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GEO-ENVIRONMENTS OF THE NORTHWEST ORINOCO DELTA, VENEZUELA

William A. White, Andrew G. Warne, Edgar H. Guevara, Andres Aslan, Thomas A. Tremblay and Jay A. Raney

William A. White. **B.S. in Geology and M. Ed. in Science Education, The University of Texas at Austin (UTA). Research Scientist, Bureau of Economic Geology, UTA. Address: John A. and Katherine G. Jackson School of Geosciences, University Station, Box X, Austin, TX 78713-8924, USA e-mail: Bill.White@beg.utexas.edu.**

Andrew G. Warne. **Deceased. M.S. in Geology, Rutgers University. Ph.D., University of North Carolina, Chapel Hill. Formerly with the U.S. Geological Survey, GSA Center 651 Federal Drive, Suite 400-15, Guaynabo, Puerto Rico, 00965-5703, USA**

Edgar H. Guevara. **B.S. in Geology, Universidad Central de Venezuela. M.A. and Ph.D. in Geology, UTA. Research Scientist, Bureau of Economic Geology, UTA.**

Andres Aslan. **B.S. in Geology, Brown University. M.S. and Ph.D., University of Colorado. Assistant Professor of Geology, Mesa State College, Grand Junction, Colorado. Address: Department of Physical and Environmental Sciences, Mesa State College, Grand Junction, CO 81501-7682**

Thomas A. Tremblay. **B.A. in Geology and M.S. in Geography, UTA. Geographic Information Systems (GIS) Analyst, Bureau of Economic Geology, UTA.**

Jay A. Raney. **B.S. in Geology, University of Massachusetts. Ph.D., UTA. Project Director of a two-year study of the geo-environmental characterization of the Delta del Orinoco, Venezuela. Associate Director for Environmental Research, Bureau of Economic Geology, UTA.**

Summary

The Orinoco Delta is a largely undeveloped complex of tropical wetlands and shallow aquatic ecosystems within the coastal plain of eastern Venezuela. It is a dynamic and complex system that is vulnerable to human activities. This article summarizes results of geo-environmental mapping in the northwestern delta. Geo-environments are land- and water-resource units that are defined by the physical, chemical, hydrological, and biological properties and processes that establish, maintain, and modify them. More than 20 geo-environments were defined and delineated in a Geographic Information System (GIS) format through integrated remote sensing, statistical, and field analyses. Map units were grouped into five major geomorphic/ecologic systems: 1) marine-influenced coast, 2) marine-influenced distributary-channel and island, 3) fluvial/marine transitional, 4) distributary-channel, and 5) interdistributary basin. The most extensive are the interdistributary basins and distributary-channel systems, which comprise 44 % and 15 % of the map area, respectively. Although the Orinoco Delta is largely undeveloped, human activity in the northwestern delta, especially construction of the Volcán dam, has substantially altered geo-environments in this region. The defined distribution and characteristics of the geo-environments provide a *basis for designing strategic plans for prudent and sustained development of this portion of the Orinoco Delta ecosystem complex.*

Resumen

El Delta del Orinoco es un complejo de humedales y ecosistemas acuáticos tropicales de aguas poco profundas en la planicie costera del oriente de Venezuela, el cual en su mayor parte aún no ha sido desarrollado. Es un sistema dinámico y complejo, vulnerable a las actividades humanas. Este artículo resume resultados de cartografía geo-ambiental en el noroeste del delta. Los geo-ambientes son unidades de recursos terrestres y acuáticos que se definen por las características y los procesos físicos, químicos, hidrológicos, y biológicos que los establecen, mantienen y modifican. Más de 20 geo-ambientes se definieron y delinearon en el formato del Sistema de Información Geográfica (SIG) mediante análisis integrado de información de sensores remotos, estadística y campo. Las unidades cartográficas se agruparon en cinco sistemas geomórfico/ecológicos: 1) costa con influencia marina, 2) canal distributario e isla con influencia marina, 3) fluvio/marino transicional, 4) canal distributario, y 5) cuenca interdistributaria. Los más extensos son las cuencas interdistributarias y los sistemas de canales distributarios, los cuales cubren respectivamente el 44% y el 15% del área cartografiada. Aunque el Delta del Orinoco está sin desarrollar en su mayor parte, la actividad humana en el noroeste del delta, especialmente la construcción de la represa de Volcán, ha modificado considerablemente los geo-ambientes en esta región. La distribución que se determinó y las características de los geo-ambientes proporcionan una base para el diseño de planes estratégicos para el desarrollo prudente y sustentable en esta parte del complejo ecosistema del Delta del Orinoco.

