zones increase with depth to nonpotable levels in the central part of the study area. Gradual increases in conductivity below the potable thickness indicate inadequate flushing of connate waters under most of the study area. Sharp increases near the coast indicate sea water contamination.

Surface Water Flow and Quality

The surface drainage of the study area is primarily through the extensive drainage canal network. Original drainage was through small creeks extending only a short distance inland. These creeks now transmit reduced outflows except where tied into the canal network. Surface water outflow from the study area was 20 inches during the 1979 Water Year with a much greater flow passing through the area, discharging primarily from the Golden Gate Canal and Cocohatchee River System. Recent study area runoff has increased from 2 to 3 times over predevelopment runoff. Surface water quality is generally good being similar to the quality of the groundwater seepage that provides much of the flow. Nutrient levels are high and dissolved oxygen levels low in the downstream reaches. Water quality deteriorates somewhat during low flow periods.

WATER BUDGET

The study area receives a long term average 52 inches of rainfall per year. Wind, temperature and natural soil and vegetation conditions were, prior to development, such that potential evapotranspiration (ET) loss was almost as great as rainfall. However, developmental stresses have considerably altered the water balance. During the 1979 Water Year, 27 inches of the 49 inches of rainfall were lost to ET and another 20 inches to net surface water outflow. This shift in water outflow is due to the drainage-canal network's effect of lowering the average water table and subsequent reduction of ET losses. The water no longer lost through ET becomes runoff through the canal network. Water budget for the 1979 Water Year is:

Input to the System	Inches	Output from the System	Inches
1. Precipitation	49.3	1. Evapotranspiration	27.3
2. Surface Water Inflow	*	2. Surface Water Outflow	20.0*
3. Groundwater Inflow	2.1	3. Groundwater Outflow	3.2
4. Imported Water	0.0	4. Exported Water	0.0
	51.4		50.5

* The surface water inflow and outflow could not be calculated directly so the difference or runoff from the area is used.

Groundwater recharge was sufficient to replace all losses and yield a one-inch increase in groundwater storage during the 1979 Water Year.

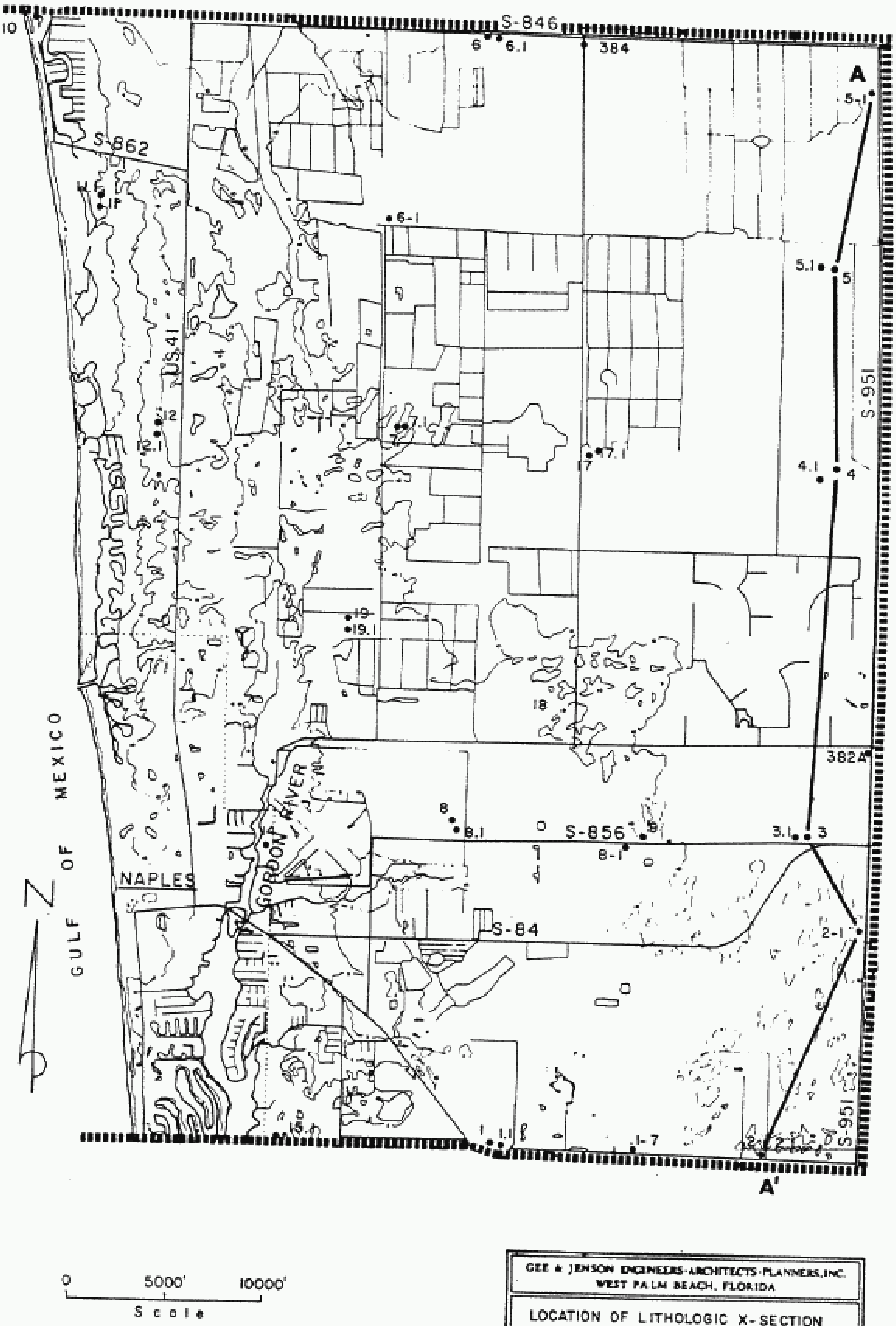
AREAS OF POTENTIAL POTABLE WATER SUPPLY DEVELOPMENT

A. Development of groundwater supplies in the 40 to 100 foot depth is feasible in three areas (Figure 4): 1. In the Lely Estates area and extending southeast along U.S. 41. 2. Between the coastal ridge and a point parallel to and approximately one mile east of Airport Road. 3. In the vicinity of the Immokalee Road and State Road 951 intersection and probably extending considerably outside the study area to the northeast.

These areas have certain hydrologic characteristics, combinations of which qualify them as potential groundwater supplies: 1. Relatively great thickness of potable water. 2. High water levels in relation to land surface. 3. Protection from lateral salt water intrusion in the form of distance inland. 4. Aquifer characteristics which will allow relatively large withdrawals within water quality restraints. 5. Low potential for surface contamination.

Consistently high water levels along the coastal ridge indicate a potential for greater withdrawals from this area than now occur. This possibility is best considered as an alternate to development in the area immediately to the East.

B. A great potential for development of groundwater supplies from the 0 to 40 foot depth exists over much of the study area. High transmissivities in this shallow zone could allow development in much of the eastern half of the study area where insufficient thickness of potable water (50 feet) prohibits withdrawals from the deeper zone. Supplies developed in this zone have a potential for considerable induced recharge from the extensive canal network in conjunction with a program designed to raise water levels through changes in the control elevation. Induced recharge can be used to improve or buffer existing groundwater quality. A logistic advantage may exist in the use of shallow groundwater over deep zone supplies due to the latter's limited area of suitability. A disadvantage of the development of shallow groundwater supplies is the increased potential for contamination. However, proper design and land management can reduce this potential just as they reduce the potential for water quality degradation from connate and salt water intrusion threat resulting from pumping the lower zone.



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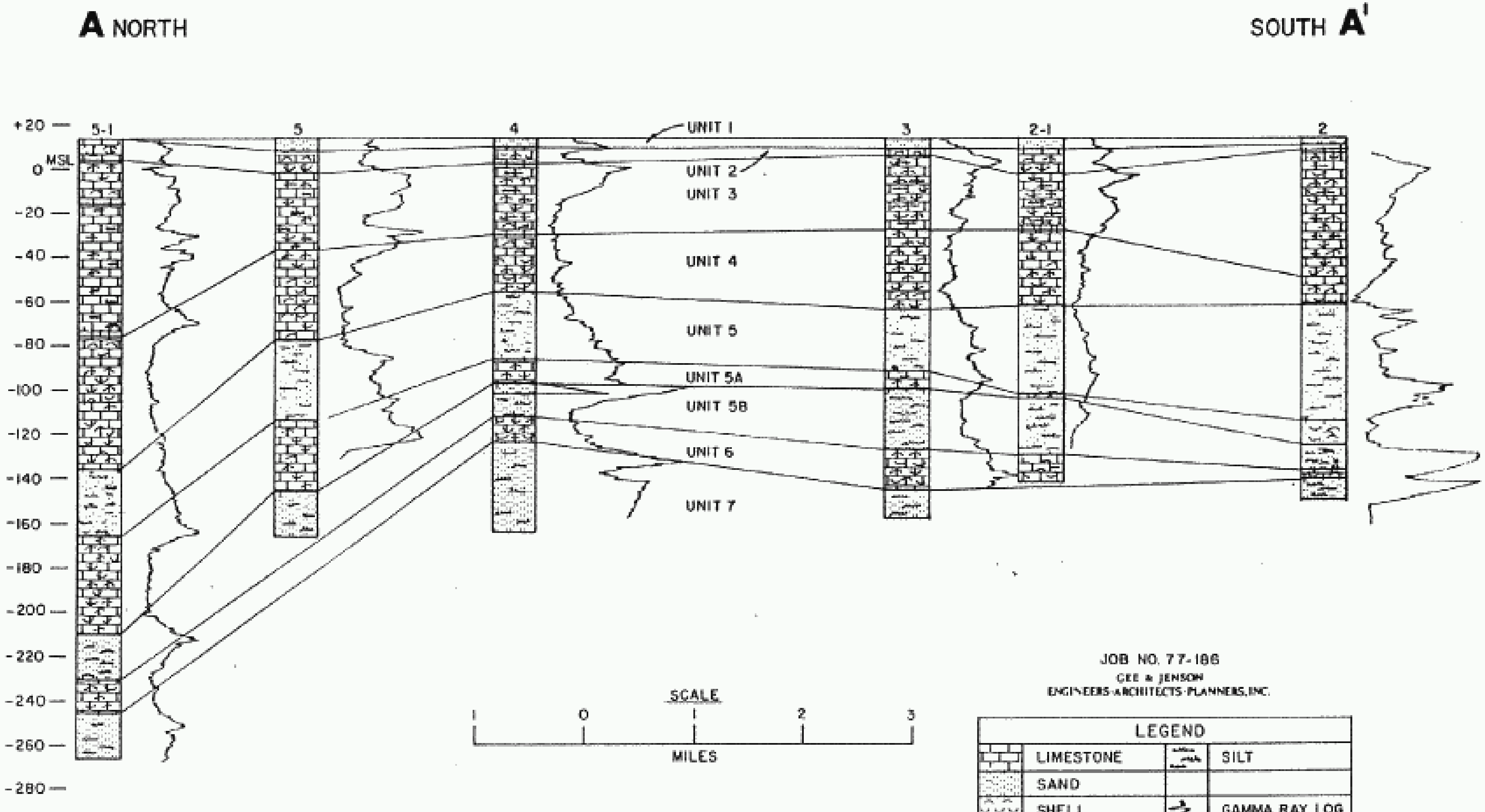
LOCATION OF LITHOLOGIC X-SECTION

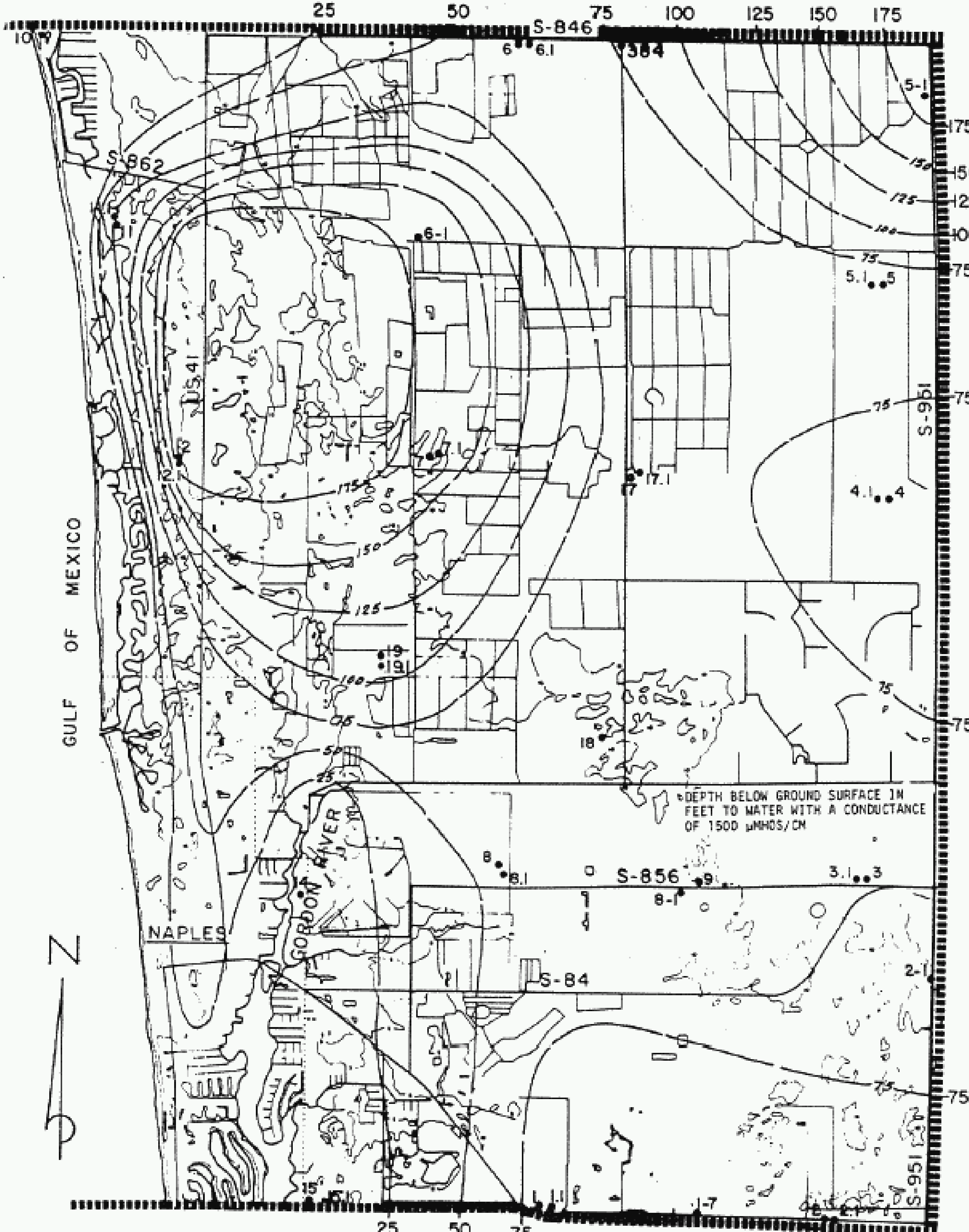
FIGURE 1



LITHOLOGIC CROSS-SECTION

A TO A'

FIGURE 2



LEGEND

TOPOGRAPHIC CONTOURS IN M.S.L

25' CONTOUR INTERVAL

1-7 • CONDUCTIVITY MONITOR WELLS

0 5,000' 10,000'

Scale

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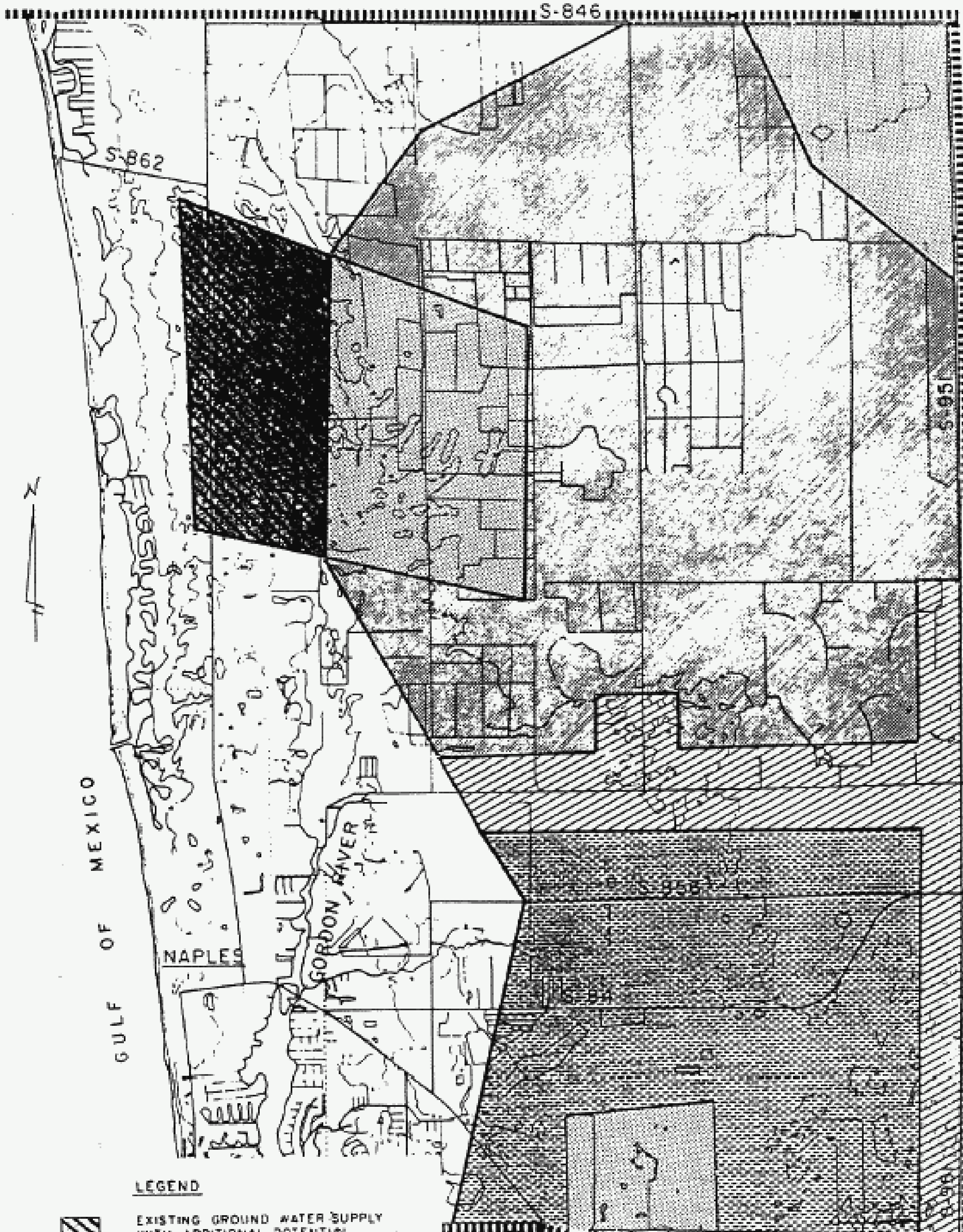
ISOCONDUCTANCE MAP
<1500 umhos/cm
MAP FOR MAY 3, 1979

