Eighth Millennium Pottery from a Prehistoric Shell Midden in the Brazilian Amazon

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from strong coupling to low frequency modes (*19*). In the M_3C_{60} materials, the most obvious low frequency modes are C_{60}-C_{60} intermolecular vibrations or C_{60} rotations. Alternatively, it has been suggested that the M^+ optical phonon could lead to strong coupling (*13*). High-frequency intramolecular C_{60} modes, which have been implicated in weak-coupling analyses (*2, 6*), are unlikely to yield the large value of $2\Delta/kT_c$ determined experimentally. Although additional work is needed to define whether the electron-phonon interaction is the operative coupling mechanism and if so, the mode relevant to pairing, our finding of strong coupling should be accounted for in models of superconductivity in these materials.

We have also characterized the temperature dependence of Δ in both K_3C_{60} and Rb_3C_{60} since this can provide additional insight into the mechanism of superconductivity. Representative normalized conductance curves recorded on K_3C_{60} and theoretical fits to these data for $4.2\ K < T < T_c$ are shown in Fig. 3. Qualitatively, we find that Δ decreases as T approaches T_c, and disappears for $T > T_c$. We have summarized the results from these temperature-dependent studies of Δ for K_3C_{60} and for Rb_3C_{60} by plotting $\Delta(T)/\Delta(4.2)$ versus T/T_c (Fig. 4). This figure explicitly shows that the normalized energy gaps of Rb_3C_{60} and K_3C_{60} exhibit a similar temperature dependence, and furthermore, that these data follow the universal temperature dependence predicted by BCS theory. Importantly, our $\Delta(T)$ data indicate that it may be possible to explain superconductivity using a mean-field theory (like BCS) modified for strong coupling. It is also interesting to consider real-space models of superconductivity since the coherence lengths in these materials are so short ($\xi \approx 25$ Å). In particular, it has been suggested that a Bose-Einstein condensation of real-space pairs may explain superconductivity in the short coherence length ($\xi_{ab} \approx 10$ Å) high-T_c copper oxide materials (*20, 21*). Since $\Delta(T)$ should exhibit a relatively sharp transition near T_c in a Bose-Einstein condensation, we believe that the observed temperature dependence of Δ argues against this interesting possibility.

In conclusion, tunneling spectroscopy has been used to define the energy gap in the M_3C_{60} superconductors. These experimental results have shown that (i) the pair coupling in these materials is strong, (ii) the energy gap scales with T_c, and (iii) the energy gap exhibits a universal temperature dependence. Regardless of the mechanism of pairing in the M_3C_{60} system, we believe that our results will be important constraints for any theoretical explanation of superconductivity in these materials.

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Eighth Millennium Pottery from a Prehistoric Shell Midden in the Brazilian Amazon

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The earliest pottery yet found in the Western Hemisphere has been excavated from a prehistoric shell midden near Santarém in the lower Amazon, Brazil. Calibrated accelerator radiocarbon dates on charcoal, shell, and pottery and a thermoluminescence date on pottery from the site fall from about 8000 to 7000 years before the present. The early fishing village is part of a long prehistoric trajectory that contradicts theories that resource poverty limited cultural evolution in the tropics.

AMAZONIA HAS BEEN DESCRIBED AS sparsely occupied by small Indian groups in prehistoric times. The resource poverty of the tropical forest habitat was thought to have precluded permanent settlement, population growth, and cultural development. Complex cultures with pottery and agriculture were supposed to have spread from the Andes and Mesoamerica and decayed in the unfavorable tropical environment (*1–4*). Archeological evidence, however, reveals a sequence that is changing understanding of the ecology of cultural evolution in the Americas. An important new finding is that the age of pottery now appears to have begun earlier in Amazonia than elsewhere in the hemisphere.

