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Morphology and controls on the evolution of a mixed carbonate–siliciclastic submarine canyon system, Great Barrier Reef margin, north-eastern Australia

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ABSTRACT

We present the most complete and new high-resolution multibeam bathymetry datasets from the shelf to the basin in the Ribbon Reef region, northern Great Barrier Reef (GBR). Analysis of these data, combined with existing side-scan sonar data provides a detailed morphologic framework of the submarine canyon system and other related features, their spatial distribution, controlling factors on their evolution, and evidence of recent sedimentary activity. Two morphologically different submarine canyon types are recognised: 1) shelf-incised canyons whose heads are indented into the shelf-break at shallow-water depths (about 60 to 80 m). These canyons can be single-fed or multi-fed depending on the number of tributaries that merge into the main canyon valley. According to the degree of connection with the shelf, these canyons can be reef-blocked, partly reef-blocked or shelf-connected; 2) slope-confined canyons, which are located at deeper waters in the slope and show a different canyon head morphology. Canyon formation and development of the different canyon types is explained according to a four-phase model. In the first phase, localised slope failures and/or sediment gravity flows may lead to the formation of an initial canyon by retrogressive headward or downslope erosion respectively. These processes continue during the second transitional phase, leading to upslope canyon progression. Finally, canyons breach the shelf-break during a mature stage that represents the more active phase in the canyon evolution. The development of an extensive shelf-edge barrier reef (Ribbon Reefs) represents a fourth phase that conditioned the sedimentary dynamics of the canyons. The location and morphology of this reef barrier determine the type and amount of sediment supply by controlling the connection of the canyon head with the shelf drainage system. Recent canyon activity is evidenced by the presence of erosive and depositional features that include submarine landslides, gullies and rills on the canyon walls and slopes, sandwaves migrating along the canyons floors, and sediment gravity flows deposited on the lower canyons and adjacent basin floor.

1. Introduction

Submarine canyons are major morphologic features sculpting continental margins worldwide (Shepard and Dill, 1966; Shepard, 1972) and constitute the main conduits for shelf-to-basin sediment transport, independently of the tectonic setting (Carlson and Karl, 1988; Alonso and Ercilla, 2003; Lastras et al., 2009; Mountjoy et al., 2009). The best known examples of modern submarine canyons and their ancient counterparts correspond to siliciclastic systems (Lewis and Barnes, 1999; Babonneau et al., 2002; Anderson et al., 2006; Shanmugam et al., 2009). Modern and ancient submarine canyons in carbonate systems are relatively scarce in the literature (Leach and Wallace, 2001; Exon et al., 2005; Ruiz-Ortiz et al., 2006; Mitchell et al., 2007), and even less is known about submarine canyons in mixed carbonate–siliciclastic settings (Braga et al., 2001; Francis et al., 2008; Puga-Bernabéu et al., 2008).

The north-eastern continental margin of Australia is the largest mixed carbonate–siliciclastic province in the world (Maxwell and Swinchatt, 1970; Davies et al., 1991). Similar to other continental margins, large amounts of sediment are delivered into the deep ocean by different shelf-to-basin transport processes. On this margin, the amount and timing of siliciclastic and/or carbonate sediment supply to the basin is controlled by sea-level and climatic changes according to a transgressive shedding model of margin sedimentation (Dunbar et al., 2000; Dunbar and Dickens, 2003a; Page et al., 2003; Francis et al., 2007). In contrast to the conventional reciprocal model (Posamentier and Vail, 1988), these authors found that maximum siliciclastic fluxes to the slope over the last 30 ka occurred towards the end of the last transgression (peak about 10–11 ka) as sea-level flooded the shelf. Additionally, enhanced precipitation and

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erosion driven by changes in monsoon hydrologic cycle during the early Holocene (Nanson et al., 1991; Nott and Price, 1994, Goodbred and Kuehl, 2000) could also have contributed to the siliciclastic pulse occurring during the shelf flooding. However, the role of submarine canyons in the processes operating within this transgressive shedding model has never been studied. This is in part because of the lack of detailed information about the structure and morphology of the sediment pathways from the shelf-to-basin (i.e. submarine canyons).

In this study, we present the most complete and high-resolution bathymetric dataset, integrated with existing GLORIA side-scan sonar images (Hughes Clarke, 1994), to provide the first detailed picture of the submarine canyons adjacent to the extensive Ribbon Reefs, here called the Ribbon Reef Canyons (RRCs), on the northern Great Barrier Reef (GBR) margin. We quantitatively describe the key geomorphologic characteristics of the submarine canyons and other related features, and discuss the processes involved in their origin, evolution, the controlling factors, and sedimentary activity. Sediments from the GBR contain geochemical and paleontological signatures of past climatic and environmental conditions, and are funnelled through the canyons to form part of the sedimentary record in the RRC system. This study provides a morphologic framework for future detailed research, and contributes to understanding the role of canyons in trapping shelf sediments and transport into the adjacent deep basin.

