ANCIENT WATER MANAGEMENT AND THE EVOLUTION OF THE LATE HOLOCENE WETLANDS. FIRST PALEOECOLOGICAL EVIDENCE FROM PREHISPANIC RAISED FIELDS OF URABÁ, NORTHWESTERN SOUTH AMERICA.

William A. Posada-Restrepo
Department of Anthropology, Universidad de Antioquia UdeA. Medellín, Colombia. Postal Code 050020. williama.posada@udea.edu.co. Corresponding autor.

Ivonne Marcela Castañeda-Riascos
Smithsonian Tropical Research Institute, Panama. Postal Code 0843-03092. castanedaim@si.edu

Bibiana Cadena-Duarte
Department of Anthropology, Universidad Nacional de Colombia. Postal Code 11001. bacadenad@unal.edu.co

Sergio A. González-Avendaño
Department of Anthropology, Universidad de Antioquia, Colombia. Postal Code 050020. albeiro.gonzalez@udea.edu.co

Omaira Rosa Sierra-Arango
Department of Biology, Universidad de la Amazonia, Colombia. Postal Code 180001. o.sierra@udla.edu.co

Jhostin Ramos.
GISMAC, Corporación Académica Ambiental, Universidad de Antioquia UdeA. Turbo (Urabá), Colombia. Postal Code 050010. jhostin.ramos@udea.edu.co

Fernando Parra

GISMAC, Corporación Académica Ambiental, Universidad de Antioquia UdeA. Turbo (Urabá), Colombia. Postal Code 050010. fjose.parra@udea.edu.co

Heazel Grajales
GISMAC, Corporación Académica Ambiental, Universidad de Antioquia UdeA. Turbo (Urabá), Colombia. Postal Code 050010. heazel.grajales@udea.edu.co

Alex Rúa
CBATA, Departamento de Ciencias Básicas y Áreas Comunes, Tecnológico de Antioquia Institución Universitaria-TdeA. Medellín, Colombia. Postal Code 050034. alex.rua@tdea.edu.co

Summary

The raised fields discovered recently in the Gulf of Urabá, northwestern Colombia, extends more than 135,000 ha among the floodplains of the rivers León, Suriquí and Tumaradocito in the Chocó biogeographic region. To understand the mechanisms by which people use the wetlands under climate change of the Late Holocene, the paleoenvironmental and cultural conditions were studied using artifacts, soil micromorphology, geochemical, chronostratigraphic and palynological analyses at El Vergel archaeological site. The aim of this study is to discuss the origin of raised fields development in the León river floodplain and its relation with progressive drought, groundwater and wetland management for permanent human occupation. The results suggest that the raised fields were built around the IX century CE, during a period marked by decreased precipitation, probably related with Medieval Warm Period. The hydrogeology reveals two aquifers in the region with some shallow springs in the floodplain where earthworks are located. The poor stratigraphic demarcation of the ridges and well dug channels, with no evidence for agriculture whatsoever, support the idea that some raised fields was strategic for distributing groundwater and rainwater over a large area and thus preserving the productivity of the wetland for fishing and hunting.

Key words: Wetlands, Raised fields, Uraba, Prehispanic cultures, Geoarchaeology, Holocene, paleoecology.

1. Introduction

The massive occurrence of prehispanic raised fields near the Colombian-Panamanian border in the Gulf of Urabá, comprise an extensive wetland across the middle basin of the León River with pervasive earthworks of prehispanic cultures (Posada et al., 2019). The regional occurrence of these raised fields indicate a long term human interactions with wetland ecosystems and could support the statements about intercultural relationships among peoples from the Isthmus, northwestern Andes and Colombian Caribbean (Bray, 1990; Castillo, 1988; Cooke and Sánchez, 2001; Fonseca and Cooke, 1993; Helms, 1979; Martin and Sánchez, 2007; Mendizábal et al., 2021; Piazzini, 2020; Reichel - Dolmatoff and Dussán de Reichel, 1961).

The raised fields are an ancient technology widespread in Central and South America for water management, usually for improving agricultural production (Comptour et al., 2018; Denevan, 2006, 1970). However, the regional applications of this technology vary with the environment, culture and the ecosystem services that peoples aimed for preservation. Previous works have shown the particular paleoenvironmental and cultural conditions that influenced fluvial ecosystems and productive behavior of societies around the widespread use of raised fields in South American floodplains (Iriarte et al., 2010; Ordóñez, 2006; Rodrigues et al., 2018; Rostain, 2010). These works highlight the diversity of functions and variables involved in the development and maintenance of raised fields beyond agricultural practices, considering the hydrologic and climatic conditions in different geographical locations.

In the floodplain wetlands, the flood pulse is between the main environmental driving forces that link nutrient fluxes to primary production, hydrobiological resources and economic exchange (Junk et al., 1989; Montoya et al., 2011). The changes in frequency and intensity of flood pulses owing to climate variability and anthropic interventions have shaped the landscape and nutrient dynamics (Junk et al., 1989; Macklin and Lewin, 2015). In the Gulf of Urabá, the performance of hydrological resources depends on the regional water cycle which includes marine and hydrogeological processes as well as the local geomorphology influenced by anthropic mounds, channels, platforms and ridges of prehispanic origin (Denevan, 2006; Lombardo et al., 2011; Palomino-Ángel et al., 2019; Poveda and Mesa, 1999; Rodrigues et al., 2014). This is particularly relevant because it affects the biocoenosis and nutrition loads for fishing, hunting, gathering or cultivation (Merten et al., 2020; Muller, 1995; Parolin and Wittmann, 2010; Vasey et al., 1984), leading to cultural changes and particular landscape and territorial patterns.

The archaeology of the Gulf of Urabá in this regard, show prehispanic populations in the transition zone between Central and South America who shared phylogenetics and cultural features (Capodiferro et al., 2021; Martín et al., 2015; Mendizábal et al., 2021; Piazzini, 2020), but material culture in the León river on the southwest of Urabá is clearly different from that of neighboring populations to the northeastern (Alzate, 2015; Arcila, 1955; GIAP, 1980; Posada et al., 2019; Santos, 1989). Similarly, the wetlands are restricted to the southern part of the gulf where precipitation are higher and topography favors the permanent flooding by river overflow and water table fluctuations. This points out the relevance of the space-time framework for the Urabá raised fields to elucidating distribution, performance and origin of this technology and the cultural practices for water use. So this study explores the paleoenvironmental conditions in El Vergel archaeological site, focusing on the hydroclimatic complexity of Urabá and its role in the cultural practices, as the first approach to the human occupation history of the León river wetlands and its lessons for contemporary water management.

2. Geographical settings

El Vergel archaeological site lies in the middle reaches of the León river, 4 km West from the river stream (Fig. 1). It is a massive wetland filled with ditches, platforms, ridges and mounds that are enclosed by the mountain ranges of Darién to the West and of Abibe to the East. The wetland links the watersheds of the rivers Atrato, León, Tumaradocito and Suriquí within a relatively homogeneous swampy lowland. The geology consists of basal sedimentary rocks from Paleogene-Neogene age comprising lithic to sublithic sandstones interspersed with mud and limestone. Quaternary alluvial sediments rest on the sedimentary layers and together form a multilayer aquifer with different levels of porosity and permeability (IDEAM, 2013). The unconsolidated sediments derived mainly from the Abibe mountain range, consist of sands and silty-clays of silicate, calcareous and oxide minerals. In addition, igneous sediments from basalts, breccias, agglomerates, granites and andesitic porphyries are transported by the Atrato river from the Darién mountain range and some isolated hills. The sediment load to the León river basin from both mountain ranges totals with 810,000 ton/a (Guevara et al., 2015; Guzmán and Ceballos, 2001). Two granitic hills alone stand out inside this massive floodplain fringed by the raised fields, El Cuchillo and Lomas Aisladas.

