Holocene Sea-Level Change and Early Human Utilization of Deltas

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ABSTRACT

Thirty-four documented archaeological sites, dated >5000 yr B.P. and located in and adjacent to marine deltas, are identified to evaluate early occupation of Holocene deltas worldwide. Modern marine deltas began to form from ~8500 to 6500 yr B.P., and our survey distinguishes at least 16 archaeological sites dated to >7000 yr B.P., which indicates that these resource-rich ecosystems were used by humans soon after their development. The model presented here links deceleration in rate of Holocene sea-level rise with the near-synchronous development of deltas and human occupation of these fertile plains. The integrated geological and archaeological database shows that conditions in and around deltas (accumulation of fertile soil, reliable water supply, perennial aquatic food sources, ease of travel and trade) were attractive to human immigration and settlement. Currently, rising sea level and land subsidence are principal natural phenomena affecting use of deltas, and humans remain vulnerable to these factors as well as to extensive ecological degradation caused by increased population pressures. The integrated geoarchaeological approach serves to refine long-term rates of change in delta evolution and thereby gauge human impact on these depocenters. Moreover, the model presented here provides insight into environmental conditions during the early to mid-Holocene transition from hunter-gatherers to sedentary communities, a major turning point in human history.

INTRODUCTION

During most of the past four million years, hominids sustained themselves by gathering wild plants and hunting and...
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In Memoriam
Ralph J. Bernhagen
Worthington, Ohio
October 24, 1997

John W. Butler, Jr.
Coos Bay, Oregon
September 27, 1996

Henry R. Cornwall
Concord, Massachusetts
September 8, 1997

Melvin Friedman
Bryan, Texas
March 11, 1997

Robert J. Hurley
Apts, California
January 2, 1997

Wilson M. Laird
North Potomac, Maryland
October 1997

Thomas A. Oliver
Calgary, Alberta
October 1997

Deltas continued from p. 1

fishing, typically in small mobile groups (Gebauer and Price, 1992; Feibel, 1997). The latest Pleistocene to mid-Holocene transition from hunting and gathering to a more settled way of life, referred to by some as the Neolithic Revolution, is a turning point in human history and has long been a keystone to archaeological research and debate. The change from foraging to sedentariness, and in some cases agriculture, which took place from about 10,000 to 5000 years ago, apparently occurred independently in different parts of the world.

Archaeologists generally attribute this widespread modification in human behavior to one or more of three principal factors: population pressure, altered social behavior, and/or climatic and environmental change (Price and Gebauer, 1995). Even though there have been extensive discussions during the past century regarding the relative importance of these three factors, there remain widely differing explanations for the remarkable transition from foraging to farming. However, most archaeologists agree that there is a close link between environment and human activity. Proponents of the climatic and environmental impetus have typically emphasized meteorological changes, especially transitions from cool to hot and wet to dry during the late Pleistocene and early Holocene (e.g., Child’s [1928] propinquity or desiccation theory). Associated with amelioration of climate in late stages of deglaciation (~8000 to 5000 yr B.P. [before present; herein all dates are uncalibrated]) are changes in vegetation communities worldwide (Adams and Faure, 1997).

In studies paralleling but generally independent of archaeological research, earth scientists are involved in identifying and measuring late Quaternary environmental changes, including those induced by anthropogenic activity. In this article, we present a new thesis that assimilates both the observed worldwide change in human settlement and subsistence behavior and near-synchronous environmental changes associated with a global deceleration in rate of sea-level rise that occurred between ~8500 and 6500 yr B.P. We propose that delta development, inextricably linked to deceleration in rate of sea-level rise (Stanley and Warne, 1994), provided newly formed, resource-rich environments conducive to occupation and subsequent development of sedentary human cultures worldwide (Fig. 1).
Deltas continued from p. 2

EARLY HOLOCENE INITIATION OF MARINE DELTAS WORLDWIDE

This study focuses specifically on deltas, although we recognize that other coastal environments, such as barrier islands that formed in the early to mid-Holocene, were extensively exploited by humans. Herein, the term delta is used in a broad sense and includes alluvial tracts of land deposited at or near the mouth of rivers near the sea. These depocenters include settings such as fan-, cuspatate-, and bird-foot–shaped silty plains, coarse fan deltas, and river mouth alluvial plains located at heads of estuarine, bay, and fjord systems.

