Effect of the Spanish Conquest on coastal change in Northwestern Peru

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Edited by Charles S. Spencer, American Museum of Natural History, New York, NY, and approved April 15, 2014 (received for review March 11, 2014)

When Francisco Pizarro and his small band of Spanish conquistadores landed in northern Peru in A.D. 1532 to begin their conquest of the vast Inca Empire, they initiated profound changes in the culture, language, technology, economics, and demography of western South America. They also altered anthropogenically modulated processes of shoreline change that had functioned for millennia. Beginning with the extirpation of local cultures as a result of the Spanish Conquest, and continuing through today, the intersection of demography, economy, and El Niño-driven beach-ridge formation on the Chira beach-ridge plain of Northwestern Peru has changed the nature of coastal evolution in this region. A similar event may have occurred at about 2800 calibrated y B.P. in association with increased El Niño frequency.

Human activity alters landscapes as well as cultures, and the synergistic processes involved have deep temporal roots (1). The Spanish Conquest of the Americas was one of the most significant human events in terms of natural and cultural consequences (2, 3). Here, we detail how the demographic and economic effects of the conquest altered landscape development on the Chira beach-ridge plain in northern coastal Peru. This region was the first in Peru to feel the direct effect of the European presence. In 1532, Francisco Pizarro and his band of conquistadores moved from their temporary camp at Tumbez on the modern Peru–Ecuador border to the Chira Valley, where they founded San Miguel de Tangarara, the first Spanish settlement in what is now Peru (4). Only later did they move south, and then inland, to Cajamarca and the fateful meeting with the Inca emperor Atahualpa and his army (5).

Beach ridges in northern Peru (Fig. 1) have been studied for more than 30 y by archaeologists and geologists with the aim of better understanding maritime economies, the influence of El Niño cycles, and the effects of sea level change and sediment supply on coastal systems. There are two distinct types of beach-ridge plains: those composed of gravel, which occur near river sources (Santa Ridges, ref. 6) or eroding cliffs and short quebrada streams (Colan, refs. 7, 8), and sandy beach ridges with abundant shell middens that are sourced by streams carrying mostly sand (Chira, Piura, refs. 7–10). In these coastal plains, there are generally 9 major ridges that date between ∼5140 ± 170 and 404 ± 87 calibrated (cal) B.P. Because of the hyperarid climate of the Peruvian coast (11), the ridges and middens are well-preserved morphologically and stratigraphically, and even El Niño events do little more than passively flood the beach-ridge plains with up to 40-cm-higher sea levels, creating salinas in the swales (Fig. 1*B*).

The northwest coast of Peru hosts 5,100 y of beach ridges, produced by a combination of extraordinary events (earthquakes and El Niños) and normal littoral processes. These beach ridges differ from both the berm and dune ridges found on barrier islands (12, 13) and the ridges associated with deltas, such as cheniers on muddy coasts (14) and sandy river-mouth accretionary strandplains (15). Northern Peruvian beach ridges form from the sequential interaction of tectonic activities, El Niño rainfall, and normal littoral processes (6, 9, 16). Sediment is carried from the interior by increased El Niño runoff, but major beach ridges form only when sufficient colluvium is available in the drainage system after major earthquakes (6). The predominant northerly longshore drift sorts material from fluvial sources into discrete ridges. The quasicentennial to quasidecadal recurrence interval of El Niño since 5800 cal B.P. is much shorter than the periodicity of the preserved ridges, so each ridge is likely a composite of multiple events and fluctuations in sediment supply. The processes driving the formation of swales and initiation of a new ridge are not yet well understood. The geomorphology does indicate a consistent southern source of sand, carried by the persistent northerly longshore current. Even though wind fields become more chaotic during El Niños, they still do not shift enough to reverse the direction of the oblique waves that drive longshore current (ref. 17, p. 163). Constant onshore winds blow the fine fraction inland, where it is either trapped in the beach ridges (Piura, Chira) or exits the coastal system. In some cases, sand returns to the coast via a more northerly river basin (16).

Uplift of this part of the Peruvian coast is slow (0.2–0.4 mm/y) (18). Local relative sea level has been stable or within a meter or two of present over the last 6 millennia. Thus, the progradation of the beach ridges has taken place on a relatively stable platform, but in the context of the variable frequency and intensity of El Niño (19, 20). After a multimillennial hiatus, El Niño returned after 5800 B.P. and increased in frequency after about 2800 B.P.

