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Environmental changes and population responses in the Sechura Desert during the late Holocene

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Different Times? Archaeological and Environmental Data from Intra-Site and Off-Site Sequences

Proceedings of the XVIII UISPP World Congress
(4-9 June 2018, Paris, France)
Volume 4
Session II-8

Edited by

Zoï Tsirtsoni, Catherine Kuzucuoğlu,
Philippe Nondédéo, Olivier Weller



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FOREWORD TO THE XVIII UISPP CONGRESS PROCEEDINGS

UISPP has a long history, originating in 1865 in the International Congress of Prehistoric Anthropology and Archaeology (CIAAP). This organisation ran until 1931 when UISPP was founded in Bern. In 1955, UISPP became a member of the International Council of Philosophy and Human Sciences, a non-governmental organisation within UNESCO.

UISPP has a structure of more than thirty scientific commissions which form a very representative network of worldwide specialists in prehistory and protohistory. The commissions cover all archaeological specialisms: historiography; archaeological methods and theory; material culture by period (Palaeolithic, Neolithic, Bronze Age, Iron Age) and by continents (Europe, Asia, Africa, Pacific, America); palaeoenvironment and palaeoclimatology; archaeology in specific environments (mountain, desert, steppe, tropical); archaeometry; art and culture; technology and economy; biological anthropology; funerary archaeology; archaeology and society.

The UISPP XVIII World Congress of 2018 was hosted in Paris by the University Paris 1 Panthéon-Sorbonne with the strong support of all French institutions related to archaeology. It featured 122 sessions, and over 1800 papers were delivered by scientists from almost 60 countries and from all continents.

The proceedings published in this series, but also in issues of specialised scientific journals, will remain as the most important legacy of the congress.

L'UISPP a une longue histoire, à partir de 1865, avec le Congrès International d'Anthropologie et d'Archéologie Préhistorique (C.I.A.A.P.), jusqu'en 1931, date de la Fondation à Berne de l'UISPP. En 1955, l'UISPP est devenu membre du Conseil International de philosophie et de Sciences humaines, associée à l'UNESCO. L'UISPP repose sur plus de trente commissions scientifiques qui représentent un réseau représentatif des spécialistes mondiaux de la préhistoire et de la protohistoire, couvrant toutes les spécialités de l'archéologie : historiographie, théorie et méthodes de l'archéologie ; Culture matérielle par période (Paléolithique, néolithique, âge du bronze, âge du fer) et par continents (Europe, Asie, Afrique, Pacifique, Amérique), paléoenvironnement et paléoclimatologie ; Archéologie dans des environnements spécifiques (montagne, désert, steppes, zone tropicale), archéométrie ; Art et culture ; Technologie et économie ; anthropologie biologique ; archéologie funéraire ; archéologie et sociétés.

Le XVIII^e Congrès mondial de l'UISPP en 2018, accueilli à Paris en France par l'université Paris 1 Panthéon-Sorbonne et avec le soutien de toutes les institutions françaises liées à l'archéologie, comportait 122 sessions, plus de 1800 communications de scientifiques venus de près de 60 pays et de tous les continents.

Les actes du congrès, édités par l'UISPP comme dans des numéros spéciaux de revues scientifiques spécialisées, constitueront un des résultats les plus importants du Congrès.

Marta Arzarello

Secretary-General / Secrétaire général UISPP

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Environmental change and population responses in the Sechura Desert during the late Holocene

Valentina Villa¹, Aurélien Christol², Christine Lefèvre³, Denis Correa⁴,
Philippe Béarez³, Patrice Wuscher⁵, Nicolas Bermeo⁶, Segundo Vásquez⁴,
Belkys Gutiérrez⁷, Nicolas Goepfert⁶

¹ Laboratoire de Géographie Physique (LGP) UMR 8591: CNRS, Universités Paris 1-
Panthéon-Sorbonne et Paris-Est Créteil Val-de-Marne (UPEC) – France
valentina.villa@lgp.cnrs.fr

² Laboratoire Environnement Ville Société UMR 5600:
Université Lyon III Jean Moulin, CNRS - France
aurelien.christol@univ-lyon3.fr

³ Archéozoologie, Archéobotanique: sociétés, pratiques et environnements (AASPE)
UMR 7209: Muséum national d'Histoire Naturelle, CNRS – France
christine.lefevre@mnhn.fr; bearez@mnhn.fr

⁴ Universidad Nacional de Trujillo – Peru
dcorreatrigoso@gmail.com; svasquezs@unitru.edu.pe

⁵ Laboratoire image ville environnement UMR 7362:
Université de Strasbourg, CNRS – France
patricewuscher@hotmail.com

⁶ Archéologie des Amériques UMR 8096: CNRS, Université Paris 1-
Panthéon-Sorbonne – France
nicbermeo@gmail.com; nicolas.goepfert@cnrs.fr

⁷ BGL Arqueología – Peru
bglarqueologia@hotmail.com

Abstract

The Sechura desert, on the north Peruvian coast, is a region characterized today by a hyperarid climate and regularly affected by extreme rainfall events linked to ENSO. The current hydro-climatic variability and its effects on coastal environments raise the question of ENSO's occurrences and evolution during the Holocene. The Sechura desert is now very sparsely occupied, while many archaeological sites indicate a significant human presence from the 5th millennium BC. Our research focuses on the adaptation of these local populations to variation in climate and evolution of the coastal environment over time. A regional approach, integrating off-site data from sedimentary archives in the Las Salinas and Nunura bay regions and on-site data from the Bayovar-01 and Huaca Grande archaeological sites, highlights the variety of responses of these populations, which adapted their subsistence economies to these environmental fluctuations. Our results show that, over the past two millennia, the Sechura desert has experienced both permanent occupations that adapted to diverse resources and that varied over time, as well as short-term, opportunistic occupations that focused on specific and temporarily available resources. Thus our reconstructions testify to the strong reactivity of landscape and people to recent Holocene environmental change affecting the coastal areas of the Sechura desert.

Keywords: Sechura desert, Late Holocene, geomorphology, archaeology, Las Salinas, Nunura

Résumé

Sur la côte nord-péruvienne, le désert de Sechura est une région caractérisée aujourd'hui par un climat hyperaride et régulièrement concernée par des épisodes de pluies extrêmes liés à ENSO. La variabilité hydro-climatique actuelle et ses effets sur les milieux littoraux posent la question de son existence et de son évolution passée, durant l'Holocène. Alors que ce désert est aujourd'hui très faiblement occupé, de nombreux sites archéologiques indiquent une présence humaine importante à partir du Ve millénaire av. J.-C. Notre recherche s'intéresse ainsi à l'adaptation de ces populations locales aux variations du climat et des

milieux côtiers. Une approche régionale, basée sur l'intégration de données hors-site provenant d'archives sédimentaires dans les régions de Las Salinas et de la baie de Nunura et des données intra-site issues des sites archéologiques de Bayovar-01 et de la Huaca Grande, nous permet de mettre en évidence diverses modalités dans la réponse des populations et de leur économie de subsistance aux fluctuations environnementales. Au cours des deux derniers millénaires le désert de Sechura a connu à la fois des occupations pérennes qui s'adaptaient à des ressources diverses et qui variaient dans le temps mais aussi des occupations opportunistes de courte durée, centrées sur une ressource spécifique et ponctuelle. Ainsi nos reconstitutions témoignent de la forte réactivité des paysages et des hommes aux changements environnementaux de l'Holocène récent qui ont affecté les espaces côtiers du désert de Sechura.

Mots-clé : désert de Sechura, Holocene tardif, géomorphologie, archéologie, Las Salinas, Nunura

1. Introduction

The Sechura Desert is a vast area (lat. 6°S–7°S) that extends over approximately 20,000 km² along the Peruvian coast, from the Piura valley to the Lambayeque valley. It is located between the Pacific Ocean and the Andes, and its width varies from some kilometres to a maximum of 100 km in its central part, which is covered by thick sand accumulations. This region is characterised by desert conditions resulting from a combination of two main factors: (i) the Peruvian upwelling–Humboldt Current system along the coast, associated with the high pressure of the Eastern Pacific to the west and (ii) the rainshadow effect of the Andes to the east (Sandweiss 2003). Currently, the region is affected by rainfall episodes of varying intensity due to ENSO (El Niño Southern Oscillation) that occur with irregular frequency (since 1976, every 3–7 years) (Sandweiss 2003; Rein 2007; Ramírez and Briones 2017).

