



Oxygen Isotopic Analysis of Archaeological Shells to Detect Seasonal Use of Wetlands on the Southern Pacific Coast of Mexico

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Oxygen isotopic ratios in modern and archaeological marsh clam shells (*Polymesoda radiata*) from the Acapetahua Estuary in southwestern Mexico record large scale salinity fluctuations caused by alternating wet and dry seasons. Thus, prehistoric patterns of rainfall can be reconstructed and the season of molluscan death can be estimated. Changes in the oxygen isotopic patterns preserved in marsh clam shells from late Archaic period (c. 3000–1800 BC) archaeological deposits indicate that the season of shellfish harvesting changed dynamically through time in this region. Based on this study, and other lines of archaeological evidence, we argue that hunter-gatherers during the early stages of the late Archaic period visited locations in the littoral zone throughout the year with a focus during dry season months. Through the late Archaic period a general trend occurred toward wet season use of these locations. This culminated at the end of the late Archaic period with the exclusive use of the littoral zone during wet season months. These data indicate a fundamental shift in the way these estuarine locations were being used. We argue that people living in this region altered their overall subsistence strategy during the late Archaic period due to scheduling conflicts that occurred with the adoption of maize agriculture.

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Introduction

Reconstructing changes in human subsistence and settlement patterns is an integral part of understanding how prehistoric people adapted to their social and natural environments through time. One component of reconstructing prehistoric subsistence and settlement is accurately determining the seasonality of resource and site use. Evidence for the seasonal use of resources and sites range from the simple presence or absence of seasonally available plants and migratory animal species (Monks, 1981; Deith, 1985) to more complex studies of bone and antler or tooth and shell growth increments (Deith, 1985; Bernstein, 1990; Lieberman, 1993).

The purpose of this paper is to discuss the seasonal use of littoral sites by hunter-gatherers who lived along the Pacific coast of southern Mexico during the late Archaic period (3000–1800 BC). Oxygen isotopic analysis of estuarine mollusc shell carbonate is used to reconstruct the season when clams were harvested by

prehistoric people living in the region during this time interval. These data are assessed with other lines of archaeological evidence to better understand the season in which these sites were occupied and how they functioned within a larger subsistence and settlement system.

The late Archaic period in Mesoamerican prehistory is of special significance because it is the time when ancient people were making an economic transition from foraging to farming. It is also the period immediately preceding the development of greater socio-political complexity. Understanding the role of coastal resources to the prehistoric hunter-gatherers in the Mesoamerican lowlands prior and during the introduction of agriculture may assist with the understanding of this important transformation. Our principal finding is that changes occurred in the use of estuarine resources throughout the late Archaic period. These changes were probably associated with scheduling conflicts that developed with the intensification of maize agriculture in the region.

Study Area

The environment

The late Archaic period shell deposits discussed in this paper are located on the Pacific coastal plain of southern Mexico (Figure 1). This region was known as the Soconusco to the Aztecs, who traded with and exacted tribute from its people, and the term continues to be used today to refer to the strip of coast between the town of Pijijiapan and the Mexican–Guatemalan border (Voorhies, 1989).

Rivers originating in the Sierra Madre de Chiapas, the mountain range flanking the coast, transect the coastal plain and flow into the coastal lagoons, swamps, and estuaries of this region. The canals and shallow water lagoons of the Acapetahua Estuary are surrounded by a patchwork of mangrove forest and cattail marsh. This productive aquatic habitat supports a wide range of marine and estuarine organisms including fish, shrimp, molluscs and waterfowl. Faunal and floral remains found in the late Archaic period shell mounds in the estuary suggest that the environment was basically similar to that of today (Voorhies, 1976; Hudson, Walker & Voorhies, 1989). Phytolith studies indicate that before 5000 years ago the coastal plain was covered by a tropical deciduous forest that was subsequently disturbed (Jones, 1988; Jones & Mora, 1993).

Southwestern Mexico is influenced by highly seasonal tropical monsoonal rains (Vivó Escoto, 1964). Rain falling on the Soconusco coastal plain and the Sierra Madre de Chiapas provides a seasonally variable supply of fresh river water to the brackish water of the estuarine system. Large volumes of fresh water flow into the littoral zone during the wet season between April and October, with a much smaller influx during dry season months between November and March. Stable carbon and oxygen isotopes indicate that this tropical monsoonal rainfall regime persisted throughout the late Archaic period (Kennett & Voorhies, 1995).

The Chantuto people

Late Archaic period occupation of the Pacific coastal plain coincides with the stabilization of global sea level, approximately at 6000 years BP (Fairbanks, 1989). Human populations inhabiting the Soconusco region at this time have been named the Chantuto people (Voorhies, 1976); evidence for their existence consists of six large shell mound sites. Five of these sites are located in the Acapetahua Estuary (Drucker, 1948; Lorenzo, 1955; Voorhies, 1976; Navarrete, n.d.). The other site, Cerro de las Conchas, is situated near the inland margin of the El Hueyate swamp adjacent to the estuary to the southeast (Clark, 1994) (Figure 1). Although these sites represent the earliest recognizable human occupation on the coastal plain, earlier deposits were probably covered by the Late Pleistocene/Early

Holocene marine transgression or have been obscured by sediments associated with this actively prograding coastline.

Cerro de las Conchas, the oldest of the six late Archaic period middens in the Soconusco region, was deposited between 4000 and 3000 BC (Blake *et al.*, 1995; Clark, 1994). This shell midden is approximately 80 m in diameter and over 5 m high. Although this deposit is presently located near the freshwater El Hueyate swamp, faunal remains at the site indicate that it was once adjacent to the littoral zone. The deposits are dominated by marsh clams; however, a lense of limpets also was discovered at the site (Clark, 1994). Although this site is considered to be an early manifestation of the Chantuto phase cultural complex, it is not the focus of this study.

This study focuses on the five shell mounds located in the Acapetahua Estuary (Figure 1) that were formed during the millennium after Cerro de los Conchas, that is, during the third millennium before the current era (Blake *et al.*, 1991). All of the shell mound sites in the Acapetahua Estuary are remarkably similar (Voorhies, 1976), consisting almost exclusively of the marsh clam *Polymesoda radiata* (Severyn, 1993),* lying in alternating beds of crushed and whole shells. These aceramic shell deposits, dating to the late Archaic period, are overlain by dark brown soil deposits with diagnostic ceramics from later time periods.

Clamshells used for this investigation are from the site of Tlacuachero, excavated by Voorhies in the early 1970s (Voorhies, 1976) and again in the late 1980s (Michaels & Voorhies, 1989).† Tlacuachero forms an artificial island within the wetlands that is approximately 140 × 128 m in size and greater than 7.4 m in height (Voorhies, 1976) (Figure 2). The predominant constituents of the lower aceramic deposits at Tlacuachero are shells of *P. radiata* (Figure 3), comprising 99.55% of the faunal assemblage (Voorhies, Michaels & Riser, 1991). Other invertebrate and vertebrate remains that comprise the faunal assemblage are from species common in the present day estuarine environment (Voorhies, 1976; Hudson *et al.*, 1989; Anikouchine, 1990). Of these, fish are the dominant vertebrate species represented (Anikouchine, 1990). Open water marine vertebrate and invertebrate species are notably scarce in the Chantuto phase layers.

The stratigraphy of the lower, aceramic component at Tlacuachero, and the other late Archaic period shell mounds, is characterized by distinct alternating beds of burned and unburned shell (Figure 4). Laterally extensive layers of unburned, whole *P. radiata* shells are interbedded with equally extensive layers of burned, broken shells of the same species. Lenses of dumped

*This clam was formerly called *Neocyrena ordinaria* but its taxonomic nomenclature recently has been revised.

†We returned to the site more recently, in 1994, during which time additional excavations were made and samples of clam shell and charcoal collected for further analysis. However, these samples were not used in the study reported here.