Results

Here, we report on geomorphic and geoarchaeological investigations on the 31-km long beach-ridge plain between the Chira River and Punta Balcones, northwestern coastal Peru. In 1997, we conducted reconnaissance geoarchaeology, including test pits and leveling surveys at several sites in northern Peru, including the Chira ridges. We dug stratigraphic test pits in seven locations on ridges and in swales. Subsequent research included a remote sensing study of the relation between ridge formation, seismic activity, and El Niño flooding (9).

Significance

Culture contact can lead to unexpected consequences. The population of Peru dropped precipitously after the Spanish Conquest, changing the patterns and intensity of economic activities. In northern Peru, such changes affected the evolution of beach ridges (narrow sand dunes many kilometers long, parallel to the shoreline) north of the Chira River. A similar hiatus in beach ridge formation about 2,800 y ago correlates with increased El Niño frequency, and possibly a local decline in population at that time. This study illustrates the value of comparing historic, archaeological, climatic, and geological data to understand change in coupled natural and human systems.

Author contributions: D.F.B. and D.H.S. designed research; D.F.B. and D.H.S. performed research; D.F.B. and D.H.S. analyzed data; and D.F.B. and D.H.S. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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www.pnas.org/cgi/doi/10.1073/pnas.1404568111

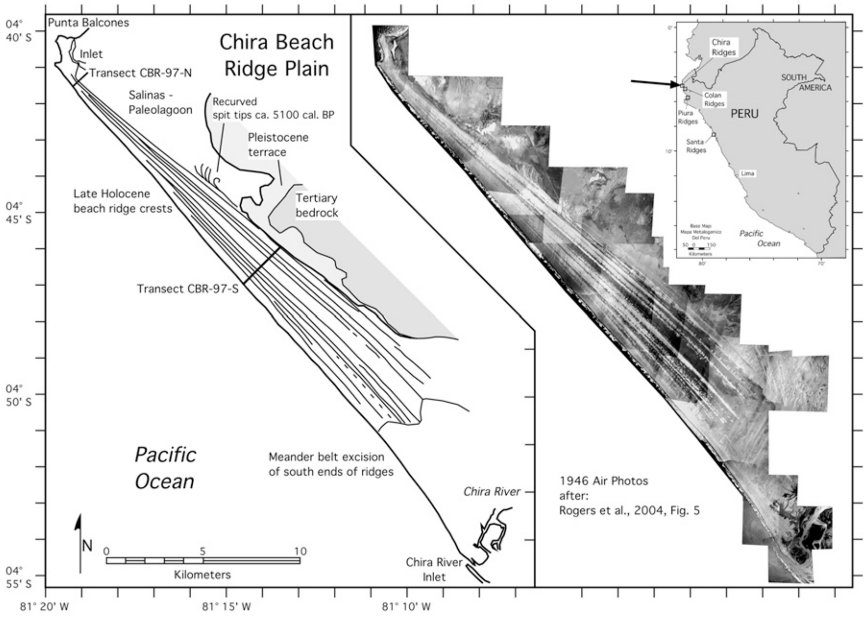


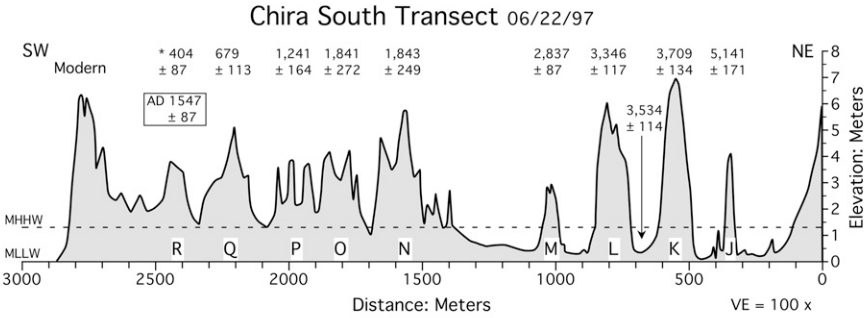
Fig. 1. Location map of Chira beach-ridge plain in northwestern coastal Peru. (Photo mosaic reproduced with permission from ref. 9, figure 5.)