FIGURE 3



LEGEND

- EXISTING GROUND WATER SUPPLY WITH ADDITIONAL POTENTIAL
- POTENTIAL DEEP GROUND WATER SUPPLY - 40 TO 100 FOOT DEPTH
- POTENTIAL SHALLOW GROUND WATER SUPPLY - 0 TO 40 FOOT DEPTH
- POTENTIAL SHALLOW GROUND WATER SUPPLY IN CONJUNCTION WITH CANAL NETWORK MODIFICATION PROGRAM TO RAISE WATER LEVELS
- POTENTIAL SHALLOW GROUND WATER SUPPLY WITH INDUCED RECHARGE IN CONJUNCTION WITH CANAL NETWORK MODIFICATION PROGRAM TO RAISE WATER LEVELS

0 5000' 10000
Scale

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WEST PALM BEACH, FLORIDA

AREAS OF POTENTIAL GROUNDWATER SUPPLY DEVELOPMENT

FIGURE 4

THE STRATIGRAPHY OF THE TAMIAMI FORMATION, SOUTHWESTERN FLORIDA

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ABSTRACT

Lithostratigraphic and biostratigraphic analysis of two Tamiami cores in Lee County support a suggested revision of the age given to the formation. Macrofossils collected in coring define a Pliocene reef complex, with alternating periods of deposition in a fresh water environment. The Miocene age sediments of the lower Tamiami Formation were produced by repeated transgressions and regressions with evidence of deltaic sedimentation. Micro- and nannofossil zonation supports previous workers, with particular emphasis placed on an extensive diatom bed.

INTRODUCTION

The Tamiami Formation in Charlotte, Lee, Hendry and Collier Counties is a complex sequence of limestones, clays, and sands of near shore marine and deltaic origin. It disconformably overlies the Hawthorn Formation and is disconformably overlain by Pliocene/Pliestocene sands and marls. Parker and others (1955) described the formation as having a "maximum thickness of 375 feet in southeastern Lee County.

Parker and others (1955) defined the Tamiami Formation to include "all the upper Miocene materials in southern Florida...", however Peck (1976) suggests that only the lower Tamiami sediments are Miocene in age, and the upper members of the formation are Pliocene in age. A detailed discussion of the history of name and age changes for the Taimiami Formation is given by Peck (1976).

During the summer of 1978 the Bureau of Geology, DNR, in cooperation with the United States Geological Survey (WRD) drilled two cores in the Corkscrew Swamp area of southeastern Lee County. The first core (W-14071) penetrated the Ochopee Limestone and part of the Buckingham Marl of the Tamiami Formation. The second and deeper core (W-14072) was drilled to 362', and came to within 20 or 30' of the base of the Tamiami. The purpose of this study was to complete a more detailed analysis of the stratigraphy and micropaleontology of the Tamiami Formation using the above mentioned cores. Of particular interest is a thick sequence of green carbonate clays and silts which contains a 10' diatom bed.

Previous Work

Mansfield (1939) proposed the name Tamiami "limestone" for a bed in ditches along highway 41 in Collier and Monroe Counties. He described its lithology as "...mainly dirty white to gray, rather hard, porous, non-oolitic limestone with inclusions of clear quartz."

Because of the great amount of quartz sand contained in the Tamiami "limestone," Parker and Cook (1944) changed the name to Tamiami Formation. Parker (1951,) later redefined the Tamiami Formation to include the "Tamiami limestone," the "Buckingham limestone" of Mansfield and the upper portion of the Hawthorn Formation of Parker and Cooke (1944).

Parker and others (1955) correlated the formation with the Miocene Duplin Marl of northern Florida, Georgia, and South Carolina using microfossils analyzed by Gardner. However, the age remained controversial as Herbert, in the same study, found Miocene, Pliocene, and Pleistocene foraminifera mixed with these Miocene forms described by Gardner. The definition given by Parker and others (1955) as all deposits, late Miocene in age in southern Florida, is still subject to debate.

Hunter (1968) recognized five lithologic members of the Tamiami Formation, and proposed a formal rock-stratigraphic name for each. She also recognized that the three time-equivalent members of the upper Tamiami formed a concurrent range zone based on mollusks for which she proposed the name Pectin tamiamiensis zone. The fauna of this zone suggested a correlation with the Jackson Bluff Formation of northern Florida, and other time-equivalent units along the Atlantic Coastal Plain.

Hunter (1970, in Oaks and Dubar, 1974) suggested that the fauna of the P. tamiamiensis zone and the presence of pre-Duplin Marl mollusk species in the older Tamiami deposits of Charlotte County place the formation age between medial Miocene and early Pliocene.

Further studies by Lamb (1970, in Oaks and Dubar, 1972) and Akers (1974) support Hunter's (1968) age assignments for the Tamiami deposits. Peck and others (1979) conclude that "the recent planktonic evidence has shown that the formation is composed of an upper set of beds equivalent to Mansfield's Taimiami Limestone and a lower set composed primarily of late Miocene calcareous clastics."

Lithostratigraphy

Peck (1976) subdivided the Tamiami Formation into eight lithologic units which consisted of sands, clays, limestones and a mixture of the three. All units were not present in all the wells studied, which suggested that they may pinch out between wells. Of Peck's eight units, only five were found in those cores used in this study. The following will include a discussion of all of the eight units, with special emphasis placed on those units found in the study cores.

Unit 1

The uppermost unit in the formation is a sandy limestone and marl sequence, which includes Mansfield's original Tamiami limestone, later called the Ochopee Limestone Member by Hunter (1968).

Core 14071 contains 22' of the Pinecrest Sand Member, 44' of the Ochopee Limestone Member and 6' of the Buckingham Limestone Member (Hunter 1968). Of particular interest in this unit is the Ochopee Limestone which consists of a sequence of marine and freshwater limestones. The marine limestone is generally composed of corals and bryozoans which suggest reefal, backreef and lagoonal paleoenvironments. The freshwater limestone is highly bioturbated and contains the freshwater mollusk, Planorbis.

This unit is of limited areal extent and thickness, and was found in only three southeastern Lee County wells by Peck (1976) and one Hendry County well by Slater (1978). Missimer (1978) traced unit 1 into Collier County, where it reaches a thickness of 170'.

Unit 2

Peck (1976) describes this unit as "a clay grading in color from gray at the top to green in the lower portion." The unit was traced throughout Lee County using gamma ray geophysical logs and attained a maximum thickness of 270' in southeastern Lee County. Missimer (personal communication) suggests that the green clay of unit 2 extends as far north as Sarasota County, and Slater (1978) has mapped it throughout Hendry County.

Core 14072 contains 40' of unit 2, from 57' - 97.5' below land surface. The upper 23' of the unit is a very sandy carbonate clay containing phosphate and foraminifera. The lower 17' is a dense olive green carbonate mud which contains abundant diatoms. These two beds are separated by a bed of large phosphate pebbles 6" thick, which suggests an erosional surface.

The green clays in this unit and units 3/5 and 6/8, below, were analyzed using x-ray diffraction. Although the material is clay-like in appearance and texture, the analysis proved it to be a carbonate mud containing predominantly dolomite, calcite, aragonite and quartz, and in the lower units, pyrite. The nature of the clay found in unit 2 suggests a lagoonal type deposit. Seismic studies by Missimer and Gardner (1976) and more recent studies by Wolansky (personal communication), suggest that the clays produce a signature much like that of a deltaic forset deposit.

Unit 3/Unit 5

This unit is a very complex sequence of sandy limestones separated by sandy carbonate clays. It is believed to be a combination of Peck's units 3 & 5, similar to Slater's unit 4 in Hendry County. In core 14072 it reaches a thickness of 194.5'. The lower 45' of this unit appears to be correlative to Peck's units, and is separated from the upper bed by an erosional surface.

Unit 4

This unit is a gray-green very sandy clay in core 14072, and has a thickness of 49'. The lower half of the unit consists of a clean to slightly marly, very well rounded quartz gravel (greater than 1000 microns), that may be correlative to Slater's (1978) "Pebble Zone," found in Hendry County.

Unit 6/Unit 8

This is the last unit encountered in core 14072. It consists of gray-green sandy limestone and clay, with abundant phosphatic sand, and shell fragments. It is very similar in description to Peck's unit 8, Slater's (1978) Unit 6, and Missimer's (1979) Ft. Myers Clay. The lower part of this unit, not found in core 14072, is often referred to as the "Rubble Zone" and marks the erosional surface of the Hawthorn Formation.

Peck (1976) also describes Units 6 and 7 which would occur between Units 4 and 6 of this study. Unit 6 is described as a gray clay unit with underlying marl and limestone beds, found only in eastern Lee County. Unit 7 is present only in one well where it is a 30' thick green phosphatic clay.

Biostratigraphy

Foraminifera

Peck (1976) defined three benthic foraminiferal zones within the Tamiami Formation. In order from youngest to oldest these zones are: Lenticulina americana Peak Zone, Valvulineria floridana Peak Zone, and Dyocibicides biserialis Zone. He bases these zones on the earliest stratigraphic occurrence or abundance of key species. The zones are defined by Peck (1976) as follows:

Lenticulina americana Peak Zone:
Definition: Interval from the first abundant occurrences of Lenticulina americana to the first occurrence of Valvulineria floridana
Remarks: This zone begins below the Tamiami-Hawthorn contact and extends through Tamiami Unit 6 deposition.

Valvulineria floridana Peak Zone:
Definition: Interval from earliest occurrence of Valvulineria floridana to the first occurrence of Dyocibicides biserialis.
Remarks: This peak zone includes Unit 5 through Unit 3. In the northwest it also occurs in a portion of Unit 2.

Dyocibicides biserialis Peak Zone:
Definition: Interval above the first occurrence of Dyocibicides biserialis (top not defined).
Remarks: This zone includes Unit 1 and part of Unit 2.

Slater (1978) agrees with Peck's zonation and notes the occurrence of the 3 zones in Hendry County. Core 14072 exhibits abundant foraminifera in the green clay of Unit 2, which correlates with Peck's Dyocibicides biserialis Peak Zone. However, the remainder of the core has too few foraminifera to define the other zones.

Diatoms

The most significant microfossil occurrence in core 14072 is a diatom bed found between 81' and 93' below land surface. The bed is contained in the green clay of Unit 2, and lacks quartz sand which is found in the remainder of the Unit. Over forty different species of diatoms are found within this zone, most being of late Miocene to early Pliocene in age. The assemblege is considerably less diverse than present day assembleges, which suggests that it was deposited in a stressed environment. All forms are marine, most being characteristic inhabitants of the littoral zone. This is contrary to Peck's (1976) suggestion that the diatoms were fresh to brackish water forms. The diatom bed is found in varying thickness throughout Lee and Hendry Counties.

Calcareous Nannofossils

Relatively abundant calcareous nannofossils occur in core 14072. Peck (1976) found the following in his Lee County cores, and suggests that they are important index fossils:

Discoaster quingeramus
D. brouweri
D. variablis
Reticulofenestra pseudoumbilica

All are found in the upper Miocene Discoaster quingeramus Zone. Study of calcareous nannofossils in core 14072 is not complete to date, so no conclusions have been drawn.

CORALS

Core 14071, as discussed above, contains a thick sequence of corals and bryozoans believed to be the Ochopee Limestone Member (Hunter 1968). Coral genera found include Stylophora, Montastrea, Siderastrea, and Porites. Meeder (1979) gives a more detailed description of the coral species found in Ochopee Limestone, and suggests that the Buckingham Limestone, Ochopee Limestone and Pinecrest Sand Members are Pliocene in age.

CONCLUSIONS

The Tamiami Formation in Lee, Hendry and northern Collier Counties is a complex sequence of sands, clays, and limestone which were deposited in a marine to brackish nearshore environment, with periods in which river sedimentation had a strong influence. Peck and others (1979) suggest a series of transgressions and regressions and gives the following as possible causes: 1) tectonic control 2) worldwide sea level fluctuations, and 3) variation in clastic sediment supply to South Florida from the north.

Although the age of the Tamiami formation has long been a subject for debate, the diatom bed found in Unit 2 and the macrofossils found in Unit 1 of cores 14072 and 14071, respectively, support Hunter's (1970 in Oaks & Dubar, 1974) findings that the unit 1 strata are Pliocene in age and that the lower units are late Miocene in age.

REFERENCES CITED

Akers, W.H., 1972, Planktonic foraminifera and biostratigraphy of some Neogene formations northern Florida and Atlantic Coastal Plain: Tulane Stud. Geol. and Paleontology, v. 9, p. 139.

Hunter, M.E., 1968, Molluscan guide fossils in late Miocene Sediments of southern Florida: Transactions of the Gulf Coast Association of Geological Societies, v. 18, p. 439-450.

Mansfield, W.C., 1939, Notes on the upper Tertiary and Pleistocene mollusks of peninsular Florida: Florida Geol. Survey Bull. 18.

Meeder, J.F., 1979, The Pliocene fossil reef of Southwest Florida: Miami Geological Society Field Trip, Guidebook, p. 1-20.

Missimer, T.M., and Gardner, R.A., 1976, High resolution seismic reflection profiling for mapping shallow water aquifers in Lee County, Florida, U. S. Geological Survey Water Resources Investigation 76-45, 30 p.

Missimer and Associates, Inc., 1978, Hydrology and geology of a proposed new well field site in north Collier County, Florida: Report to the Pelican Bay Improvement District, 144 p.

Oaks, R.Q., Jr., and Dubar, J.R., 1974, Post-Miocene stratigraphy of the central and southern Atlantic Coastal Plain: Logan Utah, Utah State Univ. Press, 265 p.

Parker, G.G., 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne Aquifer: Amer. Water Works Assoc., Jour., v. 43, p. 817-835.

________, and Cooke, C.W., 1944, Late Cenozoic geology of Southern Florida, with a discussion of the groundwater: Florida Geol. Survey Bull. 27, 119 p.

________, Ferguson, G.E., Love, S.K., 1955, Water resources of southeastern Florida: U. S. Geol. Survey Water-Supply Paper 1255, 965 p.

Peck, D.M., 1976, Stratigraphy and paleoecology of the Tamiami Formation in Lee County, Florida (MS Thesis): Florida State University, 249 p.

________, Slater, D.H., Missimer, T.M., Wise, S.W., and O'Donell, T.H., 1979, Stratigraphy and paleoecology of the Tamiami Formation in Lee, Hendry Counties, Florida: Transactions of the Gulf Coast Association of Geological Societies, v. 29.

Slater, D.H., 1978, The stratigraphy and Paleoecology of the Tamiami Formation in Hendry County, Florida (MS Thesis): Florida State University, 140 p.

POSSIBLE RESTRICTION AND REDEFINITION OF THE TAMIAMI FORMATION OF SOUTH FLORIDA: POINTS FOR FURTHER DISCUSSION

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After several year's study of outcrop and subsurface sections of units traditionally assigned to the Tamiami Formation, we have become convinced that the concept of this formation as currently defined needs to be revised (Hunter, 1978; Hunter and Wise, 1980). A synopsis of the evolution and usage of the term "Tamiami formation" is given in Table I (from a recent compendium by Peck and others, 1979b). As indicated in this table, the name Tamiami was first used for an informal limestone unit by Mansfield (1939). It was later given formation rank (Parker, 1942) and redefined (Parker, 1951; Parker and others, 1955) to include the original limestone of Mansfield (1939) and all other upper Miocene strata of South Florida. This definition is also informal since it does not conform to the U.S. Stratigraphic Code, and it has proved impractical to use because it lacks boundaries and includes unrelated strata of patently different lithologies. We propose that the Tamiami should be formally redefined, and be restricted to contain the interfingering original carbonate members (Ochopee and Buckingham Limestones) and other equivalent facies such as the Pinecrest Sand. Excluded are subjacent units "of Late Miocene age", such as the LaBelle clay and Murdock Station Member and their equivalents, all of which are for now returned to the Hawthorn Formation. An indication of how this definition might apply to the subsurface is given in Figure 1 which depicts a particularly thick section from southern Lee County described by Peck and others (1979a, 1979b). Further data to enhance a redefinition of the boundaries and extent of the Tamiami is the object of current research.