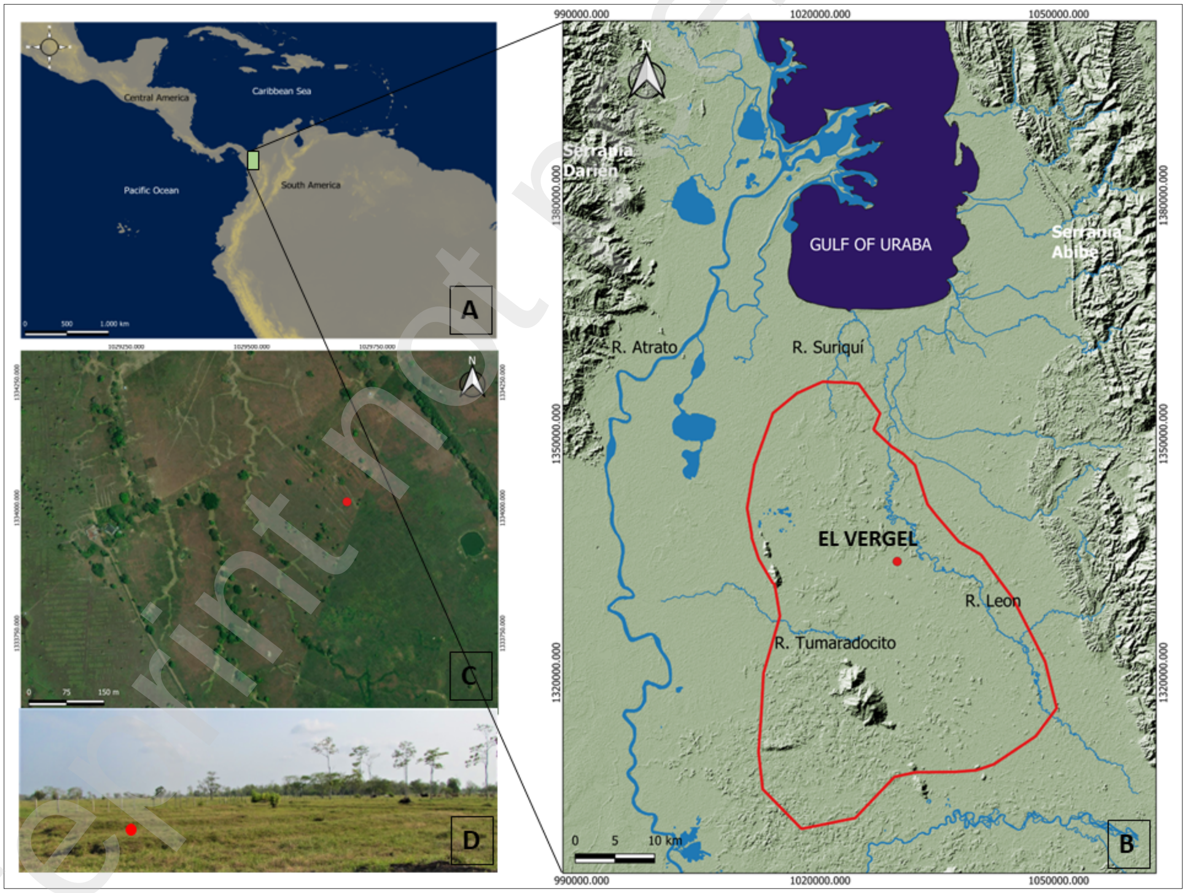

Fig. 1. Map of the raised fields distribution (red polygon) around El Vergel archaeological excavation (red dot); (A) Continental context; (B) Regional location; (C) Aerial image and (D) *in situ* photograph.

The wetland soils in the middle and lower reaches of the León river are periodically flooded during high precipitation periods, promptly recharging the two regional aquifers found underneath and increasing the runoff (Betancur-Vargas et al., 2017; Ríos and Martínez, 1995; Villegas et al., 2013). The average rate for annual rainfall varies between 2,000 mm to the North and 4,000 mm to the South, depending on the position of the Intertropical Convergence Zone (ITCZ). The precipitation pattern is unimodal with a dry season between January-March when the ITCZ is at its southernmost position, and a rainy season between April-December when the ITCZ is above the study area. The minimum rainfall rate amounts to 70 mm/month and coincides with Caribbean trade winds in the dry season. The maximum rainfall rate surpasses 200 mm/month in the rainy season (Betancur-Vargas et al., 2017; Guzmán and Ceballos, 2001). According to the climatic and limnimetric station located in Barranquillita, close to El Vergel archeological site, the average multiannual flow of the León river is 70.7 m^3/s, but increases downstream due to other tributaries.

3. Methods

Fifteen control pits were surveyed by digging in the best preserved zone of El Vergel archaeological site along a West-East transect. Six out of 15 diggings shared artifact and charcoal evidence embedded in similar soil profile, so we chose a ridge and a channel around it for excavation. Stratigraphic integrity and earthwork pattern were considered while recovering soil, artifacts and charcoal samples during the excavation. Since the channel represents a local scale micro-depositional basin, the archaeological materials were best stratified in the channel sediments. The soil horizon nomenclature followed the parameters of the USDA soil taxonomy (Soil Survey Staff –SSS, 2017, 1999), while the stratigraphy adopted the identification and description criteria established in Goldberg and McPhail (2006), and Sloss and Krumbein (1969).

3.1. Palynology and diatom sampling, preparation and identification

About 2 cm³ sediment samples were collected at different depths according to stratigraphic distribution, organic matter and soil development. All samples were mechanically and chemically dispersed with sodium pyrophosphate ($Na_4P_2O_7$) and then oxidized with hydrogen peroxide (H_2O_2). The sampling, preparation, identification and quantification of diatoms were performed after González (2022) according with Segecin et al. (1999). Only the pollen samples were subjected to acid hydrolysis by adding hydrofluoric (HF) and hydrochloric (HCL) acids (Faegri and Iversen, 1975). The material was warm-dried onto glass slides and mounted in Entellan® resin. Observations, measurements and photomicrographs were taken at 40x and 100x (Olympus CX41 microscope with AxioCam ERs 5s camera). Some photomicrographs were taken using a Scanning Electron Microscope. Owing to the differential preservation of diatoms down core, the taphonomic processes were analyzed qualitatively by fragmentation, dissolution and lamination of valves. The whole results, including artifacts and elemental geochemistry, were plotted with Grapher 13.3.754.

3.2. Soil chemistry and micromorphology

The physical and chemical properties of the soil sampled were compared with natural soils of the same physiographic unit in the León river basin reported in IGAC (Instituto Geográfico Agustín Codazzi - IGAC, 2007). The content of Fe, Ti and Al in alluvial sediments was determined by Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) after acid digestion. The organic matter content was estimated using the Walkley-Black method. Effective cation exchange capacity (ECEC) and base cations in soil (Ca, K, Na y Mg) were measured by absorption and emission spectrometry after extraction with ammonium acetate ($NH_4CH_3CO_2$) 1M at *p*H 7. Total phosphorus was determined using potassium nitrate (KNO_3)/sodium nitrate ($NaNO_3$) and a spectrophotometer. Finally, soil micromorphology was evaluated following Bullock et al. (1985), with emphasis in archaeological features described in Courty et al. (1989), Stoops and Marcelino (2010) and Stoops and Nicosia (2020).

3.3. Radiocarbon dates

The ^{14}C dates were obtained by accelerator mass spectrometry (AMS) from charcoal samples collected in stratigraphic units without post-depositional disturbance. Calibrated dates were obtained with the Calib 8.2 software using IntCal20 calibration curve and a 2σ probability interval (Reimer et al., 2020; Stuiver and Reimer, 1993).

3.4. Statistical analysis

Principal component analysis (PCA) was performed in order to explain the variability of the geochemical, biological and artifact findings. Significant correlations between these variables were obtained with the Pearson test. All statistical analyses were carried out using IBM SPSS version 25 and Statgraphics 19 Centurion.

4. Results

4.1. Archeological excavation, stratigraphy and chronology

A 4 m trench 1,7 m deep was dug between the selected channel and the ridge, which displayed five stratigraphic units in a moderately developed soil (Fig. 2). The borders between units were diffuse due to weathering, with the exception of a clear discontinuity between stratigraphic units II, III and IV (Table 1). The distribution of ceramic fragments along the sequence was multimodal, with increased density after unit I where we record a subtle typological change. Unit I share similar chronology with the most lower level of Toribio archaeological site dated to about ^{14}C 1570±53 yr BP (Posada, 2022). Pedological evolution was incipient in all units with absence of buried soil or paleosols in the whole sequence.

