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DISCUSSION

Discussion of: Lisa E. Wells, 1996. The Santa Beach Ridge Complex, *Journal of Coastal Research*, 12(1), 1–17.

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PERUVIAN BEACH RIDGES REVISITED

We have read the paper "The Santa Beach Ridge Complex" by Lisa E. Wells (1996) with great interest, and we congratulate Wells for calling attention to important, if controversial, issues. As we have carried out research on these ridges over the last 16 years (SANDWEISS *et al.*, 1981, 1983; SANDWEISS, 1986; MOSELEY *et al.*, 1992), we would like to comment on several areas of disagreement between Wells and ourselves which are critical to understanding the chronology and mechanisms of ridge formation in northern Peru.

Our disagreements are also part of a larger debate concerning paleoclimate in northern Peru and the possible onset of El Niño/Southern Oscillation (ENSO) at about 5000 BP (ROLLINS *et al.*, 1986; DEVRIES and WELLS, 1990; SANDWEISS *et al.*, 1996, 1997; DEVRIES *et al.* 1997; WELLS and NOLLER, 1997). In the early 1980's, we discovered that the Santa paleoembayment and associated archaeological sites dated shortly before 5000 BP and contained a moderately diverse assemblage of mollusks (in living position and with multiple year age classes in the fossil beach) that is characteristic of the warm-tropical waters north of *ca.* 5°S latitude but quite different from the Humboldt Current-dominated, warm-temperate molluscan assemblage that characterizes sites in the region today and for the last 5,000 years (ROLLINS *et al.*, 1981; SANDWEISS *et al.*, 1983). These data, along with information for other parts of the west coast of South America, led us to suggest that ENSO could not have functioned as it does today when the Santa paleoembayment was active (ROLLINS *et al.*, 1986). More recently, we have gathered more faunal data (mollusks and fish) from a variety of Peruvian coastal sites that indicate warmer conditions north of 10°S latitude and prior to 5000 BP; these findings, plus data from other areas of the world affected by ENSO teleconnections that suggest decreased climate variability in the millennia preceding 5000 BP, strengthen our hypothesis of an ENSO onset at that time (SANDWEISS *et al.*, 1996).

The points we raise concerning the WELLS (1996) article are:

Changing Style of Coastal Deposition

Beach ridges are linear coastal deposits formed primarily by wave processes near storm and normal high water levels. The "ridges" in Wells's Morphostratigraphic Group I are, in fact, *subaqueous* bars or shoals for most of their extent. Their form is different from the true ridges (Wells's Morphostratigraphic Groups II–V), and they are overtopped by *in situ* warm-tropical mollusks. There is clearly a change in style of coastal deposition between the formation of Morphostratigraphic Groups I and II.

Ridge Formation Process

Prior to about 5,000 years ago, while Morphostratigraphic Group I bars were forming, the coastal region north of the Santa river was an embayment inhabited by warm-tropical mollusks and fish, and bordered by human groups exploiting these species (ROLLINS *et al.*, 1986; SANDWEISS *et al.*, 1996; SANDWEISS, 1996). Through her various publications, Wells has modified her reconstruction of the evolution of the Santa beach ridge plain that now fronts this embayment. To follow her current argument, it is necessary to review its development. She originally stated, "The earliest beach ridge likely formed as a longshore bar; in this hyperarid environment, evaporation would then empty the isolated bay" (WELLS and NOLLER, 1986, p. 197). The use of the term "longshore bar" here is problematical, the proper term should be "barrier." In this scenario, the "earliest beach ridge" is either WELLS's (1996; DEVRIES and WELLS, 1990) Ridge IIa or it is the Group I features that presumably became subaerial due to total evaporation of the bay. In 1990, she wrote, "Beach Ridge II-A [the oldest subaerial ridge, aka IIa, 2a] formed an unbroken barrier to the exchange of water between the Pacific Ocean and the low ground behind this ridge. The Santa lagoon formed in the protected low area behind this ridge" (DEVRIES and WELLS, 1990, p. 18). All of these scenarios are

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flawed by the fact that the mollusks known to have lived in the paleoembayment prior to 5000 BP could not have survived in the absence of water—and Wells was right in 1987 that in this environment, a completely enclosed shallow bay would soon be bone dry. In her recent paper, Wells recognizes this problem and offers a new scenario: she writes, "the lagoon [Santa paleoembayment] must have been adequately flushed to support a diverse molluscan fauna for about 2,500 years beginning about 6.6 ka [calibrated]" (WELLS, 1996, p. 7). However, her Figure 4 and corresponding captions still reflect her earlier ideas, as they show a tidal channel at *ca.* 4000 BP but not at 6700–4150 BP.

