Changing Sea Levels Along the California Coast: Anthropological Implications

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THIS paper considers the implications for coastal California archaeology and prehistory of sea level changes over the past 15,000 years. The discussion deals first with a generalized sea level curve, grossly applicable for North America, and suggests its use in interpreting the fact that there is little evidence of human occupation along the California coast before 5000 B.P. to 7000 B.P. More specific data regarding sea level changes in San Francisco Bay are then presented in an effort to explain several characteristics of the archaeology of that region.

HOLOCENE SEA LEVEL CHANGES

It is widely accepted that sea levels changed over time during the Pleistocene and Holocene epochs in response to successive capture and release of large volumes of water during growth and melting of glaciers. Because of the numerous advances and retreats of the ocean during the several glacial and interglacial episodes of the Pleistocene, the record of pre-Wisconsin sea levels is obscure. There are also difficulties in accurately interpreting evidence of sea level change in early to mid-Wisconsin times, but there is general agreement that sea level was at a minimum about 15,000 years ago and that it rose rapidly thereafter until about 6000 B.P. in response to large scale melting (Bloom 1971; Flint 1971:324-328; Fairbridge 1976).

Figure 1 illustrates a sea level curve for the past fifteen thousand years taken from work by the oceanographer Emery (1969; Milliman and Emery 1968). The curve is based on the recovery depths of radiocarbon dated samples of various fossilized or otherwise preserved shallow water plant and animal species and geologic products such as coralline algae, saltmarsh peat, several shallow-water mollusks, beachrock, and oolites. When such indicators of shallow water are found in deep water, a change in sea level since their time of deposition or lifetime is indicated. A check on these data is provided by calculations of the rate of glacial melting and resultant volumes of water added to the ocean over the last 15,000 years. The calculations suggest that 95% of the water locked in continental glaciers had been released by 7000 years ago, during 7000 years of relatively rapid melting; the rate of melting then declined, and subsequent sea level rise occurred at a much slower rate up to the present (Bloom 1971:365, 368).

Emery's curve in its general outline up to about 7000 B.P. appears to accurately describe glacial-eustatic changes in sea level, that is,

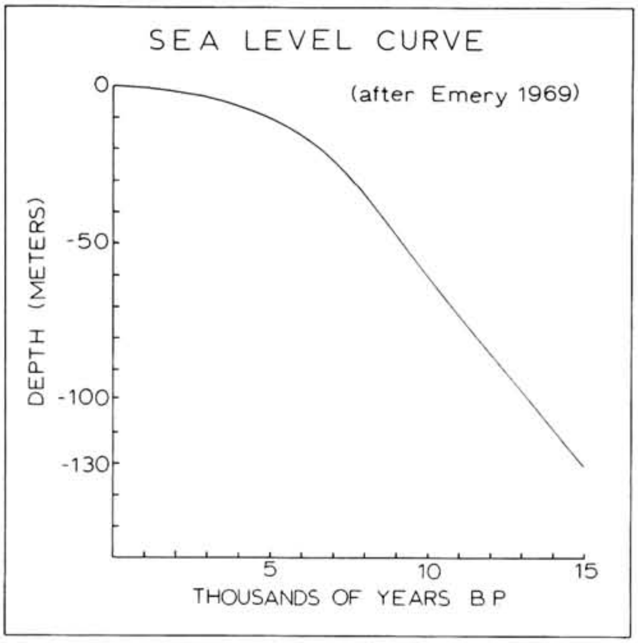

Fig. 1. Generalized eustatic sea level curve applicable to the California coast.

changes due to glacial melting which were of equal magnitude over the entire world. The applicability of the curve to specific areas varies according to local histories of tectonic change. Two factors in particular, post-glacial uplift of land areas freed from the weight of glaciers, and isostatic downwarping of land areas bearing the weight of newly deepened ocean waters, are sources of change which have differentially affected the record of sea level changes locally. Other factors not so directly connected to glacial melting and not yet clearly understood are responsible for the fact that relative sea level was not the same in different parts of the world after the completion of most of the Holocene glacial melting. At about 6000 B.P., sea level was below present off much of North America and Europe, but there were stands higher than present in parts of Australia, South America, Asia, and Africa (Gill 1971). There is also suggestive evidence from some parts of the world that the Holocene rise after 7000 B.P. may have been oscillatory rather than smooth, with small rises of 1 m. to 3 m. alternating with regressions to lower stands (Fairbridge 1976; INQUA 1969: *passim*). Because Emery's curve uses shallow water indicators which have a depth range to 20 m. below sea level, it cannot be expected to show short-term changes of a few meters. In the absence of the precise data needed to show such minor oscillations, the smooth curve seems to adequately describe changes along the coast of California, particularly in the bay and offshore regions around San Francisco, where independent work confirms its general form (Lajoie 1972; Atwater and Hedel 1976; Atwater, Helley, and Hedel 1977). No evidence of Holocene stands of sea higher than present has been found along the California coast, although it has been sought by workers familiar with recent high stands elsewhere (Gill 1971:3).

