Distribution and Depositional History of some Pre-lagoonal Holocene Sediments in the Ciénaga Grande de Santa Marta, Colombia

By

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With 5 Figures and 1 Table.

Summary

An investigation of the pre-lagoonal Holocene sediments from beneath the Ciénaga Grande de Santa Marta (Colombia) was undertaken for the purpose of better understanding the paleogeographical and paleoecological conditions of this region before the formation of the lagoon proper. Core and grab samples were collected from the lagoon for stratigraphic observation and analysis in the laboratory.

Beneath the recent lagoonal sediments a deposit of peat with intercalated sand and clay was discovered. Its surface lies at a depth of about 2 m below the hydrographic zero level of the lagoon. Three peat samples, obtained from the upper portion of this deposit, were subjected to micropetrographic and pollen analyses. These analyses revealed that, prior to marine inundation, this region was a coastal marsh-swamp complex similar to the Everglades-mangrove region in southern Florida (U. S. A.). Sample "f", taken closest to the present sea, represents a red mangrove *(Rhizophora mangle)* dominated zone, which was relatively exposed to tides and waves, so that the energy was great enough to sweep the sediment surface clean of litter. This implies that the Isla de Salamanca, an almost continuous beach barrier between the present-day lagoon and the Caribbean Sea, must not have been as prominent a barrier as it is today, but that a larger inlet existed near the site of formation of this particular peat sample. The next most inland sample "g" represents a mixed mangrove zone which was somewhat less exposed to current scour and which was presumably situated behind and protected by the former zone. The third sample "h", taken the furthest inland, represents ponded conditions within a slightly brackish to fresh water marsh dominated by leatherleaf fern *(Acrostichum aureum)* and sedges.

This relatively stable zonation of vegetational environments from marine mangrove in the north to fresh water marshes in the south briefly before the termination of peat formation suggests that the transgression which formed the lagoon was so rapid that marine floral communities had no time to migrate inland and cover more of the submerging swamp surface. This assumption is supported by C^{14} dates which show that the uppermost peat layers were formed

approximately 2 400 years ago in the north and 1 900 years ago in the south, so that the transgression over the swamp should not have taken longer than 500 years. It is recognized, however, that the small number of analyzed samples does not permit far-reaching conclusions.

Four different species of molluscs encountered in peat and clay samples from a few locations in the northern and southern Ciénaga are typical brackish water species. This is evidence for the early existence of small low-salinity lagoons and creeks within the marsh-swamp setting.

Some additional stratigraphic information was obtained by probing with a steel rod capable of penetrating the recent lagoonal sediments as well as the peat. With reference to the water level a shorter depth down to a "firm substrate" (dense sand or indurated clay) was encountered in the southern part of the lagoon than in the rest of the lagoon. This "substrate high" probably represents a submerged lobe of a former subdelta of the Magdalena River. The common association of peat with layers of sand and clay in this region also points to a nearby source for clastics. In general the discharge of sediments into the swamp was sporadic, with long periods during which the rate of clastic sedimentation was low enough to allow the accumulation of relatively pure peats.

Resumen

Los sedimentos holocénicos pre-lagunales situados debajo de la Ciénaga Grande de Santa Marta (Colombia), fueron estudiados con el propósito de obtener una mejor idea de las condiciones paleogeográficas y paleoecológicas prevalentes antes de que la laguna misma hiciera su aparición. Catas y muestras fueron sacadas de la laguna para efectuar observaciones estratigráficas y para su ulterior análisis en el laboratório.

Debajo de los sedimentos lagunales recientes un depósito de turba (detrito vegetal) fué descubierto el cual aparece intercalado con lechos de arena y arcilla. Su límite superior se encuentra a unos 2 m debajo del nivel cero hidrográfico de la laguna. Tres muestras de la turba obtenidas de la parte superior del yacimento fueron sometidas a análisis de micropetrografía y de polen. Los resultados indican que antes de que el mar invadiese el área, esta era un complejo costero pantanoso semejante a la zona de mangles de los Everglades en la Florida meridional (E. U. A.). La muestra "f", la tomada más cerca del mar actual, indica que el área estaba dominada por mangles rojos (Rhizophora mangle), bastante expuesta a la acción de olas y mareas con energía suficiente para dejar la superfície limpia de residuos. Esto significa que la Isla de Salamanca, una barra arenosa, casi contínua, entre la actual laguna y el Mar Caribe, no debió ser siempre una barrera tan marcada y por tanto, que una entrada mayor habría existido cerca del sitio donde la turba de esta muestra se formó. La muestra seguiente "g", sacada de un lugar más hacia el interior, representa una zona de mangles de varios tipos, menos expuesta a la acción de corrientes y probablemente situada detrás de, y protegida por, la faja descrita anteriormente. La tercera muestra "h", que es aquella extraida más adentro de la tierra, representa la existencia de condiciones encharcadas, dentro de una área pantanosa con aguas dulces o ligeramente saladas, monstrando el predominio de helechos (Acrostichum aureum) y juncos.

Esta estructura zonal, relativamente rstable, de vegetación que va de mangles marinos en el N hasta pantanos de agua dulce en el S, y que estuvo presente por poco tiempo antes de que la formación de turba cesase, parece indicar que la transgresión que formó la laguna fué tan rápida que las comunidades florales marítimas no tuvieron tiempo de emigrar hacia el

interior y cubrir una parte mayor de la superfície del pantano que quedó sumergida. Esta hipótesis recibe confirmación basada en C14 cronología la cual muestra que la parte superior de la turba se formó aproximadamente 2 400 años atrás en el N y 1 900 años atrás en el S. Por tanto es razonable concluir que la transgresión sufrida por el área pantanosa debió durar no más de 500 años. Es necesario reconocer que debido al pequeño número de muestras analizadas no nós es permitido llegar a conclusiones de mayor alcance.