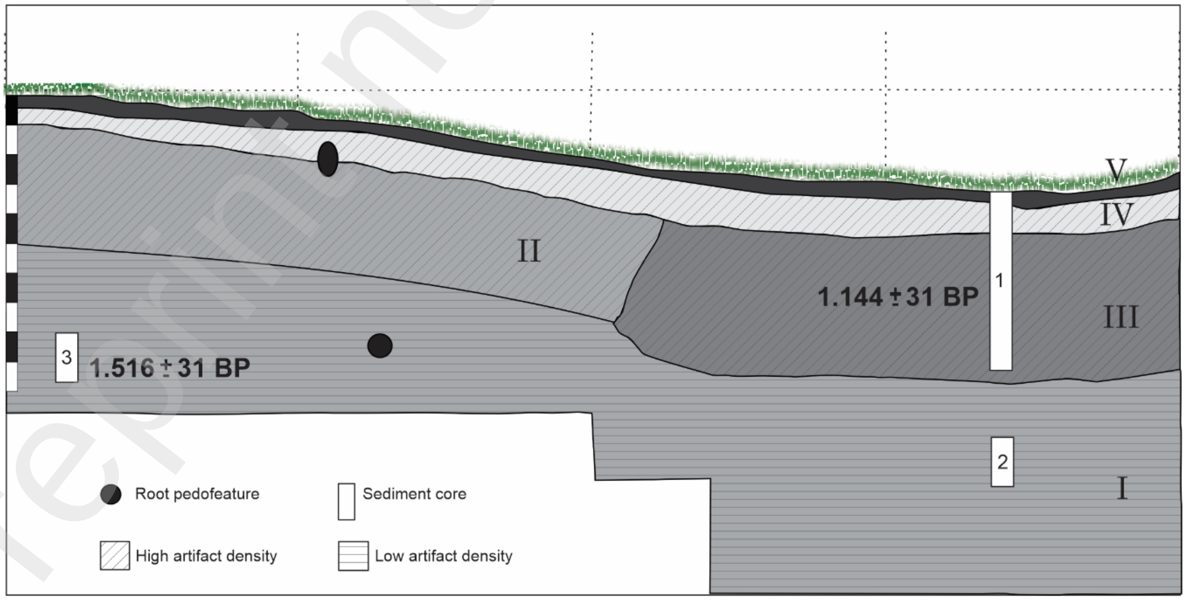

Fig. 2. Stratigraphic sequence in El Vergel excavation

Stratigraphic unit	Description
I (140-60 cm)	Clayey-silt sediment layer, densely mottled with abundant Fe/Mn oxide nodules forming a Cgu soil horizon bearing charcoal and artifacts. Its upper limit to the ridge was flat and diffuse but wavy and abrupt to the channel. Radiocarbon age at the top layer of the ridge was 531-609 CE (^{14}C 1516±31 yr BP; AA115152).
II (60-15 cm)	Loamy-clayed sediment layer occurred in the ridge only and displayed increased artifact density. The color was yellowed-brown with dispersed Fe/Mn oxide nodules forming a Cgu soil horizon. Root pedofeatures and charcoal were frequent. The upper limit was wavy and gradual but laterally discordant with unit III.
III (60-20 cm)	Channel filling clay-loam sediments, ceramic artifacts and charcoal with less pedological development. Gleyed mottle morphology with Fe/Mn oxide nodules, massive structure and root pedofeatures. The upper limit was discordant with the upper unit IV. Radiocarbon age at the middle of the unit was 868-991 CE (^{14}C 1144±31 yr BP; AA115150).
IV (20-5 cm)	This layer covered the El Vergel archaeological site throughout. It was dominated by loamy-sand sediments, pale gray color with some mottles, contained ceramic artifacts and few charcoal with no Fe/Mn oxide nodules. The upper limit was flat and abrupt, suggesting a discontinuity with the next stratum. Radiocarbon age was post bomb (1962-1977 CE), which along with the fluvial origin of sediments may suggest reworked materials.
V (5-0 cm)	Thin layer of loamy soil, brown-gray color with some mottles, strongly compacted structure and mid to high content of organic matter forming an Ap horizon. Both ceramic artifacts and charcoal were absent.

Table 1. Pedostratigraphical description.

4.2. Site formation processes

Hydromorphism was the main pedogenic process of the archaeological site. This is consistent with the high presence of Fe/Mn oxide nodules, ferruginous hypo-coatings around root voids and gleyed zones of the soil profile (Fig. 3). These features are produced *in situ* by the fluctuation of groundwater levels that lead to degradation of palynomorphs, organic and carbonate debris as those associated with faunal bones and shells. The steep reduction in diatom frequency under stratigraphic unit IV was probably due to dissolution of fragile frustules under long term waterlogging variations, opal hydration and mechanical fragmentation during transport and deposition (Barker, 1992; Flower, 1993; Reed, 1996; Sierra-Arango et al., 2014; Warnock et al., 2007). Because the ascension of alkaline groundwater and marine intrusions through the riverbed (Jiménez and Campillo, 2020;

Villegas et al., 2013), the chemistry of the channel soil stabilized at alkaline *p*H levels and were clearly depicted by the increased downcore content of Ca^{2+} and Mg^{2+}, measured in the stratigraphic units I, II and III, where Mg^{2+} saturation reached high levels (37-44 %; Table 2). Such *p*H levels increase silica dissolution of bioclasts despite being more resistant than carbonated (Fritz et al., 1999; Jorgensen, 1955; Ramírez et al., 2007).

Another relevant processes were the flood pulse and the water flow inside the channel. These featured diverse minerals, mild chemical weathering, homogeneous soil morphology, no buried A horizon and low levels of sedimentary organic matter (Table 2; Fig. 2). This concurs well with frequent but moderate water fluxes into the channel and ridge. Both processes cause further fractionation of diatoms, pollen oxidation, variation in trace elements levels and loss of suspended clay (Sierra-Arango, 2013). The preservation of the archaeological record is likewise affected by mechanical bioturbation observed in roots, microfaunal remains and fabrics (Fig. 3A). Undoubtedly, the exceptional event registered in the stratigraphic unit IV would have caused reworking and mixing ages of the layers.

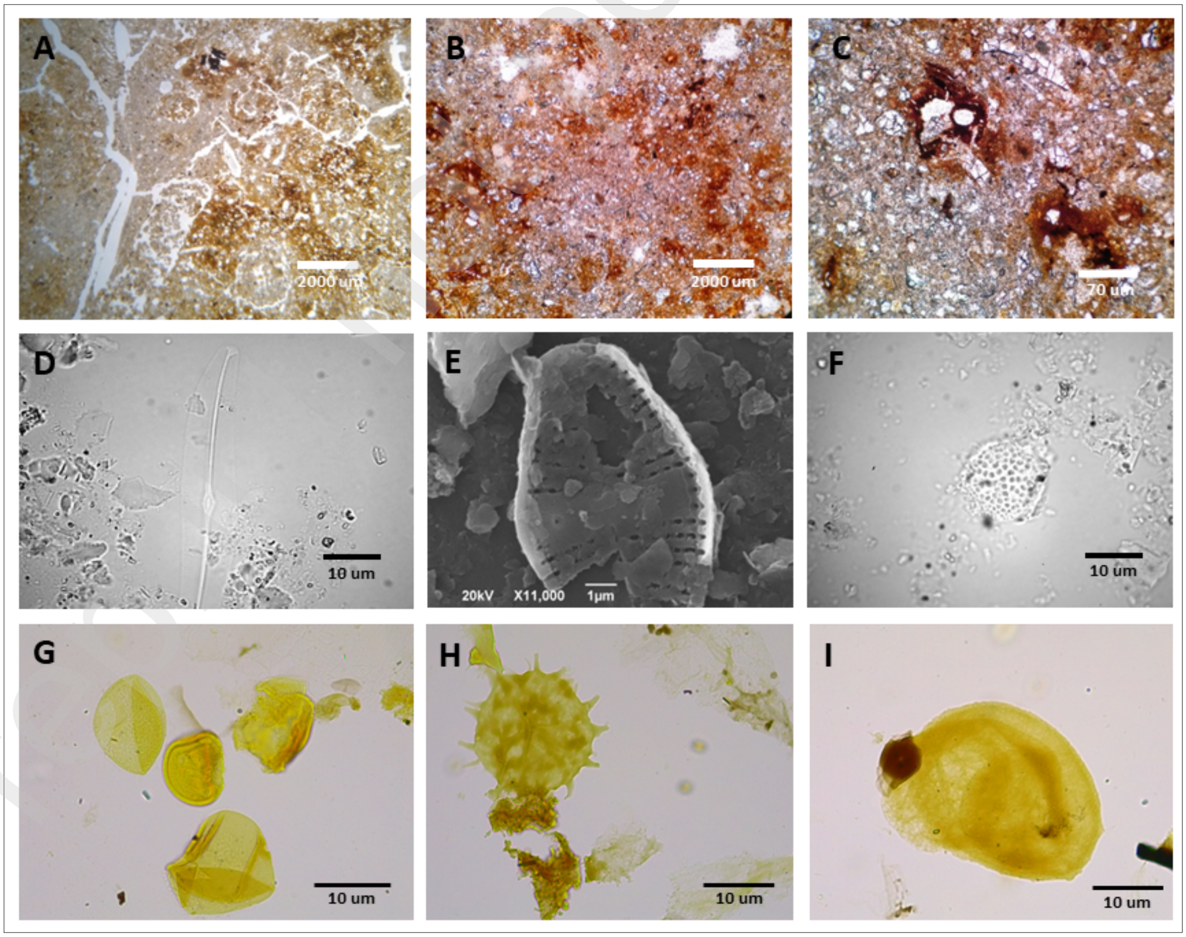

Fig. 3. Palynological and soil micromorphological features. (A) Loose continuous excremental infillings in stratigraphic unit I; (B) Weakly developed pedality in stratigraphic unit IV; (C) Fe oxide hypocoatings in a yellowish brown groundmass with dense angular quartz crystals in stratigraphic unit III; (D) *Gyrosigma scalproides* diatom; (E) *Luticola acidoclinata* diatom; (F) *Aulacoseira* spp diatom; (G) Poaceae pollen grains; (H) Convulvulaceae pollen grain; (I) Podocarpaceae pollen grain.

Channel data

Stratigraphic Unit	*p*H	% Organic carbon	% Organic nitrogen	C/N Ratio	Ca (meq/100 g)	K (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	ECEC (meq/100 g)	Total P (mg/Kg)	Cation Saturation (%)	Ca/Mg Ratio	K/Mg Ratio	Clay (%)	Silt (%)	Sand (%)
V	5.18	5.04	0.59	11.59	4.68	0.46	2.9	0.16	9.06	251.2	35.39	1.60	6.34	42.2	45.4	12.4
IV	6.19	0.81	0.10	11.59	6.49	0.06	3.76	0.14	10.45	91.57	59.98	1.72	62.66	24.1	45.2	30.7
III	7.37	0.29	0.03	11.61	8.39	0.09	7.68	0.19	16.35	88.51	86.42	1.09	85.33	26.0	41.1	32.9
III	7.38	0.23	0.03	11.60	12.29	0.18	8.67	0.15	21.29	87.92	91.18	1.41	48.16	13.2	45.5	41.3
I	7.45	0.38	0.05	11.60	9.73	0.12	8.64	0.15	18.64	127.05	80.98	1.12	72.00	19.6	49.5	30.9

Ridge data

Stratigraphic Unit	*p*H	% Organic carbon	% Organic nitrogen	C/N Ratio	Ca (meq/100 g)	K (meq/100 g)	Mg (meq/100 g)	Na (meq/100 g)	ECEC (meq/100 g)	Total P (mg/kg)	% Cation Saturation	Ca/Mg Ratio	K/Mg Ratio	Clay	Silt	Sand
V	5.68	3.50	0.41	11.59	6.71	0.23	6.32	0.35	13.61	130.40	62.26	1.06	27.47	48.5	37.1	14.4
IV	7.25	0.24	0.03	11.58	7.23	0.05	7.11	0.31	14.70	76.22	80.58	1.01	142.20	30.2	43.1	26.7
II	7.44	0.32	0.04	11.59	9.56	0.06	8.38	0.20	18.20	88.19	91.72	1.14	139.66	30.1	45.3	24.6
II	7.27	0.30	0.04	11.61	12.72	0.09	8.59	0.13	-	78.03	Saturated	1.48	95.44	32.2	43.2	24.6

I	7.35	0.39	0.05	11.59	13.30	0.11	8.71	0.12	-	75.30	Saturated	1.52	79.18	27.8	45.4	26.8

Table 2. Physical and chemical properties of soil in El Vergel pedostratigraphic sequence.