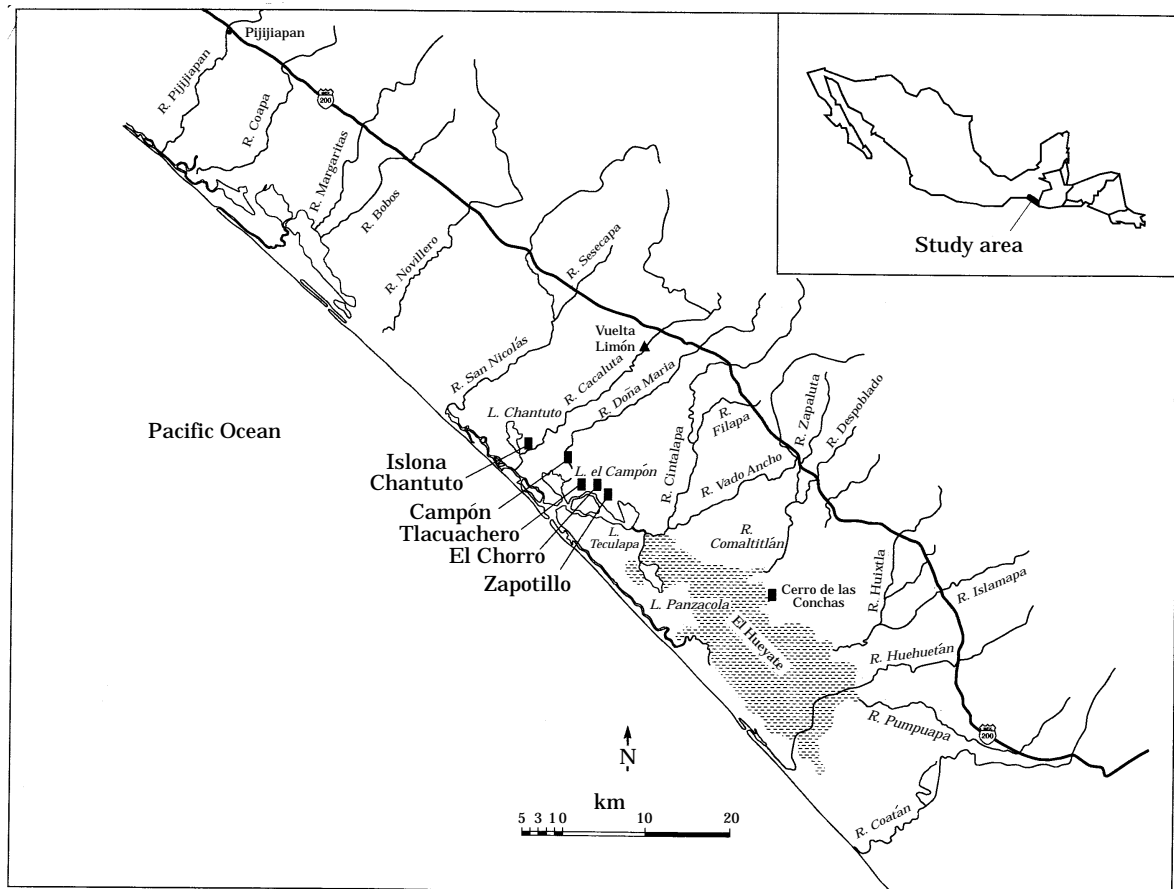


Figure 1. Study area, showing late Archaic period shell mound sites, coastal lagoons of the Acapetahua Estuary, the El Hueyate swamp and coastal rivers discussed in this paper. - - -: Freshwater swamp; ■: Archaic period shell mounds; ▲: Archaic period-site.

material (basket dumps), often found in trash midden contexts, are rare, as are pits, postmolds and other features. We believe that these bedded deposits are the actual remains of clam bakes, that appear to have been carried out by placing a large bed of clams over a bed of coals.* These blanket type middens (Waselkov, 1987) are also marked by a low diversity of stone tools. Only a small number of millingstone artefacts, hammerstones, and obsidian flakes have been found in the lower deposits at Tlacuachero.

It is likely that implements used for exploiting estuarine resources were made of perishable materials that have not survived archaeologically. The diameters of fish vertebrae at Tlacuachero indicate that the Chantuto people procured many small fish (Voorhies *et al.*, 1991), that were less than 15 cm long. This suggests to us that late Archaic period people used fine mesh baskets or nets to catch fish and probably shrimp. Similarly, the small size of some marsh clams

harvested (<1/4") indicates that a mass harvesting device, such as shovel or rake with closely spaced tines, was used to collect these bivalves *en masse* (Voorhies, 1976).

Information about sites on the Soconusco coastal plain contemporary with the shell mounds in the littoral zone is scant. One site, Vuelta Limón (Figure 1), is located upstream from the Acapetahua Estuary, where it was discovered by us in a river bank (Voorhies & Kennett, 1994). There we excavated a trash midden containing many fire cracked and waterworn rocks, as well as some stone tools. We think that this site provides evidence of a sedentary (or semi-sedentary) occupation, which Voorhies expected on the basis of her theoretical model of coastal adaptation during the late Archaic period (Michaels & Voorhies, 1989; Voorhies, 1991).

Seasonal Mobility on the Soconusco Coastal Plain: the Model

Various settlement and subsistence strategies are employed by hunter-gatherers faced with the challenges of exploiting seasonally available resources. Humans

*Voorhies, Michaels & Riser (1991: 23-24) had earlier interpreted the bedding of the shell deposits as having been caused by intentional burning of vegetation when the site was reoccupied after a period of abandonment. While this hypothesis has not been disproven, we now favour the view that the bedding at the site occurred as a result of cooking the clams.

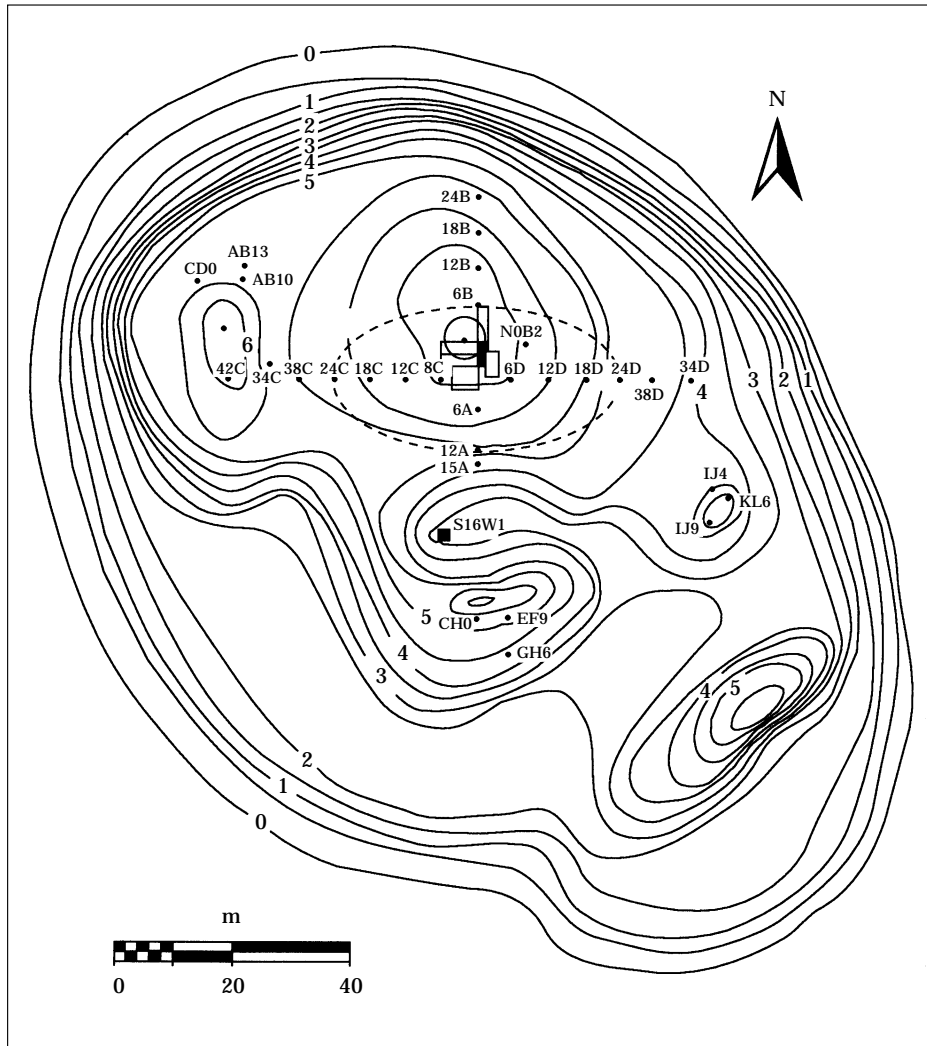


Figure 2. Plan of excavation areas and auger test locations of Tlacuachero (site CAP-7), a shell mound located in the Acapetahua Estuary. Excavation units and auger tests from the 1973 and 1988 field seasons are shown (adapted from Michaels & Voorhies, 1989). - - -: Limit of clay floor; ■: 1973 excavations; □: 1988 excavations; ●: auger locations. Contour interval=0.5 m above sea level; declination: 8 degrees East.

respond to changes in the abundance and distribution of natural resources and to other non-economic factors (Hard & Merrill, 1992). Archaeologists are faced with trying to reconstruct these dynamic patterns of prehistoric movement with the static archaeological record (Binford, 1983). To this end, Binford's (1980) forager-collector continuum has been useful for building heuristic models of prehistoric subsistence and settlement that can be tested against the archaeological record. This continuum, based on extensive ethnographic research, ranges from highly mobile foragers to relatively sedentary logistical collectors.