Cuatro diferentes especies de moluscos encontrados en muestras de turba y arcilla de varios lugares, en las partes norte y sur de la Ciénaga, son típicos de aguas salobres y marcan la existencia temprana de lagunillas y caños de baja salinidad dentro del área pantanosa.

Información estratigráfica adicional fué obtenida por medio de pruebas efectuadas con una barra de acero capaz de penetrar tanto los sedimentos lagunales recientes como los de turba. Con referencia a un "substrato duro" (arena densa o arcilla endurecida) una profundidad menor que en el resto de la laguna fué encontrada en la parte sur. Esta "alza del substrato" representa probablemente un lobo sumergido perteneciente a un antiguo subdelta del Río Magdalena. La frecuente asociación en esta región de turba con arena y arcilla sugiere también la presencia de una fuente cercana de clásticos. En general la descarga de sedimentos dentro de la marisma fué episódica, con períodos de larga duración, durante los cuales la velocidad de sedimentación clástica fué suficientemente baja para permitir la acumulación de turbas relativamente puras.

Zusammenfassung

Eine Untersuchung der prä-lagunären Holozän-Sedimente aus der Tiefe der Ciénaga Grande de Santa Marta (Kolumbien) wurde durchgeführt, um die paläogeographischen und paläoökologischen Verhältnisse jener Region vor der Bildung der eigentlichen Lagune besser zu verstehen. Für stratigraphische Beobachtungen und Laboranalysen wurden in der Lagune Greiferproben genommen und Kerne gezogen.

Unter den rezenten lagunären Sedimenten wurde ein Torflager mit eingeschalteten Sand- und Tonlagen entdeckt. Seine Oberfläche liegt in einer Tiefe von etwa 2 m unter dem hydrographischen Nullniveau der Lagune. Drei Torfproben aus dem oberen Teil dieses Lagers wurden mikropetrographisch und pollenanalytisch untersucht. Es stellte sich heraus, daß die Region vor der Meeresüberflutung ein küstennaher Marsch/Sumpf-Komplex war, ähnlich dem Mangrovegebiet der Everglades in Süd-Florida (U.S.A.). Die Probe „f", welche in geringster Entfernung zum heutigen Meer genommen wurde, repräsentiert eine von roter Mangrove *(Rhizophora mangle)* dominierte Zone, welche den Gezeiten und Wellen einigermaßen ausgesetzt war, so daß die Energie groß genug war, um die Sedimentoberfläche von Mull frei zu fegen. Das läßt darauf schließen, daß die Isla de Salamanca, ein fast durchgehender Strandwall zwischen der heutigen Lagune und der Karibischen See, seinerzeit keine so prominente Barriere gewesen ist wie heute, sondern daß ein größerer Durchlaß nahe dem Bildungsort dieser speziellen Torfprobe existiert hat. Die etwas weiter landeinwärts genommene Probe „g" repräsentiert eine gemischte Mangrovezone, welche der Abspülung durch Strömungen etwas weniger ausgesetzt war und wahrscheinlich hinter der ersten Zone und durch diese geschützt lag. Die dritte, am weitesten landeinwärts entnommene Probe „h" repräsentiert die Bedingungen in einem Teich innerhalb einer Brack- bis Süßwassermarsch, welche von lederblättrigem Farn *(Acrostichum aureum)* und Binsen beherrscht wurde.

Die relative geographische Stabilität der Vegetationszonierung von mariner Mangrove im N zu Süßwassermarschen im S gegen Ende der Torfbildung läßt vermuten, daß die Transgression, welche zur Entstehung der Lagune führte, so rasch vorangeschritten ist, daß marine Pflanzengemeinschaften keine Zeit hatten, landeinwärts zu wandern und mehr von der versinkenden Sumpfoberfläche zu überziehen. Diese Vermutung wird durch C14-Bestimmungen untermauert, welche zeigen, daß die obersten Torflagen vor ungefähr 2400 Jahren im N und 1900 Jahren mit S gebildet worden sind, so daß die Überflutung des Sumpfes nicht länger als 500 Jahre in Anspruch genommen haben sollte. Es versteht sich jedoch von selbst, daß die wenigen untersuchten Proben keine weitreichenden Schlußfolgerungen erlauben.

Vier verschiedene Arten von Mollusken, welche in Torf- und Tonproben von ein paar Lokalitäten in der nördlichen und südlichen Ciénaga gefunden wurden, sind typische Brackwasserarten. Das deutet auf die frühe Existenz kleiner Lagunen und Kanäle mit niedrigen Salinitäten innerhalb des Marsch/Sumpf-Geländes hin.

Einige zusätzliche stratigraphische Informationen wurden durch Sondierungen mit einer Stahlstange gewonnen, mit der die rezenten lagunären Sedimente ebenso wie der Torf durchstoßen werden konnten. In bezug auf die Wasseroberfläche wurde im südlichen Teil der Lagune ein „festes Substratum" (dichter Sand oder verhärteter Ton) in geringerer Tiefe angetroffen als in der übrigen Lagune. Diese „Substratum-Hochlage" repräsentiert wahrscheinlich einen versunkenen Lobus eines ehemaligen Nebendeltas des Magdalenen-Stroms. Auch die häufige Vergesellschaftung von Torf mit Sand und Ton in dieser Gegend weist auf eine nahe gelegene Quelle klastischen Materials hin. Im allgemeinen war die Sedimentzufuhr in den Sumpf sporadisch, mit langen Zwischenzeiten, wo die Rate der klastischen Sedimentation gering genug war, um die Ablagerung relativ reiner Torfe zu gestatten.