As Fig. 1 shows, sea level was about 130 m. below present level at 15,000 B.P.[1] It rose very rapidly until about 7000 years ago, when the rate of rise slowed. At that time, sea level off much of North America stood 10 m. to 20 m. below present level. The vertical displacement of the sea surface by more than 100 m. in 15,000 years affected the human and natural history of coastal areas around the world, and hence has important implications for archaeology. The discussion here will be confined to California, but the points to be made have a wider applicability.

Changing Coastlines

A major effect of changing sea level has been changing coastlines. Coastlines of the past may be approximately reconstructed by applying values from the curve in Fig. 1 to present-day bathymetric charts. Reconstructed shorelines for California show that changes were greater in areas where the continental shelf is broad and shallowly sloping, such as the area offshore present San Francisco Bay, or northward from Cape Mendocino to the Oregon border. Much of the southern California coast, where the shelf is generally narrow and steeply sloping, was affected to a lesser degree.[2]

Quite simply, the rising sea covered more land in areas of broad continental shelf than in areas of narrow shelf. For example, the 70 m. rise in sea level between 15,000 B.P. and 10,000 B.P. corresponds to an advance of the shoreline of approximately 20 km. to 25 km. eastward toward what is now San Francisco Bay, except around the jutting granitic body of the present Farallon Islands. In contrast, along most of the coast of southern California during that period, the shoreward advance of the sea averaged 5 km. or less. These figures translate to the average loss of 400 m. to 500 m. of land per century off central California, 80 m. to 100 m. off southern California. In the last 15,000 years, about 20,000 $km.^2$ of land have been submerged along the California coast.

Estuary Formation

In addition to simple inundation of lands, a second major effect of the rising sea was the creation of estuaries in indentations along the coast. The discussion of estuaries which follows is drawn from Desgrandchamp (1976: 10-24). Estuaries, formed when saline and fresh water meet in a semi-enclosed area with a free connection to the sea, are extremely productive ecosystems. This is due to chemical and physical changes which affect suspended particles when salt and fresh water mix, resulting in increased deposition of sediments and organic detritus to the extent that estuaries contain more minerals and nutrients than either the fresh or saline water sources which feed them. Estuaries are characterized by change over time. Factors such as temperature, salinity, and turbidity vary daily, monthly, and yearly in response to changes in the volume and composition of fresh and salt water entering an estuary. Organisms inhabiting estuaries must be tolerant of such variations. Over the long term, estuaries evolve through deposition and sedimentation processes into land forms. Successive changes over time in the flora and fauna observed in some estuaries are presumably responses to the changing conditions which are part of this evolution. Estuaries have been uncommon features in the earth's history, created on a large scale only during episodes of rising sea level, and gradually destroyed as sea level rise slowed or reversed.

ANTHROPOLOGICAL IMPLICATIONS

Consequences for Prehistory

It seems certain that visitors or residents on the California shore, if any, must have observed the changes caused by sea level rise, especially in wide shelf areas. Doubtless they did not simply observe, but necessarily responded to the changes. This would have required shifts of villages and territorial boundaries almost generationally during the period of rapid sea level rise. Such shifts may have contributed to the cultural diversity and complexity which characterized California at Contact. This proposition adds a new twist to the familiar "fish trap" explanation for diversity, which presumes a number of different groups coming into California at different times to settle. The twist is that, with sea level rising, the "fish trap" was getting smaller over time.

The reduction in land area may be considered for its effects on at least two factors, local environments and local population densities. The environmental change was variable. In some places, the rising sea level had little effect except to move the littoral zone further inshore. In other places, it had a major effect, such as the creation of the San Francisco Bay estuary or the creation and subsequent silting in of estuaries along the southern California coast. Thus, at times the environmental change may have attracted more people to the littoral, while at other times it may have contributed to inland movements of people. In either case, sea level changes surely contributed to changing population densities locally, and to an overall increase in population density because of the loss of so much land area.

This is of interest when considering the prehistory and ethnography of California, which show the development among some groups of relatively complex social and economic organization, with elements of social ranking and redistributive economies. Theoretical models advanced to explain social and economic evolution (e.g., Fried 1960, 1967; Carneiro 1970) almost all depend upon increasing population density as a prime mover or, at least, a necessary precondition or accompaniment to the evolution of complex societies. However, most of the theories advanced to explain social or economic evolution have been open to criticism because of their undemonstrated assumptions that human populations will maintain growth rates which continually lead them into situations of so-called population pressure (Cowgill 1975). The effects of changing sea levels over the past 15,000 years provide a mechanism independent of human cause which led to increases in population density.

Sea level changes varied in their form and in human consequences at different times and places and were certainly not the only factor contributing to social evolution anywhere. However, the effects of sea level rise should be considered in particular local areas where they may have significantly affected environment or population density. In California, it would be of interest to apply this perspective to the Santa Barbara Channel and adjacent regions, and the region around San Francisco Bay and the Sacramento-San Joaquin Delta. These regions, unquestionably affected by sea level changes, had unusually high population density at Contact (Cook 1976; Brown 1967) and also, as best we can reconstruct, relatively complex social and economic organization; they were homes to one or more "culture climaxes" during prehistory.

