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Reconnaissance of the Ciénaga Grande de Santa Marta, Colombia: Physical Parameters and Geological History

By

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With 14 Figures

Abstract

The Ciénaga Grande is a low salinity lagoon situated in the delta of the Magdalena River on the Caribbean Coast of Colombia. Water depth is generally less than 2,3 m. Temperature is stable near 30° C the year around. Tidal influence is confined to the proximity of the small inlet. The hydrography of the lagoon is thus controlled by the rates of river discharge. The mollusc fauna is characterized by a few species able to tolerate low salinities and temporary exposure to freshwater. The impact of the freshwater from a catastrophic flood of the Magdalena in December 1970 is documented. The lagoon is fringed by mangroves, which grade into freshwater swamps farther inland.

The shallow, broad lagoon gradually came into existence by a relative rise in sea level, about 2 m, during the last 2 300 years. Before the transgression this area had been an Everglades-type swamp. Extensive peat deposits represent that early period. Recent lagoonal sediments are primarily gray or black soft muds. Sandy sediments occur in the vicinity of the barrier island to the north and of some scoured channels. In the central parts of the lagoon, a thin blanket of skeletal carbonates forms the only recent sediment.

Resumen

La Ciénaga Grande de Santa Marta, con una extensión de 450 km² es la laguna costera más grande de Colombia. Está localizada en el plano deltáico del Río Magdalena, en la costa del Mar Caribe y colindando por el E con la Sierra Nevada de Santa Marta que se eleva hasta los 5 800 m. Los sedimentos cuaternarios del delta son parte de la acumulación continuada de clásticos post-orogénicos derivados de los lavantamientos tectónicos adyacentes y depositados en la Cuenca del Bajo Magdalena desde el Eoceno. Esta cuenca sedimentaria está separada del levantamiento de la Sierra Nevada, por um lineamento representado en el N por la falla de Santa Marta, que posiblemente todavía es activa. La laguna está casi completamente separada del mar por una barrera de arena, la llamada Isla de Salamanca. La profundidad del agua no excede los 2,30 m, excepto en unos pocos canales de erosión que tienen entre 2 y 7 m de profundidad. De estos, algunos están asociados con antiguas salidas a lo largo

de la costa norte, que fueron cerradas por la sedimentación costera o por la construcción de la carretera en 1956. La única salida existente tiene entre 200 y 300 m de anchura y poco más de 10 m de profundidad. Esta boca permite también la entrada de agua traida por las mareas, de tal manera que la sección NE de la Ciénaga está caracterizada por condiciones estuarinas verdaderas, con cambios drásticos en la salinidad que oscila entre lo 0 y los 36,8 ‰.*

Sin embargo, la hidrografía de la mayor parte de la laguna no está influenciada por las débiles mareas del Caribe pero sí gobernada por un régimen de baja salinidad, sujeto a cambios estacionales. La laguna está formada por casi agua dulce en diciembre mientras que en mayo la distribución de la salinidad muestra valores entre 15 y 30 ‰ en diferentes partes. La laguna obtiene agua dulce de varias corrientes que vienen de la Sierra Nevada así como también de contribuciones variables del Río Magdalena, que puede inundar el delta entero durante la estación de lluvias. La temperatura del agua permanece constante a los 30° C durante todo el año. La fauna de moluscos de la laguna está caracterizada por unas pocas especies capaces de tolerar aguas de baja salinidad é inclusive agua dulce por poco tiempo. Los efectos de una crecida catastrófica del Río Magdalena en diciembre de 1970 sobre el régimen hidrográfico y la ostricultura en la Ciénaga Grande son descritos. Durante la estación seca que dura de diciembre a abril, los vientos alisios provenientes de NE muestran una mayor constancia, así las corrientes marítimas producidas por estos vientos pueden desempeñar un papel importante en el régimen hidráulico de la laguna y de su boca.

La laguna está rodeada por manglares que progresivamente hacia el interior pasan a ser pantanos de agua dulce. Las aguas fluviales que entran en la Ciénaga a través de estos pantanos, llevan poca carga en suspensión y ninguna de arrastre. Así el promedio de sedimentación es bajo. Sedimentos arenosos están reducidos a los sitios vecinos a canales activos, especialmente cerca de la costa norte.

La Ciénaga Grande se originó gradualmente debido a un ascenso relativo del nivel de mar de cerca de 2 m durante los últimos 2 300 años. Antes de la transgressión, el área era un pantano de tipo Everglades. Depósitos extensos de turbas intercalados con lechos de arena y arcilla son representativos de los sedimentos de este período temprano. Esta plataforma de turba, ahora sumergida, está siendo cubierta gradualmente por sedimentos lagunares recientes. La topografía subacuática actual refleja directamente diferencias locales en la velocidad de acumulación de estos sedimentos. En las partes centrales y más profundas de la Ciénaga existe como único sedimento reciente una cubierta de 5 a 50 cm de espesor, compuesta por esqueletos de moluscos, percebes y serpulidos. En las áreas menos profundas del E y S de la laguna, el promedio de sedimentación es más alto (siendo estimado de unos 30 cm/1000 años). Esto sedimento está compuesto de lodos blandos grises o negros. Mas también es posible que una gran proporción de estos sedimentos arcillosos haya sido el resulto de una deposición rapida durante los últimos 200 o 300 años como consecuencia de una erosión acelerada causada por la destrucción de los bosques naturales en la Sierra Nevada y su piedemonte.

Zusammenfassung

Die Ciénaga de Santa Marta ist mit einer Wasserfläche von 450 km² die größte Küstenlagune Kolumbiens. Sie liegt im Deltagebiet des Magdalenas an der karibischen Küste und in unmittelbarer Nachbarschaft der nahezu 5800 m hohen Sierra Nevada de Santa Marta. Die quartären Ablagerungen des Deltas sind Teil der anhaltenden postorogenen Sedimentation von klastischem Material, das seit dem Eozän von den benachbarten tektonisch gehobenen Schollen abgetragen und im Unteren Magdalena-Becken abgelagert wird. Dieses Sedimentationsbecken wird gegen den Sierra Nevada-Block durch ein Lineament abgegrenzt, welches im N durch die möglicherweise noch immer aktive Santa Marta-Verwerfung repräsentiert wird.

Die Lagune ist vom Meer fast vollständig abgeriegelt durch eine Sandbarriere, die Salamanca-Insel. Das Wasser ist allgemein nicht tiefer als 2,30 m, wenige Erosionsrinnen mit Tiefen zwischen 2 und 7 m ausgenommen, von denen einige an ehemalige Durchlässe entlang dem Nordufer gebunden sind, welche inzwischen durch Küstensedimentation oder den Bau der Landstraße 1956 geschlossen wurden. Die einzige verbliebene Öffnung zum Meer ist 200—300 m breit und wenig über 10 m tief. Sie dient gleichzeitig als Zugang für Gezeitenströme, so daß der NE-Teil der Lagune ausgesprochen ästuarine Verhältnisse aufweist mit drastischen Salinitätsschwankungen im gesamten Bereich zwischen 0 und 36,8 ‰.

Die Hydrographie des größten Teils der Lagune wird jedoch von den schwachen Gezeiten der Karibischen See nicht beeinflußt, sondern von niedrigen Salinitäten beherrscht, welche jahreszeitlichen Schwankungen unterworfen sind. Im Dezember füllt sich die Lagune fast gänzlich mit Süßwasser, wohingegen sie im Mai Salinitätswerte zwischen 15 und 30 ‰ in verschiedenen Teilen aufweist. Die Lagune erhält Süßwasser von verschiedenen Flüssen aus der Sierra Nevada sowie wechselnde Mengen vom Magdalena, der während der Regenzeit sein ganzes Delta überschwemmen kann. Die Wassertemperatur ist das ganze Jahr gleichmäßig um 30° C. Die Molluskenfauna ist charakterisiert durch einige wenige Arten, welche niedrige Salinitäten und zeitweilig auch Süßwasser vertragen können. Die Auswirkungen einer katastrophalen Überschwemmung im Dezember 1970 auf die Hydrographie und Austernwirtschaft der Ciénaga Grande wird dokumentiert. Während der Trockenzeit, die von Dezember bis April dauert, weht der Nordostpassat am gleichmäßigsten, und vom Winddruck erzeugte Wasserströmungen können eine wichtige Rolle in der Hydraulik der Lagune und ihrer Mündung spielen.

Die Lagune wird von Mangrove gesäumt, welche landeinwärts in Süßwassersümpfe übergeht. Flußwässer, welche die Lagune durch diese Sümpfe hindurch erreichen, transportieren wenig suspendiertes Material und keinen Sand. So ist die Sedimentationsrate gering. Sandige Sedimente bleiben auf die Nachbarschaft aktiver Strömungsrinnen beschränkt, hauptsächlich in der Nähe des Nordufers.

Die Ciénaga Grande bildete sich erst allmählich infolge eines relativen Meeresspiegelanstiegs von ungefähr 2 m in den letzten 2300 Jahren. Vor der Transgression war die Gegend ein Sumpf vom Everglades-Typ. Ausgedehnte Torflager mit eingeschalteten Sand- und Tonlagen sind die repräsentativen Sedimente jener frühen Periode. Die ebene Oberfläche der nunmehr überfluteten Torflager wird fortschreitend von rezenten lagunären Sedimenten zugedeckt. Die heutige subaquatische Topographie ist also ein direktes Abbild der lokalen Unterschiede in der Sedimentationsrate dieser Ablagerungen. So besteht das rezente Sediment in den zentralen und tiefsten Teilen der Ciénaga lediglich aus einer 5—50 cm dicken Decke aus Schalen von Mollusken, Seepocken und Serpeln. In den flacheren Bereichen im E und S ist die Sedimentationsrate höher (im Durchschnitt 30 cm/1000 Jahre), und grauer bis schwarzer weicher Schlamm herrscht vor. Es ist aber auch möglich, daß ein Großteil dieser feinkörnigen Sedimente sehr rasch und erst in den letzten 200 oder 300 Jahren abgelagert worden ist als Folge beschleunigter Erosion, die mit der Zerstörung der natürlichen Bewaldung der Sierra Nevada und ihres Gebirgsfußes einhergeht.

Content

1. Introduction

Field work in the area of the Ciénaga Grande was conducted from mid-September to mid-December 1970, with three additional weeks in January and April 1971. Only small boats with outboard motors were used in the lagoon. For most operations a 3 m fiberglass boat was employed. It was equipped with a light derrick, hand winch, grab sampler, and dredge. Navigation was done by compass and set (maximum) speed of the engine. Stations were placed at approximately 2 km intervals on N—S or W—E transects, using landmarks at both ends of each transect for orientation. The location of marginal stations is rather accurate, whereas for some stations in the central lagoon the accuracy may be no better than a 1 km radius around the assumed location. A total of 156 stations were occupied. Bottom sediments were sampled at all stations by means of the grab. In addition short cores were taken at many stations, employing 7,5 cm diameter aluminum and plastic tubes. The detailed analytical results will be treated in a forthcoming publication.

Water depth at stations was sounded with a measuring rod, while the hydrographic level of the lagoon was recorded at two water gauges installed at the "Puente de la Barra" and "Punta de Mahoma" camps of the Instituto de Recursos Naturales Renovables (INDERENA). The hydrographic chart (Fig. 5) was drawn by reducing all soundings to a common hydrographic zero level. For the estuarine NE section of the lagoon, where water level was influenced by the tides, hydrographic zero was defined by the low tide level observed at the "Puente" camp on the mornings of April 28 and 29, 1971 (Fig. 3-d), when conditions were so calm that any interference by wind pressure could be excluded. For the greater part of the lagoon, hydrographic zero was defined by the average level registered at Mahoma from February through April 1971.