4.3. Palynomorphs and biosiliceous components

The pollen sequence showed ecological patterns and successional changes, but no evidence of agricultural crops. In the stratigraphic unit I, 82% of the pollen recorded at 180 and 100 cm corresponded to tropical rainforest taxa highlighted by *Forsteronia*, *Juglans* sp., *Desmodium* sp., *Alnus* sp. and Apocynaceae (Fig. 3). While the savannah pollen got 4.5% represented by Poaceae, and finally the swamp taxa 13.5% with Cyperaceae. A low diatom abundance with alternating dominance was recorded. *Aulacoseira* sp. dominated between 25-100 cm and *Gyrosigma cf. scalproides* below 100 cm. Some resistant structures from centric diatoms, *Actinella*, fragments of *Eunotia cf. monodon*, *Pinnularia* sp., *Stauroneis* sp. as well as some sponge spicules were also found in the unit I.

The stratigraphic unit III, was dominated by rainforest group and represented by *Carya* sp. Type, *Tapirira* sp. Type, *Podocarpus* sp. and *Forsteronia* sp. Cyperaceae increase the swamp taxa (24%) followed by savannah vegetation (17.1%) with Poaceae. Although Fabaceae and Anacardiaceae were the dominant rainforest taxa, their count decreased atop the core whilst Poaceae and Asteraceae increased. Further analysis identified some *Luticola incana* and *Pinnularia borealis* from the algal group atop the stratigraphic unit III (Fig. 3).

In the stratigraphic unit IV, open vegetation increased with Poaceae and Ambrosia sp. representing 38.3%, whereas Cyperaceae, Onagraceae and Typha type grains reached 31.3%, suggesting a transitional environment dominated by savannah and swamp vegetation with few rainforest taxa such as *Palicurea* sp., *Juglans* sp., *Desmodium* sp. and Arecaceae. The diatom assemblage at 17 cm deep was represented by *Luticola acidoclinata*, *Pinnularia borealis*, *Eunotia* and *Aulacoseira* sp., whereas the diatom *Brachysira* sp. only occurred in the record at 15 cm.

The last stratigraphic unit registered high pollen frequencies from both savannah and swamp taxa. Whereas savannah comprised 44.5% with Poaceae, *Ambrosia* sp. and Asteraceae, swamp included Cyperaceae, Onagraceae and *Thypa* type grains with 32%. Nevertheless, the rainforest ecosystem recovered slightly at 3 cm by increasing its diversity with Bromeliaceae, *Alchornea* sp., *Acalypha*, *Desmodium* sp., *Trema* sp., *Hedyosmum* sp., *Pseudobombax* sp.

and *Symphonia*. The richness of well preserved diatom taxa was high, being the genus *Pinnularia*, *Luticola*, *Frustulia*, *Nitzschia*, *Hantzschia*, *Eunotia*, *Sellaphora*, *Encyonopsis*, *Stauroneis*, *Navicula*, *Gomphonema*, *Placoneis* and *Achnantes* the most conspicuous (González, 2022).

4.4. Geochemistry and soil micromorphology

The sedimentary content of Fe, Al and Ti increased down core with one peak resolved between 10-20 cm depth (Fig. 4). The levels of Fe, Al and Ti were higher at the bottom core in unit I than in the rest of the sequence, indicating increased runoff. The levels of Fe and Al were higher than that of Ti. The micromorphology exhibited diverse biostructures and inorganic sediments slightly altered, well developed porosity and several impregnative Fe/Mn oxide nodules, some of them cut forward by pedofaunal activity (Fig. 3A). The organic carbon was very low although total phosphorus (P) reached 127 mg/kg in the deepest stratum. The levels of Fe, Al and Ti decreased gradually from 40 cm in stratigraphic unit III to 20 cm depth. The period of greatest artifact deposition within the channel load corresponded with 40 cm depth (^{14}C 1144±31 yr BP). The ECEC (Effective Cation Exchange Capacity), base saturation and *p*H levels were higher in the deeper units than those reported for natural and recent soils (Instituto Geográfico Agustín Codazzi - IGAC, 2007), but may be accentuated by groundwater salts (Villegas et al., 2013).

The features of the stratigraphic unit IV suggested a sudden flood event between 20-5 cm, when the levels of the three elements peaked. These levels of Fe and Al almost match those found in the stratigraphic unit I before anthropic occupation. However, these should be seen with caution since the apparent increase in humidity might be partially overestimated by redox conditions. In fact, the soil micromorphology showed diverse redoximorphic features, including intrusive and impregnative pedofeatures. Soil microstructures displayed less porosity and pedality than the stratigraphic unit I, with frequent root remains, coarse minerals, nucleic organic nodules, and occasional occurrence of micromollusks (Fig. 3B). The peaks of the three metals dropped suddenly between 12-1 cm to levels indicating desiccation of the León River wetlands in modern times. Accordingly, the *p*H, ECEC and base saturation decreased as opposed to the organic matter and total phosphorus (Table 2).

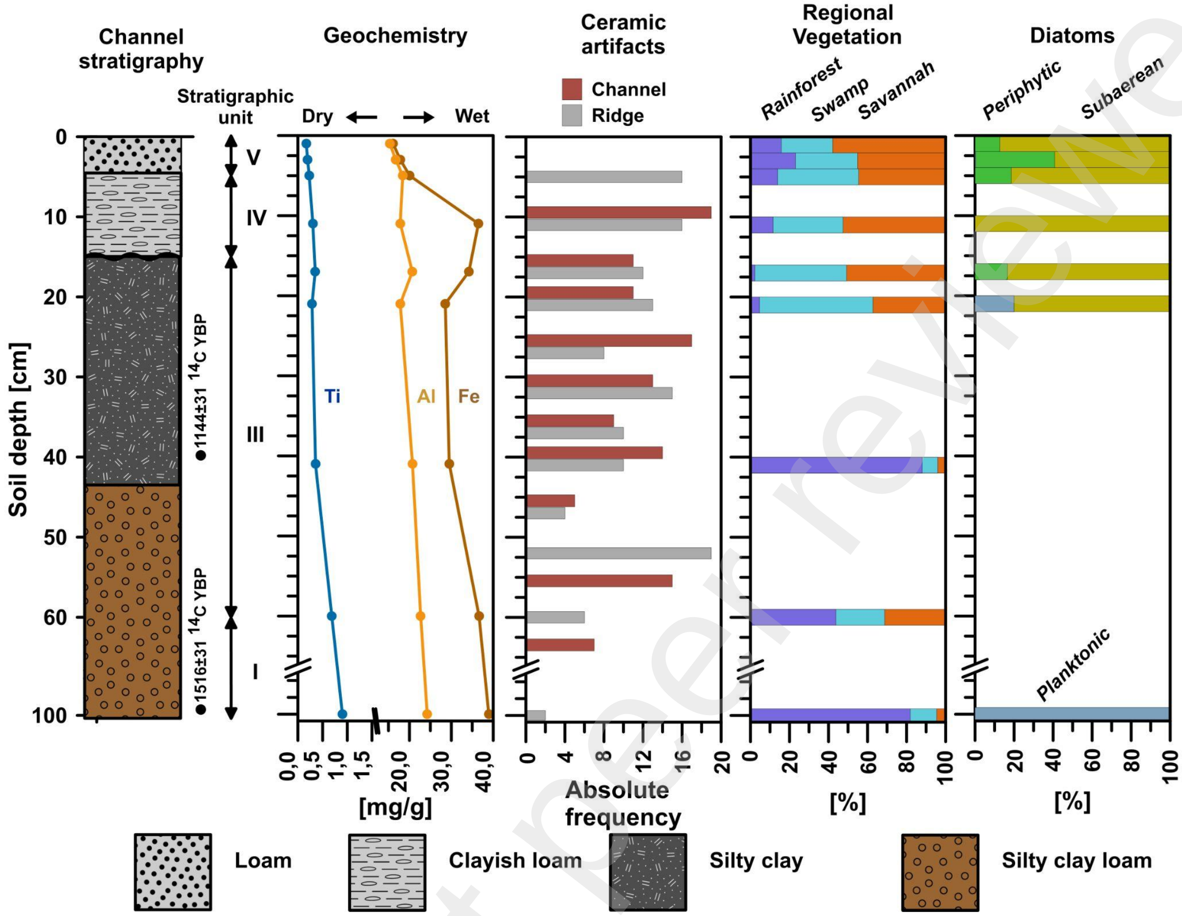

Fig. 4. Vertical distribution of multiproxy data from El Vergel channel core.