Consequences for Archaeology

Regardless of its import for social evolution, it is clear that the Holocene sea level rise affected the archaeological record. Any traces of occupancy of California's coast and the lower reaches of river valleys during the period before 8000 B.P. to 7000 B.P. are likely to be covered over, either on the submerged shelf (if settlements were not eroded away by the encroaching sea) or under alluvium deposited when river valleys were drowned by the rising ocean.

The cases of deeply buried sites in coastal California are numerous, particularly when one considers those older than a few thousand years. For example, in the San Francisco Bay region, there are four cases of human skeletal or cultural material radiocarbon dated as older than 4000 years: the BART, Stanford, and Sunnyvale specimens (see Table 1).[3] The four were recovered at depths ranging from 2 m. to 14 m. None came from sites located by surface observations. Maps of the Quaternary geology of the San Francisco Bay region show widespread units of alluvial deposits, ranging to 15 m. in depth, which were laid down in the last 10,000 years or less, representing a filling of the structural trough which comprises the region in response to rising sea level (Helley, Lajoie, and Burke 1972; Lajoie *et al.* 1974).

Distributions of Older Sites. The locations of radiocarbon dated samples representing human occupancy of the California coast previous to 5000 B.P. have a distribution which may be explained in part by the Holocene sea level rise. Virtually all dates older than 5000 B.P. come from sites along the southern California coast, and almost all of these old sites are adjacent to areas of narrow continental shelf. North of the San Luis Obispo County coast, the only dates approaching 5000 B.P. are those from the San Francisco Bay region mentioned above. Further north, there are no dated sites older than Point St. George,

Table 1

SELECTED RADIOCARBON DATES FROM THE SAN FRANCISCO BAY REGION

Site or Specimen	Lab Number	Age	Reference
Stanford Man I	UCLA-1861	5130 ± 70	Gerow 1972; Oakley, Campbell, and Molleson 1975:43
BART male	USGS W-2463	4900 ± 250	Wright 1971; Henn, Jackson, and Schlocker 1972
Sunnyvale female	I-6977	4460 ± 95	Bada and Helfman 1975; this paper, appendix
Stanford Man II	UCLA-1425A	4400 ± 270	Gerow 1972; 1974:241; Oakley, Campbell, and Molleson 1975:43
	UCLA-1425B	4350 ± 125	
West Berkeley	M-127	3700 ± 300	Wallace and Lathrap 1975:58
(Ala-307)	M-126	3140 ± 450	
	M-125	3860 ± 450	
		3700 ± 350	
	M-124	3500 ± 300	
Castro (SCl-1)	I-7897	3410 ± 100	this paper, appendix
University Village	L-187A	2950 ± 350	Gerow 1974:242; Gerow with Force 1968:142, 152
(SMa-77)	L-187B	3400 ± 300	
	I-7591	3050 ± 85	
	I-7592	3265 ± 85	
Emeryville	LJ-199	2310 ± 220	Wright 1971
(Ala-309)	I-7073	2530 ± 105	this paper, appendix
Ala-328	C-690	2339 ± 150	Wright 1971
	I-8085	2330 ± 90	Bickel 1976:62

Del Norte County, where the lower component of DNo-11 has an age of 2260 ± 210 radiocarbon years: 310 B.C. (Buckley and Willis 1970:116).

The clustering of older radiocarbon ages along the southern coast in areas of narrow shelf may be partly a function of sampling, but enough work has been done along the coast of central and northern California that sample bias in favor of the southern coast cannot totally account for the distribution observed. Radiocarbon determinations for the central and northern coast regions have come mainly from sites adjacent to a relatively shallow slope of continental shelf. These are the areas that were not near the coast until sea level approached that of the present, and that were in many cases recipients of extensive alluvial depositions as the sea level rose. Before dismissing the occurrence of earlier occupations along the northern and central coasts, it is suggested that reconnaissance be focused on areas of the coastline which might have been coastal five thousand years ago or earlier; that is, local areas of relatively narrow, steep continental shelf. For example, much of the coast from Cape Mendocino south to Point Delgada should be examined.

SEA LEVEL CHANGES AND SAN FRANCISCO BAY ARCHAEOLOGY

The points discussed so far are very general ones, depending upon the applicability of the approximated eustatic curve and present-day coastal bathymetry to shoreline configurations of the past. When one proceeds to consider the implications of rising sea level for the archaeology of a particular area, more precise information from the locality in question is needed.

