Early Maritime Economy and El Niño Events at Quebrada Tacahuay, Peru

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The archaeological site of Quebrada Tacahuay, Peru, dates to 12,700 to 12,500 calibrated years before the present (10,770 to 10,530 carbon-14 years before the present). It contains some of the oldest evidence of maritime-based economic activity in the New World. Recovered materials include a hearth, lithic cutting tools and flakes, and abundant processed marine fauna, primarily seabirds and fish. Sediments below and above the occupation layer were probably generated by El Niño events, indicating that El Niño was active during the Pleistocene as well as during the early and middle Holocene.

The lowland coastal plain of Peru was evidently first settled during the Terminal Pleistocene period (*1–5*), when much of the rest of the New World was probably also first occupied (*6*). Many of the earliest lowland Peruvian sites are in the north and are more than 24 km from the paleoshoreline of the Pacific Ocean (*1, 2*), thus making them part of an interior-oriented settlement pattern (*1*). However, at least some early migration into and through the Americas may have taken place along coastal routes by people with maritime-based economies (*7*). In addition, specialized maritime-resource procurement was important in the later development of complex state-level societies along the Peruvian coast (*8*). Knowledge of the degree to which the earliest coastal plain inhabitants exploited maritime resources may contribute to a better understanding of both processes. Previous work identified maritime components in the remains from some early sites in the north (*2, 3*) and from the Ring Site, the oldest previously described site along the far south coast (*5*). Evidence is now available concerning economic activity at two additional Terminal Pleistocene sites along the far south coast: Quebrada Jaguay, described elsewhere in this issue by Sandweiss *et al.* (*9*), and Quebrada Tacahuay, which we describe here (Fig. 1).

Profiles at Quebrada Tacahuay also expose 19 debris-flow and flood deposits. In this region today such deposits are associated with El Niño events, which typically cause widespread torrential rainfall, flooding, and disruption of fisheries (*10*), such as occurred in early 1998. Identifying prehistoric El Niño events is important to evaluating the El Niño mechanism. Some previous work indicates that El Niño events have occurred throughout the Holocene and probably much longer (*11*), but one recent study (*12*) concluded that such events did not occur from about 5000 to 8000 ^{14}C years before the present (yr B.P.) [about 5700 to 8900 calibrated (cal.) yr B.P.] or earlier.

The site we describe at Quebrada Tacahuay is 0.3 to 0.4 km inland at 17.8°S (Fig. 1). It is on an alluvial fan, about 2 km southeast of a prominent and rocky coastal headland. The current climate is hyperarid; mean annual rainfall is about 5 mm. Sediments containing archaeological materials are exposed along five near-vertical artificial cuts, as high as 7 m, made for a road and a water pipeline (Fig. 1). The cut faces are currently 47 to 56 m above sea level. When the site was occupied sea level was 60 to 70 m lower than at present (*13*), and the site would probably have been 0.7 to 0.9 km farther inland then.

The northeastern-most cut (profile 1, Fig. 1) exposes a hearth, 50 cm by 8 cm in cross section, composed of a cohesive mixture of ash, sand, and charcoal. Two ^{14}C age determinations on this charcoal have calibrated means of 12,670 and 12,730 cal. yr B.P. (10,750 ± 80 and 10,770 ± 150 ^{14}C yr B.P.; Table 1 and Fig. 2). The hearth is in a 10- to 50-cm-thick stratum composed of fine aeolian sand locally interbedded with lenses of water-laid, desiccation-cracked silt (unit 8, Fig. 2). Because the sand is loose and susceptible to wind erosion, this stratum commonly forms cave-like recesses along cut faces, and some coarse materials are scattered on the deflated sand surface.

