Archaeological Proxies for Sediment Flux to Holocene Littoral Cells of Southern California

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Abstract–**Post-glacial environments of coastal regions respond to changes in sea level, tectonics, and climate. Adjustments in sedimentary regimes along the coast also occur during periods of rising sea level, altering littoral habitats. Species diversity and biomass of marine invertebrates depend on the nature of the intertidal zone represented by rocky open coast, sandy beach, or quiet water embayment. Prehistoric human settlement of the southern California coast began in the early Holocene, and the marine invertebrate record in these archaeological deposits reflects the sedimentation history of the littoral cells over ca. 9000 years in the southern bight. Sediment flux to the coast increased markedly in the middle Holocene and led to the development of the modern Oceanside and Silver Strand littoral cells.**

I. INTRODUCTION

Prehistoric human settlement of the southern California coast began in the early Holocene. Radiocarbon dating of sites on the coast of San Diego County range from 9 kyr BP into the historic period. This archaeological record can be used to simulate coastal sediment conditions at regional scales over nine millennia. These simulations provide important baselines for calibrating coastal evolution models.

The record is based on controlled excavations of sites located on sea cliffs and coastal lagoons. Shellfish remains are useful for paleoenvironmental reconstructions because different species of mollusks require different littoral habitats: rocky open coast, sandy beach, or quiet water bays. The basic assumption is that the invertebrate fauna in the middens represent local coastal habitats at the time of harvest. Faunal analysis of the midden mollusks then permits a classification of coastal habitat, and radiocarbon dates place these coastal types in a chronological sequence.

This paper treats the two major littoral cells of San Diego County, the Oceanside cell and the Silver Strand cell (Fig. 1). The Oceanside littoral cell extends along the coast from Dana Point in the north to La Jolla in the south, a total distance of 84 km. For much of its length, semi-continuous sand or cobble beaches are backed by wave-cut sea cliffs. Eleven streams drain 6,187 square km of watershed to supply sediment to the coast. Dams and other structures have reduced natural sand delivery by as much as a third [1]. There are two major sinks, Oceanside Harbor and La Jolla Submarine Canyon. The Silver Strand littoral cell extends from Point Loma to Ensenada, Mexico, with 26 km on the U.S. side of the international border. The major sediment

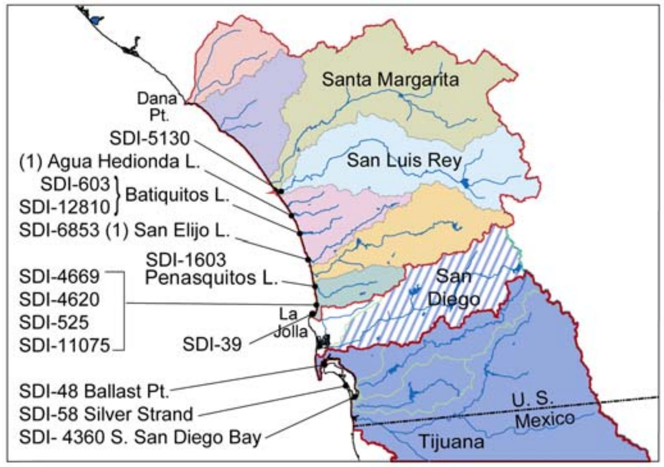

Fig. 1. The Oceanside littoral cell and its watersheds (multiple colors) are shown north of La Jolla. The Silver Strand littoral cell (blue) extends north from the Tijuana River watershed and at times included the San Diego River watershed (hatched). Archaeological sites are designed by record number or (1) to indicate the number of unrecorded sites.

source is the Tijuana River with a watershed area of 4,465 square km, but dams have caused a 72% reduction in beach sand supply [1]. The U.S. portion of the cell is unusual in that transport is northward due to the wave shadow of Point Loma. Zuniga Jetty, completed in 1904 to stabilize the entrance to San Diego Bay, has altered the cell's transport path. Sediment sinks are Zuniga shoal and offshore of the entrance in deeper water. The bay is not a sink because its tidal prism and tidal diurnal inequality induce self-scouring tidal currents at the entrance that send sand offshore. Most of the Silver Strand consists of low dunes about 3 m in elevation.