Resumo

O Delta del Orinoco é um complexo de humedales e ecossistemas aquáticos tropicais de aguas pouco profundas na planicie costera do oriente da Venezuela, o qual em sua maior parte ainda não foi desenvolvido. É um sistema dinâmico e complexo, vulnerável às actividades humanas. Este artígo resume resultados de cartografia geo-ambiental no noroeste do delta. Os geo-ambientes são unidades de recursos terrestres e aquáticos que se definem pelas características e os processos físicos, químicos, hidrológicos, e biológicos que os estabelecem, mantém e modificam. Mais de 20 geo-ambientes se definiram e delinearam na forma do Sistema de información Geográfica (SIG) mediante análise integrado de informação de sensores remotos, estatística e campo. As unidades cartográficas se agruparam em cinco sistemas geomórfico/ecológicos: 1) costa com influência marinha, 2) canal distributario e ilha com influência marinha, 3) fluvio/marinho transicional, 4) canal distributario, e 5) cuenca interdistributaria. Os mais extensos são as cuencas interdistributarias e os sistemas de canais distributarios, os quais cobrem respectivamente o 44% e o 15% da área cartografiada. Ainda que o Delta del Orinoco está sem desenvolver em sua maior parte, a atividade humana no noroeste do delta, especialmente a construção da represa de Volcán, tem modificado consideravelmente os geo-ambientes nesta região. A distribuição que se determinou e as características dos geo-ambientes proporcionam uma base para o desenho de planos estratégicos para o desenvolvimento prudente e sustentável nesta parte do complexo ecossistema do Delta del Orinoco.

KEY WORDS / Delta Ecosystems / Distributary Channel / Geo-environments / Interdistributary Basins / NW Orinoco Delta / Venezuela /

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The Orinoco Delta sustains a vast, largely undeveloped mosaic of tropical wetlands and shallow aquatic ecosystems within the coastal plain of eastern Venezuela. The triangular to trapezoidal delta plain encompasses ~22000km2 of wetlands including swamps (characterized by forested wetlands) and marshes (consisting of emergent herbaceous vegetation; the marsh unit is underlain by peat in much of the lower delta and could be classified as a fen using European terminology; see Mitsch and Gosselink, 2000). The wetlands are subdivided by networks of fluvial and tidal channels (Figure 1). The Orinoco River floodplain and delta plain comprise one of the world□s largest tropical-wetland complexes (Hamilton and Lewis, 1990).