2. General setting and tectonic history of the area

2.1 The Lower Magdalena Basin

The Spanish word "ciénaga", literally translated into English, means puddle or pool; but in northern Colombia it is applied to shallow water bodies of all sizes, such as ponds, lakes, and coastal lagoons. The Ciénaga Grande de Santa Marta, refered to as Gran Laguna by RAASVELT & TOMIC (1958), has a surface area of 450 km^2 and is the largest coastal lagoon in Colombia. Adjacent to the Caribbean Sea and as part of the delta of the Magdalena River, the lagoon is located in the Lower Magdalena Basin, a ramification of the Mesozoic Bolivar Geosyncline. This coastal geosyncline was traced by NYGREN (1950) from Ecuador to the Gulf of Panama and the Guajira peninsula in Colombia. For most of its history since the Cambrian it was a eugeosynclinal province, and was subjected to two major orogenies: the Taconic orogeny at the end of the Ordovician, and the Andean orogeny at the end of the Cretaceous (BÜRGL 1967). The Lower Magdalena Basin is one of the geosynclinal troughs that persisted into the Cenozoic. Cenozoic sedimentation may be classified as flysh and molasse. Sediments were mostly clastics, derived from adjacent tectonic uplifts and laid down in alluvial plains and deltas, on the continental shelf and slope. A Paleocene flysh sequence with serpentine graywackes was studied by ZIMMERLE (1968) and compared with the Franciscan formation of Western California. Evidence for modern offshore turbidite sedimentation was presented by HEEZEN (1956).

2.2 The Santa Marta fault

Only 7 to 30 km E of the Ciénaga Grande, the rugged mountain range of the Sierra Nevada de Santa Marta rises to the nearly 5 800 m

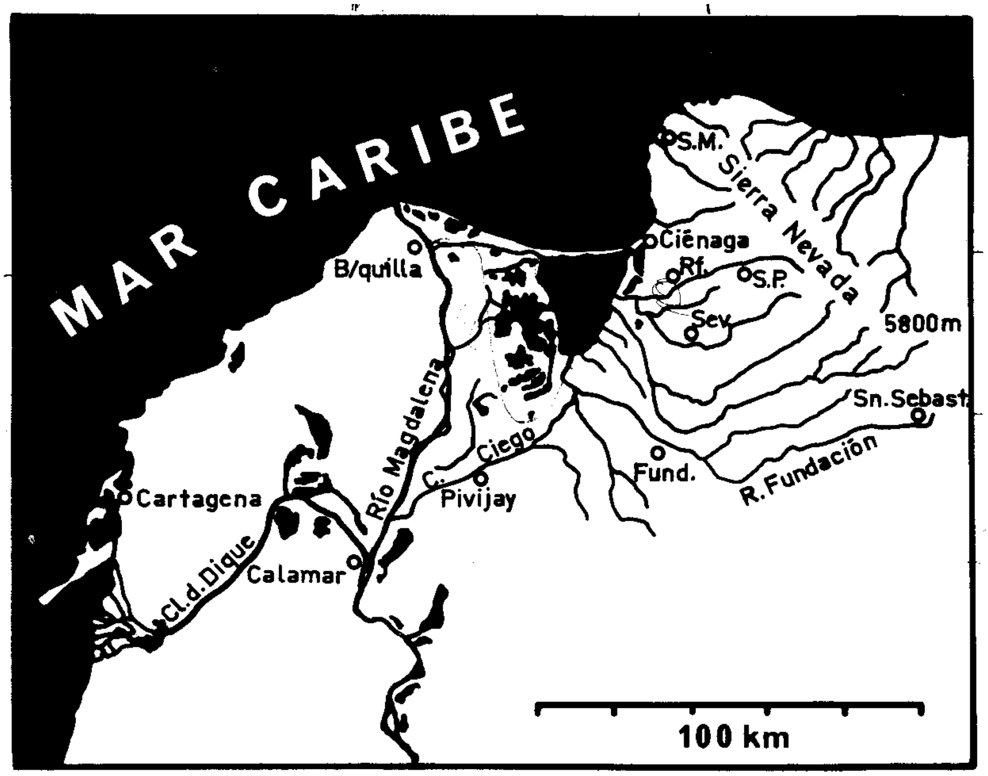

Fig. 1. Situation of the Ciénaga Grande in relation to the Caribbean Sea, the Magdalena River, and the Sierra Nevada de Santa Marta. (S. M. = Santa Marta; Rf. = Riofrio; S. P. = San Pedro de la Sierra; Sev. = Sevilla; Fund. = Fundación; Sn. Sebast. = San Sebastián de Rábago.)

high, glaciated twin peaks of Mt. Bolivar and Mt. Cristobal Colón. The sharp boundary between the Cenozoic basin and the crystalline uplift of the Sierra is formed by the Santa Marta fault, as part of a major lineament of large vertical displacement (Mapa Geológico 1969). It was previously suspected to have functioned also as wrench fault, but no evidence was presented to support this hypothesis. The main periods of uplift of the Sierra block were in the Eocene and again in post-Miocene time, lasting through the Pleistocene (Bürgl 1967). Along the rocky shores at Santa Marta, wave-cut terraces and ledges are exposed about a meter above the present sea level and may indicate recent continued uplift there.

3 km E of Ciénaga city the location of the Santa Marta fault is marked by a thermal spring of about 40° C, releasing hydrogen sulfide. The place is known as "El Volcán". The Lower Magdalena block W of the fault has probably been stalled in its downward movement since the Miocene or Pliocene. Evidence comes from a bed of fossil oyster shells, which crop out in the road cut 11 km W of Fundación on the road to Pivijay, at an altitude of 60 m above sea level. Imbedded with

coarse sand, the layer is 60 cm thick and consists of large specimens of *Crassostrea* sp. Most of the shells are articulated; only a few are bored by *Cliona* and *Polydora*. Stratigraphically, the formation is placed in the Upper Tertiary (Mapa Geológico 1969). Because the deposit is a typical shallow water estuarine facies (WIEDEMANN 1972), it indicates an Upper Tertiary sea level at 60 m above the present. THIEL (1962) calculated that if all ice now stored on the continents would melt suddenly without isostatic adjustment, sea level would rise 66,3 m. Upon evaluation of the pertinent literature, TANNER (1968) concluded that the Neogene ocean level was not higher than + 80 m, probably falling with time to near zero as the Pleistocene approached.

3. Climate

The Colombian north coast has a tropical climate with a distinct dry season. The Ciénaga Grande is located in a particularly arid zone having six to seven arid months per year (UHLIG 1966, UHLIG & MERTINS 1968). Annual precipitation rates are 800 mm in the southern and western parts, declining towards the N, where precipitation reaches a minimum of 400 mm in the average at the Isla de Salamanca (KROGZEMIS 1967: 88). The preponderance of the precipitation falls during the months of September through mid-November (MERTINS 1969). During the dry season, from mid-December through April, the northeasterly trade winds are dominant. They blow particularly steady during daytime, whereas northerly winds may die down in the night, and seaward winds may come up instead. This basic pattern also persists through the humid season, lasting from May into December, when the northerlies are much less strong and steady. Then, however, additional winds from various directions are generated by local rainstorms, especially over the foothills of the Sierra Nevada to the E of the lagoon. The annual average temperature in the area is 27—30° C, and the water temperature of the lagoon is stable near 30° C.

4. Salinity regime and some characteristic faunas in the Ciénaga Grande

The lagoon is almost completely separated from the Caribbean Sea by the Isla de Salamanca, a narrow barrier island. The only outlet, crossed by the highway bridge near Ciénaga city, is merely 200 to 300 m wide. The lagoon is governed by a low-salinity regime, subject to seasonal changes. Intermediate values are reached in May: around 20 ‰ in the center, and around 30 ‰ in the N between the inlet and Punta de Mahoma. By December salinities are very low, and freshwater is encountered at least in the remoter parts of the lagoon, if not throughout. Characteristic invertebrates thus consist of a few species having great tolerance for low salinities and temporary exposure to freshwater. Among these are crabs, barnacles, encrusting serpulid worms, and the molluscs *Polymesoda aequilaterata*, *Congeria sallei*, and *Hydrobia* sp. In the more estuarine sections of the lagoon, especially near the tidal inlet, common molluscs include *Chione subrostrata*, *Protothaca pectorina*, *Tagelus* ssp., *Crassostrea rhizophorae*, *Anomalocardia brasiliana*, *Macoma constricta*, *Brachidontes exustus*, *Littorina angulifera*, and *Neritina virginea*, as well as the predaceous gastropods *Melongena melongena* and *Thais trinitatensis*.

The lagoon is fringed by mangroves at the W, N and E shores, grading into freshwater swamps farther inland. Along the E banks of the Cga. del Chino an extensive salt flat is encountered. The sediments forming this barren plain are sand and silt. Local surface features include mud cracks, rain drop imprints, and salt crusts.

5. Human activities

The population in the vast wet-lands of the area remains small. Ciénaga (San Juan de la Ciénaga), a city of about 50 000 inhabitants, has no significant industry and fortunately is sufficiently isolated from the lagoon that it does not impose an immediate thread to the lagoonal ecology. The swamps are uninhabitable. Only the sandy Salamanca Island provides somewhat more elevated terrain. Most of the island, however, is now a national park and wild-life refuge, under management by the INDERENA. Only at the E end of the island are three villages: Tasajera, Palmira and Isla de Rosario. A fourth village, Puebloviejo, is located beyond the outlet. These settlements depend largely on the fisheries in near-shore waters and in the estuarine section of the lagoon, oyster production included. In addition, three remote pile-dwelling settlements are founded in the open lagoonal waters: Bocas de Aracataca (Trojas de Cataca) in the SE of the Cga. Grande, Buenavista and Nueva Venecia (El Morro) in the neighboring Cga. de Pájaral. Their economy is based on fishing in the lagoons and ponds (Tovar-Ariza 1950; Krogzemis 1967). The only road that comes near the lagoon and permits easy access is the paved highway from Barranquilla to Ciénaga, constructed across the Salamanca Island in the years 1956 to 1965. It is paralleled by an intracoastal waterway, the Canal del Clarin, which is navigable for motor barges especially employed for the transport of oil and gasoline from Barranquilla to Ciénaga (Fig. 13). Considering the low level of human activities, the environmental equilibria of the lagoon appear to remain little disturbed, although the possible pollution of its waters by fertilizers and pesticides applied to the agricultural zone E of the lagoon has already become a cause of some concern to ecologists.

6. Hydrography

6.1 The eastern tributaries of the Ciénaga Grande

To the E of the Cga. Grande a number of sizeable rivers (ríos) and many intermittant streams (quebradas) drain the western slopes of the Sierra Nevada de Santa Marta. From S to N the major rivers are Río Fundación, R. Aracataca, R. Sevilla, and R. Frio. They have their headwaters in the mountains, where precipitation is distributed throughout the year, generally in excess of 1 500 mm annually (G. Mertins, personal communication). Between the edge of the mountains and the lowlands associated with the lagoon, a 10 km wide piedmont has formed from coalescent alluvial fans of Quaternary sediment. As result of the drastic change in gradient upon entering the piedmont province, the streams loose their carrying capacity and deposit much of their detrital load, causing the development of swampy interior deltas (desparramados). Once the rivers leave the piedmont to enter the swamps E of the Cga. Grande, their further course and hydrographic relationships become obscure. The ultimate point of entrance of their waters into the lagoon is not known, and for most rivers and streams a definite mouth does not exist. The waters rather seep through the swamps to reach the lagoon via a number of minor channels at different locations. Freshwater that enters the lagoon through the swamps is quite clear, but has a brownish coloration due to dissolved yellow organic acids, and is usually a few degrees cooler than the lagoon.

The Río Fundación, for example, extends a branch to the Caño Palenque, but a large proportion of its waters reaches the lagoon through several other channels distributed between that caño mouth and Trojas de Cataca (Fig. 5). The photogrammetrists of the Geographical Institute (official map 1 : 100 000, 1959) understandably came to different conclusions on this difficult matter than RAASVELT & TOMIC (1958: Fig. 3), though both parties used the only available set of aerial photographs as a base. Fig. 5 is adapted from the official map and shows the mouth of the Río Aracataca at Trojas de Cataca. Consequently the official name applied to this settlement is now Bocas de Aracataca. Fig. 4, by comparison, is adapted from RAASVELT & TOMIC, who located the mouth of the Aracataca 10 km farther N and identified it with the Boca de López. According to them, the R. Frio discharges directly into the Cga. Grande, the R. Sevilla being its main tributary. This conclusion appears to be justified by the fact that local people refer to that funnel-shaped major river mouth as Río Frio only. The official maps show the R. Frio to flow instead into the southern section of the Cga. del Chino.

