Earth-Science Reviews 153 (2016) 274–300

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

From the highest to the deepest: The Gaoping River–Gaoping Submarine Canyon dispersal system

James T. Liu [a,*], Ray T. Hsu [a], Jia-Jang Hung [a], Yuan-Pin Chang [a], Yu-Huai Wang [a], Rebecca H. Rendle-Bühring [b], Chon-Lin Lee [c], Chih-An Huh [d], Rick J. Yang [a]

[a] Department of Oceanography, National Sun Yat-sen University, Kaohsiung 80424, Taiwan ROC
[b] Department of Geosciences, University of Bremen, PO Box 330440, D-28334 Bremen, Germany
[c] Department of Marine Environment, National Sun Yat-sen University, Kaohsiung 80424, Taiwan ROC
[d] Institute of Earth Sciences, Academia Sinica, Taipei, 11529, Taiwan ROC

A R T I C L E I N F O

Article history:
Received 2 September 2014
Received in revised form 22 September 2015
Accepted 27 October 2015
Available online 30 October 2015

Keywords:
Small mountainous river
Submarine canyon
Typhoon
River flood
Hyperpycnal flow
Turbidite
Terrestrial sediment
Hemipelagic sediment

A B S T R A C T

There are many different source-to-sink dispersal systems around the world, and the Gaoping River (GPR)–Gaoping Submarine Canyon (GPSC) provides an example especially as a canyon-captured system. The GPR, a small mountainous river having an average gradient of 1:150, and the GPSC, which links the river catchment to the deep-sea basin, represent two major topographic features around SW Taiwan. Together, they constitute a terrestrial-to-marine dispersal system that has an overriding impact on the source-to-sink transport of sediment in this region. The GPSC extents from the mouth of the GPR through the shelf and slope and into the northeastern Manila Trench, a distance of about 260 km. It is a major conduit for the transport of terrestrial sediment and carbon to the South China Sea and the landward transport of particles of marine and biological origin.

In the GPSC the dominant mode of suspended-sediment transport is tidal oscillations and the net direction is up-canyon. In contrast, sediment transport associated with episodic gravity-driven events is down-canyon. The steady sedimentation of the tidal regime results in hemipelagic mud across the canyon floor, whereas the gravity-driven (hyperpycnal) regime causes turbidite erosion and deposition along the canyon thalweg.

Typhoon-induced river floods often lead to hyperpycnal plumes at the river mouth, which directly and indirectly ignite hyperpycnal turbidity currents in the canyon forming an effective agent for transporting large amounts of terrestrial organic material (modern and fossil carbon) to the South China Sea basin. Therefore, the GPR–GPSC represents a source-to-sink system in which terrestrial sediment in a mountainous catchment is promptly removed and transported to the deep sea by episodic gravity flows. This is also a pathway by which modern terrestrial organic carbon is quickly and effectively delivered to the deep sea.

Contents

* Corresponding author.
E-mail address: james@mail.nsysu.edu.tw (J.T. Liu).

http://dx.doi.org/10.1016/j.earscirev.2015.10.012

1. Introduction

In a sediment-routing system the erosion of mountainous regions and the final deposition are linked when the sediment is moved from its source to its sink (Allen, 2008). Globally the amount of sediment delivered to the oceans by rivers is influenced by tectonic processes, which control the topography along the sediment-routing system, and by the climate, which controls the weathering and erosion in river catchments (Allen, 2008).

