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Anatomy of the La Jolla Submarine Canyon system; offshore southern California

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ABSTRACT

An autonomous underwater vehicle (AUV) carrying a multibeam sonar and a chirp profiler was used to map sections of the seafloor within the La Jolla Canyon, offshore southern California, at sub-meter scales. Close-up observations and sampling were conducted during remotely operated vehicle (ROV) dives. Minisparker seismic-reflection profiles from a surface ship help to define the overall geometry of the La Jolla Canyon especially with respect to the pre-canyon host sediments.

The floor of the axial channel is covered with unconsolidated sand similar to the sand on the shelf near the canyon head, lacks outcrops of the pre-canyon host strata, has an almost constant slope of 1.0° and is covered with trains of crescent shaped bedforms. The presence of modern plant material entombed within these sands confirms that the axial channel is presently active. The sand on the canyon floor liquefied during vibracore collection and flowed downslope, illustrating that the sediment filling the channel can easily fail even on this gentle slope.

Data from the canyon walls help constrain the age of the canyon and extent of incision. Horizontal beds of moderately cohesive fine-grained sediments exposed on the steep canyon walls are consistently less than 1.232 million years old. The lateral continuity of seismic reflectors in minisparker profiles indicate that pre-canyon host strata extend uninterrupted from outside the canyon underneath some terraces within the canyon. Evidence of abandoned channels and point bar-like deposits are noticeably absent on the inside bend of channel meanders and in the subsurface of the terraces. While vibracores from the surface of terraces contain thin (<10 cm) turbidites, they are inferred to be part of a veneer of recent sediment covering pre-canyon host sediments that underpin the terraces. The combined use of state of the art seafloor mapping and exploration tools provides a uniquely detailed view of the morphology within an active submarine canyon.

1. Introduction

Submarine canyons are among the most dramatic geomorphic features on Earth (Shepard, 1981). The shapes of submarine canyons imply that they are dominantly erosional features that were cut into continental margins. The presence of huge volumes of terrestrial materials within the deep-sea fans downstream from the canyons demonstrates that submarine canyons are major sediment transport conduits, shuttling both fine- and coarse-grained sediments from the continent out into the deep-sea (Menard, 1955; Normark and Carlson, 2003; Normark et al., 2009a).

Because of technological limitations of surface ships to image and sample within these topographically complex marine environments, the types of sedimentological information easily obtainable on land about sediment transport and associated landscape-shaping processes are difficult or impossible to collect in the marine realm. Much of what is known about the processes that occur within submarine canyons has come from studying the deposits they generate downstream (Normark and Piper, 1991; Piper and Normark, 2001). In recent years the application of latest-generation multibeam and other sonar technologies has provided considerable advances in outlining the shapes of some submarine canyons (e.g., Greene et al., 2002; Lastras et al., 2007, 2009; Mountjoy et al., 2009). However, a gap still persists between the spatial resolution of marine-based maps collected from surface ships and the level of detail needed to fully understand the active processes that shape marine canyons. Sampling within this environment is also difficult, and when samples are obtained, wire line coring techniques provide limited context about the environment from which the samples were taken.

Here we report on high-resolution seafloor surveys initiated to understand the processes that generated the existing morphologies within the La Jolla Canyon. Sections of the La Jolla Canyon system were investigated utilizing robotic undersea mapping and sampling tools that provide exquisite detailed views of the seafloor morphology. These tools have enabled reconnaissance of the geology of the La Jolla

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Canyon system at outcrop scale (Mutti and Normark, 1987, 1991; McHargue et al., 2011).

1.1. Regional setting

The continental margin off southern California is distinguished by a series of prominent ridges that form multiple basins separated by shallow sills (Gorsline and Teng, 1989). These basins are products of the active plate margin tectonics in this region (Vedder, 1987). The general shape of the continental margin off San Diego and the eastern flank of the San Diego Trough (Shepard and Einsele, 1962; Shepard and Buffington, 1968), the basin immediately to the west and southwest (Graham and Bachman, 1983), are known (Fig. 1) through various multibeam mapping efforts summarized by Dartnell et al. (2007).

The La Jolla Canyon is one of a series of submarine canyons that dissect the continental shelf north of San Diego (Normark et al., 2009a). These canyons are believed to have acted as conduits through which considerable volumes of sediments were transported out into the San Diego Trough during the late Quaternary (Covault et al., 2007; Covault and Romans, 2009). However, during the present sea level highstand, the La Jolla Canyon and its tributary Scripps Canyon are the only canyons with heads that extend far enough into the shelf to intercept sediments from the Oceanside littoral transport cell (Slater et al., 2002; Coastal Morphology Group, 2004; Covault et al., 2007, 2011) and to be actively conveying them into the San Diego Trough (Fig. 1).

The La Jolla Canyon and Scripps Canyon merge at ~246 m water depth (Fig. 1), approximately where the Rose Canyon fault zone (Hogarth et al., 2007; Ryan et al., 2009; Le Dantec et al., 2010) crosses the canyon. Below this depth and to the limit of our survey, the La Jolla Canyon varies in rim to rim width from 0.9 km to 1.5 km, contains a sinuous axial channel ranging from 50 m to 300 m in width, and has a total relief from the rim to the axial channel of up to 110 m. Most of the elevation changes occur along a few steep faces that separate intervening terraces. A channel can be clearly traced from the head of La Jolla Canyon ~40 km seaward onto La Jolla Fan (Piper, 1970).