A variety of data are available for the San Francisco Bay area which help to relate the known archaeology of the region to changes in sea level and bay ecology. The archaeological features to be considered are: the fact that some of the bayshore midden deposits extend below present sea level; lack of evidence for occupation of the bayshore and environs until about 5000 B.P. at earliest, with basal dates of many of the tested middens clustering around 2500 B.P. to 2000 B.P.; and the fact that material from the earliest occupation sites (dating to between 4000 B.P. and 3500 B.P.) suggests a more generalized economy, less focused on estuarine resources, than can be inferred for the later occupations. A temporal change noted in several sites in the predominant shellfish species collected will also receive comment.

Geological Data

Relevant geological and biological data come from cores from boreholes into the bay bottom, most of which were drilled during the planning phases of bridge construction. Some of these have been analyzed by researchers at the U.S. Geological Survey, Menlo Park, who are interested in the recent geological history of the bay. Their findings, reported on by Atwater and Hedel (1976) and Atwater, Hedel, and Helley (1977) have great value for students of the archaeology and human pre-history of the San Francisco Bay region. Information in the next three paragraphs is drawn from the two publications just cited.

Core analysis included the identification of separate estuarine, alluvial, and aeolian deposits in the core, determination of their positions relative to one another, determination of their depths below present sea level, and radiocarbon dating of the different components. Results pertinent to the last 15,000 years indicate that the present San Francisco Bay estuary did not begin to form until 11,000 to 10,000 years ago. Before this, the site of the bay was a set of converging river valleys, the northern arm draining the Sacramento and San Joaquin rivers, the southern arm draining Coyote Creek and other creeks of the coastal ranges. Beginning about 11,000 B.P., sea water began to cover the bedrock base of the Golden Gate which presently lies 65 m. to 70 m. below sea level. Core data show an extremely rapid filling of the bay between 11,000 B.P. and 8000 B.P., accomplished by an average sea level rise of 2 cm. per year, which meant lineal movements of as much as 30 m. per year in some places. After 8000 B.P., the rate of sea level rise decreased dramatically; sea level rise has averaged 0.1 cm. to 0.2 cm. per year for the last 6000 years. The change in rate of rise between 8000 B.P. and 6000 B.P. in the San Francisco Bay is consistent with the inflection at 7000 B.P. on the generalized eustatic curve (Fig. 1). This change in rate of rise had an important effect on bayshore environs: it permitted the development of tidal marshes along the shores.

Marsh Development. Marsh development occurs when shallow water plants such as cordgrass (*Spartina foliosa*) or tules (*Scirpus* spp., predominantly *S. californicus*), which can tolerate submergence even at low tide, establish themselves on mudflats adjacent to shore. They act as sediment traps, and gradually build up a base of land which is not submerged at low tide. This may then be colonized by plants such as pickleweed (*Salicornia pacifica*) and saltgrass (*Distichlis spicata*) which can tolerate some submergence, but which require some open air exposure daily. Where sea level is static, marshes may often prograde, that is, advance out into the water. Where the sea rises slowly enough, marshes can keep pace with the rise and maintain themselves at a certain size. Where the rise is too great, plants are drowned before they can trap enough sediment to allow marsh development.

Evidence from the borings suggests that there were only narrow, discontinuous bands of marshes along the shores of the growing estuary in the period between 10,000 B.P. and 8000 B.P. As the rate of sea level rise slowed after 8000 B.P., sediment accumulation in some areas began to permit growth and maintenance of marshes. A series of borings along all shores of the bay is lacking, but there is proof of continuous presence of marshes in the western part of the Sacramento-San Joaquin Delta beginning about 6000 B.P. In other areas of the bay, even more time was needed to permit extensive development of marshes. For example, core analysis indicated that many of the living marshes of the southern arm of the bay are young, as shown by the very slight depth of deposit beneath them.

Marsh growth is of interest to the archaeologist because most of the San Francisco Bay shell middens were located in proximity to marshes (Nelson 1909; Desgrandchamp 1976). It was mentioned above that estuaries are very productive ecosystems. Marshes are places where humans can harvest some of that productivity, in the form of fish, shellfish, birds and land mammals which live or feed in or near the marsh, as well as the marsh plants themselves. Perhaps marsh growth can be taken as a sign of the maturing of the San Francisco Bay estuary from the viewpoint of human users.

Shellfish Population Growth. Another resource of interest is shellfish, especially mussel (*Mytilus edulis*), oyster (*Ostrea lurida*) and clam (*Macoma nasuta*), which are the species which predominate among the shellfish remains found in bayshore sites. Although a systematic mapping of the prehistoric distribution of these species is lacking, there is some information regarding the prehistoric distribution of *Ostrea* in the vicinity of the San Mateo Bridge. A number of corings were made in this area as part of a study to assess the extent of fossil oyster beds (fossil oyster beds provide a calcareous raw material for the manufacture of cement). Results of the study were interpreted to suggest a notable increase in the oyster population in this area about 2500 B.P. (Story, Wessels, and Wolfe 1966). This was deduced from the presence of a bed of oyster shells 4 ft. to 15 ft. deep under 2 ft. to 4 ft. of bay mud. Deeper deposits of oyster shell, which are older, are less extensive. The argument for this "population explosion" rests on only a few localized dated samples and needs to be confirmed in other parts of the bay, particularly in areas closer to the 2500 B.P. shoreline where oyster beds could have been easily reached by humans. However, the dating is interesting, since it is after 2500 B.P. that most of the dated San Francisco Bay middens were established.

