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Accumulation Rates Using the ^{210}Pb Dating Method in a Sediment Core of the Cispatá Bay, a Marine Protected Area in the Southwestern Colombian Caribbean

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Abstract

Sedimentation rates in coastal environments are controlled by different natural processes and could be affected by anthropic activities. To evaluate how was the evolution of the sedimentation along recent time, one sedimentary core (P01-BDC) from the Cispata bay was collected and analyzed to determine the sediment accumulation rates by ^{210}Pb dating. Using the constant flux (CF) model and validating by the activity of ^{137}Cs, the mass accumulation rates varied from 0.02 g cm^{-2} $year^{-1}$ during 1888 until 0.29 g cm^{-2} $year^{-1}$ in 2019. Increasing low sedimentation rates in a transitional estuarine -marine environment with variable fluvial sediment supply was explained by changes in the salinity due to the relocation of the main tributary of the bay.

Keywords: *Sediment accumulation rates, Pb-210, Marine protected area, Colombian Caribbean*

Introduction

Coastal zones are essential and integral components of the land since they constitute critical areas for environmental, economic, and social well-being. These environments have unique characteristics because of the exchange of matter and energy between the atmosphere, the land, and the sea, those which promote the development of coastal ecosystems and habitats such as estuaries, deltas, beaches, among others [1,2]. Estuaries are inlets open to coastal oceans that receive freshwater inputs and increasingly face the effects of climate change, including sea-level rise, habitat loss, hurricanes, and anthropic effects such as changes in land use, pollution, among others [1-3]. These stressors affect the distribution and behavior of animal and plant species, chemical components, and sedimentation processes [2] Sedimentation in estuaries is driven by runoff from hydrographic basins and tidal currents that vary with different time scales, it is one of the most relevant management challenges since it can negatively affect the environment by modifying flood regimes, and circulation and water quality [3]. On the Colombian Caribbean coast, in the southwest of the Morrosquillo Gulf is the Cispatá Bay, an estuary made up of fine sediments and some coral fossil deposits [4]. The Cispatá bay was formed from the evolution of the deltaic lagoon system of the Sinú River, whose flow is thrown into the Caribbean Sea through three mouths, Corea, Tinajones, and Los Llanos [5]. This river ended up in the Cispatá Bay until 1938, beginning its avulsion in the Tinajones area, whose mouth opened completely around 1945. Since then, different disturbances to the flow regime of the Sinú River have caused changes in the hydrodynamics and the contribution of sediments to the Cispatá Bay [6]. Using ^{210}Pb technique, we dated a sediment core collected in Cispatá bay in 2019 to evaluate the temporal trends of sediment accumulation rates (SAR) in the last century, under the hypothesis that changes in the input of sediments to the bay are related to the changes in the channel of the Sinú River. The results achieved will be valuable to understand the role of changes in the Sinú River delta, erosive processes, textural features, and pollution trends.

Methodology

Area of Study

Cispatá Bay is located in the Colombian Caribbean Coast, enclosed in The Mestizos peninsula on the western side of the Morrosquillo Gulf (Figure 1), Cordoba department, between 09°25'12"–09°20'8"N and 75°47'37"–75°55'30"W [7,8]. The Bay is a Holocene depositional landform formed by Rio Sinú before its diversion occurred between 1937 and 1945, when the Tinajones delta started to grow [6]. Rio Sinú is one of the most important fluvial systems of the Colombian Caribbean, draining the Andes with a total length of about 415 km and is a very intervened catchment area of 17,000 km^2. Its mean discharge is about 398.09 m^3/s (max. 858.2 m^3/s, min. 29.1 m^3/s) [9] and its sediment load is estimated to be in the order of 4.2 million t/y [10]. The bay has a tropical climate affected by Intertropical Convergence (ITC) annual displacements between the latitudes 5°S and 15°N, which produces an arid xerophytic savanna climate, with annual mean temperatures of 28.3°C (max. 28.8°C in January and