Although stereotyped as resource-poor (*5*), Amazonia has large areas of alluvial soils (*6*) that would not have presented severe limitations to human adaptation. In fact, researchers working between 1830 and 1945 uncovered evidence for cultural development: deep stratified middens, earthworks, elaborate art and artifacts, and abundant ancient biological remains (*7–11*). Later, archeologists dismissed this research as not scientific and focused on excavating pottery, assuming most other material was not preserved; they took contemporary foragers and shifting horticulturalists as models for prehistory and interpreted complex cultures as ephemeral foreign invasions (*2–4*). This view was criticized on environmental and archeological grounds (*12–14*), but it persisted in the empirical vacuum and

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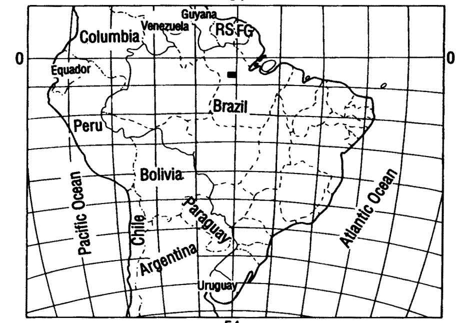

Fig. 1. Location of Santarém in Brazil.

greatly influenced natural scientists.

Recent archeological research in the tropical lowlands east of the Andes reveals a trajectory of development from Paleoindians, about 12,000 years ago, to populous agricultural chiefdoms by about 2000 years ago (*12, 14–19*). An important region is Santarém on the Amazon in Brazil (Figs. 1 and 2). There, geologically heterogeneous uplands overlook late Pleistocene and Holocene floodplains, and seasonal rainfall creates a mosaic of forests, savannas, lakes, and streams with plentiful fish, game, and plant food. The human occupation appears to have begun in the late Pleistocene with nomadic foragers who made large, bifacial projectile points and left paintings at rock shelters (*9, 11, 18*). Soon after, people settled into villages along rivers and began to make pottery.

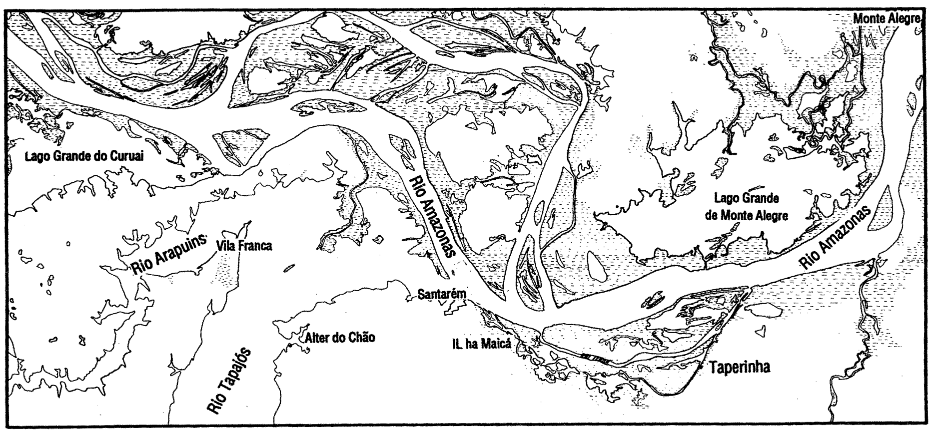

Fig. 2. Location of Taperinha in Santarém region.

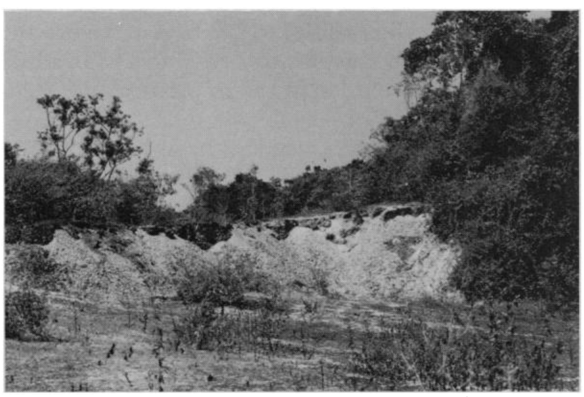

Fig. 3. Taperinha, a pottery-age shell midden in the Brazilian Amazon. The mound stands 6 m tall and occupies several hectares on the edge of an ancient river terrace.

