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STRATIGRAPHIC EVIDENCE OF PRO-THROMBOLITHIC GROUND FORMATION AROUND THE LA PAZ LAGOON (MÉXICO)

Evidencia estratigráfica de formación de suelo protrombolítico alrededor de la laguna de La Paz (México)

RESUMEN. Recientemente se propuso que procesos protrombolíticos promueven la formación de barras arenosas que transforman ensenadas en lagunas costeras. Se muestran evidencias estratigráficas que sustentan la hipótesis de que procesos protrombolíticos son responsables de la formación de suelos costeros de la laguna de La Paz que ya están urbanizados o colonizados por manglar. Se propone que éste bien podría ser el caso para varias lagunas costeras del NW mexicano.

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Based on classic descriptions of coastal lagoon formation (Phleger, 1969; Kjerfve, 1994) the La Paz lagoon began to form around 6000 years ago by mechanisms of coastal transportation of sediments that generated the sand bar El Mogote (Nava-Sánchez & Cruz-Orozco, 1989). The latter authors also estimate that the spite that gave rise to the El Conchalito estuary dates back between 5000 years to 6000 years. El Conchalito is located in the western limits of La Paz city between 24° 08' 34" N and 24° 07' 40" N and 110° 21' 04" W and 110° 20' 35" W (Fig. 1) and has a length of 1.5 km, with mangrove cover reaching up to 18.5 hectares and that of marshes over 20.8 hectares, *i.e.*, around 39.3 hectares of coastal wetlands (González-Acosta, 1998). Pro-thrombolites formations are common here. These have been described as non lithified sedimentary structures generated by the growth of cyanophyte mats, *i.e.*, clotted sediments with inclusions of shell fragments, irregularly packed, surrounded by a sheet of active cyanophytes (Siqueiros Beltrones, 2008).

Figure 1. Sites where cores from the estuary were extracted (T1 and T2). Foundation dig and maintenance ditch (Pz and Z). Sites where pro-thrombolites occur in El Conchalito (Pe, P0,1 ,2, 3) La Paz, B. C. S. Modified after Siqueiros-Beltrones (2008).

It has been proposed that spites and peninsulas, such as El Mogote sand bar, result from the seaward growth of pro-thrombolithic formations (Siqueiros Beltrones *et al*., 2006a, b; Siqueiros Beltrones, 2006, 2008; Siqueiros Beltrones *et al*., 2008), thus being responsible for the transformation of primitive coves into coastal lagoons. Likewise, this same process may explain accretion of the lagoon margins that gain ground seaward generating terrains such as El Conchalito and other peninsulas that become colonized by mangrove and marsh vegetation and eventually populated.

The theory on the role of pro-thrombolites in the geomorphology of coastal lagoons requires evidence for contrasting the hypothesis that pro-thrombolithic growths have occurred further landward, thus appearing at sea level within a stratigraphic sequence. An archaeological study in the area (Fig. 1) recorded several stratigraphic strata (Rosales & Fujita, 2000) that further support our recorded sequence. The flood layer described by these authors co-

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rresponds to a pro-thrombolithic stratum. Here we present evidence for that expectancy.

Stratigraphic observations were made in the CICIMAR-IPN campus where building operations took place during 2005 (2m deep foundation excavation) and for electric maintenance (1 m deep ditch) in 2007, roughly 80 m and 120 m from the coastal line, respectively. These allowed us to make a photographic record of the stratigraphic sequences aimed toward to locating pro-thrombolithic strata that emerge in the near intertidal (Siqueiros Beltrones, 2008). This was completed using previous records of pro-thrombolites located in several sites of the El Conchalito península.

We also looked for pro-thrombolithic strata using data from another ongoing investigation that described the stratigraphy of the study area through core sampling in the internal part of the mangrove swamp and close to the estuary mouth (Stratigraphic study of the El Conchalito estuary**,** Félix-Pico *et al*., *pers. com*.). Those samplings were done in November 2000 and December 2001, and elaborated stratigraphic columns for measuring and describing horizons. C^{14} dating techniques with a Delta-R of 250 years ± 50 years were also used. Shell samples were dated adjusting estimations to the Christian calendar.