The Sechura Desert is today very sparsely occupied, while many archaeological sites indicate an almost continuous occupation since the Preceramic, right up to the Inka period (Milla Villena 1989; Cárdenas *et al.* 1991, 1993; Goepfert *et al.* 2016, 2018, 2019). This archaeological setting suggests available natural resources exploited by local human communities for their subsistence during several millennia. However, at present the Holocene environmental history of the region is not well-known due to a lack of high resolution palaeoenvironmental and climatic local archives (continental or marine).

We can refer to many previous studies which highlighted strong environmental and climatic variability at a macro-regional scale. Marine sedimentary records and archaeological data (archaeofaunal assemblages) indicate that the climate (South American monsoon influence) was different from the current one and that ENSO activity varied significantly (Sandweiss *et al.* 1996; Sandweiss 2001; Rein *et al.* 2005, Carré *et al.* 2012, 2014).

After a humid phase with maximum ENSO activity during early Holocene, a shift to cooler and drier conditions and reduced ENSO activity is attested to during the middle Holocene (Rein *et al.* 2005; Carré *et al.* 2012). At 5.8 ka BP, archaeological evidence records a reactivation of ENSO activity after a pause of several millennia (Sandweiss 2001). A rapid increase in ENSO frequency was recognized around 3000 cal BP (Sandweiss 2003).

The last two millennia can be divided in three different phases: (i) between 0 and 750 AD, humid climate with rare strong ENSO events (similar to the 1982–83 event), (ii) between 750 and 1250 AD, a dryer period with weak ENSO activity and (iii) after 1250 AD, more humid conditions and a higher frequency of intense ENSO events (Rein 2007).

This climatic variability is an essential key to understanding human frequentation of the Sechura desert during the Holocene. Our research focuses on the adaptation of local populations to variations in coastal environments in relation to regional and macro-regional geomorphological and hydro-oceanic-climatic forcing.

Our research is based on a regional multiproxy approach, involving the excavation of two archaeological sites, located in the north-west of the Sechura Desert, and the geomorphological study of the surrounding areas (Figure 1). In this article, we present a synthesis of the data acquired for the Bayovar-01 site, located on a marine Pleistocene terrace on the edge of the Las Salinas depression, and compare them with the new data from the archaeological excavations of the Huaca Grande site and the geomorphological investigations carried out in Nunura Bay (Figure 1).

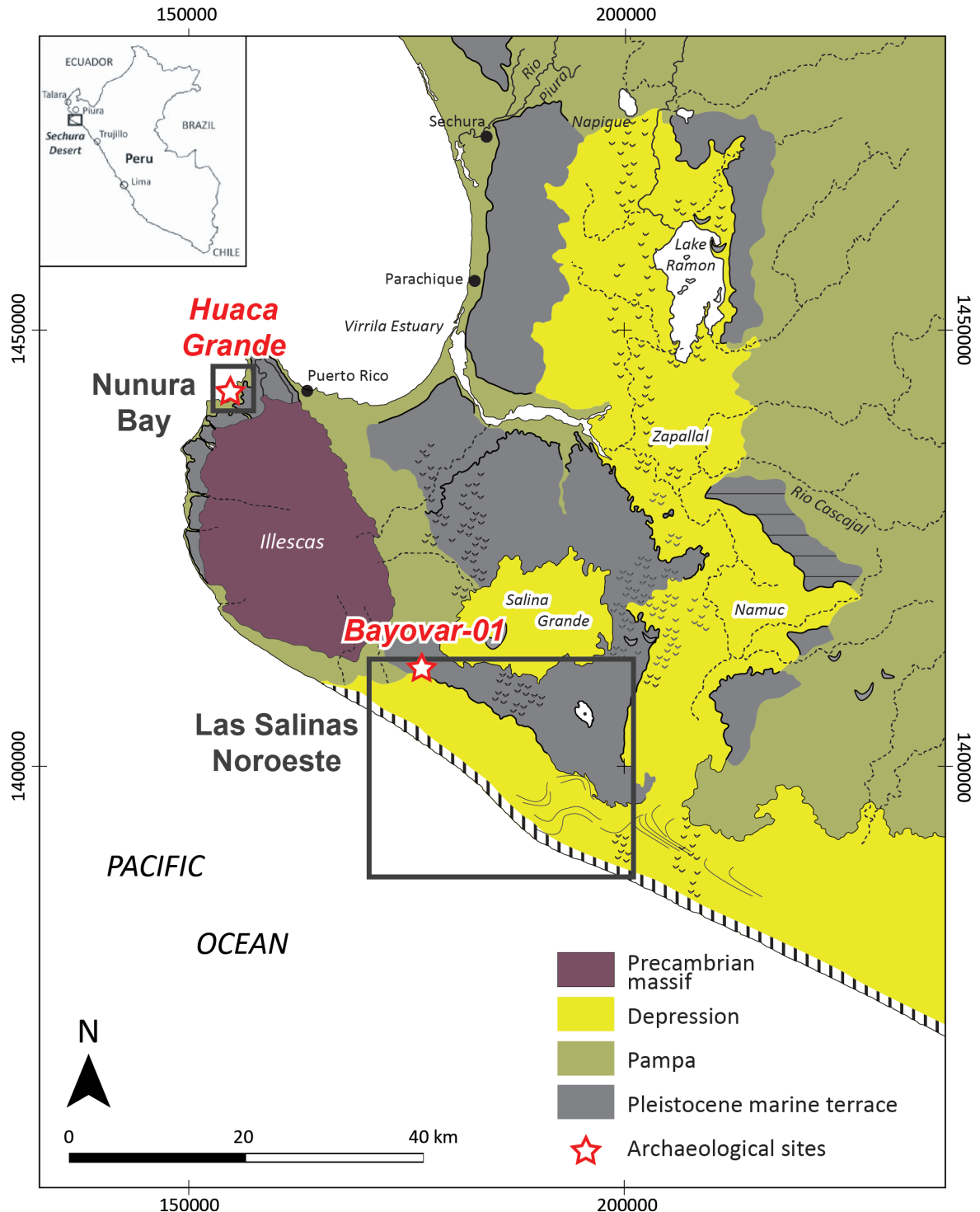


Figure 1. Geomorphological setting of the studied area (in green for palaeogeographic survey) and location of the Bayovar-01 and Huaca Grande archaeological sites (red stars). Drawn with data compiled from ASTER GDEM (2011), IGN (1996-2005), INGEMMET (1980-1999), and LANDSAT (2001).

2. Methods

The archaeological occupations of Bayovar-01 (Goepfert *et al.* 2016) and Huaca Grande (Goepfert *et al.* 2017) have been the subject of detailed studies (stratigraphy, zooarchaeology, malacology, archaeobotany) in order to identify the activities carried out and the resources exploited by the communities that inhabited these sites, as well as the nature of these facilities (opportunistic or permanent). In parallel with the archaeological excavations, we collected field data in the areas surrounding the two sites.

In Las Salinas, a geomorphological study of the entire depression and surrounding areas was combined with a geomorphological profile (6 km long; 18 pits, each 1-2 m deep) perpendicular to the coastline, located between the archaeological site of Bayovar-01 to the west and the shore bar to the east (Figure 2). Chronostratigraphic, geochronological, and malacological studies have been carried out on sedimentary successions identified along this profile (Christol *et al.* 2015, 2017).

At Nunura, we carried out geomorphological surveys and sampled the best preserved and more representative sedimentary sequences. We opened ten pits in the intertidal zone, mainly along the main and secondary channels. We present below the sedimentary succession of the main profile, named Nunura 1 (172 cm deep), which was the object of multiproxy sedimentological analyses (laser granulometry, magnetic susceptibility, Total Organic Carbon and CaCO₃ content, pH).