Archaeological Patterns

The information just discussed may now be applied to certain archaeological patterns observed in the San Francisco Bay region.

Submerged Sites. First, there is the fact that basal deposits of some San Francisco Bay middens extend below sea level. Nelson, reporting his survey of shellmounds in the early 1900's, noted that at least 10 of his 425 sites extended below sea level (1909:329). These included sites from all shores of the bay. According to Nelson (1909:330), depths below sea level ranged from 3 ft. to 18 ft. (roughly 1 m. to 6 m.) in three sites which had been tested, presumably Ellis Landing (CCo-295), West Berkeley (Ala-307) and Emeryville (Ala-309) (Nelson 1909:311, 352, 1910:369-370; Peterson 1904, cited in Follett 1975:71; Uhle 1907:9, 11; cf. Schenck 1926: 163-165). Nelson (1909:354) also indicated that Brooks Island (CCo-290) extended 15 ft. below high tide level. (See Fig. 2 for site locations.)

Sea level rise seems to explain at least some of this. As mentioned above, the rate of rise since 6000 B.P. has averaged between 0.1 cm. and 0.2 cm. per year, or 1 m. to 2 m. per thousand years. Considering the basal dates of about 2500 B.P. for Emeryville and about 4000 B.P. for West Berkeley (Table 1), a rise of 2.5 m. to 5 m. at the former and 4 m. to 8 m. at the latter can be accounted for since their initial occupation. The bases of Ellis Landing and Brooks Island are undated, but probably were initially occupied sometime within the range spanned by dates on the other two sites. These figures vindicate Greengo's (1951:15-16) judgement that sea level rise at least

