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Introduction

Towards a new and integrated approach to submarine canyon research

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1. Background

Submarine canyons, steep-walled valleys that cut across virtually every continental margin around the world (Harris and Whiteway, 2011), are considered major sediment transport pathways between continental shelves and the deep sea (e.g., Shepard, 1963; Puig et al., 2014). Owing to their steep topography and high terrain heterogeneity, in addition to their unique current patterns and episodic down-canyon flushing events, which result in locally increased nutrient concentrations and food availability, submarine canyons are often considered as biodiversity hotspots (e.g., Tyler et al., 2009; De Leo et al., 2010). On the other hand, considerable differences have been observed between individual canyon systems, and between different faunal groups in terms of their response to the typical canyon environment (e.g., Cunha et al., 2011; Ingels et al., 2011; Schlacher et al., 2007). Unfortunately, in addition to transporting sediment, submarine canyons also tend to funnel our human litter and pollutants into the deep sea, extending the anthropogenic impact on the oceans far beyond our shores (e.g., de Jesus Mendes et al., 2011; Mordecai et al., 2011; Schlining et al., 2013).

Submarine canyons have been the subject of research for a long time. Shepard (1972) refers to a study from as early as the late nineteenth century, carried out by Milne (1897), which looked at the instability of canyon floor sediments as a possible cause for the repeated breaking of submarine cables that had been laid across a canyon. However, as a result of the steep terrain, locally enhanced currents and occasional down-canyon flushing events, the initial submarine canyon investigations were extremely challenging, and the number of studies was limited. Acoustic methods had to deal with excessive scatter and noise, in-situ instruments were regularly washed away and the coarse canyon thalwegs and rocky walls proved difficult to sample (e.g., Paull et al., 2003; Shepard, 1972). Direct observations were limited to shallow waters, within reach of divers or early submarines. With the increasing availability of new sampling and surveying technologies (deep-towed acoustic instruments, drop-down video systems, and eventually robotic vehicles), submarine canyon research increased dramatically (Fig. 1). Particularly the advent of Remotely Operated Vehicles (ROVs) in many research institutes in the last ~10 years opened up a new perspective on submarine canyons, allowing a wider community of researchers to access parts of the deep ocean that had been hidden until then (Tyler et al., 2009).

As a result of this increased research effort, our understanding of submarine canyons is gradually growing. A number of individual canyon systems have received considerable attention (e.g. the Portuguese Canyons offshore Lisbon & Nazaré (Masson and Tyler, 2011 and references therein); Monterey Canyon (e.g., Hall and Carter, 2011; Paull et al., 2011; Robison et al., 2010) or the Cap de Creus Canyon and the other canyons in the Gulf of Lions (e.g., Canals et al., 2006; Lastras et al., 2007; Orejas et al., 2009; Palanques et al., 2008)) but most canyons around the world have not yet been studied, or only to a very limited extend. Furthermore, many of the studies carried out so far are focussing on one aspect (geology, geomorphology, sediment dynamics, hydrography, current patterns, mega-, macro-, meiofauna distribution, biogeochemistry…) of a single canyon or canyon system. The time seems right to start putting all those pieces of the jigsaw together, and to start looking at canyons in a more holistic way. To this end, the first International Symposium on Submarine Canyons was organised in Brest, France in July 2012. Canyon research from all over the world was presented, followed by cross-disciplinary discussions and networking. A good proportion of those studies are presented here, in this Special Issue. In addition, the meeting resulted in the formation of INCISE: the International Network for submarine Canyon Investigation and Scientific Exchange (www.incisenet.org). Further meetings and sessions at international conferences are planned, and an active forum has been set up, with the aim to stimulate cross-disciplinary discussions and research activities.

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2. Integrated submarine canyon research

This Special Issue presents submarine canyon research from all over the world (Fig. 2). Particularly the large number of studies on the Sable Gully, off Nova Scotia, illustrates the type of integrated picture INCISE hopes to achieve for many individual canyons, and for submarine canyons as a whole. The Sable Gully was the first Canadian Marine Protected Area (MPA) to be designated in the Atlantic. The area is known to be an important cetacean habitat; especially northern bottlenose whales seem to have a great affinity for this canyon and similar canyons in the region (Moors-Murphy, 2014). Oceanographic/hydrographic observations by Greenan et al. (2014) illustrate the unique tidal environment of the canyon, which is dominated by unusual non-linear constituents that create overtides and compound tides. In addition, there is strong evidence for enhanced mixing and up-canyon flow within the canyon. The surface waters, however, do not seem to be very much affected by the presence of the canyon: they are mainly influenced by the regional NE–SW current pattern. To further enhance our understanding of the 3-dimensional circulation throughout the canyon, Shan et al. (2014) applied a multi-nested ocean circulation model, investigating the influence of shelf-scale circulation, tide-topography interaction and wind forcing on the circulation within and above the canyon. The authors found that wind, especially during storm events, is a significant factor affecting the circulation above the canyon, while especially the tide-topography interaction is a dominant factor within the Gully. This water mass structure and current pattern may well affect the pelagic fauna. For example, the crustacean micronekton and macrozooplankton are mainly structured by depth and diel cycle (MacIsaac et al., 2014). The upper waters (< 750 m) are dominated by species typical of the mid- to higher latitudes in the N. Atlantic, which spend part of their daily cycle in the surface waters brought in by the overall NE–SW current. Inter-annual variability in species abundance is limited, however, despite substantial changes in oceanographic conditions during the 3-year study by MacIsaac et al. (2014). In contrast, Kenchington et al. (2014) looked at the epibenthic macrofauna living in the tidally dominated deeper parts of the canyon, beyond 1000 m depth. They found that those fauna mainly consist of filter-feeders, which probably reflects the influence of the tidal currents in the canyon. Furthermore, apart from depth, benthic communities are also structured by food availability (total organic carbon and labile carbon) at a spatial scale of 10 s of km, while on shorter distances (10 s of m) substratum seems to be an important factor determining species associations.