Introduction

The Ciénaga Grande de Santa Marta is a brackish to fresh water lagoon approximately 450 km² (174 sq miles) in area situated upon the delta plain of the Río Magdalena in northcentral Colombia (Fig. 1). The Sierra Nevada de Santa Marta forms high mountains to the E of the lagoon and the main channel of the Magdalena River occurs to the W. The lagoon is almost completely seperated from the Caribbean Sea to the N by the Isla Salamanca, a sandy barrier island.

Three types of vegetation characterize this region: 1) xerophytic and halophytic vegetation on the seacoast; 2) a fringe of marine to brackish swampy (mangrove) vegetation on the west, north and east shores of the lagoon; and 3) fresh water marshes and swamps on the south shores of the lagoon and further inland. On the arid seacoast, e. g., the Salamanca Island (SCHNETTER 1969), xerophytic plants such as cacti and thornbushes grow at higher elevations and on the dunes, whereas the lower levels are subject to occasional flooding and may support a diverse salt marsh flora or may be barren salt flats. The dominant saline swamp vegetation consists of red mangrove *(Rhizophora mangle)*, black mangrove *(Avicennia nitida)*, and white mangrove *(Laguncularia racemosa)*. In less

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saline regions, the mangrove may be mixed with marsh plants, such as, sedges and grasses, leatherleaf ferns *(Acrostichum aureum)*, and a few hardwoods, including the buttonwood *(Conocarpus erecta)*. According to KROGZEMIS (1967:90) and SCHNETTER (personal communication) the fresh water marshes and swamps contain numerous swamp hardwoods and such aquatics as *Sagittaria* sp. and *Nymphaea* sp. On the banks of the Rivers Sevilla, Fundación and others, trees are represented by *Sydero-xylon colombianum, Guarea trichiloides* and others. In creeks and ponds solid floating mats are formed by water hyacinths *(Eichhornia azurea)*, pickeral weeds *(Pontederia crassipes)*, and water lettuce *(Pistia stratoites)*.

The present-day lagoon began to form about 2 300 years B. P. (WIEDEMANN 1973). Its initiation may have been due to a combination of a recent eustatic rise in sea level, compaction of underlying sediments, and northward growth of the Magdalena delta. At any rate, prior to the transgression, this area was probably a coastal marsh-swamp complex similar to that of the Everglades-mangrove region of southern Florida (U. S. A.). This is indicated by the presence of an extensive submerged deposit of peat and intercalated sand and clay now being covered by recent lagoonal sediments. The upper surface of this pre-lagoonal swamp is now submerged at an average depth of 2 m below hydrographic zero of the lagoon. The distribution and depositional history of these pre-lagoonal sediments (particularly the peats) are the main focus of this paper.

Methods

The investigation of the lagoonal sediments (WIEDEMANN 1973) was extended into the subsurface by means of short cores and by probing with a steel rod. With the rod it was possible by resistence and "feel" to distinguish between soft sediments (mud or peat), shell layers, and sand layers. The total thickness of penetrable sediments down to a "firm substrate" was also determined. The impenetrable substrate probably consists of dense sand or indurated clay.

In order to generate some precise data with respect to vegetational and depositional environments within the original swamp, some of the peat samples were placed in plastic bags (to preserve their moisture) and were shipped to the laboratory at Southern Illinois University for detailed petrographic and palynologic analyses. Smalls pieces were cut from the relatively uncontaminated centers of the samples, dehydrated with tertiary butyl alcohol, and embedded in paraffin, using the method described by COHEN & SPACKMAN (1972). From these embedded chunks of peat, oriented microtome thin sections, 15 microns in thickness, were cut. These were then examined under the microscope for such micropetrographic features as had been determined from

previous research in the Everglades of Florida (COHEN & SPACKMAN 1972) to be of use in establishing the environments of deposition of peat deposits.

One of the characteristics which has been found to be of particular importance in this regard is the microscopic "texture" of the peat. This can be exhibited in a quantitative manner as the ratio of the area of a thin section occupied by "framework" to that area occupied by "matrix". "Framework" constituents are the larger objects, i. e., greater than 100 microns in any diameter as viewed in vertically oriented microtome sections; and "matrix" constituents are those constituents in the same sections which are less than 100 microns in all dimensions. In many peats, the "framework" constituents form the structural components which give the peat supportive strength and/or cohesiveness. These constituents are large enough to be described as organs (i. e., leaves, roots, fruits, stems, etc.). The "matrix" component of a peat consists of fine-grained materials which may, in some cases, form the interstitial debris between the "framework" or, in other cases, as for example in highly altered peats, may form the bulk of the sample. The "matrix" is composed of such things as plant cell walls or cell fillings, microorganisms, fecal pellets, and minerals (such as quartz or pyrite). The proportions and characteristics of all of these constituents as well as the ratio of "framework" to "matrix" were determined for each oriented microtome section.

Approximately 50 g of material from the centers of the same peat samples as above were macerated for pollen. Each sample was sieved. treated with 10 % HCl, boiled in 5 % KOH, acetolyzed, bleached, stained in Safranin O, and mounted in glycerin jelly. A more detailed description of these procedures can be found in KUMMEL & RAUP (1965). Each sample was mixed thoroughly before mounting and two drops of macerated material were mounted on each slide. All grains on two slides of each sample were counted.