On-site and off-site data were then combined to understand human occupations, their subsistence economies, and their relationship with climate and environmental change.

3. Results and Interpretations

3.1. Archaeology

3.1.1. The Bayovar-01 site

The Las Salinas area is a large depression (about 2000 km²) partly located below sea level, bordered by a Pleistocene marine terrace and separated from the ocean by a shore bar. The Bayovar-01 site is located on the top of this Pleistocene terrace at 9-18 m above sea level, 6 km from the shore inland. The site was occupied between cal AD 469 and 766 (Goepfert *et al.* 2016), a period corresponding to the transition from the Early Intermediate Period (200 BC–AD 600) to the Middle Horizon (AD 600-1000). The archaeological excavation revealed the presence of two structures formed by several rows of marine formation blocks. A large activity area was also discovered, formed by the accumulation of fish remains, charcoal and other charred materials, such as seeds and camelids faeces, found in several superimposed hearths. The large amount of fish bones and otoliths of species living in warmer and shallow coastal waters (e.g. *Micropogonias altipinnis*, *Albula* sp.), indicate different environmental and climatic conditions than those prevailing today (Goepfert *et al.* 2016). They suggest the presence of a lagoon, which could have been formed by the flooding of the sandy depression of Las Salinas by fluvial and/or marine inputs (Christol *et al.* 2015, 2017). In this area, episodes of flooding and coastal lake/lagoon settlements are attested to during the 20th century and were observed in 2017 during one 'El Niño costero' (*tr.* coastal El Niño) phenomenon (Figure 3), related to episodes of intense ENSO activity.

We conclude that the fisherfolk who inhabited Bayovar-01 took advantage of such favourable environmental conditions to settle in this spot. The site appears to have been a specialised site for fishing and the preparation of fish for transport to other areas (Bermeo *et al.* 2019; Goepfert *et al.* 2019).

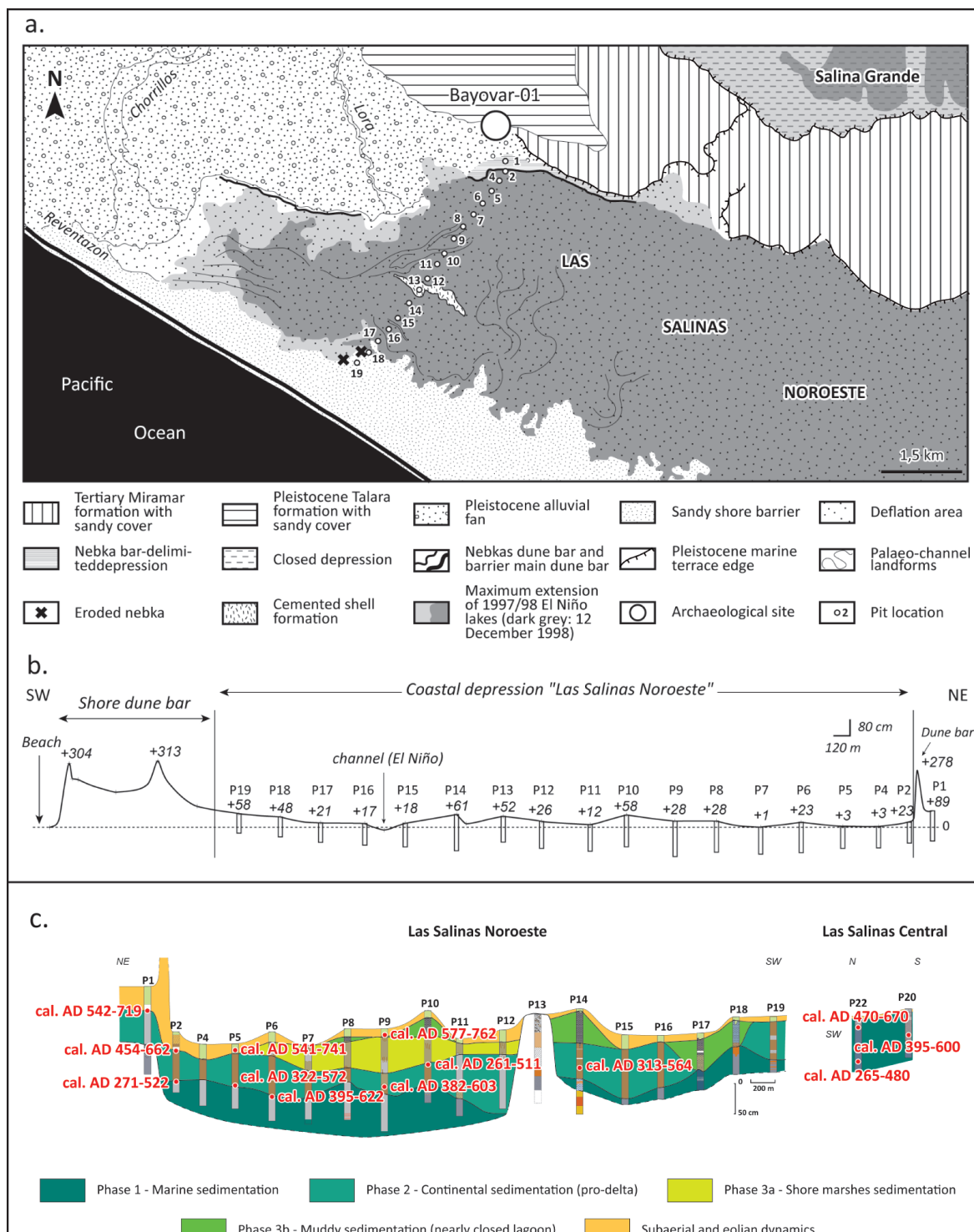


Figure 2. Las Salinas Noroeste. a) Geomorphology. Drawn from LANDSAT (12 December 1998). b) Topographical profile, transect and pit locations (P), and elevation asl as measured at Reventazon in February 2014. c) Chronostratigraphy of the Las Salinas Noroeste infilling and lagoon phases (modified from Christol *et al.* 2017).

3.1.2. The Huaca Grande site

Huaca Grande is a big mound, measuring 176 m long, 73 m wide, and 7-8 m high, located at approximately 400 m from the Pacific Ocean, on the edge of Nunura Bay (Figure 4). The site was partially excavated by Cárdenas (Cárdenas *et al.* 1991, 1993), who dug three pits. Investigations

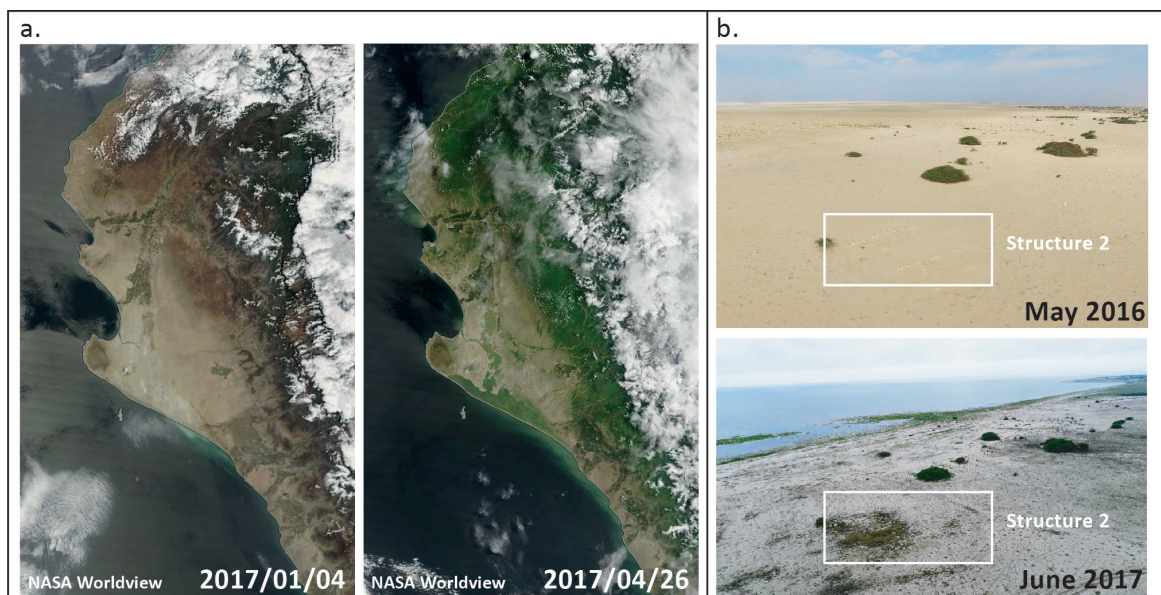


Figure 3. Effects of the *El Niño costero* that occurred during spring 2017. a) Satellite view of the Sechura Desert in January 2017 and at the end of April 2017. b) View of the Bayovar-01 archaeological site in May 2016 and in June 2017.