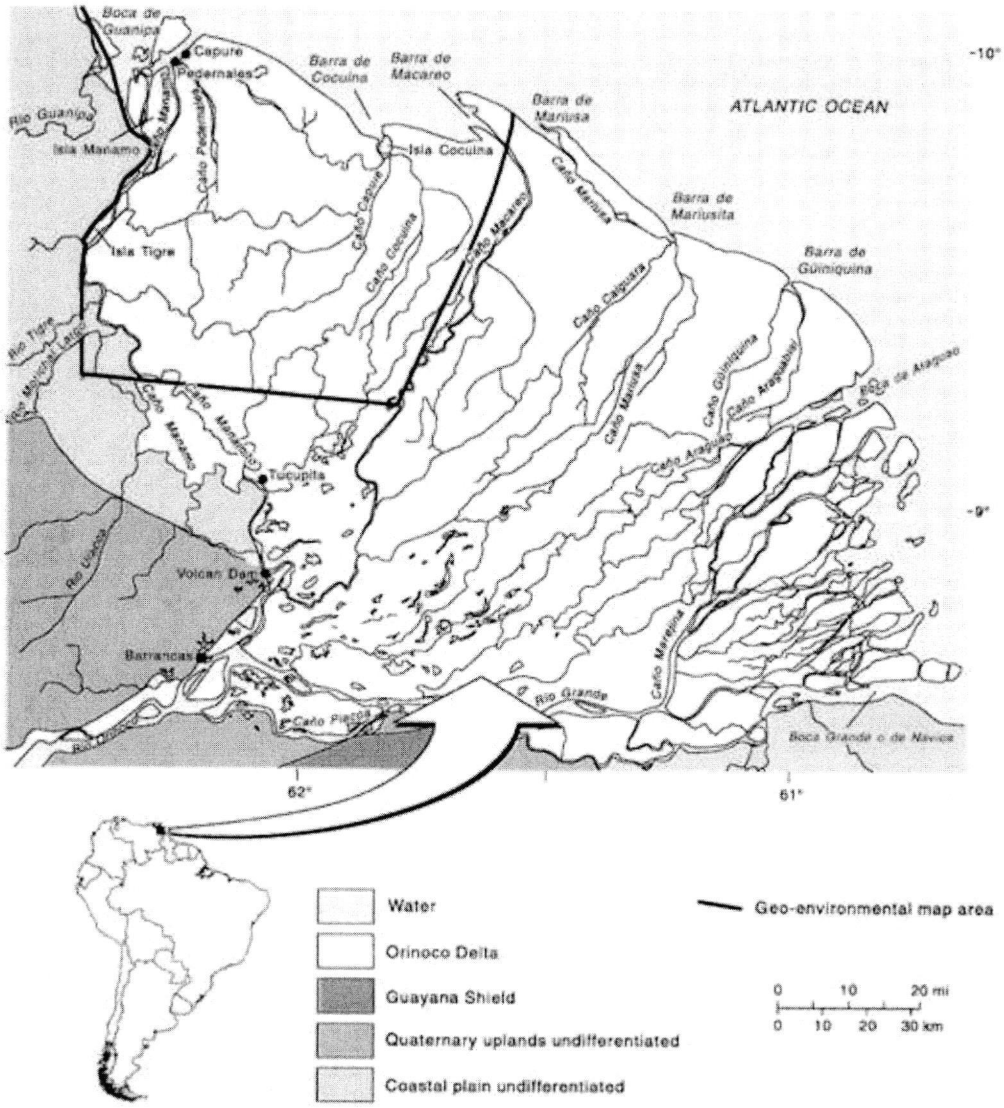

Figure 1. Index map of study area.

A multidisciplinary study was conducted to identify and evaluate the physical processes and process linkages that control stability and integrity of the Orinoco Delta ecosystems (Warne *et al.*, 1999; 2002a,b). The aim of this study was to generate, compile and interpret baseline information needed to anticipate, avoid and mitigate impacts associated with human activity in the delta. In the present article we describe geo-environments of the northwestern delta. By geo-environments are meant mappable land- and water-resource units that are defined by the physical, chemical, hydrological and biological properties and processes that establish, maintain and modify them.

The northwest-delta map area encompasses more that 6000km2 and is bounded on the north by the marine shoreline from Punta Pescadores to Boca de Guanipa and extends inland ~90km along Caño Manamo, which marks the western boundary (Figure 1). The eastern boundary is near Caño Macareo.

Approach

Classification and delineation of map units integrated remote sensing and field analysis. Initially map units were delineated on Landsat imagery on the basis of visual interpretations. Field observations and overflights in early 1998 and published data were used as guidance for the preliminary identification of the characteristic vegetation of the mapped environments. To complement these preliminary interpretations, a computer-assisted automated classification of the Landsat image was conducted using digital statistical methods. Digital classifications depend on reflectance and spectral response and cannot substitute for the visual interpretation of environments. Visually interpreted units were locally adjusted on the basis of the statistical analysis. A revised geo-environmental map was then field-checked during visits to the delta in October and November 1998. Field observation included both aerial reconnaissance and onsite observations. Plants listed in the following sections provide only a small sampling of typical plants that may be found in the mapped environments. Pictorial descriptions of some of the more frequent plants are provided in appendix 1 of Warne *et al.* (1999).

Landsat imagery was used to interpret, classify, and delineate delta environments. Mapped environments and geomorphic units are associated with marine, fluvial/marine, distributary channels and interdistributary flood-basin processes. The distinctions among mapped delta environments are integrally connected to geomorphology, lithology, hydrology and associated vegetation. Of the factors that affect imagery reflectance, vegetation and degree of inundation/saturation are most important.

Geo-environmental map units were interpreted from August 1996 Landsat TM imagery using a combination of bands 4, 5, and 7 plotted at a scale of approximately 1:125000. Units, distinguished on the basis of color, tone, texture, and depositional setting, were mapped on clear acetate overlays. Where clouds obscured the land surface, other Landsat TM scenes from other dates or Radarsat scenes were used as collateral information. In a few areas where cloud-free Landsat images were not available, map-unit boundaries were approximated. Boundaries defined on other images were transferred to the base map using a zoom transfer scope. Map lines were manually digitized, and a plot of digitized polygons was hand colored to define map units. All polygons in the hand-colored map were coded in a Geographic Information System (GIS). Full-color GIS plots were checked for accuracy and completeness.

Geo-environmental Map Units of the Northwest Delta

More than 20 map units were defined and delineated through integrated visual, statistical and field analysis (Table I and Figure 2). Map units were grouped into five major depositional environments: 1) marine-influenced coastal environments, 2) marine-influenced distributary-channel and island complexes, 3) fluvial/marine transitional environments, 4) distributary-channel systems, and 5) interdistributary basins (Table I). The most extensive systems are the interdistributary basins and distributary-channels, which comprise areas of 2950km2 and 980km2, respectively (Table II and Figure 2).