Distribution and description of pre-lagoonal sediments

Subsurface peat deposits were encountered throughout the lagoon and probably also extend as a nearly continuous blanket into the surrounding swamps and marshes. The Caño Palenque, for example, was found to have scoured down into compact peat at a station 2 km upstream from its mouth where the river itself is 2,5 m deep (Fig. 1). The peats range in color from reddish brown to very dark brown (almost black) and in texture from coarsely fibrous to finely granular. In general they are little contaminated, but locally, and in certain layers of the profiles, they contain shells or grade into medium-size sand or into clay. The clay associated with the peat deposits is normally

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light gray or stained brown from peat contamination. At a few stations in the lagoon and also in the vicinity of Buenavista only clay was encountered beneath the recent sediment (Fig. 1).

In clay samples of some cores, well preserved shells of the brackish water pelecypods *Polymesoda aequilaterata* and, more rarely, *Congeria sallei*, were found. This is an indication that during the time of peat formation small low-salinity lagoons and creeks existed, at least tem-
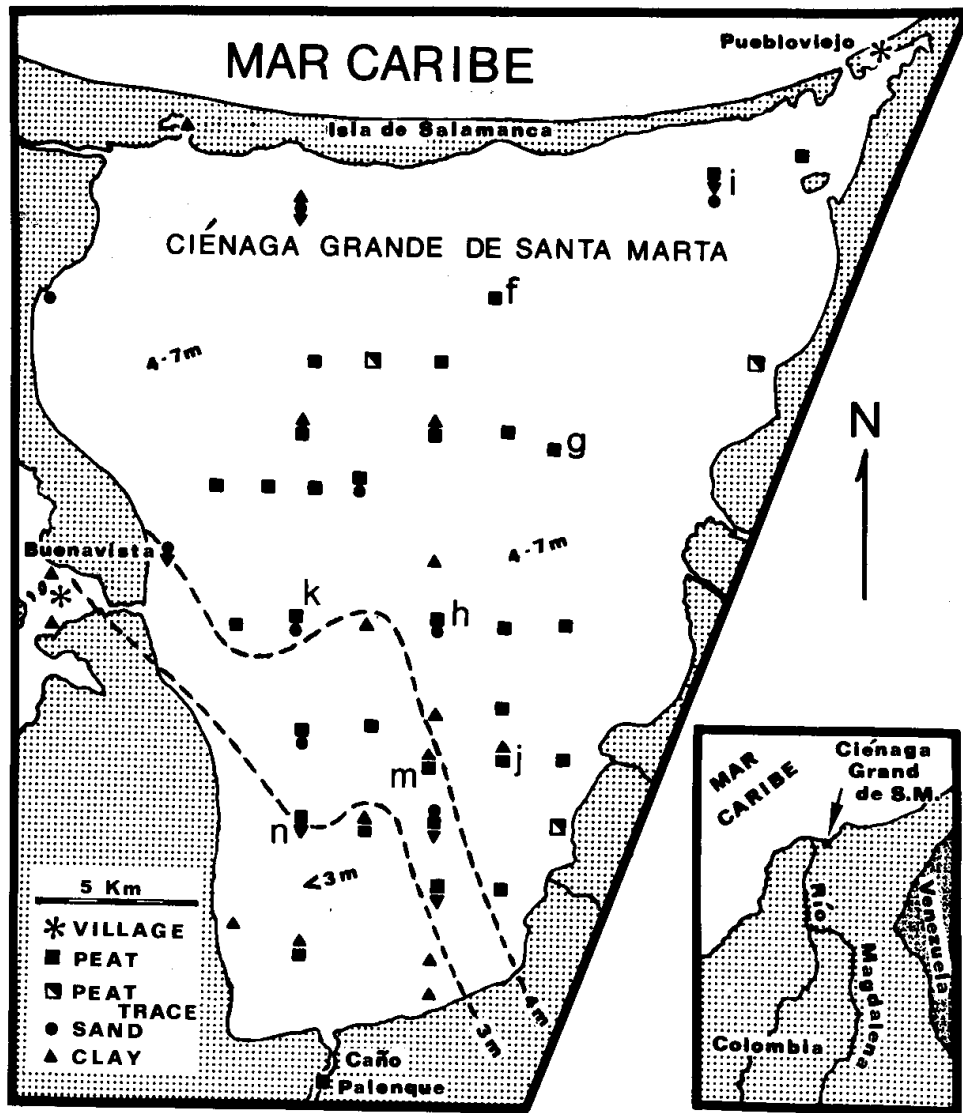

Fig. 1. Distribution of pre-lagoonal Holocene sediments in the Ciénaga Grande de Santa Marta. Depth to a "firm substrate" is given in meters below hydrographic zero. Samples "f", "g", and "h" are peat samples for which micropetrographic and palynologic analyses were made. Peat layers within cores "i", "j", "k", "m", and "n" were analyzed for their molluscan faunas.

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porarily, within the swamp areas. The sediment accumulating in such channels was predominantly clastic (clay or sand). Profiles across the pre-lagoonal Holocene sediments of the Ciénaga Grande area would thus consist of laterally interfingering lenses, layers, and stringers of peat, clay, and sand, with minor shell deposits. This association of sediments is similar to that of the recent backswamp deposits of the Magdalena delta.

By probing with a steel rod capable of penetrating the recent lagoonal sediments as well as the peat, a "firm substrate" was encountered in the northern and central Ciénaga at random depths between 4 and 7 m below hydrographic zero. The only exceptions to this occurred in the very north, near the shore of the Salamanca Island. There the sediments (peat, clay, mud) are either replaced or buried by recent sand sheets derived from the barrier island, so that neither peat nor its substrate could be located by the probing rod. A "firm substrate" was encountered at all southern stations at a depth of less than 4 m (Fig. 1). The common occurrence of beds of sand and firm clay in the pre-lagoonal Holocene record of that region suggests that the underlying "substrate high" may be a submerged lobe of a former subdelta of the Magdalena River that built out from a local break in the stream embankment. Inspection of aerial photographs and topographic maps gives ample evidence for the former existence of minor delta arms extending into the area of Nueva Venecia and Buenavista (see RAASVELDT & TOMIC 1958, Fig. 3). One such arm can also be traced to the Ciénaga Grande where it once entered the lagoon about 2,5 km S of the Caño Grande (WIEDEMANN 1973, Fig. 5).

