Marine Geology 315–318 (2012) 29–43

Contents lists available at SciVerse ScienceDirect

Marine Geology

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

Efficient transport of terrestrial particulate carbon in a tectonically-active marginal sea off southwestern Taiwan

J.-J. Hung [a,*], Y.-T. Yeh [a], C.-A. Huh [b]

[a] Institute of Marine Geology and Chemistry, Asian-Pacific Ocean Research Center, National Sun Yat-sen University, Kaohsiung, Taiwan, ROC
[b] Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, ROC

ARTICLE INFO

Article history:
Received 26 July 2011
Received in revised form 28 February 2012
Accepted 28 May 2012
Available online 13 June 2012

Communicated by G.J. de Lange

Keywords:
particulate organic carbon
particulate inorganic carbon
source-to-sink
burial efficiency
benthic flux
Gaoping River

ABSTRACT

This study investigates the fluvial and marine burial fluxes of particulate carbon in the source-to-sink system of the mountainous Gaoping (GP) river system to elucidate the efficient transport of terrestrial particulate carbon via a submarine canyon in an active margin. The river fluxes of total suspended matter (TSM), particulate organic carbon (POC) and particulate inorganic carbon (PIC) were much higher in the wet season than in the dry season, mainly because of extremely high sediment yield associated with typhoons in the summer. The TSM, POC and PIC were carried mainly in <63 μm particles and showed difference in size distribution between the dry and wet seasons for TSM and POC but not for PIC. The river transported around 226 Gg C yr^{-1} POC (64% particulate carbon (PC)) and 125 Gg C yr^{-1} PIC (36% PC) into the Gaoping coastal sea during the study period. The POC flux accounts for only 0.074−0.164% of the global river flux, but the POC yield (69.2 ton C $km^{-2}yr^{-1}$) is about one order of magnitude higher than the global average, and may be the second highest among global small mountainous rivers. If integrated over an area of 3045 km^2 around the Gaoping Canyon with a maximum water depth of 1500 m, the mean burial fluxes of total organic carbon (TOC) and inorganic carbon (TIC) were 13.0 g C $m^{-2}yr^{-1}$ and 9.5 g C $m^{-2}yr^{-1}$, respectively. The buried PC comprised ~58% TOC (39.6 Gg C TOC yr^{-1}) and ~40% TIC (28.9 Gg C TIC yr^{-1}). From the isotopic composition ($\delta^{13}C$) of TOC in the surface sediments, around 62% of the TOC was estimated to be sourced from the river. The diagenetic and benthic flux of dissolved carbon (DIC + DOC) may account for 18.1% of the deposited TOC flux or 12.9% of the deposited total carbon (TOC + TIC) flux. The burial efficiency of terrestrial TOC was therefore estimated to be only 10.9% of the riverine POC input. Despite the lack of direct evidence, the ratio of buried terrestrial TIC to riverine PIC input may be roughly equal to that of terrestrial TOC, as river POC/PIC and sedimentary TOC/TIC ratios did not differ significantly from each other. The low accumulation of terrestrial sediment and particulate carbon suggests that most POC and PIC that were derived from the Gaoping River may have been recycled and/or moved out of the study area. The active margin associated with the canyon appears to act as an efficient conduit for the transfer of terrestrial POC and PIC into the deep ocean.

1. Introduction

The fate of terrestrial and marine organic carbon (OC) as well as carbonate in the continental margin is crucial to understanding the global carbon cycle, as the continental margin usually receives high autochthonous (marine) and allochthonous (terrestrial) carbon inputs and plays an important role in modulating ocean elemental cycles (Walsh, 1991; Wollast, 1991; Ducklow, 1995; Mackenzie et al., 1998; Liu et al., 2000, 2010). Many studies have established that riverine and marine organic carbon and carbonate are transformed and buried on the continental shelf and little is transported into the deep sea under the present sea level condition (Berner, 1982, 1989; Wollast, 1991; Hedges, 1992; Smith and Hollibaugh, 1993; Hedges and Keil, 1995; Hedges et al., 1997). Other studies, however, have shown that terrestrial and marine sediments as well as carbon were largely accumulated on the continental slope and rise in the NE and NW Atlantic margins (Anderson et al., 1988, 1994; Biscaye et al., 1994; Bianchi et al., 1997; van Weering et al., 1998, 2002; Jouanneau et al., 2002) and margins located elsewhere (Lin et al., 1992; Reimers et al., 1992; Buscail and Germain, 1997; Blair et al., 2004; Inthorn et al., 2006). Nevertheless, Brunskill et al. (2002) reported very low accumulation rates of sediment, organic carbon and carbonate carbon in the Great Barrier Reef lagoon shelf and slope, because of intensive algal and microbial respiration. Therefore, the extent of the accumulation and burial of organic carbon and carbonate in continental margins is highly site specific and is determined by the interplay between numerous factors including river fluxes, margin types and oceanic forcing. Burdige (2005) estimated the global burial of terrestrial carbon in continental margin sediments to be 58 ±

* Corresponding author. Tel.: +886 7 5255147.
E-mail address: hungjj@mail.nsysu.edu.tw (J-J. Hung).