Observations in the digs inside the CICIMAR-IPN campus confirm the presence of a superficial non-consolidated beach hori- zon and at a depth of 50 cm - 90 cm a compact beach horizon rich in shells of approximately 50 cm thick and that corresponds with the pro-thrombolithic spites observed in the intertidal (Fig. 2) south of site 1 (Figures 1, 3). The pro-thrombolithic stratum in the foundation dig shows higher humidity than the ditch stratum, very likely due to its nearness to the beach (Fig. 4). The appearance of that strata is consistent with that of the pro-thrombolites; clotted sediments irregularly packed with inclusions of shell fragments. This seems to correspond with the first flood layer (61 cm thick) observed during archaeological excavations carried out in the lower part of the north beach of El Conchalito (Rosales & Fujita, 2000). This also agrees with the finding in 2005 of superficial pro-thrombolithic strata extending in other sites (flood area) of El Conchalito (Fig. 5).

Figure 2. Prothrombolithic stratum located below the non-consolidated superficial beach stratum in the CICIMAR-IPN foundation site.

Figure 3. Prothrombolithic formation in the intertidal corresponding with the stratum at the CICIMAR-IPN excavations. Mangrove (*Avicennia germinans*).

Based on the above observations and composition of the horizons (core data), stratigraphic layers were standardized at a determined depth (Fig. 6). Thus, the first one, a mangrove soil layer was set at 0.9 m for core 1, followed by an intercalated beach and fluvial deposits layer with a mean thickness of 20 cm at a depth of 98 cm to 184 cm. Below this point the coring device could not break through, indicating the presence of a lithified plate. The mangrove soil deposit in core 2 had a thickness of 1.08 m, followed by a third layer of beach and shell deposits with 25 cm mean thickness at a depth of 119 cm to 228 cm, and a lagoon deposit at 229 cm to 260 cm. No lithified plate was located here.

Figure 4. Prothrombolithic stratum exposed in an electric maintenance ditch at CICIMAR-IPN.

Figure 5.- Excavation at the perimeter of CICIMAR-IPN campus (flood area) showing superficial prothrombolithic stratum.

No datable remains were obtained with the first core, although in the beach deposit stratum from the second core shells were found which were used for dating. In this stratum texture was coarse grain sand and abundant shell material in the 165 cm -169 cm, 170 cm - 187 cm and 198 cm - 207 cm horizons. The first layer, dating with C^{14} indicated an age of 3170 years ± 70 years before present (BP). Standard calibration of 2 SIGMA with a Del- ta-R value of 250 years ± 50 years BP, gave an estimated 2920 years to 3380 years BP. The second dating (at 198 cm - 207 cm) indicated an age of 3110 years ± 60 years BP, while the 2 SIGMA calibration gave an approximation of 2850 years to 3330 years BP.

The above values are below the estimated interval (5000 years - 6000 years) for these and other coastal lagoons. This could indicate that the accretion processes of the lagoon margins that accompanied pro-thrombolithic growth (which originated the sand bar) started much further inland; stratigraphic observations should aid in contrasting the estimated age of the La Paz lagoon.

Although it is supposed that the sand bar growth decelerated around 3 ka BP, low energy conditions in the lagoon had favored accelerating sediment deposition in the lagoon margins, mainly in the southern part which accreted northward (Nava-Sánchez & Cruz-Orozco, 1989). However, the lithified (thrombolithic) plate located at site 1 (which we assume to be the same found by Rosales & Fujita, 2000), would agree with the W growth direction (where pro-thrombolithic formations merge) of El Conchalito peninsula , contrary to that (E) of El Mogote sand bar.