Radiocarbon-dated late Pleistocene to Holocene sections beneath modern delta plains typically contain three distinct stratigraphic units (Fig. 2). From base to top these units comprise: stratatal unit I, late Pleistocene fluvial deposits (to as young as ~11,000 yr B.P.); stratatal unit II, late Pleistocene to early Holocene shallow marine transgressive deposits (~18,000 to 8000 yr B.P.); and stratatal unit III, Holocene deltaic deposits of variable lithologies (~8000 yr B.P. to present). Deltaic unit III, the focus of this article, is typically a coarsening-upward, prograding sequence with datable deposits of variable lithologies (~8000 yr B.P. to present). Deltaic unit III, the focus of this article, is typically a coarsening-upward, prograding sequence with datable deposits of variable lithologies (~8000 yr B.P. to present). Deltaic unit III, the focus of this article, is typically a coarsening-upward, prograding sequence with datable deposits of variable lithologies (~8000 yr B.P. to present).

Global survey of radiocarbon-dated sedimentary sequences in modern marine deltas reveals that many (>50) of these depocenters began to develop during the period ~8500 to 6500 yr B.P. in a variety of geographic and geologic settings on coastal margins of world oceans (Stanley and Warne, 1994; Warne and Stanley, 1995; additional dated delta sites available from the authors). Having considered all major controls (including climate, tectonic setting, isostasy, coastal hydrodynamics, fluvial and sediment discharge, and sediment accumulation rates), we conclude that sea-level change is the only process that could bring about the coeval worldwide initiation of Holocene deltaic sequences (Fig. 2).

In order to determine the timing of initiation of modern deltas, we identified the oldest radiocarbon age available at or near the dated base of documented Holocene deltaic sequences (Fig. 2). For example, early Holocene deltaic sequences began to accumulate as former incised river valleys filled with sediment to the point that the rate of fluvial sediment input exceeded the declining rate of sea-level rise along coasts. This threshold, from marine transgression and coastal erosion to sediment accretion and progradation at the mouth of rivers, took place on a worldwide basis within a span of ~2000 yr.

DOCUMENTING EARLY HUMAN OCCUPATION OF DELTAS

Studies of the Nile and Yangtze deltas, where evidence for occupation extends to as early as ~7500 yr ago (Stanley and Warne, 1993; Stanley and Chen, 1996), were the catalyst for the present geoarchaeologic investigation. Findings from these two systems demonstrate that humans expanded onto the two depocenters within 5000 yr of their development as fertile plains. We reviewed archaeological literature to identify and document prehistoric sites in and adjacent to these depocenters. Our aim was to determine if there is a worldwide correlation between early development of modern marine deltas (~8500–6500 yr B.P.) and human exploitation of these resource-rich environments shortly after their formation.

The focus of this survey is to determine timing of earliest recorded occupation, rather than the specific nature of human activity (foraging, sedentariness, plant cultivation, domestication, pottery-making, etc.) at the 34 identified sites. Thus, we do not discuss specific cultures, typologies, or other archaeological designations. To evaluate the timing of human occupation of deltas shortly after development of these new ecosystems, we selected sites for this study on the basis of the following: (1) only those with material older than 5000 yr B.P. (Table 1); and (2) availability of radiocarbon-dated material, such as charcoal, plant, and bone (20 sites).

