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Sediment dynamics and the burial and exhumation of bedrock reefs along an emergent coastline as elucidated by repetitive sonar surveys: Northern Monterey Bay, CA

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ABSTRACT

Two high-resolution bathymetric and acoustic backscatter sonar surveys were conducted along the energetic emergent inner shelf of northern Monterey Bay, CA, USA, in the fall of 2005 and the spring of 2006 to determine the impact of winter storm waves, beach erosion, and river floods on biologically-important siliclastic bedrock reef habitats. The surveys extended from water depths of 4 m to 22 m and covered an area of 3.14 km^2, 45.8% of which was bedrock, gravel, and coarse-grained sand and 54.2% was fine-grained sand. Our analyses of the bathymetric and acoustic backscatter data demonstrates that during the 6 months between surveys, 11.4% of the study area was buried by fine-grained sand while erosion resulted in the exposure of bedrock or coarse-grained sand over 26.5% of the study area. The probability of burial decreased with increasing water depth and rugosity; the probability of exhumation increased with increasing wave-induced near-bed shear stress, seabed slope and rugosity. Much of the detected change was at the boundary between bedrock and unconsolidated sediment due to sedimentation and erosion burying or exhuming bedrock, respectively. In a number of cases, however, the change in seabed character was apparently due to changes in sediment grain size when scour exposed what appeared to be an underlying coarser-grained lag or the burial of coarser-grained sand and gravel by fine-grained sand. These findings suggest that, in some places, (a) burial and exhumation of nearshore bedrock reefs along rocky, energetic inner shelves occurs over seasonal timescales and appears related to intrinsic factors such as seabed morphology and extrinsic factors such as wave forces, and (b) single acoustic surveys typically employed for geologic characterization and/or habitat mapping may not adequately characterize the geomorphologic and sedimentologic nature of these types of environments that typify most of the Pacific Ocean and up to 50% of the world's coastlines.

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1. Introduction

Approximately 500 km (28%) of California's coast, and much of the remaining Pacific Ocean coast, is characterized by uplifted, rocky shorelines along tectonically active margins. Typical coastal landforms include coastal mountains, seacliffs, and small pocket beaches at stream mouths. The near-shore and innermost shelf off these siliclastic rocky shorelines in central and northern California is commonly sparsely covered by sediment, with bedrock commonly exposed on the shoreface (e.g., Cacchione et al., 1984, 1987; Anima et al., 2002). Reviews by Foster and Schiel (1985) and Leet et al. (1992) describe the diverse and numerous plant and animal species that inhabit these subtidal siliclastic bedrock outcrops, generally termed, “bedrock reefs”, on the inner shelf of California. Numerous species of giant kelp form dense forests that support numerous invertebrates (e.g., sponges, tunicates, anemones, cup corals, and bryazoans), commercial species (e.g., rockfish, crabs), marine mammals (e.g., sea otters, harbor seals, sea lions), and birds (e.g., gulls, terns, egrets, cormorants), some of which are listed as endangered species. Mann (1973) suggests the giant kelp forests that occupy the shallow bedrock reefs along central California are second only to tropical rainforests in biomass production per area.

Starting in the 1970s, a number of researchers (North, 1971; Ostarello, 1973; Grigg, 1975; Weaver, 1977; Johnson, 1980; Foster and Schiel, 1985) noted that sediment could negatively impact kelp, gorgonians, hydrocorals, cowrys, and other plants and sessile animals by inhibiting recruitment, clogging filter-feeding apparatus, or burying them. Connell (1978) suggests that disturbances such as sedimentation and abrasion likely play into the life history of many organisms and the structure of ecosystems (e.g., species diversity). Studies by Dingler and Reiss (2002) showed that the beaches along this high-energy coastline undergo significant erosion during the winter, on the order 50–150 m^3/m of beach (12,500–37,500 m^3 for a 0.25 km-long beach),

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with most of the sediment moving offshore to water depths of greater than 3 m below mean sea level. Although rocky coasts in areas of tectonic uplift are common worldwide and often support highly diverse and productive ecosystems, there is little high-resolution documentation of how bedrock and sediment are distributed in this sort of environment and how these patterns change in space and time due to sediment dynamics.

Spatially- and temporally-variable wave conditions and the complex, shallow, rocky sea floor off central California have restricted comprehensive field surveys of the energetic inner shelf in the past to more benign summer or early fall conditions (e.g., Watt, 2003; Watt and Greene, 2007). Recent innovations in field techniques and equipment, however, now make it possible to perform a detailed analysis of the morphology and physical processes operating on the inner shelf of this type of complex coastline. The goal of this effort is to understand the distribution of sediment and bedrock on the inner shelf of a rocky, emergent coastline, and how these patterns change over the course of an energetic winter due to storm waves and beach erosion.