6.2 Connections to the Magdalena River

The extensive flood plain of the Magdalena River lies W and SW of the Cga. Grande. Especially during periods of high water, much of the area is inundated. The exact relationships between the multitude of channels, lakes, ponds, lagoons and associated swamps have not been established, even though some of the waterways are known to local fisherman and are trafficable by their dug-out canoes, at least during the rainy season. The inhabitants of Nueva Venecia, for example, maintain close ties to settlements along the Magdalena and traditionally bury their dead in Sitio Nuevo, which can be reached through a string of caños, except during periods of low water (KROGZEMIS 1967: 96). When the water level falls, the lakes become swampy and narrow channels become choked with aquatic vegetation.

The Magdalena River thus supplies overflow water to the Cga. Grande during the rainy season. The most prominent channels conducting this water are, from S to N, (1) the Caño Ciego system (Figs. 1 and 4), which leads water from Piñón on the Magdalena to the Caño Palenque that discharges directly into the southern tip of the Cga. Grande; (2) a cryptic channel system, including the Caño El Condazo, C. El Salado, C. del Cojo and C. Alfandoque, all of which lead water from Santa Rita and Remolino to the Cga. de Alfandoque and Cga. de Conchal; (3) the Caño Aguas Negras system, which leads water from somewhere near Sitio Nuevo to the C. El Tambor and C. de Los Morranos, discharging into the Cga. de Pájaral, from where waters are conducted through the Caño Grande into the Cga. Grande; (4) the Canal del Clarin — Caño Hondo intracoastal waterway.

6.3 Hydrography of the lagoonal outlet and tidal inlet

The tides of the Caribbean Sea are mixed diurnal to semi-diurnal, having unequal amplitudes, and are rather weak. At Santa Marta the tidal range is normally 20—30 cm, rarely exceeding 50 cm. During the arid months and well into the rainy season, i. e., from January through October, the lagoonal outlet (Boca de la Barra) is primarily the passway for tidal currents. In addition, wind-driven currents may play a role, generated by steady wind from sea or from land. Ingressions of sea water alternate with discharge of brackish water. The northeastern section of the lagoon, limited to the SW by a line from Palmira to the Boquerón Islands, is thus characterized by truly estuarine conditions experiencing drastic changes in salinity. An invers relationship can be observed between the salinity of the estuarine waters and their turbidity and temperature. Sea water invading the estuary is usually greenish, much clearer and 2—3° C cooler than the lagoonal brackish

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Fig. 2. Freshwater discharge through the lagoonal outlet (Boca de la Barra) into the sea, photographed Dec. 13, 1970. Note differences in turbidity and a distinct foam line separating two water masses near the INDERENA camp. The great turbulence north of the bridge was caused by the poles of a demolished wooden bridge.

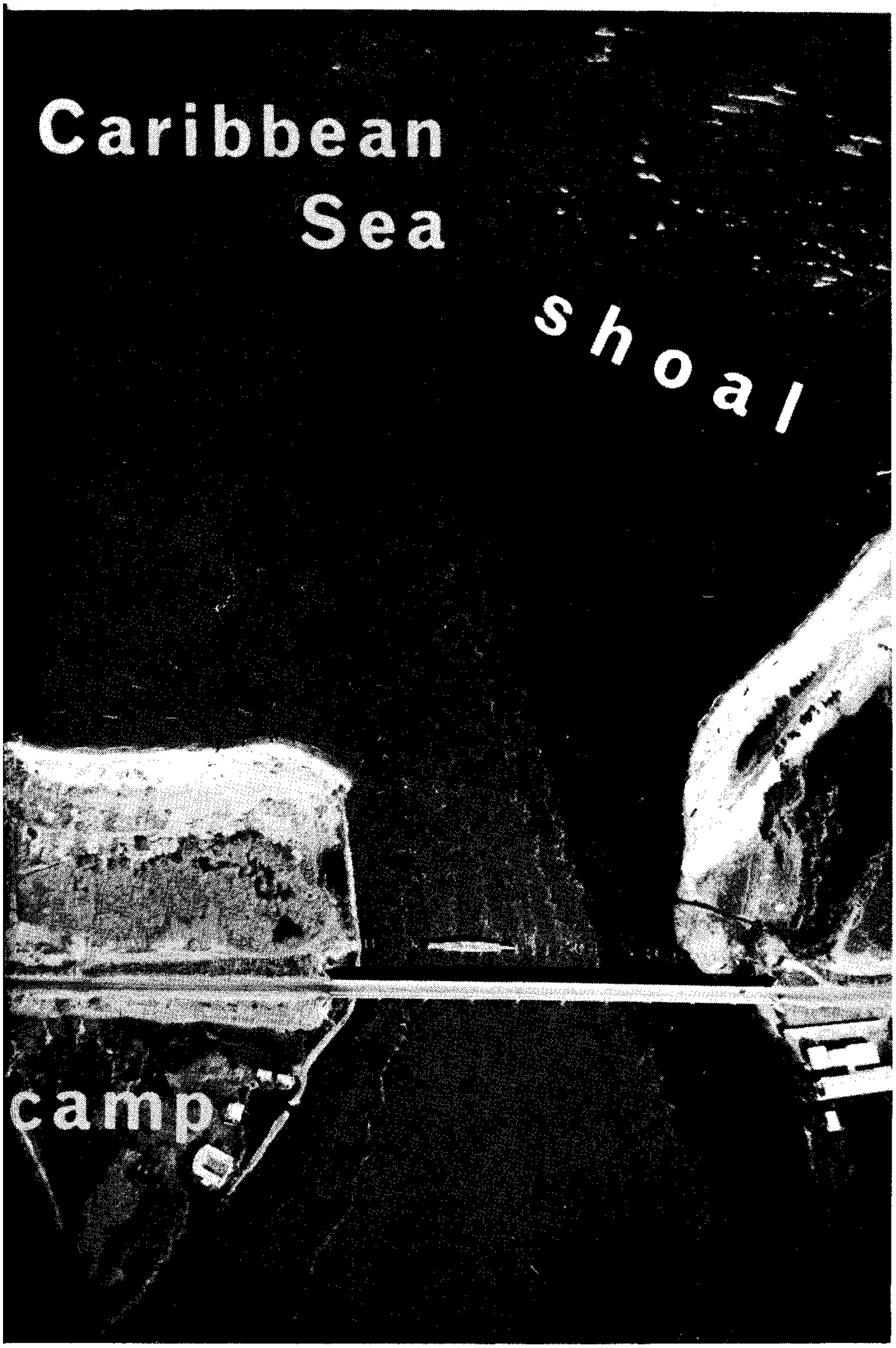

Fig. 2

or fresh waters, which are turbid grayish to brownish in appearance. This indicates that more suspended matter is transferred from the lagoon to the sea than in the opposite direction; much of this material probably is plankton and organic detritus. Development of surficial foam lines is common at the sharp boundaries between the water masses of different salinities and/or temperatures (Fig. 2).

Observations on the hydrography of the Boca were made at intervals during the entire investigation period, from September 1970 till April 1971. Studies of currents and related salinity changes were conducted from the bridge (Puente de la Barra). Water samples were collected both at the surface and closely above the channel bottom, at 7 to 10 m depht. A Nansen-bottle was employed. This also gave indications of direction and relative strength of currents at depth, by the drag deflection of the wire rope with which the bottle was lowered to the bottom. The water samples were taken to the laboratory, where the densities were determined areometrically at controlled temperature and converted into salinity equivalents using standard tables.

Typical tidal currents were observed on Sept. 26, Sept. 29—30, and Oct. 27—28, 1970 (Fig. 3). Later in the year, when the seasonal flooding of the Magdalena delta converted the Cga. Grande and its outlet into a river mouth extension, only discharge of freshwater through the Boca was registered at Nov. 28—29 and through December. Normal tidal currents were observed again Jan. 26 and April 21, 27—28, 1971. Salinity variations over the entire range from 0 to 36,8 ‰ were encountered under the bridge during this investigation period. Most of the time the salinities were higher at depth than near surface. With the rising tide the intrusion of sea water at depth usually commenced about one hour earlier than current direction changed at the surface from ebb to flood. The salt wedge forced its way into the Boca against the superficial ebb current of brackish water.

For control of the rise and fall of water level associated with the tides in the Boca, the hydrometric gauge at the INDERENA camp "Puente de la Barra" was read at half hour to one hour intervals on April 27—28, 1971, in conjunction with current observations and the sampling of water. As shown in Fig. 3-d, the rhythmic change of water level in the Boca was synchronous with the tides predicted for Santa Marta, although the tidal range was smaller than expected. The highest water level coincided with the strongest flood current, and the lowest water level coincided with the strongest ebb current. Maximum velocity of surface currents under the bridge was approximately 1 m/sec in both directions. Possibly the ebb velocities slightly exceeded the flood velocities. Current velocities were characteristically highest near the W bank of the outlet, rather than in the middle of the channel. This observation relates to the asymmetrical cross section of the channel. It is deepest near the W bank, whereas sand bars form and persist along the E bank.

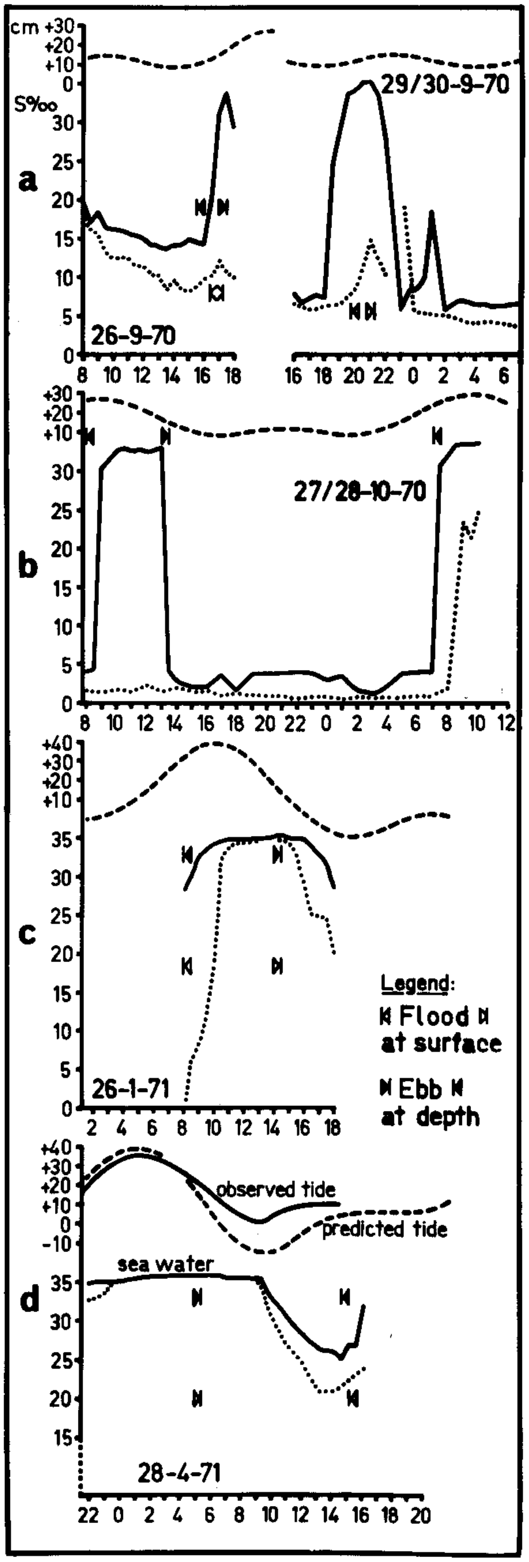

Fig. 3. Records of tidal currents through the inlet of the Ciénaga Grande. Duration of observed flood an ebb is indicated. (Dashed lines = tides predicted for Santa Marta by U. S. C. & G. S. Tide Tables; dotted lines = salinity changes in surface water; solid lines = salinity changes near channel bottom).

Tidal current velocities significantly higher than 1 m/sec are normally not reached in the Boca, because the Caribbean tides are weak. Higher stream velocities were observed, however, during the event of exclusive freshwater discharge from the lagoon to the sea in the rainy season of 1970. Surface velocities of 2 m/sec were reached, for example, on Nov. 29 between 9:30 and 11:00 A. M. The time is noteworthy; a high tide of + 42,7 cm at Santa Marta was predicted for 10:59 A. M. that day, but this tide was not able to slow down the powerful discharge through the Boca. Then too, the top speed was observed near the W bank; the surface velocity in the channel middle reached only 1,5 m/sec.