Micropetrographic analyses of the peats

Three samples of peat (labeled "f", "g", and "h") were taken approximately perpendicular to the coastline and at 5—6 km distances apart, sample "f" being closest to the ocean and sample "h" most inland (Fig.1). Sample "f" was a near-surface sample picked up from the bottom of the lagoon with a grab sampler. It occured beneath about 5—10 cm of recent shell hash. Sample "g" was a core sample collected at the depth interval from 20 to 30 cm. It was overlain by 15 cm more of peat (which was used for C^{14} dating) and 5 cm of recent shell hash. Sample "h" was also from a core. It was underlain by a sand bed (with in situ roots) and overlain by about 30—40 cm of soft mud with shells.

Table 1 gives a summary of the important micropetrographic features of the three samples. The dominant recognizable plant tissue fragments in both "f" and "g" are derived from the red mangrove (Rhizophora mangle), a tree forming the dominant species in the present-day marine to brackish coastal swamps of this region. On the other hand, sample "h"

Table 1. Analysis of Oriented Microtome Sections of Peat Samples "f", "g" & "h"

		SAMPLE "f"	SAMPLE "g"	SAMPLE "h"
DOMINANT PLANT SPECIES		RHIZOPHORA MANGLE	RHIZOPHORA MANGLE	ACROSTICHUM SP.
RATIO FRAMEWORK TO MATRIX*		1:1	2:1	1:7
FRAMEWORK COMPOSITION		MOSTLY ROOTS & ROOTLETS	MOSTLY LEAVES & BARK; SOME RTS.	LEAF FRAGMENTS & FEW SMALL ROOTLETS
MATRIX CHARACTERISTICS				
	COLOR	DARK RED-BR.	LIGHT YELLOW-BR. TO TAN	LIGHT TAN
	PLANT REMAINS	RED-BR. CELL FILLINGS COMMON	MOSTLY CELL & TIS. FRAGMENTS; CELL FILLINGS OCCAS.	MOSTLY CELL & TIS. FRAGS.; CELL FILLINGS RARE
	DIATOMS	FEW CENTRALES	RARE	ABUNDANT PENNALES
	FUNGI	RARE	HYPHAE & SPORES IN LEAVES & TWIGS BUT RARE IN MATRIX	RARE
	SPONGE SPICULES	COMMON-MONAXON	RARE	RARE
	FECAL PELLETS	COMMON	OCCASIONAL	OCCASIONAL
	MINERAL MATTER	QUARTZ-RARE PYRITE-4.2%	QUARTZ-RARE PYRITE-14.3%	QUARTZ-PRESENT PYRITE-21.2%
CHARCOAL		RARE	OCCASIONAL	OCCASIONAL-COMMON

* Framework-constituents measuring greater than 100 microns in any diameter (measured in microtome sections cut perpendicular to the bedding)

*Matrix-constituents which have no dimension greater than 100 microns (measured in microtome sections cut perpendicular to the bedding)

is dominated by *Acrostichum aureum* (the leatherleaf fern) which is also somewhat salt tolerant, but much less so than red mangrove. It is presently a common constituent of the marginal, slightly brackish marshes adjacent to the mangrove zones.

Although both samples "f" and "g" are dominated by the same plant, they represent markedly different sedimentary environments. This should first be apparent from the ratio of "framework" to "matrix". Sample "f" has approximately equal proportions of coarse and fine-grained material, whereas sample "g" has about twice as much "framework". In addition the "framework" component of "f" (Fig 2) is mostly roots and rootlets (i. e., "ingrown" constituents), whereas that of "g" (Fig. 3) is mostly leaves and bark (i. e., "sedimentary" derived debris). This implies

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Fig. 2. Photomicrograph of an oriented microtome section of peat sample "f".
Note the cross sections of red mangrove *(Rhizophora mangle)* rootlets
which form the "framework" and the fine granular debris which forms
the "matrix". The only framework constituents capable of surviving
the highly energetic marine conditions of this environment are the
"ingrown" ones (i. e., roots and rootlets).