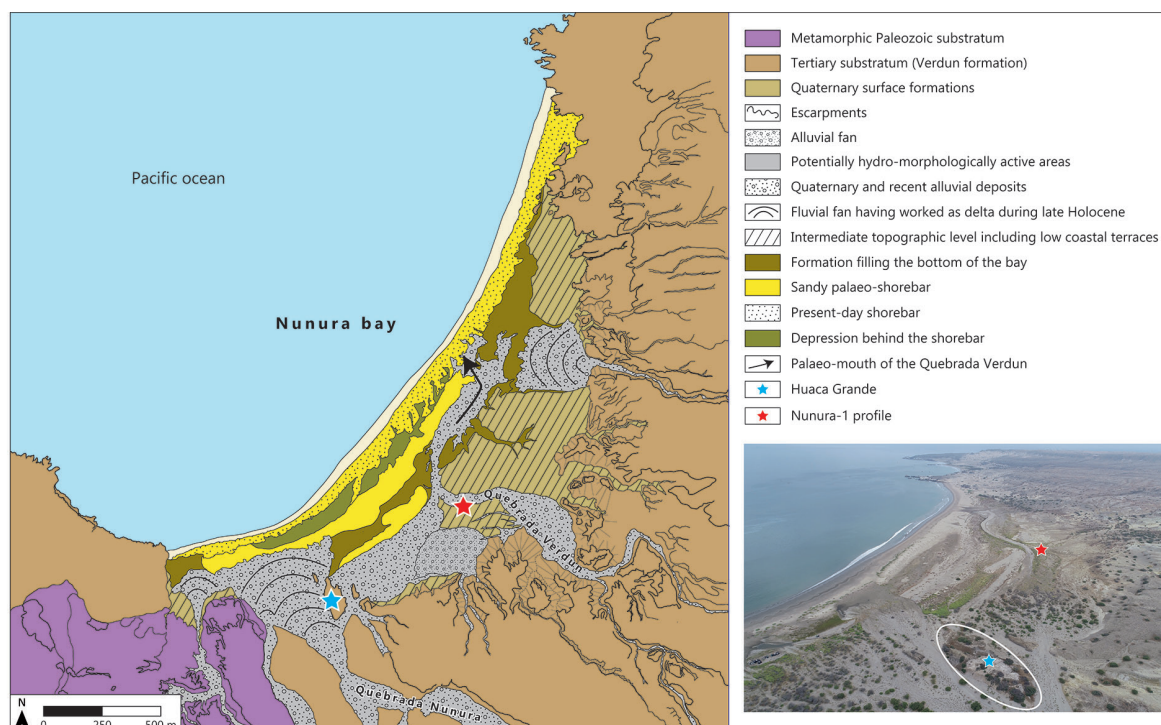


Figure 4. Geomorphological map of the Nunura area (drawn from Google Earth © and field data), location of the Huaca Grande archaeological site (blue star) and the Nunura 1 stratigraphic profile (red star), and aerial view of the bay in May 2018 (credit N. Goepfert).

restarted in 2015 with the objective of establishing a precise chronological and cultural framework for the archaeological sequence preserved at this site. The recent excavations revealed an exceptional stratigraphic succession, about 2.6 m thick.

The sedimentary succession includes deposits with a generally sandy texture, extremely rich in organic debris of various types. Layers of mollusc shells and fish remains without matrix

alternate with finer, sandy-clayey, dark brown levels, rich in charcoal, burnt seeds and camelid faeces. Powdery whitish layers, most likely composed of ash, are quite frequent (Figure 5). The archaeological excavation appears to have reached the sterile substrate, located at a depth of about 2.6 m. The succession of occupation levels can be subdivided into five main phases (Figure 5).

In the first stage at the base, the space seems well organized. A compact, east-west oriented clay wall more than 3 m long has been identified at a depth of 2.2 m (Figure 6a). Given its width and height (50 x 50 cm), it is probably a collective structure rather than a housing structure. Circular depressions are present on the upper surface of the wall (Figure 6b). They are most likely postholes,

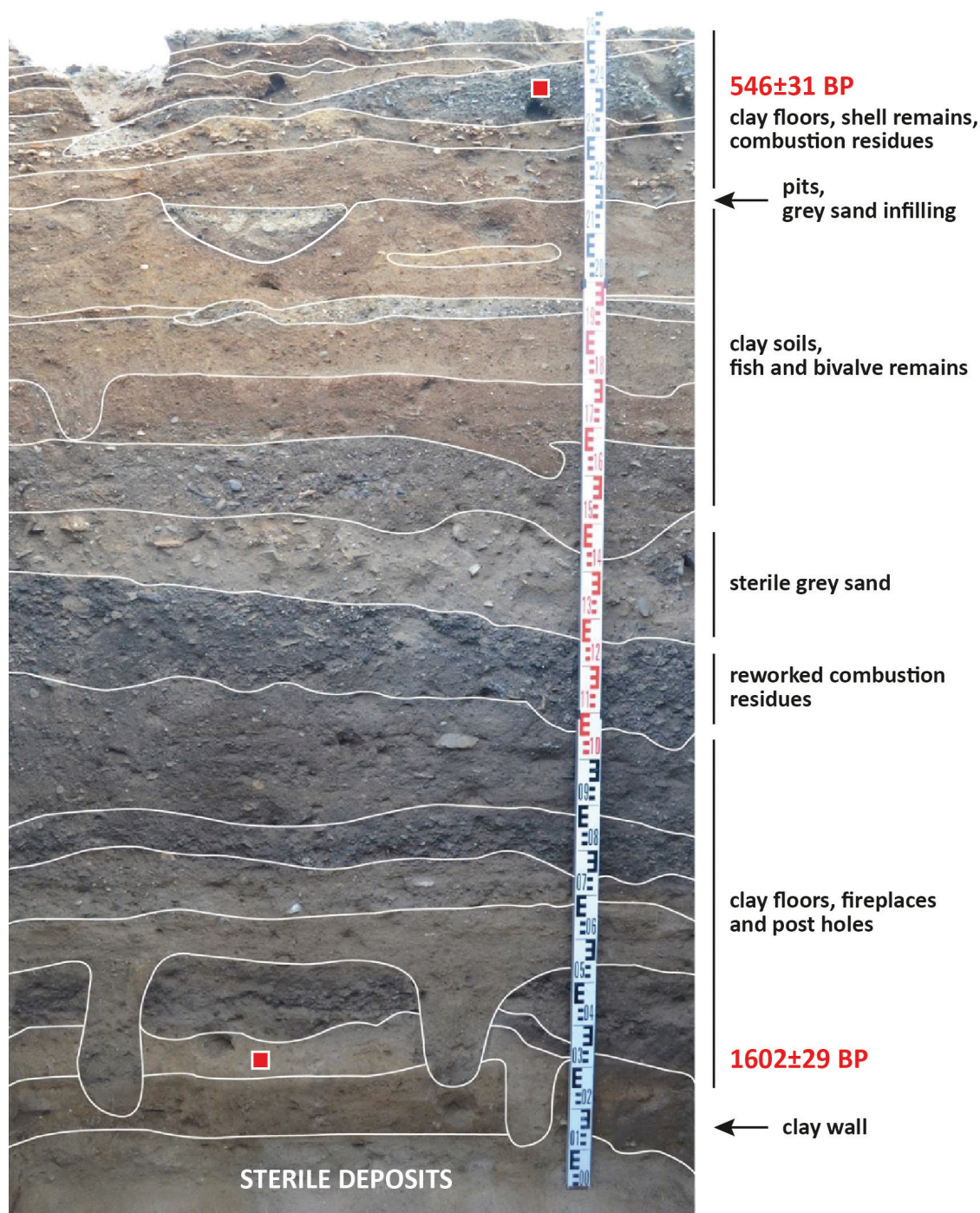


Figure 5. Archaeological sequence of the Huaca Grande site with a brief description and/or preliminary interpretation of the stratigraphic units. The location of the two radiocarbon dates constraining the occupation of the site is also indicated.