REFERENCES CITED

Akers, W.H., 1972, Planktonic foraminifera and biostratigraphy of some Neogene formations; northern Florida and Atlantic Coastal Plain: Tulane Stud. Geology and Paleontology, v. 9, 139 p.

Cooke, C.W. and Mossom, S., 1929, Geology of Florida: Florida Geol. Survey, 20th Ann. Rept., p. 29-227.

Dall, W.H., and Harris, G.D., 1892, Correlation paper: Neogene of North America: U.S. Geol. Survey Bull., v. 84, p. 100.

Dubar, J.R., 1958, Stratigraphy and paleontology of the late Neogene strata of the Caloosahatchee River area of southern Florida: Florida Geol. Survey Bull., v. 40, 267 p.

Hunter, M.E., 1968, Molluscan guide fossils in late Miocene sediments of southern Florida: Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 439-450.

__________ 1978, What is the Caloosahatchee Marl?, in M.P. Brown, ed., Hydrogeology of south-central Florida: 22nd Field Conf. Southeastern Geol. Soc. Pub. No. 20, p. 61-88.

__________ and S.W. Wise, 1980, Possible restriction and redefinition of the Tamiami Formation of South Florida: points for discussion: Florida Scientist, v. 43, Suppl. no. 1, p. 42.

Mansfield, W.C., 1931, Some Tertiary mollusks from southern Florida: U.S. National Museum Proc., v. 79, p. 1-12.

__________ 1932, Miocene pelecypods of the Choctawhatchee Formation of Florida: Florida Geol. Survey Bull., v. 8, 240 p.

__________ 1939, Notes on the upper Tertiary and Pleistocene mollusks of peninsular Florida: Florida Geol. Survey Bull., v. 18, 75 p.

Missimer, T.M., 1978a, The Tamiami Formation-Hawthorn Formation contact in southwest Florida: Florida Scientist, v. 41, p. 31-39.

__________ 1978b, the Tamiami aquifer system in southwest Florida in M.P. Brown, ed., Hydrogeology of south-central Florida: 22nd Field Conf., Southeastern Geol. Soc., Pub. No. 20, p. 89-102.

Oaks, R.Q., Jr., and Dubar, J.R., 1974, Post-Miocene stratigraphy of the central and southern Atlantic Coastal Plain: Logan, Utah, Utah State Univ. Press, 265 p.

Olsson, A.A., 1964, Geology and stratigraphy of southern Florida, in Olsson, A.A., and Petit, eds., Some Neogene mollusca from Florida and the Carolinas: Bull. Am. Paleontology, v. 47, no. 217, p. 509-574.

Parker, G.G., 1942, Notes on the geology and ground water of the Everglades in southern Florida: Proc. Florida Soil Science Soc., v. 4, p. 47-76.

______________ 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne Aquifer: Am. Water Works Assoc., Jour., v. 43, p. 817-835.

______________ and Cooke, C.W., 1944, Late Cenozoic geology of southern Florida, with a discussion of the ground water: Florida Geol. Survey Bull., v. 27, 119 p.

______________ Ferguson, G.E., Love, S.K., 1955, Water resources of southeastern Florida: U.S. Geol. Survey Water-Supply Paper 1255, 965 p.

Peck, D.M., Missimer, T.M., Slater, D.H., Wise, S.W., and O'Donnell, T.H., 1979a, Late Miocene glacio-eustatic lowering of sea level: evidence from the Tamiami Formation of south Florida: Geology, v. 7, p. 285-288.

______________ Slater, D.H., Missimer, T.M., Wise, S.W., and O'Donnell, T.H., 1979b, Stratigraphy and paleoecology of the Tamiami Formation in Lee and Hendry Counties, Florida: Gulf Coast Assoc. Geol. Socs. Trans., v. 29, p. 328-341.

Puri, H.S., and Vanstrum, V.V., 1971, Stratigraphy and paleoecology of the late Cenozoic sediments of south Florida, in Oertle, H.J., ed., Paleoecologie Ostracodes, Pau, 1970: Bull. Centre Rech. Pau SNPA, 5 suppl., p. 433-448.

______________ and Vernon, R.O., 1964, Summary of the geology of Florida and a guidebook to the classic exposures: Florida Geol. Survey, Spec. Pub. 5, 312 p.

Sanford, S. 1909, The topography and geology of southern Florida: Florida Geol. Survey, 2nd Ann. Rept., p. 175-231.

Schroeder, M.C., and Bishop, E.W., 1953, Foraminifera of the late Cenozoic in southern Florida: AAPG Bull., v. 37, p. 2182-2186.

______________ 1954, Notes on the Foraminifera from the late Cenozoic in southern Florida: Jour. Paleontology, v. 28, p. 210-213.

______________ and Klein, H., 1954, Geology of the western Everglades area, southern Florida: U.S. Geol. Survey Circ. 314, 26 p.

TABLE 1

SYNOPSIS OF NAMES, AGES, AND DISPOSITION BY VARIOUS AUTHORS OF ROCKS NOW ASSIGNED TO THE TAMIAMI FORMATION

AUTHOR(S)	UNIT NAME(S) DISPOSITION	AGE
Dall and Harris, 1892	Described limestone samples from the head of Lostmans and Allens Rivers, Southwest Florida.	
Sanford, 1909	Named Lostmans River Ls.	Pleistocene
Cooke and Mossom, 1929	1) Abandoned Lostmans River Ls. (considered a facies of Miami Oolite); 2) Described a limestone on the Tamiami Trail; mapped as Caloosahatchee Fm.	Pleistocene; Pliocene
Mansfield, 1931	Described fossils from a sand near Pinecrest along Tamiami Trail.	Late Miocene or Pliocene
Mansfield, 1932	Described fossils collected by Cooke and Mossom (1929) along Tamiami Trail.	Pliocene
Mansfield, 1939	1) Named Buckingham Ls. 2) Named Tamiami Ls. (superjacent to Buckingham Ls.)	Uppermost Miocene; Basal Pliocene (below Caloosahatchee Marl)
Parker, 1942	Adopted name Tamiami Formation.	Pliocene: younger or = Caloosahatchee Marl
Parker and Cooke, 1944	Considered Lostmans River Ls. = Cooke and Mossom's limestone on Tamiami Trail = Tamiami Limestone of Mansfield (1939); also considered Tamiami Fm., Buckingham Marl, and Caloosahatchee Marl all gradational facies equivalents.	Pliocene
Parker, 1951	Included in the Tamiami Fm. the upper Hawthorn beds of Parker and Cooke, (1944) and all upper Miocene deposits of South Florida.	Late Miocene
Schroeder and Bishop 1953, 1954	Examined benthic foraminifers of the Tamiami Fm.	Late Miocene
Schroeder and Klein, 1954	Noted Tamiami Fm. (including Buckingham Ls.) lies unconformably below Caloosahatchee Fm.	Late Miocene
Parker, Ferguson and Love, 1955	Again defined Tamiami Fm. to include all late Miocene deposits of South Florida.	Late Miocene (including Duplin Marl equivalents)
Dubar, 1958	Noted in outcrop Tamiami Fm. unconformably overlain by Caloosahatchee Fm.	Miocene
Puri and Vernon, 1964	Suggested Alva and Labelle clay mbrs.	Late Miocene (<u>Arca</u> Faunizone)
Olsson, 1964	Placed "Pinecrest beds" between Tamiami Ls. of Mansfield and Caloosahatchee Marl.	Miocene (all units)
Hunter, 1968	Formally proposed five members of Tamiami Fm.: 1) Upper units (all time equivalent): Pinecrest Sand Mbr.; Buckingham limestone Mbr.; Ochopee Ls. (=Tamiami Ls. of Mansfield); 2) lower units: Murdock Station Mbr., Bayshore Clay Mbr.	Miocene
Puri and Vanstrum, 1971	Suggested Ortona sand mbr.	Late Miocene
Akers, 1974	Dated coccoliths of Pinecrest Sand Mbr.	Pliocene
Hunter, 1970 in Oaks and Dubar, 1974	Tamiami Formation	Medial Miocene to Early Pliocene
Missimer, 1978a, b	Suggested Ft. Myers clay and Lehigh Acres sandstone mbrs. of Tamiami Fm.	Pliocene-Miocene

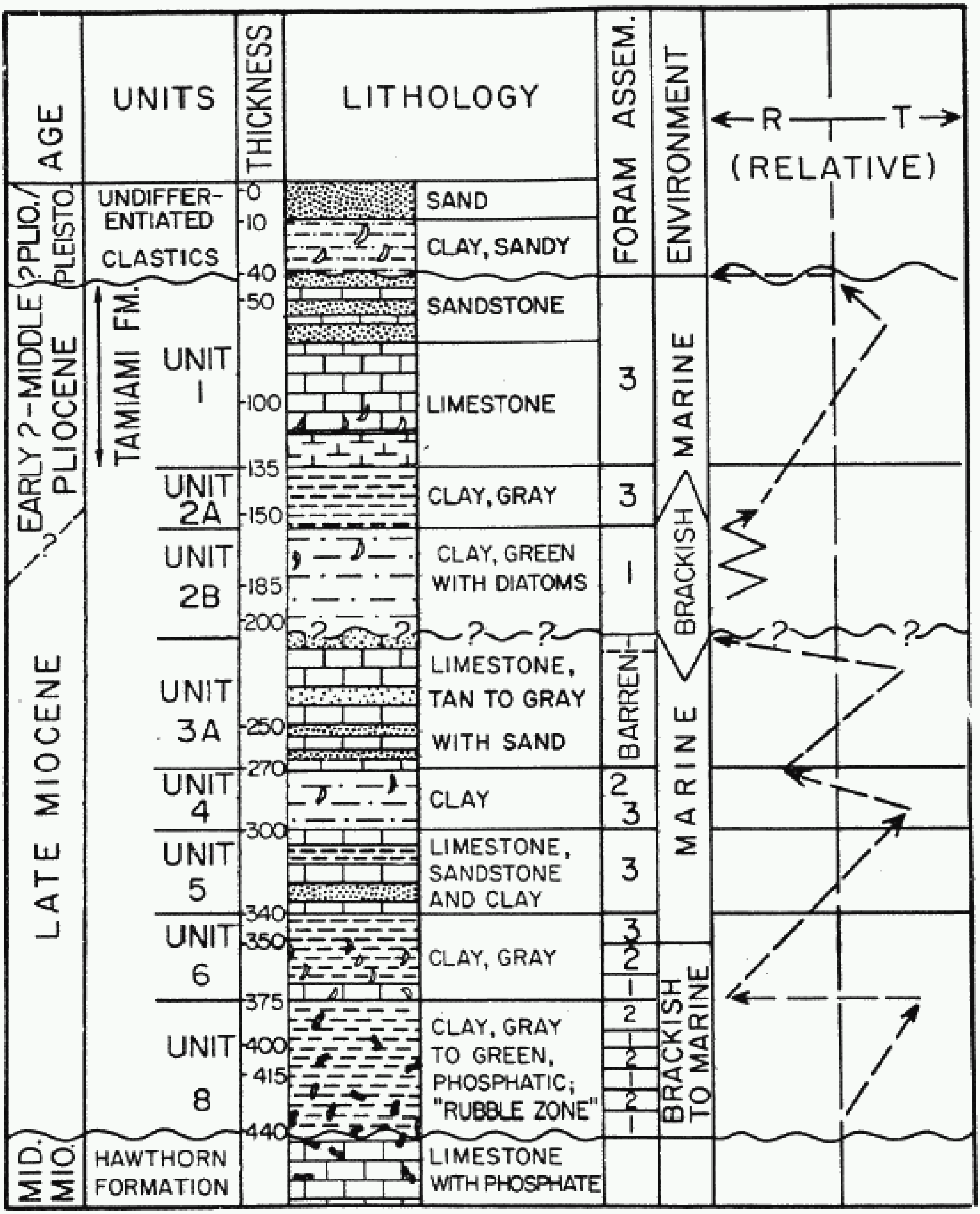

Figure 1. Lithologic section for reference well L-1984 (southern Lee County) showing suggested restriction of the Tamiami formation in the subsurface to Unit 1 of Peck and others (1979b). Units 2A to 8 would for now be returned to the Hawthorn Formation. Cumulative thickness is given in feet; also shown are patterns of regressions and transgressions deduced from lithologic and biologic characteristics (modified from Peck and others, 1979a and 1979b).

HOW LONG WILL THE WATER LAST? - WATER CHRONICLES FOR THE SOUTHWEST COAST

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ABSTRACT

The increasing demands for water in the southwest coast of Florida will continue for the next twenty years, while existing water sources will come under great pressure to serve these increased needs. If funding and inflation continue to constrain water supply facility development it will be necessary to use the existing facilities to the maximum degree possible. It is suggested that by converting conventional treatment plants to be able to handle a variety of raw water sources, that future demands can be effectively and adequately met without major impacts on the environment, and with minimum additional cost to the users in a specific area.

INTRODUCTION

The southwest coast of Florida is currently being studied by the South Florida Water Management District to develop a Water Use Plan as required by Chapter 373 of the Florida Statutes. A major part of this Plan is to determine how growth will impact the area's water resources, how much water will be required in the future, and where this water will come from. Technology assessments have been made to project what might happen if certain types of advanced systems get adopted for wide spread water supply use. This paper briefly summarizes some of these assessments and what their impact might be from 1980 to the year 2000, as population growth and agricultural expansion occurs.

CURRENT WATER USE FOR THE SOUTHWEST COAST

There are about 300,000 people that now live within the area, which includes all or parts of Lee, Collier, Hendry, and Charlotte Counties. They currently use about 50 MGD of water based on utility records. The other major user, agriculture, requires about 96 MGD for the consumptive use of crops, including citrus, truck, ornamentals and sugar cane. Self-supplied drinking water and other agricultural uses may account for an additional 10-15% of the total, but there is little quantitative data available on these uses.

The sources of water now used to meet these demands are both from the surface (49%) and from groundwater (51%), although there is a wide range depending on the specific county. For example, Collier County gets about 95% of its total water from groundwater, while Hendry County gets about 29% of its total needs from aquifers. Groundwater withdrawals for public water supply furnish almost all the population in the area, using conventional treatment plants, and some desalination plants where available aquifers are all high in salt content.

A CHRONICLE OF WATER SUPPLY DEVELOPMENT FOR THE 1980-2000 PERIOD

The southwest coast will grow by about 118,000 people by the year 1990, if the population achieves the average growth rate projected by the counties and the University of Florida (for a total population of about 418,000). The population might reach over 500,000 by the year 2000 based on these same projections. This in turn will mean an increased demand for water approaching 83 MGD, or about 33 MGD more than is currently being used.

During the 1980-2000 time period there will probably exist the same type of constraints that now exist for the funding and implementation of new water supply facilities. These include high, or double-digit inflation, concerns over the environmental impacts of increased freshwater withdrawals, high power costs and great uncertainty over federal and state funding participation. On the positive side over the next twenty years, based on projects now underway, improved technologies will probably be available to offset some of these water supply problems, (e.g. low pressure seawater/brackish desalination, deep well storage, ocean thermal power sources, new water quality treatments etc.).

While regionalization (partial or full) in the southwest coast offers promise for meeting some of the future demands, there may be funding problems that prevent the effective realization of this method. A local utility would therefore have to look to local solutions, which would include maximizing the use of its existing facilities and systems. With the considerable amount of brackish groundwater and low quality surface water available throughout most of the southwest coast, attention would be drawn to the possible uses of these water sources to augment the freshwater supplies. Site specific analyses of current conventional water treatment plants would show that by adding a dual water system, capable of furnishing both fresh and brackish water to residential, commercial, industrial and agricultural developments, a large part of the demand for water of drinking quality could be reduced. Also, wastewater generated from sewage treatment plants would be capable of being recycled and used in conjunction with the dual water system. Tests now being conducted in Lee county on storage of excess surface water in deep aquifer layers will be completed towards the end of the 1980's and show at this time that almost 75% recovery will be possible. The research and development on low pressure (therefore low energy) desalination processes will be completed and provide the potential for meeting even the most stingent EPA water quality requirements.

When all the technologies and capabilities were reviewed with the needs of the local utility in mind, a multi-source water supply facility could be designed which uses existing facilities to the maximum degree, minimizes land expansion requirements and environmental impacts. This facility would have at its base the existing conventional plant, to which would be added a series of deep storage wells, dual supply system hardware, and brackish water desalination plant, all on the land controlled by the utility. Additional buildings and equipment would be provided for the pre-treatment, mixing and distribution of the various water sources used.

In addition to the benefits noted for this multi-source facility would be the ability to add-on only those increments of additional supply that were needed over a specified time period, reduced power costs, minimum new institutional requirements (including administrative, operating and maintenance costs), minimized monitoring requirements for permit compliance, and compatibility with any form of future partial or incremental regionalization accomplished by a specific county. Also the centralization of these facilities would make them logical candidates for medium scale solar or wind power energy sources.

It must be remembered that this is only one possible scenario of a future development. Where regionalization is capable of being accomplished it should take the first priority as the means of providing for increased water supplies.