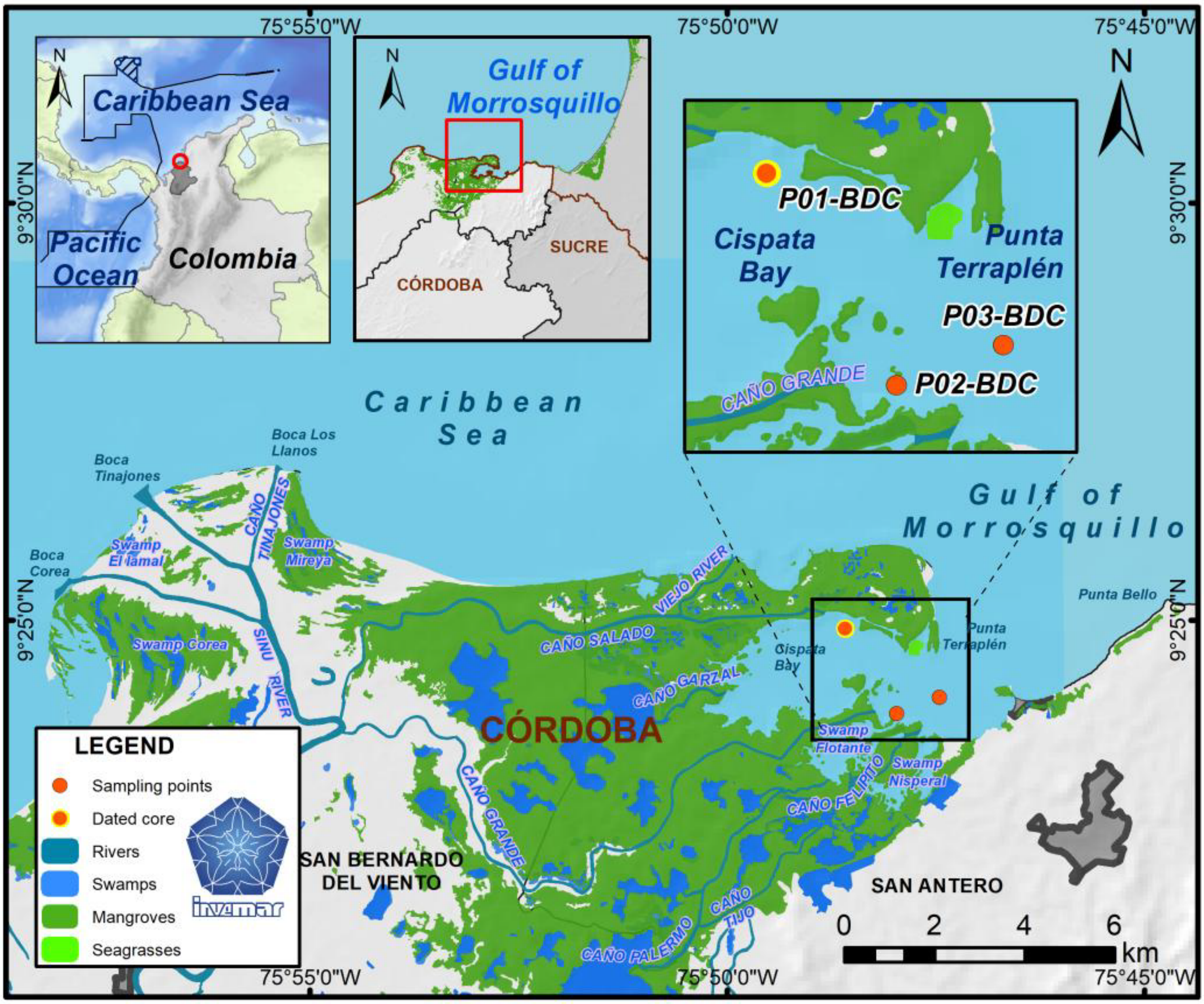

Figure 1: Dated core in the study area, Cispatá Bay Colombian Caribbean.

April; min. 27.9°C in October and November). Mean annual rainfall is about 1230 mm, with 3.3 mm in January and 177.6 mm in September (data for Monteria from IDEAM [11]. During the dry season (from December to April), north-east and north Trade winds prevail with speeds between 4 and 23 kt, whereas the wet season (from August to November) is characterized by calms and slow winds mostly from the west and south-west. Cispatá Bay is surrounded by a dense mangrove forest where some urban settlements live on fishing and wood production [12]. The surrounded areas have shown in the last years an increment in anthropic activities like agriculture, large variety of commercial fishing and tourism, as well as, some industrial activities such as an oil port which is located approximately 12 km from the Cispatá Bay [13]. This mangrove ecosystem also has the potential of saving high amounts of blue carbon [14], being in this way an important area for climate change politics.