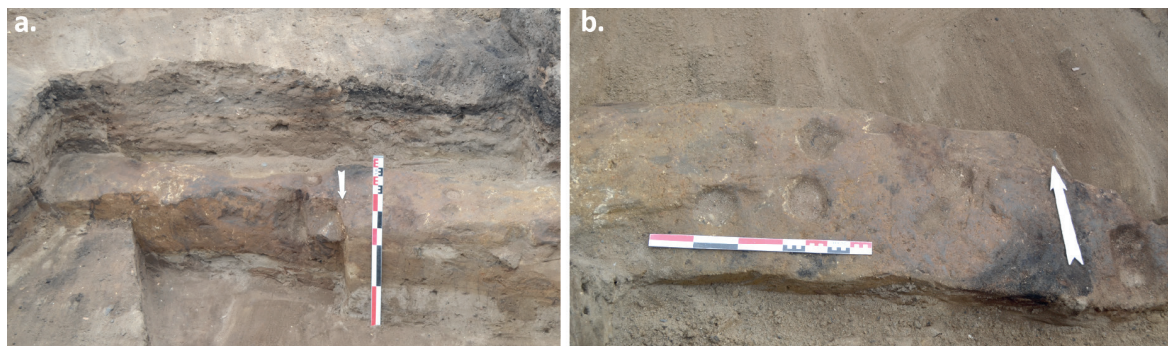


Figure 6. a) Front and b) upper views of the wall discovered at the base of the Huaca Grande archaeological site (credit N. Goepfert).

which may represent the remains of a roof made of perishable material. At this time, we do not have any additional information on this impressive structure, but further research and archaeological excavations will allow us to identify it more clearly and to specify its scope and function. More recent layers that cover the wall consist of a superimposed clay floor, well-preserved fireplaces, and postholes that seem to indicate a later domestic occupation.

In the next phases, Huaca Grande is clearly used as a dumpsite, recorded by a thick black layer (up to 80 cm thick) of reworked combustion residue, comprising mainly plant remains, seeds, and camelid faeces. Afterwards, sedimentation continues with a layer of sterile grey sand covered by a succession of clay soils that alternate with layers composed exclusively of fish and bivalve remains.

A new phase of occupation is attested to by a series of pits that deeply cut the underlying layers. They contained large-sized vases (*tinajas*), whose profiles are well preserved. The fill of these pits consists of a sterile grey sandy sediment that appears to be of natural origin and could indicate a (short?) phase of abandonment of the site. The occupation sequence finally ends with a new succession of stacked clay floors, shell remains, and combustion residue.

The study of the faunal and botanical remains is in progress, but a major distribution within the sequence can already be recognized regarding the resources exploited by the inhabitants of Huaca Grande. The remains of marine mammals, frequent in the lower part of the sequence, decrease considerably over time (four times less frequent in the upper layers than in the lower ones), whereas the opposite trend is apparent for malacofauna, whose importance in the wildlife spectrum increases significantly, from 714 remains at the bottom of the sequence, under the thick black layer (Figure 5), to 19,611 at the top. The abundance of seabirds remains constant throughout the occupation. The most represented species are *Donax obesulus*, *Olivella columellaris*, *Acanthopleura echinata*, *Policines uber*, and *Argopecten purpuratus*. The great majority of the species found at Huaca Grande are still currently present in the region surrounding the archaeological site. However, some species are rather typical of tropical waters in regions located at lower latitudes than Nunura Bay, such as *Cerithium muscarum*, *Semicassis centiquadrata*, *Mazatlanian fulgurata*, and *Oliva incrassate* (DeVries and Wells 1990; 'WoRMS – World Register of Marine Species – Mollusca,' n.d.).

Two ^{14}C dates (Figure 7) allow us to place the archaeological sequence between cal AD 423-575 (1602±29 BP; UBA-30844) and cal AD 1399-1448 (546±31 BP; UBA-35563). The site has therefore been occupied for more than a thousand years. Research is still ongoing, and we plan to run several more dates in the future. They are expected to provide a more detailed chronology of the five main occupation phases identified, and to evidence possible phases of abandonment as well as their duration.

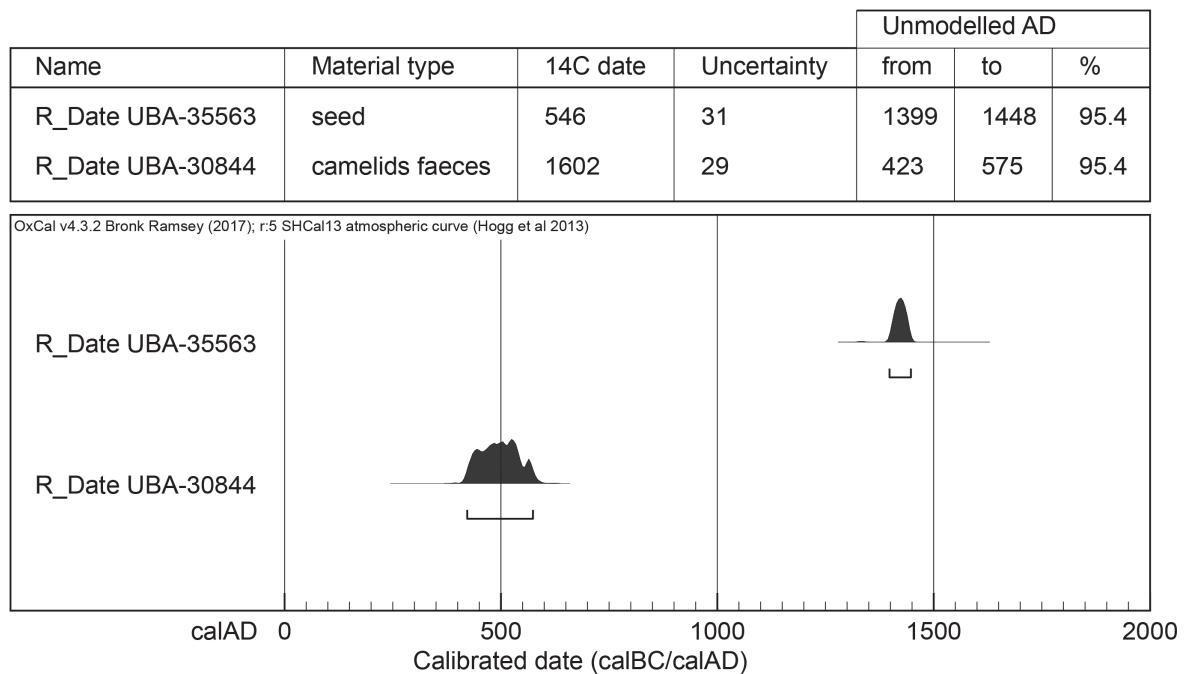


Figure 7. Chronology of the Huaca Grande archaeological sequence. ^{14}C and calibrated dates.