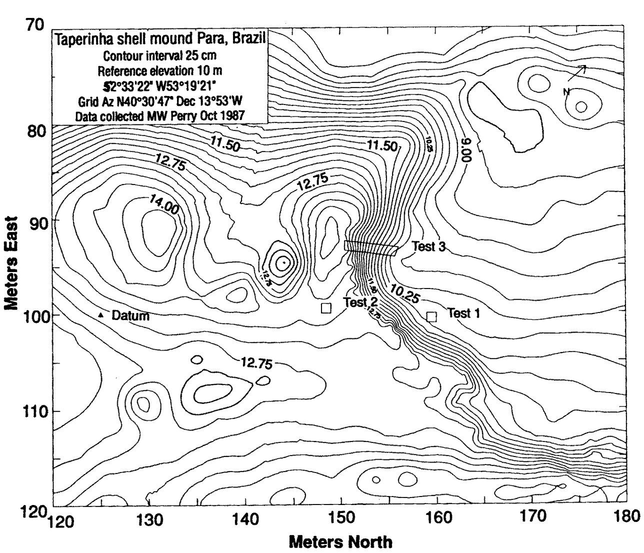

Fig. 4. Map of excavations at site with mined area at right.

The early Holocene age of the large shell middens at such villages in the Lower Amazon was recognized in the 19th century on the basis of geologic evidence (*10–11*), but mid-20th-century archeologists thought they were only 1000 to 1400 years old (*4*). The considerable age of shell midden pottery at the mouth of the Amazon was established in 1981 when sites produced 19 dates between about 4000 and 6600 years old (*19*). However, most archeologists have assumed that the craft originated in northwestern South America (*20*), even though pottery there is the same age or younger than pottery from the Amazon estuary.

A riverine shell midden identified in the last century as an early pottery-age fishing village is Taperinha (Figs. 2 and 3). It was excavated in 1870–71 by geologist C. F. Hartt, a student of L. Agassiz (*11*). We obtained a radiocarbon date on shell from his excavations (*21*), but the date of 6665 to 6415 years B.P. (Table 1) was inconclusive because of poor stratigraphic context and the possibility that the shell was contaminated with extraneous carbon in the ground or in the museum.

To verify the chronology, we excavated there in 1987 (*18*). The mound, reduced since 1871 by lime-mining, lies on an ancient shore under later prehistoric refuse and colluvium. The team mapped its topography and geophysics and placed three test excavations (Fig. 4). Test 1 cut through the mound's base, exposed by mining. Test 2 cut the upper strata of the mound, and test 3 cut through from the top to the base. The excavations uncovered 48 strata of shells, charcoal, faunal bone, rocks, pottery fragments, rare human bone, and little soil. Strata were hand-excavated and sieved with graduated mesh (1/4 to 1/32 inch). To avoid slumping and intrusions, we took samples for dating from the basal strata 4 to 5 m below the top of the mound (Fig. 5).

Radiometric dates were computed on 12 samples of shell, charcoal, and pottery (Table 1). Accelerator mass spectrometry (AMS) radiocarbon dating was performed on 11 samples: four charcoal pieces graduated; five shells; and elemental carbon and humic/fulvic acids extracted from the base of a broken pottery vessel. All dated specimens but pottery had been excavated without handling. To remove depositional contaminants, charcoal samples were treated with a dilute acid wash to remove carbonates, an alkali wash to remove humic and fulvic acids, and a further acid wash to prevent incorporation of CO_2 during drying. The dry product was oxidized to CO_2 by heating with CuO. The shell samples were surface cleaned by shot-blasting with alumina powder, etched to remove secondary carbonate,

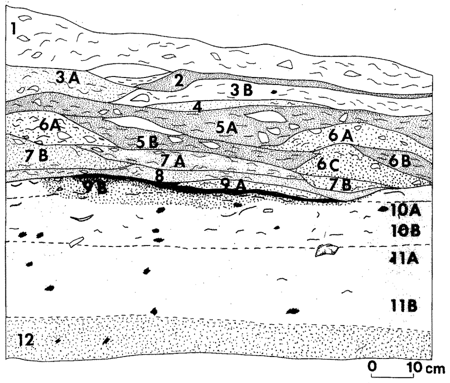

Fig. 5. Stratigraphy in test 1, south cross section. (Darker layers of sand or soil are stippled or shaded. Shells are shown as arcs or elipses and sherds as rectangles. Charcoal is black, and rock is shaded.) Strata 1 and 2 (levels 1–3): talus fallen from the top of the mound onto lenses of soil and shell. Strata 3–8 (levels 4–9): shells, ash, and soil lenses. Stratum 9 (level 10 and hearth feature 2): charcoal and ash lense with bones, shells, and burnt rocks on beach sand reddened by heating. Stratum 10 (levels 11 and 12): charcoal and ash over layer of pottery fragments, shells, a few bones, and burnt rocks in sand with a post mold. Strata 11 and 12 (levels 13–16): sand with base of post mold and rare shell, charcoal, and pottery.