A third type of hydrographic regime for the outlet was reported by the Labor. Centr. d'Hydraul. de France (1968). The French team worked in February and March 1968, evidently under conditions of particularly strong and steady trade winds that overruled the normal tidal flow through the Boca. Induced by winds towards the coast over day and towards the sea over night, strong currents into the lagoon were observed daily from 10:30 till 21:30 (11 hours), having a velocity of about 0,8 m/sec. A total water volume of 9,180,000 m³ was estimated. Water was discharged from the lagoon to the sea during the remaining 13 hours of the night, having a current velocity of around 1,3 m/sec. An average volume of 16 820 000 m³ was calculated for the nightly discharge, far exceeding the intrusion of sea water by day.

6.4 Hydrography of the Ciénaga Grande

In most parts the Cga. Grande is too shallow for the establishment of marked vertical gradients of temperature or salinity. Horizontally, however, minor temperature and significant salinity gradients occur during the dry season, when saline waters from the sea can penetrate deep into the lagoon. In the lagoon a large-scale counterclockwise circulation is maintained (Fig. 4). Sea water, intruded into the lagoon from the NE, spreads primarily towards the W, below the shores of the Salamanca Island. The area just S of the villages Isla de Rosario, Palmira and Tasajera as far W as Punta de Mahoma have thus always been the most productive waters for the food oyster. In May these waters achieve a salt content of about 30 ‰. On their way westward the saline waters mix slowly with the brackish water mass in the center of the lagoon, which obtains a salinity of around 20 ‰ by May.

The Canal del Clarin (Caño Hondo) is the only permanent connection of the Magdalena River with the Cga. Grande, and discharges freshwater into the NW corner of the lagoon all through the year (Fig. 12). Blocked off by the saline waters from the E, this freshwater current turns southward to the Rincón de Tamborcito, usually separated from the brackish waters by a distinct foam line. The Caño Grande does not deliver water to the Cga. Grande during the dry season. On the contrary, it conducts brackish water into the Cga. de Pájaral. In the central parts of the Cga. Grande the various water masses mix, while freshwater from several eastern rivers diffuses northward along the eastern shore of the lagoon.

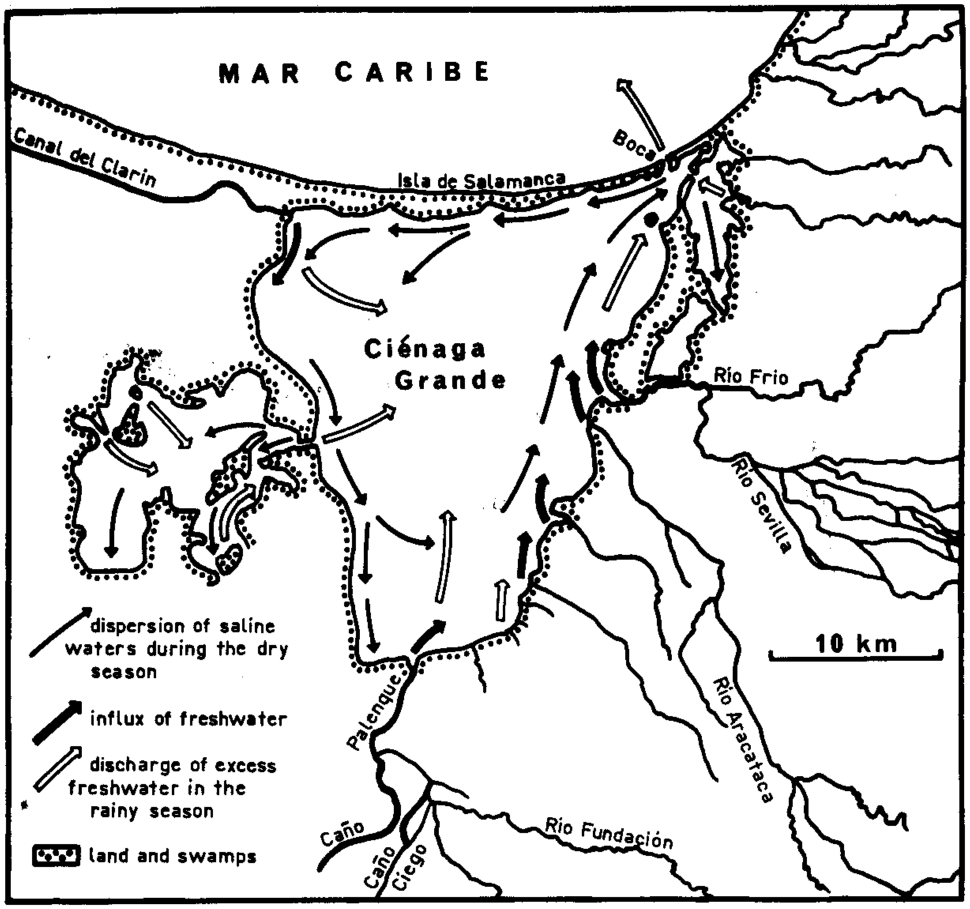

Fig. 4. Scheme of water circulation in the Ciénaga Grande and adjacent waters in the dry and in the rainy season (Base map adapted from RAASVELT & TOMIC 1958: Fig. 3).

Changes in water level of the lagoon are usually insignificant. During the dry season a base level (hydrographic zero) is assumed in response to mean sea level at the outlet. Readings of the hydrometric gauge at the Mahoma camp (Fig. 9), made from February trough April 1971, indicate short-term oscillations of the water level within no more than 20 cm, probably resulting from wind pressure onto the lagoonal surface.

7. History of the Ciénaga Grande and the Isla de Salamanca

If tectonic subsidence of the Lower Magdalena block, or displacement of the coast by wrench faulting may be excluded as probable causes for the formation of the Cga. Grande, then this coastal embayment has formed by processes related to: (1) the rapid northward growth of the Magdalena delta W of the lagoon, (2) the compaction of underlying

Quaternary sediments, or (3) a recent eustatic rise in sea level. Any of these three processes was not matched by an equivalent rate of sedimentation in the area under consideration. The lagoon probably developed in a complex way similar to bays and lakes associated with the Mississippi delta (COLEMAN 1966). The shallow lagoon came

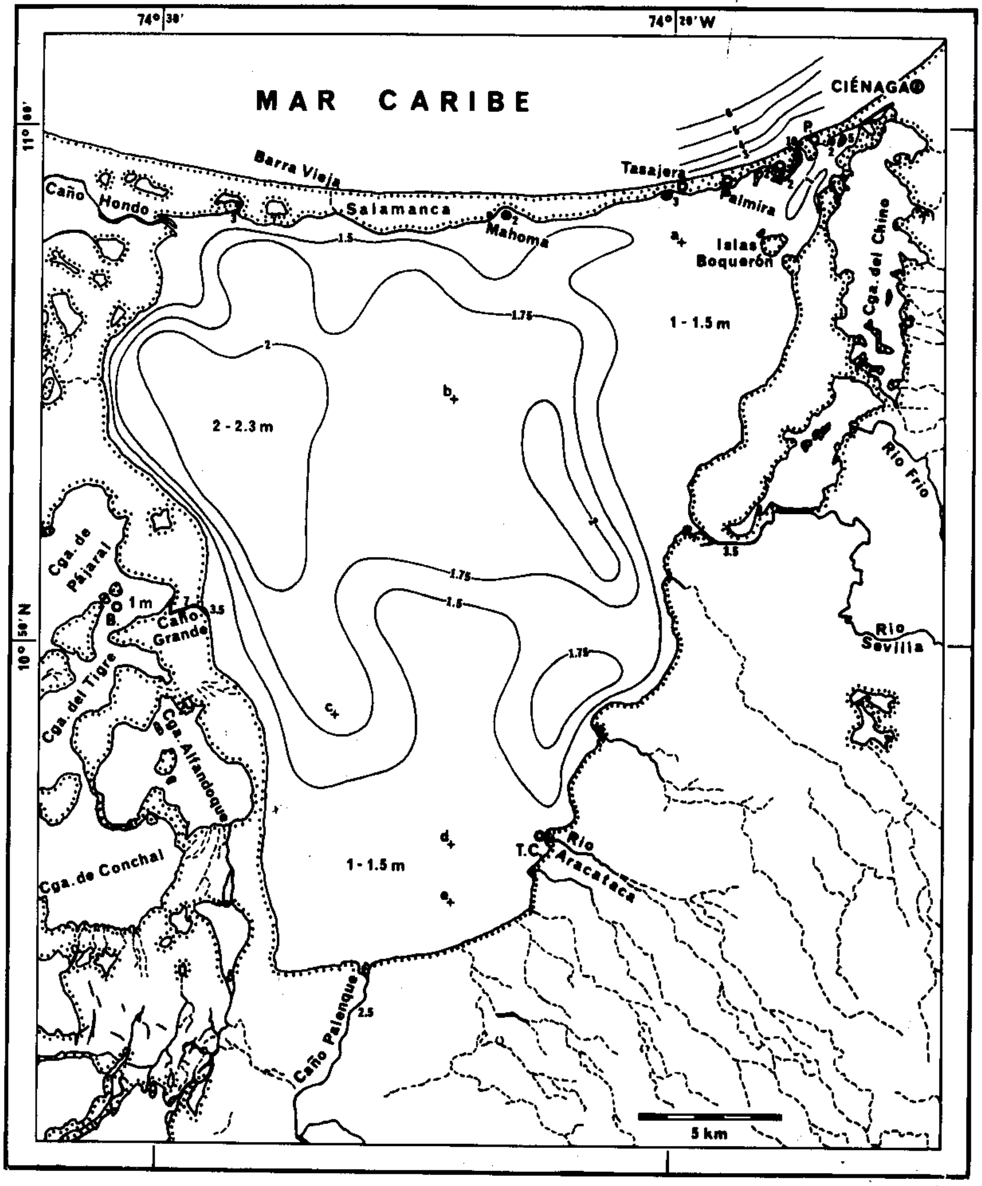

Fig. 5. Hydrographic chart of the Ciénaga Grande. All numbers refer to depth in meters below hydrographic zero. Local depressions of 2 m and more are presented in black. P. = Puebloviejo; B. = Buenavista; T.C. = Trojas de Cataca; Cga. = Ciénaga. — Base map adapted from Carta General 1 : 100 000.)

gradually into existence by a relative rise in sea level of little more than 2 m during the last 2 300 years. Before the transgression, the area had been an Everglades-type swamp. Extensive peat deposits intercalated with sand layers are the representative sediments of that early period. The level surface of the peat deposits is now submerged at an average depth of 2 m below hydrographic zero of the lagoon, and covered by recent lagoon sediments.

Employing a coring tube capable of penetrating the generally muddy lagoonal sediments to the underlying peat deposits, samples were collected from the top of the peat record at many stations distributed throughout the lagoon. Four of those samples — stations **a** through **d** (Fig. 5) — were selected for dating by carbon-14, and gave age values listed in Table 1. The dates were obtained on peat material from the uppermost 5 or 10 cm of the deposits and thus relate to the period when the area was still a swamp. The formation of peat finally ceased when the swamp submerged in the rising sea, earlier in the N than in the S. The lagoon reached its present size about 1 800 years ago, but may still grow deeper and larger if sea level continues to rise with respect to land surface. Analysis of the shell content of the lagoonal sediments above the peat platform shows that *Polymesoda, Congeria,* and *Crassostrea* have always been the dominant molluscs. The Cga. Grande never was a high-salinity lagoon. Hydrographic conditions similar to the present ones persisted troughout the two thousand years of its existence.

Table 1. Carbon-14 ages of samples from stations **a** through **e** (Fig. 4), dated by the Geochronology Laboratory of the University of Georgia.

