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Palynological research in the Caribbean Islands and Central America: An overview

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ABSTRACT

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There is rich literature on palynological research in the Caribbean Islands and the adjoining regions of Central America. However, these papers were published in a variety of diverse journals originating from several countries mainly in the Americas, Europe, and a few from the Caribbean countries as well. An overview of the palynological research in the Caribbean and the adjoining regions provides information on the diverse application of palynology in the Earth and Environmental Sciences. This study also provides a survey of significant papers useful to researchers in this field of science interested in initiating a research project in this region. However, some aspects of palynology such as Melissopalynology (study of pollen and spores in honey), Forensic Palynology (study of palynomorphs in Criminology), Entomopalynology (pollen studies in the body of insects) and study of pollen allergens have not yet been addressed in this region.

Keywords: Archaeology, Palynology, Non-pollen palynomorphs (NPP); Caribbean Islands; Central America

INTRODUCTION

Palynological literature in the Caribbean and the adjoining regions (Figure 1) is generally scattered since most published work appeared in local and few in the international journals. Mostly the local journals are not widely known outside the country of their publication; thus, they have become obscure for the international audience. The objective of this paper is to present an overview of palynological research in this region and evaluate what has been done and what needs to be done in the future. This paper provides a literature base for anyone interested in initiating a palynological research project in this region. It also demonstrates that palynological literature in this region published during the past six decades is quite rich and shows a diverse application of palynology in wide ranging research in the fields, such as, archaeology, biological sciences (vegetation and floral history), climate and palaeoclimate, earth and environmental sciences, forestry, limnology and palaeolimnology, oceanography and palaeoceanographic, and exploration of sedimentary basins for hydrocarbon resources etc.

The Caribbean Sea region comprises of many small and large tropical islands. The adjoining regions of Central and South America share a large coastline with the Caribbean Sea. Thus, it provides a long coastal zone comprising of terrestrial and marine biomes such as evergreen and deciduous forests, scrublands and savannas, mangroves, salt marshes, estuaries, coral reefs, sea grasses, and other coastal shelf communities.

Such coastal biomes record impacts of climate, environmental and anthropogenic changes at a range of time scales (G'meiner 2016). It is well documented that palynological studies play a significant role in inferring such changes as has been demonstrated by several published papers briefly discussed later in this paper.

Fossil pollen has been of great utility for reconstructing past vegetation community changes and the mechanisms driving them such as climate, sea level variability, and anthropogenic activities etc. Pollen of entomophilous and anemophilous plants are well represented in the Neotropical sediments. This region has a remarkably high plant diversity, but their pollen types are not well documented. There are very few pollen keys, for example, in Central America (Colinvaux et al. 1999a, b) and the Bahamas (Snyder et al. 2007). In addition to pollen and spores, non-pollen palynomorphs (NPP) such as dinoflagellate cysts, acritarchs, fungal and algal remains and a variety of palynomorphs of animal affinities have been studied both from fossil and recent sediments. Types and richness of organic matter and their thermal maturation, palynofacies along with sequence stratigraphy have been used for hydrocarbon exploration in this region. Microscopic remains of charcoal and phytoliths have been reported from this region as well.

The Greater Antilles of the Caribbean region were first settled around 6000 calyr BP by small populations of hunter-gatherers, and later migrations of people, who were horticulturalists, impacted the vegetation that is detectable in the palaeoecological record. One line of evidence for the detection of prehistoric people is the presence of maize (*Zea mays*) pollen, which is an indicator of settlement and agriculture. Maize pollen are of large size, thus easily identifiable, and they do not travel far from their source. Between 1350 and 1700 CE, *Zea mays* pollen occurred in Lake Miragoâne, that indicates the presence of Taino agriculture in the area, and low pollen concentrations and carbonate-rich sediments since 1950 CE documented severe deforestation (G'meiner 2016).

PALYNOLOGICAL RESEARCH IN THE CARIBBEAN ISLANDS AND CENTRAL AMERICA

During the past six decades extensive palynological research has been published from different parts of the Caribbean Islands and the surrounding regions of Central America. This overview does not consider palynological studies on the extant flora of the region; instead, it concentrates only on the palynological research on the recent and fossil sediments. Morphological and taxonomic studies of fossil pollen and spores have described many new taxa from this region. Palynological studies of late Quaternary marine, brackish-water coastal and terrestrial sediments, such as from mountains, lakes, bogs, and other wetlands have provided significant information about environmental and climatic changes, vegetation and floral history of this widespread region that have been useful to archeological studies.

Various palynomorph groups including non-pollen palynomorphs (NPP) have been used as proxies for palaeoenvironmental, palaeoecological and biostratigraphic studies with an emphasis on hydrocarbon exploration. Additionally, palynology has been used as a tool for oceanographic, palaeoceanographic and palaeoproductivity of phytoplankton studies. There are few publications on source rock palynology and geochemistry identifying stratigraphic units with the potential for hydrocarbon generation.