4.5. Data correlation and paleoecological reconstruction

The vertical and statistical correlation of data show the reliance of pollen, diatoms and geochemistry for hydroclimatic interpretation in spite of Fe oxidation. The variance explained by two principal components is 82.04% (Fig. 5). The component 1 explained 58.64% of the variance and was mostly weighed by Fe, pollen and subaerial and periphytic diatoms. The component 2 was represented by Al, Ti, planktonic diatoms and ceramic artifacts. The contents of Fe, Al and Ti correlated significantly ($p<0.05$) among them with Pearson correlation coefficients ranging 0.76-0.92. The Fe reverse correlated ($p<0.05$) with subaerial and periphytic diatoms as well as pollen, with Pearson correlation coefficients between 0.67-0.88. Neither Al or Ti correlated significantly with biological data. Pollen of the three assemblages correlated highly (p<0.01) among them and with subaerial diatoms (Pearson r=0.85-0.97). The periphytic diatoms correlated (p<0.05) with subaerial diatoms as well as pollen from tropical rainforest and savannah (Pearson r= 0.67-0.89). No significant correlation was found between ceramic density and chemical or biological data.

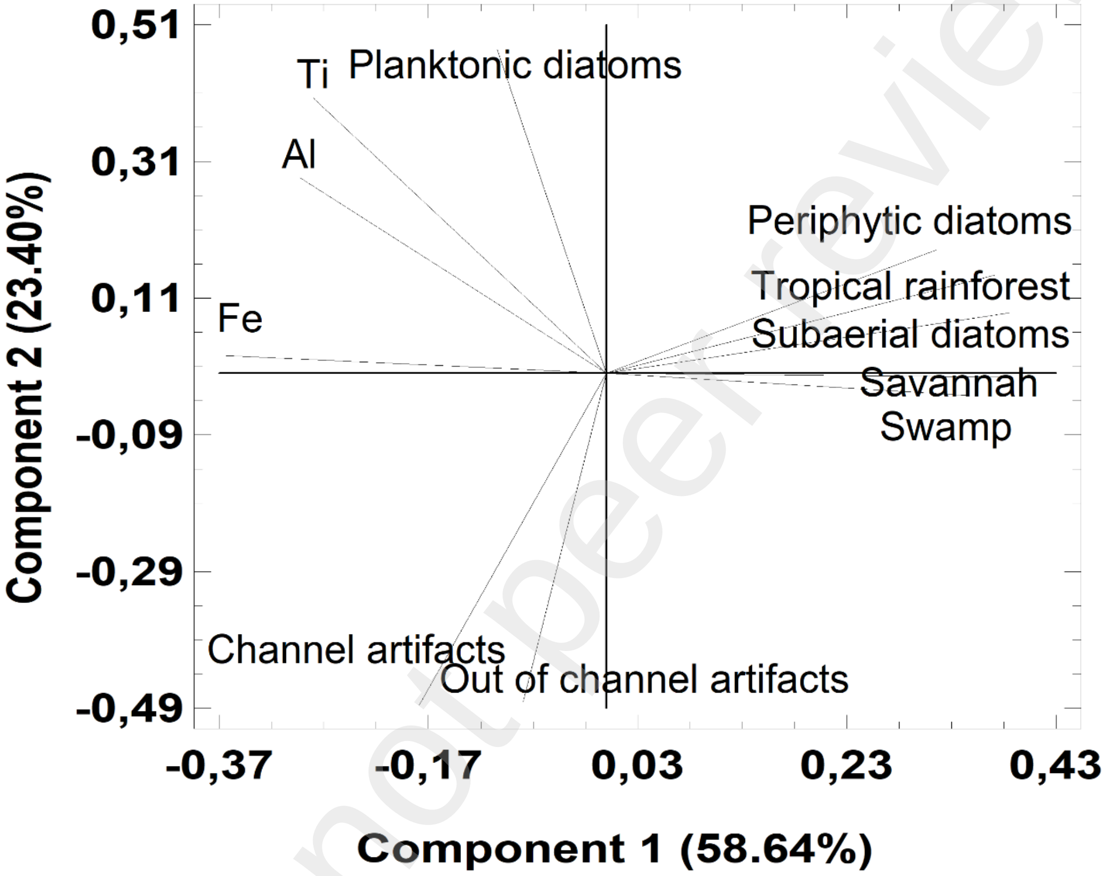

Fig. 5. Principal Component Analysis for pollen assemblages, diatoms, artifacts and geochemistry.

The sediment load to the floodplain arises from weathering of the densely forested mountains of Serranía de Abibe, therefore the content Fe, Al and Ti in channel sediments can be used for elucidating the frequency of fluvial events by hydroclimatic forcing. Indeed, high sedimentary content of Fe, Al and Ti was found in the channel along with high pollen density from tropical rainforest and low density for both human pottery and planktonic diatoms (Fig. 5).

The human occupation began at 531-609 CE before channel development, when the record of *Forsteronia* sp. woody creepers in the palynomorphs indicated prevailing humid conditions with a long term decreasing trend towards present. According to artifact deposition, this first human incursion was not permanent but stationary. The prevailing humid conditions depicted by the palynomorphs concur well with high levels of Fe, Al and Ti derived by high sedimentation rates and runoff. The amount of diatom valves in the channel soil was low with sparing occurrence of *Aulacoseira* sp. and *Gyrosigma cf. scalproides* (Fig. 4). The raised fields were built before 868-991 CE, when human occupation became permanent, coinciding with decreased precipitation that caused diminished pollen accumulation rates although the rainforest remained yet the main local ecosystem. The low rates for accumulation of rainforest pollen continued until fading within the stratigraphic unit IV. The occurrence of subaerial diatoms indicated reduction in aquatic habitat as well.

The geochemistry suggested a light increase in runoff that was not confirmed by either pollen or diatom records during this period in the stratigraphic unit IV. This apparent contradiction needs to be interpreted in the light of newly increased erosion rates due to human earthworks and the mixing properties of this altered stratigraphical unit by an atypic flood event. Clearly, this event was out of control of the raised fields because it is widespread around the site on both the channel and ridge. The Fe peak atop this stratigraphic unit could be regarded as an effect of oxidation (Muñoz et al., 2017; Petersen et al., 2000) probably during plant diversification due to warming and dry weather. This peak was concomitant with a lull for Ti and Al, which could thus reliably be interpreted as decreased deposition of sediments.

In fact, diatoms were very scarce and forest regenerated slightly displaying other new taxa, but savannah vegetation persisted as long as artifacts deposition reached the highest count. The incipient soil development, the diversity of biological remains and redoximorphic features observed micromorphologically, along with chronostratigraphic data, suggest that the stratigraphic unit IV was caused by a local, strong and short term flood event during a dry and warm environment. The environmental conditions beyond the stratigraphic unit IV changed progressively to dryness and evinced people suddenly disappearing.

5. Discussion

The first humans arrived at El Vergel archaeological site around VI century CE, but the earthworks seem to have been developed for permanent use a few centuries later. Our paleoecological and chronostratigraphic data highlighted the prevalence of a wet environment in El Vergel during this first stage of occupation. Additionally, the data depicted a long term trend towards a dry period after construction of the raised fields around the IX century CE. It is consistent with palynological records from the western Colombian Andes (Muñoz et al., 2017; Rangel et al., 2005; Velásquez, 2005) and the Panamanian Darien (Bush and Colinvaux, 1994; Lachniet et al., 2004) during a fairly dry period between CE 1100 and 1200 year BP regarded as Medieval Warm Period (Acevedo et al., 2020; Berrío et al., 2000; Plazas et al., 1988; Van der Hammen et al., 2005; Velásquez, 1999). Hence the runoff reduction could not have the anthropic influence only.

Additional palynological data coming from the coastal plains is, however, challenging due to elution by large sediment loads collected in the lowlands (Lazala et al., 2010; Romero and Rangel, 2013). Other factors adding to this elution are the anthropogeomorphic disturbances and ENSO variability that result in increased precipitation, erosion and runoff (Haug et al., 2001; Martin et al., 1993; Muñoz et al., 2017). The sediment load arising from ENSO variability is particularly high in the southern Gulf of Urabá owing to massive precipitation caused by the convergence of the low level atmospheric jets Panama and Chocó beyond the seasonal migration of the intertropical convergence zone (ITCZ) (Poveda and Mesa, 1999; Rúa et al., 2015; Vélez-Agudelo and Aguirre-Ramírez, 2016). Besides climatic patterns, the León river basin is a groundwater dependent system which floods the wetland regardless of rainfall at short term (Arana, 2015; CORPOURABA, 2019), so regional hydrogeology plays an important role in the water storage and transfer to the ecosystem.

The whole data suggest a reduced, continued and slow deposition of sediments, without organic accumulation and mild mineral weathering associated with unstable geomorphic processes. Most of these processes were influenced by water table fluctuations and increased flow through artificial ditches. This led to incipient soil development and low fertility according to poor organic carbon and phosphorus contents, besides the potentially toxic soluble salts enrichment in the soil. For this reason along with the lack of cultivars, clearing or plowing evidence, we cannot link the studied raised fields with agricultural practices. Conversely to other raised fields in South America with cultivation evidence (Berrío et al., 2001; Boixadera et al., 2019; Iriarte et al., 2010; Plazas et al., 1988; Rodrigues et al., 2020, 2014), the El Vergel profile does not show either buried soils nor peat that could be related to organic rich/manure accumulation model (Lombardo et al., 2011).