No.	Station location	Material	Lab-No.	Years	B. P.
a	2 km south of Tasajera	peat	UGa-152	2 430	± 85
b	north-central lagoon	peat	UGa-149	2 300	± 65
c	south-central lagoon	peat	UGa-151	1 920	± 65
d	4 km west of Trojas de Cataca	peat	UGa-150	1 920	± 65
e	1 km off the south shore	oyster	UGa-146	280	± 80

Additional information pertaining the history of the Cga. Grande comes from a number of archeological sites distributed around the lagoon, the remnants of settlements or seasonal fishing camps of the pre-Colombian coastal population (Krogzemis 1967: 14). Very common, especially on the Salamanca Island, are shell mounds composed of surf clams (*Donax*), marsh clams (*Polymesoda*), and oysters (*Crassostrea*). Some of the sites have been excavated; others have been destroyed by the highway construction. A number of C^{14} dates, which have been obtained by archaeologists on shells from kitchen middens of various sites are listed in Table 2. Though the possibility remains that still older strata await excavation at those or other archaeological sites, the presently known dates, all no older than 1,5 thousand years, fit well into the geological history of the lagoon. They also give an indication of the age and remarkable stability of the Salamanca Island. Probably the barrier beach is even older than the lagoon and was already giving protection to the swamps in which the peat accumulated. With rising sea level, water invaded the lowlands behind the beach/dune ridge system, converting it into a barrier island (HOYT 1967).

Table 2. Carbon-14 ages from archaeological sites north and south of the Ciénaga Grande, dated by Humble Oil and Refining Co., Houston, Texas (N sites) and Geochronology Laboratory of the University of Michigan (S sites); communicated by Carlos Angulo, Barranquilla.

North of the lagoon:	Years	B. P.
village of Tasajera	1 100	± 105
	1 450	± 110
village of Palmira	1 000	± 105
	900	± 105
South of the lagoon:		
Loma del Cuchal (Caño Palenque)	720	± 105
	1 020	± 100
Mina de Oro (Caño Palenque)	1 490	± 100

In the past, the Salamanca Island was a chain of smaller barrier islands rather than a single long barrier beach. From the bathymetry of the lagoon, the present as well as former inlet channels are clearly recognized as local depressions of several meters depth within the monotonously shallow lagoon (Fig. 5). These depressions were formed by current scour and are floored by sand, if they are or have recently been active channels. The surface and subaquatic morphology strongly suggest that as many as seven different channels once connected the lagoon with the sea, at least temporarily. From E to W these are:

Fig. 6. The Rincón de Aguaviva is suspected to have been a major inlet in relatively recent times. After it was closed by a beach barrier, a minor beach ridge formed also on the lagoonal shore in the northernmost extension of the bight. The road dam across the bight is new (1956). — To the right, the village of Tasajera was flooded; provisional camps had been set up on higher elevations north of the highway.

Fig. 7. Barra Vieja site and Rincón de Barravieja. The shallow bight is beeing invaded by mangrove. The marshes north of the highway were flooded and the excess run-off broke through the beach ridge of the Barra Vieja. — Remnants of a former road system can be recognized.

Fig. 8. Mangrove in the vicinity of the Caño de Caiman, a narrow but deeply scoured channel, which connects the lagoon with a small pond.

Fig. 9. The Punta de Mahoma with the INDERENA camp. The bight to the right is part of the Rincón de Jaguey, which is suspected to have been a major inlet in more recent times than the Barra Vieja site. Note the tonal difference between the mangrove in the temporarily flooded area and the thornbush vegetation on the higher terrain of the barrier island.