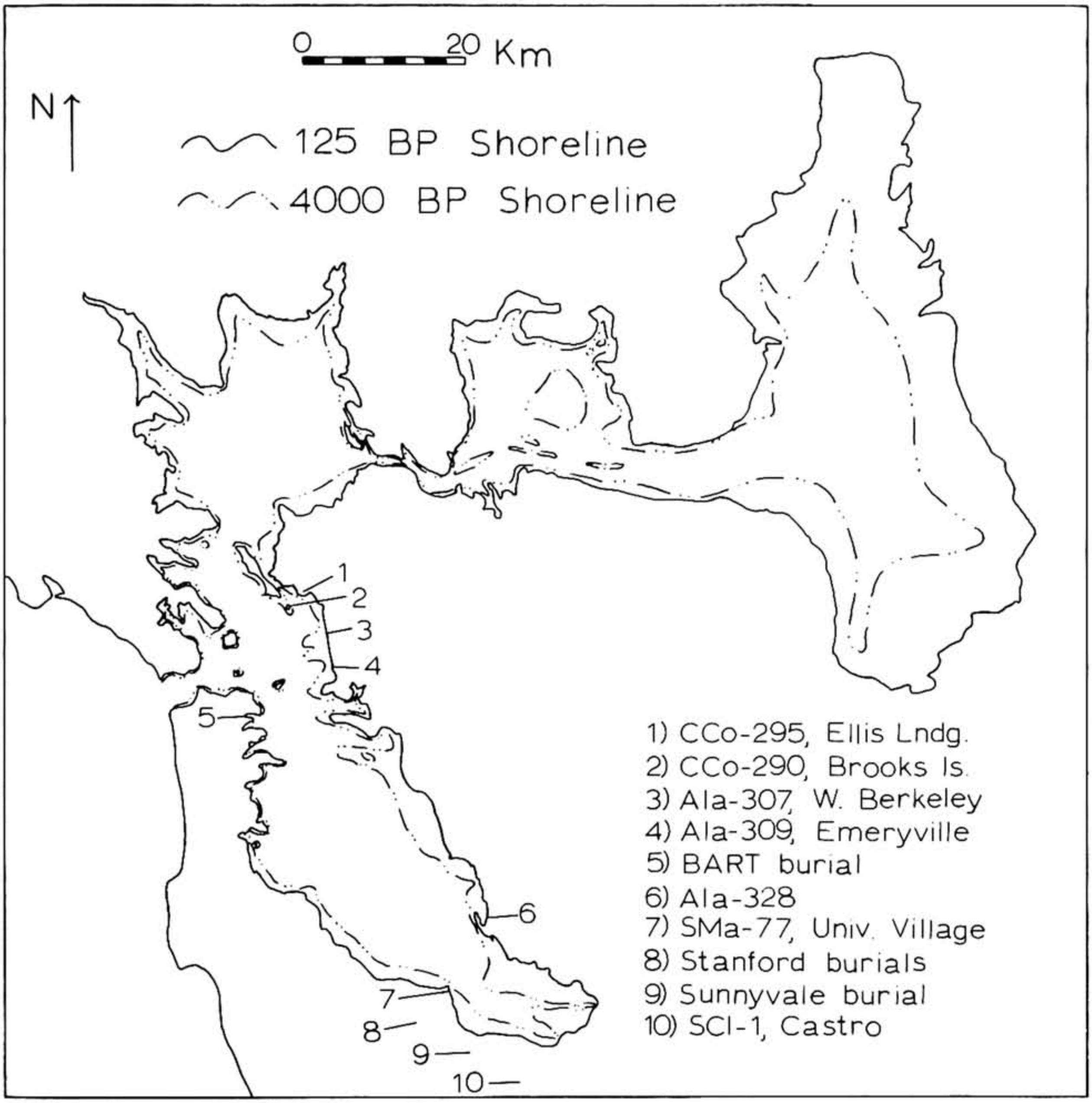

Fig. 2. Locations of sites mentioned in text, shown in relationship to past shorelines of San Francisco Bay as reconstructed by Atwater and Hedel (1976:Plate 1). Base shoreline of 125 B.P. is used to avoid effects of historic filling activities which have reduced bay size and drastically decreased the extent of natural tidal marshes (Atwater and Hedel 1976: *passim*).

partially explained site submergence. Because his estimate of the rate of rise was too low, Greengo was left with some submergence unaccounted for, and he postulated bay subsidence as a contributing factor. Uhle (1907) and Nelson (1909, 1910) had also proposed subsidence as the cause of site submergence. There is some evidence for tectonic subsidence of bay sediments, but it is most significant in the southern part of the bay, and even there it is of the order of one hundredth of the magnitude of the ongoing sea level rise (Atwater, Hedel, and Helley 1977:13). Thus, sea level rise appears to be an adequate explanation for the amount of submergence evident in human prehistory on San Francisco Bay.

Changes in Shellfish Remains. A second pattern to be explained is the shift over time in predominant shell species which is observed in some bay middens. Where observed, this consists of a relative increase in the amount of clam (*Macoma nasuta*), often with a corresponding decrease in the amount of oyster (*Ostrea lurida*) (see Gifford 1916; Greengo 1951).

Previous explanations of the shift, where it occurs, pointed to either cultural or natural causes. Gifford and Gerow advanced cultural interpretations. Gifford (1916:10) felt that over-exploitation of one molluscan species was responsible for observed shifts to a different species. Gerow (with Force 1968:31-32) suggested that humans initially harvested non-burrowing mollusks such as oysters and mussels because they were more easily collected, and subsequently added burrowing clams to the diet after other more easily acquired food resources (including various land mammals) had been depleted by human exploitation. Nelson (1909:338, 1910:376-378) and Greengo (1951:14-16) advanced natural interpretations, suggesting that the estuarine environment over time became less favorable for one molluscan species and more favorable for another. Both analyses presumed changing bottom conditions, resulting from increased sedimentation in the bay, which Nelson linked to subsidence and Greengo to sea level rise and subsidence. In addition, Greengo proposed that sites could be crossdated by equating levels where the shift to clam is observed (1951:5, Fig. 1B).

It is well known that similar shifts occur, from attached molluscan species such as oyster and mussel to burrowing species such as various clams, in shell middens in many parts of the world. This suggests, as Greengo appreciated, a connection with a worldwide phenomenon such as sea level change. In most cases, however, changing sea levels do not affect molluscan species directly, but rather through their effects on estuaries, each of which has a unique history in response to local conditions of geology, rainfall, temperature, and so forth. Furthermore, estuaries are internally variable, and this variability is sustained by complex circulation patterns within estuaries and by differing external changes around their shores. It is incorrect to think of shifts in estuarine environments taking place simultaneously over an entire estuary. Thus it is inappropriate to crossdate sites within one estuary or among several estuaries by evidence of change in shellfish species. While sea level change, in its effect on estuarine conditions, is ultimately related to the observed shifts in molluscan species, the precise timing of such shifts, and their immediate causes, must be investigated separately for each site. A number of variables will be found to contribute in each case, but it seems unlikely that human over-exploitation will qualify as a cause; there are too many examples of the continuing use of one species over long periods of time where they remained available, such as the dependence on oysters almost to the exclusion of other species in many sites of the southern part of San Francisco Bay.

Absence of Early Occupation. A third feature of San Francisco Bay area archaeology to be considered is the absence of evidence for early occupation along the bay shore. The oldest dated evidence comes from isolated human burials with ages in the range of 5000 radiocarbon years (Table 1). Three burials, the Stanford males and the Sunnyvale female, lay several kilometers from the historic shoreline, and would have been slightly farther away in their lifetimes (Fig. 2). The fourth burial, the BART male, was located in an area which would have been close to shore at 5000 B.P. (Fig. 2). In fact, the matrix of vegetation and silt adhering to the bones included plant matter and diatoms indicative of a brackish marsh setting, with fresh water nearby and occasional tidal influx (Henn, Jackson, and Schlocker 1972).