The low content of sedimentary organic matter and coarse granulometry during channel operation, is probably because the water in the channels was not stagnant, but rather flowing, leading to suspension transport of low gravity sediments, accumulation of coarser ones and allowing mechanical diatom fragmentation. This is reinforced by the domination of mottled or redoximorphic features instead of gleyed morphology in the whole profile. Therefore, there is a clear probability that prehispanic communities in El Vergel site managed a climate transition towards a less humid environment by developing raised and ditched fields for reasons different from agricultural production (Lombardo et al., 2011; Morlon, 2006; Rodrigues et al., 2018).

The lack of agriculture should not be overestimated because of the restrictions of our survey and the differential performance of raised fields (Morlon, 2006; Renard et al., 2012). Nonetheless, the cultivated plants could be a marginal food resource regarding fishing, turtle farming, hunting and gathering as important strategies against local ecosystem services (Comptour et al., 2018; Erickson, 2000; Jaramillo and Jiménez, 2008; Márquez, 2008). By the way, Posada (2022) reports a domestic context in the Toribio archaeological site, near 13.5 km from El Vergel, with hearth evidence and frequent remains of mollusks.

The use of ditched fields for managing flood pulses proposed by Lombardo et al. (2011), seems also plausible in El Vergel. However, there is evidence to support a wider hypothesis including the use of this technology for regional distribution of water during a period of hydric stress. Sourcing would be fluvial as well as subterranean from available shallow springs (Betancur-Vargas et al., 2020; Ríos and Martínez, 1995) and developed by wells and ditched fields, in the same way of Maya wells and reservoirs in seasonally dry regions

(Isendahl, 2011; Johnston, 2004). Water redistribution would be akin to that of natural flood pulses to mitigate progressive dryness, and could explain the pervasive occurrence of the raised fields with interconnected channels and no clear boundaries among the watersheds of the rivers León, Suriquí and Tumaradocito (Posada, 2022).

This study is unable to provide a rationale for the practical disuse of these raised/ditched fields at the end of the prehispanic period. Nevertheless, the sudden event related to the occurrence of the stratigraphic unit IV must be taken into account, since it broke the historical sequence. Despite bearing potentially reworked materials at this stratum, accounting for the above mentioned strong depositional event together with both demographic increase and intense alteration of the landscape, constitute valuable clues for further research to understand the abandonment of the site before the Spanish conquest of Urabá

After reviewing these ideas through multiproxy data and specific geographic conditions in the Gulf of Urabá, considerable insight has been gained in regard to the hydrological system management of prehispanic communities beyond agricultural practices. Thus, people profited on a wide range of hydrobiological resources taking advantage of the hydric and hydraulic predictability of the raised/ditched fields to reduce cultivation dependence and climatic change risks.

6. Conclusions

Our study at the El Vergel archaeological site shows that around 531- 609 yr CE, the first evidence of human occupation was recorded in the León River wetlands with no signs of earthworks stratigraphically associated. The occupation seems to be sporadic or seasonal according to the vertical variability of ceramic deposition. Prevailed humid climatic conditions and forest cover in the wetland at this stage.

Geochemical, palynological, and diatom data reveal a progressive shift toward drier climatic conditions. At the same time, human occupation of the site intensifies, peaking around 868 – 991 yr CE. The peak of the occupation occurs when channel and ridge have been developed earlier.

In spite of critical effects on the palynomorphs and biogenic silica bodies preservation, and the redoximorphic conditions, salt accumulation and fluvial transport processes, we found low levels of natural fertility in the soil by physical and chemical properties and no evidence of agriculture by macro and micromorphological features, so we cannot to establishing clear associations between raised fields and agricultural practices.

Instead, the presence of well-formed channels in the warming period, the spatial distribution of shallow springs from the aquifer and the report of aquatic faunal remains in the nearby archaeological site Toribio, suggest the development of raised fields for water use and management, probably for wetland conservation and aquaculture during drought period. These results highlight the role of raised fields for hydric control as the primary resource of the wetland ecosystem in Urabá, encouraging new lines on research for the Colombian-Isthmic archaeology, paleoecology and conservation.

Acknowledgements

This research was funded by Universidad de Antioquia (CODI project 28455). We thank the people in Barranquillita town and the El Vergel farm (Urabá). Thanks are also due to Semillero de Investigación ETNOS, specially to Angie Katherine Sanchez. Besides to the Grupo de Investigación y Gestión del Patrimonio GIGP and Grupo de Investigación en Sistemas Marinos y Costeros GISMAC. Support was given by Tecnológico de Antioquia Institución Universitaria, who funded this work in its latest stages.

References

Acevedo, A., Velásquez, C., Pardo-Trujillo, A., Vélez, M., Vallejo, F., Jaramillo, D.L., Trejos, R., 2020. Dinámica del clima y la vegetación de los últimos 6700 años en el sector de Mistrató (Cordillera Occidental, Colombia). Bol. Cient. del Cent. Museos 24, 48–67. https://doi.org/10.17151/bccm.2020.24.1.3

Alzate, L.A., 2015. Arqueología Histórica y Arqueometría para el Estudio de la Cerámica Colonial en Fundaciones de Terra Firme – Siglo XVI. Universidad de Barcelona.

Arana, V., 2015. Análisis y valoración de los servicios de los ecosistemas de humedales asociados al río León (Urabá antioqueño - Colombia). Su relación con el sistema hídrico subterráneo y con el bienestar humano. Universidad Nacional de La PLata.

Arcila, G., 1955. Informe de las investigaciones realizadas en Dabeiba - Chigorodó y Acandí en Septiembre de 1954. Boletín Antropol. 3, 246–264.

Barker, P., 1992. Differential diatom dissolution in Late Quaternary sediments from Lake Manyara, Tanzania: an experimental approach. J. Paleolimnol. 7, 235–251. https://doi.org/10.1007/BF00181716

Berrío, J.C., Behling, H., Hooghiemstra, H., 2000. Tropical rain-forest history from the Colombian Pacific area: A 4200-year pollen record from Laguna Jotaordo. Holocene 10, 749–756. https://doi.org/10.1191/09596830094999

Berrío, J.C., Boom, A., Botero, P.J., Herrera, L.F., Hooghiemstra, H., Romero, F., Sarmiento, G., 2001. Multi-disciplinary evidence of the Holocene history of a cultivated floodplain area in the wetlands of northern Colombia. Veg. Hist. Archaeobot. 10, 161–174. https://doi.org/10.1007/PL00006928

Betancur-Vargas, T., Duque-Duque, J.C., Martínez-Uribe, C., Garcia-Giraldo, D.A., Villegas-Yepes, P.P., Paredes-Zuñiga, V., 2020. Delimitación de las potenciales zonas de recarga-caso de estudio: acuífero multicapa del eje bananero del Urabá Antioqueño-Colombia. Rev. Politécnica 16, 41–55. https://doi.org/10.33571/rpolitec.v16n32a4

Betancur-Vargas, T., García-Giraldo, D.A., Vélez-Duque, A.J., Gómez, A.M., Flórez-Ayala, C., Patiño, J., Ortiz-Tamayo, J.Á., 2017. Aguas subterráneas, humedales y servicios ecosistémicos en Colombia. Biota Colomb. 18, 1–28. https://doi.org/10.21068/c2017.v18n01a1

Boixadera, J., Esteban, I., Albert, R.M., Poch, R.M., 2019. Anthropogenic soils from Llanos de Moxos (Bolivia): Soils from pre-Columbian raised fields. Catena 172, 21–39. https://doi.org/10.1016/j.catena.2018.08.007

Bray, W., 1990. Cruzando el tapón del Darién: una visión de la arqueología del Istmo desde la perspectiva colombiana. Boletín Mus. del Oro 29, 3–51.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., 1985. Handbook for soil thin section description. Waine Research Publications, England.

Bush, M., Colinvaux, P., 1994. Tropical forest disturbance: paleoecological records from Darien, Panamá. Ecology 75, 1761–1768.

Capodiferro, M.R., Aram, B., Raveane, A., Rambaldi Migliore, N., Colombo, G., Ongaro, L., Rivera, J., Mendizábal, T., Hernández-Mora, I., Tribaldos, M., Perego, U.A., Li, H., Scheib, C.L., Modi, A., Gòmez-Carballa, A., Grugni, V., Lombardo, G., Hellenthal, G., Pascale, J.M., Bertolini, F., Grieco, G.S., Cereda, C., Lari, M., Caramelli, D., Pagani, L., Metspalu, M., Friedrich, R., Knipper, C., Olivieri, A., Salas, A., Cooke, R., Montinaro, F., Motta, J., Torroni, A., Martín, J.G., Semino, O., Malhi, R.S., Achilli, A., 2021. Archaeogenomic distinctiveness of the Isthmo-Colombian area. Cell 184, 1706-1723.e24. https://doi.org/10.1016/j.cell.2021.02.040

Castillo, N., 1988. Complejos arqueológicos y grupos étnicos del siglo XVI en el Occidente de Antioquia. Boletín Mus. del Oro 20, 16–34.

Comptour, M., Caillon, S., Rodrigues, L., McKey, D., 2018. Wetland Raised-Field Agriculture and Its Contribution to Sustainability: Ethnoecology of a Present-Day African System and Questions about Pre-Columbian Systems in the American Tropics. Sustainability 10, 3120. https://doi.org/10.3390/su10093120

Cooke, R., Sánchez, L., 2001. El papel del mar y las costas en el Panamá prehispánico y del período del contacto: redes locales y relaciones externas. Rev. Hist. (Costa. Rica). 43, 15–60.