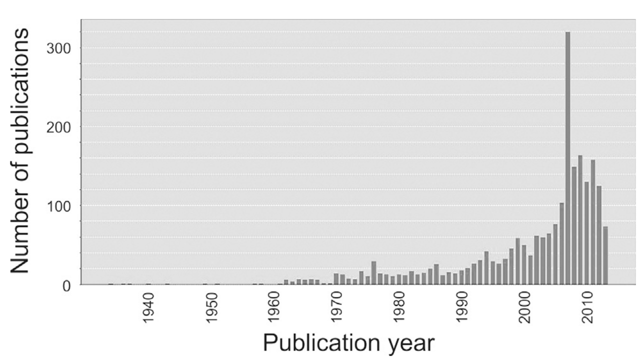

Fig. 1. Number of publication records in the Web of Knowledge database related to the search topic 'submarine canyon' as of 5 August 2013.
Source: Thomson Reuters.

Of course, as indicated before: patterns emerging from a single canyon system may not necessarily be universal. Comparing canyons located on the active transform margin off Haida Gwaii, British Columbia, with the Sur Canyon system on the other well-known transform margin south of Monterey Bay, California, Harris et al. (2014) demonstrate that several factors are at play in the creation of canyon morphologies. Considerable variability has also been found between canyons as close as a few 10s–100s of kilometres apart. For example, Lo Iacono et al. (2014) present two submarine canyons located offshore N Sicily. Although both are placed within the same tectonically active geological setting, the canyons have a very different morphology, and are governed by different sedimentary processes. Bottom-up, retrogressive slope failures have driven the formation of the Palermo Canyon, while top-down, erosive turbidity currents, linked to fluvial sedimentary input, have shaped the meandering Castellamare Canyon. Similar, although less extreme, differences were found by Obelcz et al. (2014) in the fine-scale morphology of four submarine canyons, spaced over 200 km along the US Mid-Atlantic passive margin, pointing to slightly different levels of canyon activity and sediment transport processes.

However, in terms of recent, short-term sediment transport in shelf-incising canyons, most observations seem to confirm the overall two-step mechanism already hinted by Shepard (1963), and recently reviewed by Puig et al. (2014). For example, tidally mobilised shelf sediments are intercepted by the Cook Strait Canyon heads offshore New Zealand, and accumulate in depocentres in the upper/central part of the canyon system. They are then remobilised in more catastrophic events and transported towards the lower canyon and deep ocean as a result of tectonic (earthquake) processes with a return period of ca. 100 years (Mountjoy

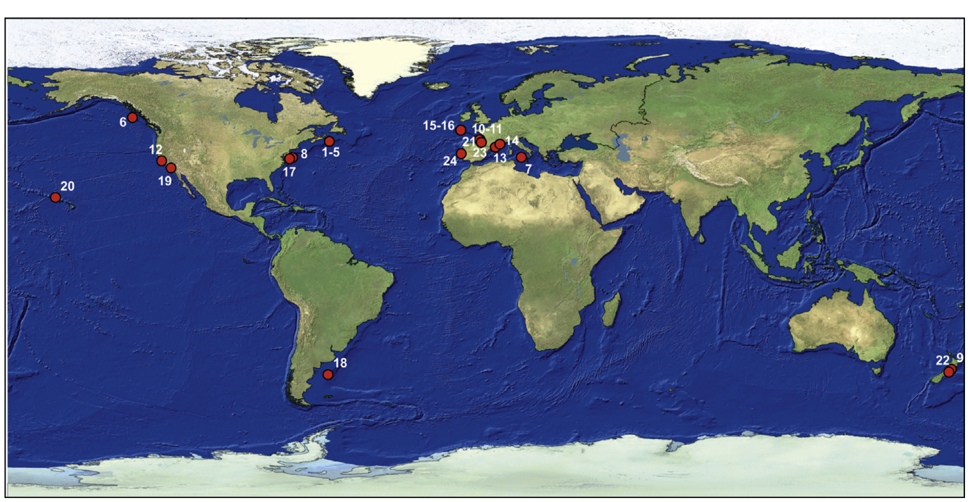

Fig. 2. Locations of submarine canyon studies published in this Special Issue. Labels refer to the order of the papers in this journal.