The Chira beach-ridge system has experienced progradation up to 4 km seaward on a wedge-shaped plain that is broadest to the south and narrows to the north, away from the river mouth sediment source. The Chira River carries primarily sand at its inlet, and the ridges are built entirely of sand, as observed on the surface and in test pits, and as reported in refs. 6 and 7. Most ridges with sharp crests are covered by mollusk and barnacle shells, clearly associated with fire-cracked rocks, fire pits, and artifacts indicative of human middens (8) (Fig. 2). Throughout the entire ridge sequence, the mollusks are almost entirely the species *Tivela hians* and *Donax obesulus*, which are still fished in the area today (7, p. 112). Ortlieb and colleagues (7) pointed out that these midden shells are instrumental in holding the sandy ridges in place in the face of relentless southwest onshore winds. There are sparse clumps of brush that stabilize some dunes within several hundred meters of the coast, watered by spray and condensation. Our primary hypothesis is that only the shell-armored ridges are stabilized and maintain their sharp-crested morphology. Otherwise, the prevailing onshore southwest winds blow loose sand inland. We conducted a field examination of the ridges in 1997, including leveling transects, shovel test pits, and differential global positioning system navigation, to ground-truth a photomosaic geomorphic study (9). The southern transect (Fig. 3) was ∼3 km northwest of, and parallel to, Ortlieb and colleagues' (7) transect of dating sites J–R (Table 1).

Fig. 2. Surface of ridge J and test pit surface test pit-Chira-1997-number 4: STP-C-97-4.

Sourced on the south by the Chira River, the accretion plain narrows to the north, and the continuity/identity of the individual ridges lessens (Fig. 1). The northern leveling line (Chira beach ridges-1997-North: CBR-97-N) found numerous ridges smaller than at the southern transect, more difficult to separate definitively, and crossing a distance of 800 m. However, the distinctive midtransect swale does seem to persist at this location. Recurved spits at the eastern edge of the plain, adjoining the paleo-salinas, demonstrate longshore transport to the north. These first ridges did not extend the full length of the plain, suggesting an open embayment before ca. 5100 cal B.P. During extreme El Niños, the modern salinas floods and drains through an inlet just north of Punta Balcones (Fig. 1). The morphology of the beach-ridge plain demonstrates progressive infilling of a shallow embayment, straightening of the coast, and possible sediment bypassing of Punta Balcones for the past ca. 5,100 y, since the first ridge reached Punta Balcones. The Chira River and its inlet on the south end of the plain actively meander, excising parts of the proximal beach ridges (Fig. 1) (9).

Richardson (8) was the first to carry out archaeological research on the ridges and throughout the Chira region. He reported that most ridges were completely covered with midden shell, fire-cracked rocks, and other artifacts, an observation we confirmed in the field (Fig. 4). The surface 20–50 cm contain much more abundant shells, in discrete layers, than are found in underlying sediment sections. From our field observations, we concur with Richardson that the shells are largely an anthropogenic deposit. Were the shells solely a natural deposit, we would expect them to be more uniformly distributed in the dunes. Radiocarbon dates (Table 1) and artifact types demonstrate that occupation of the ridges was time-transgressive from east to west, with occupation always on the active seawardmost ridge (8). Ortlieb et al. (7) provided additional dates for the ridges and noted (p. 110), "These sheets of midden shells played an important role in preserving the ridges from erosion and deflation."



* Radiocarbon Minimum Dates, Ortlieb et al. (1995), recalibrated in this paper to Calibrated Years BP: Calib 7.0.1

Fig. 3. Automatic survey level line of Chira South (CBR-97-S) 2907.6 m in length aligned 225° magnetic from global positioning system survey point 04° 45.854′ S 81° 13.340′ W to the water line. Magnetic declination at this point is negligible (0° 04′ W; http://magnetic-declination.com/Peru). Survey closure resulted in −0.149 m elevation and 1.9 m distance. Sea level was estimated based on predicted tides for the day, on a normal climate and weather day (21). Designation of ridges by letter follows ref. 10.