Professor Alan Graham and his associates from the Missouri Botanical Garden, USA, carried out extensive palaeobotanical and palynological research on the late Cretaceous-Cenozoic sediments of the Caribbean Islands and Central America for almost four decades. Their pioneering contribution to the geological history of this region, Cenozoic floristic evolution, pollen and spore floras, climate and environmental changes of this vast region has been synthesized in Graham (2010, 2011) that laid the foundation for future research. Graham (1995) stated that the mangrove community of the Neotropics shows a progressive increase in diversity through the Cenozoic. During the early Eocene ~50 Ma ago brackish-water coastal areas were occupied by four main genera-*Acrostichum*, the extinct *Brevitricolpites variabilis*, *Nypa* and *Pelliciera*. Genus *Avicennia* was first reported in the late Miocene ~10 Ma ago. Extinctions and introductions of new pollen taxa, and adaptations varied the composition and increased the net diversity to six mangroves and three associated genera by the middle Pliocene (~3.5 Ma ago); they are, *Acrostichum, Avicennia, Crenea, Laguncularia, Pelliciera, Rhizophora, Acacia, Hampea/Hibiscus*, and *Pachira*.

The present overview describes the palynological research and its significance published from different countries arranged alphabetically in this region. Figure 1 shows locations of the countries bordering the Caribbean Sea in Central and South America, large island countries of the Greater Antilles and smaller islands of the Lesser Antilles. Names of the smaller island countries is not shown in the figure except for Barbados and Trinidad and Tobago. This overview primarily discusses publications in order of their year of publication and does not claim that every published paper from this region has been included in this overview.

Bahamas

Traverse and Ginsburg (1966) studied palynology of the surface sediments of the Great Bahama Bank with reference to sedimentation patterns. Fossil pollen and other maceration-resistant microfossils are present in fair abundance in the Bahama surface sediments. Their distribution patterns were interpreted to various environmental factors operating in the Bahama Platform.

Figure 1. The Caribbean Sea and the surrounding regions of Central America showing the locations of various countries of Central and South America, large islands of the Greater Antilles towards north and smaller islands of the Lesser Antilles towards east. Smaller islands of the Lesser Antilles are not named except for Barbados and Trinidad and Tobago. Location of ODP Site 999 is in the southwestern part of the sea. (JA: Jamaica; DR: Dominican Republic; PR: Puerto Rico; BE: Belize; ES: El Salvador; CR: Costa Rica; BA: Barbados; TT: Trinidad and Tobago). Base map downloaded in July 2022 and labels added. https://en.wikipedia.org/wiki/Caribbean_Sea#/media/File:La2-demis-caribbean.png

Microforaminiferal lines are calcareous remnants of benthic foraminifers, hence they are deposited mostly in situ rather than being swept about freely on the Bank.

A dry period was recorded from 3200 to 1500 calyr BP at Church's Blue Hole on Andros Island, as evident by the presence of *Dodonaea, Piscidia*, and *Xylosma* pollen. These are shrubs tolerant to dry conditions. This was followed by a moist mesic climate from ~1500–740 calyr BP. A significant increase in the percentage of *Pinus caribaea* pollen occurred at about 900 calyr BP. (Kjellmark 1996).

Head and Westphal (1999) recovered abundant and generally well-preserved dinoflagellate cysts from the Pliocene sediments of the Bahamas. A total of 30 taxa were recorded and nearly all were neritic. These assemblages were related to sea-level changes.

Cremer et al. (2007) documented diatoms (*Bacillariophyceae*) and dinoflagellate cysts (*Dinophyceae*) from the sediment core and water samples from the Rookery Bay, Florida, U.S.A. It is a subtropical estuary from which 88 diatom taxa belonging to 48 genera were recorded. Additionally, 20 dinoflagellate cyst species belonging to 14 genera were identified as well. This paper is included here because Rookery Bay, Florida, is in geographical proximity to the Bahamas.

Steadman et al. (2007) reported Quaternary vertebrate fossils and plant fossils including palynomorphs from the Sawmill Sink (a water-filled sinkhole) on Great Abaco Island, in the Bahamas. The fossils were well preserved because of their deposition in an anoxic saltwater environment. The fossils suggest a grassy pineland as the dominant plant community on Abaco Island during the Late Pleistocene, with a heavier component of coppice (tropical dry evergreen forest) in the Late Holocene.

On Abaco Island, a shift to pine-domination was recorded at ~1000 calyr BP, suggesting a regionally dry climate. From 1150–1350 CE increased charcoal and pine pollen is interpreted to represent the arrival and settlement of the Lucayan Tainos on Abaco Island (Slayton 2010).

Verhoeven et al. (2014) carried out a biostratigraphic study of Oligocene and Miocene sediments of the Bahamas using dinoflagellate cysts. *Leiosphaeridia spongiosa* was described from the upper Oligocene and Miocene deposits of the Bahamas.

Barron (2015) studied core samples from Deep Sea Drilling Project (DSDP) Site 98 in the Bahamian Platform for their palynological contents (pollen, spores, acritarchs, dinoflagellate cysts, and dispersed organic matter) and inferred palaeoenvironmental and palaeoceanographic history for the middle Eocene to middle Miocene interval. The samples yielded low diversity palynomorph assemblages in which terrestrially derived palynomorphs were rare. The dominance of dinoflagellate cysts and amorphous organic matter indicated deposition in the marine environments.