The *forager* strategy is generally practiced by hunter-gatherers living in highly productive, homogeneous environments where resources are abundant and continuously available throughout the year. Generally, these small, highly mobile, groups move from habitat to habitat throughout the year in synchrony with the



Figure 3. Two valves of a modern marsh clam, *Polymesoda radiata* (Photograph by B. Voorhies; scale in cm).



Figure 4. Photograph of bedded stratigraphy at Tlacuachero (CAP-7). Notice layers of unburned whole clamshell valves interbedded with layers of burned broken shells (Photograph by B. Voorhies).

seasonal distribution of the resources. During this seasonal migration, foragers establish a residential base in a resource zone to gain access to resources within a 2 h walk of the encampment. Once the resources in this zone are depleted, the group moves to a different location. Binford (1980) argues that because there are no seasonal food shortages there is no reason to store resources. Most food is prepared for immediate consumption, and processing occurs at centralized residential base camps.

Two settlement types are generated by this type of subsistence-settlement strategy: *residential bases* and *locations*. The size of residential bases depends on the number of occupants and the intensity and length of occupation, but, in general, these sites are more ephemeral than the base camps of collectors. Highly mobile groups deposit relatively homogenous refuse that is functionally related to the activity performed in each habitat (Bettinger, 1991). Most of the processing, manufacturing, and tool maintenance occurs at the base camps because they are the loci of all subsistence activities. Task groups are deployed to *locations* to exploit plants and animals. These locations generally show evidence of a single extractive task (e.g. butchering).

Conversely, a *collector* strategy is employed by hunter-gatherers in environments where the distribution of resources is spatially and temporally variable. *Collectors* inhabit semi-permanent encampments

and extract resources with planned logistical forays to different environmental zones. Seasonal shortfalls in resources that cannot be easily mitigated by periodic movement require advanced planning and more complex strategies for survival. Collectors intensely exploit seasonally available resources and store the excess food yields for times when productivity declines. Storage extends the temporal availability of resources but reduces a group's mobility so that shortfalls that were once solved with periodic movement become more costly. A greater degree of internal specialization and coordination is needed to develop extraction techniques to procure seasonally available resources in bulk. Special task groups are deployed to collect specific resources for a group as a whole. These activities usually involve the development, curation and maintenance of specialized tools that make extracting resources more efficient (Torrence, 1983; Bamforth, 1986). Sometimes large, bulky equipment is cached close to the location of the resource. Base camps are usually centrally located, and task groups travel from this locus to hunt or collect in different resource zones and return to the base camp.

Archaeologically, the assemblages found at the residential bases of collectors are more heterogeneous than forager base camps, reflecting a greater diversity in activities carried out over a larger area. Evidence for storage is also a good archaeological indicator of this more logistically organized subsistence strategy. In addition residential bases and locations, *collectors* also leave a greater variety of site types including *field camps*, *caches* and *stations* for gathering environmental information. *Locations* used by collectors generally exhibit evidence for the procurement and processing of resources in bulk.

It is probable that people living in the coastal lowlands of Mesoamerica during the late Archaic period were primarily hunters and gatherers, although we lack a comprehensive picture of their subsistence economies. Michaels & Voorhies (1989) postulate that in addition to hunting and gathering wild food, coastal dwellers in the Soconusco were practicing some form of early horticulture. Regional settlement data of the type necessary to establish how these hunter-gatherers were moving around the landscape are limited. Based on the available evidence of coastal populations in Mesoamerica, Michaels & Voorhies (1989) have developed a heuristic subsistence-settlement model for human populations who lived in the Mesoamerican lowlands during the late Archaic period. In this model, the organization of subsistence and settlement strategies resembles *collectors* rather than *foragers*. This hypothetical settlement system consists of one or two relatively sedentary base camps that were used as loci for logistically organized groups that exploited resources from different habitats on the coastal plain and adjacent mountain ranges.

Large residential bases were probably located on the coastal plain (Michaels & Voorhies, 1989), and we

think that Vuelta Limón is the first such site to be found. The Chantuto phase shell mounds are interpreted as specialized locations for extracting shellfish, shrimp, fish and other estuarine resources. This interpretation is supported by (1) the great areal extent and depth of the deposits, indicating intense exploitation of estuarine resources beyond the need of the group collecting them, (2) the distinct bedded stratigraphy of shell mound sites, suggesting periodic visits to these locations, (3) the undisturbed nature of the deposits, indicating short term occupation, (4) the virtual absence of evidence for structures* and domestic cooking areas including postmolds, floors, pits or hearths, and (5) the limited range of unspecialized stone tools.

A survey of the present day seasonal availability of resources in the Acapetahua Estuary suggests that the dry season is the optimal time for people to exploit wild resources from the littoral zone. Although most plants and animals in this aquatic habitat are available throughout the year, there is a resource pulse starting in the early dry season and continuing to the beginning of the wet season. Migratory waterfowl appear in the region during the late wet season/early dry season. This is followed by a peak in shrimp availability during the dry season, of great importance to present day populations living in the estuary (Voorhies *et al.*, 1991). Female turtles, crocodiles, and iguanas also carry their eggs at this time. Finally, there may be a general reduction in terrestrial biomass during the dry season that would have made the littoral zone of the Acapetahua estuary especially attractive during that time of the year.

Based on the available archaeological evidence it appears that the Chantuto phase shell mound sites were occupied periodically, possibly seasonally, throughout the late Archaic period by logistically organized *collectors*. Determining precisely when the littoral zone was occupied during the annual cycle is one component in deciphering this ancient pattern of settlement. It may also provide insight into why agriculture was adopted on the coastal plain and why the hunting and gathering subsistence strategy of the late Archaic period cultural complex came to an end.

Seasonal Determinations with Oxygen Isotopic Analysis: the Test

Oxygen isotopic analysis of molluscan shell carbonate is a well established technique for determining the season of prehistoric shellfish harvesting. The method was initially recognized as a powerful tool for palaeo-environmental reconstruction because oxygen isotopic ratios in calcareous fossils contain information about the physical and chemical environment of their growth (Wefer & Berger, 1991). Two environmental factors

*Evidence for structures is present on the one clay surface that was discovered at Tlacuachero but this floor construction and the structures that were upon it, appear to be unique (Voorhies *et al.*, 1991).

contribute to the isotopic composition of shell carbonate: the isotopic composition of seawater and water temperature. Urey (1947) showed that the stable oxygen isotopic composition of calcium carbonate deposited by marine molluscs was temperature dependent and thus of great value as a palaeothermometer. A paleotemperature equation was developed by Epstein *et al.* (1951, 1953) based on oxygen isotopic measurements of mollusc shell carbonate precipitated at known water temperatures. In the equation:

$$T = A - B(\delta c - \delta w) + C(\delta c - \delta w)^2$$

T is equal to temperature in °C and A , B , C are constants respectively equalling 16.4, 4.2 and 0.13. The symbol δc is the oxygen isotopic ratio of the carbonate, expressed as a deviation in ‰ (ppm) from a standard carbonate.

$$\delta c = \left(\frac{\delta^{18}\text{O sample}}{\delta^{18}\text{O standard}} - 1 \right) \times 1000$$

δw represents the oxygen isotopic composition of the water expressed in a similar fashion, as a deviation from standard mean ocean water (smow). In order to solve the equation for temperature (T), the delta value of the water must be known. When the delta value for the water (δw) is constant, the oxygen isotopic ratio increases by approximately 0.2‰ for every 1°C increase in water temperature.

Thus, in the open ocean, where the composition of sea-water has been relatively stable since the middle Holocene (~6000 years to present day), oxygen isotopic measurements of calcium carbonate extracted from the sequential growth increments of molluscs reflect seasonal fluctuations in water temperature and the season of death can be estimated. Shackleton (1969) was the first to point out the applicability of this technique for archaeologists interested in determining the season of mollusc collection from shells in archaeological deposits.