The common theme of all of Wells's reconstructions of the pre-5000 BP geography of the Santa area is the presence of a long beach ridge or barrier island, her Ridge IIa, seaward of Morphostratigraphic Group I. Unfortunately, the available chronological data contradict this scenario, as does the presence of mollusks in living position in what would be dry land under most of Wells's scenarios (see above). A proper understanding of this issue is crucial not only to deciphering Santa beach ridge formation processes and timing, but also to evaluating paleoclimate indicators in this region (SANDWEISS *et al.,* 1996, 1997).

The context as well as absolute values of dated materials is essential to reconstruct past environments; WELLS (1996) violates this principle in several instances. First, there is only one date directly relevant to the formation of Ridge IIa or to its stabilization in its present position: 4215 ± 115 (cal. 3.6–4.5 bp) (SANDWEISS *et al.,* 1983, p. 286; SANDWEISS, 1986, p. 19). Contrary to WELLS's (1996, p. 9) statement that this date was run on "a *Prisogaster operculum* from the surface deposits of Ridge IIa" and therefore after the ridge had formed or stabilized, in fact the date was on *Prisogaster* with their opercula in the matrix of Ridge IIa (Figure 1) (SANDWEISS *et al.,* 1983, p. 285–286; ROLLINS *et al.,* 1986, p. 8–9; SANDWEISS, 1986, p. 19). The association with opercula shows that these shells had not been transported after death, and the presence of the shells in (not on) the ridge therefore dates its formation or stabilization at this location. One scenario for formation of Ridge IIa, similar to WELLS (1996), is a barrier offshore of its present location (Figure 2A), with subsequent migration to its present position by *ca.* 4 ka (Figure 2B). This scenario would allow growth of mollusks in lagoonal sediments seaward of the present ridge position, followed by coastal erosion and barrier migration landward to its present position. The eroding shoreface would expose the former lagoonal sediments under a ravinement unconformity (*e.g.,* BELKNAP and KRAFT, 1985). The shells presently within Ridge IIa thus date its ultimate stabilization/abandonment, while the shells west of Ridge IIa are formerly lagoonal or embayment shells exposed by the shoreface ravinement unconformity.

Further support for the 4215 ± 115 bp date for the formation or stabilization of Ridge IIa is provided by DEVRIES and WELLS's (1990) date of 4180 ± 55 BP (cal. 4.3–4.2 bp) on a *Trachycardium* shell from the surface of the paleoembayment. WELLS (1996:Table 1, Figure 5, and p. 7) uses this date to argue that "lagoonal deposits" landward of Ridge IIa continued to exist well past 5000 BP. In fact, Wells previously indicated that the dated shell came from "washover deposits" (DEVRIES and WELLS, 1990, p. 27 and Table 3). Therefore, the date is consistent with a time when Ridge IIa existed but says nothing about conditions in the paleoembayment at that time. *Trachycardium procerum* is adapted to environments ranging from warm-tropical to the warm-temperate conditions that prevail in the region today and indeed is commonly found near the Santa Valley (*e.g.,* ALAMO and VALDIVIESO, 1987, p. 133).

Second, WELLS (1996:Table 1 and Figure 5) provides three dates on shell prior to cal. 6000 bp. Two of these dates come from the floor of the paleoembayment east of Ridge IIa. Only one of the shell species is identified, and it is a warm-tropical/warm-temperate species. The third date is from an unidentified shell to the west of Ridge IIa found in a deposit including both sand-dwelling, warm-tropical/warm-temperate razor clams (*Tagelus*) and rock-dwelling, warm-temperate slipper shells (*Crepidula*). There are several problems with interpreting the third date. First, DEVRIES and WELLS (1990, p. 18) write that this deposit had "occasional fragments of *Tagelus dombeii* and *Crepidula dilatata.*" As disparate faunules represented by shell fragments, this is not an *in situ* assemblage of mollusks in living position. Second, contrary to Wells's assertion that this association is "generally found in protected environments", *Tagelus* can live on open shores without protection from barrier islands; in 1979, Sandweiss collected live *Tagelus* from the open coast north of Cerro Guañape, about 70 km north of Santa. *Crepidula* (probably *Crepipatella dilatata* in this case) is a rock-dwelling, intertidal shell living in fairly high energy environments. The association of these two species is biologically unlikely, and they probably represent two different environments at two different times. If the date is on *Tagelus* and the dated specimen was found close to where it lived, it could date a westward extension of the paleoembayment; one alternative is that this extension occurred prior to the formation of Ridge IIa and seaward of the Group I bars, as shown by alternate interpretation A′ of Figure 2. This would be further support for warming of the open ocean and not just the paleoembayment. However, fragmentary shell could be redeposited from the paleoembayment deposits to the east of Ridge IIa.