Discussion

We suggest that the precontact period human activity was, in fact, essential to preserving the sandy beach ridges from eolian erosion by persistent onshore winds. No sandy ridges can remain stable for long without middens for armor. The Spanish Conquest in Peru, starting in 1532 A.D., resulted in extreme depopulation of the Chira coast within a century of the conquest (4, p. 125), which drastically changed the local economy, devastating traditional coastal shellfish harvesting. Richardson (8, 22–24) reports that from ∼5,100 y through the Colonial Period, archaeological survey recorded settlements in the lower Chira River, in the quebradas east of the ridges, and around Punta Balcones and Pariñas at the northern end of the ridges. This settlement pattern continued through the Inca conquest of the region, but not into the Colonial Period, consistent with the ages of deposits on the ridges and with the ethnohistoric data on regional depopulation.

The last well-preserved ridge corresponds in age with the Spanish conquest of this region, and we correlate the devastation of the coastal population after European contact with a distinctly different geomorphology that we recognize west of the ninth ridge (beach ridge R: 1546 ± 87 A.D.; Table 1 and Fig. 3). By 1600 A.D., the population of neighboring Piura was concentrated in the interior at higher elevations (4), and presumably the same was true for Chira. Population growth into the 19th and 20th centuries no longer resulted in deposition of shells on the coastal beach ridges; rather, the mollusks were exported to interior markets, as occurs today. Thus, for the past 500 y, demographic decline and economic change have eliminated shell midden deposition on the coast, so as progradation continued, the newly formed dune ridges eventually lost their vegetation cover, dried up, and blew away inland.

There might have been more than nine ridges formed in the Chira beach-ridge plain, but for cultural or climatic reasons, there were no shell middens produced to stabilize them. In particular, the largest prehistoric swale dates to ca. 2800 cal B.P. (Figs. 3 and 4), when El Niño suddenly increased in frequency at the end of the Initial Period (19). In fact, the 2800 cal B.P. swale appears remarkably similar to the ridge plain formed over the last 500 y. The Initial Period climatic downturn could have caused abandonment or depopulation of the region, and thus a lack of shell deposition on the contemporary ridge. If such an unarmored ridge existed, it has since blown away, down to the level of groundwater-saturated salinas.

Methods

We used a Nixon AE-5 Survey Level to complete the transect in both directions, closing the survey loop and distributing minor errors. We confirmed nine major ridges and/or ridge clusters, separated by swales, although designation of separate ridges within the O and P cluster is somewhat arbitrary. Ridges K and L reached to 6 and 7 m above mean lower low water, whereas the swales on the inner half of the transect are up to a meter below mean higher high water, and well below elevated sea levels expected in El Niño conditions, as seen in aerial photographs from the 1982–1983 El Niño event (ref. 25, figure 4.2). The swale between ridges M and N is 300 m wide and must represent a period of general coastal aggradation without the preservation of a distinctive ridge. We noted in the field that the last 400–500 m of progradation on the Chira strandplain comprises hummocky, low-relief dunes with few shells and little evidence for human activity, although faced on the seaward side by the currently forming, vegetated high ridge in the southern and central extent of the plain. Shovel test pits were limited to less than a meter deep because of the loose dry sand making up the ridges. Stepwise excavations down the flanks revealed undisturbed internal strata. The lower portions of ridges demonstrate planar flat to gently southwest-inclined

Table 1. Published radiocarbon dates and new calibrations for the Chira beach ridges

Beach ridge (6)	Laboratory number	Nature of sample	Measured ^{14}C age y B.P.	∂^{13}C normalized age y B.P	Minimum ^{14}C age of beach ridge y B.P.	Midpoint and 2-sigma range of calibrated ages y B.P.
J	By 693	Charcoal	4570 ± 50	4540 ± 50	4540 ± 50	5141 ± 171
K	By 648	Charcoal	3520 ± 50	3490 ± 50	3490 ± 50	3709 ± 134
Interridge	By 672	*Tivela*	3370 ± 40	3790 ± 40		3534 ± 114
L	By 691	Charcoal	3190 ± 45	3160 ± 45	3160 ± 45	3346 ± 117
M	By 689	Charcoal	2760 ± 40	2730 ± 40	2730 ± 40	2837 ± 87
N	SI-1423	Charcoal	1955 ± 100		1955 ± 100	1843 ± 249
O	GK-1566	*Tivela*	1550 ± 110	1900 ± 110	1900 ± 110	1841 ± 272
P	SI-1424A	Charcoal	1405 ± 75		1405 ± 75	1241 ± 164
Q	SI-1457	Charcoal	805 ± 60		805 ± 60	679 ± 113
R	By 647	Charcoal	380 ± 40	350 ± 40	350 ± 90	404 ± 87