3.2. Geomorphology

3.2.1. Las Salinas

The wide variety of sedimentary facies identified along the geomorphological profile through the Las Salinas depression illustrates the complexity of its history and the deposition environments that occurred during the Middle and Recent Holocene (Figure 2) (Christol *et al.* 2015, 2017). During the past two millennia in particular, the deposits attest to the evolution of a large, open lagoon system, drained but regularly filled with inputs from both marine and continental sources, which led to continuous sedimentation until the 8th century AD. Marine sedimentation was predominant until the 3rd century AD, before being replaced by continental inputs typical of pro-deltaic environments, with the most recent ones dating back to the 6th century AD. From the 8th century, the depression was disconnected from the ocean, causing the filling-in and the drying up of the lagoon (Christol *et al.* 2017).

The geomorphological data thus confirm that the site of Bayovar-01 was established on the edge of a warm-water lagoon, rich in fish and probably bordered by tropical, mangrove-type vegetation. This lagoon environment was subject to several low water level/drying phases (salt crusts were observed within sedimentary sequences). It persisted for more than 500 years due to continental water inputs responding either to a mean-climate and/or to ENSO activity. Bayovar's fisherfolk would have benefited from such an environment, which offered abundant tropical resources. This opportunistic human occupation was highly responsive to environmental changes. Indeed, the site was abandoned in the 8th century AD, when, because of a shift to more arid climatic conditions, the lagoon dried up (Christol *et al.* 2017).

3.2.2. Nunura Bay

Nunura Bay is located north-west of the Illescas massif (Figure 4). It is a small bay, measuring about 3 km wide, bordered by two rocky outcrops cut into Palaeozoic rocks covered by tertiary formations eroded into glacis (with a marine erosion and tectonics origin) during the Pleistocene (Figure 4). The bay is supplied by two main *quebradas* (*tr.* ravines), the longer being the *quebrada* Nunura,

which opens to the south after being connected to the secondary, shorter *quebrada*, the *quebrada Verdun*, which connects to the bottom of the bay in its central part (Figure 4). These *quebradas* show active and inherited forms reflecting the activation of these talwegs during older, more humid climatic phases (prior to the 9th century AD – see Las Salinas) or during more recent ENSO events. Within this context, Nunura Bay forms a hydro-sedimentary system connecting upstream a relatively modest catchment area of about 35 km² and a maximum altitude of 478 m, downstream to the sea. The slopes of this system are not insignificant but are nonetheless quite moderate, with an average of 2.5% in the Precambrian piedmont. Accordingly, the detrital elements discharged from upstream and passing through the *quebradas* present proximal characteristics with a fairly homogeneous mineralogical composition.

3.2.3. Description of Nunura 1 sequence

3.2.3.1. Location and geomorphological context

The studied sequence is located close to the sea-side on the south bank of a channel about 50 m wide (Figure 4). This channel corresponds to the extension of the *quebrada Verdun*, which, originating at an altitude of slightly more than 300 m from the Palaeozoic metamorphic formations of the Illescas massif, incises the yellow Tertiary deposits of the Verdun Formation. The channel crosses the coastal zone in a northward curve before its morphology, clearly identifiable in the field and on satellite images, disappears at the back of the shore bar (Figure 4). Because of its position, this channel could have functioned as much as a river channel with a palaeo-mouth, as it could have as a tidal channel only. Its prominent shape and important bed load suggest different hydro-sedimentary dynamics than today, with a dominant alluvial sedimentation in the area.

3.2.3.2. Associated sedimentary forms and deposits

The channel edges, slightly less than 50 cm high and still well defined on both sides of the active bed, suggest relatively recent erosional processes. These processes exposed deposits underlying a small terrace whose surface corresponds to the main topographical level of the studied area and leads to the Huaca Grande mound. Along the embankment, several profiles were cleaned on both the left and right side over a length of about 100 m. The sedimentary successions are thick and continue several tens of centimetres below the current channel bottom. It was however often impossible to excavate stratigraphical profiles more than 1 m deep, except for the Nunura 1 sequence, which reaches a thickness of 172 cm.

3.2.3.3. Description of the Nunura 1 sequence sedimentary units

The sequence is composed of five more or less homogeneous groups that can be easily distinguished in terms of facies or assemblage of sedimentary facies (Figure 8). The contacts between these different groups are quite regular and rather horizontal.

At the bottom of the sequence, Unit 1 is formed by a massive grey, sandy-silty facies. It is 69 cm thick, and its upper limit is 103 cm below the surface. Then, between 103 and 75 cm deep, Unit 2 develops, having more diversified layers, ranging from brown to yellowish silty-clayey deposits. Some of these thin facies show relatively large bedding, with horizontal structures. The upper part of this unit shows undulating contact with Unit 3, where a more silty-clayey bed is present, suggesting ripple marks in the sandy deposit. Unit 3 develops between 75 and 58 cm. It consists of grey, sandy-silty deposits, similar to the lower unit, Unit 1. This central part of the profile also shows frequent traces of oxidation, mainly impregnation and stains, but also lenticular forms at the contact with some beds. Unit 4, more homogeneous in its texture and developed over a thickness of about 40 cm (58-20 cm), shows yellowish, brown silty facies with thin silty-clay beds. The structure is generally well bedded, highlighted by variations in colour from one bed to another. According to the colours, three main sub-units can be identified: i) a first, yellowish one delimited by two clayey yellow beds

(layer 8); ii) a brown layer in slightly gullying contact with the lower one and showing undulations (layer 9); and, finally, iii) a brown layer whose structure is less visible, with convolutions in its lower part (layer 10). The upper part of the sequence (Unit 5) corresponds to a slightly gresified medium beige sand (with concretions of salt) without any visible structure, underlying the roof of the terrace. This deposit covers the finer deposits on the various stratigraphic profiles observed along the channel.

3.2.3.4. Interpretation and reconstruction of sedimentation environments

In terms of texture, except for the subsurface unit, the deposits observed in the Nunura 1 profile vary from massive sandy-silty facies to rather bedded silty-clayey facies. Moreover, the yellowish colour of most of the finer deposits, particularly in the upper part of the profile, suggests a direct influence of the catchment area and erosion of the Verdun Tertiary Formation. The grey colour of the sandy units suggests a marine influence with material inputs from the ocean and coastal drift associated with sea breezes. The brown and quite dark colour of some silty facies can be explained by a higher organic matter content (Figure 8). Thus, the silty deposits of the middle and top of the sequence could correspond to a reworking of continental elements in a relatively calm water environment allowing bedded sedimentation. The more or less undulating and discontinuous bedded structure of the deposits indicates at least a low-energy current associated with either a restricted opening of the system to the ocean or limited water inputs from the inlands, or a combination of the two. As for the grey sandy deposits, they could correspond to old beach levels or ridges deposited either in a shallow water context, as suggested by the oxidation of Unit 2 and Unit 3, or in sub-aerial conditions. The range of sedimentation environments observed at Nunura is similar to that of the deposits studied at Las Salinas Noroeste (Christol *et al.* 2015, 2017).

3.2.3.5. Relative chronostratigraphy and evolution of the Nunura coast

The absence of precise chronological markers prevents us from placing the Nunura 1 sedimentary record in a broader temporal context and cross-referencing these off-site data with the on-site data. However, these deposits, eroded by a channel incision somewhat recent in the longer history of the coastline, provide a first relative chronology of an environmental evolution preceding the aridification phase recorded at the end of the 1st millennium AD (Christol *et al.* 2017). The diversity and the succession of these environments suggest periods of impoundment of the low topographical areas in the form of lagoons alternating with periods of coastal aggradation under sub-aerial and evaporative conditions.

Nunura 1 record thus begins with a coastal aggradation phase that has allowed the accumulation of almost 1 m of sand (Unit 1; this deposit continues deep into the ground). The low organic matter content of this deposit supports the hypothesis of dominant wind dynamics with ocean material (Figure 8).

Afterwards, the coastline undergoes water infilling and lagoon formation associated with dominant inputs of detrital elements rich in organic matter from the catchment area (Unit 2). This lagoon phase is interrupted by a temporary and unstable period of sandy accumulations (Unit 3), starting with the deposition of a fine, yellow silty-clay bed interbedded in the grey sands at a depth of 75 cm (Figure 8).