THE HYDROGEOLOGY OF THE HAWTHORN AND SUWANNEE AQUIFER SYSTEMS, SANIBEL ISLAND, FLORIDA

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ABSTRACT

Water supply problems created by increased population growth in the late 1960's and 1970's have caused a need to study the saline-water aquifers within the Hawthorn Formation and Suwannee Limestone beneath Sanibel Island. Six aquifers have been defined and studied. Four zones occur within the Hawthorn Formation and two zones within the Suwannee Limestone. The confining beds between the Hawthorn zones are formed by relatively thin beds of many different lithologies. The Suwannee zones are separated by lime muds and dense, hard limestones.

Hawthorn Aquifer System-Zone IV will be the source of water supply for the future on Sanibel Island. It has a transmissivity of about 50,000 gpd/ft and is located between two aquifers which contain similar quality water. Water quality decline in the aquifer, as caused by pumpage, will be slow and will stabilize at an acceptable level.

INTRODUCTION

Water supply has been a significant problem on Sanibel Island since the days of early settlement. Being a barrier island, Sanibel is totally surrounded by seawater. When only a few families settled on the island, water was obtained either by transport from the mainland, by retaining rainwater in large cisterns, or by utilizing very shallow sand-point wells.

In the early part of the 19th century, agriculture became a significant industry on the island. During agricultural production years, the first deep artesian wells were drilled on Sanibel. Subsequent hurricane activity in 1926 and 1935 essentially eliminated farming on the island, but many new residences and some resort areas were built during the late 1930's and in the 1940's. Again, most of the population still relied on cisterns and shallow wells for irrigation. It was found that during very dry years, the rather limited quantity of water available in the upper part of the water-table aquifer would increase in salinity until it became unusable. From the late 1940's through 1960, more than 40 deep artesian wells were drilled into the Hawthorn Formation to replace the shallow water source.

In 1965, the Island Water Association was formed to become the supplier of potable water for Sanibel Island and Captiva Island. During the 15 years of its existence, the Island Water Association has conducted a large amount of exploratory drilling and aquifer testing. This paper contains a brief summary of the existing knowledge on the geology and hydrology of the Hawthorn and Suwannee Aquifer Systems beneath Sanibel Island.

GEOLOGY

During the past 2 years, five exploratory wells have been drilled into the lower part of the Hawthorn Formation and through part of the Suwannee Limestone section. Also, suites of geophysical logs have been made on these wells and gamma ray logs have been made on roughly 25 other wells located in the general vicinity. A stratigraphic column of well L-M-987 is herein presented to illustrate the major characteristics of the formations.

Hawthorn Formation

The top of the Miocene Hawthorn Formation occurs at a variable depth below Sanibel Island because it is an erosional unconformity and has been structurally deformed to a minor degree (Missimer and Gardner, 1976). Placement of the formational contact was based on the occurrence of bedded quartz sand and pebble phosphorite within the Fort Myers Clay Member of the Tamiami Formation (Missimer, 1978).

Hawthorn Formation sediments range between 400 and 450 feet in thickness beneath Sanibel Island. There are some very interesting general observations which can be made concerning the Hawthorn section. First, there is a distinctive increase in the percentage of clastic sediment going from the base to the top of the formation. Quartz sand is virtually absent and the nodular phosphorite is fine sand-size in the lowermost limestone unit. Second, there are three distinct limestone units which are separated by relatively thin beds of many different lithologies. Third, the number of thinly-bedded lithologies increases with depth at each separation. For example, there are three different lithic units separating the uppermost major limestone unit from the top of the formation, five different lithic units separating the upper from the middle limestone, and twelve different lithic units separating the middle from the lower limestone.

There are a few general conclusions which can be drawn concerning the Hawthorn Formation beneath Sanibel. First, the three major limestone units probably represent extensive periods with a relatively constant depositional environment and constant rate of subsidence. The large number of thin lithic units represent a period of time when there was a large number of short duration changes in the depositional environment caused by either eustatic events or structural instability. This assumes of course a relatively constant sedimentation rate, which could also affect the number of changes. Second, the increase in clastic sediment percentage could have been caused by a shoaling of the relative sea level or the source of clastic sediment moving closer, such as a prograding delta. Based on some high resolution seismic profiles made in the area by Missimer and Gardner (1976), it is probable that some periods of rapid uplift occurred during Hawthorn time. If the structural changes occurred as episodic events during this time, then relatively rapid sea level changes would occur, which would produce shoaling and a number of depositional environment changes.

Suwannee Limestone

The Oligocene Suwannee Limestone lies beneath the Hawthorn Formation. There is no evidence that the Tampa Formation exists in this section. This is confirmed by recent work performed by King and Wright (1979), which shows termination of this unit in the middle of Sarasota County to the north.

The formation contact between the Hawthorn and Suwannee appears to be gradational. Only the upper 160 feet of the formation have been explored in any test hole on Sanibel Island. The part of the Suwannee studied is very similar to the type section and typical of the formation in other areas of Florida. It ranges in lithology from a tan, micritic limestone to a calcarenite with some interbedded lime muds to a light tan mudstone.

HYDROLOGY

Definition of water-bearing zones within the Hawthorn Formation and Suwannee Limestone is based on both geologic data and a number of aquifer tests. The uppermost aquifer in the system is termed Hawthorn Aquifer System-Zone I. It occurs at the contact between the Tamiami and Hawthorn Formation. It has not been studied to any great detail, but it does yield nearly potable water at the northwest part of Sanibel. The other aquifers within the Hawthorn System occur within each of the major limestone units. Confinement is provided by clays and dense carbonates between each of the units. Hawthorn-Zone II lies in the uppermost of the major limestones. It also has not been studied because it contains high salinity water in most areas beneath the island.

The principal aquifer utilized in the past for water supply on Sanibel lies within the middle limestone and is termed Hawthorn-Zone III. Zone III has a transmissivity that varies from 6000 to perhaps 20,000 gpd/ft and a leakance ranging from about 5×10^{-4} to 5×10^{-5} gpd/ft^3. Water quality within the aquifer ranges from a dissolved chloride concentration of 400 mg/l to near seawater. Water quality declines have been observed in production wells at many localities. Degradation of water quality has been caused by both over-development of the aquifer and poor well construction.

Hawthorn Aquifer System-Zone IV is a recently studied aquifer lying in the lowest limestone unit. It is quite productive with a transmissivity of over 50,000 gpd/ft and a leakance on the order of 1×10^{-3} gpd/ft^{-3}. It contains similar quality water to that observed in Hawthorn-Zone III. The Island Water Association is presently developing the aquifer as a source of raw water for the new reverse osmosis treatment plant.

The Suwannee Aquifer System contains two separate water-bearing zones. Suwannee-Zone I ranges from some confining beds at the base of the Hawthorn Formation to some confining beds, which occur between 834 and 840 feet below surface. Suwannee Zone-I is about 80 feet thick and contains water with slightly higher dissolved solids than found in Hawthorn-Zone IV. There is no density stratification of the water in the aquifer. Suwannee-Zone II occurs below 840 feet. There is a large increase in the dissolved chloride concentration below the separation (2000 mg/l) and a potentiometric head increase. Zone II is density stratified with very high salinity water at the 900-foot level in the aquifer.

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I wish to thank Mr. Ian Watson, General Manager, and the members of the Board of Directors of the Island Water Association for permission to release the information contained in this paper.

REFERENCES

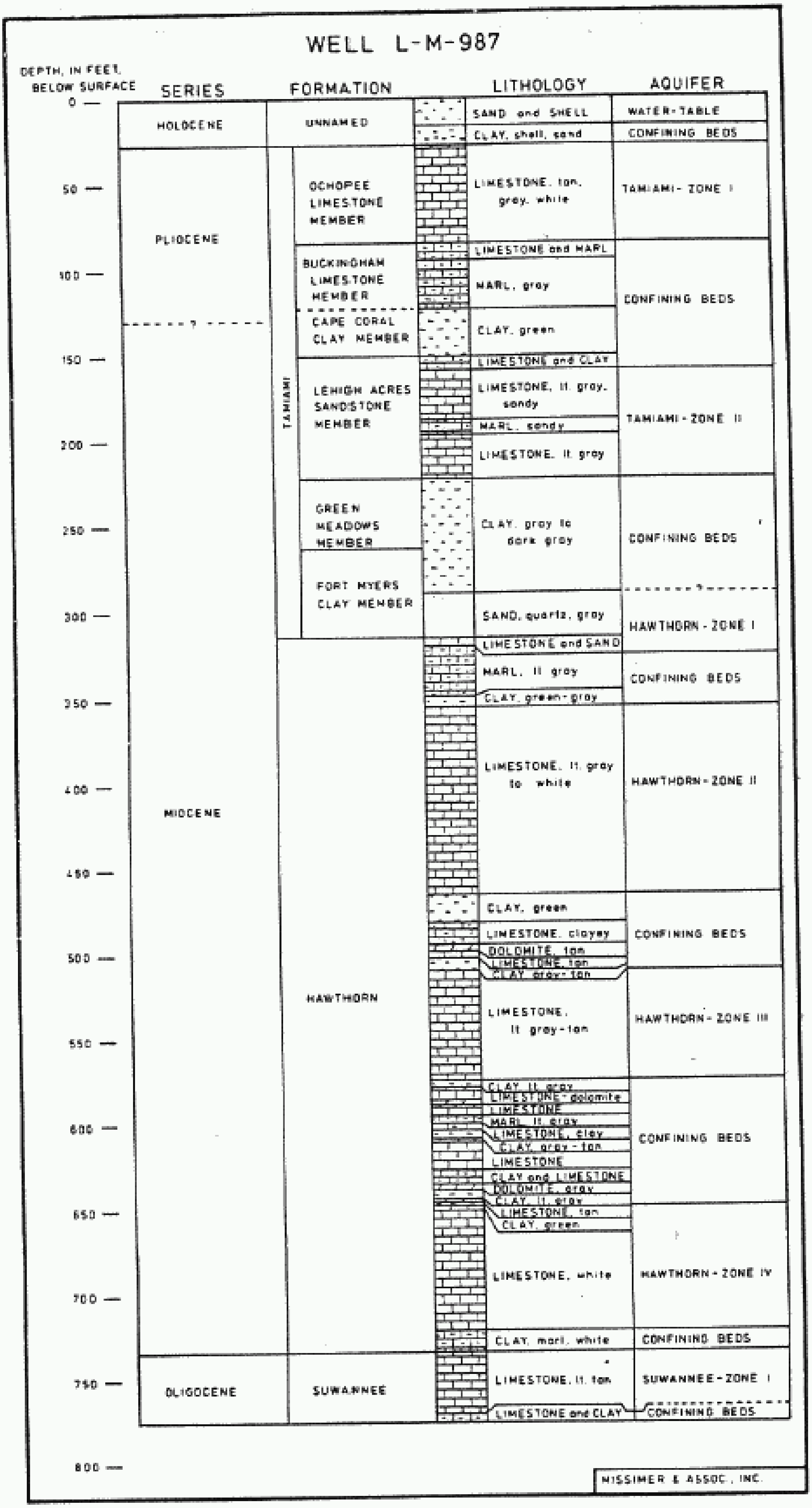
King, K.C., and Wright, R., 1979, Revision of the Tampa Formation, West-Central Florida: Trans. of the Gulf Coast Assoc. of Geological Soc., v. 29, p. 257-262.

Missimer and Associates, 1978, Hydrologic investigation of the Hawthorn Aquifer System in the northwest area, Sanibel, Florida: Rept. to the Island Water Association, 101 p.

Missimer and Associates, 1979, Hydrologic investigation of the Hawthorn and Suwannee Aquifer Systems in the central area, Sanibel, Florida: Rept. to the Island Water Association, 98 p.

Missimer, T.M., 1978, The Tamiami Formation-Hawthorn Formation contact in southwest Florida: Florida Scientist, v. 41, p. 31-38.

Missimer, T.M., and Gardner, R.A., 1976, High-resolution seismic reflection profiling for mapping shallow aquifers in Lee County, Florida: U.S. Geological Survey Water Resources Investigations/NTIS, WRI 76-45, 30 p.


WELL L-M-987
DEPTH, IN FEET, BELOW SURFACE
SERIES
FORMATION
LITHOLOGY
AQUIFER
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
HOLOCENE
PLIOCENE
MIOCENE
OLIGOCENE
UNNAMED
TAMIAMI
OCHOPEE LIMESTONE MEMBER
BUCKINGHAM LIMESTONE MEMBER
CAPE CORAL CLAY MEMBER
LEHIGH ACRES SANDSTONE MEMBER
GREEN MEADOWS MEMBER
FORT MYERS CLAY MEMBER
HAWTHORN
SUWANNEE
SAND and SHELL
CLAY, shell, sand
LIMESTONE, tan, gray, white
LIMESTONE and MARL
MARL, gray
CLAY, green
LIMESTONE and CLAY
LIMESTONE, lt. gray, sandy
MARL, sandy
LIMESTONE, lt. gray
CLAY, gray to dark gray
SAND, quartz, gray
LIMESTONE and SAND
MARL, lt gray
CLAY, green-gray
LIMESTONE, lt. gray to white
CLAY, green
LIMESTONE, clayey
DOLOMITE, tan
LIMESTONE, tan
CLAY, gray-tan
LIMESTONE, lt gray-tan
CLAY, lt. gray
LIMESTONE-dolomite
LIMESTONE
MARL, lt. gray
LIMESTONE, clay
CLAY, gray-tan
LIMESTONE
CLAY and LIMESTONE
DOLOMITE, gray
CLAY, lt. gray
LIMESTONE, tan
CLAY, green
LIMESTONE, white
CLAY, marl, white
LIMESTONE, lt. tan
LIMESTONE and CLAY
WATER-TABLE
CONFINING BEDS
TAMIAMI-ZONE I
CONFINING BEDS
TAMIAMI-ZONE II
CONFINING BEDS
HAWTHORN-ZONE I
CONFINING BEDS
HAWTHORN-ZONE II
CONFINING BEDS
HAWTHORN-ZONE III
CONFINING BEDS
HAWTHORN-ZONE IV
CONFINING BEDS
SUWANNEE-ZONE I
CONFINING BEDS
MISSIMER & ASSOC., INC.

BARRIER ISLAND SEDIMENTATION: SANIBEL ISLAND, FLORIDA

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ABSTRACT

Sanibel Island formed as a eastward prograding spit between 4200 and 6000 years ago. It consists of 7 to 12 sets of subparallel beach ridges. Within each set the ridges are subparallel, but older sets are truncated by younger sets.

The beach ridges represent periods of rapid deposition and seaward progradation, while the truncations represent periods of erosion and non-deposition at the shoreface.

Deposition and erosion have been episodic during the geologic history of the island. It is probable that sea level was rising during periods of erosion and falling during periods of deposition (Bruun Theory). If this is the case, then sea level was near the present level at about 6000 years ago and has varied up and down 1 to 2m since the island originated.

INTRODUCTION

Barrier islands, as common landforms, have been studied by numerous geologists over the past 150 years. Early investigators were interested principally in the genesis of barrier islands, but many more recent studies emphasize the persistence of barrier islands through geologic time and preservation in the stratigraphic record.

Theory on barrier island formation and subsequent modification by processes has undergone considerable change. The works of deBeaumont (1845), Gilbert (1885), Merrill (1890), Davis (1912), Gulliver (1899), Shepard (1960), Shepard and Suess (1956), Hoyt (1967), and Price (1963) have suggested various significant ideas concerning the genesis of barrier islands. Many of these scientists believed that barrier islands form by a single unique combination of physical events. However, it is now the consensus of most coastal geomorphologists that barrier islands form in a number of different ways as described in a summary by Schwartz (1971). There are examples of barrier islands that probably formed as emergent structures (Johnson model), as submergent structures (Shepard model), as segmented spits emanating from a headland, and as emergent structures occuring adjacent to existing tidal inlets.

Despite the abundance of theories regarding barrier island formation, there are a number of factors common to the genesis and evolution of all barrier islands. The growth and evolution of barrier islands are principally controlled by: 1) the abundance of sediment entering the system, 2) changes in relative mean sea level caused by either eustatic, structural, or isostatic events, and 3) the relative stability of the coastal area (e.g. barrier islands are common along passive rather than active margins.)

Barrier Islands of the Southwest Florida Coast

Barrier islands occur adjacent to the coastline along much of the Gulf of Mexico from northern Mexico to south Florida. The barrier islands of concern in this paper range from the Tampa Bay area south to Marco Island. Sanibel Island is the southernmost in a segment of the barrier island chain which runs about 50 miles from north of Lemon Bay to San Carlos Bay. Sanibel is a rather unique island compared to the others located in the chain because it does not have a thin lenticular shape. It is approximately 13 miles long with a curved axial trend which runs from north around to the east. The island varies from ½ to 2 miles in width, which gives it the most land area of any southwest Florida barrier island. Sanibel Island was originally chosen for study because it is at the end of a coastal "subcell" and contains more uninterrupted geologic record than the other islands in the chain.

Holocene Stratigraphy of Sanibel Island

More than 40 cores have been made through the Holocene section beneath Sanibel Island. Three stratigraphic units were found in all of the cores. The uppermost unit is a white to light tan quartz sand and shell hash. It ranges from 10 to 15 feet thick and is not homogeneous, but consists of alternating sand and shell beds. This unit represents shoreface deposition to backbeach deposition. A second sand unit occurs beneath the uppermost unit. It is a gray, fine to very fine quartz sand with a small percentage of lime mud. This 8 to 10-foot thick unit represents shallow sublittoral deposition from below the wave-break zone to about 1 mile offshore. The lowest stratigraphic unit is a 10 to 15-foot thick mixture of sand, shell, and lime mud with some clay. It is quite inhomogeneous and represents several different depositional environments. The upper part of the unit represents an offshore deposit, perhaps one mile or more away from the shoreline and the remaining part of the unit represents various shallow marine environments associated with a rising sea level.