Third, the date on the "allochtonous peat" on the surface of Ridge IIa (WELLS 1996, p. 7, Table 1, and Figure 5) means nothing concerning the age of either the ridge or the paleoembayment; as Wells has indicated, washover deposits are common on the Santa ridge plain (DEVRIES and WELLS, 1990).

WELLS (1996, p. 9) writes that Ridge IIa "migrated inland across the lagoon" to reach its present position. We have already demonstrated that:

(1) this Ridge as now constituted is younger than *ca.* 4500 BP;
(2) there are serious flaws in the arguments that the shell assemblage located west of Ridge IIa and dated on one sample to cal. 6890–6350 bp must a) be an *in situ* assemblage and b) must have lived in a sheltered environment.

Given these problems, we offer two alternate scenarios for mid-Holocene coastal evolution in the Santa region. In the first scenario (Figure 2A′), prior to *ca.* 4500 BP, the Santa paleoembayment was fronted only by largely subaqueous

Figure 1. Borrow pit profile in Ridge IIa showing *Prisogaster* shells *in situ,* associated with their opercula.

bars (Wells's Morphostratigraphic Group I), and subaerial ridges (Morphostratigraphic Groups II–IV) began forming only after that date with the onset of ENSO rainfall providing the necessary sediment pulse for episodic ridge formation. This is the version that we have proposed in prior publications (SANDWEISS *et al.,* 1983; SANDWEISS, 1986). A possible analog for conditions prior to ridge formation is found in the Guañape bay north of the Virú valley, some 65 km north of the Santa region. There, an open embayment in the lee of a rocky promontory still provides a habitat for mollusks such as *Tagelus dombeii* (contra DEVRIES and WELLS, 1990; WELLS 1996 re. *Tagelus* ecology). Prior to formation of the Santa beach ridge plain, the Santa paleoembayment was sheltered by a rocky promontory (see WELLS, 1996:Figure 4A and B), but we are uncertain whether the geometry is correct to prevent formation of a barrier in front of the paleoembayment. This leads us to the second scenario, closer to WELLS's (1996) most recent version. Here, Ridge IIa represents the final position of a transgressive barrier that was migrating inland for several thousand years in a framework of rising sea level (Figure 2A), as WELLS (1996) suggests. As she indicates in the text, this barrier must have been broken by tidal channels, to account for the mollusk and fish found in the Ostra beach and associated archaeological sites. Around 4000 BP, the barrier stopped migrating inland at a time of sea-level highstand (Figure 2B). After 3600 BP progradation of the beach ridges began (Figure 2C), in a framework of stable to slowly falling sea level. This scenario also supports our hyposthesized onset of ENSO after 5000 BP. If sea level stabilized by *ca.* 6500 BP and yet the barrier continued to migrate inland for the next 2,000 years, as Wells argues, then a significant change in sediment supply must have occurred to cause the shift from shoreline retreat to progradation. Pulses of sediment associated with torrential ENSO rainfall following tectonic destabilization of the Santa drainage basin would provide an appropriate mechanism (as suggested in SANDWEISS *et al.,* 1983, and SANDWEISS, 1986, and supported for the mid-late 20th century by MOSELEY, *et al.,* 1992).

Driftwood Dates and Tsunamis

Another issue involving context and chronology is the interpretation of the driftwood deposits. WELLS (1996, p. 10) found driftwood only on the modern, Group IV ridges, not on the older ridges (Groups III and II). This modern observation actually has little to do with the original distribution of driftwood on the Santa ridge plain: REY Y BASADRE (1896), a Peruvian civil engineer who first described the ridges 100 years