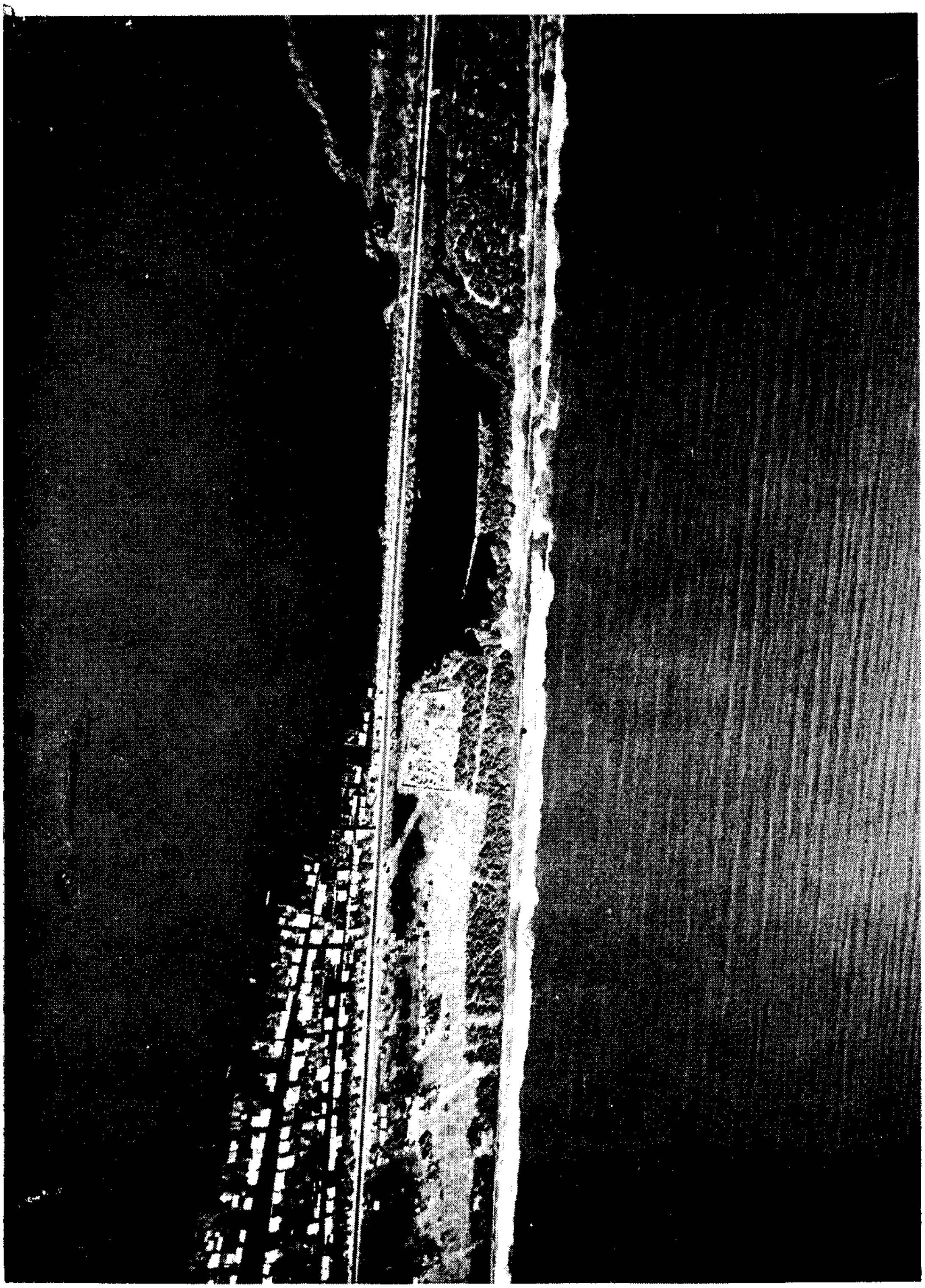

Fig. 6

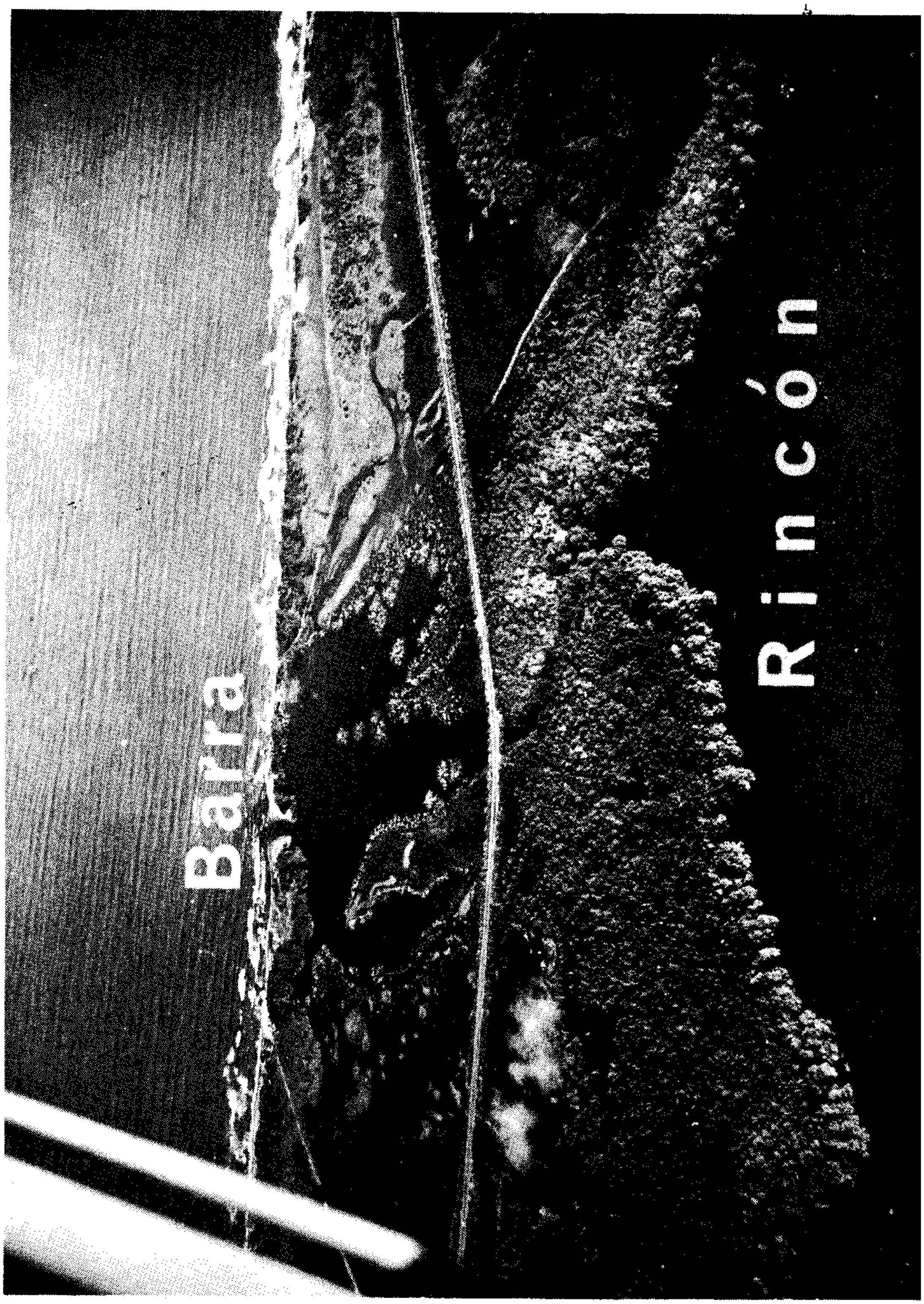

Fig. 7

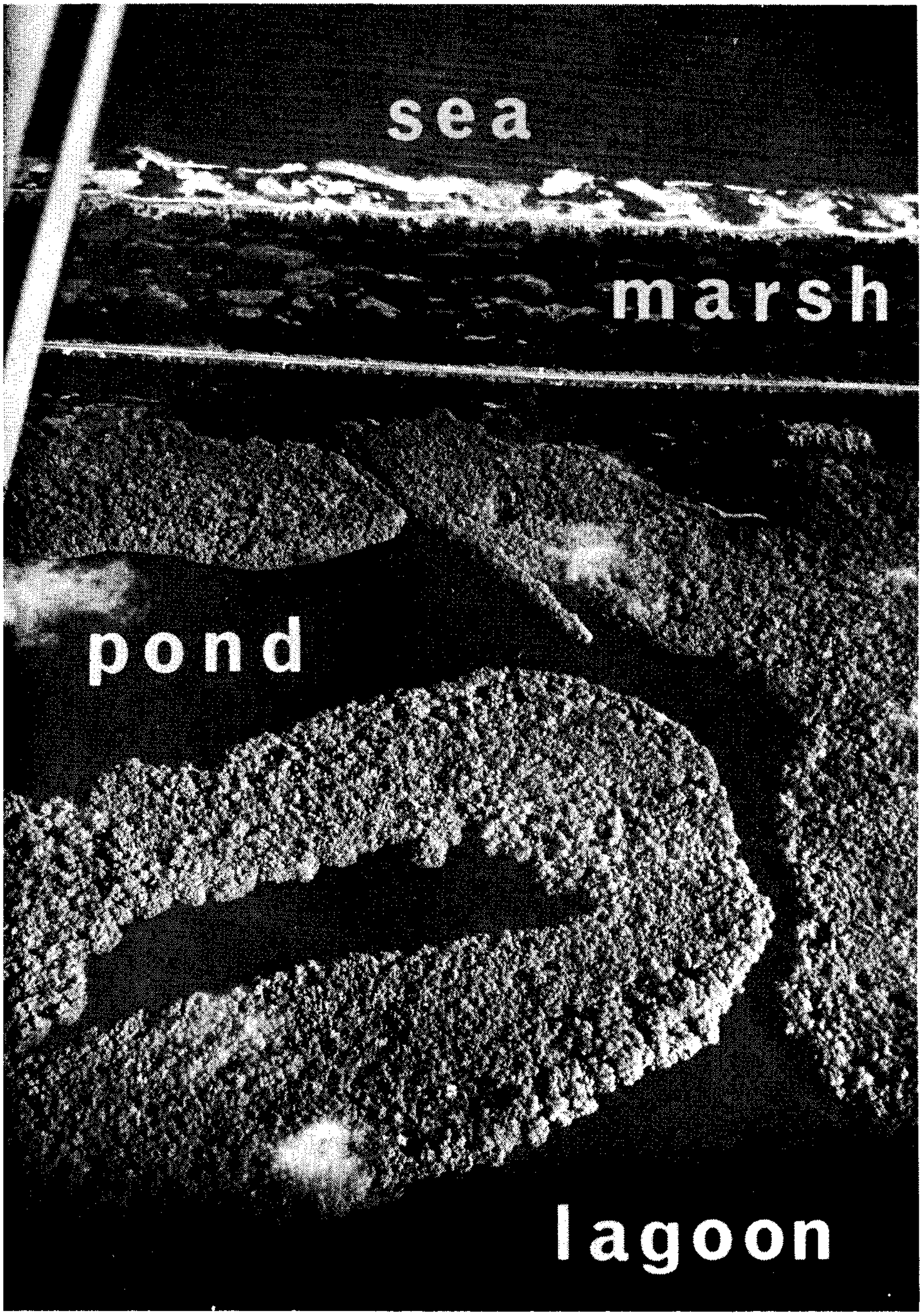

Fig. 8

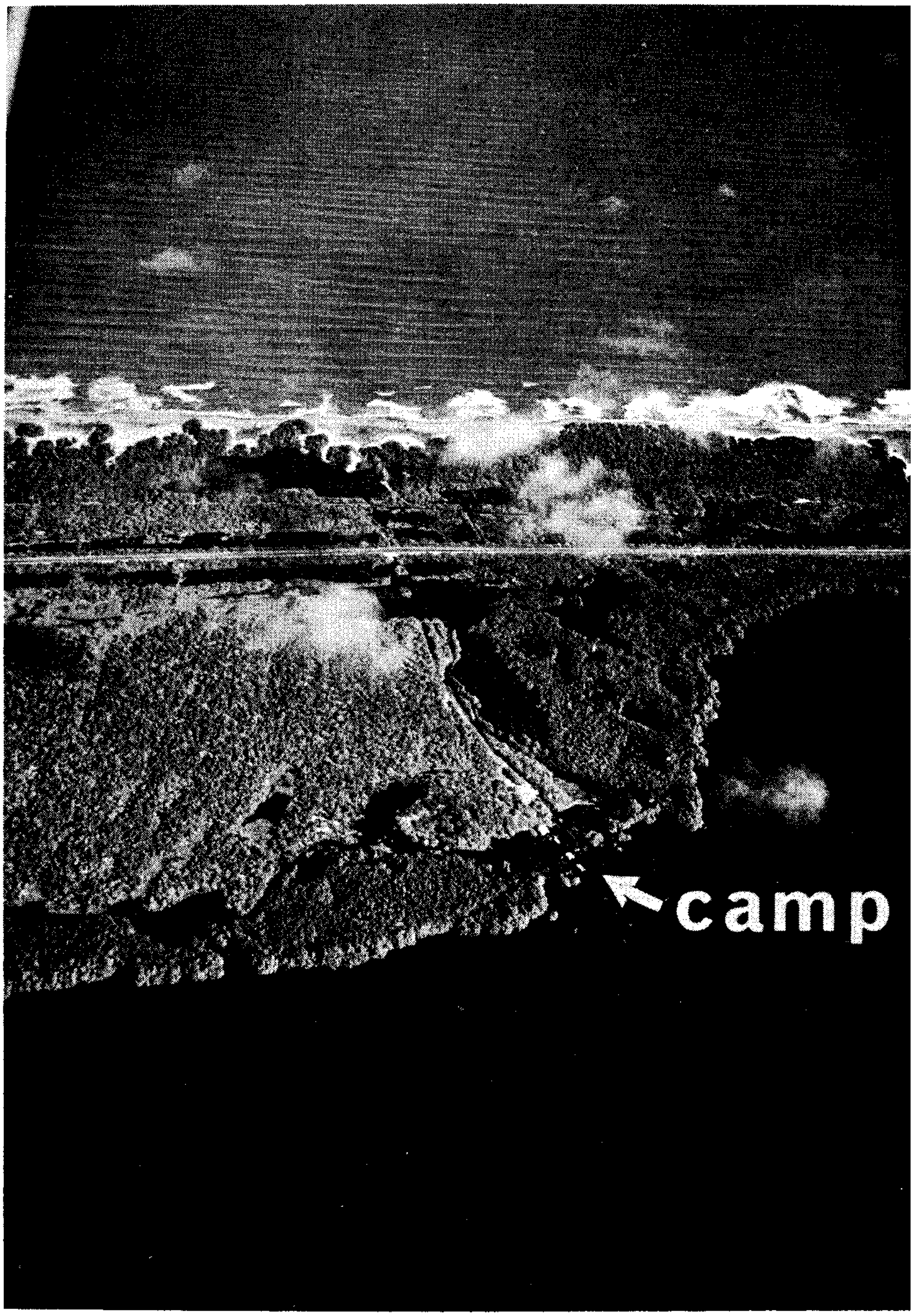

Fig. 9

1) Two sand-floored depressions that still mark the pre-1956 outlet E of Puebloviejo. This outlet has been closed by the highway construction. The depressions have 2 m and 5 m maximum depth, respectively.
2) The active channel of the new outlet (Boca de la Barra), scoured to a depth of more than 10 m under the bridge (Fig. 2). It is traceable between the mangrove islands S of Isla de Rosario, where it is still 2,2 m deep and floored by a shell lag deposit.
3) A small sand-floored depression of 2 m depth between Isla de Rosario and Palmira.
4) The Rincón de Aguaviva W of Tasajera (Fig. 6), a large depression of up to 3 m depth, floored by a mud blanket over sand.
5) The Rincón de Jaguey E of the Punta de Mahoma (Fig. 9), which is a similar depression of 2 m depth having a thicker mud blanket over sand.
6) No topographic depression is discernible in the Rincón de Barravieja (Fig. 7). The water is only about 1,5 m deep. The bight, however, is underlain by as much as 3,3 m of soft black mud, filling a former sand-floored depression here (Fig. 10-b).
7) The Caño de Caiman, up to 3 m deep and sand-floored, which connects a small pond with the Cga. Grande (Fig. 8).

These characteristics suggest that a relationship exists between the time that passed since the channels were active and the amount of fine mud that accumulated in the depressions. The following conclusions thus appear inescapable. At least one minor outlet just W of Isla de Rosario (no. 3) has been active in quite recent time in addition to the known outlets E and W of Puebloviejo. Furthermore, both the Rincón de Aguaviva and the R. de Jaguey have once been major outlets, evidently during a comparatively more recent period than the Barra Vieja site. Because the original scour hole of the R. de Barravieja has long been filled by mud, this site cannot have been a major inlet and outlet during the latest history of the lagoon, as is generally assumed. More likely it served merely as a safety valve for excess run-off. If one may offer a recommendation to coastal engineers concerned with the problem of opening a second artificial outlet in order to improve the hydrographic conditions in the Cga. Grande and to take pressure off the Boca de la Barra and its endangered bridge, it seems to be the better option to break through the island at Tasajera or possibly even at Mahoma rather than at the Barra Vieja site.

8. Recent sediments and bathymetry in the Ciénaga Grande

8.1 General aspects

Following the early formation of the lagoon, the submerged platform of peat is gradually being covered by recent lagoonal sediments. With the exception of local scour holes, the present subaquatic topography thus directly reflects the differences in sedimentation rate. Where the peat is covered by little sediment, the lagoon is around 2 m deep as, for example, in the central and NW parts. Clastic sediments

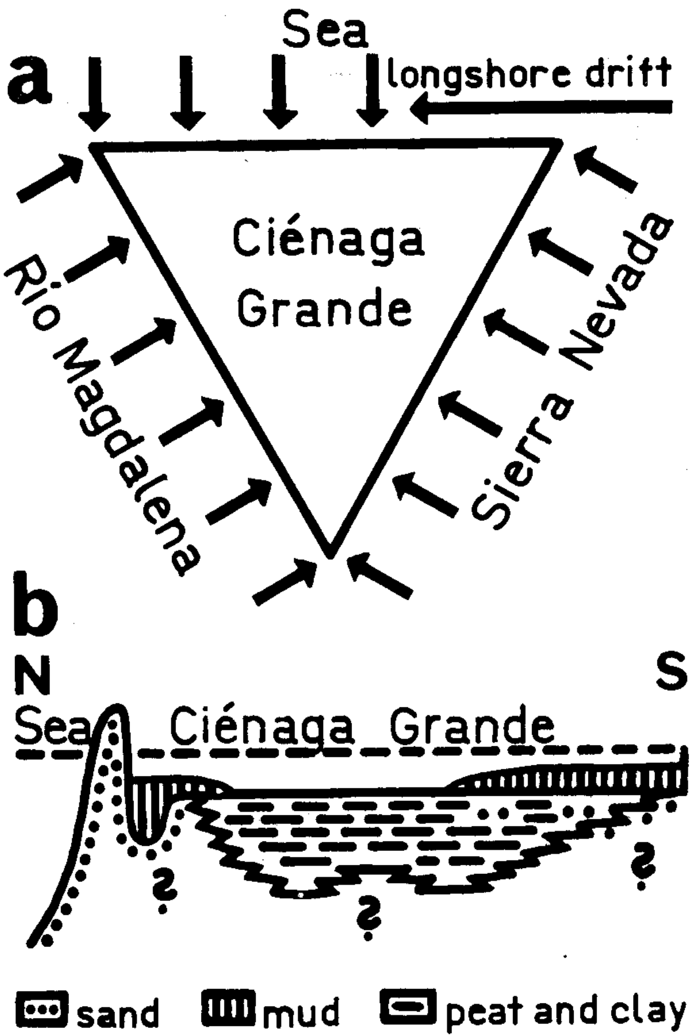

Fig. 10 a. Scheme of provenance of clastic sediments in the Ciénaga Grande, supplied (1) from longshore and offshore sources by wind, washover, and tidal currents, (2) by the eastern rivers from the Sierra Nevada de Santa Marta and its piedmont, and (3) by the flood waters of the Magdalena River..

b. Schematic cross-section through the Holocene sediment record of the Ciénaga Grande. Recent lagoonal mud is deposited on top of the platform of pre-lagoonal sediments and in current-scoured depressions.

are transported into the lagoon from three different source areas (Fig. 10-a). The distribution and deposition of fine clastic material is governed by currents and wave energy acting on the lagoonal bottom. Even though the content of suspended matter in the lagoonal water is high, limiting visibility to about one meter, no mud deposition takes place in the central, deepests parts of the lagoon. The general absence of mud deposits there may be attributed to the frequent sweeping of