Multibeam sonar and chirp profiling surveys were conducted with an autonomous underwater vehicle (AUV) in the La Jolla Canyon to obtain a better understanding of the history of this canyon and the processes acting within submarine canyons in general. The AUV surveys reveal the present geomorphology of the La Jolla Canyon at a level of detail unattainable with surface vessel multibeam data. Observations and sampling conducted with a remotely operated vehicle (ROV), and minisparker seismic profiles collected from a surface ship, provide supporting data to infer the processes that produced the existing morphology.

2. Methods

2.1. AUV surveys

The AUV used to survey the La Jolla Canyon was developed at the Monterey Bay Aquarium Research Institute (MBARI) specifically for seafloor mapping (Caress et al., 2008). The AUV carries a 200-kHz Reson 7125 multibeam sonar and an Edgetech 2- to 16-kHz chirp sub-bottom profiler. The AUV was pre-programmed to proceed to >200 waypoints during each dive. Missions were up to 18 h in duration and were designed for the vehicle to fly at a speed of 3 knots while maintaining an altitude of 50 m above the seafloor. Tracklines were spaced ~150 m apart. In this mode, the AUV obtains overlapping multibeam bathymetric coverage at a vertical resolution of 0.15 m,

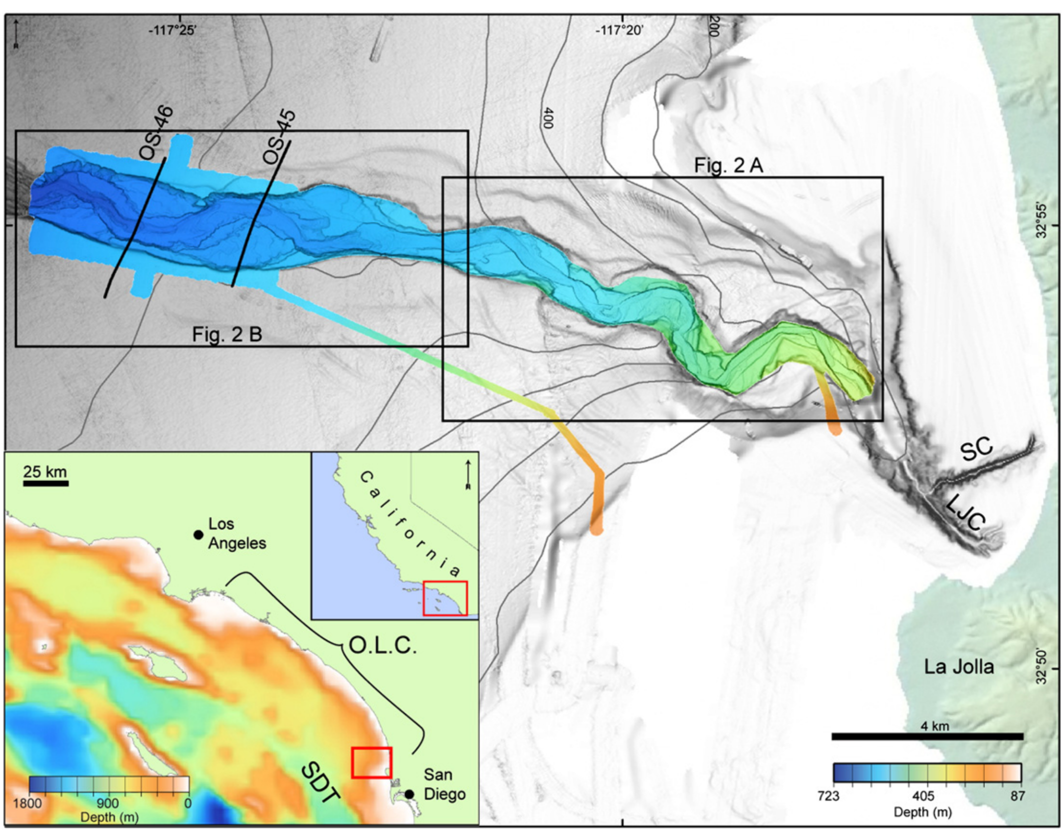

Fig. 1. Regional bathymetry of the continental margin off San Diego, California, in gray hues collected from surface ship (Dartnell et al., 2007) and higher resolution AUV collected bathymetric surveys of the La Jolla Canyon, indicated in colored bathymetry. Location of USGS collected minisparker seismic profiles (OS-45 and OS-46) are indicated. Contour interval is 100 m. Heads of the La Jolla Canyon (LJC) and Scripps Canyon (SC) are indicated. Inset maps show locations of survey both with respect to California and the California Continental Borderland at telescoping scales. Areas covered in parts A and B of Figs. 2 and 4 are indicated with boxes. SDT—San Diego Trough and O.L.C.—Oceanside Littoral Cell.