Then a rather calm water sedimentation begins, which lasts long enough for 40 cm of sediment to be deposited (Unit 4; Figure 8). This sedimentation occurred in three stages that could reveal changes in environmental conditions. In the first stage, the detritic influence of the continent is clearly visible, with a yellowish colour indicating, however, low organic matter contents (yellow facies). This could be linked to a lower vegetation cover and rhexistasy in the upstream part of the *quebrada* outlet in the lagoon. In the second stage, organic matter inputs seem to increase (Figure 8), potentially signifying production conditions in the lagoon and/or biostasy in the upstream

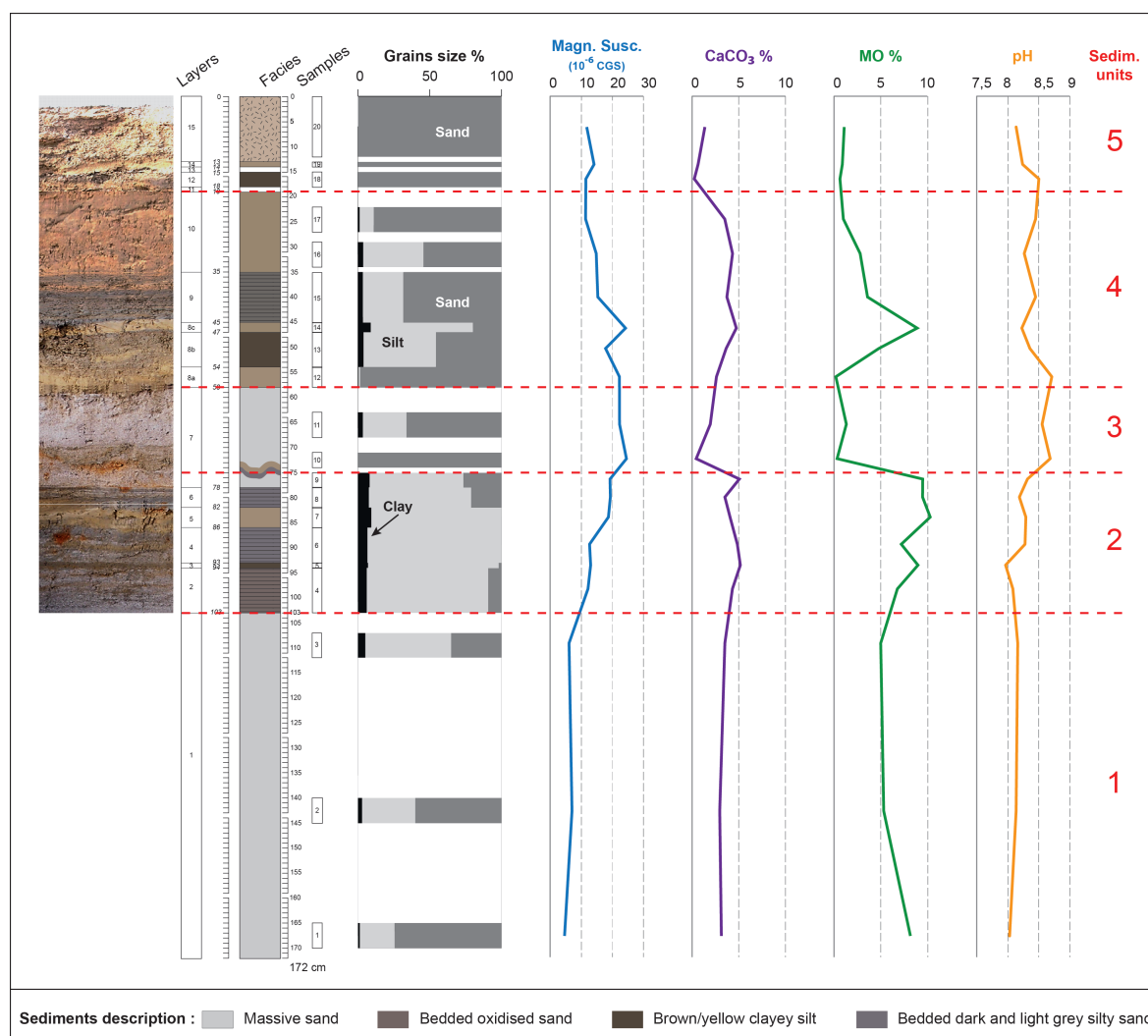


Figure 8. Nunura 1 profile. Description of the sediments; location of the samples; and results of the grain size, magnetic susceptibility, CaCO_3 , TOC, and pH analyses. The five major sedimentary units are also identified on the profile.

area. This environment is similar to the marsh lagoon phase identified at Las Salinas Noroeste. The final stage is not associated with significant organic inputs, but sedimentation still seems to be sustained by the erosion of the inland from catchment area.

Finally, the upper deposit of the Nunura 1 sequence indicates, as at Las Salinas Noroeste, an aridification of climatic conditions (Unit 5; powdery sand with salt nodules and crusts). This succession represents a major change compared with the lower units, which record relatively humid climatic conditions, which would have been necessary to both activate the hydro-sedimentary dynamics eroding the Illescas massif upstream, and a stream discharge maintaining yearlong a minimum water level in the Nunura lagoon.

4. Discussion

All data exposed above give us information on the landscape and climate evolution of the northern Peruvian coast and on the human occupation of these territories over the past two millennia. Geomorphological data indicate that the region possesses a high environmental sensitivity, which has been and is still being influenced by several factors. Sedimentary archives record environmental changes over several centuries in relation to the variability of the mean climate, but they also reveal the effects of ENSO activity timing and intensity.

Both in Nunura and Las Salinas, a major contrast can be observed between humid and arid climatic phases. During these periods, sediment inputs come from both the ocean and the continent: marine sedimentation alternates with aeolian and alluvial deposits. Particularly significant are the lagoon phases identified at the two sites studied, which correspond to climatic periods which are in average more humid than the current one (Figure 9). In addition to this long-term evolution, ENSO's activity also probably had an influence on the maintaining of lagoon environments. Their presence at Las Salinas up to the 8th century AD was made possible by constant freshwater inflows from the continent, but was most likely enhanced also by one or more intense ENSO events during this period (Rein 2007).

Regarding Nunura, information is currently more limited and less precise, although the presence of lagoon environments is well documented. In addition, the hypothesis of climatic conditions more humid than the current ones is corroborated by the presence of organic sediments indicating vegetation development phases, either along the coast or farther upstream. Afterwards, the sedimentary archives of both sites record the drying of the lagoons, attested to by evaporate deposits with high salt concentrations. This environmental change occurred at Las Salinas around the 8th century, when more arid climatic conditions became established. At Nunura a similar evolution can be observed, but the lack of chronological data does not allow us to affirm that it corresponds to the same aridification phase recorded at Las Salinas, as seems possible.

The coastal environments of northern Peru appear to be particularly sensitive and reactive to the climate changes that have characterized the past two millennia. Consequently, populations living in the Sechura desert had to face several changes over time, in terms of both the variety and the abundance of resources.