Sample Collection

Sediment cores were collected in three different points of the Bahia de Cispatá in September of 2019, using a gravity corer UWITEC™ with a transparent liner (1,2 m long, 8.5 cm inner diameter). The depth of the water was around 1,8 m. The cores were immediately transported to the laboratory, where they were extruded and subsampled every 1 cm. The mass of each section was recorded before and after drying at 40°C. Sediments were ground to powder by using agate mortar and pestle. The samples were stored in polyethylene bags and the analysis were carried out at the Marine Environmental Quality – LABCAM of INVEMAR. The core collected at 9°24'54,2" (N) - 75°48'35,2" (W) (point P01-BDC, Figure 1) had a length of 72 cm and was dated with ^{210}Pb. The activities are expressed on a dry weight basis.

Laboratory Analyses

Total ^{210}Pb activities ($^{210}Pb_{Tot}$) in the core were estimated by measuring the activity of its daughter product ^{210}Po assuming secular equilibrium between the two isotopes by alpha spectrometry [15,16]. Accuracy was evaluated by measuring a certified reference material DL1-A (Uranium -Thorium Ore DL1-A, Canada Centre for Mineral and Energy Technology) for ^{210}Pb. Polonium isotopes were measured using a silicon surface barrier (EG&G Ortec Mod. ENS-U450) α-spectrometer. This detector is characterized by high energy resolution, low background, and stability. Discs were measured until achieving less than 5% of uncertainty in the ^{210}Po counting rate, according to IAEA (2012) [20]. Standard gamma spectrometry was used to measure ^{137}Cs via its emission at 662 keV and ^{226}Ra (supported ^{210}Pb) by the activity of ^{214}Pb at 295 keV and 351 keV [17]. Samples were placed and measured in a coaxial type (8 cm diameter) high-purity germanium detector (HPGe) from CANBERRA and counted for one week. Energy and efficiency calibrations were made using a certified reference material DL1-A (Uranium -Thorium Ore DL1-A, Canada Centre for Mineral and Energy Technology) for ^{210}Pb and ^{226}Ra, IAEA-375 (Radionuclides and trace elements in soil) for ^{137}Cs, and ^{40}K in a high purity (≥99.5%) salt KCl salt (manufactured for Merck)

Data Processing

Constant flux (CF) of ^{210}Pb model was used. In the CF model non-linearities of the ^{210}Pb profile are interpreted assuming a constant net rate of supply of unsupported ^{210}Pb ($^{210}Pb_{uns}$) from sea-water to the sediment, irrespective of changes which may have occurred in the net dry mass sedimentation rate [18]. Supported value ($^{210}Pb_{sup}$) is determined by two methods: first one by averaging the ^{210}Pb activities in the base of the core where they become constant [19] and second one by the activity of ^{226}Ra measured by gamma spectrometry. Then, unsupported value ($^{210}Pb_{uns}$) is obtained by subtracting $^{210}Pb_{sup}$ from $^{210}Pb_{Tot}$. This model allows to estimate the age of the sediment as well as the mass accumulation rates (MAR) and sediment accumulation rates (SAR). More information about age models and calculations are explained in detail by Sanchez [20].