that conditions for preservation of intact surface litter were not as good
in the environment characterized by sample "f" as they were in the
environment of deposition of sample "g". The "matrix" composition also
differs markedly. Sample "f" has a high proportion of the relatively
resistant reddish-brown (taniniferous) cell fillings, common in the bark
and leaves of red mangrove, and few of the less resistant tissue remains.
This would also account for the difference in color between the "matrix"
of sample "f" and that of "g". In addition the presence of abundant
fecal pellets in sample "f" suggests enough aeration of the surface so that
certain animals (such as snails, crabs, or insects) could feed upon the
surface debris. A more marine environment for sample "f" than "g" is
also suggested by the presence of marine diatoms (Centrales type) and
sponge spicules. Another marine trait of sample "f" is the rarity of
fungal remains and charcoal. Most fungal growth is retarded by high
salinities, and fires apparently cannot persist in an environment which is
periodically wet by tidal waters. Both of these constituents are char-
acteristically low in the most marine mangrove environments of southern
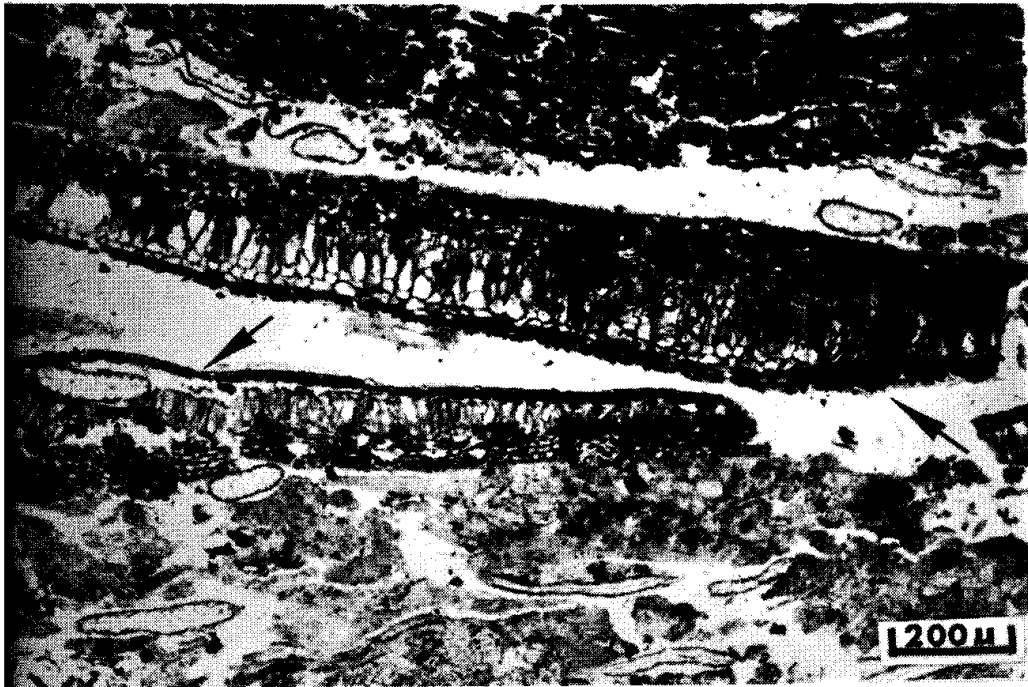Florida.

Fig. 3. Photomicrograph of an oriented microtome section of peat sample "g". This sample is also dominated by *Rhizophora* tissues; however, the more protected nature of the sedimentary environment is evident from the large proportion of the "framework" which is surface litter (especially leaves and twigs). The arrows point to some cross sections of red mangrove leaves.

The micropetrographic descriptions of samples "f" and "g" are identical to those of the "*Rhizophora* Root Peat" and "*Rhizophora* Sedimentary Peat" respectively of COHEN (1968). These were described from the coastal swamps of southern Florida. "*Rhizophora* Root Peat" occurs in that portion of the marine mangrove fringe which is closest to the ocean and thus most exposed to the actions of the tidal waters. The surface of the swamp is periodically inundated by high tides and exposed at low tides, thus, usually being swept clean of most of its surface debris. In addition, during low tides, numerous marine organisms feed upon the debris at the surface leaving behind abundant fecal matter. In this type of environment, the major structural ("framework") components of the peat become the "ingrown" organs (e. g., roots and rootlets). A very dense fibrous peat is produced, with the spaces between the roots filled with fecal pellets, fine-grained (fragmental or chemically altered) remains of plant tissues, resistant substances (such as, "tannin fillings" of leaves or bark), and skeletal remains of marine organisms (such as, diatoms and sponge spicules).

"*Rhizophora* Sedimentary Peat", on the other hand, forms further
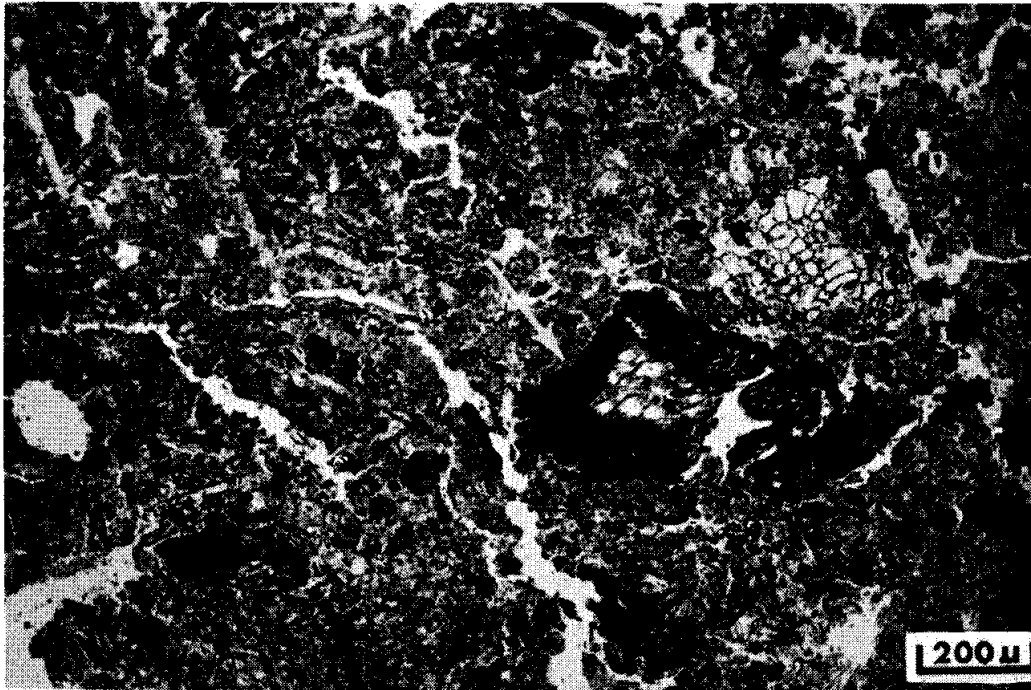
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Fig. 4. Photomicrograph of an oriented microtome section of peat sample "h". Note the much greater proportion of "matrix" to "framework" in this sample than in the previous two. This organic debris probably settled out from a shallow pond within a slightly brackish marsh dominated by leatherleaf ferns (Acrostichum aureum) and sedges. The arrow points to a partially charred remnant of some Acrostichum tissue.