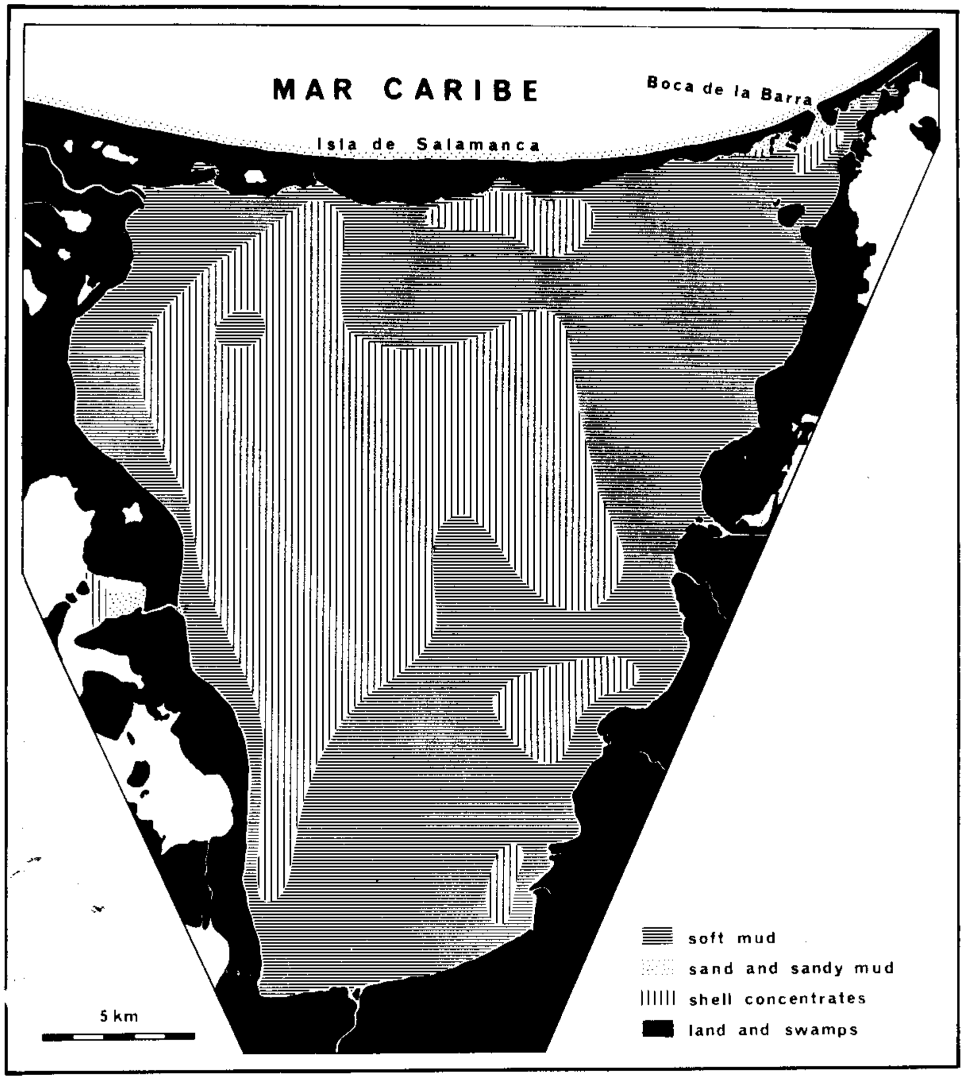

Fig. 11. Distribution of recent sediments in the Ciénaga Grande.

the bottom by waves and currents. A thin blanket of debris of molluscs, barnacles and serpulid worm tubes constitutes the only recent sediment there.

Certain evidence indicates particularly rapid sedimentation at the mouth of the Caño Hondo (Fig. 5). Comparison of older aerial photographs*) with the present shore configuration there suggests a progradation of the pair of subaerial natural levees at the canal mouth into the open lagoonal water. This heavy accumulation is presumably associated with the traffic of motor barges in the shallow canal, keeping in suspension a large amount of fine grained matter which is constantly shifted with the eastward current to the mouth and washed onto the levees by shoaling waves there (Fig. 12).

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*) U. S. Army Map Service Flights M-7 and M-13, Dec. 1953.

Two other sedimentary features, associated with the lagoonal inlet (Boca de la Barra), are worthy of mention. One is a sand lobe, which persists N of the Boca in dynamic equilibrium between longshore drift and water discharge from the outlet. For limited periods of time, a sand bar can become exposed on top of it. The other feature, a tidal delta S of the Boca, has formed from material transported into the lagoon by flood currents. This extensive shoal, having les than one meter water over the crest, forces the intracoastal traffic of barges from Barranquilla to a route S of the Boquerón Islands and a channel E of the Isla Boquerón Grande, as access to the harbor of Ciénaga city (Fig. 5). The formation of both shoals goes along with the progressive erosion of the nearby inlet. Current scour of unusually high discharge rates in the rainy seasons of 1969 and 1970 deepened the channel under the concrete bridge from a maximum depth of 5 m in spring 1968 (Lab. Centr. d'Hydraul. de France 1968) to more than 10 m only three years later.

In the Cga. Grande, three types of recent sediments can be differentiated: sandy deposits, fine muds, and skeletal carbonates (Fig. 11).

8.2 Sandy deposits

Sandy sediments occur almost exclusively in areas adjacent to Salamanca Island. Like the barrier island sand, it is composed mostly of quartz, having considerable proportions of feldspar and heavy minerals. This sand was carried into the lagoon by wind, washover, and by tidal currents through the various former inlets. Clean sands are confined to still active or recently active channels, grading into muddy sands and sandy muds where current energy decreases. One additional occurrence of sand is the Caño Grande, the major channel that connects the Cga. Grande with the Cga. de Pájaral. The channel is scoured to a depth of 7 m. The subaquatic fan deposits at both ends of the channel are also sandy.

8.3 Mud deposits

Sand is lacking in the open lagoon. Here the most common recent sediment is gray or black soft mud containing varying admixtures of shells. Thick deposits of mud are found in the E and S parts of the lagoon. Sedimentation rate in these areas was around 30 cm/1000 years if averaged over the entire history of the lagoon. Even higher averages are encountered locally, as for instance in the depression of the Rincón de Barravieja (Fig. 10-b).

Fig. 12. The digital delta which is being built at the mouth of the Caño Hondo (Canal de Clarin). The future extent of the natural levee to the right is already marked by a number of small islands in the foreground. For scale note the huts on the opposite river bank. Note the turbidity of the freshwater discharging into the lagoon.

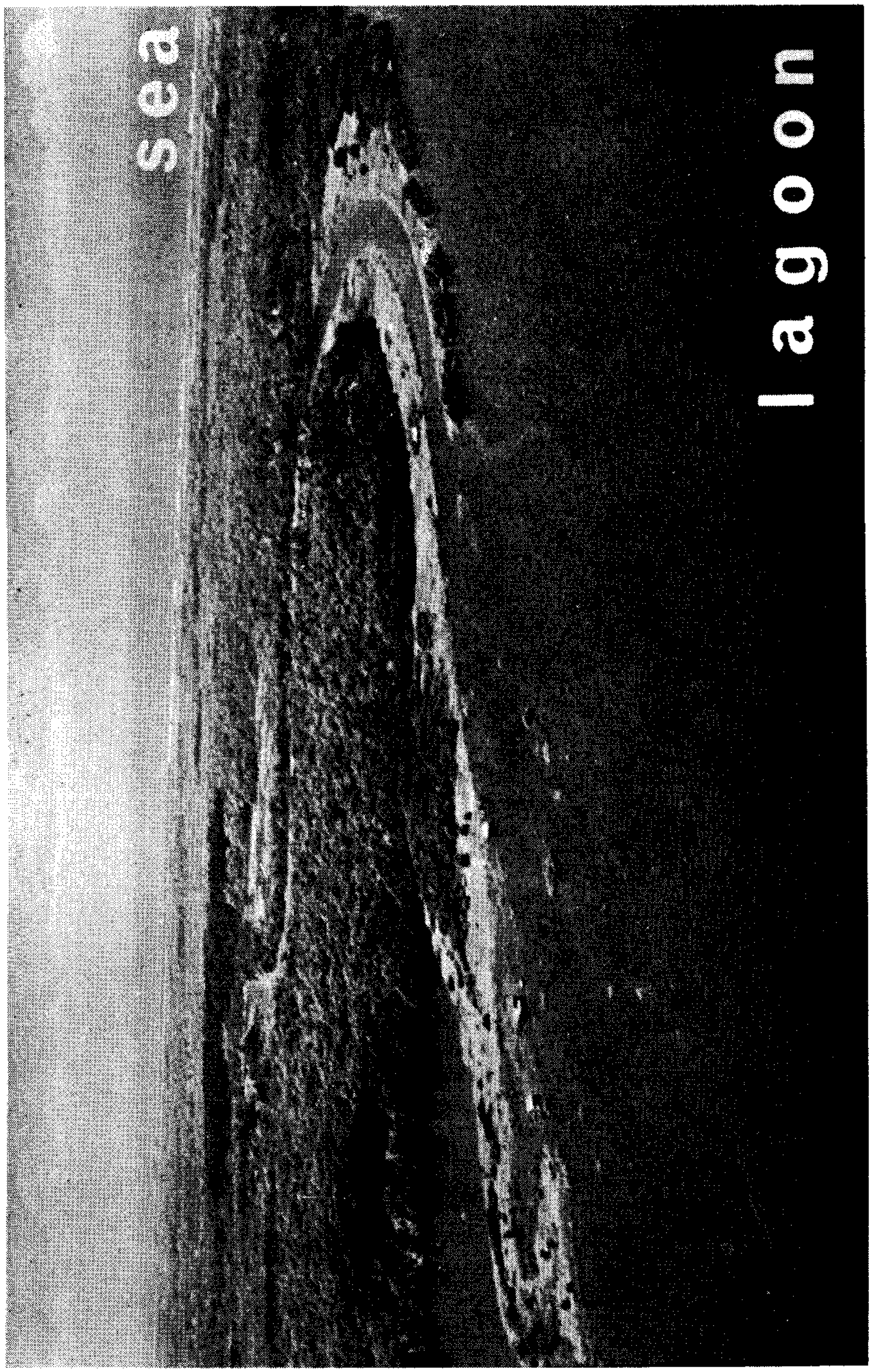

Fig. 12

8.4 Skeletal carbonates

Among the carbonate sediments, three intergradational sub-types can be distinguished: (1) the expansive shell concentrates in the central lagoon, (2) the oyster bottoms in the more estuarine N and NE, and (3). shell lag deposits in places with high current flow. The faunal composition varies with the salinity factor, whereas contamination by detrital sediment depends on local differences in supply and current energy.

In the central lagoon, autochthonous shell concentrates form a 5 to 50 cm thick blanket directly overlying the peat platform. Thicker deposits of the same type, up to 2,50 m thick, occur within 1—2 km S of the Rincón de Barravieja and the R. de Jaguey. The bulk of the shells stem from *Polymesoda* and *Congeria* with considerable contributions of barnacles, serpulid worms, *Crassostrea,* and sometimes *Protothaca.* The material forms a rubble having little coherence, even though individual shells may be densely overgrown and oysters commonly form clusters. The growth form of *Crassostrea* is irregular, the animals having thick valves.

The oyster bottoms below the N shore between Punta de Mahoma and the outlet, by comparison, are characterized by shallow water (about 1 m), patch-like distribution and limited extend. Firm reefs are absent. These deposits also constitute a rubble, but the growth form of *Crassostrea* is more commonly tall and upright, the animals having thin valves. This form indicates greater competition for space and possibly a faster rate of upward accretion of these shell deposits. The following generalizations are based on surface investigations and on the faunal analysis of four cores, 60 to 80 cm long, from typical near-shore oyster bottoms encountered just E of Isla de Rosario, just NNE of Isla Boquerón Chiquito, just E of Palmira, and just E of the INDERENA-FAO fisheries research station at Punta de Mahoma. — As in the central lagoon the boring sponge *Cliona* ist not in evidence. Other borers are also rare or absent. The bulk of the skeletal material stems from *Crassostrea, Congeria* and *Balanus.* Subordinate contributors are, in order of decreasing abundance, *Protothaca, Neritina, Tagelus, Hydrobia, Polymesoda, Brachidontes, Tellina,* bryozonas, serpulid worms, crab claws, and otoliths. This is a faunal association typical for the low-salinity lagoonal environment. When such near-shore, estuarine oyster bottoms become increasingly shallower, they are ultimately overgrown by mangrove, yielding a shell deposit of approximately one meter thickness, sandwiched between muddy sand (characterized by *Tagelus* ssp.) or lagoonal mud below and a veneer of peat or peaty mud above.