The methods for extracting seasonal information from mollusc shells were initially worked out by Shackleton (1973) and have changed little since. Calcium carbonate samples are extracted along a shell's growth axis from the growth margin towards the hinge. Using specimens of *Patella tabularis* collected alive from Nelsons Bay Cove, South Africa, Shackleton determined that oxygen isotopic changes through the growth of mollusc shells paralleled seasonal fluctuations in temperature and that the shell margin samples accurately reflected the season of molluscan death. Shells from prehistoric midden deposits, dating between 9000 and 5000 years ago, in the region indicated that molluscs were harvested primarily during winter (cold weather) months.

Based on this study, Shackleton (1973) outlined a number of criteria that should be met to make seasonal temperature determinations using oxygen isotopic analysis. First, shell growth must take place under

conditions of isotopic equilibrium with the surrounding water. Second, the isotopic composition of the water in which the shellfish lives must remain constant throughout the year. Third, the shell must precipitate carbonate throughout the year at a relatively fast rate. Finally, the seasonal temperature range must be greater than the week-to-week variations in temperature.

Post depositional diagenesis of shell carbonate presents a potential problem to archaeologists applying this technique to shells from prehistoric midden deposits. Shell surface carbonate is particularly susceptible to dissolution and recrystallization (Shackleton, 1973; Bailey, Deith & Shackleton, 1983), and chemical exchange with percolating ground water can alter the shell's original isotopic signature. In some depositional contents diagenesis is expedited by endolithic blue-algae that bore into the surface of the shells (Deith, 1985). Oxygen isotopic values in these cases will be lowered, because ground water has lower $\delta^{18}\text{O}$ values (i.e. relatively more $\delta^{16}\text{O}$) than ocean water. Establishing the isotopic systematics if living molluscs of the same species provides one baseline for evaluating the integrity of the isotopic composition of archaeological samples.

More recent literature has focused on establishing the precision of the oxygen isotopic method for determining seasonality. Based on a study of modern and archaeological *Myrtilus californianus* specimens from the California coast (Killingley, 1980, 1981; see also Killingley & Berger (1979) and Glassow *et al.* (1994)) proposed that the month of prehistoric shellfish collection can be determined by statistical treatment of oxygen isotopic data. Bailey *et al.* (1983; also Deith (1985)) argued, in contrast, that determining the season of molluscan death to the month was unrealistic because of known oxygen isotopic differences between species and regional climatic variation through time.

Oxygen isotopic analyses of marine molluscs have been successful because the isotopic composition of ocean water has remained relatively constant since the middle Holocene, whereas variations in temperature cause predictable changes in isotopic composition. However, this is not the case in coastal estuaries where large fluctuations occur in isotopic composition of estuarine waters. This dynamic situation is largely caused by changes in the influx of river water, as well as by seasonal temperature changes. The influx of river water causes significant changes in $\delta^{18}\text{O}$ composition of estuarine waters because fresh water from the continent has relatively low $\delta^{18}\text{O}$ values (Keith, Anderson & Eichler, 1963). This complex interaction may cause difficulties in deciphering the environmental causes of oxygen isotopic change in estuarine molluscs, especially in temperate regions where there are large seasonal changes in temperature. Deith (1983, 1988) argued that oxygen isotopic analysis is best suited for open ocean marine molluscs, but some estuarine forms are suitable if they retain a temperature-dependent signal.

Little oxygen isotopic work has been carried out using tropical molluscan species, because large seasonal differences in temperature do not occur. Tropical estuaries, however, provide a context in which water temperature remains relatively constant throughout the year, while seasonal fluctuations in freshwater runoff cause distinct changes in the oxygen isotopic composition of the water, overwhelming the temperature effect (Kennett & Voorhies, 1995). In these settings, oxygen isotope analysis of molluscan shells is potentially a powerful tool for reconstructing ancient water regimes and determining the season of shellfish harvesting.

The rainfall regime along the southern Pacific coast of Chiapas is highly seasonal. The Soconusco region receives an average rainfall of 3200 mm (based on measurements taken by the Comisión Nacional de Agua at Escuintla between 1975 and 1990). Much of this rain falls between April and October, with negligible amounts falling during the rest of the year. During the rainy season, the rivers that transect the Soconusco coastal plain flood the coastal estuaries with fresh water. Kennett & Voorhies (1995) hypothesized that during wet season months, waters of the Acapetahua Estuary would exhibit lower $\delta^{18}\text{O}$ values compared with the dry season, and that this seasonal variability should be recorded in the shells of the marsh clam *Polymesoda radiata*. If such relations existed throughout the Holocene, they should provide a basis for determining the seasons of collection by prehistoric populations living in the Soconusco region during the late Archaic period. This will, in turn, provide valuable information about site function.

Materials and Methods

Modern clam shells

Living specimens of *P. radiata* were collected from the Acapetahua Estuary to better understand the relationship between fluctuating environmental factors and the oxygen isotopic variation in the shells. Monthly collections of these clams were taken from the Los Cerritos Lagoon (see Figure 1) during the course of one annual cycle spanning the calendar years 1989 and 1990, excluding the months of June and July. Water samples were collected from the lagoon at the same time.

Five right valves were randomly selected for analysis from each of the 10 monthly collections. The shells were thoroughly cleaned to remove any extraneous organic material that might contaminate the sample. Any obvious organic material on the surface of the shell, including the periostracum, was removed with a razor blade. The shells were then rinsed in deionized water and baked in an oven at 85°C until they were dry (Killingley & Bergery, 1979). It was often necessary to repeat this process until all of the visible organic material was removed.

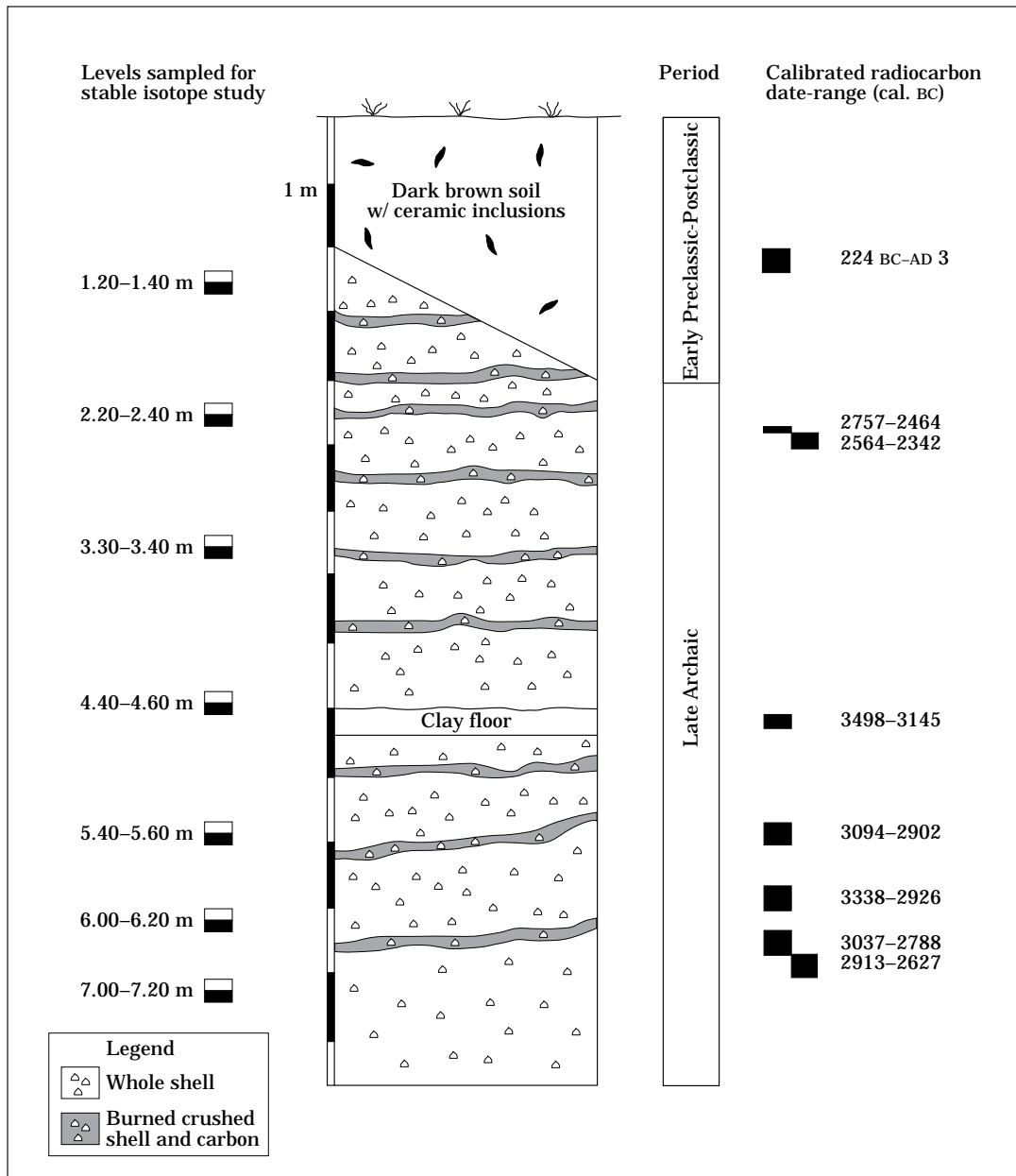


Figure 5. Idealized stratigraphic profile of excavation unit NOE2 at Tlacuachero (CAP-7).