GSA TODAY, December 1997

TABLE 1. EARLY TO MIDDLE HOLOCENE ARCHAEOLOGICAL SITES IN AND ADJACENT TO MARINE DELTAS

<table>
<thead>
<tr>
<th>Delta seq. (Fig. 1)</th>
<th>Delta or lower plain</th>
<th>Age (yr B.P.)</th>
<th>Dating method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>North and Central America</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Mackenzie</td>
<td>~5000</td>
<td>4</td>
<td>Clark (1991)</td>
<td></td>
</tr>
<tr>
<td>2 Mississippi</td>
<td>6220–5345</td>
<td>1</td>
<td>Russo (1996)</td>
<td></td>
</tr>
<tr>
<td>3 Tecolutla, Veracruz</td>
<td>7600</td>
<td>3A</td>
<td>Wilkerson (1980)</td>
<td></td>
</tr>
<tr>
<td>4 Santa Maria</td>
<td>6810</td>
<td>1</td>
<td>Ranere and Hansell (1978)</td>
<td></td>
</tr>
<tr>
<td>South America</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Magdalena</td>
<td>5050</td>
<td>1</td>
<td>Meggers (1979)</td>
<td></td>
</tr>
<tr>
<td>6 Orinoco system</td>
<td>~6000</td>
<td>1, 3A</td>
<td>Sanoja (1989)</td>
<td></td>
</tr>
<tr>
<td>7 Valdivia</td>
<td>5800</td>
<td>1, 3A</td>
<td>Stothert (1985)</td>
<td></td>
</tr>
<tr>
<td>8 Las Vegas</td>
<td>8250–6600</td>
<td>1, 3A</td>
<td>Stothert (1985)</td>
<td></td>
</tr>
<tr>
<td>9 Huaca Prieta</td>
<td>~5000</td>
<td>1</td>
<td>Quilter (1991)</td>
<td></td>
</tr>
<tr>
<td>10 Santa</td>
<td>~7000</td>
<td>4</td>
<td>Wells (1992)</td>
<td></td>
</tr>
<tr>
<td>11 Camiña</td>
<td>~6000</td>
<td>1</td>
<td>Martínez (1979)</td>
<td></td>
</tr>
<tr>
<td>12 Porto Alegre plain</td>
<td>~7000</td>
<td>1</td>
<td>Rodríguez (1992)</td>
<td></td>
</tr>
<tr>
<td>13 Near Amazon coast</td>
<td>5045</td>
<td>1, 3B</td>
<td>Meggers (1979)</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Alta</td>
<td>~5600</td>
<td>1, 3A</td>
<td>Nygaard (1989)</td>
<td></td>
</tr>
<tr>
<td>15 Ume</td>
<td>~5500</td>
<td>3A</td>
<td>Ramqvist et al. (1985)</td>
<td></td>
</tr>
<tr>
<td>16 Rhône-Maas</td>
<td>~7000</td>
<td>3A</td>
<td>Whittle (1996)</td>
<td></td>
</tr>
<tr>
<td>17 Rhône</td>
<td>8000–7000</td>
<td>4</td>
<td>Whittle (1996)</td>
<td></td>
</tr>
<tr>
<td>18 Tagus</td>
<td>~7000</td>
<td>4</td>
<td>Whittle (1996)</td>
<td></td>
</tr>
<tr>
<td>19 Danube</td>
<td>~7000</td>
<td>3C</td>
<td>Whittle (1996)</td>
<td></td>
</tr>
<tr>
<td>20 Dimini Bay–Seskolitis</td>
<td>8000–6400</td>
<td>1</td>
<td>Zangger (1991)</td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23 Nile</td>
<td>~7000</td>
<td>1, 3B</td>
<td>Stanley and Warne (1993)</td>
<td></td>
</tr>
<tr>
<td>24 Niger</td>
<td>~5000</td>
<td>4</td>
<td>Devisse and Vernet (1993)</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 Oren</td>
<td>~8100–7500</td>
<td>1, 3A</td>
<td>Galli et al. (1993)</td>
<td></td>
</tr>
<tr>
<td>26 Tigris-Euphrates</td>
<td>7600–7000</td>
<td>1</td>
<td>Sanlaville (1992)</td>
<td></td>
</tr>
<tr>
<td>27 Indus</td>
<td>~5600</td>
<td>1</td>
<td>Mughal (1990)</td>
<td></td>
</tr>
<tr>
<td>28 Bang Pakong</td>
<td>~8000–7000</td>
<td>2, 3C</td>
<td>Higham (1989)</td>
<td></td>
</tr>
<tr>
<td>29 Zhu Jiang (Pearl)</td>
<td>6000</td>
<td>4</td>
<td>Lo (1990)</td>
<td></td>
</tr>
<tr>
<td>30 Peinan</td>
<td>~5600</td>
<td>3C</td>
<td>Lien (1993)</td>
<td></td>
</tr>
<tr>
<td>31 Han Jiang (Yangtze)</td>
<td>~7500</td>
<td>1</td>
<td>Stanley and Chen (1996)</td>
<td></td>
</tr>
<tr>
<td>32 Tokyo Bay</td>
<td>9450</td>
<td>4</td>
<td>Chard (1974)</td>
<td></td>
</tr>
<tr>
<td>33 Ramu</td>
<td>~5600</td>
<td>3B</td>
<td>Gorecki (1993)</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34 Murray</td>
<td>6020</td>
<td>1</td>
<td>Mulvaney (1969)</td>
<td></td>
</tr>
</tbody>
</table>