Beach Ridge Deposition and the Growth of Sanibel Island

The most distinguishing geomorphic feature of Sanibel Island is its very prominent sets of beach ridges. These beach ridges have been described in detail by El-Ashry (1966), Shepard and Wanless (1971), and Missimer (1973b). An aerial photograph of Sanibel Island is given in Figure 1 to illustrate these features.

Sanibel Island contains between 7 and 12 sets of subparallel beach ridges. While the linear ridges are subparallel within each set, the older sets are truncated by younger sets leaving the intersections between them at distinguishable angles. The relative height of individual beach ridges varies within each set, and sometimes the variations are systematic. The ridges are separated by swales, which are 2 to 3 feet lower than the peak of the adjacent ridges.

Each beach ridge represents a former position of the shoreline and represents a time line in the geologic history of the island. The beach ridges were deposited during periods of rapid seaward progradation of the shoreline caused by a heavy influx of littoral transported sediment from the north. A study of beach ridges, accomplished by use of radiocarbon dates, has concluded that the average growth rate ranges between 8 and 15 years per ridge (Missimer, 1973b).

The truncations between beach ridge sets represent periods of erosion and non-deposition. The truncation lines also represent a position of the shoreline or a time line which immediately preceded the deposition of the next younger beach ridge. Therefore, the influx of littoral-transported sediment has not been constant, but has been episodic.

A model for the depositional history of Sanibel Island has been constructed by utilizing a combination of the beach ridge set geometrics and radiocarbon data (Figure 2). The island formed as an eastward prograding lobe or spit. After 3000 B.P. the only major changes to the island were the addition of sediment to the south and the general modification of the island geometry to its present configuration.

Holocene Sea Level and the Growth of Sanibel Island

Much controversy has occurred in recent years concerning the position of sea level during the Holocene. There are two general theories: 1) sea level has risen at a relatively constant rate from a position 4m below present at 7000 B.P. to the present level with no level ever going above present (Scholl, and others, 1969), and 2) sea level rose to about the present level at around 6500 B.P. and has varied around this level since that time (Shepard, 1960).

Sanibel Island formed sometime prior to 4200 B.P. or perhaps near 6000 B.P. according to the radiocarbon data. This appears to support the second theory that sea level was near present 6000 years ago (Shepard, 1960). Further, the beach ridges in the Wulfert set, located in the northwest part of the island, vary systematically to an altitude near 11 feet M.S.L. These ridges are quite pronounced and bedded shell occurs at the top of the sequence, which is evidence that the set is not a decorated dune complex, but beach ridges deposited at a sea level higher than present. Sea level probably rose from 1 to 2m above present between 2400 and 1800 B.P. as evidenced by the Wulfert ridge set (Figure 3).

It is quite possible that each major truncation of a ridge set on Sanibel Island represents a minor upward sea level trend and each depositional period of ridge progradation represents a lowering sea level trend. This follows the sea level rise-erosional theory of Bruun (1962) as modified by Schwartz (1965, 1967). Therefore, with additional study the beach ridge sets of Sanibel Island may be utilized to construct a new Holocene sea level curve (Missimer, 1976).

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REFERENCES

Bernard, H.A., Major, C.F., Jr., and Parrot, B.S., 1959, The Galveston barrier island and environs: a model for predicting reservoir occurrence and trend: Gulf Coast Geol. Soc. Trans., v. 9, p. 221-224.

Bruun, P., 1962, Sea-level rise as a course of shore erosion: Jour. of the Waterways and Harbors Division, Am. Soc. of Civil Engineers.

Davis, W.M., 1912, Die Erklarende Bescnreiburg der Landformen: Leipzig and Berlin, p. 471-473.

deBeaumont, E., 1945, Lecons de Geologic Protique: Paris, p.p. 223-252.

El-Ashry, M.F., 1966, Photointerpretation of shoreline changes in selected areas along the Atlantic and Gulf Coasts of the United States (Ph.D. Thesis): Univ. Illinois, p. 73-87.

Gilbert, G.K., 1885, The topographic features of lake shores: U.S. Geol. Surv., 5th Ann. Report, p. 87.

Gulliver, F.P., 1899, Shoreline topography: Proc. Amer. Acad. Arts and Sciences, XXXIV, p. 183-185.

Hoyt, J.H., 1967, Barrier island formation: Geol. Soc. Am. Bull., v. 78, p. 1125-1136.

Johnson, D.W., 1919, Shore processes and shoreline Development: Hafner Pub. Co.

Merrill, F.J.H., 1890, Barrier beaches of the Atlantic Coast: Popular Science Monthly, v. XXXVII, p. 744.

Missimer, T.M., 1973a, The depositional history of Sanibel Island, Florida (M.S. Thesis): Florida State University, 121 p.

Missimer, T.M., 1973b, Growth rates of beach ridges on Sanibel Island, Florida: Trans. Gulf Coast Assoc. Geological Societies, v. 23, p. 383-388.

Missimer, T.M., 1976, Structural stability, coastal subsidence, and the late Holocene eustatic sea level rise in south Florida (abs.): Florida Scientist, v. 39, supplement 1, p. 14.

Price, W.A., 1963, Origin of barrier chain and beach ridge, Geol. Soc. of Am., Abstracts for 1962, p. 219.

Scholl, D.W., Craighead, F.C., and Stuiver, M., 1969, Florida submergence curve revised: Its relation to coastal sedimentation rates: Science, v. 163, p. 562-564.

Schwartz, M., 1965, Laboratory study of sea-level rise as a cause of shore erosion: Jour. Geology, v. 73, p. 528-534.

Schwartz, M., 1967, The Bruun Theory of sea level rise as a cause of shore erosion: Jour. Geology, v. 75, p. 76-92.

Schwartz, M., 1971, The multiple causability of barrier islands: Jour. Geology, v. 79, p. 91-94.

Shepard, F.P., 1960, Gulf coast barriers, in Shepard, F.P., and others, eds., Recent Sediments, Northwest Gulf of Mexico: Am. Assoc. of Petroleum Geologists, p. 197-220.

Shepard, F.P., 1960, Rise of sea level along northwest Gulf of Mexico, in Shepard, F.P., and others, eds., Recent Sediments, Northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 338-344.

Shepard, F.P., and Suess, H.E., 1956, Rate of postglacial rise of sea level: Science, v. 123, p. 1082-1083.

Shepard, F.P., and Wanless, H.R., 1971, Our Changing Coastlines: McGraw-Hill Book Co.

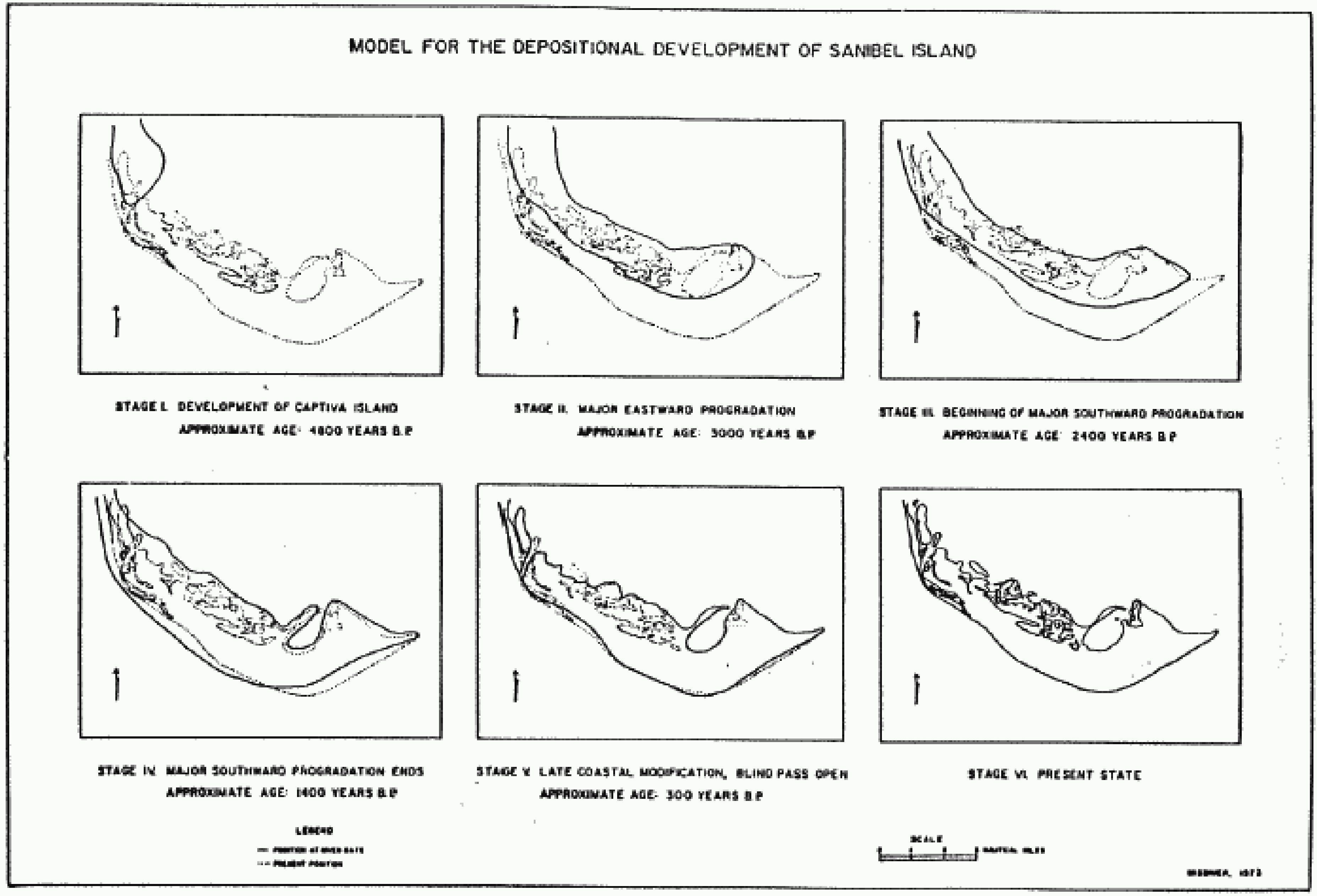

Figure 2. General Model for the Depositional History of Sanibel Island.

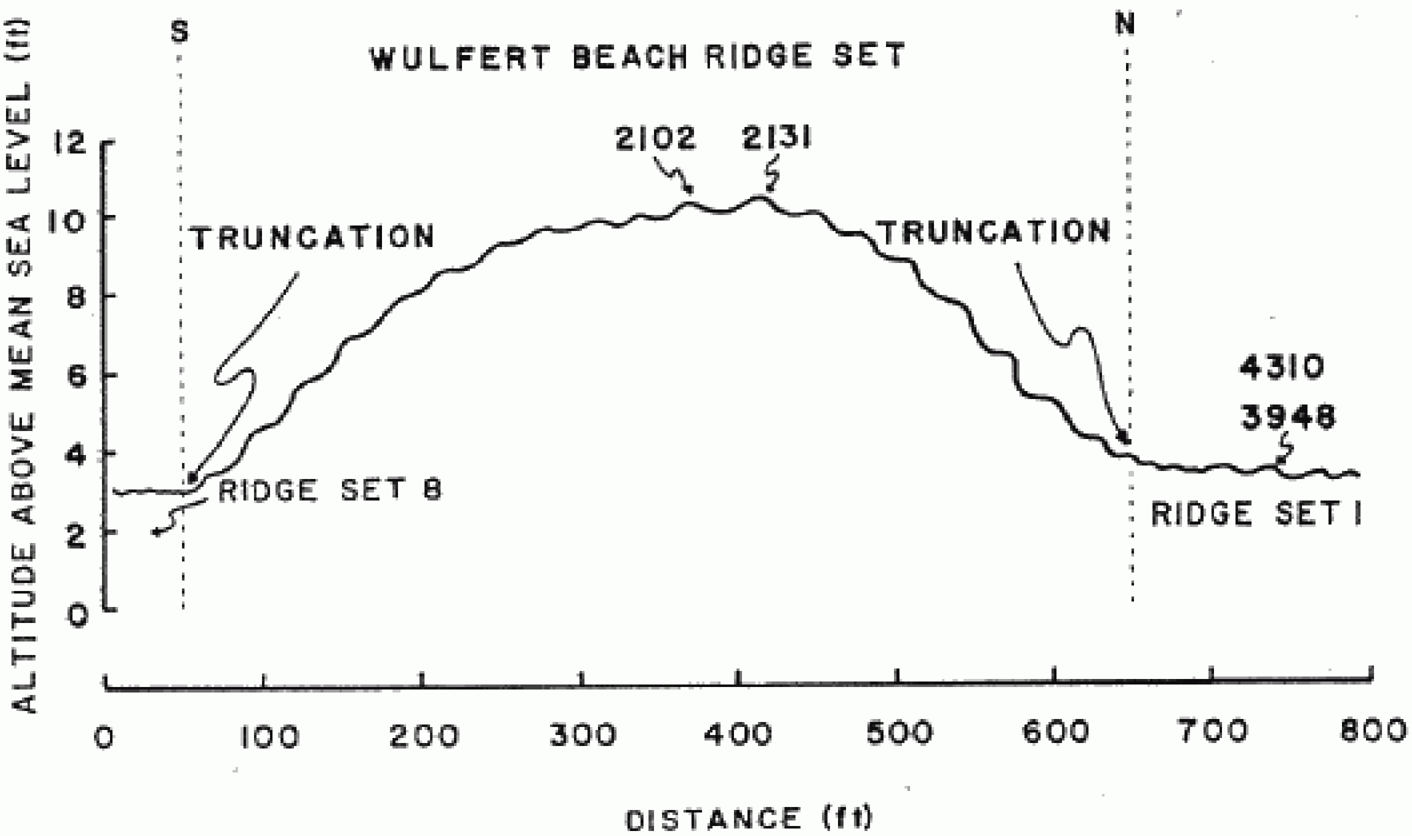

Figure 3. Geometry of the Wulfert Beach Ridge Set.

THE SHALLOW WATER FAUNA OF SANIBEL AND ITS RELATIONSHIP TO UPPER CENOZOIC FOSSILS IN SOUTH FLORIDA

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Sanibel is famous for the large number of mollusc shells that wash up on the beach. This is an area of high productivity, and the water is usually murky with suspended particulate matter. The substrate is fine quartz sand, with some carbonate material from dead molluscs, foraminifera, echinoderms and other animals with calcareous hard parts. Most plants are the microscopic single-celled type drifting in the water column. This is the sort of environment in which bivalve molluscs thrive; a look at the beach at Sanibel will show the truth of this statement (Perry and Schwengel, 1955).

The mollusc shells washed up on the beach are shallow water species that prefer a stenohaline environment. A few of these species also live behind the islands in Pine Island Sound. Chione cancellata (Linnaeus) is a very common medium-sized clam that likes to live in turtle grass and similar areas in shallow bays and lagoons, but usually not in the open sea. C. cancellata is also a common fossil from the Pliocene or Upper Miocene to the present. It is especially common in the upper sand bed along the Caloosahatchee River at Ft. Denaud. Its present day distribution is from Cape Hatteras in the north to southern Brasil. It has been reported from the upper Miocene of northern South America. Although this species prefers shallow bays, it has, on rare occasions, been found living a little offshore.

There are a number of other clams, mostly shallow burrowers, that live in large numbers in the shallow sea a little offshore. They include: Dinocardium robustum (Lightfoot), Anadara notabilis (Roding), Dosinia elegans (Conrad), Macrocallista nimbosa (Lightfoot), Spisula solidissima (Dillwyn), Noetia ponderosa (Say), and Raeta plicatella (Lamarck), all rather large and handsome species. The gastropods, to a large extent, are carnivores and feed mostly on bivalve molluscs. The larger species include Polinices duplicatus (Say), Melongena corona (Gmelin), Busycon perversum (Linnaeus), and Oliva sayana (Ravenel). Herbivorus gastropods include three species of Strombus: S. gigas (Linnaeus), S. pugilis (Linnaeus), and S. alatus (Gmelin). The strombs are successful because they can eat macro algae or can sweep across open sand bottom using the proboscis like a vacuum cleaner, and picking up the microalgae in the top millimeter or so of sand. The much smaller herbivorus species of Crepidula actually compete with bivalves for food because they live a sedentary life and, like bivalves, trap drifting micro algae with their gills.

Many of the shallow coastal species can live in the more saline parts of shallow bays and lagoons. However, when salinity drops below the 25-30°/00 range, most marine species drop out. Then the only oyster species to be found is Crassostrea virginica (Gmelin) which forms oyster bars on muddy sand bottoms. Although many people think of all oysters as living in brackish water, C. virginica is the only one of our species that does. Ostrea eqnestris (Say) is a small, usually solitary oyster, living in shallow water along the shore or in the more saline parts of lagoons. Lopha frons (Linnaeus) usually attaches to octocorals a little distance offshore under stenohaline conditions. Ostrea permollis (Sowerby) lives in the Crumb-of-Bread sponge well offshore in 20 to 150m. Pycnodonte lives on the outer shelf. So in this area there are four oyster species living in stenohaline conditions while only one species lives in brackish water.