There is, thus, one documentation of human presence in a marsh setting near the bayshore about 5000 years ago. However, this find was recovered 22 m. below present ground surface, an estimated 14 m. below the 1850 ground surface. The other burials, further up the alluvial slope, were not as deeply covered, but even they lay at 2 m. to 5 m. depth. This suggests that evidence is lacking for early occupation around the bay at least partly because it is buried, or perhaps submerged under water. Sites far enough from the shore to have escaped being covered were probably also far enough so that their location was not directly related to exploitation of the estuarine resources.

Aside from the four early burials, the earliest dated occupation sites are University Village (SMa-77) and West Berkeley, initially occupied about 3500 B.P. and 4000 B.P., respectively, and the less well known Castro site (SCl-1) with a basal date close to 3500 B.P. (see Table 1 for exact dates). The bulk of evidence suggests that most other bayshore sites which were occupied relatively early, such as Emeryville and Ala-328, were initially occupied about 2500 B.P. The oldest sites were somewhat covered. University Village lay under 1 m. to 2 m. of silt (Gerow with Force 1968:7, 15) and the deepest levels of West Berkeley were 1 m. below present ground surface (Wallace and Lathrap 1975:1). These facts again suggest that alluvial deposition may partly account for the relative paucity of evidence of early occupation.

Different Subsistence Focus. Another factor emerges from consideration of dietary remains from University Village and lower levels of West Berkeley. They indicate that subsistence was not as oriented to estuarine resources in these early components as later, or perhaps, as Gerow (with Force 1968:27-33, 124) suggests for University Village, that these represented less intensive occupations than later components. Compared to later sites, including Emeryville and Ala-328, both University Village and the lower levels of West Berkeley have a relatively smaller shellfish component (Gifford 1916:Table 1; Cook and Heizer 1951:304, Table 7; Bickel 1976:35-37, Table 2-1; Gerow with Force 1968:29; Greengo 1951:Table 3). Both also lacked bones of the sea otter (*Enhydra lutris*), while among faunal remains from upper levels of West Berkeley and sites such as Ala-328, sea otter is one of the most commonly occurring mammal species (Gerow with Force 1968:33; Busby 1975:102, Table B; Bickel 1976:41-42, Tables 2-3, 2-4, 2-5).

If, as these data suggest, the early occupations were not so bay-oriented or intensive as later ones, this may help to explain why there were not more sites occupied before 2500 B.P. Perhaps 2500 B.P. is the rough date for the maturing of San Francisco Bay from the perspective of human users, when marshes were well-developed, shellfish populations established, and the estuary productive enough to support the visits of sea otters in abundance.

Comparison: San Diego County Coast

The San Diego County coast offers an area for comparison with the San Francisco Bay region. Sea level rise also had an effect on archaeological patterns in the San Diego area, but timing and details were different. The brief summary offered here for comparative purposes draws from the works of Shumway, Hubbs, and Moriarty (1961), Warren, True, and Eudey (1961), and Warren and Pavesic (1963). It is not intended as a new interpretation.

The San Diego County coast was relatively densely occupied from about 7000 B.P. until about 4000 B.P. to 3000 B.P. Subsequently there was relative disuse and depopulation of much of the coast, except in areas around large bays or lagoons where fresh water was available year round, the same areas which continued to be occupied until Contact. Midden analyses of San Diego County coastal sites show a shift over time from clinging shellfish such as oyster or mussel to burrowing clams of various species.

There is disagreement about exactly when depopulation took place, and about how extensive it was. It is probably best seen as a gradual process, occurring over perhaps a thousand years, in response to gradual shrinking of the estuaries and a decline in their productivity. One factor contributing to the estuarine changes was presumably the lag in sea level rise, which allowed estuaries to be cut off from the sea by formation of sand and gravel bars which were less and less frequently breached; thus sediment carried by entering streams was trapped and came to fill up the estuaries. Human groups living on the back edges of estuaries would not have found base camps there worthwhile after a time, and so would have begun to spend more time inland; the formerly seasonal inland camps came to be base camps, and the former base camps on the shore became seasonal camps.

Comparing these trends with the San Francisco Bay region, one sees a similar effect of sea level rise in both places, in the creation of estuaries attractive for human settlement and in successive changes in estuarine environments. However, the timing of optimum estuarine productivity for human users differed in the two places. This serves as a reminder that investigation of the effects of sea level changes on human prehistory must proceed on a case by case basis.

SUMMARY

Changing sea levels have affected human prehistory and archaeology worldwide. Along the California coast, a rise in sea level of about 130 m. in the last 15,000 years has submerged approximately 20,000 km.[2] of land and has created numerous estuaries. These processes have contributed to the destruction or obliteration of archaeological sites, and to population movements resulting in local changes in population density during prehistory. The effects of such population shifts should be considered in analyzing the development of complex social and economic organization among some Native Californian groups. Archaeological features such as site submergence, changing settlement patterns and shifts in diet may be illuminated by consideration of local histories of sea level rise and accompanying effects.

