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Twenty-nine months of geomorphic change in upper Monterey Canyon (2002–2005)

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Abstract

Time serial multibeam bathymetry is used to evaluate geomorphic trends and submarine processes in the upper 4 km of Monterey Canyon, California. Seven high-resolution bathymetric surveys conducted between September 2002 to February 2005 show that the upper canyon axis and head grew in volume 1 000 000 $m^3 \pm 700\,000$ m^3, at an average annual rate of 400 000 $m^3/a \pm 300\,000$ m^3/a through lateral erosion and vertical incision. This net loss of substrate during the 29-month period is parsed between local erosion of 1 400 000 m^3 and local deposition of 350 000 m^3. A submarine landslide with a scar void volume of 70 000 m^3 and debris pile of 52 000 m^3 occurred between March 2003 and September 2004. During the subsequent months until February 2005, the slide scar grew 40% in volume while the debris pile shrank by 80%. The canyon-head rim adjacent to Moss Landing Harbor prograded seaward and retreated shoreward significantly (up to 50 m) during the study suggesting frequent episodes of sediment build up and subsequent down-canyon failure. A large field of sand waves located in the channel axis was completely reworked in each time series except for a 24 h period where no wave crest movement was noted, and a 32 day period where up-canyon migration of approximately 7 m was recorded in the northern tributary.

Keywords: Monterey Bay; submarine canyon; geomorphology; bathymetry; coastal process; sediment transport; bedforms

1. Introduction

Advances in multibeam imagery systems, including narrower and more numerous signal beams, improved motion sensors, and real-time kinematic positioning, have provided unprecedented high-resolution views of the earth's submerged continental margins and submarine canyons (e.g., McAdoo et al., 2000; Greene et al., 2002; Lee et al., 2003; Smith et al., 2005; Barnard et al., 2006). Consequently, recent studies of seafloor morphology are rapidly expanding our understanding of Quaternary submarine processes and the potential for those processes to generate coastal hazards (Orange, 1999; McAdoo et al., 2004; McAdoo and Watts, 2004). This paper analyzes serial high-resolution multibeam bathymetry spanning 29 months to interpret modern

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submarine processes from a study of geomorphic change in the upper 4 km of Monterey Canyon, California (Fig. 1).

1.1. Sediment budget and transport processes

Monterey Canyon has built a 95 600 km^2 submarine fan complex (e.g., Normark and Carlson, 2003) that reaches a maximum thickness of over 1.5 km (Fildani and Normark, 2004). This enormous volume of terrestrial sediment was delivered to the Monterey Fan since late Pleistocene time, with approximately half of the total volume delivered in Late Quaternary time (Fildani and Normark, 2004). Although the Monterey submarine fan is relatively inactive at present (e.g., McHugh et al., 1992), more than 200 000 m^3 of littoral sand and gravel enters the canyon head each year (Best and Griggs, 1991; Eittreim et al., 2002). Therefore, the canyon is presently storing sediment rather than conveying it directly to the fan (Paull et al., 2005).

Sediment budgets and transport processes in Monterey Canyon have been assessed indirectly through littoral cell analysis (Best and Griggs, 1991) and canyon geomorphology (Paull et al., 2005; Smith et al., 2005), and directly via current and turbidity measurements or by documenting the unintentional, rapid, down-canyon movement of "moored" instruments (Garfield et al., 1994; Paull et al., 2003; Xu et al., 2004). A synthesis of those studies and a growing body of unpublished data demonstrate that Monterey Canyon presently conveys sand and gravel part-way along its axis via sediment transport events that occur several times annually. In the present paper we use the term "sediment gravity flow," or "sediment transport event" when the grain-support mechanism is unclear. We use the term "turbidity current" when previous authors have made that interpretation, or when we are speculating about the meaning of our data set. Paull et al. (2003) and Xu et al. (2004) provide clear evidence that sediment is transported, at least in part, by large turbidity currents generated in the Monterey Canyon and a major tributary, Soquel Canyon (Fig. 1A). Although the catastrophic sediment transport events reported by Garfield et al. (1994) and Paull et al. (2003) could have been turbidity currents as well, debris flow processes cannot be ruled out. Paull et al. (2005) were not able to isolate a dominant transport mechanism in their study of sediment cores along the canyon axis, but suggested that sand moves down canyon via slumps, debris flows, and turbidity currents with a wide range of magnitudes and time scales.

Sediment transport events have been better documented in the deeper reaches of the canyon (7300 m) than they have in the study area (e.g., Paull et al., 2003; Xu et al., 2004), but geomorphic studies near the canyon head are beginning to reveal transport processes as well (Smith et al., 2005). The asymmetry of large sand waves on the floor of the upper canyon indicates down-canyon sediment motion (Smith et al., 2005). Smith et al. (2005) also inferred the presence of sporadic, strong down-canyon currents to explain deep scours (several meters deep) that occurred along the margins of the canyon axis and in the outer edges of intra-canyon meanders during their six-month time-series study. Despite the evidence for strong down-canyon flows, published and unpublished current records from the same reach of the canyon have found dominantly up-canyon currents driven by shoaling of internal tidal flow, and the absence of strong down-canyon current events (Rosenfield et al., 1999; Charlie Paull, personal communication, 2006). Moored Doppler velocity instruments have recorded turbidity currents in deeper reaches of the canyon, but the locations of the slope failure sources have not been established (Xu et al., 2004). This paper further explores these issues by analyzing small scale bathymetric changes and sand-wave motion, using a wider variety of time scales than were previously available.

1.2. Submarine landslides

The seafloor of Monterey Bay has evidence of large landslides that may have been tsunamigenic (Greene and Ward, 2003). A clear understanding of the physical processes that trigger submarine landslides can be the basis for estimating the probability and frequency of future tsunamis in a slide-prone region. Submarine slope failure is commonly ascribed to co-seismic shaking (e.g., Hampton et al., 1996), storm-driven waves and currents (e.g., Inman et al., 1976; Prior et al., 1989; Normark and Piper, 1991), and oversteepened deltas (summarized in Normark and Piper, 1991). The 1989 Loma Prieta earthquake was large enough to generate a significant turbidity current in Monterey Canyon and to produce a 0.5 m tsunami near the canyon head (Schwing et al., 1990; Garfield et al., 1994). On the other hand, several sediment gravity flows in Monterey Canyon have no links to seismicity (Paull et al., 2003; Xu et al., 2004). Transient changes in water pressure associated with high surf conditions have been circumstantially invoked to cause slope failure and turbidity currents (Prior et al., 1989; Paull et al., 2003; Xu et al., 2004), but energetic sediment gravity flows also occur in Monterey Canyon in the absence of both high surf and seismicity (Xu et al., 2004). Other landslide triggers suggested for slides in the Monterey Canyon include groundwater springs, gas