GEO-ENVIRONMENTAL MAP UNITS BASED ON VISUAL INTERPRETATION OF LANDSAT IMAGERY

Marine-Influenced Coastal Environments	
1.	Mangroves on coastal facies, mud and locally sandy mud substrates, prominent depositional features apparent locally, permanently flooded
2.	Swamp, mud and peat substrates, permanently flooded
3.	High (topographically) marsh, organic/peat substrates, permanently flooded
4.	Low (topographically) marsh, ponded water, organic/peat substrates, permanently flooded
5.	Mixed marsh and swamp, organic/peat substrates, permanently flooded
Marine-Influenced Distributary-Channel and Island Complexes	
6.	Mangroves, mud and sandy mud substrates, depositional patterns apparent locally, semipermanently flooded
7.	Swamp, mud and sandy mud substrates, semipermanently to seasonally flooded
8.	Marsh, mud, sandy mud, and organic substrates, semipermanently flooded
9.	Transitional areas between mangrove and swamp or marsh, channel-flank environments, low swamp with local mangroves and herbaceous vegetation, muddy peat and peat substrates, semipermanently to permanently flooded
Fluvial/Marine Transitional Environments	
10.	Low (topographically) marsh, organic/peat substrates, permanently flooded
11.	High (topographically) marsh, organic/peat substrates, permanently flooded
12.	Mixed marsh and swamp, organic/peat substrates, permanently flooded
Distributary-Channel Systems	
13.	Levee and crevasse splay, forested, locally tidally modified, sand and mud substrates, moriche palms dominant in some areas, seasonally flooded
14.	Levee and crevasse splay, herbaceous vegetation, sand and mud substrates, seasonally flooded
15.	Tidal creek/crevasse splay, moriche palms dominant, mud and sand substrates, seasonally flooded
Interdistributary Flood Basins	
16.	Low (topographically) swamp, mud and organic substrates, permanently flooded
17.	Intermediate (topographically) swamp, mud and organic substrates, semipermanently to permanently flooded
18.	High (topographically) swamp, mud and organic substrates, semipermanently to seasonally flooded, locally includes transitional forested areas between levee/crevasse splay and flood basins
19.	Low marsh and open water, mud and organic substrates, semipermanently to permanently flooded, locally mapped along channel margins
20.	High marsh, mud and organic substrates, seasonally flooded
21.	Primarily marsh but with mixtures of swamp, mud and organic substrates, semipermanently to seasonally flooded