Barbados

Palaeoenvironmental records from Barbados suggest that mangrove formation began around 6000 calyr BP when the rate of post-glacial sea-level rise slowed (Ramcharan 2005).

Belize

Jones (1994) analyzed fossil pollen from the Maya site of Colha, Belize. It revealed a complex history of human caused forest and land modifications; for example, forest clearing, an irrigation canal and raised field construction, and prehistoric domesticated plant use. This study demonstrated the use of pollen analysis in archaeological research and provided a wealth of data unavailable through any other means.

Palaeoenvironmental records show lower sea levels at about 7000 calyr BP (Ramcharan 2004; Ramcharan and McAndrews 2006; Monacci et al. 2009), indicated by the establishment of mangroves. The presence of *Rhizophora* pollen coupled with mangrove peat indicates changes in relative sea levels since *Rhizophora* occupies the upper half of the intertidal zone (Ramcharan 2004; Ramcharan and McAndrews 2006).

Morse (2009) studied palynology of the Mayan archaeological site at Blue Creek, northwestern Belize covering more than 4,500 years of environmental and agricultural history of the region, related to human incursion, habitation and plant use, abandonment, and reoccupation of the region. This led to an assessment of the possibility of drought or soil degradation during the height of Mayan civilization and contributes to the current understanding of the Maya collapse at the Blue Creek.

Bhattacharya et al. (2011) used pollen spectra to reliably distinguish modern ecosystem types in the Maya Lowlands of Central America. They studied 23 soil and sediment samples from eight ecosystem types, including upland, riparian, secondary, and swamp (bajo) forests; pine savanna; and three distinct wetland communities, and analyzed their pollen spectra. They found significant compositional differences in various ecosystem types of pollen spectra demonstrating that pollen assemblages can accurately reflect the differences between ecosystem types.

Monacci et al. (2011) studied a sediment core (SR–63) from a mangrove ecosystem along the Sibun River in Belize, to define changes in the sea-level and characteristics of the river's drainage basin. Changes in the sedimentation rates observed in mangrove ecosystems offshore is related to the rate of sea-level rise. Pollen analyses show a decreased abundance of *Rhizophora* (red mangrove) pollen and an increased abundance of *Avicennia* (black mangrove) pollen and non-mangrove pollen contemporaneous with the decreased sedimentation rates. The decrease in the sedimentation rate supports the idea that regional changes in hydrology occurred during the Holocene in Belize, influencing both mainland and offshore mangrove ecosystems.

Rushton et al. (2012) studied palynology of a 3 m long core from the New River Lagoon, adjacent to the Maya city of Lamanai, Northern Belize showing a continuous record of vegetation change between ca.1500 BC and 1500 AD. The study demonstrated that during the late Classic period the Maya people managed the vegetation resources using a combination of field-based agriculture, arboreal resources, and palm cultivation.

Larmon (2016) studied a 60 m deep karstic sinkhole in an Ancient Maya Water Temple. Cara Blanca Pool 1 is one of 25 pools (sinkholes and lakes) in the Cara Blanca region. This study presents the preliminary palynological analysis of a sediment core extracted from Pool 1. Fossil pollen was extracted from the Pool 1 sediments to interpret environmental reconstruction. The assemblages were compared to a nearby Pool 6's sediment assemblages. This study provides an environmental history of Central Belize.

According to Pohl et al. (2017) palynological studies in northern Belize provide the earliest evidence for the development of agriculture in the Maya Lowlands. Pollen analysis shows introduction of maize and manioc before 3000 BC, deforestation beginning ca. 2500 BC, and intensification in wetland environments ca.1500–1300 BC marks an expansion of agriculture. By 1000 BC a rise in groundwater level led farmers to construct drainage ditches coeval with the emergence of Mayan complex society ca. 1000–400 BC.

Colombia: The Caribbean coastal region

During the past few decades, many palynological studies describing fossil palynomorph assemblages and their biostratigraphic and palaeoecological significance were published from Colombia. These papers were written primarily in English but few in Spanish as well. Here I include only the most significant recent papers from the Caribbean Sea coastal and adjoining regions of Colombia.

Palynological signals of land clearance and deforestation due to human settlement is evident from a decrease in tree pollen and an increase in invasive species and/or herbaceous species, such as *Ambrosia*. Some examples are the San Andres Island (Colombia) palynological record, that shows a marked decrease in mangrove pollen around the time of the establishment of large coconut plantations on the island (González et al. 2010).

Urrego et al. (2010) studied pollen spectra in mangrove surface sediments from the Caribbean Island of San Andrés, Colombia. They found that mangroves dominated the spectra in surface sediments. Tree basal area of true mangrove taxa correlated highly to their pollen percentages. As expected non mangrove taxa were poorly represented in the pollen spectra. True mangrove pollen taxa reflect the environment and disturbances of these forests.

Boonstra et al. (2015) studied dinoflagellate cysts and calcareous foraminifera from the Miocene sediments of northwestern Amazonia to estimate salinity ranges, palaeoenvironments and palaeogeography. They studied samples from Peru, Colombia, and the coastal regions of the Caribbean coast. The study concluded that during the early and middle Miocene marginal marine conditions reached at least 2000 km inland from the present Caribbean Sea coast. Global high sea-levels and fast subsidence in the sub-Andean zone were the controlling mechanism of this marine incursion.