Because of typical overburden depths of several meters above unit 8, we elected to sample the occupation layer by excavating horizontal sections 20 cm to 1 m long from exposed cut faces. In addition to the hearth, we selected areas for sampling (Fig. 1) on the basis of locations of exposed bones and two lithic artifacts. We collected bulk samples of sediment and hearth material using trowels and brushes. All excavated material was sifted dry through a 2.00-mm fiberglass mesh. We removed 2.0 liters of material from the hearth. Volumes of other bulk samples ranged from 0.3 to 0.9 liter. Pieces of charcoal, found interspersed with lithic flakes in sample 44 (Fig. 1), were dated to 12,490 cal. yr B.P. (10,530 ± 140 ^{14}C yr B.P.; Table 1 and Fig. 2).

All analyzed faunal remains were from excavated material found in place in the hearth or in unit 8 sediment (Fig. 1). Among these remains, seabirds are the most abundant (number of elements, n = 3484; minimum number of individuals, MNI = 16). The guanay cormorant (*Phalacrocorax bougainvillii*) is the most abundant species (n = 181,

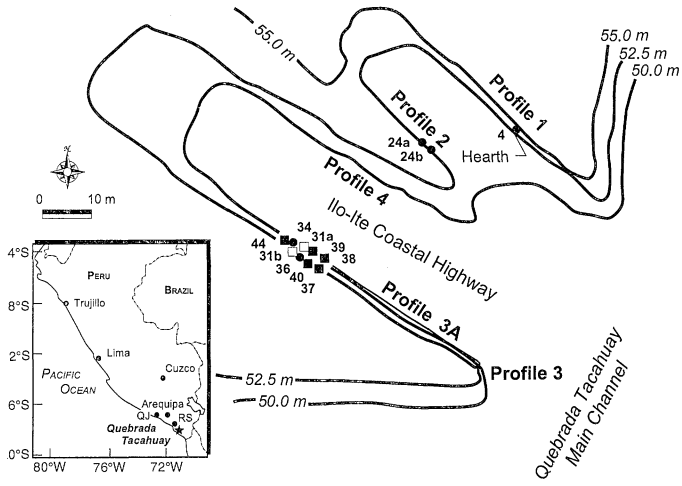

Fig. 1. Site plan and location. Contour interval 2.5 m. Filled squares and circles show locations of samples. Squares are samples containing lithic tools or flakes. Samples 39 and 44 contain both lithic materials and bones. Open squares show locations of lithic artifacts found on the surface. RS is the Ring Site and QJ is Quebrada Jaguay.

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MNI = 7). Also present are the Neotropical cormorant (*Phalacrocorax brasilianus*; n = 6, MNI = 2), undetermined species of booby (*Sula* spp.; n = 79, MNI = 5) and cormorant (*Phalacrocorax* spp.; n = 64, MNI = 1), and one immature pelican (*Pelecanus* sp.; n = 1). Although the remains are well preserved, most elements are unidentified bird shaft fragments (n = 3153).

Marine fish (Osteichthyes) are the second most abundant remains (n = 280; MNI = 13). Species present include anchoveta (*Engraulis ringens*), anchovy (*Anchoa* spp.), and an unidentified bony fish (Osteichthyes uid). The anchovy remains are the earliest known from an archaeological context in the New World, and remains of such small, schooling fish at the site suggest the use of specialized fish-netting technology. Fragments of three marine mollusks were found in the hearth: a Veneroid clam, a choro mussel (*Choromytilus chorus*), and an unidentified mollusk (*14*). Of the 3775 bones and shell fragments recovered from the site, only eight (0.2%) are terrestrial: four shell fragments from unidentified terrestrial gastropods, three rodent bones, and one unidentified tetrapod bone.

Butchering is evident from cut marks on 18 seabird bones, all from axial and forelimb parts of the skeleton (*15*), where most cut locations suggest that the meaty breast parts of the birds were removed. Fifteen butchered specimens were found with lithic debitage in profile 3A, and three were found in the hearth. Twenty percent of the seabird bones (n = 692) were burned, and these burned remains were also concentrated in the hearth and near the lithic artifacts. A few (n = 8) anchovy (Engraulidae) and unidentified bony fish (Osteichthyes) specimens (n = 7) were burned, and 22 anchovy vertebrae are slightly discolored, suggesting low-temperature alteration.