back in the marine intertidal zone so that tidal energy is not great enough to break up or remove much of the surface litter. The "frame-work" component of the peat is consequently enriched in leaves, bark, twigs and other surface litter. The presence of fungi in the "framework" but not in the "matrix" implies either occasional drying of the surface litter before incorporation into the peat or greater influence of fresh water so that more fungi can inhabit the surface environment.

Sample "h" (Fig. 4) differs greatly from "f" or "g". As already indicated, the dominant identifiable plant species is the slightly salt tolerant fern Acrostichum aureum; but, it should be noted that the ratio of "framework" to "matrix" is approximately 1 to 7; in other words, the sample is mostly fine-grained debris. Thus, there are very few frag-ments large enough to be identified. It is therefore likely that other marsh plants could have contributed as much to this peat as Acrostichum (see discussion of the pollen spectrum). The much fresher nature of this environment than the previous two is also indicated by the presence of abundant fresh water diatoms (Pennales types) and the lack of sponge spicules. The rarity of roots and rootlets indicates environmental condi-

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tions such that few marsh plants were actually rooted at the site of peat accumulation. Furthermore, the scarcity of fungal remains would suggest that the fineness of the sediment is primarily a result of sedimentological rather than microbiological processes. The natural conclusion is that this fine-grained sediment, with its complement of fresh water diatoms, charcoal flecs, and occasional fragments of *Acrostichum*, settled out at the bottom of a quiet, shallow, brackish to fresh water pond.

The percentage of pyrite (an authigenic mineral related to salinity) was established for each sample by a point count (1000 points) of each microtome section. It is interesting to note that there is a steady increase in pyrite from samples "f" to "h". Point counts of large numbers of samples from the Everglades-mangrove region of southern Florida (COHEN, SPACKMAN & DOLSEN 1971) revealed that the pyrite content varied with salinity, but not as had been expected. The pyrite content was lowest in strictly fresh water samples, higher in strictly marine samples, and the highest in brackish samples. This is additional evidence that sample "h" represents a slightly brackish rather than strictly fresh or strictly marine environment.
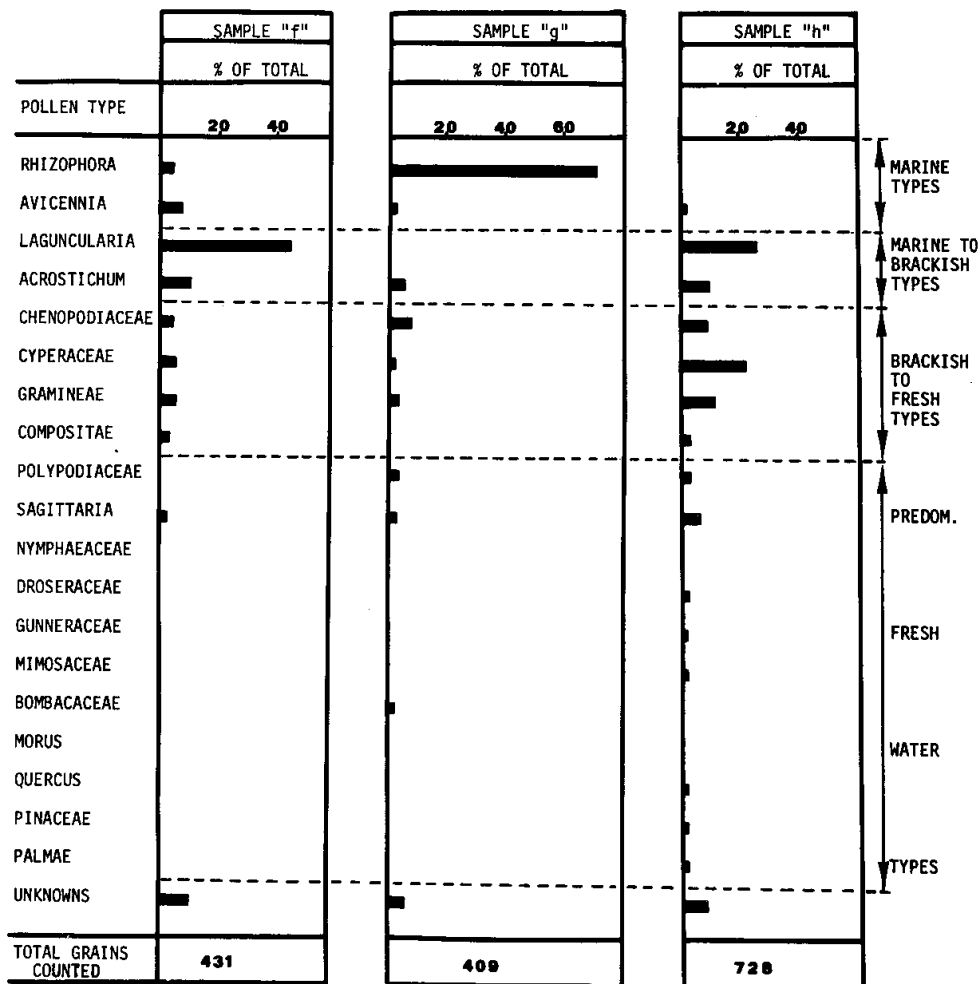
Pollen Analysis

In order to verify the conclusions which have resulted from the micropetrographic analyses and also to obtain additional information of a botanical nature, samples "f", "g", and "h" were analyzed for their pollen content.