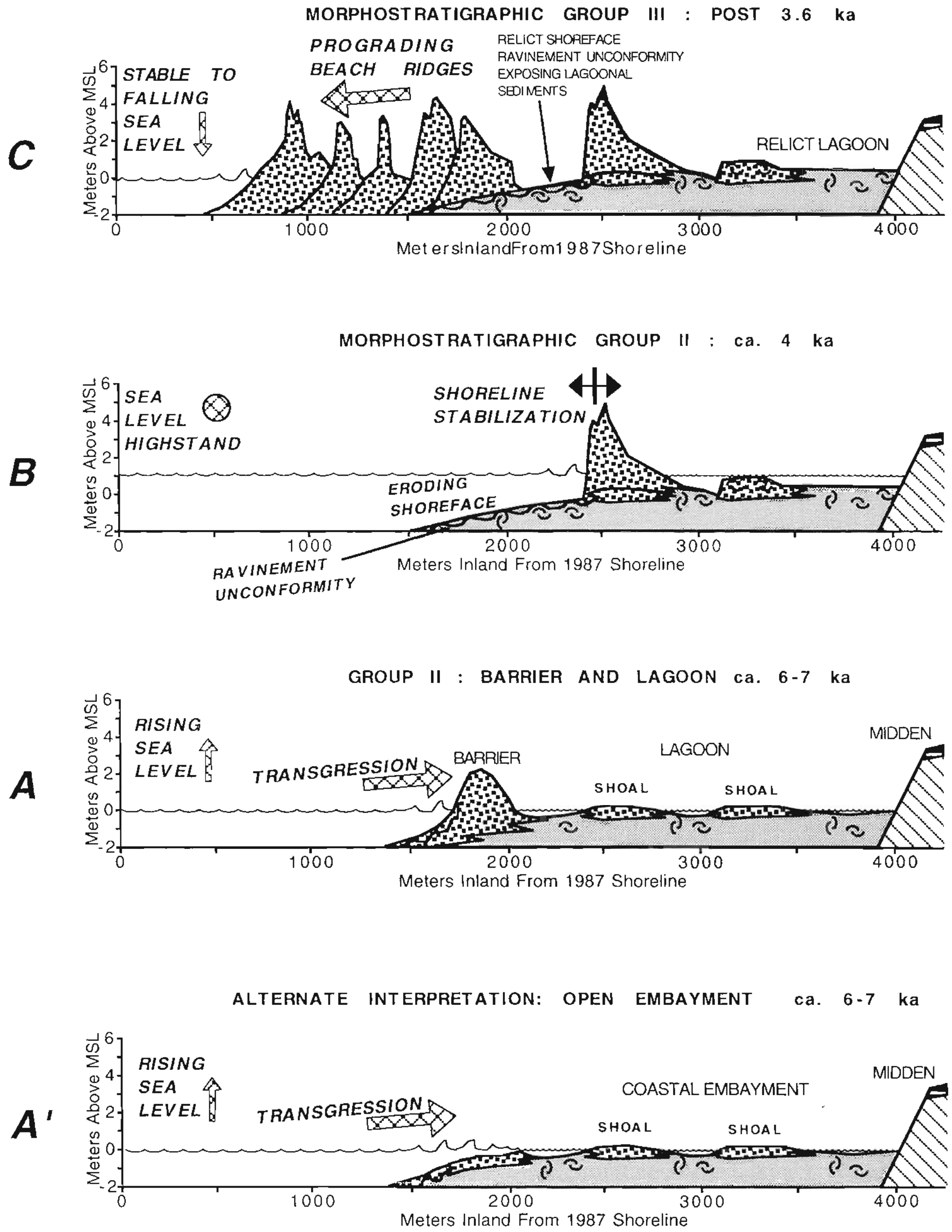

Figure 2. Alternative scenarios for Santa beach ridge formation processes (see text).

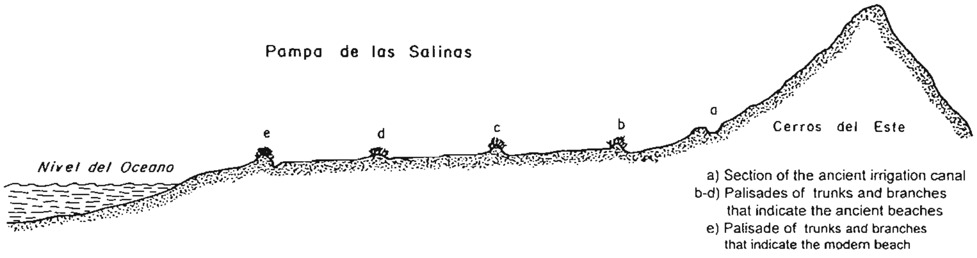

Figure 3. REY Y BASADRE's (1896) diagram of Santa beach ridges showing palisades of driftwood on all ridges.

Figure 4. Worked driftwood with nails from the Santa beach ridges.

ago, clearly shows large palisades of driftwood on *all* of the ridge sets (Figure 3). Firewood collection on the ridges most easily reached from the Panamerican Highway (built beginning in the 1920's) probably accounts for the disappearance of the easternmost driftwood deposits.