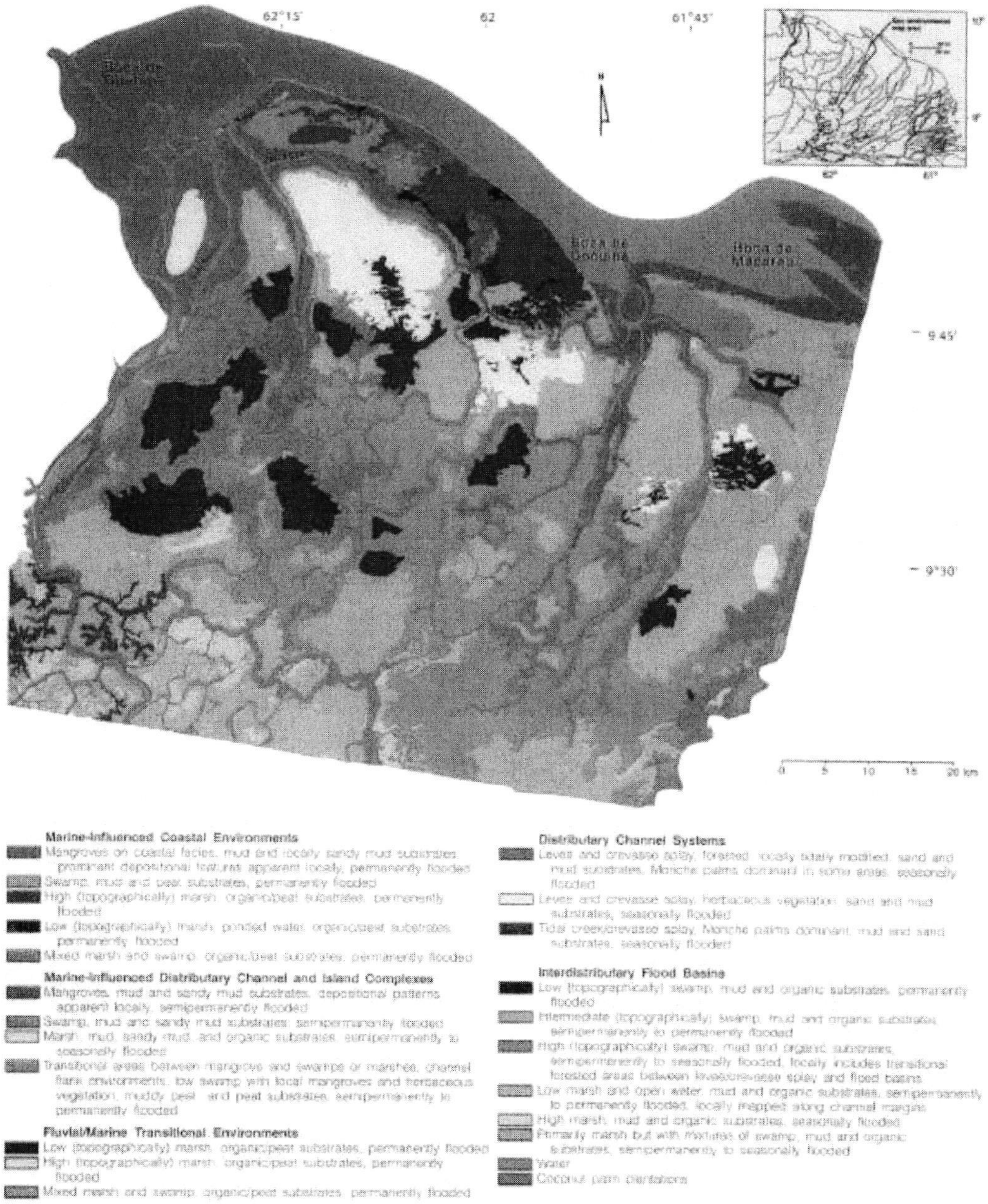

Figure 2. Geo-environments of the northwest Orinoco Delta, Venezuela. A digital, georeferenced (ArcView) version of this map is available in Warne *et al.* (1999). An interactive version of this map is available at www.beg.utexas.edu/geoenviro/orinoco/summary/main/geoenv/nw_main.htm.

TABLE II
EXTENT OF MAPPED ENVIRONMENTS IN THE NORTHWESTERN ORINOCO DELTA*

		km²	Percent
Marine-Influenced Coastal Environments			
1.	Mangroves on coastal facies	165.51	2.48
2.	Swamp, mud and peat substrates, permanently flooded	125.21	1.87
3.	High (topographically) marsh	178.19	2.67
4.	Low (topographically) marsh	12.37	0.19
5.	Mixed marsh and swamp	124.54	1.86
Subtotal		605.92	9.06
Marine-Influenced Distributary Channel and Island Complexes			
6.	Mangroves, mud and sandy mud substrates	546.98	8.19
7.	Swamp	27.67	0.41
8.	Marsh	32.85	0.49
9.	Transitional forested areas between mangrove and swamp or marsh	50.43	0.75
Subtotal		657.92	9.85
Fluvial/Marine Transitional Environments			
10.	Low (topographically) marsh	53.19	0.80
11.	High (topographically) marsh	294.04	4.40
12.	Mixed marsh and swamp	180.26	2.70
Subtotal		527.49	7.89
Distributary-Channel Systems			
13.	Levee and crevasse splay, forested, locally tidally modified	908.93	13.60
14.	Levee and crevasse splay, herbaceous vegetation	1.76	0.03
15.	Tidal creek/crevasse splay, moriche palms dominant	68.63	1.03
Subtotal		979.32	14.66
Interdistributary Flood Basins			
16.	Low (topographically) swamp	370.87	5.55
17.	Intermediate (topographically) swamp	881.39	13.19
18.	High (topographically) swamp	997.36	14.93
19.	Low marsh and open water	76.99	1.15
20.	High marsh	97.38	1.46
21.	Primarily marsh but with mixtures of swamp	527.62	7.90
Subtotal		2951.62	44.18
Water		956.57	14.32
Villages (Pedernales and Capure)		0.55	0.01
Mud volcanoes visited in 1998		0.16	0.00
Coconut plantation		1.92	0.03
Subtotal		959.21	14.36
Total		6681.47	100.00

Marine-influenced coastal environments

Marine-influenced coastal environments compose the seaward-most system in the map area. Map units include mangrove-covered coastal facies, landward of which are swamps and marshes (Figure 3a). Except for a narrow beach and berm along the shoreline, environments in this system are perennially flooded or saturated. Most are strongly affected by diurnal tides.