A reconstruction of paleocoastlines during the last transgression based on coastal dynamics has suggested that early Holocene beaches were rocky and largely lacking in sand cover [2]. As sea level rose across the shelf, incised stream valleys were flooded and deep, tidally flushed lagoons developed. Sediment deposited in these lagoons gradually filled them. By the time sea level rise had nearly stabilized, sand made its way to the outer coast and formed beaches.

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II. OCEANSIDE LITTORAL CELL

Fifteen prehistoric sites from the open coast and lagoons were selected to reconstruct the sedimentation history of the two littoral cells (Fig. 1). The four sites dated 7-9 kyr BP show predominantly rocky coast and bay habitats prevailed along the Oceanside cell in the early Holocene (Fig. 2). The two largest rivers of the cell, the Santa Margarita and San Luis Rey, enter the coast within about 3 km of each other and deliver over 50% of the total source sand at a point midway along the cell [1]. As sea level rise slowed around 6 kyr BP, coalescing sand deltas may have formed. A site in the San Luis Rey river valley 6 km from today's coast, SDI-5130 (Fig. 2), is the earliest site known on this coast to contain substantial amounts of *Donax* shell. This species is found within the swash zone of exposed sandy beaches. In one locus of the site, dated at ca. 6 kyr BP, *Donax* accounts for 20% by weight of total mollusk remains [3]. The typical proportion of *Donax* in contemporaneous sites is 0-3% [4].

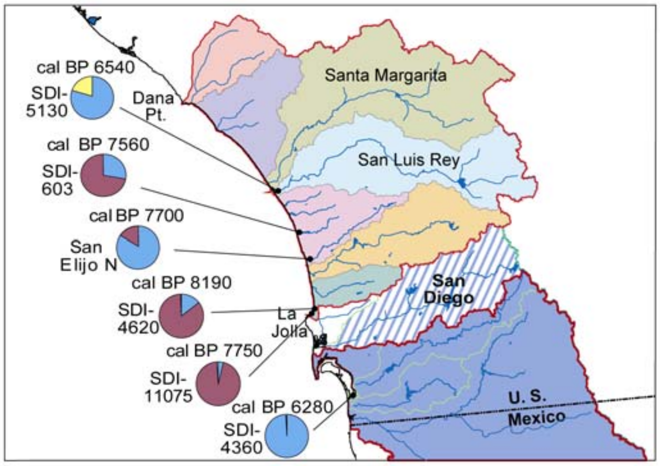

Fig. 2. Coastal archaeological sites dating between 9 and 6 kyr BP. The charts represent proportions of rocky coast (red), bay (blue), and sandy beach (yellow) species of mollusks in the sites.

At the end of the Oceanside cell, in the vicinity of Scripps Submarine Canyon, there are four sea cliff sites dating to the early Holocene. This extraordinary record was preserved by the good fortune of being located on relatively undeveloped portions of the campus of Scripps Institution of Oceanography (SIO) and UCSD. One site is now part of the University of California Natural Reserve System. Carl Hubbs was an early investigator of these sites and remarked on the lack of correlation between the rocky coast mollusks found in the middens and the present-day sandy beaches [5]. SDI-11075, on the sea cliff at SIO, contains a continuous record of Holocene occupation from 800 to nearly 8000 years ago (Fig. 3). The faunal successions show 80-90% rocky open coast species such as mussels and rock oysters predominated from ca. 8 kyr BP to ca. 5 kyr BP. A transition occurred between 4 and 5 thousand years ago when rocky species dropped off and sandy beach species surpassed 50% by weight of total mollusks. There were no *Donax* in the midden levels at 5 kyr BP, but *Donax* accounted for 36% by weight at 4 kyr BP.