Jaramillo et al. (2020) analyzed pollen-spore floras from the Neogene sediments of the Guajira Peninsula in northern Colombia with the objective to understand the origins of the modern biome of this peninsula. They also analyzed the pollen and spore assemblages of 10 Holocene samples to establish a modern baseline. They concluded that the early Miocene vegetation was dominated by a rainforest biome with a mean annual precipitation of ~2,000 mm/yr which strongly contrasts with Guajira's modern xerophytic vegetation and a precipitation of ~300 mm/yr. They found that the shift to the dry modern vegetation probably occurred over the past three million years, but the mechanism that led to this change is still uncertain.

Cárdenas et al. (2020) studied Miocene marine palynomorph assemblages (dinoflagellate cysts, acritarchs, foraminiferal test linings and prasinophytes) from 40 samples from a well drilled in northernmost Colombia, southern Caribbean Sea. They proposed a biostratigraphic scheme based on dinoflagellate cysts and acritarch events and demonstrated a palaeoproductivity shift from nutrient-rich shallow waters from Aquitanian peridinioid-dominated assemblages to nutrient-poor shallow waters Burdigalian gonyaulacoid-dominated assemblages.

Cárdenas et al. (2021) described two new dinocyst species and one actitarch species from upper Oligocene–lower Miocene (upper Chattian–upper Burdigalian; ~ 24–17/ Ma) shallow-marine succession drilled in northern Colombia. They are peridinioid cyst *Cristadinium lucyae* and *Trinovantedinium uitpensis* and an acritarch *Quadrina? triangulata*.

Cárdenas (2021) described Neogene dinoflagellate cysts and acritarchs from Southern Caribbean Sea region. The assemblage constituted proxies for biostratigraphic and palaeoceanographic studies in neritic sequences. He proposed a biostratigraphic scheme for the region that is the upper Chattian-lower Aquitanian *Minisphaeridium latirictum* Interval Zone (~23.9–22.0 Ma), the upper Aquitanian *Achomosphaera alcicornu* Interval Zone (~22.0–20.3 Ma), and the Burdigalian *Cribroperidinium tenuitabulatum* Interval Zone (~20.3–17.5 Ma).

Costa Rica

According to Graham (1992) plant microfossil assemblages from Costa Rica, Panama and northern South America reveal differences that extend into late Cenozoic time. He concludes that the isthmian land bridge was utilized by plants from North and South America, until post-middle Pliocene times. The main migrating plants were living in lowlands with effective means of dispersal across at least moderate marine barriers.

Hooghiemstra et al. (1992) established two pollen records from La Chonta Bog (2310 m altitude) and one pollen record of a soil profile (2430 m altitude) and reconstructed the vegetational history and climatic sequence of the last ca. 80,000 yr of the Cordillera de Talamanca, Costa Rica, using radiocarbon dates and palynostratigraphy.

Islebe et al. (1996) studied pollen records of Holocene sediment cores from the Costa Rican Cordillera de Talamanca to demonstrate the postglacial development of the montane oak forest zone from ca. 9500 to 1500 yr BP. In comparison to modern environments, the early Holocene had similar average temperatures, but the moisture level was probably higher. Pollen evidence for the late Holocene indicates drier environmental conditions in comparison to today.

Graham and Dilcher (1998) described an assemblage of pollen and spores from the Rio Banano Formation (Pliocene) of southeastern Costa Rica and divided it into two palaeo-communities: mangroves and the lowland tropical rain forest. This data is consistent with those of other Miocene and Pliocene palynofloras from northern Latin America.

Kennedy (2001) reported pollen evidence of maize cultivation in Costa Rica much earlier than previously known. Pollen grains of maize (*Zea mays* subsp. *mays*) preserved in sediments from the Cantarrana Swamp indicate that maize cultivation occurred between 700 yr and 300 yr BP thus extended the record of human occupancy in the region.

Lane et al. (2004) found close correspondence between stable carbon isotope ratios (δ13 C), pollen, and charcoal profiles in sediment cores from Laguna Zoncho and Machita Swamp, Costa Rica. The study demonstrated that prehistoric forest clearance and crop cultivation can be detected in the stable carbon isotope ratios of total organic carbon (δ13C TOC). Stable carbon isotope analyses are particularly useful in situations where other evidence of forest clearance and agriculture are limited.

Medeanic et al. (2008) studied organic walled non-pollen palynomorphs (NPP) from thirteen surface sediment samples from the mangroves in the southern part of Costa Rica. NPP were represented by dinoflagellate cysts, algal palynomorphs of *Chlorophyta*, cyanobacteria, fungal spores, and hyphae, microforaminifers, scolecodonts and phytoliths. The result showed that the frequencies of *Botryococcus* and microforaminifers changed depending on the salinity of environments related to marine influence. Chlamydospores of the fungus *Glomus* are related to erosive processes. Cyanobacteria of the *Rivularia*-type may be connected to an increase in eutrophication by organic phosphates within an estuary. The pollen of *Rhizophora*, *Lagencularia*, *Avicennia*, *Poaceae*, *Cyperaceae*, and spores of various mangrove vegetation ferns co-occur in the assemblages.