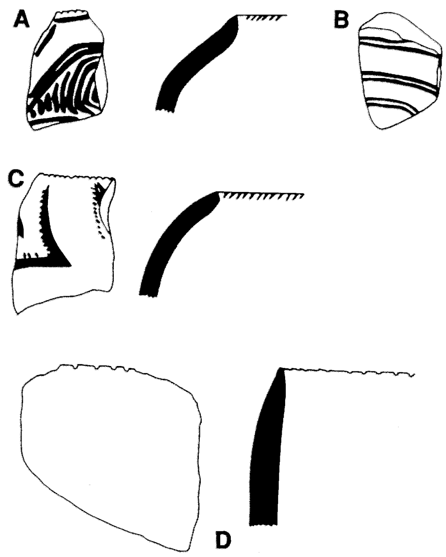

Fig. 6. Pottery vessel fragments from the excavations. (**A**) Incised rim (stratum 10B, level 12 base, test 1). (**B**) Incised sherd (stratum 5B, level 8B, test 1). (**C**) Incised and punctate rim (stratum 34, step 4A, level 2A, test 3). (**D**) Incised rim (stratum 29, step 4A, test 3). Length, 7 cm.

Table 2. Pottery in test excavation 1.

Levels	Pottery fragments (>1 cm)	
	Taperinha culture	Santarém culture
Surface	20	7
Level 2	2	2
Level 3	11	2
Level 4	4	
Level 5	10	
Level 6	16	
Level 7	31	
Level 8	19	
Level 9	8	
Level 10/F2	5	
Level 11	3	
Level 12	18	
Level 13	1	
Level 14	0	
Level 15/16	4	

and treated with phosphoric acid. The evolved CO_2 was collected and dried. The pottery was processed to obtain two fractions: humic acids and elemental carbon. The pottery was crushed, ultrasonicated in HCl, and the lipids removed before the humic acids were extracted with NaOH. The elemental carbon was then obtained after treatment by HF and HCl to remove inorganic material.

Thermoluminescence (TL) dating was performed on another piece of the same pottery dated by AMS (laboratory number Ox-581a36) (*22*). The sample was dated with the fine-grain technique. Before measurement, the sample was irradiated and stored at 90°C for two weeks to remove the unstable TL component that gives rise to anomalous fading. The internal annual dose-rate of the pottery fragment was measured by thick source alpha counting and flame photometry. The environmental dose-rate was calculated from measurement of soil blocks excavated near the sherd. The saturation water contents of both the sherd and soil were measured, and it was assumed that both had been fully saturated throughout their lifetimes, as they were moist when excavated. The age, 7110 ± 1422 years B.P., is quoted with a ±20% error range because of uncertainties due to incomplete environmental data, uncertainties about the degree of lifetime saturation of the sherd and soil, and the fact that the date is derived from a single sherd.

The radiometric analyses produced a series of quite consistent dates. The 1-sigma ranges of the 11 AMS radiocarbon dates fall from 8025 to 7170 years B.P., a span of about 855 years in the early part of the culture. The radiocarbon date on Hartt's shells, 6665 to 6415 years B.P., extends its span 755 years. The dates on associated charcoal and shell are within 160 years of each other, and carbon dates from pottery differ at most 215 years from the nearest charcoal and shell dates. The mean thermoluminescence date on pottery falls within the range of radiocarbon dates.

Table 1. Radiocarbon dates from Taperinha (*26*). CI, confidence interval.

Lab no.	Level	Material	Uncalibrated age (years B.P.)	Calibrated age (years B.P.)	
				68% CI	95% CI
		Conventional radiocarbon date			
GX-12844		Calcined shell fragments	5705 ± 80	6665–6415	6730–6310
		AMS radiocarbon dates			
OxA-1540	8B	Calcined shell	6300 ± 90	7290–7170	7425–6950
OxA-1541	10	Charcoal fragment	6860 ± 100	7770–7580	7920–7490
OxA-1542	10	Shell	7010 ± 90	7930–7690	8030–7600
OxA-1760	10 F2	Charcoal fragment	6880 ± 80	7770–7590	7910–7530
OxA-1543	10 F2	Charcoal fragment	6930 ± 80	7905–7610	7930–7580
OxA-1544	10 F2	Charcoal fragment	6980 ± 80	7915–7685	8020–7590
OxA-1545	10 F2	Shell	7000 ± 80	7920–7690	8025–7600
OxA-2431	12 base	Reduced carbon in pottery fragment	6590 ± 100	7570–7365	7600–7280
OxA-2432	12 base	Humic/fulvic acids (same fragment)	6640 ± 80	7580–7430	7600–7335
OxA-1546	13 top	Shell	7090 ± 80	8025–7785	8050–7690
OxA-1547	13 top	Shell	7080 ± 80	8025–7780	8050–7690