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NOTES

1. Flint (1971:322) suggests a minimum of 100 m., rather than 130 m., which is Emery's (1969) value; Fairbridge (1976:354) suggests 135 m. The difference of 30 m. to 35 m. between Flint's estimate and the others is due to Flint's effort to separate the glacial-eustatic component of apparent sea level

rise from the effect of isostatic downwarping under the weight of newly deepened ocean waters. It is thought that the apparent rise in sea level in some places may include an isostatic component up to one third the magnitude of the glacial-eustatic component (Flint 1971:318; Bloom 1971:357). Hence the 130 m. to 135 m. minimum may reflect 100 m. of glacial-eustatic rise and 30 m. to 35 m. of isostatic downwarping. Aside from this disagreement over the depth of the sea level minimum at 15,000 B.P., Flint agrees with the form of the curve. The 130 m. value is used in this paper in order to consider the maximum extent of Holocene sea level change; use of Flint's lower value would not change any conclusions.

2. Due to scale difficulties, specifically, the great length of the California coast compared to the distance affected by shoreline change, reconstructed shorelines of the past are not shown here. Readers may trace them out by applying values from the curve in Fig. 1 to a map of coastal bathymetry (e.g., Welday and Williams 1975).

3. Dates on material farther than 10 km. from the present coastline or reconstructed 1850 bay shoreline are not considered since occupation of such areas may not have been directly affected by factors related to sea level change.

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APPENDIX

Previously Unpublished Radiocarbon Dates from the San Francisco Bay Area

Edward J. Helley and Kenneth R. Lajoie of the U.S. Geological Survey, Menlo Park, arranged to have several radiocarbon determinations made by Teledyne Isotopes on samples from San Francisco Bay area archaeological sites as part of their study of the Holocene geological history of the Bay region. Among these, three referred to in the preceding article have not been previously published.

Sunnyvale Female. This was a burial discovered in the side wall of a drainage ditch, approximately 3 m. below ground surface. It was not directly dated because there was insufficient bone collagen in the sample submitted. However, the burial is presumed contemporaneous to a hearth feature and associated antler wedge artifact, found about 500 m. away in the same ditch. According to E.J. Helley (personal communication), the hearth and gravepit were in the same geologic stratum of hardpan, both cutting through a shell bed stratum dating to 10,000 B.P. Tests by E. Peterson of the U.S. Geological Survey indicated that racemization of amino acids in the antler and human bone has proceeded to the same degree (E.J. Helley, personal communication). An age of 4460 ± 95 radiocarbon years: 2510 B.C. (I-6977) was obtained for charcoal from the hearth. An age of 70,000 years for the burial, suggested by Bada and Helfman (1975), seems irreconcilable with the stratigraphic context of the grave.

Castro Site. To obtain a basal date on the Castro mound (SCl-1), several fragments of ornaments of *Haliotis* (*H. cracherodii* and *Haliotis* sp.) were sacrificed. These had been recovered from a cremation inhumed into sterile subsoil. Associated with the cremation, besides the shell submitted for dating, were rectangular *Haliotis* beads with double perforations, some with serrated edges (*Haliotis* type 2 beads); at least two small circular *Haliotis* ornaments with double perforations, with incised edges in part (type C(2)a ornaments); 2 *Olivella* thick rectangular beads (type 2b); and 1 *Olivella biplicata* spire-lopped bead of 7.5 mm. diameter (type 1a). Types specified refer to the Bennyhoff and Heizer (1958) classification. Unique *Haliotis* ornaments, one with 3 perforations, and a half-disc with perforations near the edge, made up part of the sample submitted for dating. James Bennyhoff examined the assemblage and agreed that it compares with "Early Horizon" or "Windmiller" material from the Sacramento Delta area. The age of 3410 ± 100 radiocarbon years: 1460 B.C. (I-7897), determined in 1974, is presumed to apply to the shell artifacts, and to approximate the period of initial use of the site. Further information may be obtained from Bert A. Gerow, who examined the location of the cremation and suggested it be dated, and who curates the remaining shell artifact specimens as lot A-272 in the archaeological collections at Leland Stanford Jr. Museum.

Emeryville Site. A composite sample of charcoal fragments from Ala-309 was radiocarbon dated in 1974. The sample was collected in 1973, under the direction of R.F. Heizer, in connection with industrial construction at the Pfizer Plant which is situated atop part of the archaeological site. Charcoal in the sample came from approximately 9.6 m. below the 1907 site surface, according to estimates by James Bennyhoff. The excavated area from which the sample came was approximately 75 m. south of the northeast corner point on Schenck's map (1926:274). Charcoal was collected from the lowest midden level above the contact with the sterile substratum. The age of 2530 ± 105 radiocarbon years: 580 B.C. (I-7073) is similar to the previously determined basal age of 2310 ± 220 radiocarbon years (LJ-199), also based on a composite charcoal sample.