Johanson et al. (2019) presented a 4200–year record from the lake-sediment of pre-Columbian agriculture and fire history from the lowlands of the southern Pacific Costa Rica. It was the first microfossil and geochemical evidence of vegetation and fire prior to the establishment of maize agriculture. They suggested that agricultural proxies indicated reduced watershed activity during the 'Little Ice Age' following Spanish contact in southern Central America until the 20th century.

Cuba

Graham et al. (2000) described an assemblage of fossil pollen and spores from the middle Eocene Saramaguacàn Formation in eastern Cuba. Many forms represented unidentified or extinct taxa, but several could be identified to the family *Arecaceae*, *Bombacaceae*, *Poaceae*, *Moraceae*, and *Myrtaceae*. They interpreted palaeoclimate to be warm-temperate to subtropical which was consistent with other floras in the region of comparable age and with the global palaeotemperature curve.

In north-central Cuba, expansion of mangroves was documented at around ~1700 calyr BP (Peros et al. 2007). The published pollen records for Cuba are mainly the middle and late Holocene, that have low temporal and taxonomic resolution and may have age dating problems. Peros et al. (2015) carried out a multi-proxy palaeoenvironmental study to investigate the lagoon response to sea-level and climate change and changes in the frequency of past hurricane strikes. They studied a sediment core from a lagoon in southeastern Cuba using proxy data from benthic foraminifera, fossil pollen, particle size analysis, and macrocharcoal influx values. The results showed that the lagoon formation began approximately 4000 years ago, and the lagoon environment evolved through four phases. The study demonstrated that coastal lagoons are useful archives of palaeoclimatic and palaeoenvironmental information in the Caribbean region.

G'meiner (2016) studied a coastal sinkhole (cenote) and developed a continuous ~9000 year-long fossil record from Cayo Coco, northern Cuba, by analyzing fossil pollen, microcharcoal, and dinoflagellate cysts from a sediment core extracted from Cenote Jennifer. The study interpreted vegetation changes on Cayo Coco during the Holocene, and addressed how sea level changes, climate changes and human impacts have caused changes in vegetation.

Dominican Republic

Kennedy et al. (2005) studied pollen, spores, and pine stomata in surface pond and bog sediments and surface soils to characterize modern pollen deposition in highland (elevations between 1200–3000 m) plant communities of the Cordillera Central, Dominican Republic. The results revealed that the modern pollen spectra of forested uplands and open wetland sites are clearly distinct, while the intermediate sites in terms of vegetation are intermediate in terms of modern pollen spectra as well.

Lane et al. (2008) reported the earliest evidence of maize pollen on the island of Hispaniola at 1060 CE from Taino agriculture. They (Lane et al. 2009) further studied two lakes on the Cordillera Central, Dominican Republic, and produced evidence of a dry period which could have been due to a shift in the position of the Intertropical Convergence Zone (ITCZ), resulting in decreased moisture in the region. A drought was recorded around ~1210 calyr BP, inferred from a decline in pollen from arboreal taxa and an increase in herbaceous pollen, indicating a period of aridity.

Caffery and Horn (2014) examined sedimentary charcoal records from lake Laguna Saladilla in the Dominican Republic. These records were based on charcoal fragments observed from pollen slides that cover the last 7,000 or more years of the Holocene and compared charcoal influx values to archeological and palynological evidence of human activity. The results showed intervals of synchronous, climate-driven burning are distinct from more localized anthropogenic burning.

Rhizophora pollen was noted in a core from Laguna Saladilla, Dominican Republic, at around ~8030 calyr BP, although it is unclear whether the mangrove was growing near the site or elsewhere in the region (Caffrey et al. 2015).

Guatemala

Graham (1998) reported on Late Tertiary vegetation and environments of southeastern Guatemala by studying palynofloras from the Mio-Pliocene Padre Miguel Group and the Pliocene Herrería Formation. The Padre Miguel flora reveals the presence of northern cool temperate elements. The younger Herrería flora is more lowland and warmer temperate. The data provided evidence for the present tropical rain forest to be of recent origin that has undergone considerable change in its range and composition throughout the late Cenozoic.

Mueller et al. (2008) used palynology as a tool to show causes of forest disappearance during the late Holocene in the tropical Maya lowlands of northern Guatemala. They studied multiple palaeoclimate and palaeoenvironmental proxies from sediment cores collected in the Lake Petén Itzá, northern Guatemala, and concluded that vegetation changes in Petén during the period from ~4500 to ~3000 calyr BP were largely a consequence of dry climatic conditions.

Teste et al. (2020) studied phytoliths of Naachtun (Petén, Guatemala) as palaeoenvironmental proxies and characterized plant communities in the Mayan tropical lowlands. They described six plant communities in the Petén and identified ecosystems through phytolith assemblages.

Haiti

Brenner and Binford (1988) examined fluctuations in arboreal pollen, weed types, and erosion in the sediment cores from Lake Miragoâne in Haiti. The study provided evidence of a "temporary reestablishment of local forests and reduction of soil loss" that correlated with land-use changes at the beginning of the nineteenth century. After Haitian independence in 1804, large plantations were abandoned as people moved out to establish smaller agricultural settlements at higher elevations. This transformation correlated with changes in pollen levels reflect an arboreal expansion during this historical period.