Molluscs in very low salinity waters would include the bivalves Rangia cuneata (Sowerby), Polymesoda caroliniania (Bosc), and the mytilid, Brachidontes recurvus (Rafinesque). Mytilopsis leucophaeta (Conrad) is a freshwater mussel-like bivalve which, however, can live in slightly brackish water. Gastropods are rare in slightly brackish water, and usually consist of Neritina reclivata (Say) and microscopic hydrobiids. In strictly freshwater are found unionid clams and snails such as Heliosoma.

The Fort Thompson Formation fauna is virtually the same as the Recent fauna. You can find many species which are not found in the Sanibel area, but there are good reasons for this. The total Fort Thompson fauna includes species that lived in reef habitats, in calcareous as well as quartz sand, and on various types of hard bottom. The present Sanibel fauna lives in quartz sand or muddy sand in more protected waters (Gunter and Hall, 1965).

Unit A of Olsson (1964) or Glades Formation of McGinty (1970) (Bermont of DuBar, 1974) was described by Olsson as lying between the Fort Thompson and Caloosahatchee and separated from both by a sharp unconformity. A typical Glades fauna at Belle Glade was listed by Hoerle (1970), and it consisted of 85% Recent species. At least one of the extinct species, Panopea floridana (Heilprin) = Panopea bitruncata (Conrad), has been reported living from various localities (Dall, 1898; Robertson, 1963) from North Carolina to Texas. The list by Hoerle contains 434 species, but may reflect changing conditions over a considerable length of time. Depth of water is one of these conditions. Murex belleqladeensis (E.H. Vokes) has been found living in the Recent fauna from Savannah, Georgia, to

Galveston, Texas, in depths of about 45 to 73 m. The fossils probably lived under similar conditions and imply a depth of 50 m or so where now the land is a good 10 m above sea level.

The Caloosahatchee Formation has been a problem for more than twenty years, or since DuBar (1958) moved it up from the Pliocene to the Sangamon, Upper Pleistocene. This was based on finding horse teeth and other vertebrate remains along the Caloosahatchee River. DuBar (1974) has modified his viewpoint somewhat, but still places the Caloosahatchee in early Upper Pleistocene. He was also guilty of circular reasoning when he stated that the Waccamaw Formation was Pleistocene in age because of the close similarity of this fauna to that of the Pleistocene Caloosahatchee.

Whatever its age, the Caloosahatchee fauna is only about 40% Recent. Such a large number of extinct species would be astounding in an Upper Pleistocene fauna, and very unusual for the Lower Pleistocene. One thing that compounds the confusion is the reworking that some beds have undergone, mixing younger species with the old. Characteristic Caloosachatchee fossils include Siphocypraea problematica (Heilprin), Vasum horridum (Heilprin), the left handed cone, Conus tryoni (Heilprin), Strombus leidyi (Heilprin), Turritella perattenuata (Heilprin), Arca wagneriana (Dall), Anadara crassicosta (Heilprin), Phacoides disciformis (Heilprin) and Miltha caloosaensis (Dall). Siphocypraea is extinct in United States waters and the northern Caribbean. Only two or three species still hang on along the coast of northern South America. The left handed (sinistral) cones are entirely extinct.

The Caloosachatchee, in general, is a shallow marine stenohaline fauna. There is still much to be done in this area, especially in the field of paleoecology.

Olsson (1964) separated the Pinecrest from the Caloosahatchee, and found a contact between the two formations. The Pinecrest is a fine quartz sand deposit with an abundant fossil fauna. Olsson estimated 1200 mollusc species with a northern element composed of such species as Mulinia congesta (Conrad) and Astarte symmetrica (Conrad). The difference in substrate would make a considerable difference in the fauna, but no one knows how much. The so-called "northern element" may be there not because of temperatures but because they moved south with the clastic sediments they preferred. This fauna, tropical and northern, appears to have lived in very shallow water. In places, flattened and rounded quartz pebbles characteristic of wave action and strong currents have been found. Species such as Mercenaria tridacnoides (Lamarck) were certainly dwellers in very shallow water habitats. One can speculate that the Pinecrest was a transgressive stage just before the somewhat deeper water Caloosahatchee stage. DuBar places the Wicomico with the Caloosahatchee, but the few Wicomico fossils that I have seen were all Recent species, and certainly not compatible with the Caloosahatchee.

The Tamiami is the last of the formations that can be seen in shallow canals or borrow pits in southern-most Florida. Typically, this formation is a shelly limestone in which all aragonite shells have been leached out, leaving oysters and pectens more or less in their original state. The large oyster is Pycnodonte haitensis (Sowerby), a marine form that presumably lived a little offshore. Some of the pectens are quite large and include Lyropecten collierensis (Mansfield) and Aequipecten tamiamensis (Mansfield). Most of the molluscs, however, are found only as internal or external molds. One species that can be identified fairly easily from an external mold is Chione ulocyma (Dall) but this fauna is as yet poorly known due to the difficulty in identifying molds.

The molluscs living around Sanibel are the descendants of prior faunas inhabiting the shallow areas which covered south Florida. These faunas have been tropical in composition although some more northern elements have appeared from time to time. The depth of water may have been over 50 m at times, but probably very little more than that. The substrate was usually calcium carbonate, but quartz sands were present during the Pinecrest and Upper Pleistocene beds. However, the sedimentation rate was so low all through this time that stratigraphy is a problem. Relief in southernmost Florida is usually measured in centimeters. It is the paleontology that enables the geologist to decide where he is in the stratigraphic column. This method is not terribly precise, and there are many opinions of the ages of various formations. However, in undisturbed beds the fossils are excellent guides to the approximate stratigraphic position of the beds. They will be better guides as time goes by and more people work on the problems.

REFERENCES CITED

Dall, W.H., 1898, Contributions to the tertiary fauna of Florida: Trans. Wagner Free Institute Sci. Phila., v. 3, p. 571-947, pls. 23-35.

DuBar, J.R., 1958, Stratigraphy and paleontology of the late Neogene strata of the Caloosahatchee River area of southern Florida: Bull. Fla. Geol. Survey, v. 40, p. 1-267, pls. 1-12, figs. 1-49.

__________ 1974, Summary of the Neogene stratigraphy of southern Florida, in Oaks, R.Q. and DuBar, J.R., eds., Post Miocene stratigraphy - central and southern Atlantic coastal plain: Utah State University Press, p. 206-231.

Gunter, G. and Hall, G.E., 1965, A biological investigation of the Caloosahatchee estuary of Florida: Gulf Res. Repts, v. 2, no. 1, p. 1-71.

Hoerle, S.E., 1970, Mollusca of the "Glades" unit of southern Florida: Part II, List of molluscan species from the Belle Glade Rock Pit, Palm Beach County Florida: Tulane Stud. Geol., v. 8, no. 2, p. 56-68.
McGinty, T.L., 1970, Mollusca of the "Glades" unit of southern Florida: Part I. Introduction and observations: Tulane Stud. Geol., v. 8, no. 2, p. 53-56.
Olsson, A.A., 1964, Some Neogene mollusca from Florida and the Carolinas. Part I. The Geology and stratigraphy of South Florida: Bull. Amer. Paleo., v. 47, p. 511-526.
Perry, L.M., and Schwengel, J.S., 1955, Marine shells of the western coast of Florida: Paleontological Research Institution, Ithaca, New York, 318 p.
Robertson, R., 1963, Bathymetric and geographic distribution of Panopea bitruncata: Nautilus, v. 76, no. 3, p. 75-82.

HYDROLOGIC MONITORING FOR 4,200-ACRE LAND TREATMENT SITE

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INTRODUCTION

Land treatment of municipal wastewater involves the use of crops and the soil matrix to remove wastewater constituents. Compared to other forms of wastewater treatment, land treatment systems are very site specific. Parameters within a study area that usually need to be characterized include: topography, susceptibility to flooding; physical, hydraulic, and chemical characteristics of the soil; climate; geology; groundwater and surface-water hydrology; existing land use; vegetation and wildlife; and social and economic aspects (U.S. EPA and others, 1977). An investigation being conducted by Law Engineering for a 4,200-acre land treatment site near Fort Myers, Florida, provides an example of the consideration of many of these factors.

Purpose of Study

The proposed land treatment site is in Lee County about 12 miles southeast of Fort Myers (Figure 1). The site overlies important freshwater aquifers, and it is several miles north of Corkscrew Swamp, a wildlife sanctuary operated by the National Audubon Society in Collier County. The investigation being conducted is designed to obtain hydrogeologic, hydraulic, and environmental data to assess the impact of the proposed site and to design a monitoring network to determine baseline parameters. At present (spring 1980), the investigation is still in progress, and a final report has not been prepared. However, most parts of the investigation are complete, or nearly so, making it possible to discuss the regional setting and some highlights of the preliminary site-specific results.

Regional Setting

Climate

Lee County is located along the southwest coast of Florida and has a subtropical climate (Boggess, 1974). The average annual air temperature at Page Field near Fort Myers is about 74°F. Monthly averages range from 64°F in January to 83°F in August, and temperature extremes are modified by the tempering influence of the Gulf of Mexico. Annual rainfall averages about 53 inches and occurs during well-defined wet and dry seasons (Missimer and O'Donnell, 1976). More than 60 percent of the annual rainfall occurs from June through September; almost 80 percent occurs from May through October.

Topography and Drainage

Lee County is part of the sandy flatlands of south Florida, an area which is low-lying and poorly drained (Parker and others, 1955). Transpiration and evaporation account for a large part of the outflow from the area, and surface runoff, which is on the order of 10 to 20 inches per year (Kenner, 1966), occurs primarily during the rainy season. Watersheds in Lee County are characterized by a coastal marsh usually 1 to 2 feet above sea level, a relatively steep transitional zone that ranges from 5 to 20 feet above sea level, and a flat upstream prairie area (Johnson Engineering, 1979). In the eastern part of the county south of State Route 82, natural drainage occurs via sheetflow in poorly defined channels through cypress domes and strands and wet prairies and marshes southwestward towards the Estero and Imperial rivers and southward towards Corkscrew Swamp in Collier County.

Hydrogeology

Groundwater in Lee County is obtained from wells that tap one or more of five principal water-bearing zones or units that have varying degrees of continuity beneath the county (Boggess and others, 1977). In order of increasing depth, these are the water-table aquifer, water-bearing zones in the Tamiami Formation, the upper part of the Hawthorn Formation, and the lower part of the Hawthorn Formation, and a water-bearing zone in the Tampa and Suwannee Limestones. Locally, the four lower units are also considered aquifers and, in order of increasing depth, are informally called the Tamiami aquifer, the upper Hawthorn aquifer, the lower Hawthorn aquifer, and the Suwannee aquifer. Generally, the water-table, Tamiami, and upper Hawthorn aquifers contain freshwater, and the lower Hawthorn and Suwannee aquifers contain salty water (Figure 2).

The water-table aquifer consists primarily of unconsolidated fine- to medium-grained quartz sand with interbedded sandy limestone and shell units (Boggess and others, 1977). The overall thickness of the water-table aquifer varies from less than 5 feet to nearly 100 feet. In southeastern Lee County, a tan, gray sandy limestone, which is called unit 1 of the Tamiami Formation and considered to be the Ochopee Limestone Member (Peck and others, 1979), is present. This unit, which is also considered part of Zone I of the Tamiami Aquifer System by Missimer (1978), is an important water-bearing zone in the southeastern part of the county. Water levels and water quality in this unit are very similar to the water levels and water quality in the surficial water-table deposits that overlie this unit (PBS&J/M&A, 1978). Generally, this unit is hydraulically connected to and is a part of the water-table aquifer.

A gray and green clay unit, called unit 2 of the Tamiami Formation (Peck and others, 1979), underlies the water-table aquifer. This unit is made up of a light gray clay which overlies a somewhat thicker, silty, calcareous green clay. The unit underlies most of the county, is on the order of 50 feet thick, and forms a semipermeable confining bed over the underlying Tamiami aquifer (Sproul and others, 1972).

The Tamiami aquifer consists of hydraulically connected sandy limestone and calcareous sandstone and sand that are confined by the overlying clay unit. This aquifer corresponds to unit 3 of the Tamiami Formation, a unit which was named the Lehigh Acres Member by Peck and others (1979). The Tamiami aquifer has also been called the sandstone aquifer (Sproul and others, 1972, and Boggess and Missimer, 1975), the water-bearing zone in the Tamiami Formation (O'Donnell, 1977), and Zone II of the Tamiami Aquifer System (Missimer, 1978). In the eastern part of Lee County, the aquifer is very permeable, and it yields relatively large volumes of water to wells.

The upper Hawthorn aquifer is not considered an important aquifer in eastern Lee County (Boggess and Missimer, 1975). The lower Hawthorn and Suwannee aquifers occur at depths several hundred feet below land surface and contain water that is hard and sulfurous (Boggess, 1974).

Preliminary Site-Specific Results

At the land treatment site, 10 test borings, each about 200 feet deep, have been drilled around the perimeter of the site. Geophysical logs have been run in four of the test borings, and thirty piezometers are being installed to measure water levels and obtain groundwater samples. Baseline groundwater and surface-water conditions are being established on the site and in nearby downstream areas.

Preliminary results indicate that the site is underlain by four lithologic units to a depth of about 200 feet. The uppermost unit consists of surficial sands with traces of silt and clay, and the second unit consists of partially cemented sand, shell fragments, and sandy limestone. The third unit consists of gray and green silty clay, and the fourth unit consists of calcareous sand and partially cemented layers of shell. The first unit comprises the water-table aquifer, and the second unit has been identified as the Ochopee Limestone Member, or unit 1 of the Tamiami Formation. The third unit has been identified as unit 2 of the Tamiami Formation. This clay unit overlies the fourth unit, which has been identified as the Lehigh Acres Member, or unit 3 of the Tamiami Formation. The total thickness of the water-table aquifer and unit 1 ranges from about 70 to 140 feet, and these two units appear to be hydraulically connected over most of the site. Very dense rock was encountered in three of the borings at a depth of about 25 feet. This rock layer may separate the water-table aquifer from unit 1 in these localized areas, but there is no indication that this occurs over most of the site. The thickness of the gray and green silty clay is about 40 to 45 feet, and this unit is apparently continuous beneath the site. The unit acts as a semipermeable confining bed overlying unit 3, and it separates unit 3 from the overlying water-table aquifer and unit 1 at the site.

A management scheme for disposing of the 24 million gallons per day of treated wastewater effluent discharged from the site is being developed, taking into account the expressed desire of the National Audubon Society that none of the effluent be discharged into the Corkscrew Swamp watershed. Tentatively, it will be recommended that the discharge from the site be routed southwestward from the site into the Imperial River watershed. This discharge path is through a natural surface-water drainage system which flows through section 22, Township 46 South, Range 26 East. This is the location for a new well field proposed by Lee County, and it is likely that this route of discharge will contribute to the recharge of the proposed wellfield.

Additional Work

To finish the investigation, the 30 piezometers will be installed, and water levels will be measured and water samples taken. Hydrographs and water-level maps will be constructed, and water-quality analyses performed. The effects that discharging 24 million gallons per day from the site will have on low flow and high flow conditions downstream will be determined. If it is decided that a perimeter canal around the site is required to control water levels and drainage on the site, the effects that lowering groundwater and surface-water levels will have on adjacent areas will be investigated. Finally, baseline parameters will be documented, and guidelines for routine monitoring of groundwater and surface water will be provided to the City of Fort Myers and regulatory agencies long before any wastewater is applied to the site.

REFERENCES CITED

Boggess, D. H., 1974, Saline ground-water resources of Lee County: Florida, U. S. Geological Survey Open-File Report, 74-247, 61 p.

Boggess, D. H., and Missimer, T. M., 1975, A reconnaissance of hydrogeologic conditions in Lehigh Acres and adjacent areas of Lee County, Florida: U. S. Geological Survey Open-File Report, 75-55, 88 p.

Boggess, D. H., Missimer, T. M., and O'Donnell, T. H., 1977, Saline-water intrusion related to well construction in Lee County, Florida: U. S. Geological Survey Water Resources Investigation, 77-33, 29 p.

Johnson Engineering, Inc., 1979, Water management in Lee County, Consulting Report, 202 p.

Kenner, W. E., 1966, Runoff in Florida: Florida Division of Geology Map Series No. 22.

Missimer, T., M., 1978, The Tamiami aquifer system in southwest Florida, in Brown, M. P., compiler, Hydrogeology of south-central Florida: Southeastern Geological Society, 22nd Field Conference, Guidebook, Pub. No. 20, p. 89-102.

Missimer, T. M. and O'Donnell, T. H., 1976, Fluctuations of ground-water levels in Lee County, Florida, in 1974: U. S. Geological Survey Open-File Report, FL-75008, 75 p.

O'Donnell, T. H., 1977, Municipal water supplies in Lee County, Florida, 1974: U. S. Geological Survey Open-File Report, 77-277, 96 p.

Parker, G. G., Ferguson, G. E., Love, S. K., and others, 1955, Water resources of southeastern Florida: U. S. Geological Survey Water-Supply Paper 1255, 965 p.

Peck, D. M., Slater, D. H., Missimer, T. M., Wise, S. W., Jr., and O'Donnell, T. H., 1979, Stratigraphy and paleoecology of the Tamiami formation in Lee and Hendry Counties, Florida: Gulf Coast Association of Geological Societies Transactions, v. XXIX, p. 328-341.