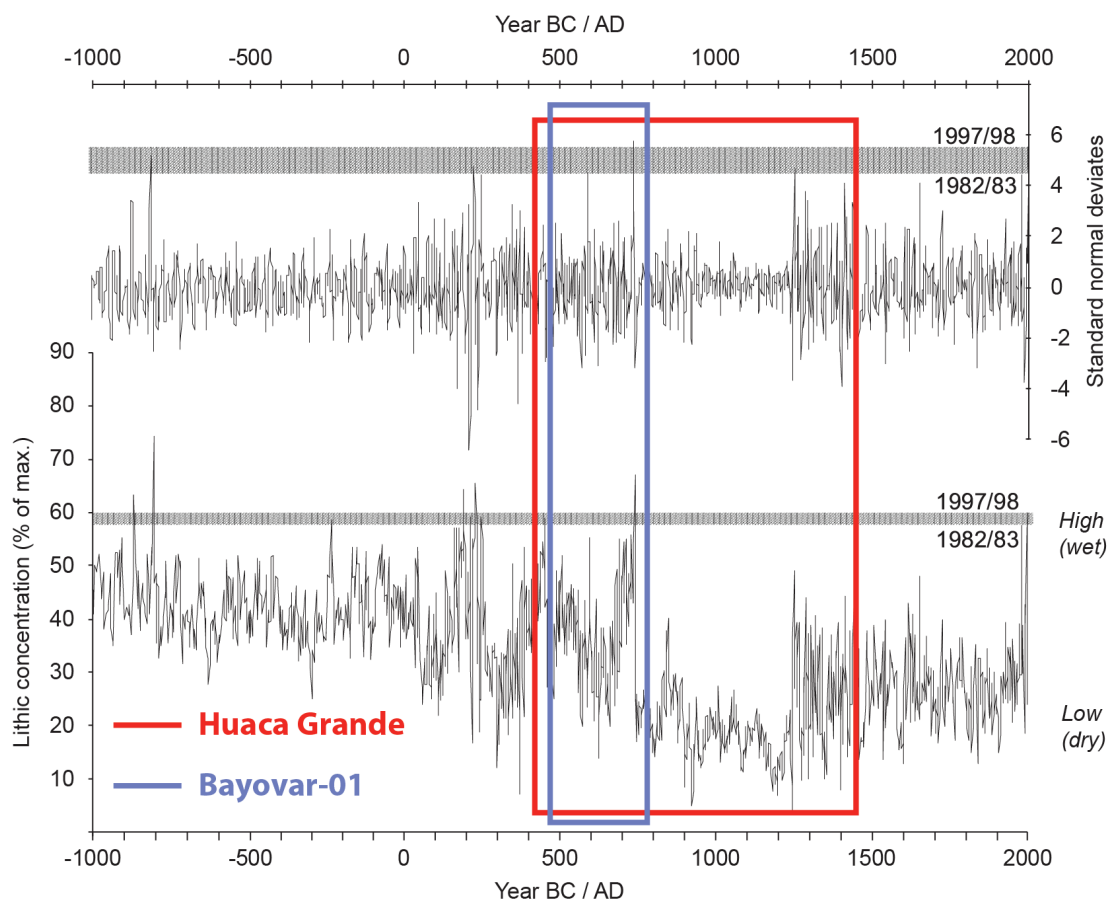


Figure 9. Climatic variability (highlighted by the El Niño flood proxy) during the occupation of the Bayovar-01 and Huaca Grande sites. After Rein (2007). The hatched horizontal bars indicate the magnitude of the 1982/83 and 1997/98 El Niño flood signals.

The archaeological sites of Bayovar-01 and Huaca Grande illustrate two different and complementary ways in which these populations adapted. Bayovar-01 corresponds to a continuous occupation, over a short period of time (at most three centuries), related to the exploitation of a particular resource. Indeed, Bayovar fisherfolk settled on the edge of the Las Salinas lagoon and took advantage of favourable conditions that allowed the development of a new fauna of warm-water fish and molluscs coming from the north. This is an ephemeral and opportunistic occupation, as the site was abandoned when the lagoon dried up during the 8th century AD, and it was not occupied after that time (Goepfert *et al.* 2016, 2019).

On the contrary, the Huaca Grande site hosted a very long-lasting installation, which extends over about a millennium, between the 5th and 15th centuries AD. During this period, the site appears to have been reorganized, changing its function several times, and it was abandoned at least once.

For the moment, the most significant data concerning the occupation are the faunal remains, which indicate an important change in habits and resource supply for the inhabitants of the site. Marine mammals, which are very common in the lower part of the sequence, seem to be progressively replaced by molluscs and fish in the more recent occupation phase. It is necessary to try to understand whether this change is the result of a deliberate choice or whether it is linked to climatic and environmental pressure that would have led to a modification of the resources available near the site. The settlement of Huaca Grande corresponds to a period during which the average climate is affected by several variations (Figure 9): i) a wet phase characterized by a high frequency of extreme ENSO events comparable to 1982/1983 and 1997/1998 until the middle of the 8th century AD, followed by ii) an arid phase marked by the weakening of ENSO between AD 750 and 1250, and then iii) a return to more humid conditions with a restart of ENSO activity (Rein *et al.* 2004; Rein 2007). Thus, climate data show that the inhabitants of Huaca Grande faced significant climate changes. We do not have off-site archives that enable us to reconstruct the evolution of the landscape during the occupation, but the malacological data provide some important information. Nunura Bay is located on the 6th parallel, in the area where the warm waters of the Ecuador-Peru Coastal Current (EPCC) and the cold waters of the Peru Coastal Current (PCC) converge. In biogeographical terms, this corresponds to the transition between the Panamic Province (3.5-4.5° S), characterized by tropical species, and the Peruvian Province (6-13.5° S), dominated by cold water species (Ibanez-Erquiaga *et al.* 2018 and references therein). Nunura Bay is therefore located at the northern limit of the Peruvian Cold Province.

Considering these data, the presence of tropical molluscs in the Huaca Grande site is of particular concern in relation to the evolution of the climate and coastal landscapes of Nunura during the Holocene. It could indicate i) a coastal landscape different from the current one, including confined lagoon environments characterized by warm waters and/or ii) a variation in ocean circulation related to ENSO activity. Indeed, during ENSO events, the species distributed primarily in the equatorial region spread into latitudes where normally cold-upwelling species occur along the southeast Pacific coast (Paredes *et al.* 2004; Hooker 2009). Some of these tropical species can therefore settle and persist in refuge areas for some time after events (Ashton *et al.* 2008; Gárate and Pacheco 2016). If these hypotheses are correct, the third occupation phase identified at Huaca Grande would date to after AD 1250.

Indeed, from that moment on, a more humid climate became established in the area, allowing the conservation of lagoon-type environments. Furthermore, ENSO events were stronger and could have caused shifting of warmer waters southwards, carrying tropical mollusc species to Nunura.

The sedimentary sequence of the Nunura 1 profile cannot be replaced chronologically in relation to human occupations, but it clearly indicates that such environments occurred in the bay and lasted for some time (see Unit 2 and Unit 4; Figure 8). New dates are required to specify the times

of occupation of Huaca Grande, but the available data show us a very different type of occupation from that at Bayovar-01, extending over a long time span and based on varied resources, whose diversification is probably linked to the evolution of the environment around the site in relation to climatic oscillations.

5. Conclusion

Our research highlights the high sensitivity of the Sechura Desert's coastal environments to successive climatic changes over the past two millennia and provides insight into how humans adapted to them. Data from sedimentary archives indicate the establishment of lagoon environments characterized by warm and shallow waters during phases of average climate more humid than the current one, between the 3rd and 8th centuries AD, and again from the middle of the 13th century onwards. These environments persisted for several centuries, probably favoured by the occurrence of some particularly intense ENSO events. A shift was recorded during the 8th century AD, when more arid conditions set in and caused the lagoon of Las Salinas to dry up.

The populations living in the Sechura Desert adapted to these changes in two different ways, as illustrated by the two archaeological sites of Bayovar-01 and Huaca Grande. A fishing community settled in Bayovar-01 in an ephemeral and opportunistic manner, exploited the important resource represented by the fish living in the Las Salinas lagoon, and abandoned the site three centuries later, when the lagoon dried up due to more arid climatic conditions and the disappearance of the resource.

In contrast, Huaca Grande corresponds to a more or less continuous and permanent occupation of the same site where people changed their subsistence economy according to the resources available in the vicinity of the site. However, these two modes of occupation are not opposed, but, rather, are integrated in a complementary way into an occupation strategy that had to be flexible to be able to adapt to the very marked constraints that characterize the Sechura desert. Bayovar-01 is most likely part of a larger commercial network linked to other sites. Further research is needed at Huaca Grande to define its function and possible links with contemporary sites.

Our study therefore shows the need to apply a regional approach integrating off-site data from sedimentary archives and on-site information from archaeological excavations in order to assess the variety of human occupation patterns in a highly variable environment, such as the northern Peruvian coast.

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