According to Higuera-Gundy et al. (1999) stable isotope ($\delta^{18}O$) study of a 7.6 m core from Lake Miragoâne, Haiti, a high-resolution record of changing evaporation/precipitation (E/P) since ~10300 ^{14}C yr BP was provided and the corresponding pollen record documented climate influences and human impacts on vegetation in Hispaniola. A long-term, Holocene vegetation trend in southern Haiti was comparable to the trends from continental, lowland circum-Caribbean sites, suggesting a common response to regional climate change.

Caffery and Horn (2014) examined sedimentary charcoal records from Lake Miragoâne in Haiti. These records covered the last 7,000 or more years of the Holocene. The charcoal influx values were compared to the archeological and palynological evidence of human activity. The results showed that intervals of synchronous, climate-driven burning are distinct from more localized anthropogenic burning.

Holocene palaeoenvironmental studies have been a major part of Quaternary Palynology in this area. One of the longest palaeoenvironmental record (11960 calyr BP to the present) from the Caribbean region is a sediment core (7.67 m) from Lake Miragoâne in Haiti which is a large natural freshwater lake. From 11960–9500 calyr BP, the pollen record is dominated by shrub and tree pollen, including an abundance of *Podocarpus*, an evergreen tree common to montane forests. From 9500–6500 calyr BP, an increase in *Amaranthaceae* pollen and a decline in shrub pollen, suggests an open landscape. Between ~8200 to 4200 calyr BP, the palaeoenvironmental record indicated that the lake levels were at their highest between 8200 and 6400 calyr BP, and the establishment of forests was inferred from an increase in tree pollen percentages. From 6500 to 4250 calyr BP, tree pollen from *Trema* and *Cecropia* dominated at Lake Miragoâne. Both taxa are common in upland and lowland moist forests. Also present were *Ambrosia* and *Pinus* during this time. From 4250 to 3050 calyr BP a wet period is identified by high percentages of *Moraceae* and other moist forest taxa. By 750 calyr BP, drier conditions returned, and early agriculturists had colonized the area around this lake in Haiti. Between 1350 to 1700 CE, dry forest tree species were dominant around Lake Miragoâne, and an increase in *Poaceae* pollen indicated potential human activity. An increase in *Cladium* and *Typha* suggests a marsh expansion around this lake. From 1700 CE to present, the pollen record indicated that deforestation occurred, represented by an increase in pioneer and successional taxa (*Celtis, Cecropia*) and dry-adapted *Bursera* and *Sapindus* trees. The decline in forest pollen around 1700 CE indicates land clearance. However, pollen concentration and organic matter increased between 1850 and 1950 CE, reflecting forest recovery (G'meiner 2016).

Jamaica

Kumar (1985) used visual kerogen studies and palynology as a tool to show that the Hanover Shale (Campanian) of western Jamaica cannot be considered a source rock for petroleum generation in economic quantity as suggested by Kashfi (1983).

Cherry et al. (2018) conducted geochemical and palynological studies on 800 samples from on- and offshore Jamaica and gave evidence for the deposition of source rocks and quantified their source potential for hydrocarbon generation. They suggested that the island may become an attractive region for future oil exploration in the Caribbean.

A detailed multiproxy biostratigraphic framework and palaeoenvironmental interpretations of marine Cretaceous-Miocene sediments were carried out using larger benthic foraminifera, planktonic foraminifera, nannopalaeontology and palynology of outcrop samples, well and corehole samples to create a regional relative sea-level curve by Gold et al. (2018).

Nicaragua

Urquhart (2009) used palaeotempestology and fine-resolution palynology to provide insight into the impacts of hurricanes and the post-hurricane regeneration of forests. He studied a 5 m sediment core from a swamp lagoon on the Caribbean Coast of Nicaragua that covered the entire 8000-year history of the swamp. He identified a sand layer dating c. 3300 BP of the type deposited by hurricanes and pollen analyses showed that this sand layer was deposited following a major change in vegetation and fires.

The vegetation of the Central American Dry Corridor (CADC) is composed of Dry Tropical Forests (DTF), which are susceptible to variations in climate and anthropogenic development. Harvey et al. (2019) examined the vulnerability of past DTF surrounding the Asese Peninsula, Nicaragua, to climatic and anthropogenic disturbances over the past1200 years. Past vegetation, climate, burning, and animal abundance were reconstructed using proxy analyses of fossil pollen, diatoms, macroscopic charcoal, and *Sporormiella*. The DTF of the Nicaraguan region of the CADC was found to be highly resilient to climatic and anthropogenic disturbances.

ODP Site 999 (12°44'N; 78°44'W)

There are few significant oceanographic and palaeoceanographic studies in the Caribbean Sea region that used palynological proxies. van Renterghem (2012) studied Pliocene dinoflagellate cysts from ODP Site 999 (12°44'N; 78°44'W) cores as proxies for palaeoceanography and palaeoclimate in the Caribbean Sea.