Ridge numbering follows (7). Original data from ref. 7, table 2). Note that SI and GK dates were originally from ref. 8. Calibrations in 2014 using Calib 7.0.1 (26). SHcal13 (27) was used for the charcoal samples, Marine13 (28) with ΔR155 y regional marine reservoir correction was used for the *Tivela*.

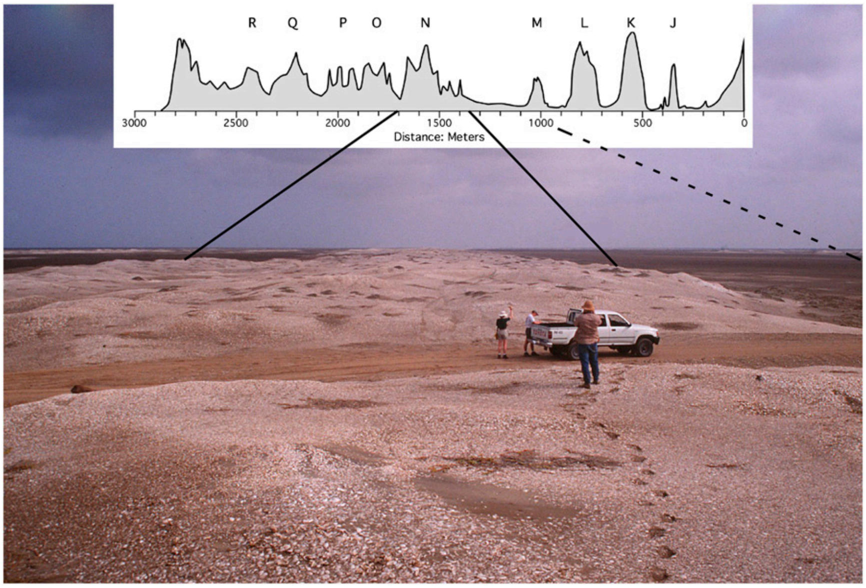


Fig. 4. Photo June 20, 1997 to northwest from crest of Ridge N, near southeastern end of the beach-ridge plain, 4° 49.748′S 81° 10.662′W. Note the massively extensive midden shell cover of the dune ridge, and the large, nearly flat swale to the northeast.

laminae of well sorted M-F quartz and feldspar sands, with numerous heavy mineral layers and very few shells. We interpret these as beach laminae. The upper 1–2 m of ridges reveal cross-bedded very well sorted quartz and feldspar F sand, dipping at various angles including steeply northwest, interbedded with concentrations of *Tivela* and *Donax* shells with fire-cracked rocks and charcoal (Fig. 2). We interpret this association as dunes with shell middens and human occupations. In 2006, we carried out a georadar study of the Chira ridges that confirmed their internal structure.

Conclusions

This study demonstrates that local maritime people were major geomorphic agents throughout the late Holocene, providing the mechanism for maintenance of steep sandy beach ridges armored by shell middens. The arrival of the Spaniards caused a profound change in coastal morphology, in addition to the other well-documented changes in human culture, health, and well-being. We show that humans had a clear effect on a coastal system that now appears to be an uninhabited, natural landscape, yet is the product of millennia of anthropogenic modification of the environment. Our research also provides evidence for a previously unrecognized consequence of the Spanish conquest.

ACKNOWLEDGMENTS. Stacy Shafer Rogers and Jeff Rogers provided invaluable assistance in the field. Alice, Joe, Kate, and Taylor Kelley; Kurt Rademaker; and David Reid assisted with this work. During both field seasons, PetroPeru provided access, housing, and other aid with the research. The 1997 fieldwork was funded by a Maine Science and Technology Foundation/National Aeronautics and Space Administration grant (to D.H.S.). The 2006 georadar study was funded by a Foundation for Exploration and Research on Cultural Origins/Thor Heyerdahl grant (to D.H.S.).

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