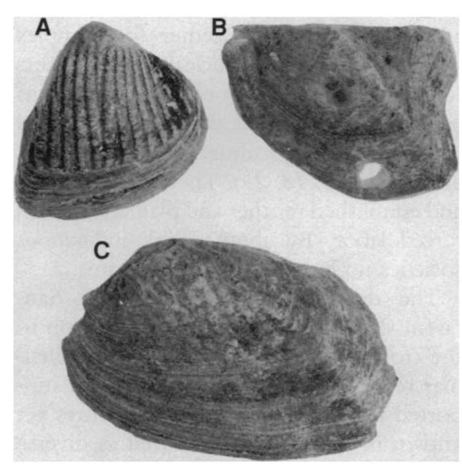

Fig. 7. Prehistoric freshwater pearly mussels from the excavations. (**A**) *Castalia ambigua* (Lamarck). (**B**) *Paxyodon ponderosus* (Schumacher). (**C**) *Triplodon corrugatus* (Lamarck). Length, 8 cm.

These results are strong evidence for the antiquity of the culture because the different materials and methods are not considered subject to the same sources of error. The statistically identical dates on shell and charcoal indicate a lack of contamination of those materials, but we cannot eliminate the possibility that the pottery could have been slightly contaminated with modern carbon from handling or with mobile humic acids in ground water.

The fragile, red-brown fragments of pottery bowls found throughout the shell midden (Table 2) were grit-tempered, unlike later, organic-tempered pottery. Of the 383 sherds, 3% have incised rim decoration (Fig. 6). Although similar to some other early pottery, Taperinha pottery is at least 1000 years earlier than northern South American pottery and 3000 years earlier than Andean and Mesoamerican pottery and could not be derived from them, although the reverse is possible, or independent origins.

Lithic artifacts were limited to hammerstones, flake tools, and unshaped grinding and cooking stones. A bone awl, mollusc and turtle shell scrapers, and a plug of aquatic mammal bone were also found. The faunal food remains represent an economy of intensive riverine foraging. Pearly freshwater mussels predominate (Fig. 7), and turtles and fish, mostly catfish and characins, are common. Plant remains other than charcoal are rare, although abundant in later deposits. Foraging apparently supported relatively permanent settlement, in view of the size of the mound and the pottery, rare among nomads without draft animals (*23*). In the Old World, early pottery-age societies also subsisted on fish and shellfish, resources that may have underwritten incipient horticulture worldwide (*24*).

Later people made elaborate pottery vessels and statues, groundstone tools and ornaments of nephrite jade, and by 1000 years ago Santarém was a center for complex societies with large, nucleated settlements (*8, 17, 18*). In the 17th century, Europeans encountered populous warlike chieftaincies supported by agriculture, foraging, trade, and tribute (*8, 18, 25*). They defeated them and established ranches and plantations with forced labor. By about 1850, indigenous societies no longer existed in the area.

The developmental sequence at Santarém sheds light on human adaptation to the tropical environment over the millennia, revealing that tropical resources supported the earliest pottery-age cultures yet known in the Americas, as well as diverse other cultures. It does not show that the environment was a barrier to development or that cultures necessarily came from other areas. The findings illustrate the frailty of evolutionary scenarios that rely on negative evidence from the vast tropical lowlands, where little systematic research has been done.

Lowland archeology is important untapped evidence relevant to evolutionary ecology, conservation, and planning. It shows that Amazon floodplains were intensively exploited for thousands of years and may be more appropriate for development efforts than poorer hinterlands still inhabited by native groups vulnerable to acculturation and extinction under contact. Protecting Indians' cultural and territorial integrity and ancient occupation sites is both a practical and ethical priority, for they hold unassailable ancestral rights to the land and indispensable knowledge about effective, long-term management of tropical resources.

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