Panama

Graham (1977) published new records of fossil pollen of *Pelliciera* (*Theaceae*/*Pellicieraceae*) from the Eocene of Jamaica, Eocene of Panama, and Oligo-Miocene of Panama extending both the stratigraphic and geographic range of this genus in the Antilles and Central America. In a series of papers Graham (1987, 1988a, b, 1989, 1991a, b, c) published on palynology of the Miocene and Pliocene formations describing ancient plant communities, palaeoclimate, and palaeoenvironments of Panama.

Martinez et al. (2013) presented a Neogene palynological study tracing the fossil pollen records of *Hedyosmum* (*Chlorantahaceae*) and concluded that this taxon migrated from South America to Central America after early Miocene.

Jaramillo et al. (2014) carried out an extensive study of the palynological record of the past 20 million years in Panama. They studied many outcrops of newly exposed expansion of the Panama Canal and analyzed the palynological record of the interval 19.5–1.2 Ma. Results indicated that since the Early Miocene, Panamanian forests have been dominated by Gondwana-Amazonian taxa. The landscape was dominated by tropical rainforest and lower montane to montane forest. Plant diversity seems to have increased over the past 10 My.

Puerto Rico

Graham and Jarzen (1969) reported on the palynology of the San Sebastian Formation (Oligocene) of Puerto Rico. The assemblages indicated a plant community that included coastal, brackish water assemblage of *Rhizophora* and *Pelliciera*, an upland tropical to subtropical community, and an arboreal cool temperate community.

Cintrón et al. (1978) studied mangroves of Puerto Rico and adjacent islands and showed their relationship with arid environments of the region.

Burney et al. (1994) analyzed charcoal on a sediment core from Laguna Tortuguero, Puerto Rico, and concluded that charcoal records started at 7000 calyr BP; however, from 7000–5300 calyr BP, exceptionally low charcoal counts were recorded, suggesting uncommon wildfires.

Caffrey and Horn (2014) examined sedimentary charcoal records from Laguna Tortuguero in Puerto Rico. They recorded charcoal fragments from pollen slides that covered the last 7000 or more years of the Holocene. They compared charcoal influx values to archeological and palynological evidence of human activity. The study highlighted possible intervals of climate-driven burning as distinct from more localized anthropogenic burning.

Trinidad and Tobago

Muller (1959) described the distribution of palynomorphs in the recent sediments of the Orinoco Delta in which the samples were studied from the Gulf of Paria and surrounding seas of the islands of Trinidad and Tobago. This study demonstrated relative influence of location of source area and transport by air and water currents on dispersal of palynomorphs.

Germeraad et al. (1968) presented the results of an extensive palynological study of Tertiary sediments across the Tropics covering northern and western Venezuela, Trinidad, Colombia, and Nigeria. The study demonstrated the application of palynology as a tool for determining age of sedimentary rocks and correlating stratigraphic sections by establishing palynological biozones across continents.

The present author studied palynology of the Pitch Lake in Trinidad. A diverse palynomorph assemblage was obtained by developing a novel maceration technique used to isolate palynomorphs from the solid hydrocarbon. The assemblage suggested that pitch was sourced from the Miocene reservoir rocks underlying the Pitch Lake (Kumar 1979, 1981).

Lamy (1985) published on the Plio-Pleistocene palynology along with visual kerogen studies in Trinidad.

Payne (1991) discussed the palynological zonation system developed by E. Gonzalez for post-Middle Miocene sediments of offshore Trinidad that showed some consistency with seismic correlation and was applied on a broad basis for correlating formations and seismic events in time across major fault boundaries.

According to Pocknall et al. (2001) the offshore Eastern Venezuela Basin contains thick sections of Pliocene-Pleistocene strata that were deposited in environments ranging from non-marine to the basin floor. A variety of palynomorphs occur in abundance in these sediments. A detailed sampling of well and outcrop sections in Trinidad provided a useful palynostratigraphic framework to build a chronostratigraphic and depositional history of the basin.

Palaeoenvironmental records from Trinidad suggest lower sea levels at about 7000 calyr BP (Ramcharan 2004; Ramcharan and McAndrews 2006; Monacci et al. 2009). This is indicated by the establishment of mangroves (mainly *Rhizophora mangle*, red mangrove) which form at or near mean sea level (Tomlinson 1986). The presence of Rhizophora pollen coupled with mangrove peat indicated changes in relative sea levels since *Rhizophora* occupies the upper half of the intertidal zone (Ramcharan 2004; Ramcharan and McAndrews 2006).

Kumar (2022) studied palynology of the upper section of the Rockly Bay Formation (mid-Pliocene) of Tobago since it was described as unfossiliferous (Donovan 1989). The study demonstrated occurrence of angiosperm pollen, spores, and non-pollen palynomorphs (NPP) such as dinoflagellate cysts, acritarchs, algal cysts, fungal palynomorphs, crustacean palynomorphs, annelid palynomorphs, and arcellinidan palynomorphs. The study suggested that this section of the Rockly Bay Formation was deposited under supratidal environment, where lakes and ponds existed in which a variety of algal forms thrived. This environment was periodically influenced by high tides and storms. Ascidian spicules are calcareous mineral microfossils also occur in this section.