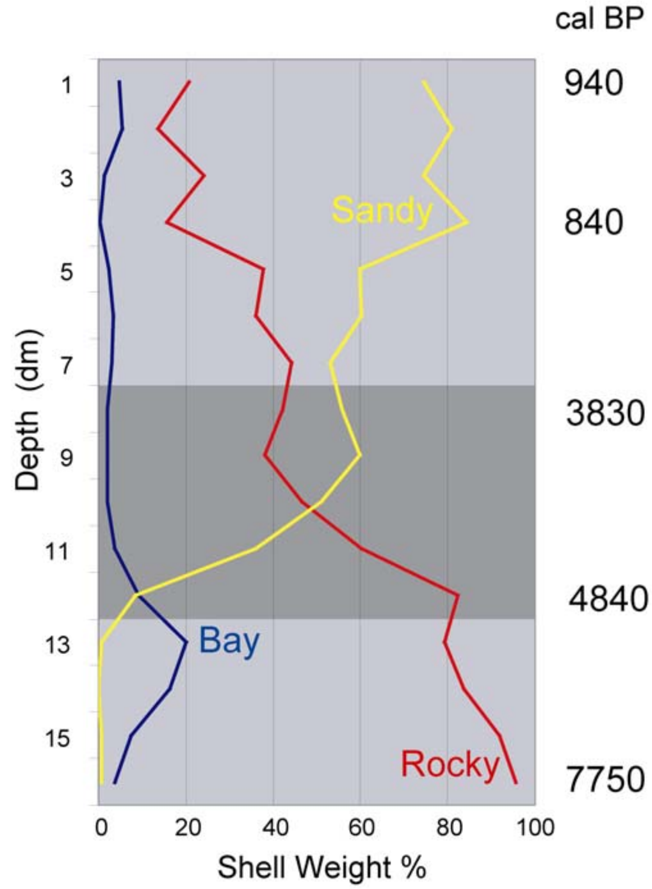

Fig. 3. Changes in the proportions of mollusk species representative of rocky coast, sandy beach, and bay habitats in site SDI-11075 on the campus of Scripps Institution of Oceanography (modified from [6]). Radiocarbon dates are calibrated by the Calib 4.3 program available from the University of Washington [7].

Another indicator species of sandy beaches is *Tivela*, the Pismo clam, that inhabits high-energy sandy areas from the intertidal to depths of over 20 m. The oldest *Tivela* date for San Diego County comes from a burial at SDI-39 in La Jolla Shores at the head of La Jolla Submarine Canyon. This age of cal BP 4570 [8] is similar to a *Tivela* dated cal BP 4390 at SDI-11075 [9].

Therefore, it seems plausible that sand beaches began to build at least ephemerally by 6 kyr BP in the vicinity of the Santa Margarita and San Luis Rey river mouths. It appears to have taken about 1000 years for sand beaches to fill in the remainder of the cell south to the submarine canyons at La Jolla.

III. SILVER STRAND LITTORAL CELL

Turning to the Silver Strand littoral cell, a site at the south end of the modern bay (Fig. 2), SDI-4260, reveals almost exclusively bay species of shellfish were collected around cal

BP 6280 [10]. The strand itself was well established by the middle Holocene as indicated by a *Tivela* date of cal BP 4410 at SDI-58 within the Silver Strand State Beach [11]. This age is equivalent to the oldest *Tivela* dates at La Jolla. At Ballast Point, near the entrance to San Diego Bay, a maritime adaptation centered on bay species of fish and shellfish had emerged by cal BP 5660 [12]. Consequently, the bay appears to have developed in its modern configuration close to 6 kyr BP [13].

IV. CONCLUSIONS

In summary, we see maturation of two very different littoral cells in the time range of 4-6 kyr BP based on archaeological records. The *Tivela* dates indicate that wide dissipative sand beaches were established in both littoral cells by the middle of the fifth millennium BP. Sediment flux within the Oceanside littoral cell appears to have been sufficient to build sand beaches to the end of the cell in about 1000 years. The sandy beaches of these cells are a relatively recent phenomenon in the geologic history of the last transgression. They are threatened now by urbanizing watersheds and dams that reduce source sand. At current rates of sediment flux, it would take even longer than a millennium to rebuild the beaches once they are lost.

Acknowledgments

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