Archaeological clam shells

The archaeological specimens of *P. radiata* analysed are from the site of Tlacuachero (CAP-7). In the field, 10 cm³ of matrix were collected at intervals of 10 cm (corresponding to the lower 10 cm of each 20 cm excavation level). The clam valves used in this study were removed from these matrix samples, but only shells from seven levels were analysed, the levels being separated by approximately 1 m intervals (Figure 5). The highest group of samples came from the top of the late Archaic period deposits 1.20-1.40 m below the surface whereas the lowest group of samples came from the 7.00-7.20 m level below the surface.

Several methods were used to establish that there has been no postdepositional alteration of the archaeological shell carbonate. Thin sections of modern and archaeological shells were first examined with conventional and scanning electron microscopes. Visual inspection of the crystalline structure of the archaeological shells indicated that they are well preserved. Modern and archaeological shells also were examined using X-ray diffraction. The crystal lattice of contemporary *P. radiata* shells consists of aragonite. We determined that the primary aragonite in the archaeological specimens is intact and that secondary deposits of calcite, indicative of diagenesis, are absent.

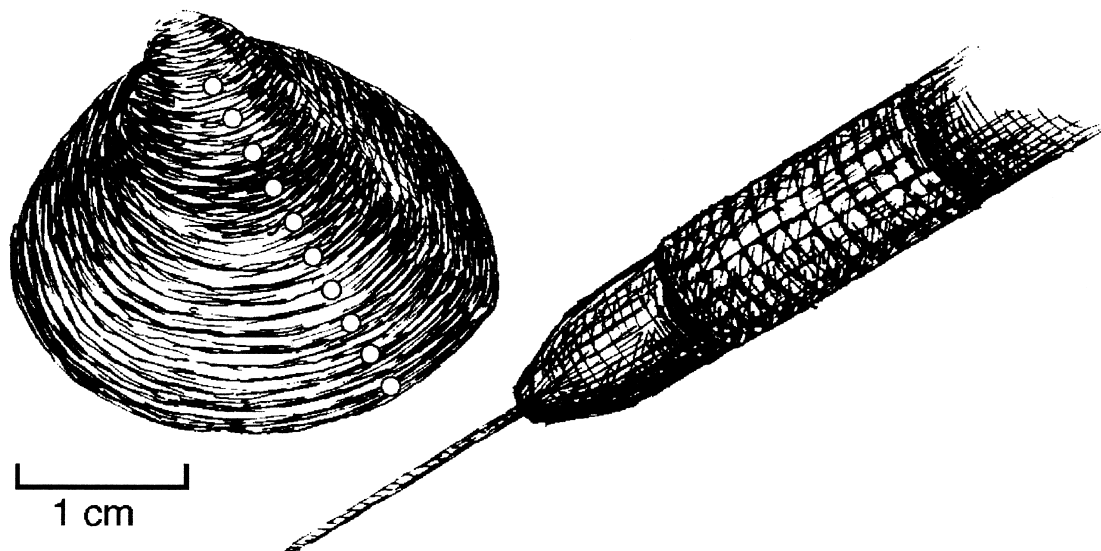


Figure 6. Drawing of *Polymesoda radiata* shell showing how successive growth increments were sampled for oxygen isotopic analysis (Drawing by Meredith Kennett).

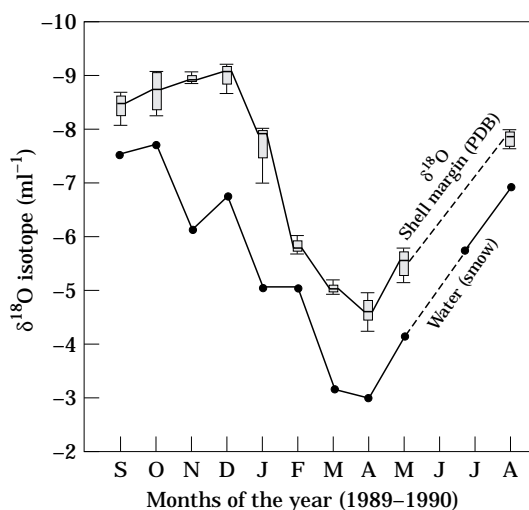


Figure 7. Oxygen isotopic composition of modern shell margins ($N=5$ per month) plotted against the $\delta^{18}\text{O}_{\text{SMOW}}$ of estuarine water samples collected at the same time from the surface of the Los Cerritos Lagoon.

Twenty archaeological clams were selected from each level sampled for oxygen isotopic analysis. Each valve was rinsed with deionized water to remove the adhering soil matrix and then dried in an oven at 85°C . The surface of each archaeological shell was etched with a weak solution of HCl to remove any possible diagenetically altered carbonate (Bailey *et al.*, 1983). After the outer fraction of the shell was removed, the samples were rinsed again with deionized water and dried at 85°C .

The margin of each modern and archaeological shell, representing the final stages of growth prior to harvest-

ing, was removed with a sterile razor blade. Several modern ($N=6$) and archaeological ($N=14$) shells were further sampled (Figure 6) to reconstruct the oxygen isotopic variation throughout the life of the molluscs. Samples were extracted in 1.5 mm increments along the growth axis of the shell using a 0.5 mm dental drill.

Each sample was ground into a fine powder with a mortar and pestle, loaded into a small copper vessel and roasted, under vacuum, at 350°C for one hour. The roasting process oxidizes any remaining organic material. After roasting, the pure calcium carbonate sample was reacted in orthophosphoric acid at 90°C . The oxygen isotopic ratios of the resulting CO_2 were determined by mass spectrometry (Finnegan MAT-251 Mass Spectrometer). All measurements are expressed as a deviation from an internationally accepted standard, PeeDee belemnite, a carbonate fossil from South Carolina (Herz, 1990). The precision of the oxygen-isotopic ratios is 0.1%. More negative δ values indicate higher proportions of the lighter ^{16}O isotope compared to the heavier ^{18}O isotope and vice versa.

Results

The range of $\delta^{18}\text{O}$ variation of the monthly modern shell margin samples from September, 1989 to August, 1990 is shown in Figure 7. This represents an annual $\delta^{18}\text{O}$ range of 4‰ (~ -8 to -9 ‰ between the months of July and January and ~ -5 to -6 ‰ between the months of February and June). The annual range of oxygen isotopic composition of shell margin carbonate is greater (4‰) than that of any single month (1‰), thus meeting Shackleton's criterion. Moreover, comparing both lines in Figure 7 it can be seen that the $\delta^{18}\text{O}_{\text{PDB}}$ of the shell margin

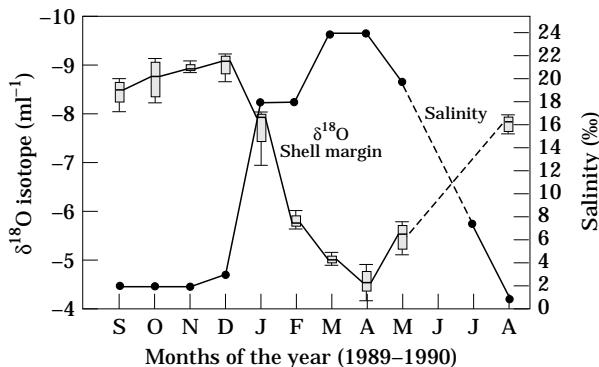


Figure 8. Oxygen isotopic composition of modern shell margins plotted against the salinity of estuarine water samples taken from the surface of Los Cerritos Lagoon.