Lithic artifacts comprise one tool and 17 smaller flakes recovered from excavated unit 8 sediment (Fig. 1) and two tools (31a and 31b, Fig. 1) found on the surface in contexts indicating they were derived from unit 8 (*16*). All artifacts have features consistent with use as cutting tools, and all are composed of chalcedony. All are unifacial, but the largest also has a bifacial cutting edge (Fig. 3). Eight of the smaller flakes are evidently debitage from tool manufacture, whereas nine are probably use or resharpening flakes. Artifact materials and other characteristics are similar to those in the assemblage recovered from the approximately contemporary Ring Site 20 km to the north (*5*); these similarities suggest that there was some association between populations at the two sites.

The occupation at Quebrada Tacahuay may have been abandoned when the site was inundated by a debris flow, because partly articulated seabird bones from the occupation layer were impressed into the base of the overlying debris-flow deposit (unit 7, Fig. 2). Other sediments covering the occupation layer in at least three of the profiles include four debris-flow deposits (units 1, 2, 3, and 6, Fig. 2), a sheetflood deposit composed of sand and gravel (unit 4, Fig. 2), and a layer of aeolian sand (unit 5, Fig. 2). Additionally, profile 4 exposes a small paleochannel, cut into units 2 through 8 and capped by unit 1. This paleochannel contains an additional aeolian sand layer (unit 4c3, Fig. 2) overlain by two thin and fine-grained, channelized debris-flow deposits (units 4c1 and 4c2, Fig. 2). Embedded in the aeolian deposit (unit 4c3) is a dense shell midden from a younger occupation (Table 1 and Fig. 2). A flood deposit consisting of coarse, bouldery sands and gravels as much as 3.5 m thick (unit 9, Fig. 2) underlies unit 8 throughout the site. Older units, exposed in profile 3 and the southeastern part of profile 3A, consist of eight debris-flow deposits, three layers of aeolian sand, and two flood deposits.

All of the debris-flow deposits are massive and contain coarse clasts distributed in cohesive sand-silt-clay matrices. All except unit 1 are red, reddish brown, or reddish yellow in color. Unit 1 is dark brown to gray, probably due to incorporation of significant organic material. Several debris-flow deposits contain desiccation cracks filled with aeolian sand or are capped by thin aeolian lenses or layers.

All sediments except the aeolian sands and the unit 8 silts are of types typically produced by intense precipitation, high flood discharge, or both. Characteristics that also indicate deposition under arid conditions include (i) the desiccation cracks in many deposits, (ii) the aeolian sands, (iii) the absence of in situ soil development in any unit, (iv) the lack of significant

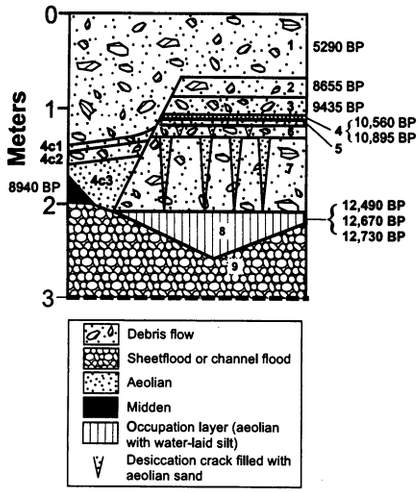

Fig. 2. Composite stratigraphic column compiled from profiles 1, 2, 3A, and 4, showing relations and thicknesses of units 1 to 8, 4c1 to 4c3, and the uppermost part of unit 9. Unit 8 is the occupation layer, containing the hearth, lithic artifacts, and faunal remains. Units 1 to 5 and 7 to 9 are present in all profiles. Unit 6 is present in profiles 1, 2, and 4. Units 4c1 to 4c3 are present only in a small paleochannel that locally truncates units 2 through 8 in the central part of profile 4. Radiocarbon dates are calibrated means or intercepts (in calibrated years before the present), from Table 1.