Results

The core shows an exponential decay of the total ^{210}Pb ($^{210}Pb_{Tot}$) activity with mass depth (Figure 2a), with values ranging between 13.0 ± 1.1 Bq kg^{-1} and 43.7 ± 4.5 Bq kg^{-1}. and an average $^{210}Pb_{Tot}$ activity of 24.78 ± 7.3Bq kg^{-1} However, there are clear differences mainly after 15 g cm^{-2} where the profile shows a peak with the lowest activity of 13.0 Bq kg^{-1}, increasing to 25.5 Bq kg^{-1} at 17.7 g cm^{-2}. The activities behavior until the end of the core is erratic. Values for $^{210}Pb_{sup}$ are very similar by the two methods of calculation, i.e. via ^{214}Pb (^{226}Ra) emission peaks (Table 1) and by averaging the activities of $^{210}Pb_{Tot}$ (Figure 2a) at the bottom of the core (20.9 ± 3.1 Bq kg^{-1}). Due to the uncertainties associated to both methods, the average activity determined by alpha spectrometry was used for calculations of $^{210}Pb_{ex}$. The $^{210}Pb_{exs}$ activity (Figure 2b) shows values between 22.7 and 4.3 Bq kg^{-1} with an average value of 13.8 Bq kg^{-1} fitted to an exponential decay profile (r^2=0.75). The $^{210}Pb_{exs}$ activities in the first 15 cm of the sediment section were used to calculate the age sediments applying the CF model (Figure 2c), allowing to date the period since 1888 until 2019. The model was validated by gamma detection of ^{137}Cs in the core at 7.7 g cm^{-2} which was dated at 1983 ± 4, with this uncertainty the result could be associated with the Chernobyl accident in 1986. MAR and SAR profiles (Figure 3) present the same trends with time, a low and constant rate in the bottom increasing little by little until the top of the core. MAR increase from 0.02 g cm^{-2} year^{-1} in 1888 to 0.30 g cm^{-2} year^{-1} in 2019. By the other hand, SAR increase from 0.02 cm year^{-1} in 1888 to 0.45 cm year^{-1} in 2018 and decreasing to 0.38 cm year^{-1} in 2019. Due to the low sedimentation rates each analyzed section enclose several years having decadal or five-years period resolution.

Discussion

Activity of $^{210}Pb_{tot}$ is comparable with the reported values of 12.8 ± 0.4 to 46.6 ± 1.1 Bq kg^{-1} in Soledad Lagoon [21] which is part of the Cispatá swampy system. This low activity values are expected in some marine areas previously explained as the result of low atmospheric ^{210}Pb fluxes

Table 1: Gamma emission for ^{226}Ra ($^{210}Pb_{sup}$) for the bottom sediment section for the core P01-BDC, Cispatá Bay Colombian Caribbean.

Core section	$^{214}Pb_{295kev}$ (Bq kg^{-1})	$^{214}Pb_{351kev}$ (Bq kg^{-1})
67-68	17.99	17.25
70-71	18.54	18.38
71-72	17.85	20.30
Average	18.39	
Std. Dev	1.04	

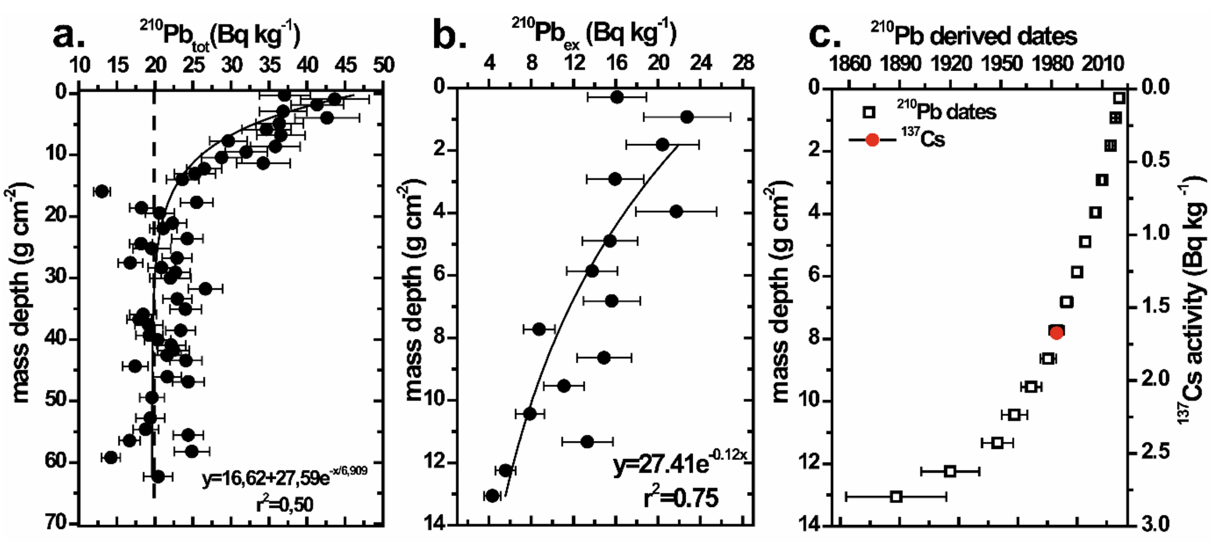

Figure 2: Dated core P01-BDC in Cispatá Bay Colombian Caribbean. a) total activity profile of ^{210}Pb, b) excess activity profile of ^{210}Pb, c) Age model.

