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Soil development on a beach ridge chronosequence in the Gulf of Mexico coastal plain and its relation to the ancient land use

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ABSTRACT

A soil chronosequence study is presented in a beach ridge system at the mouth of the Usumacinta and Grijalva Rivers, Mexico, formed since a strong decrease in the rate of sea level rise some 6000 years ago. Four sites were selected for the chronosequence study: Simón Sarlat (SS), Rancho Magdaleno 1 and 2 (RM1, RM2), Cocoteros (CC), and Playa Cocoteros (PC), located on beach ridges that range in age between 5000 years old to recently formed. The soils show poor to moderate degree of development, and the change in the pedogenic properties has been clearly evaluated. The most pronounced changes are the following, from the older (SS, RM2) to the younger soils (PC, CC): color (becoming yellowish brown in the better developed soils); an increase in the amount of organic matter, clay, and Fed (iron extracted with dithionite solution); a better structure with more stable aggregates; a decrease in the Feo proportion (Fe extracted with oxalate solutions); and an increase in the content of fine magnetic particles (formed by pedogenesis). This area was densely populated and thus affected by human activities since the pre-Classic period (800–300 BC), as many archaeological sites have been registered. We evaluated soil agronomic quality, in order to understand the ancient land use. The results show that the soils in this area, no matter their age, have low agronomic quality, which must have limited their use by ancient population. However, the strategic position near main trade routes, near rich aquatic resources, and a low susceptibility to flooding were favorable for human settlement on the beach ridges.

1. Introduction

Chronosequences are good models to reconstruct the rates and trends of pedogenesis (Vreeken, 1975), taking into account that the soil forming factors (relief, organisms, climate, and parent material) remain “stable” through the time (Stevens and Walker, 1970). Many studies have used this approach in different climatic zones and parent materials (e.g. Nieuwenhuyse et al., 2000; Tsai et al., 2007; Zhang et al., 2007; Sauer et al., 2008; Peña et al., 2015).

Coastal environments are especially useful to study soil chronosequences, because geomorphic processes are very active, resulting in landforms of different ages. Particularly, chronosequence studies have been conducted on marine terraces (Jenny, 1941; Bockheim, 1980; Muhs, 1982; Bockheim et al., 1996; Langley-Turnbaugh and Bockheim, 1998; Tsai et al., 2007), coastal dunes (Eger et al., 2011; Jangid et al., 2013; Rohani et al., 2014), and beach ridges (Nieuwenhuyse et al., 1993; May et al., 2015). These studies are focused in the understanding of the evolution of coastal environments, while the changes on soil quality are less frequent.

The large beach ridge system at the Gulf of Mexico coast offers an opportunity to study soil chronosequences. Since a rapid retreat of the sea level some 6000 years ago, more than 500 sandy beach ridges were formed (Fig. 1). The formation of this beach ridge system has been described by Psuty (1965), Ortíz-Pérez (1992), Aguayo et al. (1999) and Ortíz-Pérez et al. (2005).

Most of the chronosequence studies covers long periods of pedogenesis, in consequence the changes in soil properties are easily distinguished (e.g. Bockheim, 1980; Sauer et al., 2008, 2009). In our study, the soils distribution includes Arenosols in the younger beach ridges, Gleysols in the swales between ridges, and