2. Regional physiography and sedimentology

The north-eastern Australia margin is a passive continental margin extending between about 14°S and 20°S latitude and 145°E and 150°E longitude (Fig. 1). This area can be divided into three broad physiographic regions: 1) the continental shelf and Great Barrier Reef; 2) the Queensland and Townsville Troughs, including the slope and basin environments; and 3) the Queensland Plateau, an isolated carbonate reef platform (Davies et al., 1991, Heap and Harris, 2008).

The study area lies in the northern part of the margin adjacent to an extensive shelf-edge barrier system, called the Ribbon Reefs (Fig. 2). These reefs are elongate, up to 28 km long (Hopley et al., 2007), and are separated by narrow inter-reef passages. Here, the shelf is relatively narrow (<50 km), with the shelf-break located at

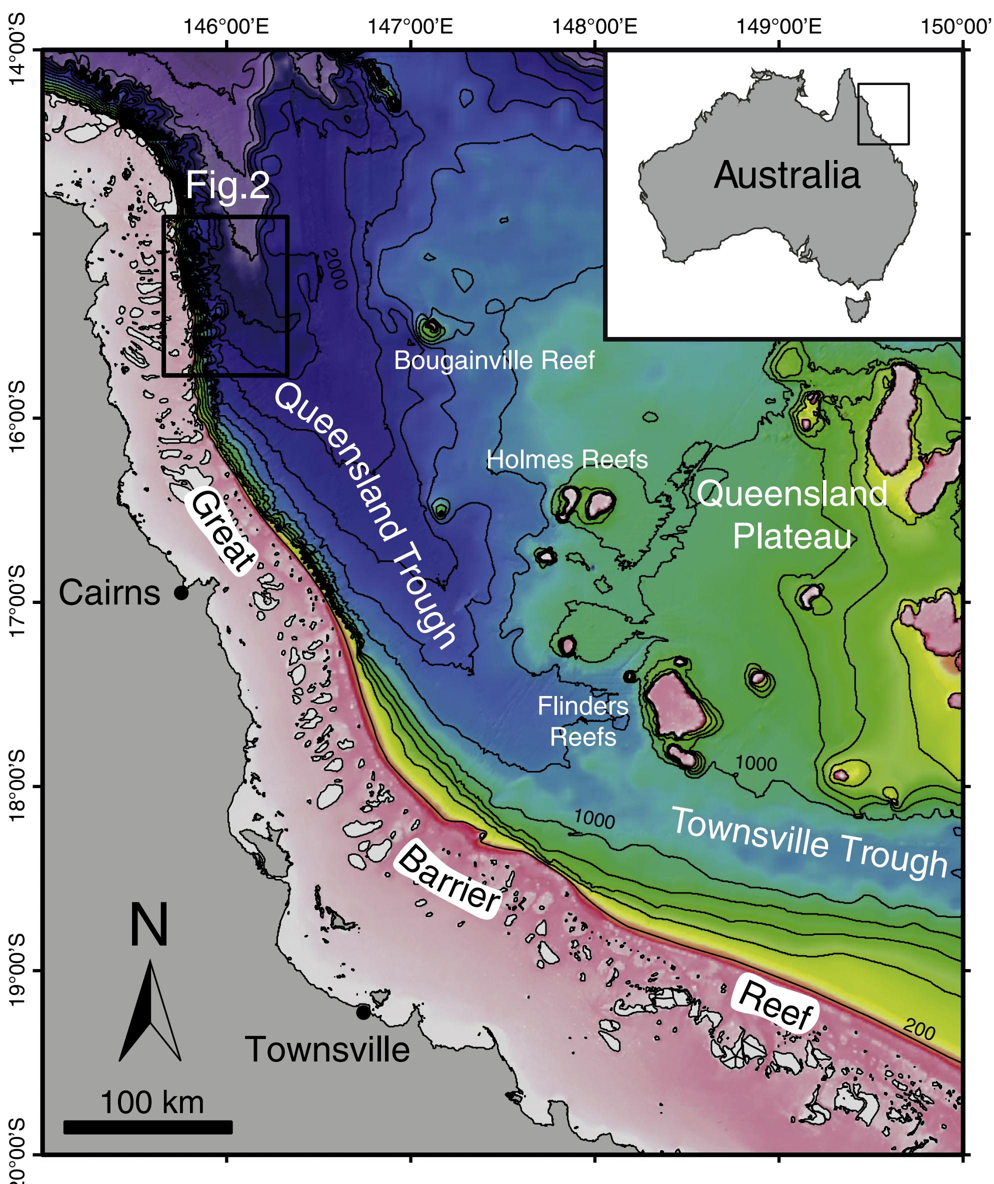

Fig. 1. General bathymetry (contours at 200 m intervals) of the northern Queensland margin showing the main physiographic regions: the Great Barrier Reef, Queensland and Townsville Troughs, and the Queensland Plateau. Inset shows the location of the study area in north-eastern Australia.