There is a great diversity of sediment-routing systems in the world, which have a range of source and sink characteristics on continental margins (Walsh and Nittrouer, 2009). There are numerous examples including systems on passive continental margins such as the Po River (Fox et al., 2004; Traykovski et al., 2007), the Amazon River (Nittrouer and DeMaster, 1996), the Mississippi River (Bianchi and Allison, 2009), the Yangtze River (Changjiang), and the Yellow River (Huanghe). Some of these systems form active deltas (Bianchi and Allison, 2009; Saito et al., 2001; Wu et al., 2007). Examples on active continental margins include the Ganges-Brahmaputra River (Goodbred, 2003), and the Eel River (Warrick, 2014). Along the Pacific Rim there are small mountainous rivers on high standing islands, such as the Lanyang, Zhuoshui, and Gaoping in Taiwan (Liu et al., 2009b, 2013) and the Waipaoa River in New Zealand (Kuehl et al., in this volume; Marsaglia et al., 2010; Parra et al., 2012). A great majority of these rivers flow into a bay or a gulf and wide or narrow shelves. There is another kind of sediment-routing system that includes river-associated submarine canyons (Baker and Hickey, 1986; Choi and Wilkin, 2007; Hsu et al., 2014; Lopez-Fernandez et al., 2013; Palanques et al., 2005; Walsh and Nittrouer, 2009), which comprise only 2.62% of all the 4025 submarine canyons in the world (Harris and Wihteway, 2011). Most of these submarine canyons are separated from their associated river mouths by a portion of the continental shelf (Liu and Lin, 2004). Only in rare cases does the submarine canyon head reach into or very near the mouth of the river, such as the Sepik River (Kineke et al., 2000), the Biobio River (Sobarzo et al., 2001), and the Gaoping River (GPR) (Liu et al., 2002).

Among all the river dispersal systems, the Gaoping is particularly interesting because there is a strong coupling between the dynamics that move the sediment and the sediment record in the system that links the catchment of a mountainous river and a submarine canyon on an active tectonic setting. The characteristics of this sediment-routing system makes it an ideal natural laboratory to study source-to-sink processes and responses across the boundaries of different environmental units within short time and space scales.

Based on topographic features, the Gaoping sediment dispersal system in southern Taiwan is geographically divided into three segments (Fig. 1A), each with its own source-to-sink implications: 1) the southern part of the Taiwan orogen (Fig. 1B); 2) the tectonically active drainage basin of the GPR which includes the Gaoping coastal plain; 3) the Gaoping Submarine Canyon (GPSC) that extends from the mouth of the GPR into the NE corner of the South China Sea basin, which is fronted by the steep slope of Taiwan Strait to the north (Yu et al., 2009).

This paper reviews the three key segments of the GPR–GPSC system and discuss their influence on the form and function of this dispersal system. The emphasis is on the process–response linkages between sediment processes and the associated geochemical signals carried by fine-grained sediment through the system.

2. Background

2.1. System morphology

The GPR is the largest river in Taiwan in terms of drainage area (3257 km^2) and the second largest in terms of suspended-sediment load (49 MT per year) (Liu et al., 2009a) (Fig. 2A). The headwater of the GPR is located in the southern part of the Central Range near Mt. Jade (Yu-Shan) whose elevation is 3952 m above sea level (Fig. 2B). It is a small mountainous river, with 48% of its drainage basin above 1000 m, 32% between 100 and 1000 m, and 20% below 100 m (Liu et al., 2009a). Consequently, the riverbed gradient is 1:15 in the upper reaches, 1:100 in the middle reaches, and 1:1000 in the lower reaches, with an average of 1:150 (Fig. 2C, Liu et al., 2009a).

Located ~1 km from the mouth of the GPR, the head of the GPSC cuts across the narrow Gaoping shelf and slope, and merges into the northern end of the Manila Trench about 260 km away (Yu et al., 2009, Fig. 1C). The morphology of the canyon is closely affected by the intrusions of mud diapers in the upper reaches and thrust faulting in the middle and lower reaches of the canyon (Chiang and Yu, 2006). High and steep walls characterize the head region of the canyon (Yu et al., 1993). The canyon has relief exceeding 600 m, with a cross-sectional geometry varying from V-shaped to broadly U-shaped +/− irregular troughs (Chiang and Yu, 2006, 2011). The formation of this submarine canyon was controlled by the tectonic evolution of the arc-continent collision between the Chinese continental margin and the Luzon volcanic arc, which generated many structural deformations in the Taiwan accretionary wedge, including the GPSC (Liu et al., 1997).

2.2. Strong forcing: typhoons and earthquakes

In addition to tectonic deformation, typhoons and earthquakes are two major factors that affect the system (Liu et al., 2013). On average, approximately four typhoons pass through Taiwan per year (Liu et al., 2013). Among the historical typhoons, 23% were from the western Pacific Ocean, and 13% were from the SCS (Liu et al., 2013). Typhoons can affect the system when still hundreds of kilometers away by bringing marine-sourced foraminifera into the upper reaches of the GPSC.