*Italicics indicate deltas that have been radiocarbon dated.
†1—Standard 14C radiocarbon; 2—accelerator mass spectrometer (AMS); 3—artifact type: lithic = A, ceramic = B, other = C; 4—undefined.

Deltas continued on p. 4
and/or dated artifacts (lithic, ceramic) assigned a numeric age (14 sites). In this preliminary evaluation of the timing of early occupation of deltas, data are subdivided into two temporal categories (Fig. 1): sites known to be older than 7000 yr B.P., or shortly after delta development ($n = 16$); and those somewhat younger, between 7000 and 5000 yr B.P. ($n = 18$).

This preliminary survey, which is representative but not comprehensive, shows that sites we identified occur in a wide range of latitudes (Fig. 1). However, most are within tropic and northern temperate latitudes, primarily in northern South America, the circum-Mediterranean, and eastern-southeastern Asia. Our database records a near-equal number of sites dated >7000 and <7000 yr B.P., older sites being concentrated in European and Mediterranean areas. Sites occur on all continents except those at highest latitudes, and we found few documented early delta sites (>5000 yr B.P.) in North America (Coastal Environments, Inc., 1977), southern South America and Africa, Eurasia, and Australia. Also, our research did not identify documented early Holocene sites on some major world deltas, such as the Congo, Ganges, and Yellow, and those of northern Russian rivers.

**LIMITATIONS OF CURRENT DATABASE**

By early Holocene time, humans were widely dispersed in temperate and tropic regions. The majority of prehistoric sites are recorded on inland and upland landscapes rather than on the coast (Price and Gebauer, 1995). Current distributions of documented early settlement sites appear in marked contrast to modern demographics, where almost 80% of the world’s population lives within 100 km of the coast. Thus, one might expect a larger number of sites positioned on or close to delta plains and submerged offshore (Stright, 1990), and evidence of human occupation is most commonly found along more stable and somewhat higher margins and apices of these depocenters. In addition, subsequent anthropogenic activity may have further modified and obscured prehistoric sites.

It is possible that the irregular distribution of documented early delta sites is influenced by other factors, such as uneven intensity of archaeological exploration and access to literature and records. Other explanations for the uneven distribution of sites include increased logistical difficulty of exploration in areas such as densely vegetated tropics, climatically isolated (polar) regions, and submarine settings.

Additional challenges associated with the systematic worldwide survey of early and mid-Holocene archaeological sites on deltas pertain to dating. In some regions, sites are dated typologically—that is, by identifying characteristic lithic and ceramic manufacture method and/or style and correlating with sites elsewhere that contain similar artifacts that have been radiocarbon dated. Materials are now commonly dated by the standard radiocarbon method, but ages cited in the literature vary in format—e.g., in yr B.P., uncalibrated or calibrated, or in yr B.C.E. At this time, material at only a few delta sites has been dated using the accelerator mass spectrometer (AMS) method, and none that we reviewed in the literature incorporate reservoir corrections (cf. Stuiver and Brazunas, 1993).