CORPOURABA, 2019. Plan de Ordenamiento y Manejo de la Cuenca Hidrográfica del río León. Ajuste del plan de ordenación y manejo de la cuenca del río León SZH (1202).

Courty, M., Goldberg, P., Macphail, R., 1989. Soils and micromorphology in archaeology, First. ed. Cambridge University Press, Cambridge.

Denevan, W., 2006. Una perspectiva histórica sobre el descubrimiento de Campos Elevados (Camellones) prehispánicos en Sudamérica, in: Valdéz, F. (Ed.), Agricultura Ancestral, Camellones y Albarradas. Contexto Social, Usos y Retos Del Pasado y Del Presente. Coloquio Agricultura Prehispánica Sistemas Basados En El Drenaje y En La Elevación de Los Suelos Cultivados. Ediciones Abya Yala, Quito, pp. 17–24.

Denevan, W., 1970. Aboriginal Drained-Field Cultivation in the Americas. Science (80-.). 3946, 647–654.

Erickson, C.L., 2000. An artificial landscape-scale fishery in the Bolivian Amazon. Nature 408, 190–193. https://doi.org/10.1038/35041555

Faegri, K., Iversen, J., 1975. Textbook of pollen analysis. Hafner Pub. Co., New York.

Flower, R.J., 1993. Diatom preservation: experiments and observations on dissolution and breakage in modern and fossil material. Hydrobiologia 269–270, 473–484. https://doi.org/10.1007/BF00028045

Fonseca, O., Cooke, R., 1993. El sur de América Central: contribución al estudio de la región histórica Chibcha, in: Carmack, R. (Ed.), Historia General de Centroamérica. Ediciones Siruela, Madrid, pp. 217–282.

Fritz, S., Cumming, B., Gasse, F., Laird, K., 1999. Diatoms as indicators of hydrologic and climatic change in saline lakes, in: The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press, pp. 41–72. https://doi.org/10.1017/CBO9780511763175.011

GIAP, 1980. Investigación arqueológica y prehistórica de un yacimiento conchal en la costa Atlántica colombiana, Turbo - Antioquia. Univ. Antioquia.

Goldberg, P., Macphail, R.I., 2006. Practical and Theoretical Geoarchaeology. Wiley, London. https://doi.org/10.1002/9781118688182

González, S., 2022. Paleohidrología y ocupaciones humanas prehispánicas en las tierras bajas inundables del golfo de Urabá , Colombia : un acercamiento a las condiciones de riesgo y vulnerabilidad económicas en el sitio arqueológico El Vergel. Universidad de Antioquia.

Guevara, N., Montes, J., Diederix, N., Gómez-Tapias, J., 2015. Mapa Geológico de Colombia. Escala 1:1.000.000.

Guzmán, H., Ceballos, J., 2001. La difluencia del río León hacia el caño Tumaradó. Región de Urabá.

Haug, G.H., Hughen, K.A., Sigman, D.M., Peterson, L.C., Röhl, U., 2001. Southward Migration of the Intertropical Convergence Zone Through the Holocene. Science (80-.). 293, 1304–1308. https://doi.org/10.1126/science.1059725

Helms, M., 1979. Ancient Panama: Chiefs in Search of Power. University of Texas Press, Austin.

IDEAM, 2013. Aguas Subterráneas en Colombia: una Visión General.

Instituto Geográfico Agustín Codazzi - IGAC, 2007. Estudio semidetallado de suelos de las áreas potencialmente agrícolas. Urabá. Departamento de Antioquia. Imprenta Nacional de Colombia, Bogotá.

Iriarte, J., Glaser, B., Watling, J., Wainwright, A., Birk, J.J., Renard, D., Rostain, S., McKey, D., 2010. Late Holocene Neotropical agricultural landscapes: phytolith and stable carbon isotope analysis of raised fields from French Guianan coastal savannahs. J. Archaeol. Sci. 37, 2984–2994. https://doi.org/10.1016/j.jas.2010.06.016

Isendahl, C., 2011. The weight of water: A new look at pre-hispanic puuc maya water reservoirs. Anc. Mesoamerica 22, 185–197. https://doi.org/10.1017/S0956536111000149

Jaramillo, Ú., Jiménez, L., 2008. La pesca en la ciénaga Tumaradó Bajo Río Atrato, Colombia. Dahlia 10, 16.

Jiménez, G., Campillo, L., 2020. Caracterización termohalina de las masas de agua en el golfo de Urabá. Caso específico desembocaduras del río León y el río Atrato. Universidad de Antioquia.

Johnston, K.J., 2004. Lowland Maya water management practices: The household exploitation of rural wells. Geoarchaeology 19, 265–292. https://doi.org/10.1002/gea.10117

Jorgensen, E., 1955. Solubility of the Silica in Diatoms. Physiol. Plant. 8, 846–851.

Junk, W., Bayley, P., Sparks, R., 1989. The flood pulse concept in river-floodplain systems, in: Dodge, D. (Ed.), Proceedings of the International Large River Symposium (LARS). Canadian Special Publication of Fisheries and Aquatic Sciences 106, Ontario, pp. 110–127.

Lachniet, M.S., Burns, S.J., Piperno, D.R., Asmerom, Y., Polyak, V.J., Moy, C.M., Christenson, K., 2004. A 1500-year El Niño/Southern Oscillation and rainfall history for the Isthmus of Panama from speleothem calcite. J. Geophys. Res. D Atmos. 109, 1–8. https://doi.org/10.1029/2004JD004694

Lazala, M., Rangel, O., Romero, I., Valderrama, Y., Parra, N., 2010. Cambios en la vegetación y el clima en las ciénagas de Córdoba, in: Rangel, O. (Ed.), Colombia Diversidad Biótoca IX. Ciénagas de Córdoba: Biodiversidad, Ecología y Manejo Ambiental. Universidad Nacional de Colombia, Bogotá D.C, pp. 72–100.

Lombardo, U., Canal-Beedy, E., Fehr, S., Veit, H., 2011. Raised fields in the Bolivian Amazonia: a prehistoric green revolution or a flood risk mitigation strategy? J. Archaeol. Sci. 38, 502–512.

Macklin, M.G., Lewin, J., 2015. The rivers of civilization. Quat. Sci. Rev. 114, 228–244. https://doi.org/10.1016/j.quascirev.2015.02.004

Márquez, G., 2008. El hábitat del hombre caimán y otros estudios sobre ecología y sociedad en el Caribe. Corporación Parque Cultural del Caribe - Universidad Nacional de Colombia, Barranquilla.

Martín, J.G., Mendizábal, T., Scherg, R., Cook, R., Piperno, D., 2015. Pre-Columbian raised fields in Panama: First evidence. J. Archaeol. Sci. 3, 558–564.

Martin, J.G., Sánchez, L.A., 2007. El istmo mediterráneo: intercambio, simbolismo y filiación social en la bahía de Panamá durante el período 500-1000 D.C. Rev. Arqueol. del Área Intermedia 7, 113–122.

Martin, L., Fournier, M., Mourguiart, P., Sifeddine, A., Turcq, B., Flexor, J.-M., Absy, M.L., 1993. Southern Oscillation Signal in South American Palaeoclimatic Data of the Last 7000 Years. Quat. Res. 39, 338–346. https://doi.org/10.1006/qres.1993.1040

Mendizábal, T., Martin, J.G., Pourcelot, J.-S., 2021. Síntesis y apuntes hacia la definición de una secuencia cerámica del Gran Darién, in: Martin, J.G., Mendizábal, T. (Eds.), Mucho Más Que Un Puente Terrestre. Avances de La Arqueología En Panamá. Editora Novo Art, S. A., Panamá, pp. 239–294.

Merten, J., Stiegler, C., Hennings, N., Purnama, E.S., Röll, A., Agusta, H., Dippold, M.A., Fehrmann, L., Gunawan, D., Hölscher, D., Knohl, A., Kückes, J., Otten, F., Zemp, D.C., Faust, H., 2020. Flooding and land use change in Jambi Province, Sumatra: integrating local knowledge and scientific inquiry. Ecol. Soc. 25, art14. https://doi.org/10.5751/ES-11678-250314

Montoya, J., Catillo, M., Sánchez, L., 2011. La importancia de las inundaciones periódicas para el funcionamiento y conservación de los ecosistemas inundables de grandes ríos tropicales: estudios en la cuenca del Orinoco. Interciencia 36, 900–907.

Morlon, P., 2006. Los camellones alrededor del lago Titicaca: ¿modificación radical de los peores terrenos o aprovechamiento de uno de los más favorables.?, in: Valdez, F. (Ed.), Agricultura Ancestral, Camellones y Albarradas. Contexto Social, Usos y Retos Del Pasado y Del Presente. Coloquio Agricultura Prehispanica Sistemas Basados En El Drenaje y En La Elevación de Los Suelos Cultivados. Ediciones Abya Yala, Quito, pp. 251–272.

Muller, N., 1995. River dynamics and floodplain vegetation and their alterations due to human impact. Large Rivers 9, 477–512.

Muñoz, P., Gorin, G., Parra, N., Velásquez, C., Lemus, D., Monsalve, C., Jojoa, M., 2017. Holocene climatic variations in the Western Cordillera of Colombia: A multiproxy high-resolution record unravels the dual influence of ENSO and ITCZ. Quat. Sci. Rev. 155, 159–178.

Nicosia, C., Stoops, G., 2020. Archaeological soil and sediment micromorphology. Wiley Blackwell, Chichester, UK.