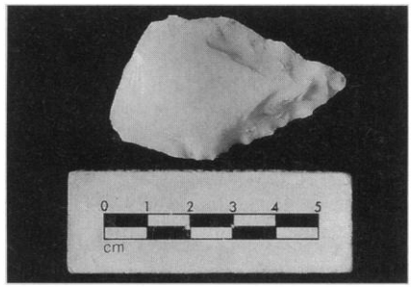

Fig. 3. Bifacially edged artifact (31b in Fig. 1).

Table 1. Radiocarbon dates from Quebrada Tacahuay, Peru. All samples were analyzed by Beta Analytic, Miami, Florida, and all dates were corrected for $^{13}C/^{12}C$ ratios. Dates younger than 10,000 ^{14}C yr B.P. were dendrocalibrated by Beta Analytic. Older dates were calibrated with the University of Washington, Quaternary Isotope Lab Radiocarbon Calibration Program, Calib 3.0.3 Method A (*18*). The age range given in the last column has a 95% probability.

Profile unit	Sample number/ type*	Material/context	Uncalibrated age mean ± σ (^{14}C yr B.P.)	Calibrated intercept/ mean (cal. yr B.P.)	Calibrated ±2σ age range (cal. yr B.P.)
1-1	108536A	Bulk sediment/debris flow	4,550 ± 60	5,290	5,540–4,995
4-c3	109354C	Charcoal/midden	7,990 ± 80	8,940	9,005–8,550
2-2	108861A	Root/debris flow	7,920 ± 80	8,655	8,975–8,485
2-3	110330A	Root/debris flow	8,430 ± 60	9,435	9,490–9,350
1-4	108858A	Charcoal/sheetflood	9,550 ± 90	10,560	10,960–10,355
1-4	108859A	Terrestrial gastropod shell	9,630 ± 60	10,895	10,970–10,520
3A-8	108860C	Charcoal pieces interspersed with lithic flakes	10,530 ± 140	12,490	12,790–12,070
1-8	108692A	Charcoal/hearth	10,750 ± 80	12,670	12,860–12,460
1-8	95869C	Charcoal/hearth	10,770 ± 150	12,730	13,030–12,390

*A indicates accelerator mass spectrometry analysis and C indicates conventional radiometric analysis.

organic material in any unit below unit 1, and (v) the lack of evidence of vegetation growth except locally within units 2 and 3. Because intense precipitation along the arid Peruvian coast is typically associated with El Niño events today, we infer that such events also produced the debris-flow and flood deposits at Quebrada Tacahuay.

Radiocarbon dating of units 1, 2, 3, 4, 4c3, and 8 (Table 1 and Fig. 2) divide the sedimentary history of the site after deposition of unit 8 into three periods. First, between about 12,500 and 8900 to 8700 cal. yr B.P., four extensive debris flows (units 2, 3, 6, and 7) and an extensive sheetflood (unit 4) covered the site—an average of one sedimentation event every 700 to 800 years. In contrast, between about 8900 to 8700 and about 5300 cal. yr B.P., the only flood or debris-flow sediments deposited were two thin and fine-grained debris-flow units confined to a small channel and exposed in only one profile (units 4c1 and 4c2, Fig. 2). Flood and debris-flow activity thus diminished significantly in both severity and frequency during this period, which corresponds to the ~8900 to 5700 cal. yr B.P. (8000 to 5000 ^{14}C yr B.P.) hiatus in El Niño activity deduced from shell-midden data farther north (*12*). Finally, at ~5300 cal. yr B.P., another extensive debris-flow deposit (unit 1) covered the site at Quebrada Tacahuay before sediment supply was cut off by incision of the present main channel (Fig. 1). The debris-flow and flood deposits underlying unit 8 have not been dated but are older than the ~12,700 to 12,500 cal. yr B.P. age of that unit. The similarities between them and the younger sediments suggest that conditions producing El Niño events were also present there in the Pleistocene.