Fig. 5 shows the percentages of the various identifiable pollen types found in each sample. The dotted lines separate plant groups which at the present time, in northern Colombia, are known to primarily inhabit: 1) marine environments; 2) marine to brackish environments; 3) brackish to fresh environments; and 4) strictly fresh water environments. Note that samples "f" and "g" both contain some strictly marine types (i. e., *Rhizophora* or *Avicennia*) and sample "h" contains almost none. In addition, note that sample "f" contains only one fresh water type, sample "g" contains three, and sample "h" contains eight.

A relatively large proportion of the pollen spectrum of sample "h" is composed of brackish to fresh water types. Notable among these are the sedge pollen (Cyperaceae). Interestingly enough, the description of the vegetational community producing one of the Peat Types of COHEN (1968) from southern Florida compares favorably with the pollen spectrum of sample "h". He refers to this peat as *Acrostichum-Mariscus* Peat. The two dominant plants in the community are *Acrostichum* and *Mariscus* (a sedge) with occasional *Sagittaria*, Gramineae (grasses), and Compositae.

A gradual increase in the percentage of Chenopodiaceous pollen

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Figure 5. Pollen Analysis of Peat Samples "f", "g", & "h"

POLLEN TYPE	SAMPLE "f" % OF TOTAL	SAMPLE "g" % OF TOTAL	SAMPLE "h" % OF TOTAL	
	20 40	20 40 60	20 40	
RHIZOPHORA				MARINE TYPES
AVICENNIA				
LAGUNCULARIA				MARINE TO BRACKISH TYPES
ACROSTICHUM				
CHENOPODIACEAE				BRACKISH TO FRESH TYPES
CYPERACEAE				
GRAMINEAE				
COMPOSITAE				
POLYPODIACEAE				PREDOM.
SAGITTARIA				
NYMPHAEACEAE				
DROSERACEAE				
GUNNERACEAE				FRESH
MIMOSACEAE				
BOMBACACEAE				
MORUS				WATER
QUERCUS				
PINACEAE				
PALMAE				TYPES
UNKNOWNS				
TOTAL GRAINS COUNTED	431	409	728	

from marine to fresh water deposits was observed by RIEGEL (1965) for samples from southern Florida. Such an increase can also be observed from samples "f" to "g" to "h". This apparent increase in number of Chenopodiaceae (especially from "g" to "h") would be much more striking if plotted on the basis of pollen per gram, since sample "h" contained many more pollen per gram than samples "f" or "g". This can be roughly determined from the total pollen counted. For sample "f" 431 grains were counted, for sample "g" 409, and for sample "h" 728. Approximately equal amounts by weight of sample were processed, approximately equal amounts were mounted on each slide, and all grains per slide were counted (see methods). This means that sample "h" contained nearly twice as many grains per slide as sample "g". Thus the peak in Chenopodiaceae per gram for sample "h" would be strikingly larger

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than that for "f" or "g". This strengthens our case for a decidedly fresher environment for sample "h".

In general mangrove peats from southern Florida have much fewer pollen than fresh water peats (COHEN 1968). The relatively small number of pollen in samples "f" and "g" compared with sample "h" is, therefore, additional evidence, of an indirect nature, that "f" and "g" are mangrove dominated peats.

The relative peak in white mangrove pollen *(Laguncularia)* in sample "h" can perhaps be explained by the nearness of the marsh to the mangrove fringe. However, the peak in *Laguncularia* in sample "f" is somewhat anomolous since it would suggest that sample "f" is less marine than sample "g". The overwhelming evidence from the petrographic analyses and other features of the pollen spectra would overule this assumption.

It can therefore be concluded that the paleoecological interpretations derived from the pollen spectra generally confirm the interpretations that samples "f" and "g" are marine mangrove peats and sample "h" is a brackish to fresh water type. In addition the occurence of various plant types whose tissues are not present or recognizable in thin sections provides a broader picture of the types of plants occuring in and around each peat-forming environment. In particular, the pollen spectrum of sample "h" adds considerably to our interpretation of its original vegetational environment, since this sample contained very few identifiable plant fragments. The pollen spectrum suggests that this peat type might have been formed in a small pond within a marsh similar to the *Acrostichum-Mariscus* marsh of southern Florida (COHEN 1968).

Mollusc fauna associated with some peat samples

It is evident that on the basis of three peat samples taken from the top of the deposit and analyzed in great detail it is still not possible to make generalizations about the entire peat sequence nor to relate these generalizations to the entire area under consideration. In this regard it is helpful to consider also the evidence from mollusc shells encountered in peat layers of five cores from stations "i" to "n" (Fig. 1). The shells typically appeared where peat was grading upward out of or into clastic deposits (which also generally contained shells). This means that the molluscs were living in shallow lagoons or creeks at the margins of peat-forming swamps, while the sedimentary facies in their environment was gradually changing. All molluscs encountered, even in the southern part of the Ciénaga, were indicative of brackish environments rather than fresh water ones. These species were *Polymesoda aequilaterata* (found at all fives sites), *Congeria sallei* (at sites "i" and "k"), *Anomalo-*

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cardia brasiliana (at "k"), and *Hydrobia* sp. (at "i"), four molluscs which are also very common in the present-day Ciénaga Grande and other lowsalinity lagoons in the Magdalena delta.

Acknowledgements

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