Our observations show pro-thrombolithic activity in the El Conchalito area where urban settlements such as the CICIMAR-IPN now exist, and near the head of El Conchalito estuary in the middle of the mangrove swamp; this supports the proposed hypothesis. This in turn is consistent with the underlying theory and complements the oceanographic models presented to explain the origin of coastal barrier lagoons (Phleger, 1969; Kjerfve, 1994). Likewise, it supports the proposed origin for vast coastal ground extensions around coastal lagoons (Siqueiros Beltrones, 2008), through accretion of their margins due to pro-thrombolithic processes which have been observed to occur also in the W coast of southern Baja California peninsula (Siqueiros Beltrones *et al*., 2008). This may well be the case in most of the coastal lagoons in the Mexican (subtropical) NW.

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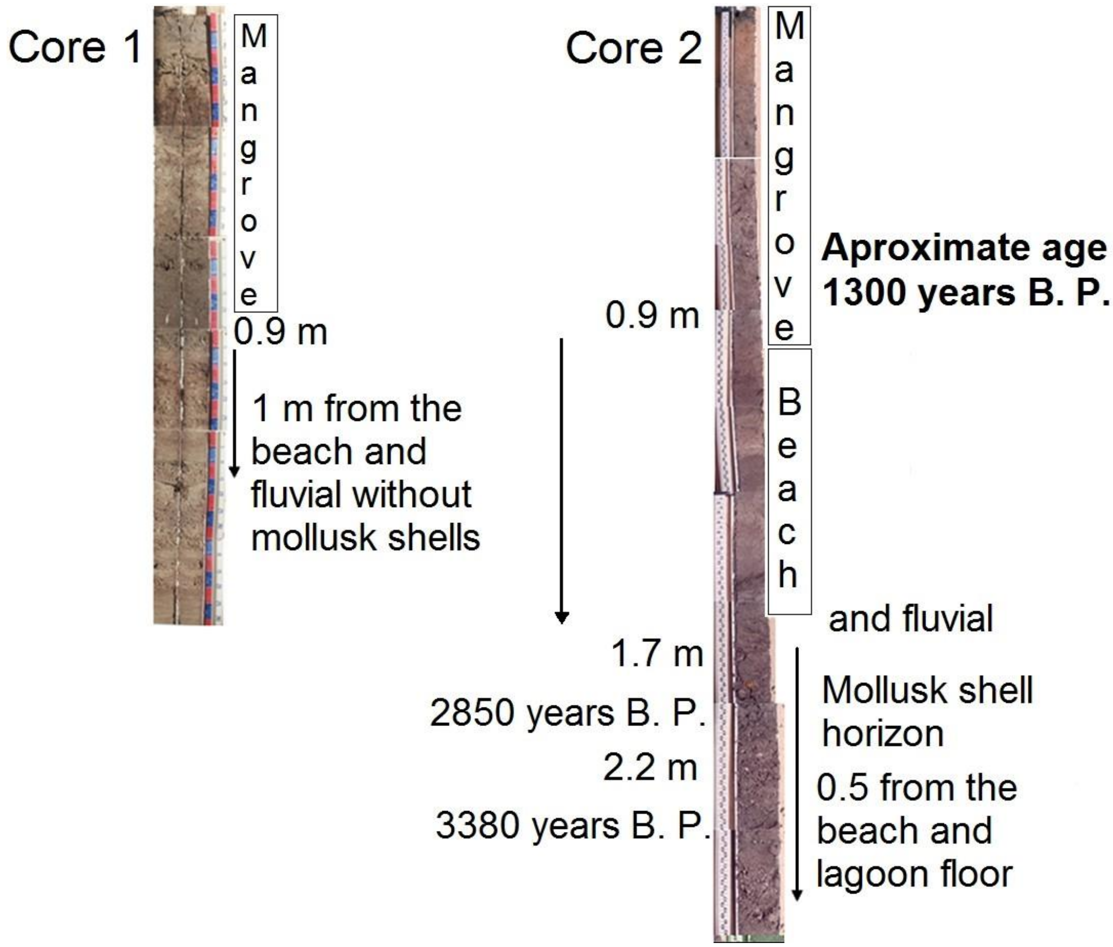

Figure 6. Stratigraphic layers identified in the two core samples from El Conchalito mangrove swamp (After Félix-Pico *et al*., pers. comm.).

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