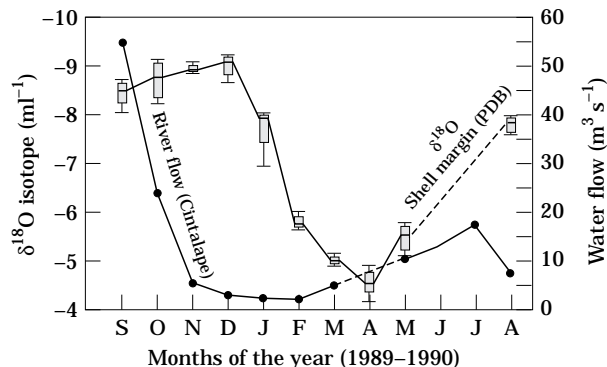


Figure 10. Oxygen isotopic composition of margins of modern shell plotted against water flow in the Cintalapa River (Comisión Nacional de Agua) between September, 1989 and August, 1990.

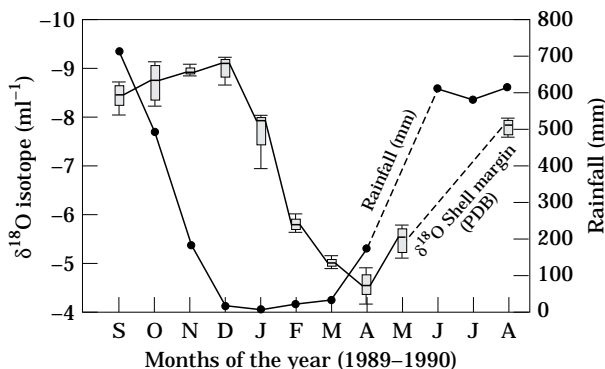


Figure 9. Oxygen isotopic composition of margins of modern shell, plotted against average monthly rainfall measured on the coastal plain at Escuintla (Comisión Nacional de Agua), between September, 1989 and August, 1990.

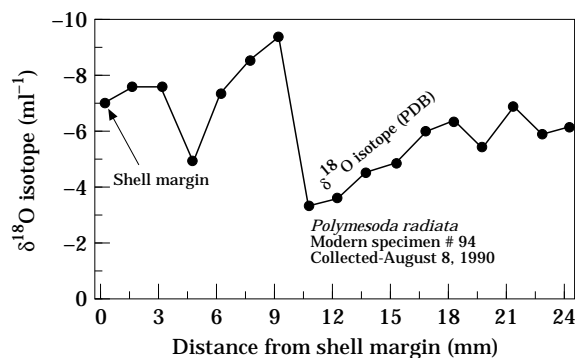


Figure 11. Oxygen and carbon isotopic profiles of a modern clam shell collected from the Los Cerritos Lagoon in August, 1990.

carbonate parallels the $\delta^{18}\text{O}_{\text{SMOW}}$ of the water samples collected each month from the Los Cerritos Lagoon. Oxygen isotopic composition of the estuarine water is higher between January and June (~ -3 to -5%) and lower from July to December (~ -6.1 to -7.8%).

Successive changes in the oxygen isotopic composition of both shells and water are inversely correlated with salinity fluctuations in the Acapetahua Estuary (Figure 8). The oxygen isotopic values of the estuarine water (Figure 7) and the shell margin carbonate (Figures 7 and 8) are higher (~ -4.2 to -6.2%) when the water is more saline (18–20‰) between February and June (dry season). Oxygen isotopic values are consistently lower (~ -7 to -9.2%) between July and January when the estuarine waters are almost fresh (1–2‰).

Figure 9 compares the oxygen isotopic composition of shell margin carbonate and rainfall for the same interval of time. The total rainfall recorded at the Escuintla Meteorological Station on the coastal plain between September 1989 and August 1990 was 3370 mm, and ranged from 700 mm in September 1989 to 4.8 mm in January of 1990. Although similar trends

are exhibited between changes in $\delta^{18}\text{O}$ values recorded in shell margins and rainfall, a lag of ~ 3 months is apparent between the two signals (Figure 9). This lag is also apparent between changes in the oxygen isotopic composition of shell carbonate and the velocity of the Cintalapa River flowing into the Los Cerritos Lagoon (Figure 10). During this particular annual cycle (1989–1990), water velocity was highest ($55 \text{ m}^3 \text{ s}^{-1}$) during September, 1989. Water flow decreased rapidly after September and remained low ($2\text{--}4 \text{ cm}^3 \text{ s}^{-1}$) until March of 1990, when it began to increase again.

Oxygen isotopic variation in the growth increments of all shells analysed record successive fluctuations in estuarine salinity. The amplitude of oxygen isotopic change in modern shell profiles is consistent with the range exhibited in the shell margin samples from molluscs collected at month intervals. An oxygen isotopic profile for a modern marsh clam collected in August of 1990 is displayed in Figure 11. The amplitude of oxygen isotopic change in the two years of growth represented by this profile is 6‰, ranging from -3.5 to -9.5% . The oxygen isotopic value at the shell growth margin is -7.0% , which is consistent with values (see Figure 7) from other specimens of *P. radiata* collected from the Los Cerritos lagoon during August of 1990.

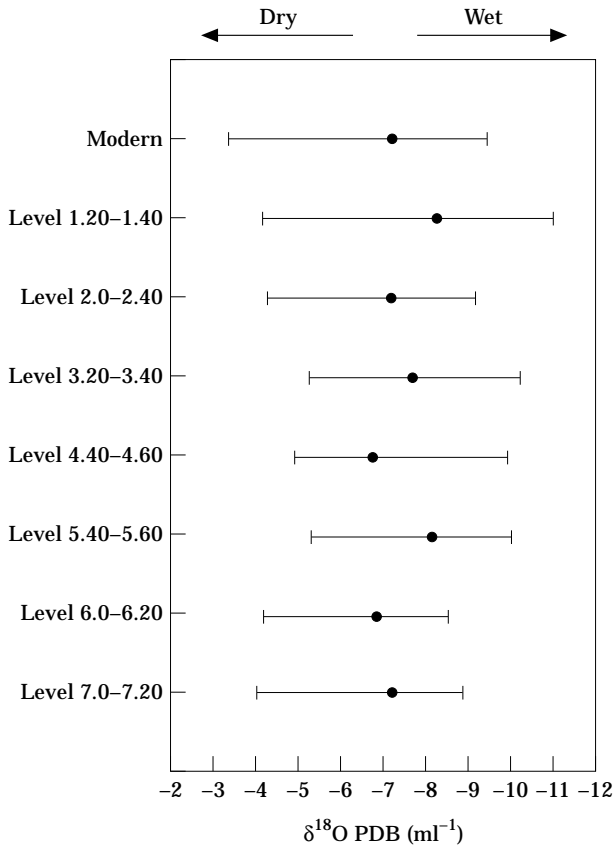


Figure 12. Summary of the range and mean of the $\delta^{18}\text{O}$ measurements from analysed archaeological shells from Tlacuachero ($N=2$ per level) and modern ($N=6$) specimens of *Polymesoda radiata* from the Los Cerritos Lagoon. For each excavation level investigated, a line shows the range and a dot indicates the mean of the values for profiles of two archaeological clams. In addition, the mean and range of the six modern shell profiles are shown.

The range of oxygen isotopic values of all analysed archaeological and modern shells is similar (Figure 12). Marsh clam shells from the late Archaic period deposits exhibit mean oxygen isotopic values between -7‰ and -8‰ . The mean oxygen isotopic value of all modern shells was -7‰ . In general, the amplitude of annual oxygen isotopic variation in the archaeological shells is comparable to the modern forms. Archaeological *P. radiata* shells collected from the uppermost deposits (1.20–1.40 m; c. 1800 BC) at the late Archaic period site of Tlacuachero deviate slightly from this pattern (Figures 12 and 13). Dry season conditions apparently were similar, but the lower δ values during the wet season (2‰ lower) suggest greater rainfall than today.

Shell margin samples from each level ($N=20$ per level) are plotted in Figure 14 against the entire range of oxygen isotopic variability exhibited by the modern and archaeological specimens. A clear trend occurs toward lower $\delta^{18}\text{O}$ values during the late Archaic period. Oxygen isotopic values of terminal shell edge samples in the lowest three levels extend across the full

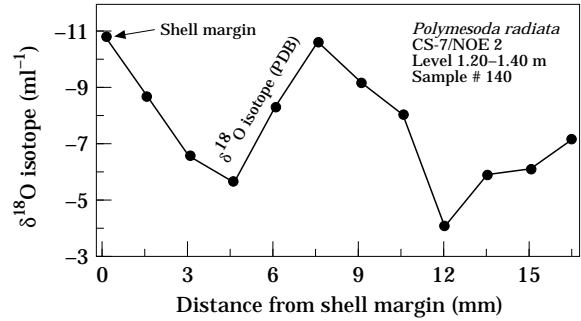


Figure 13. Oxygen isotopic profile of an archaeological clam shell from the late Archaic period shell deposits at Tlacuachero (level 1.20–1.40 m).