2. Study area

2.1. Geology

The coast of central California lies along an active tectonic margin whose uplift has resulted in a rugged coastline with sea cliffs cut into coastal mountains, narrow river valleys, and a relatively narrow continental shelf. The Monterey Bay (Fig. 1) area lies within the broad dextral strike-slip transform boundary between the Pacific and North American plates (Anderson et al., 1990; Greene, 1990). The study area is wedged between the onshore San Andreas fault and the offshore San Gregorio fault (Weber, 1990). Differential movement along these faults has resulted in uplift rates in the area averaging 0.3 mm/yr over the last 500,000 years (Bradley and Griggs, 1976; Anderson et al., 1990; Dupre, 1990). This uplift results in the shoreline being characterized by steep, up to 20 m high, actively eroding coastal bluffs often incised into uplifted marine terraces and commonly fronted by low, wave-cut shore platforms, or small pocket beaches. These sea cliffs are dissected at irregular intervals by larger pocket beaches that form at the mouths of coastal streams and by less common continuous beaches in sheltered bays. The small, steep perennial streams and the San Lorenzo River (357 km^2 drainage area) in northern Monterey Bay are the primary sources of coarse-grained sediment to the littoral environment (Best and Griggs, 1991).

During the last glacial maximum at 22 ka (Hanebuth et al., 2000), streams in the study area flowed across the exposed continental shelf and cut channels through the bedrock (Anima et al., 2002); the mouths of many of these streams were inundated during the late Pleistocene to Holocene transgression, forming low-gradient floodplains, coastal lagoons, and marshes in their lower reaches (Griggs and Savoy, 1985). Sea cliff erosion, with long-term rates ranging from zero to >30 cm/yr, is episodic and locally variable (Hapke et al., 2006),

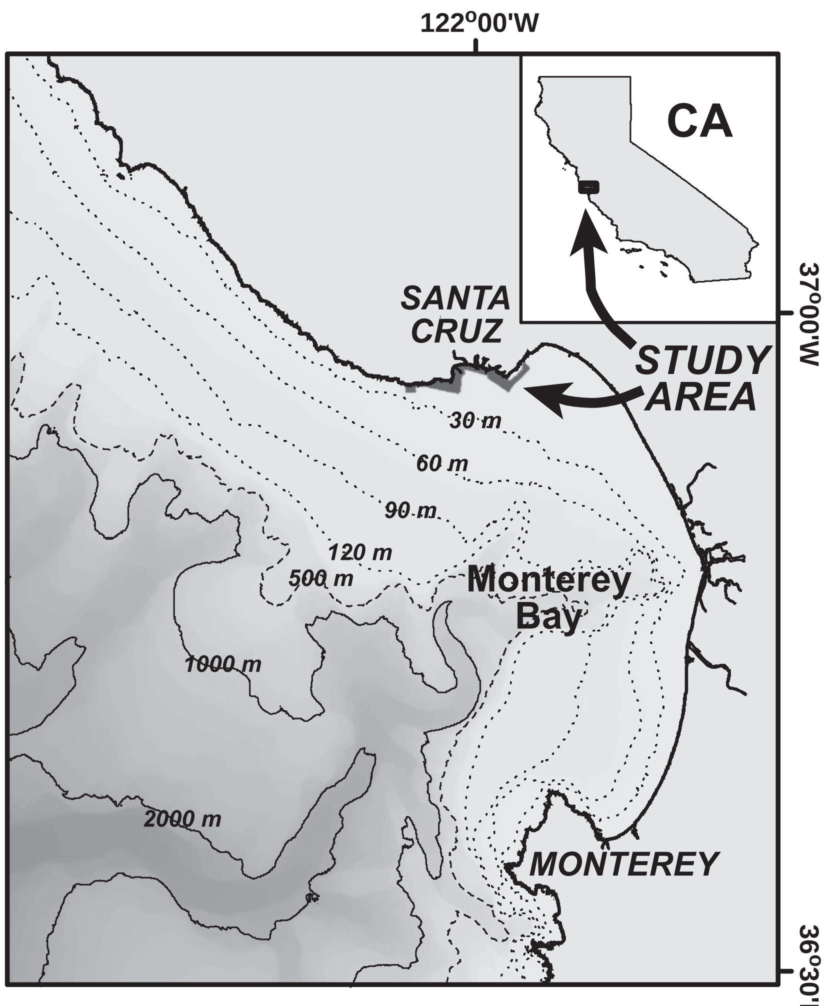

Fig. 1. Map of study area showing regional bathymetry and location of the sonar surveys off Santa Cruz, California.