Figure 3. Examples of geo-environments. a: Mangroves intergrading with marshes in the Marine-Influenced Coastal Environments. b: Mangroves lining the shore of Boca de Guanipa in the Marine Influenced Distributary Channel and Island Complexes. c: Marsh in the Fluvial/Marine Transitional Environments. d: Forested tidal influenced splay in the Distributary Channel Systems. e: Topographically high marsh in the Interdistributary Flood Basins.

The mangrove-covered coastal facies, along the seaward margin of the map area, is characterized by muddy substrates, where three species of red mangroves (*Rhizophora* spp.; Valois González, personal communication, 1998), as well as black mangroves (*Avicennia germinans*) and white mangroves (*Laguncularia racemosa*), are dominant. The mangrove community typically grades landward into a fresher water assemblage of forested or herbaceous areas characterized by thick organic deposits or raised peats. A good example of the swamp assemblage is located between Caño Macareo and Isla Cocuina (Figures 1 and 2).

Typical forest species include *Symphonia globulifera*, *Tabebuia insignis* var. *monophylla*, *Euterpe* sp. and *Virola surinamensis* (Geohidra Consultores, 1997a, b; Valois González, personal communication, 1998).

Marshes form a broad coast-parallel belt between Isla Cocuina and Capure. This area was mapped as permanently inundated open savanna by Canales (1985). These areas of herbaceous vegetation are permanently flooded and are sites of standing water that produce dark signatures on the Landsat imagery. These environments were delineated separately as topographically low marshes to define areas of prolonged and deep inundation. Such sites may indicate higher rates of subsidence and could eventually become coastal lagoons and open water.

Thick peat deposits (to >5m) characterize marsh substrates. Vegetation includes *Lagenocarpus guianensis*, *Blechnum serrulatum* and *Rhynchospora gigantea*. Scattered trees include *Mauritia flexuosa* and *T. insignis* var. *monophylla* (Geohidra Consultores, 1997a, b; Valois González, personal communication, 1998). In some areas, such as east of Capure, herbaceous species include *Eleocharis* spp., *Typha domingensis* and *Cyperus articulatus,* among others.

Small areas within these marshes are periodically burned during the dry season, producing complex patterns on the imagery as a result of plant succession. These burned areas consist of herbaceous vegetation with varying concentrations of shrubs and trees that are rather difficult and meaningless to map separately because of their gradational and ephemeral nature. Where herbaceous vegetation is dominant, these areas were mapped as marsh. However, in some areas, complex configurations of herbaceous and forested vegetation were mapped together as mixed marsh and swamp. These areas generally coincide with areas mapped by Canales (1985) as savanna with trees and shrubs. Substrates are primarily peat in these permanently flooded environments (Figure 4). Predominant vegetation is similar to that listed earlier for forested and herbaceous communities.

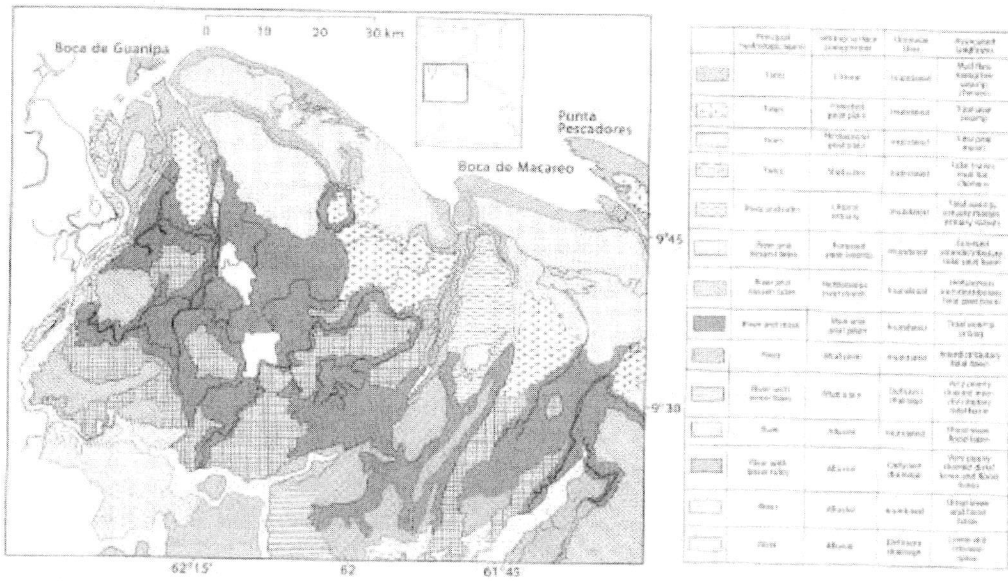

Figure 4. Geomorphology of the northwest Orinoco Delta plain. Modified from CVG-TECMIN, C.A. (1991a-f).