**INCIPIENT SETTLEMENT OF RESOURCE-RICH DELTA PLAINS**

Humans occupied a broad spectrum of environments by the end of the Pleistocene, and the transition to agriculture was under way in widely different regions of the world between that time and the mid-Holocene. By identifying 34 delta sites occupied by at least 5000 yr B.P., our database suggests that delta environments...
may have been a component in this transition. Eight documented sites are dated to 7000 yr B.P. or earlier and are positioned on or adjacent to deltas that are known to have begun at least 7000 yr ago. These include (Table 1): Tecolutla (Mexico), Santa (Peru), Rhine-Maas (Netherlands), Rhône (France), Danube (Romania), Nile (Egypt), Tigris-Euphrates (Iraq, Kuwait), and Yangtze (China). These sites are in diverse geologic, geographic, and climatic settings along the lower stretches of rivers characterized by variable flow and sediment load. These localities, nevertheless, have the following common features: a generally prograding shoreline and increasing land area, permanent freshwater sources, high water table, aquatic habitats (fresh, brackish, marine), well-developed and relatively stable system of distributary channels, and fertile silt-rich soil.

Archaeological research indicates that sedentariness occurred in diverse geographic and climatic settings, but essential to site location was availability of a reliable water supply such that risks of drought were minimized. Other advantages associated with proximity to water sources include perennially available protein and other aquatic food sources and ease of regional travel and trade.

INTEGRATED GEOLOGICAL-ARCHAEOLOGICAL DELTA MODEL

A delta model that incorporates the geological and archaeological records emphasizes the near-synchronous development of resource-rich deltaic environments, which offered soil and water resources conducive to human immigration and settlement (Fig. 3). Although climate is the fundamental driving force for late Pleistocene and Holocene sea-level oscillations, as well as regional environmental and associated vegetation changes, our model identifies sea level as the principal worldwide mechanism that directly controls delta formation and early human occupation of these coastal environments. From ~20,000 to 18,000 yr B.P. (Fig. 3A), when sea level was at least 120 m below present level (Fairbanks, 1989), river gradients were greater than those of today, braided-river systems incised preexisting coastal plains, and deltas formed seaward of present shorelines, near the present shelf edge. Late Pleistocene alluvial plain deposits on the subaerially exposed continental shelf (Fig. 2) served as habitat as well as land bridges between continents for forager groups.

From ~18,000 to 8000 yr B.P. (Fig. 3B), sea level rose rapidly (to as much as 1 cm/yr), while shelf-edge deltas and continental shelves were concurrently submerged. Coastlines retreated landward, and shelf sediments were extensively reworked by nearshore waves and currents from ephemeral braided to more stable meandering river systems.

During initial stages of development, the seaward parts of deltas generally comprise a series of ephemeral lowlands and islands isolated by shallow distributaries (van Heerden and Roberts, 1980), as illustrated by the nascent Atchafalaya delta (see background photo). These frequently inundated lowlands compelled humans to overcome difficulties associated with isolation on islands, periodic inundation, and forced migration (Büdel, 1966). Technological advances during the early and middle Holocene enabled some humans to exploit these evolving coastal lowland environments. Abundant freshwater resources and access to inland settlements via rivers made deltas more attractive than other coastal areas to some prehistoric groups. In some deltas, such as the Nile and Yangtze, increasing technology and human manipulation eventually gave rise to well-developed hydraulic civilizations (Butzer, 1976).

The Yangtze in eastern China (Fig. 4) is the most extensively documented example that demonstrates the close relation between sea-level change and early human occupation of deltas. By integrating archaeological information and petrologic and radiocarbon data derived from cores, it has been shown that this depocenter was occupied by ~7500 yr B.P. or within five centuries of the beginning of delta formation (Stanley and Chen, 1996). Geoarchaeological studies reveal that positions of Neolithic settlements are related to geography (selection of topographic highs, which are less vulnerable to inundation) and advancing techniques in adapting to wetland occupancy, and that their distributions changed systematically through time in direct response to sea-level rise. The integrated record indicates a progressive eastward expansion of settlements as sea-level rise inundated former topographic lows, inducing relocation toward higher elevations associated with coastal ridges that served as protective barriers (Fig. 4).

RAMIFICATIONS OF THE INTEGRATED STUDY

This integrated geological and archaeological investigation of early to middle Holocene deltas can serve to refine the archaeological record for deltas and other coastal settings and to foster development of effective, long-term coastal protection strategies.

Systematic geological analyses of continuous borings in deltas and their lateral correlation define three-dimensional lithofacies distributions and associated environments of deposition. Such analyses provide a context for interpreting both

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change through time and formulate effective, long-term coastal protection strategies.

**ACKNOWLEDGMENTS**

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