Ordóñez, S., 2006. Cualidades agrofísicas del sistema Waru Warus en el altiplano de Puno-Perú, in: Valdez, F. (Ed.), Agricultura Ancestral, Camellones y Albarradas. Contexto Social, Usos y Retos Del Pasado y Del Presente. Coloquio Agricultura Prehispanica Sistemas Basados En El Drenaje y En La Elevación de Los Suelos Cultivados. Ediciones Abya Yala, Quito, pp. 17–24.

Palomino-Ángel, S., Anaya-Acevedo, J.A., Simard, M., Liao, T.-H., Jaramillo, F., 2019. Analysis of Floodplain Dynamics in the Atrato River Colombia Using SAR Interferometry. Water 11, 875. https://doi.org/10.3390/w11050875

Parolin, P., Wittmann, F., 2010. Struggle in the flood: tree responses to flooding stress in four tropical floodplain systems. AoB Plants 2010. https://doi.org/10.1093/aobpla/plq003

Petersen, L.C., Haug, G.H., Hughen, K.A., Röhl, U., 2000. Rapid Changes in the Hydrologic Cycle of the Tropical Atlantic During the Last Glacial. Science (80-.). 290, 1947–1951. https://doi.org/10.1126/science.290.5498.1947

Piazzini, E., 2020. Entre Colombia y Panamá. Arqueologías del Chocó norte. Instituto de Estudios Regionales, Universiad de Antiquia, Medellín.

Plazas, C., Falchetti, A.M., Van Der Hammen, T., Botero, P., Sáenz, J., Archila, S., 1988. Cambios ambientales y desarrollo cultural en el bajo río San Jorge. Boletín Mus. del Oro 20, 55–88.

Posada, W., 2022. Paleoambientes y estructuras hidráulicas en la cuenca del río León: un estudio sobre estrategias adaptativas y desarrollos territoriales en el Urabá prehispánico.

Posada, W., Cadena, B., González-Severiche, C., Arroyave-Flórez, E., 2019. El sistema de canales y camellones prehispánico del golfo de Urabá, noroccidente de Colombia. Un reporte arqueológico y geográfico preliminar. Rev. Colomb. Ciencias Exactas 43, 628–637. https://doi.org/http://dx.doi.org/10.18257/raccefyn.856

Poveda, G., Mesa, O., 1999. La Corriente de chorro superficial del oeste “del Chocó”: Climatología y Variabilidad durante las fases del ENSO. Rev. la Acad. Colomb. ciencias exactas, físicas y Nat. 23, 517–528.

Ramírez, H., Zárate, P., García, M., De la Torre, O., Isarde, I., Meulenert, Á., 2007. Disolución de sílice biogénica en sedimentos de lagos utilizados como bioindicadores de calidad del agua. e-Gnosis 5, 1–19.

Rangel, O., Moyano, E., Van Der Hammen, T., 2005. Estudio palinológico del Holoceno de la parte alta del macizo de Tatama, in: Van Der Hammen, T., Rangel, O., Cleef, A. (Eds.), Estudios de Ecosistemas Tropiandinos, Vol. 6. Cordillera Occidental Colombiana, Transecto Tatama. Ecoandes, Berlín, pp. 757–795.

Reed, J., 1996. The potential of diatoms, ostracods and other indicators for Holocene palaeoclimate research in southern Spanish salt lakes. Limnetica 12, 25–39.

Reichel - Dolmatoff, G., Dussán de Reichel, A., 1961. Investigaciones arqueológicas en la Costa Pacífica. I. Cupica. Rev. Colomb. Antropol. 10, 237–330.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon 62, 725–757. https://doi.org/10.1017/RDC.2020.41

Renard, D., Iriarte, J., Birk, J., Rostain, S., Glaser, B., McKey, D., 2012. Ecological engineers ahead of their time: The functioning of pre-Columbian raised-field agriculture and its potential contributions to sustainability today. Ecol. Eng. 45, 30–44.

Ríos, M., Martínez, C., 1995. Exploración y evaluación de aguas subterráneas en la región de Urabá. Corpourabá - Ingeominas, Bogotá D.C.

Rodrigues, L., Lombardo, U., Fehr, S., Preusser, F., Veit, H., 2014. Pre-Columbian agriculture in the Bolivian Lowlands: Construction history and management of raised fields in Bermeo. CATENA 132, 126–138. https://doi.org/10.1016/j.catena.2014.08.021

Rodrigues, L., Lombardo, U., Veit, H., 2018. Design of pre-Columbian raised fields in the Llanos de Moxos, Bolivian Amazon: Differential adaptations to the local environment? J. Archaeol. Sci. Reports 17, 366–378. https://doi.org/10.1016/j.jasrep.2017.11.023

Rodrigues, L., Sprafke, T., Bokatola Moyikola, C., Barthès, B.G., Bertrand, I., Comptour, M., Rostain, S., Yoka, J., McKey, D., 2020. A Congo Basin ethnographic analogue of pre-Columbian Amazonian raised fields shows the ephemeral legacy of organic matter management. Sci. Rep. 10, 10851. https://doi.org/10.1038/s41598-020-67467-8

Romero, I., Rangel, J.O., 2013. Cambios en la vegetación y en el clima durante el Holoceno tardío en el complejo cenagoso de Zapatosa (Cesar, Colombia). Colomb. Divers. Biótica XIII. Complejo cenagoso Zapatosa y ciénagas del sur del Cesar Divers. Conserv. y manejo 165–202.

Rostain, S., 2010. Pre-Columbian earthworks in Coastal Amazonia. Diversity 2, 331–352. https://doi.org/10.3390/d2030331

Rúa, A., Liebezeit, G., Molina, R., Palacio, J., 2015. Unmixing Progradational Sediments in a Southwestern Caribbean Gulf through Late Holocene: Backwash of Low-Level Atmospheric Jets. J. Coast. Res. 32, 397. https://doi.org/10.2112/JCOASTRES-D-14-00216.1

Santos, G., 1989. Las etnias prehispánicas y de la conquista en la región de Urabá. Boletín Antropol. 6, 1–118.

Segecin, R., De Santi, V., Segenci, S., 1999. Avaliação das técnicas de oxidação comumente empregadas na limpeza de valvas silicosas. Bol. da Soc. Bras. Limnol. 1, 17–25.

Sierra-Arango, O.R., 2013. Analisé paleoecológica e tafonômica de alta resolução em depósitos holocênicos no Páramo de Frontino, Antioquia, Colômbia, com base em diatomáceas. Universidade Federal do Rio Grande do Sul.

Sierra-Arango, O.R., Souza, P.A. de, Velásquez, C., 2014. Taphonomic signatures and paleoecology of Holocene diatom assemblages in the Llano Grande Basin, northwestern Andean Cordillera, Colombia. Rev. Bras. Paleontol. 17, 123–140. https://doi.org/10.4072/rbp.2014.2.02

Sloss, L., Krumbein, W., 1969. Estratigrafía y sedimentación. Departamento de Geología Universidad Northwestern, México D.F.

Soil Survey Staff –SSS, 2017. Soil Survey Manual. Soil Survey Division Staff.

Soil Survey Staff –SSS, 1999. Soil Taxonomy. A Basic System of Soil Classification for making and interpreting Soil Survey, Second. ed. United States Department of Agriculture, Washington D. C.

Stoops, G., Marcelino, V., Florias, M., 2010. Interpretation of Micromorphological Features of Soils and Regoliths. Elsevier, Ámsterdam. https://doi.org/10.1016/C2009-0-18081-9

Stuiver, M., Reimer, P.J., 1993. Extended 14 C Data Base and Revised CALIB 3.0 14 C Age Calibration Program. Radiocarbon 35, 215–230.

https://doi.org/10.1017/S0033822200013904

Van der Hammen, T., Rangel, O., Cleef, A., 2005. La Cordillera Occidental Colombiana transecto Tatamá. Cramer-Borntraeger, Berlin - Stuttgart.

Vasey, D.E., Harris, D., Olson, G., Spriggs, M., Tunner, B., 1984. The Roles of Standing Water and Water-Logged Soils in Raised-Field, Drained-Field and Island-Bed Agriculture. Singap. J. Trop. Geogr. 5, 63–72.

Velásquez, C., 2005. Paleoecología de alta resolución del holoceno tardío. Páramo de Frontino. Universidad Nacional de Colombia - Sede Medellín, Medellín.

Velásquez, C., 1999. Atlas palinológico de la flora vascular paramuna de Colombia: Angiospermae. Universidad Nacional de Colombia - Colciencias, Medellín.

Vélez-Agudelo, C., Aguirre-Ramírez, N., 2016. Influencia del Río Atrato en el Golfo de Urabá Durante el Holoceno Tardío, Mar Caribe Colombiano. Boletín Investig. Mar. y Costeras 45, 73–97.

Villegas, P., Paredes, V., Betancur, T., Ribeiro, L., 2013. Assessing the hydrochemistry of the Urabá Aquifer, Colombia by principal component analysis. J. Geochemical Explor. 134, 120–129. https://doi.org/10.1016/j.gexplo.2013.08.011

Warnock, J., Scherer, R., Loubere, P., 2007. A quantitative assessment of diatom dissolution and late quaternary primary productivity in the Eastern Equatorial Pacific. Deep Sea Res. Part II Top. Stud. Oceanogr. 54, 772–783. https://doi.org/10.1016/j.dsr2.2007.01.011