The Quebrada Tacahuay site was almost certainly used largely or entirely for obtaining maritime resources as indicated by the overwhelming proportion of maritime elements (99.8%) in the faunal remains. Indications that most or all of these remains were associated with anthropogenic activity include evidence of butchering, the large numbers of burned bones, the presence of marine mollusk fragments, and the spatial association of the remains with the hearth and lithic artifacts. The primary activity at the site evidently was processing seabirds, and secondary activities included processing fish and shellfish. We therefore infer that people with a maritime-based economy were present there about 12,700 to 12,500 years ago, during the period when the Andean coast was first settled. After that time, catastrophic floods and debris flows may have affected the occupation history of the site. A debris flow inundated the site, possibly when it was still in use, and the locality was not reoccupied until ~3500 years later, when flood and debris-flow activity had substantially diminished.

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14. The marine mollusk fragments are almost certainly of anthropogenic origin, as evidenced by their terrestrial location and context. Fish remains may be transported in the digestive systems of seabirds [D. G. Ainley, D. W. Anderson, P. R. Kelley, *Condor* **83**, 120 (1981); D. C. Duffy and L. J. B. Laurenson, *ibid.* **85**, 305 (1983)], but the burned anchovy remains in the hearth and the lack of any evidence of digestive changes from stomach acids indicate that the fish remains are also of anthropogenic origin.
15. The following skeletal elements contain butchering evidence: *Sula* spp. (booby)—one furcula, two coracoids, one scapula, one ulna; *Pelecanus* sp. (pelican)–one digit; *Phalacrocorax bougainvillii* (guanay cormorant)—one scapula, three humeri; *Phalacrocorax* spp. (cormorant)—one furcula, one coracoid, one radius, one ulna; Aves unidentified—one rib, one radius, two shaft fragments.
16. One artifact (31b, Fig. 1) was on the deflated sand surface of unit 8, under an overhang. The other (31a, Fig. 1) was on the surface immediately below the contact between units 8 and 9, partly covered by a thin layer of slope wash.
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18. We thank J. Alley, M. E. Moseley, and P. R. Williams for assistance in the field; the Asociación Contisuyo del Perú for logistical and financial support; the Florida Museum of Natural History for access to comparative skeletal collections; and K. R. Lajoie, D. H. Sandweiss, D. W. Steadman, and L. E. Wells for comments.

4 June 1998; accepted 31 July 1998

Turbulent Transport Reduction by Zonal Flows: Massively Parallel Simulations

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Three-dimensional gyrokinetic simulations of microturbulence in magnetically confined toroidal plasmas with massively parallel computers showed that, with linear flow damping, an asymptotic residual flow develops in agreement with analytic calculations. Nonlinear global simulations of instabilities driven by temperature gradients in the ion component of the plasma support the view that turbulence-driven fluctuating zonal flows can substantially reduce turbulent transport. Finally, the outstanding differences in the flow dynamics observed in global and local simulations are found to be due to profile variations.

Turbulence shear suppression by $\mathbf{E} \times \mathbf{B}$ flows (plasma flows induced by an electric field perpendicular to a magnetic field line) is the most likely mechanism responsible for the transition to various forms of enhanced confinement regimes observed in magnetically confined plasmas (*1*). Understanding the mechanisms of turbulence suppression (*2*, *3*) and developing techniques to control turbulence are needed for developing magnetic fusion. Recent experimental data from tokamaks (*4*) revealed the presence of small radial-scale $\mathbf{E} \times \mathbf{B}$ flows that cannot be explained by the existing neoclassical (Coulomb collisional) theory. These observations point to the possibility that $\mathbf{E} \times \mathbf{B}$ zonal flows generate spontaneously and regulate the turbulence. Turbulent transport is believed to arise from electrostatic pressure-gradient–driven instabilities. These highly complex nonlinear phenomena can be most effectively investigated by numerical experiments. One of the most promising approaches is gyrokinetic particle-in-cell simulation (*5*), which suppress-

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