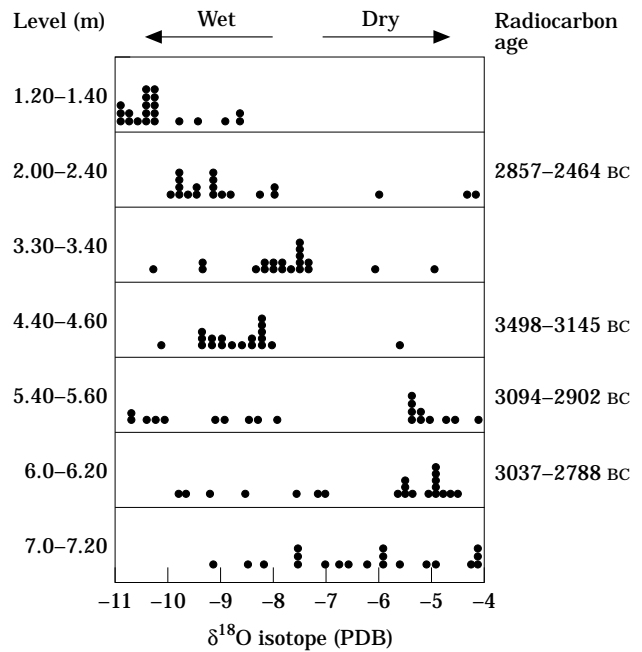


Figure 14. Summary of shell margin samples from each level analysed at Tlacuachero ($N=20$ per level) plotted against the full oxygen isotopic range determined from the modern and archaeological studies. ●: One shell margin.

range of isotopic variability, but concentrate between -6 and -4‰ (dry season). The oxygen isotopic values in shells from the upper portion of the sequence tend to cluster between -7 and -11‰ (wet season). This culminates with a clear focus between -11 and -10‰ (wet season) in the stratum just prior to late Archaic period site abandonment.

Discussion

The analyses of modern *P. radiata* indicate that changes in the oxygen isotopic composition of shell carbonate accurately reflect fluctuations in estuarine salinity caused by seasonal changes in rainfall. Comparison of the oxygen isotopic ($\delta^{18}\text{O}_{\text{SMOW}}$)

composition of estuarine water with $\delta^{18}\text{O}$ of shell margin samples indicates that the carbonate precipitated by the mollusc is in isotopic equilibrium with the water. Changes in the oxygen isotopic composition of the water and shell margin carbonate are clearly related to fluctuations in estuarine salinity. Estuarine salinity fluctuations are controlled by the intensity of rainfall on the coastal plain and bordering Sierra Madre de Chiapas mountains, although there is a lag of approximately 3 months before the changes in rainfall affect estuarine salinity. Presumably the lag between rainfall and estuarine salinity occurs because the influx of freshwater continues following the cessation of the monsoonal rains and lags at the beginning of the following wet period until the water table rises on the coastal plain.

Prehistoric shells from all stratigraphic levels at Tlacuachero (CAP-7) exhibit oxygen isotopic profiles similar to modern specimens. This suggests that the patterns of rainfall were much the same throughout the late Archaic period (3000–1800 BC) and also similar to those of today. Like most hunters and gatherers, the people in this region during the late Archaic period must have been affected by changes in resource availability, both the terrestrial and littoral environments. Large fluctuations in the intensity and timing of rainfall would have caused significant changes in the distribution of resources and we expect that humans would have responded to them. The bedded deposits at Tlacuachero and other littoral shell mounds of this age appear to be uniform and are thought to be indicative of a relatively stable subsistence strategy during the late Archaic period (Michaels & Voorhies, 1989). Stable patterns of middle Holocene rainfall in this region must have contributed to the stability of human subsistence and settlement strategies.

Significant changes in rainfall did not occur at the end of the late Archaic period before the cessation of shell accumulation. However, it is clear that populations living on the Pacific coastal plain during the succeeding Formative period did change their subsistence strategies (Blake *et al.*, 1992a), combining maize agriculture with hunting and gathering wild resources. In the Mazatán region people were hunting game animals, fishing the freshwater swamp and gathering wild plant foods. These activities were complemented by maize horticulture. Simultaneously, higher levels of sociopolitical complexity began to develop (Clark, 1991, 1994) on the coastal plain. The results of the study reported here suggest to us that this socioeconomic transformation was not influenced by dramatic environmental change at the end of the late Archaic period (Kennett & Voorhies, 1995).

Our findings suggest that patterns of late Archaic period shellfish harvesting were more complex than previously suspected. A dynamic change in the use of shellfish occurred throughout this 1000 year time interval. Early inhabitants of the Pacific coastal plain collected shellfish and other estuarine resources at all

times during the year, with a focus during dry season months. Although later populations in the region continued to collect marsh clams throughout the year, there was a distinct shift towards wet season collection, apparent at the 4.40–4.60 cm level and above at Tlacuachero (Figure 14). Just prior to the termination of late Archaic period deposition at Tlacuachero, as judged from the surviving record,* this trend culminated with exclusive collection of marsh clams during wet season months.

A shift in the seasonal collection of these molluscs suggests that the use of this location evolved throughout the late Archaic period. Deith (1985) has aptly pointed out that the season of hunter-gatherer site occupation does not always correspond with seasonal patterns of shellfish consumption. However, based on the available archaeological evidence from Tlacuachero, primarily the overwhelming presence of marsh clam shells and the near absence of structures and intensive habitation debris, it would appear that the season of molluscan harvesting is a good measure of when this location was occupied.

These new data allow us to reconsider the subsistence-settlement model proposed by Michaels & Voorhies (1989). The seasonal patterns of clam use in the early stages of the late Archaic period could have been created by mobile *foragers* occupying and re-occupying these locations at different times during their seasonal rounds. However, it seems to us more likely that these sites were created by *collectors*, making frequent logistical forays to the estuary. By the end of the late Archaic period it is clear that these locations were being used logistically by *collectors* as special locations for extracting estuarine resources, as proposed by Michaels & Voorhies (1989). This more dynamic and changing model of subsistence and settlement warrants further testing and will require investigating other site types farther inland dating to the early and late stages of the late Archaic period.

Intensive use of estuarine locations in dry season months during the early part of the late Archaic period conforms to the expected pattern based on modern resource availability, marked by highest productivity in the lagoons during these months. The question is, then, why did later late Archaic period populations apparently shift away from using these locations during the most productive time of the year? There are several possible explanations for this observed phenomenon, two of which we shall examine here.

One possible explanation is that the emphasis on wet season clam collection at the end of the late Archaic period marsh clams represents a different scheduling pattern of the use of littoral resources compared

*The uppermost bedded shell deposits at Tlacuachero have been removed by later people, who may have been mining them to make lime. For this reason, the surviving record of archaeological deposits does not document the final stages of the shell collecting adaptation.

with earlier times. Perhaps clams were being collected mainly during the wet season months whereas other estuarine resources were being given priority during the dry season. For instance, shrimp exploitation could have intensified during the dry season to such a degree that at that time other resources (including clams) in the estuary were ignored. If this were the case, human populations would have visited or lived in the estuarine environment throughout the annual cycle, but the focus of their subsistence activities would have changed seasonally during the year. This scenario resembles the procurement economy of modern inhabitants of these wetlands: people in the village of Las Palmas focus their procurement strategies on shrimp when they are abundant in the lagoons and on fin fish during other times of the year. However, other lines of archaeological evidence do not support the idea that this pattern prevailed for the Chantuto people. For example, new site types associated with exclusive shrimp exploitation do not appear in the littoral zone at the end of the late Archaic period. Moreover, there is no evidence for heightened occupation of the known shell mound locations, such as increased frequency of domestic architecture, as might be expected with increased sedentism at the shell mounds. Finally, Voorhies *et al.* (1991) have suggested that the presence of small fish vertebrae throughout the deposits at Tlacuachero may be interpreted as indirect indicators of shrimp procurement. They argue that net fishing does not allow a fisherman to target specific prey: small fish and small crustacea are generally present in the same net catch. Following this reasoning, if shrimp exploitation intensified at the end of the late Archaic period, a higher percentage of small fish vertebrae would be expected in the upper deposits at Tlacuachero and other late Archaic period sites, compared with the lower deposits. This is not the case.