A shell lag deposit tops the extensive tidal shoal S of the lagoonal outlet (compare Figs. 5 and 11). It is composed chiefly of *Protothaca,* but also contains *Tagelus, Macoma, Tellina, Anomalocardia, Neritina,* and *Melongena.* A similar lag deposit was encountered in the nearby 2,20 m deep channel between the mangrove islands S of Isla de Rosario.

8.5 Shell layers within the lagoonal mud deposits

An important observation with regard to the history of lagoonal sedimentation, is that layers of shell concentrates similar to those in the central lagoon also occur intercalated in the mud accumulations of the E, S, and NW lagoon. These indicate widespread irregularities in sedimentation rate of the fine sediments that are not yet understood. By probing with a thin steel rod, such shell layers were discovered by the "feel" at fourty out of sixty stations within the realm of mud accumulation. As identified in several cores, the concentrates consist chiefly of *Polymesoda.* In the NE, *Anomalocardia* is also present. Scattered oysters occur in the shell layers everywhere, even near the S shore of the lagoon. From one core, taken at station **e** (Fig. 5), *Crassostrea* valves from a shell concentrate, which was buried under 20 cm of mud[*]), were submitted for C^{14} dating. Their age of 280 ± 80 years B. P. (Table 1) suggests that the sedimentation rate of the mud above the shell layer was 6 to 10 cm/100 years, which is twice to three times the maximum sedimentation rate arrived at if the total thickness of the lagoonal sediments is averaged over the entire history of the lagoon. If feasible to date similar subsurface shell concentrates throughout the Cga. Grande, the results might show that a large proportion of the fine sediment accumulated only in the last 200 to 300 years. This hypothesis is supported by the observation that in seven of the cores, including station **e**, the mud above the shell concentrate was dark and soupy, but below the shell bed was light gray and more coherent, suggesting a marked difference in content of organic matter and water, and thus age.

A recent increase in accumulation rate, in turn, would suggest an increase in sediment supply from the source areas. Such an increase could result from accelerated erosion in the Sierra Nevada and the piedmont province to the E of the lagoon. The area of Santa Marta was settled by the Spaniards from 1526 on, gradually replacing the original Indian population. The indigenous cultures were destroyed by 1600. SIEVERS, in 1886, still saw the piedmont area between Riofrio and Fundación under virgin forest, grading into uninhabited dry open woodland S and W of Fundación. The United Fruit Company developed the "Zona Bananera" in this area, starting in 1899 (MERTINS 1969). According to KROGZEMIS (1967: 124 f.) large tracts of forest have also been destroyed in the Sierra Nevada during the last 100 years, to supply firewood for raw sugar manufacture and to provide new pasture and farmland, thus promoting soil erosion. The last phase of colonization of various river basins started in the early 1950's, the settlers fleeing the civil war (violencia) of the interior of Colombia.

9. Documentation of the flooding of the lower Magdalena River in 1970 and its impact on the hydrography and oyster production in the Ciénaga Grande

9.1 The food oyster

The Caribbean food oyster, *Crassostrea rhizophorae* (GUILDING 1828), is one of the most valuable natural resources of the Cga. Grande. Like its North American close relative, *C. virginica,* this species lives only in sheltered coastal estuaries and lagoons. It is commercially exploited in many areas of the Caribbean Sea and has been studied in

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[*]) encountered at 1,7—1,9 m below hydrographic zero.

Puerto Rico (Mattox 1949), Venezuela (Simpson & Griffiths 1967), and Cuba (Nikolić & Meléndez 1968). In the Cga. Grande the oyster is found attached to mangrove roots, poles, pilings and other man-made structures, but the mayor yield comes from regular subaquatic oyster bottoms. Banks in the estuarine NE section are particularly rich, extending to the W as far as Punta de Mahoma. In addition, oysters were picked or dredged from shell beds in the central lagoon prior to November 1969.

In the rainy seasons of 1969, 1970 and 1971 the Cga. Grande received unusually abundant quantities of freshwater, which replaced the normally brackish lagoonal waters for sufficiently long periods to kill off the oyster in the entire lagoon. From November 1969 till November 1970, the occurrence of living oysters was already restricted to the vicinity of the villages of Isla de Rosario, Palmira, Tasajera and the Boquerón Islands (Fig. 5). In the rainy season of 1970, this estuarine section was also dominated by freshwater for seven weeks, from mid-November 1970 to Jan. 9, 1971, killing off the remaining oysters there. Fresh oyster spat were observed in the estuary again in the first months of 1971, but were killed by freshwater at the end of the year (R. v. Cosel, personal communication).

9.2 Provenance of the abundant freshwater

Perhaps the rainy seasons of 1969 to 1971 brought more rain than usual to the Sierra Nevada, where the eastern tributaries of the Cga. Grande have their headwaters. No doubt, however, the excess supply of freshwater in 1969 and then the catastrophic flooding in 1970 was largely due to unusually high waters in the Magdalena River. The official fluviometric gauge at Calamar measured a maximum level of 8,04 m on Dec. 16, 1969, and even 8,44 m on Nov. 29, 1970. With almost 4 m above mean water there, this was the highest water level recorded since the installation of the gauge in 1940.

Downstream from Calamar, the Caño Ciego and numerous other channels conduct water towards the Cga. Grande (Fig. 1). The lowlands adjacent to the C. Ciego were inundated by the unusually high water. The road from Pivijay to Salamina was closed from mid-November 1970 into January 1971; all traffic switched to canoes. The road dam had to withstand the buildup of water from the S and was ripped at several places by the flood, which also carried away small bridges. At Pivijay the water rose to a maximum of 1,7 m above the base level of the C. Ciego, damaging many houses.

→

Fig. 13. The extent of the flooding on Dec. 13, 1970. Flooding of the western outskirts of Ciénaga and of the marshes on both sides of the road dam, where storage tanks for petroleum products and the radio station are located. — Note large motor barges in the harbor.

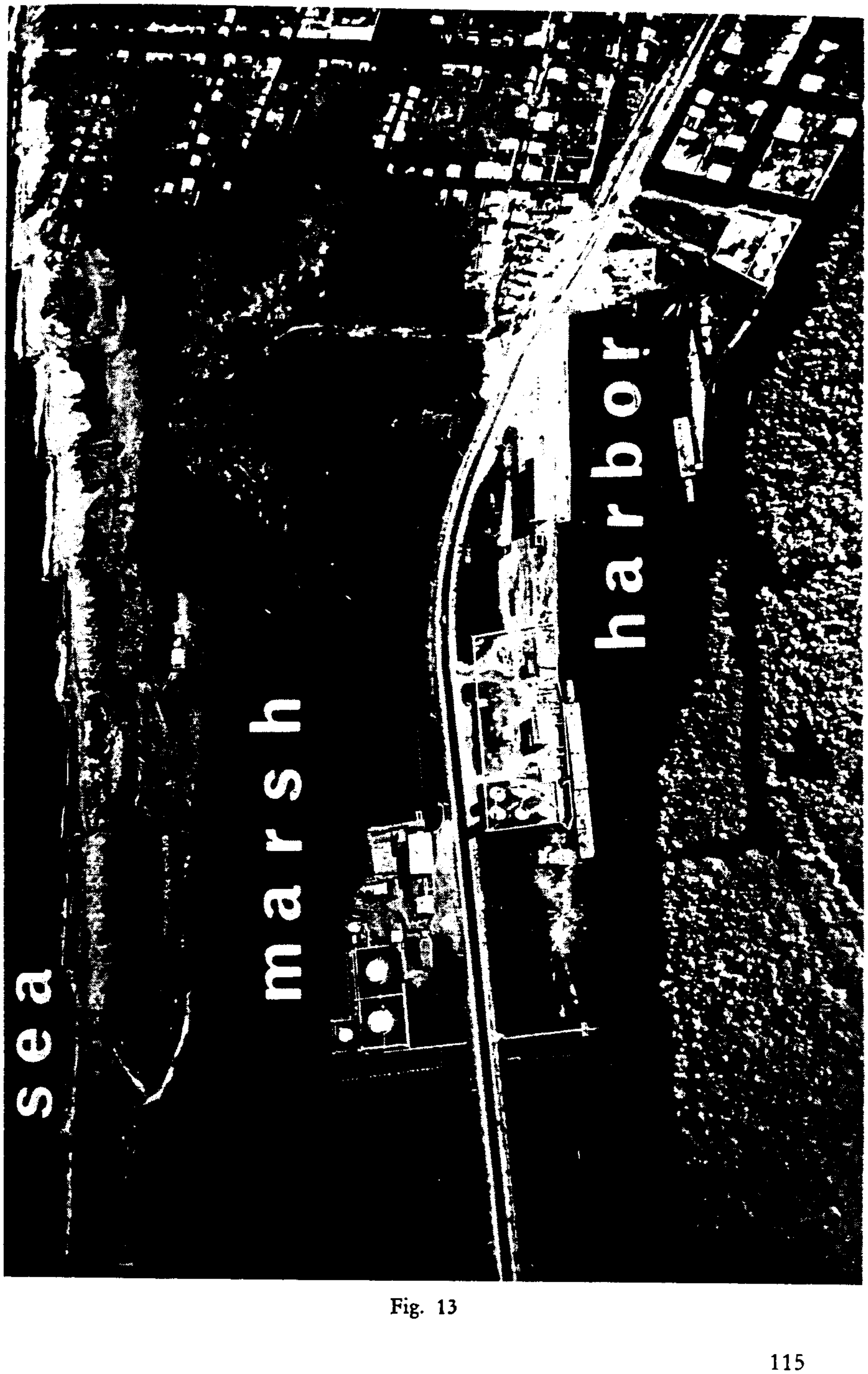

Fig. 13

Fig. 14

In 1969, by comparison, no such detrimental flood occured; the road to Salamina remained trafficable. But people in Pivijay remember a similar inundation in 1955 or 1956. In those two years the Magdalena also rose to over 8,3 m at Calamar.

9.3 Flooding of the Ciénaga Grande in 1970

The gradual replacement of the brackish waters of the Cga. Grande by freshwater started in October. On Oct. 14, 1970, the water level of the Canal del Clarin at Los Cocos was at least 10 cm higher than observed on Sept. 24, and a strong current from the Magdalena towards the Cga. Grande was noticed. By that time salinities were already down to 5 ‰ in the central lagoon and 4 ‰ in the Cga. de Pájaral S of Nueva Venecia. There, crystal-clear, cool freshwater was observed to enter through the Caño de Los Morranos and the three outlets of the neighboring Cga. de Cherle NW of Nueva Venecia. The Caño Grande, too, had a noticeable current towards the Cga. Grande. By Nov. 3 the Caño Grande discharged freshwater into the Cga. Grande with a current velocity of 0,6 m/sec at the surface. The salinity in the central lagoon was down to 2 ‰.

The first noticeable rise of the lagoonal level coincided with spring tides at the oulet, holding back the lagoonal water, which rose to 0,7 m above sea level at 9 : 30 A. M. on Nov. 11, the time of high tide. The water then remained high until the end of December. A maximum of 0,95 m above sea level at the outlet was observed Dec. 9. A maximum of 1,10 m above hydrographic zero was read off the hydrometric gauge at Punta de Mahoma camp on Dec. 12, 1970 (Fig. 9). The aerial photographs, reproduced here, were taken on Dec. 13 and give an idea of the extent of the flooding. The entire delta plain was inundated, and waters flowed unhindered across the lowlands to the Cga. Grande, coverting its outlet into a river mouth extension of the Magdalena. The existence of the road dam across the Salamanca Island aggravated the buildup of water in the lagoon. The western outskirts of Ciénaga city and the villages on Salamanca were inundated (Fig. 13—14), rendering many houses uninhabitable. Their owners camped on higher elevations along the highway and in the dunes. Water that could press through drainage pipes emplaced in the road dam at several locations also flooded the marshes N of the highway and broke through the beach ridge at different sites, including the Barra Vieja (Fig. 7) and a location N of Palmira (Fig. 14).

Fig. 14. The extent of the flooding on Dec. 13, 1970. Flooding of Palmira, which is located on the lagoon shore. The marshes between the highway and the feeble beach ridge were also flooded and the excess runoff broke through the beach (arrow).

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