Post, Buckley, Schuh & Jernigan, Inc., and Missimer and Associates, Inc., 1978, Feasibility of landspreading disposal of secondary treated effluent on a site in southeast Lee County, Florida, Consulting Report.

Sproul, C. R., Boggess, D. H., Woodward, H. J., 1972, Saline-water intrusion from deep artesian sources in the McGregor Isles area of Lee County, Florida: Florida Bureau of Geology Information Circular No. 75, 34 p.

U. S. Environmental Protection Agency, Army Corps of Engineers, and Department of Agriculture, 1977, Process design manual for land treatment of municipal wastewater, EPA 625/1-77-008 (COE EM1110-1-501).

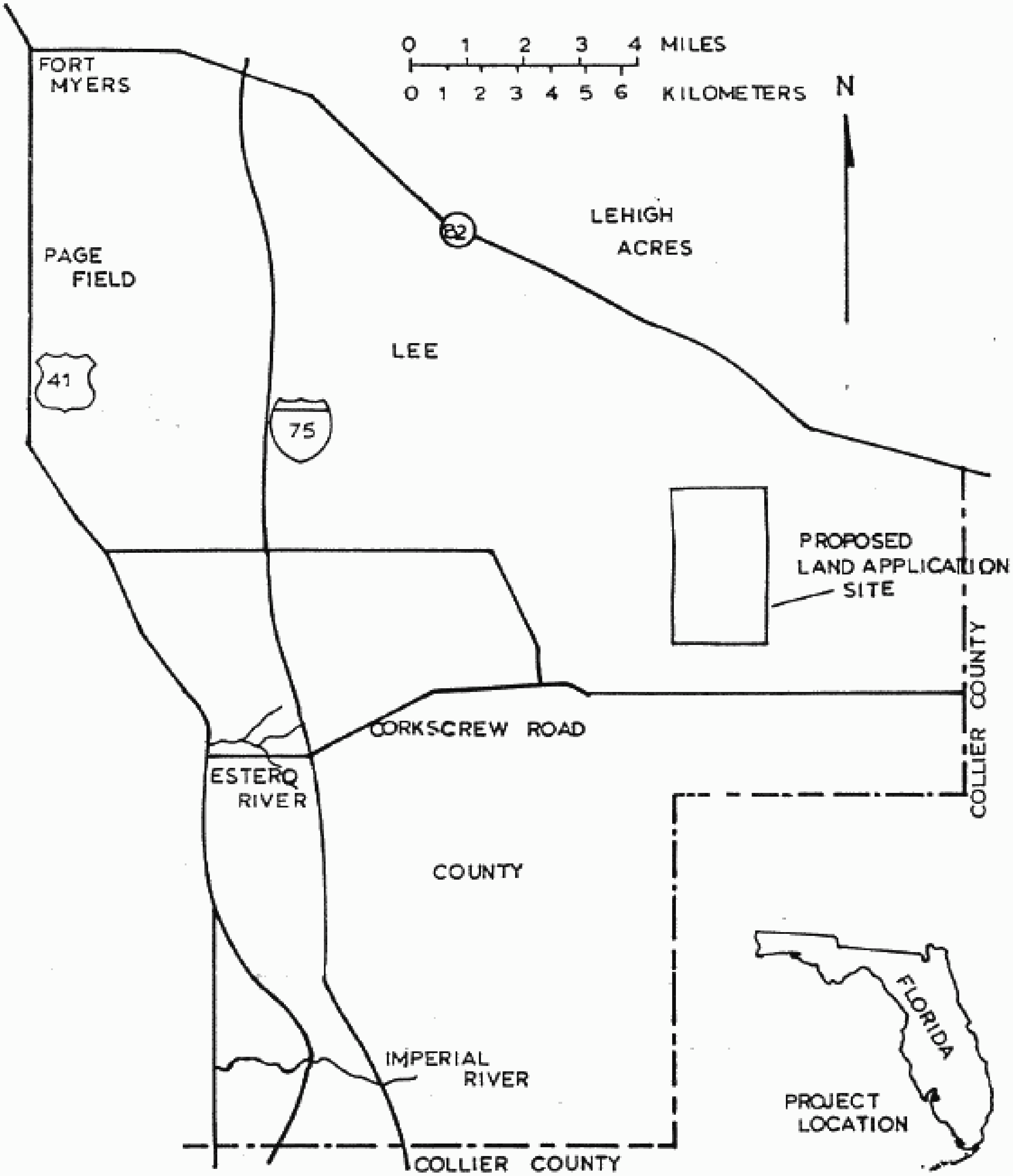

Figure 1. Site Location Map.

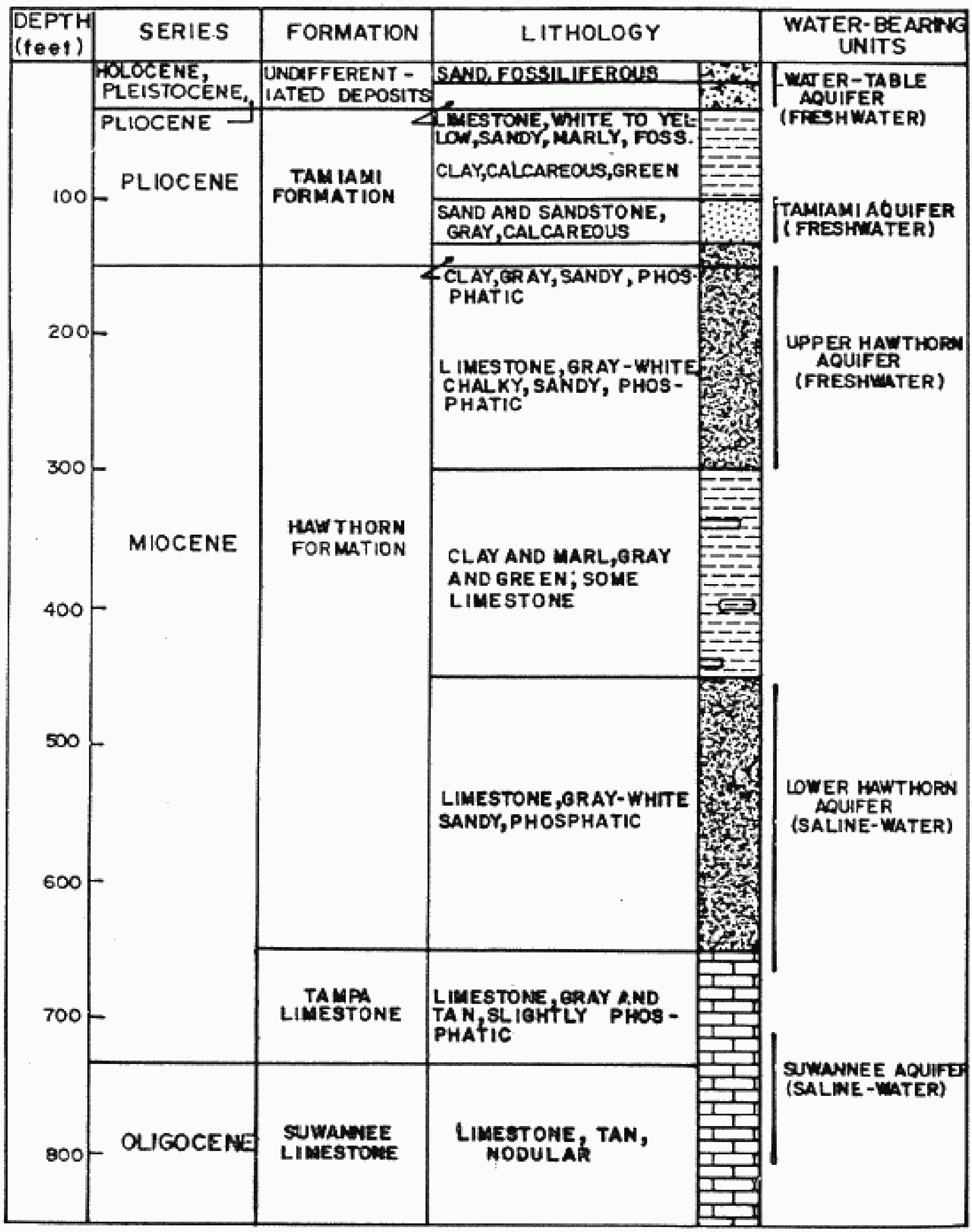

Figure 2. Generalized Hydrogeologic Section For Lee County (From Boggess and Others, 1977).

USING GEOLOGIC SEARCH TECHNIQUES
TO LOCATE A MAJOR GROUND-WATER
RESOURCE NEAR LABELLE, FLORIDA

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ABSTRACT

The fresh ground-water resource is being developed in the vicinity of LaBelle to serve a growing, new community. The source of water will be water-producing sands and shells above the Floridan Aquifer. Units that can be tapped by production wells exist at depths between 100 and 200 feet below land surface and between 200 and 300 feet below land surface. However, these units do not appear to be areally extensive; geophysics and test drilling are being used in combination to define the extent of the water-producing materials.

INTRODUCTION

General Development Corporation has been developing the community of Port LaBelle on a 40-square-mile tract east of LaBelle, Florida. General Development Utilities, Inc., has been exploring for ground-water resources on the property since 1971, with the assistance of Geraghty & Miller, Inc., Ground-Water Geologists and Hydrologists, of West Palm Beach, Florida.

Initially, test drilling was undertaken in areas planned for early development. Recently, test drilling and geophysical techniques have been used in combination to delineate areas of material favorable to the installation of production wells.

Regional Geology

The formations underlying Glades and Hendry counties consist of a sequence of consolidated sedimentary rocks and unconsolidated beds. The sedimentary section forms part of the southern flank of the regional Ocala uplift. The beds conform to the regional uplift and dip gently to the south, where the total thickness is in excess of 10,000 feet. The deeper rock units are limestones and dolomites that reportedly range from middle Miocene to Eocene in age. Rock units younger than middle Miocene are chiefly clastic deposits of shells, sand, silt, and clay (Klein and others, 1964).

The limestone and dolomite rocks that predominate in the geologic section in the basal portion of the Hawthorn Formation and older units combine to form the Floridan Aquifer, a regionally-extensive hydrologic unit that nearly everywhere yields large volumes of water to wells. In Glades and Hendry counties, fresh water suitable for irrigation is obtainable only from the upper part of the Floridan Aquifer (from the limestones of the Hawthorn and immediately underlying Tampa formations). Older limestones contain brackish to saline water not suitable for irrigation or public supply.

The limestones comprising the Floridan Aquifer appear to have been deposited in a shallow marine environment. Above its basal limestone unit that occurs at depths between about 325 and 375 feet in the vicinity of LaBelle (Klein and others, 1964), the Hawthorn Formation consists of predominantly detrital materials--sandy marls and clays, silty sands, quartz sands, and shells. Although these sediments also appear to be of shallow marine origin, there appears to have been a source of sediments, perhaps associated with a regional uplift to the north. Evidence from Highlands and northern Glades counties suggests that a delta that formed in Highlands County during Hawthorn time extended southward into Glades County. The coarser detrital deposits in Glades and Hendry counties appear to be associated with southward advances of the delta.

Clays and marls of the lower part of the Hawthorn Formation serve to confine water in the Floridan Aquifer. Within the Hawthorn Formation, isolated masses of sand, shell, and quartz pebbles have been tapped by wells for moderate to large quantities of fresh water.

The Tamiami Formation of upper Miocene age overlies the Hawthorn Formation. The top of the Hawthorn occurs at depths of about 75 feet below land surface near LaBelle (Klein and others, 1964). The Tamiami deposits of sand, silt, marl, and shells appear to be reworked Hawthorn sediments. Thin limestone beds occur in southern and eastern Hendry County in association with these deposits. In southern and eastern Hendry County where the limestones are tapped, large quantities of fresh water are available to shallow wells. In the remainder of Hendry County and in Glades County, local beds of sand and shell yield quantities of fresh water suitable for domestic and small irrigation wells.

Exploration in LaBelle

Initially, seven test holes were drilled on General Development lands in the vicinity of properties slated for early development. Subsequently, seven additional test holes were drilled. Two of the initial seven holes encountered beds of sand and shell that were sufficiently permeable to warrant the installation of a test well. At the site of the present water plant, a unit of sand and shells extended from 245 feet below land surface to the total depth of the test hole at 300 feet below land surface The three-hundred-foot depth represents the maximum desirable drilling depth above the Floridan Aquifer. It is not desirable to penetrate the Floridan Aquifer at Port LaBelle because a large diversion from the upper Floridan Aquifer probably would be threatened by upconing of saline water from below.

Test holes drilled north, east, west, southeast, and southwest of the water plant did not encounter similar material between 200 and 300 feet below land surface. One thousand feet north of the water plant, a test hole encountered sand suitable to warrant the installation of a test well from 102 feet below land surface to the total well depth of 142 feet That permeable unit has been found in subsequent test holes. Two thousand feet north of the water plant, shell and sand extended from 110 feet to 200 feet below land surface. Two thousand feet east of the water plant, the unit extended from 110 to 190 feet below land surface.

It is apparent that fresh-water aquifers above the Floridan Aquifer are not areally extensive in the vicinity of LaBelle. Considerable geophysical exploration will have to be combined with test drilling in order to locate production well sites and define well fields at Port LaBelle. A program of electrical resistivity, borehole geophysics, and test drilling is currently under way.

REFERENCES CITED

Klein, H., and others, 1964, Geology and Ground-Water Resources of Glades and Hendry Counties, Florida: Florida Geological Survey, Report of Investigations No. 37.

THE SUNNILAND TREND OF SOUTH FLORIDA

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EXPLORATION SUMMARY

The discovery well for the South Florida Basin was the Humble Oil Company Gulf Coast Realties Well No. 1, (Permit 42) at Sunniland Siding, Collier County, Florida. This field had original oil-in-place of 37,685,000 barrels, and total recoverable oil of 18,842,000 barrels, for a recovery factor of 50 percent. Productive acreage is 2,080 acres.

The most productive field discovered in the South Florida Basin is West Sunoco Felda Field which has estimated oil-in-place of 142,857,000 barrels and recoverable reserves of 50,000,000 barrels. Productive acreage is 7,500 acres. Production is primarily from algae, bioclastic debris, and pellets, which have been winnowed by wave action to create favorable porosity and permeability.

Depth of production from the Sunniland Formation is between 11,322 feet and 11,892 feet. The average API (American Petroleum Institute Standard) gravity of this oil is between 25 and 26 degrees. The average gas-oil ratio is approximately 100:1. The moderately low gravity and low gas-oil ratio is believed to be due to the fact that the oil has been generated near the low temperature limits of oil generation. This observation is supported by geochemical analyses.

Stratigraphy

The strata from the onshore portion of the South Florida Basin consists mainly of carbonates and evaporites. These rocks range in age from possible late Jurassic to Pleistocene.

Basement rocks found in the study area consist of an altered quartz diabase found in the Humble Oil Company No. 1, Lehigh Ares Development Well, located in Sec. 14, T45S, R27E, in Lee County (Permit 407). The rock was dated by Exxon Corporation as 163 million years old (K/Ar), possibly late Jurassic. Rhyolite porphyry was encountered in the Bass Collier Company Well, located in Sec. 12, T52S, R27E, in Collier County (Permit 778). This rock was dated by Shell Oil Company as 189 ± 5 million years old (Rb/Sr), possibly early Jurassic.

The emphasis of this report is on the Sunniland Formation. Because of their stratigraphic relation to the Sunniland, only two other formations will be discussed: the Punta Gorda Formation, which underlies the Sunniland, and the Lake Trafford Formation, which overlies the Sunniland.

Punta Gorda Formation

The Punta Gorda Formation is composed chiefly of anhydrite, with lesser amounts of limestone, dolomite and shale. The type section for the Punta Gorda is in the Humble Oil and Refining Company Lowndes Trendwell Well No. 1A (No Permit), located in Sec. 17, T42S, R23E, Charlotte County, from 11,690 feet to 12,157 feet, (Applin and Applin, 1965, p.39).

The Punta Gorda Formation averages about 500 feet thick in the producing trend. Downdip over 1,000 feet of this formation has been drilled.

The top of the Punta Gorda throughout the study area is composed of a nodular anhydrite unit. Oglesby (1965) suggested that some of the relatively thin limestone units could have been caused by storms breaching barrier reefs. The thicker units of limestone within the Punta Gorda Formation were probably the result of continuous sea water influx, perhaps from higher sea levels, before the last regression at the end of Punta Gorda deposition.

Sunniland Formation

The Sunniland Formation was described and a type section given by Applin and Applin (1965). The type section of the Sunniland Formation is in the Humble Oil and Refining Company, Gulf Coast Realties Corporation Well No. 2 (W-961), Sec. 20, T48S, R30E, Collier County, in the Sunniland Field.

The Sunniland Formation is composed mainly of dark, argillaceous micrite beds in the bottom of the section, with light-tan, chalky limestones near the top. These units are interbedded with sucrosic to micro-sucrosic, sometimes oil-stained, brown dolomite. Some anhydrite inclusions are found in these dolomites.

Stylolites filled with argillaceous or bituminous residue are common in the Sunniland, indicating post-depositional alteration of these carbonates. These pressure-solution features are probably a result of compaction coupled with loss of volume, as is evident in the "tight" micritic sections.

Bioclastic limestones composed predominantly of rudistid, algal, foraminiferal and pelletal debris form the "reef" trend.

The length of the productive Sunniland reef trend (Lee to Dade County) is approximately 145 miles and averages about twelve miles wide. Of the 10 fields found to date, production comes from approximately 18,280 of the estimated 1,100,000 acres in the producing trend.