An alternative explanation for this dramatic shift to wet season utilization of molluscs is that a scheduling conflict developed with other resources elsewhere in the region. We target the initiation of farming, perhaps with maize (*Zea mays*) as one crop, as worthy of further consideration in this respect. Maize was established as a cultigen in the highlands of Mexico by 3500 years ago (Long *et al.*, 1989; Fritz, 1994; but see MacNeish, 1967, 1991; Flannery & Marcus, 1983; Flannery, 1986), a date that coincides closely with the scheduling change observed in the record at Tlacuachero (Figure 14; *c.* level 4.40–4.60 m). Apparently, maize was present even earlier in the Pacific watershed of Central Panama, where microscopic ecofacts are identified in sediment core levels dating to approximately 7000 years ago (Piperno, 1985). On the eastern seaboard, Pohl & Pope (pers. comm.) have discovered indicators of maize as early as 5000 years ago. Thus, maize might have been introduced into or developed in the Soconusco at any time during the late Archaic period. In view of its role as a staple in the diet of later Mesoamerican peoples, its introduction and

increasing importance could have set in motion other subsistence changes.

The pattern of subsistence change that was manifested by the people of the Soconusco is complex and has not yet been fully identified by prehistorians (Blake *et al.*, 1992*a*). Macrobotanical remains of cultigens, including maize, now have been identified as early as the Barra phase (1550–1400 BC) deposits in the Soconusco (Feddemma, 1993). Thus, it is indisputable that by the Barra phase, immediately after the Chantuto phase in the area, cultigens formed a component of the subsistence of the people of the Soconusco.

However, it is very difficult to determine the relative importance of these cultigens at any point in time, given the gaps in the presently known ecofactual record (Feddemma, 1993). The best data come from studies of the bone chemistry of the people themselves (Blake *et al.*, 1992*b*; but see Ambrose & Norr, 1992). Analysis of the osteological remains of two Chantuto people* gave a $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios closely similar to each other and to ratios of populations eating maize as a staple, as well as to later peoples in the Acapetahua region whose dependency on maize can be reasonably assumed (Blake *et al.*, 1992*b*). This shows that the shell mound builders were heavily dependent on C4 plant foods, although which plants were being used and their wild versus domesticated status are unknown at present. It is noteworthy, however, that the Early Formative people of the Mazatán region, who we know were growing maize because its remains are present in the archaeological record that they produced, have $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that indicate a much lower utilization of C4 plants, compared with the earlier Chantuto people of the Acapetahua region.

Thus, we have meager but consistent evidence that the people who were occupying Tlacuachero at the time of the clay floor construction, were heavily dependent upon plant foods. Whether these were wild plants, cultigens or, as is more likely, a combination of the two has yet to be determined. It is likely that maize was initially adopted by these hunter-gatherers in the Soconusco as another resource in their broad-based subsistence economy. As subsequent genetic changes increased the productivity of maize, it would have become a more viable alternative to the well established hunting-fishing-collecting strategy practised by the people of this region. This is the rationale for speculating that scheduling conflicts may have arisen during the last part of the late Archaic period.

The potential for farming varies in the study area, especially across the coastal plain from the sea to the mountains. The wetlands in the Acapetahua area are not especially well suited for maize growing because arable land is scarce, the soils are saline, rainfall is seasonal, and the lower reaches of the rivers are subject

*These two individuals are the only ones that have been recovered from the Chantuto phase deposits. Both sets of remains came from the clay floor level at Tlacuachero.

to periodic flooding during the rainy season. However, small corn patches are located today on some river levees and old barrier islands, so it is clear that maize can be produced in a limited way within the estuary. Modern farmers report that the productivity of maize and other domesticates increases as one moves from the coast to the piedmont area, located 20–40 km inland (Voorhies, pers. comm.; Clark, 1994). The traditional farming pattern in recent times has been to plant two or three crops annually (Clark, 1994). The first crop is planted in May, just as the monsoonal rains begin and harvested in August near the end of the rainy season. The second crop is planted in September at the end of the rainy season and harvested in December. A third crop was planted whenever possible at the height of the dry season and harvested in April. In the Mazatán area the *chahuities*, abandoned stream channels that are lower and moister than the surrounding terrain, are used for this purpose, but in the Acapetahua region where *chahuities* are lacking, the lower piedmont is used. In general, maize is grown in this region virtually year-round during optimal years using dry farming techniques.

We hypothesize that by the late stages of the late Archaic period the horticultural activities of the Chantuto people were such that people were becoming increasingly tethered to their plots, which we predict were situated on the coastal plain, between the coastal wetlands and the piedmont. Perhaps maize was first grown only during the dry season when wild plant foods would have been most scarce. Or, if maize was grown throughout the year, as it is today, it may have been especially important for people to have protected their fields from herbivores during the dry season when wild plant foods would be relatively scarce and competition among animals particularly high.

The proposed seasonal shifts in subsistence and settlement are somewhat comparable to ethnohistorically recorded strategies practised by aboriginal groups on the northeast coast of North America. With the introduction of maize around AD 900 there was adaptive shift from hunting and gathering wild resources to an economy that combined farming with the exploitation of estuarine and marine resources. This led to a progressively more sedentary way of life and the growth of settlements on the coastal plain, away from the coast, where farming was most productive. The inland settlements of the Beothuk of New Foundland, located near farming plots, were almost completely vacated during the summer months when people were drawn to the coast to exploit coastal shellfish beds (Snow, 1978, 1980). Only a few very young and old people would stay behind at the inland settlements to protect the crops during the summer. Similarly, the Maliseets of Northern Maine and New Brunswick would make several trips back and forth between garden plots and prime fishing sites during the summer months (Erickson, 1978). In both of these cases, maize crops were planted at the beginning of the summer

and left essentially unattended until the harvest in the fall.

Our evidence suggests that the prehistoric people living on the Pacific coastal plain of Mexico at the end of the late Archaic period had a subsistence strategy that combined horticulture and the procurement of estuarine resources. Our *working* hypothesis is that the demands of farming became increasingly great during the dry season, thus causing the rescheduling of procurement activities in the littoral zone during the wet season.

In summary, reconstruction of the seasonal use of molluscs through the late Archaic period using oxygen isotopic analysis has defined an interesting change in resource use that would have gone unrecognized using standard archaeological procedures. There is a clear shift from year round procurement of clams with a focus during dry season months at the beginning of the Tlacuachero record of the late Archaic period, to their use exclusively during wet season months just before the cessation of intensive use of these locations. This shift is best understood when scheduling conflicts associated with the development of maize agriculture in the region are considered.

Conclusions

- (1) The results presented in this study indicate that oxygen isotopic analysis of shell carbonate from estuarine molluscs can be used to reconstruct ancient water regimes along the Pacific coast of southwestern Mexico. Predictable changes in oxygen isotopic composition of the water in the Acapetahua Estuary occur in accordance with changes in salinity. Lower $\delta^{18}\text{O}$ values correlate with the influx of fresh water into the estuary during the wet season, although a lag of about 3 months exists between the onset of monsoonal rains and changes in estuarine salinity.
- (2) Oxygen isotopic fluctuations in the estuary are recorded and preserved in the shells of the marsh clam *Polymesoda radiata*. Oxygen isotopic profiles in shells are used to reconstruct ancient rainfall regimes and the establishment of patterns of prehistoric mollusc harvesting. The lag between the onset of monsoonal rains and changes in estuarine salinity restrict these determinations to gross seasonal, rather than monthly, estimates.
- (3) Analysis of shells from archaeological deposits at the site of Tlacuachero indicate that patterns of rainfall remained virtually constant during late Archaic period (~3000 to 1800 BC) with a slight increase in rainfall c. 1800 BC.
- (4) These data indicate that there was no *significant* increase or decrease in rainfall at the end of the late Archaic period that might account for changes in use of estuarine resources.
- (5) Based on this study and other lines of archaeological evidence it is clear that early in the late Archaic

period (~3000–1800 BC) the site of Tlacuachero was visited by hunter-gatherers throughout the year with a focus during dry season months. Although it is likely that the hunter-gatherers at this time were making logistical forays to these locations from base camps farther inland, it is also possible that smaller, more mobile groups were occupying and reoccupying these sites.

(6) Throughout the late Archaic period there was a trend towards wet season use of Tlacuachero. By the end of this period (~1800 BC) the site was used exclusively during wet season months by logistically organized *collectors*.

(7) The changing use of sites in the littoral zone of the Acapetahua Estuary is attributed to scheduling conflicts that developed as maize agriculture intensified elsewhere on the coastal plain.

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