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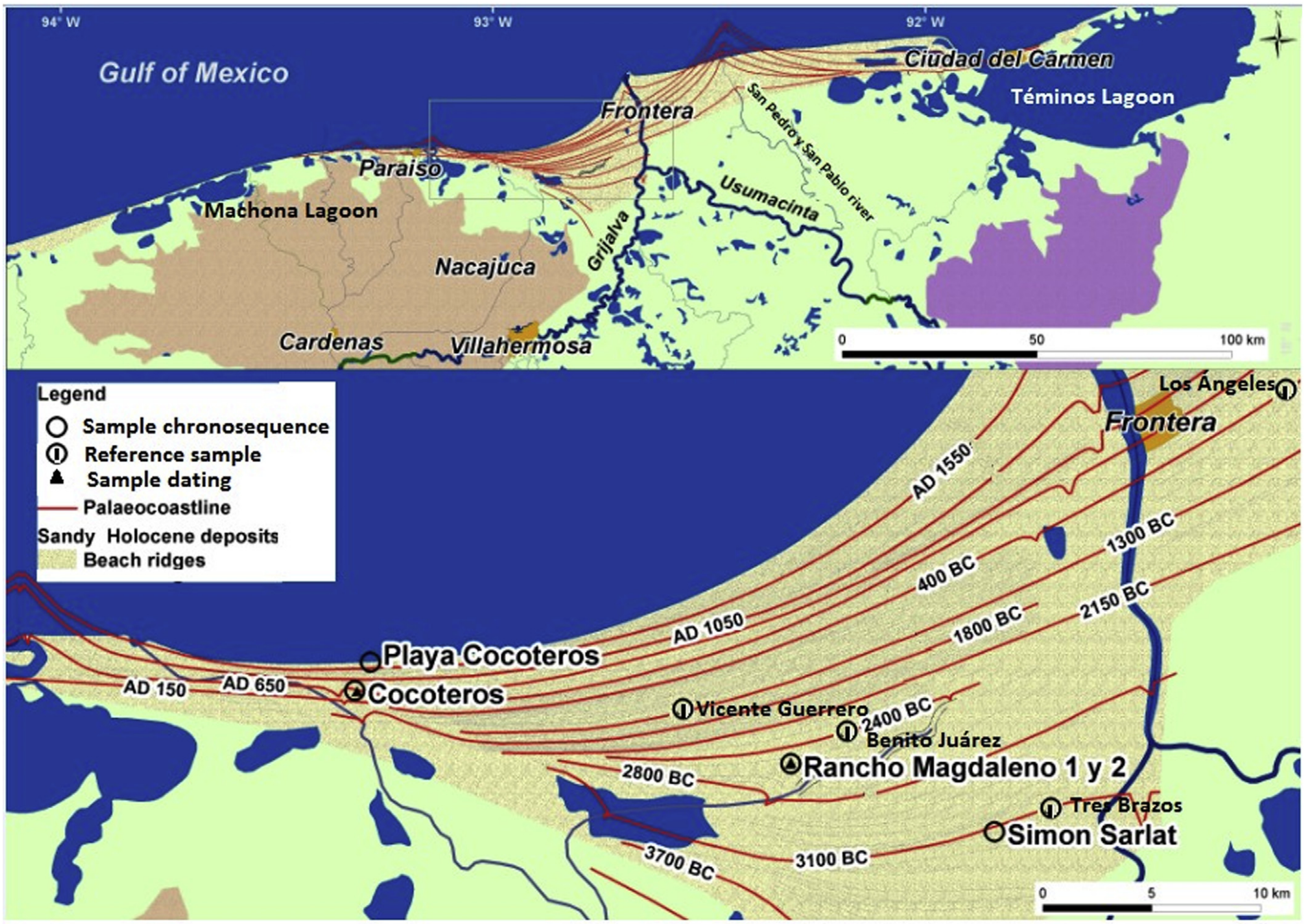

Fig. 1. Location of the study area, indicating the position of the beach ridges, their age and the sites where the soil profiles were sampled and described.

Regosols and Cambisols on the older ridges (Ortíz-Pérez et al., 2005). This distribution clearly documents the existence of poorly developed soils.

The area was densely, but unevenly populated in the past and many archaeological sites have been found on the beach ridges (Berlin-Neubart, 1960; Sanders, 1963) as well as evidences of maize cultivation some 6000 years ago, at its western part (Pope et al., 2001). These archaeological sites were rural settlements, with small ceremonial centers made of earth architecture (Sanders, 1963). Sanders (1963) suggested the soils were fertile but differentially distributed through the region, while Jiménez-Valdez (1984) considers the soils formed on the top of the beach ridge were used for cultivation, while the bottom (the area between two ridges) were irrigation canals.

In this paper, we present an evaluation of the change in several soil properties, in a chronosequence along the beach ridge system to demonstrate that even these poorly developed soils show modifications with time, that are detectable. Additionally, we analyze the dependence of agronomic soil quality and soil development, and the influence of both aspects in the ancient land use.

2. Study area

2.1. Geology and geomorphology

The study area is part of one of the Mexico's largest beach ridge systems (Aguayo et al., 1999; Fig. 1). Beach ridges refer to "relict, semiparallel, multiple ridges, either of wave (berm ridge) or wind (multiple backshore foredune) origin" (Otvos, 2000), which usually form strandplains (Otvos, 2000).

Although beach ridges in the study area were formed along the whole delta coastline, the largest sequence developed at the mouth of the Usumacinta and Grijalva River (Psuty, 1965; Ortíz-Pérez et al., 2005), since the stabilization of the sea level rise some 6000-5000 years ago (Ortíz-Pérez, 1992; Aguayo et al., 1999), and gradually progradated to the north about 6–10 m/y. (Aguayo et al., 1999). The sandy beach ridges run parallel to the coast and have elevations up to 5 masl. The oldest ridges in the area are 'drowned' due to sea level rise and are partly covered by peat.

Our study sites are located in the area near the confluence of Usumacinta and Grijalva Rivers where the beach ridge sequence is over 20 km wide (Fig. 1). The chronology of the beach ridge formation has previously established by Aguayo et al. (1999), by radiocarbon dates on carbonate shells, and more recently by Nooren et al. (unpublished data), which is based on 35 radiocarbon and 20 OSL samples, allowing the reconstruction of the palaeo-coastline since 5000 BP (Fig. 1).

The composition of the beach ridges consists of detrital sediments from the Sierra de Chiapas, constituted by limestones, plutonic, metamorphic and volcanic materials (Aguayo et al., 1999; Ortíz-Pérez et al., 2005; Padilla-Sánchez, 2007). Sediments are transported by the rivers to the coast, reworked, and then redistributed along the coastline by littoral currents, waves, and winds.