Marine-influenced distributary-channel and island complexes

The marine-influenced distributary-channel and island complex is defined in large part by mangroves that are the dominant vegetation on the islands and along the lower reaches of the caños (Figure 3b). This complex has its broadest distribution near the mouths of Caño Manamo and Caño Pedernales, where Isla Manamo is the largest in a series of islands that have formed in Boca de Guanipa Estuary (Figure 1). In more inland areas, the influence of salt and brackish water declines, as does the abundance of mangroves. At Isla Tigre, ~45km upstream from the mouth of Caño Pedernales along Caño Manamo, mangroves cover the seaward tip of the island but upstream intergrade with and are replaced by other types of forest vegetation. Other major occurrences of this mangrove-dominated system are along Caño Pedernales, Caño Cocuina and Caño Capure, where significant stands of mangroves extend upstream along the channels ~45 to 50km from the marine shoreline. Narrow stands of mangroves, too narrow to show on the map, occur along channels much farther upstream than indicated on Figure 2 (Colonnello and Medina, 1998).

Marshes that are part of this system are located principally in the central part of Isla Manamo. On the basis of image interpretation and field surveys, water regimes appear to range from semipermanently to seasonally flooded. Substrates are predominantly clay and silt, with organics increasing away from the channels. The predominantly clastic, or mineral, composition of substrates is in general agreement with soils mapped by CVG-TECMIN (1991a through f), and reflects the fluvial influence in this environment (Figure 4).

Mangroves in this system include *Rhizophora* spp., *A. germinans*, *L. racemosa*. Dominant species in forested swamps generally include *M. flexuosa*, *S. globulifera*, *Pterocarpus officinalis*, *Tabebuia* spp., *Euterpe* spp., *V. surinamensis*, *Ficus* spp., *Machaerium lunatum*, *Manicaria saccifera*, *Bactris* spp. and *Clusia* sp., among others. Scattered mangroves occur in many areas. This forested community is similar to the mixed swamp forest and palm swamp of Muller (1959).

Marsh vegetation consists of species similar to those listed in the preceding section of marine-influenced coastal environments, including *L. guianensis*, *B. serrulatum* and *Rhynchospora gigantea*, with local occurrences of *Montrichardia arborescens*, *M. flexuosa* and *T. insignis* var. *monophylla*.

Fluvial/marine transitional environments

Fluvial/marine transitional environments are generally located in a coast-parallel zone landward of the marine coastal environments. Although mapped areas include relict marine features, these environments are influenced by a combination of fluvial and marine processes (Figure 4). The most important environments are marshes with thick peat substrates, possibly peat mounds, that appear to be topographically higher than adjacent areas but nevertheless are permanently flooded. The most extensive marsh in this system (~200km2) occurs east of Caño Pedernales (Figure 2). This area was mapped as permanently inundated open savanna by Canales (1985). It is part of a chain of marshes that extends to the southeast parallel to the modern coast. In some areas along this trend, mixed marshes and swamps were mapped.

Typical vegetation in these marshes, as in those of the marine-influenced marshes, includes *L. guianensis*, *B. serrulatum* and *R. gigantean* (Figure 3c). Mixtures of forest vegetation include *M. flexuosa*, *T. insignis* var. *monophylla*, *S. globulifera*, *P. officinalis*, *Euterpe* spp., *V. surinamensis*, *Ficus* spp., *M. lunatum*, *M. saccifera* and *Bactris* spp., among others.

Distributary-channel systems

The distributary-channel systems consist principally of channels, channel banks, levees and crevasse splays but also includes abandoned channels, tidal creeks and forested levee-flank environments. In many areas, the levee map unit is broad and includes adjacent forested belts that are significantly affected by overbank flooding and sedimentation. Among the more prominent levees and tidally induced splays are those along and between Caños Manamo, Pedernales and Macareo. The flood basin between these caños has been partially filled by tidal splays, the most seaward of which is marine influenced and has numerous bifurcating tidal channels that are lined with mangroves (Figures 2 and 3d). In the eastern portion of the map area, numerous smaller channels with narrow levees and adjacent forest zones are considered to be part of the distributary-channel complex.

Substrates appear to be predominantly mud and muddy sand or sandy mud, with increasing amounts of organics toward the flood basins. In general, mapped levees and crevasse and tidal splays coincide with mineral soils delineated by CVG-TECMIN (1991a through f).