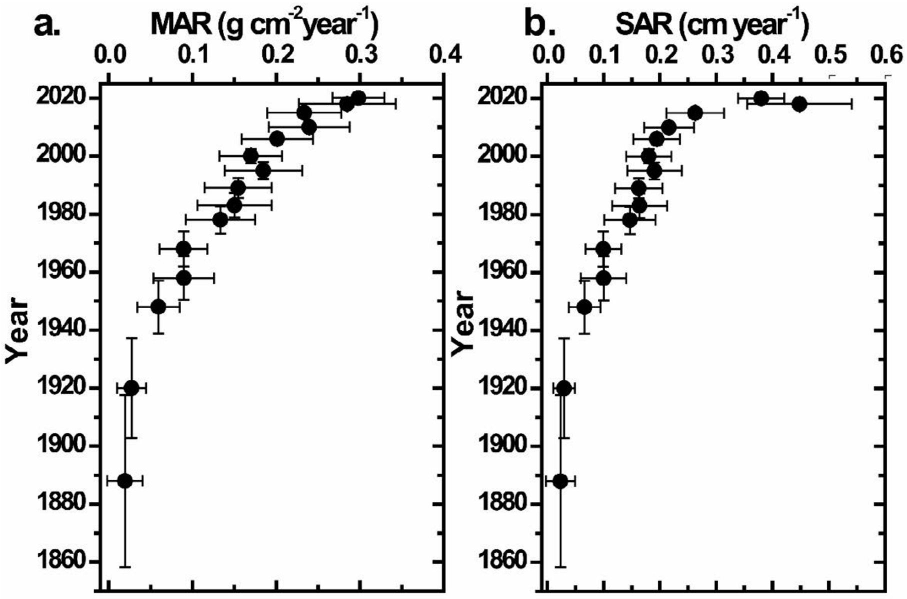

Figure 3: Sediment rates for core P01-BDC: a) Mass accumulation rates, b) Sediment accumulation rates.

and low production of ^{210}Pb [22]. Sedimentation rates (MAR ad SAR) are higher in Cispatá bay compare with those calculated for Soledad Lagoon MAR 0.08 ± 0.01 g cm^{-2} year^{-1} and SAR 0.154 ± 0.018 cm year^{-1} [21], due to the differences in the type of system, being Cispatá bay a more dynamic system influenced directly by the Caribbean sea and the fluctuations of the Sinú river mouth relocation, that control the sediment supply.

The Sediment rates in Cispatá bay showed changes associated with the geomorphological variations during the last 100 year. The relocation of the principal mouth after 1938 is evidenced in the increase of MAR and SAR. Before this time, the system was an estuarine system with high input of fresh water [6] and with variable hydrodynamics because of the changes in the Sinú river mouth which have been occurring since 1762 according to the available registers [6,11]. The transitional events occurring between an estuarie and a marine system in which salinity changes could form a salt wedge or significant differences in density, causing the fine sediment to remain more time in the water column. Thus, the sedimentation rates are low even with high sediment supply. The gradually increase trend of the sedimentation rates are in agreement with [6] who showed bathymetrically that during the period 1762-1849 the area where the core was recollected, presented erosive processes which implies a minor sediment input, meanwhile for the period 1849-1938 occurred a siltation process. According with the MAR and SAR calculated between 1938 and 2019, the sedimentation process has increased slowly evidencing that sedimentary behavior of Cispatá Bay is driven by: the morphodynamical characteristics of the surrounding environment, the input of water and sediment from the Sinú River remaining channels, the possible income of sediments from the erosion process occurring in the previous river mouth in Punta Terraplen, and by changes in land use.

Conclusion

The age model, based on ^{210}Pb activities, give valuable information about the sedimentary rates (MAR and SAR) in Cispatá Bay during the last ~100 year, evidencing changes in the sedimentary regime associated with geomorphological events which are important for the management of this marine protected area with high ecological potential, especially in blue Carbon sequestration. These preliminary results should be part of complementary research about flux of organic matter, pollutants as heavy metal, hydrocarbons, and other variables of environmental interest.

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