WELLS (1996; see also WELLS *et al.,* 1987) correlates the age of the surviving Santa driftwood with five dates on driftwood from other parts of the coast, associates these dates with a tsunami event at 1618 AD, and uses that event to "set a minimal age for the end of Group III progradation." If, indeed, the driftwood on Group IV dates to the 1618 tsunami, that would provide a minimum age for Group IV as well as Group III. However, among the driftwood on the Group IV ridges, Sandweiss has observed worked wood with what appear to be cut nails, suggesting a date after the late 18th century (Figure 4). Furthermore, three of Wells's dates have calibrated ranges ending in 0. Considering that several tsunamis have impacted Peru in the historic period (last 450 years) and that storms may also account for driftwood deposition, the assignment of the Santa driftwood exclusively to the 1618 event is unlikely.

El Niño and Ridge Formation

We are pleased that WELLS (1996, p. 13–14) now recognizes the role of ENSO in Santa ridge formation, as we have argued for many years (SANDWEISS *et al.,* 1983; SANDWEISS, 1986; MOSELY *et al.,* 1992). We have also argued that it is not ENSO alone, but the combination of ENSO's episodic torrential rainfall with the production of loose sediment by prior seismic activity that accounts for the pulses of material that form the ridges. This is exactly what MOSELEY *et al.* (1992) observed in their study of coastal progradation at Santa using remote sensing imagery spanning some 40 years. Obviously, we do not and have not argued that the ridges can provide a complete record of extreme ENSO events; however, they do mark some of those events, and a task for the future is to separate seismic and ENSO histories from the ridges. We do not believe that ridges achieve their final morphology overnight, but do suggest that they form more rapidly than the precision of dating techniques applicable to paleoridges. The borrow pit exposure in Ridge IIa indicates that initial ridge deposition occurs rapidly, as it has poorly sorted basal deposits with large sub-angular clasts in a sand and gravel matrix (Figure 5) (SANDWEISS *et al.,* 1983, p. 286; SANDWEISS 1986, p. 19).

Although WELLS (1996, p. 10) cites the ENSO/seismic hypothesis, she apparently gives it little weight, as she suggests (*ibid,* p. 14) that "Dam building in the upper drainage basin [together with glacial expansion] . . . may

Figure 5. Borrow pit profile in Ridge IIa showing poorly sorted lower deposits with large subangular clasts.

explain the absence of ridge formation subsequent to the AD 1982–1983 El Niño event." However, the dam in question (at Cañón del Pato) was built prior to the 1972 ENSO (WELLS, 1992, p. 197) which, following the strong seismic event of 1970, did precede formation of a ridge at the mouth of the Santa river (MOSELEY *et al.,* 1992). Low coastal deposition during the 1982–1983 event more likely resulted from the lack of local seismic activity after the 1970 earthquake and the prior transport of material produced then by the 1972 rains.

El Niño Rains or Glacial Meltwater Peaks?

WELLS (1996, p. 14) argues that "Sediment discharge should peak during . . . periods of glacial contraction when meltwater discharge peaks." We would suggest that ENSO rainfall peaks are a more frequent, proximal, and larger magnitude source of peak Santa river discharge. Only ENSO rains will move sediment loosened by seismic activity from the lower drainage into the river and out to the coast. This postulated source of the sediment pulses (SANDWEISS *et al.,* 1983; SANDWEISS, 1986) is supported by the observations of MOSELEY *et al.* (1992) concerning progradation following the 1972 ENSO rains and the fact that the Cañón del Pato dam has trapped material from the glaciated highlands since the late 1950's. Furthermore, three other north Peruvian ridge sets (at Piura, Colán, and Chira) have numbers of ridges and dates for the onset of ridge formation similar to the Santa beach ridge plain, and an ENSO rainfall origin has been suggested as a mechanism for the formation of these ridges (RICHARDSON, 1983; ORTLIEB *et al.,* 1993). The Piura and Chira rivers do not have headwaters in the glaciated Andes, and the Colán ridges emanate from normally dry coastal quebradas that have flow only during ENSO events. Clearly, Peruvian beach ridges do not require glacial meltwater as a source of sediment.

Summary

WELLS (1996) has provided an interesting scenario for coastal evolution north of the Santa river, Peru, since the mid-Holocene. We have detailed our disagreements with several specific and general points, but we recognize that many issues can only be resolved through further research. We present a clarified set of interpretations of the Santa beach ridges, summarized in Figure 2, proposing testable hypotheses for ridge origins. Stratigraphic studies using ground-penetrating radar and test excavations are two possible avenues of testing these alternate scenarios. We need to know more about the internal structure of the ridges; we need better chronological constraints on the development of individual ridges and ridge groups; we need further information on environmental conditions within the paleoembayment prior to 4500–5000 BP. We thank Wells for bringing these matters to light.

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