Almost all of the porosity found in the South Florida Basin is concentrated on the northwest-southeast reef trend. Downdip in the Sunniland, there was an abrupt change to a restricted, more saline environment. This anaerobic and low energy environment prevented reef formation and resulted in the formation of dense micrites.

On the reef trend, the dolomite in the formation attains a maximum thickness of 60 feet, which is approximately 20 percent of the total Sunniland Formation. This thickness decreases away from the reef trend in both the updip and the downdip directions.

Updip from the reef trend, the dolomite thickness decreases to less than 20 feet and then gradually increases to a maximum thickness of approximately 100 feet in Palm Beach County.

All the oil fields discovered to date in the Sunniland Formation lie on the reef trend where the dark argillaceous carbonates comprise approximately 30 to 60 percent of the total formation. Downdip in the basin, the dark micrite percentage increases to 100 percent. Updip of the reef trend, the dark organically-rich micrite indicates that it is a potential source rock for oil.

The thickness of the Sunniland varies from approximately 100-150 feet northeast of the reef trend, to 250-300 feet along the reef trend, to 70-100 feet southwest of the reef trend. Southwest of the reef trend the upper section of the Sunniland is replaced by anhydrite.

Near the bottom of the section a bio-zone of *Orbitolina* and *Dictyoconus* foraminifers is found. Applin and Applin (1965) reported that "This association is the unique and characteristic faunal feature of the Sunniland Limestone...." Within the Sunniland are found lenses of bioclastic limestone, coarsely broken shell fragments, algal plates, and unidentified species of the miliolid foraminifera genera *Quinqueloculina.*

Lake Trafford Formation

The term Lake Trafford Formation was proposed by Oglesby (1965) to replace the names "Upper Anhydrite" or "Upper Massive Anhydrite". The "Upper Anhydrite" is an impervious bed directly overlying the Sunniland Formation. The Lake Trafford Formation incorporates this "cap rock" with some limestone and other anhydrite units.

The type section of the Lake Trafford Formation is in the Humble Oil and Refining Company, J.A. Curry Well No. 1 (Permit 222), located in Sec. 8, T47S, R29E in Collier County, from 11,612 feet (Oglesby, 1965).

REFERENCES CITED

Applin, P.L. and Applin, E.R., 1965 , The Comanche Series and associated rocks in the subsurface in central and south Florida: U.S.G.S. Professional Paper 447.

Oglesby, W.R., 1965, Folio of the South Florida Basin, a preliminary study: Map Series 19, Florida Department of Natural Resources, Bureau of Geology.

Pontigo, F.A., Applegate, A.V., Rooke, J.H., Brown, S.W., 1979, S. Florida's Sunniland oil potential: Oil and Gas Journal, July 30, 1979, p. 226-232.

OIL PRODUCTION IN SOUTH FLORIDA

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ABSTRACT

Oil in south Florida is produced only from the Sunniland formation at some 11,000 feet.

The Lower Sunniland is productive only in the one-well Lake Trafford field from fractured, dense, black, worm-burrowed limestone. The worm burrows are filled with a chalky low-permeability limestone. The Upper Sunniland produces from a trend some 12 miles wide. This trend is defined up-dip by the change in facies from grainstone to a chalky, micritic limestone impermeable to oil, but permeable to water. Down-dip, the trend is defined by the change from rudistid and grain limestone to dense, black limestone and anhydrite.

The Sunniland formation is the thickest of scores of sedimentary cycles in the Comanchean Lower Cretaceous. Reservoir characteristics are developed only in the middle portion of the cycle.

The principal component of the reservoir rock at Sunniland and Bear Island fields is leached rudistids and rudistid debris. At Felda, West Felda and Lehigh Park fields, the principal component is grainstone.

Although both source and reservoir rock as well as gas and oil shows are present in the Dollar Bay Formation, to date there has been no oil production.

South Florida production for 1979 was 4.7 million BO, or some 13,000 BOPD.

REFERENCES

Winston, G.O., 1969, A deep glimpse of west Florida's platform: Oil and Gas Journal, December 1, 1969, p. 128-133.

______ 1970, Watch out for some unexpected accumulations as exploration continues in Florida: Oil and Gas Journal, October 26, 1970, p. 98-99.

______ 1971a, Regional structure, stratigraphy and oil possibilities of the South Florida Basin: Transactions of the Gulf Coast Association of Geological Societies, v. 21, p. 15-29.

______ 1971b, Five potentially productive horizons in South Florida: Oil and Gas Journal, December 27, 1971, p. 174-175.

______ 1972, Oil Occurrence and the lower Cretaceous carbonate-evaporite cycle in South Florida: Bulletin AAPG, v. 56, p. 158-60.

______ 1978, The Rebecca Shoal Reef complex of upper Cretaceous and Paleocene in South Florida: Bulletin AAPG, v. 62, p. 121-127.

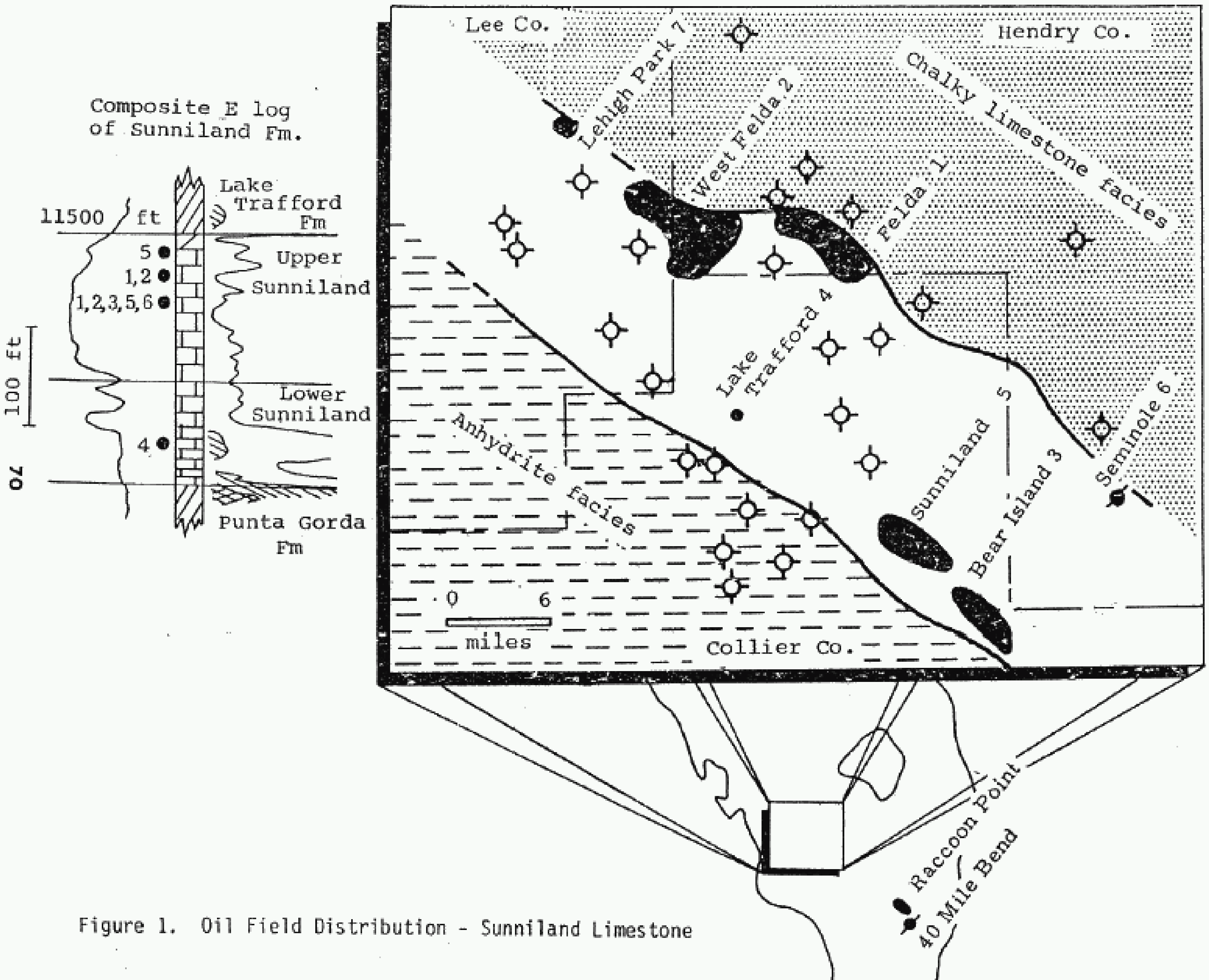
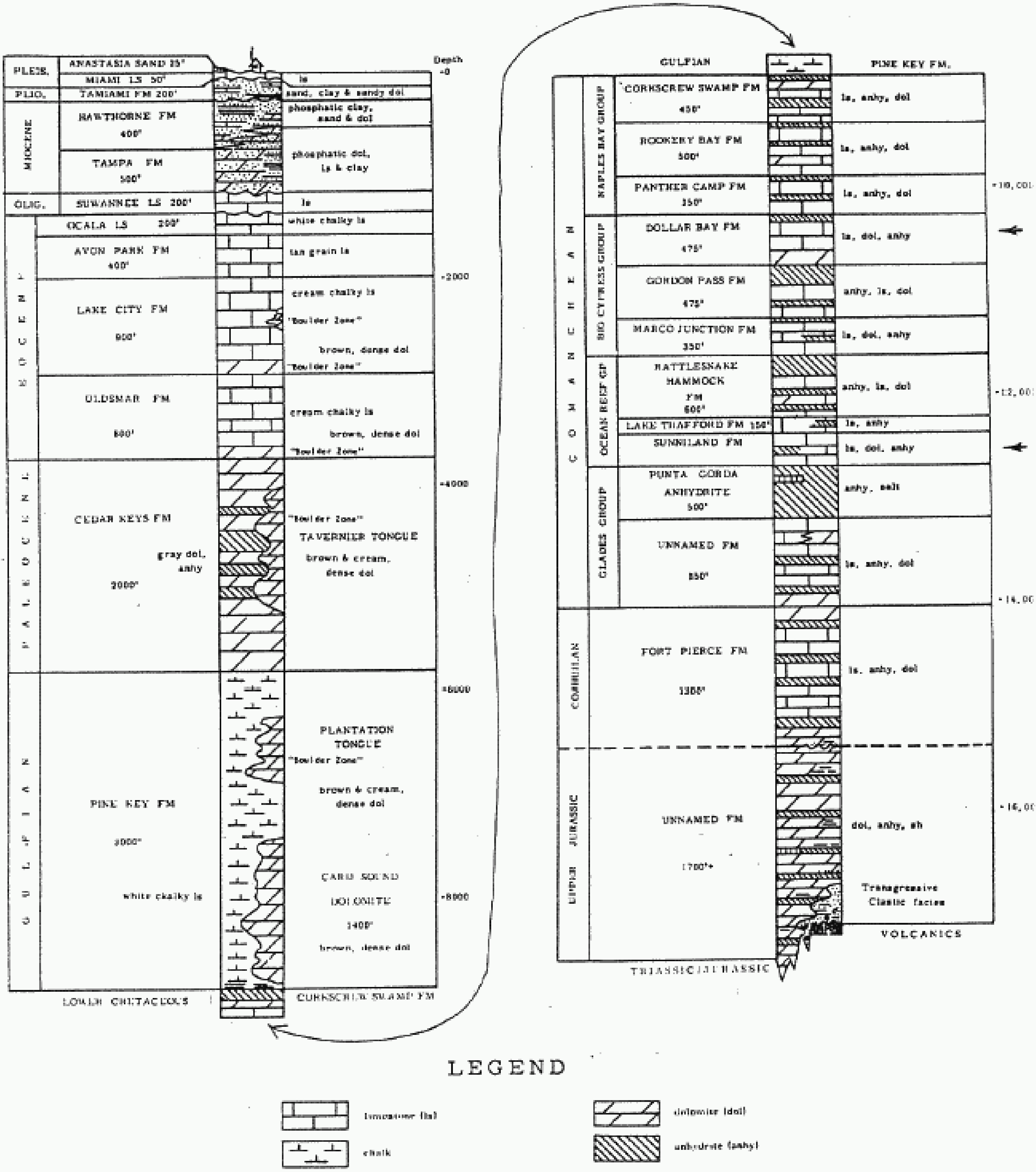
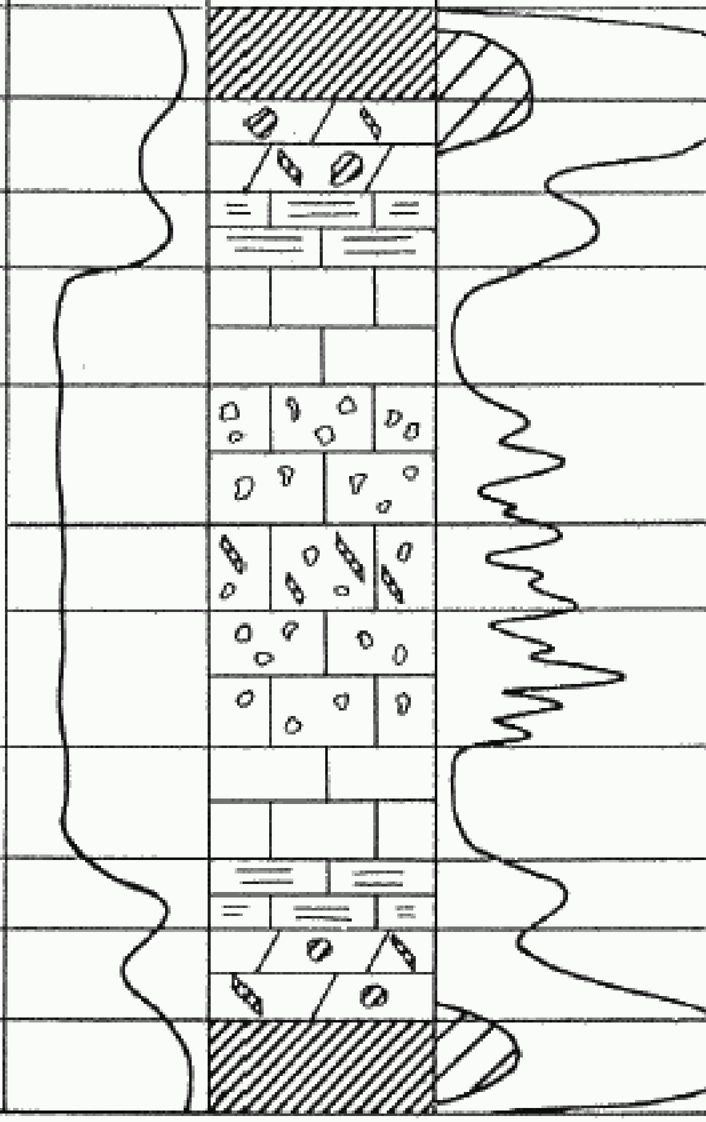


Figure 1. Oil Field Distribution - Sunniland Limestone

Figure 2.

GENERALIZED GEOLOGIC COLUMN
SOUTH FLORIDA BASIN





RESERVOIR CHARACTER	SP	LITHOLOGY	RESISITIVITY	BED NO.	COMPOSITION	DESCRIPTION	CAN BE:
seal				10	anhydrite	bedded; any color	micritic limestone
rarely porous				9	dolomite	microcrystalline with anhydrite crystals or nodules	limestone
seal				8	limestone	micrite, gray, argillaceous	dolomite
usually impermeable to oil				7	limestone	micrite or micrograined calcarenite, cream, Miliodidae; chalky porosity	dolomite
effective porosity				6	limestone	calcarenite, tan; skeletal, oolite, pellet or foraminiferal grains; intergranular or vug porosity	euhedral dolomite
				5	limestone	calcarenite with brown anhydrite crystals intergranular or vug porosity	euhedral dolomite
				4	limestone	calcarenite, tan; skeletal, oolite, pellet or foraminiferal grains; integranular or vug porosity	euhedral dolomite
usually impermeable to oil				3	limestone	micrite or micrograined calcarenite, cream, Miliodidae; chalky porosity	dolomite
seal				2	limestone	micrite, gray, argillaceous	dolomite
rarely porous				1	dolomite	microcrystalline with anhydrite crystals or nodules	limestone
seal				10	anhydrite	bedded; any color	micritic limestone

Winston 1972

Figure 3. Lower Cretaceous Sedimentary Cycle


LEHIGH PARK FIELD
WEST FELDA FIELD
MID-FELDA FIELD
SUNOCO FELDA FIELD
LAKE TRAFFORD FIELD
SUNNILAND FIELD
SEMINOLE FIELD
BAXTER ISLAND FIELD
BEAR ISLAND FIELD
RACCOON POINT FIELD
FORTY MILE BEND FIELD
ROAD MAP OF OIL FIELDS
N
Scale: One inch: approximately 17.5 miles
North Ft. Myers
Cape Coral
Naples
East Naples
Immokalee
Everglades
Clewiston
Pahokee
Belle Glade
South Bay
WEST PALM BEACH
LAKE WORTH
BOYNTON BEACH
DELRAY BEACH
BOCA RATON
DEERFIELD BEACH
POMPANO BEACH
FORT LAUDERDALE
HOLLYWOOD
HIALEAH
MIAMI
MIAMI BEACH
CORAL GABLES
Homestead
Florida City
Key Largo
KEY LARGO CORAL REEF PRESERVE