The distributary-channel systems vary from the lower to middle to upper delta plain. On the upper delta plain, levees have higher relief and are less frequently flooded as compared with the middle and lower delta. Vegetation communities on upper-delta-plain levees are similar to that of the rain forest described by Muller (1959) and semideciduous forest of La Salle (1996). Species include *Ceiba pentandra*, *Ficus* spp., *Spondias mombin*, *Inga* spp., *Erythrina* spp., *Vismia macrophylla*, *Cecropia peltata*, *T. insignis* var. *monophylla*, *Sapium* sp., *Macrolobium bifolium* and *Gynerium sagittatum*, with increasing abundance of species such as *P. officinalis* and *M. flexuosa* on lower delta levees. Along channels in the middle and lower delta *Rhizophora* spp. and *M. lunatum* are common.

In the southwest corner of the map area, near Caño Manamo, are several tidal crevasse splays that are vegetated primarily by *M. flexuosa* (moriche palm). These areas were classified and mapped separately as tidal creek/crevasse splays (Figure 2). The adjacent flood basins have been cleared for agricultural purposes, which accentuates the moriche palms along the channels. These features were mapped by Canales (1985) as seasonally flooded dense forest of medium height. Substrates are predominantly mud and sandy mud deposited primarily by Caño Manamo.

Interdistributary flood basins

The interdistributary-basin system is the most extensive system in the map area (Figure 2). Mapped environments include three topographically varying swamps, two marshes, and a mixed marsh and swamp class (Table I). Topographically-high, -intermediate and -low swamps were delineated on the basis of variations in imagery reflectance, which are influenced by relative heights of the land surface (topographic setting), flood regime and associated vegetation. Topographically-low swamps appear to be permanently flooded, intermediate swamps permanently to semipermanently flooded, and high swamps semipermanently to seasonally flooded. Low and intermediate swamps have their broadest distribution 1) in flood basins between Caño Manamo and Caño Pedernales, 2) in the area immediately east of Caños Pedernales and Cocuina, and 3) in the lower delta near the marine-influenced environments. High swamps are more widely distributed in the central part of the map area from Caño Pedernales eastward toward Caño Macareo.

Differentiation of topographically high and low marshes in flood basins was based primarily on interpreted hydrologic regimes, or duration of flooding, as indicated on the imagery. The most extensive marshes occur in the southwest portion of the map area, where higher elevations associated with the upper delta plain are apparently better suited for agricultural purposes (Figure 3e). Much of this area, which was probably forested in the past, has been cleared and is periodically burned to establish and maintain herbaceous vegetation for grazing.

Substrates are predominantly mud on the upper delta plain with increasing amounts of organics and peats toward the centers of basins (Figure 4). Substrates are predominantly peat and organics in the middle and lower delta plain, where they can be several meters thick. Low swamps immediately east of Caño Manamo near Isla Tigre (Figure 2) were mapped by Danielo (1976) as peat-flat with dense morichal (palms) and by Canales (1985) as permanently inundated dense, low forests and dense palm forests with organic soils. As mapped by CVG-TECMIN

(1991a through f), topographically low and intermediate flood basins roughly coincide with organic soils, and high flood basins with mineral soils.

Forested vegetation in the flood basins includes *M. flexuosa, M. saccifera, Euterpe oleracea, T. insignis* var. *monophylla, Erythrina glauca, P. officinalis, Bactris* spp., *S. globulifera, M. arborescens* and others. Herbaceous vegetation includes *R. gigantea, Thalia* sp., *Ludwigia* spp., *C. articulatus, Cyperus* spp., *Eleocharis* spp., *Nymphoides indica, Paspalum repens, Paspalum* sp., *Andropogon* sp., *Hydrocotyle umbellata, Gynerium sagittatum* and others, with local occurrences of *M. arborescens* and *M. flexuosa*.

Conclusions

Geo-environmental maps provide an environmental inventory of land and water resources of the northwestern part of the delta that incorporates active processes and physical attributes with characteristic vegetation. They establish baseline information to document change and provide a framework for formulating more specific scientific studies, including geomorphology, substrate lithology, hydrology, active processes, and vegetation. In addition, the geo-environmental analysis establishes preliminary map units for analysis of land and water resources in other parts of the delta.

The Orinoco Delta is a dynamic and complex system characterized by relatively rapid geologic and physical changes, which produce modifications in related ecosystems. Dynamic systems are particularly vulnerable to human activities, which can result in degradation of delta ecosystems. Geo-environmental maps in a GIS format help to define and delineate natural resources and thereby assist in the prudent and sustainable management and use of delta environments.

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Calle Vera Cruz, Residencia La Hacienda Apto. 31-M
Las Mercedes, Caracas 1080. Venezuela
Telefonos: (58-0212) 992-32-24, 991-75-25

eMail

interciencia@ivic.ve