US Virgin Islands

Jessen et al. (2008) analyzed a core from a lagoon in St. Croix, US Virgin Islands, and found an increase in mangrove pollen, indicating the development of mangrove swamps at 2500 calyr BP.

Venezuela: The Caribbean coastal region

Kuyl et al. (1955) was a pioneering work in this field that carried out palynological studies on mainly Cenozoic sedimentary rocks of western Venezuela and demonstrated application of palynology in hydrocarbon exploration. This study was followed by another historic paper by Muller (1959). Muller's study demonstrated the distribution of palynomorphs in the recent sediments of the Orinoco Delta in which the samples studied were from the Gulf of Paria and surrounding seas of the islands of Trinidad and Tobago.

Germeraad et al. (1968) was another landmark paper that presented the results of palynological research of Tertiary sediments across the Tropics by demonstrating the application of palynology as a tool for determining age of sedimentary rocks and correlating stratigraphic sections by establishing palynological biozones. This study established palynological correlations across northern and western Venezuela, Trinidad, Colombia, and Nigeria.

Muller et al. (1987) presented a detailed Venezuelan Cretaceous through Quaternary biostratigraphic study and proposed a palynological zonation scheme.

Salgado–Labouriau (1991) reported on the palynology of sediments covering 13000 years from the Venezuelan Andes. The study concluded that composition of high montane vegetation and its altitudinal position was not constant during the late Quaternary. The climate changed by the end of Pleistocene and small climatic oscillations occurred during the Holocene.

According to Pocknall et al. (2001) the offshore Eastern Venezuela Basin contains thick sections of Pliocene-Pleistocene strata that were deposited in environments ranging from non-marine to the basin floor. This paper is referred under the heading Trinidad because a detailed palynological study of samples from well and outcrop sections in Trinidad provided a useful palynostratigraphic framework to build a chronostratigraphic and depositional history of the basin.

Rull (2002) demonstrated application of high-impact palynology (HIP) in hydrocarbon exploration from Maracaibo Basin, Venezuela. It is a significant study that defines HIP as coupling of high-resolution sequence biostratigraphy, multidisciplinary work aligning them with attainment of exploration goals.

Helenes et al. (2003) carried out palynological studies of subsurface sections in eastern Venezuela, an area close to Trinidad and Tobago, describing two palynomorph assemblages each from the Cretaceous and the Tertiary strata.

Several studies on oceanographic and palaeoceanographic studies of the Cariaco Basin, offshore Venezuela were published during the past few decades. Ferraz-Reyes (1983) published an early report on the phytoplankton study from this basin. González et al. (2008a) carried out a palynological study to demonstrate response from neotropical vegetation to rapid climate changes during the last glacial in the Cariaco Basin. Subsequently, González et al. (2008b) used dinoflagellate cysts to reconstruct marine productivity of this basin during marine isotope stages 3 and 4.

Bringué et al. (2018) presented results of Physico-chemical and biological factors influencing dinoflagellate cyst production in the Cariaco Basin. A 2.5 year–long sediment trap record of dinoflagellate cyst production in the Cariaco Basin, off Venezuela (southern Caribbean Sea), documented changes in dinoflagellate cyst production between November 1996 and May 1999 at ~14–day intervals and interpreted in the context of in situ observations of physico-chemical and biological parameters measured at the mooring site. Dinoflagellate cyst assemblages were diverse and dominated by cysts of heterotrophic taxa, mainly *Brigantedinium* spp. (51% of the total trap assemblage). Average cyst fluxes to the trap were high and showed great seasonal and interannual variability. Bringué et al. (2019) extended their study on seasonal and interannual variability in dinoflagellate cyst production and assessed a 12.5–year long sediment trap time series from the Cariaco Basin. Cyst production was interpreted in the context of physico-chemical properties measured in situ at the mooring site reflecting seasonal upwelling. They found that on seasonal time scales, dinoflagellate cyst production is closely coupled with upwelling strength, and higher cyst fluxes were consistently observed under active upwelling conditions compared to non-active upwelling intervals. Dinoflagellate cyst assemblages were dominated by *Brigantedinium* spp. (59.1%), followed by *Echinidinium delicatum* (10.8%), *Bitectatodinium spongium* (8.4%), Spiny brown type A (2.9%) and *Echinidinium* spp. (2.4%). Cysts produced by both autotrophic and heterotrophic dinoflagellates generally responded positively to upwellings in the basin.

CONCLUSIONS

1. An overview of the palynological research in the Caribbean and adjoining region provides valuable information on diversity of applications of palynological research in the fields of earth and environmental sciences. Palynology of Late Quaternary marine and terrestrial sediments provided information about environmental and climatic changes, vegetation, and floral history of the region useful in archeological studies.
2. Morphological and taxonomic studies of fossil pollen and spores including the non-pollen palynomorphs (NPP) have described many new taxa from this region.
3. Palynological research in this region has served as a basis for proxies for palaeoenvironmental, palaeoecological and biostratigraphic studies, and along with source rock palynology it has been used in oil and gas exploration. It has also been used as a tool for oceanographic, palaeoceanographic and palaeoproductivity of phytoplankton studies.
4. This paper provides a valuable bibliographic source for palynological research of this region.

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