0025-3227/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.margeo.2012.05.006

17 Tg C yr^{-1}, accounting for <20% of the global river flux of TOC (370–434 Tg C yr^{-1}) (Meybeck, 1993; Schlünz and Schneider, 2000).

Terrestrial OC and carbonate are delivered to the ocean primarily through rivers. Globally, approximately 35% of POC may come from small mountainous islands of the Pacific Rim (Lyons et al., 2002) or up to 50% of OC and carbonate may come from Oceania and other tropical rivers (Schlünz and Schneider, 2000). It is also well known that many small mountainous rivers can deliver terrestrial materials through narrow margins and/or deep canyon systems without deposition onto the coastal zone (Milliman and Syvitski, 1992; Blair et al., 2004; Liu et al., 2008). The Gaoping River originates from Mt. Yu-shan (3952 m a.s.l.), the highest mountain in Taiwan's Central Range. The river's watershed area (3257 km^2) is of the largest in Taiwan and much of it is covered by forest and agricultural lands. This mountainous river's catchment is subject to an extremely high physical weathering rate, resulting in a sediment yield (3600 g m^{-2} yr^{-1}) that greatly exceeds the mean (150 g m^{-2} yr^{-1}) for global rivers (Hung et al., 2009). According to Dadson et al. (2003), the river delivered 49 Mton of suspended sediment annually into the sea off southwestern Taiwan, particularly during the typhoon periods in the summer. This tectonically active margin features a narrow shelf and the GP Canyon. Extending almost from the mouth of the GP River into the Manila Trench in the South China Sea, the GP Canyon is an effective conduit for terrestrial sediment between the shelf and deep ocean (Liu et al., 2002; Yu et al., 2009). Undoubtedly, the GP Canyon plays an important role in determining the fate of PC in this river–sea system.

Following the discharge of the expectedly large amounts of terrestrial POC and PIC, their fates in this active margin will have profound impact on the carbon cycling and carbon budget in the system. Export fluxes of POC and PIC from the GP River can be estimated from the river's sediment load (Huh et al., 2009; Hung et al., 2009) and relevant chemical analyses. This study aims at measuring river fluxes of POC and PIC and their deposition, mineralization and burial in the GP continental shelf and slope. A conceptual model is proposed to decipher the fate of particulate carbon in this active margin from a source-to-sink perspective.

2. Materials and methods

2.1. Study area and sampling sites

Samples used for this work were taken from a river station (Wann-Ta Bridge) in the lower reaches of the GP River and over the GP continental shelf and slope (Fig. 1) where 14 box cores and more surface sediments were collected and used for this study. The sediment cores and surface sediments were extracted using a box corer and Shipek grab, respectively. The stations were laid out in a rectangular area of 3045 km^2 (Fig. 5) and distributed at various depths along the canyon and across the shelf/slope area to facilitate budget calculations. Seawater samples were also taken from the box core stations at 5 meters above bottom (5-mab) for the determination of dissolved organic carbon (DOC) and inorganic carbon (DIC) concentrations.

2.2. Sampling and pretreatment

Biweekly river water samples (4 l in size) were taken year round from the Wann-Ta Bridge Station for the measurements of total suspended matter (TSM), POC and PIC. In addition, large-volume (15 l) samples were taken regularly in the dry and wet seasons and especially during the typhoon periods to recover enough TSM for partitioning into different size classes for more detailed analyses (Table 1). The size-fractionated particles of each TSM sample were separated (10–63, 63–153 and >153 μm) using a "CATNET" sampler (Ho et al., 2007) followed by filtration through either Nucleopore PC filters to determine TSM contents or precombusted glass-fiber filters to determine POC and PIC contents in various size fractions (0.3, 0.7 and 2.7 μm). Annual fluxes of TSM, POC and PIC from the GP River were estimated by summing the monthly fluxes which were calculated by multiplying mean monthly concentrations by mean monthly discharge obtained from the Water Resource Bureau of Taiwan (Water Resources Bureau, 2007).

Sediment cores were sub-sampled immediately following the retrieval of box cores. Subcores taken with cylindrical plastic liners

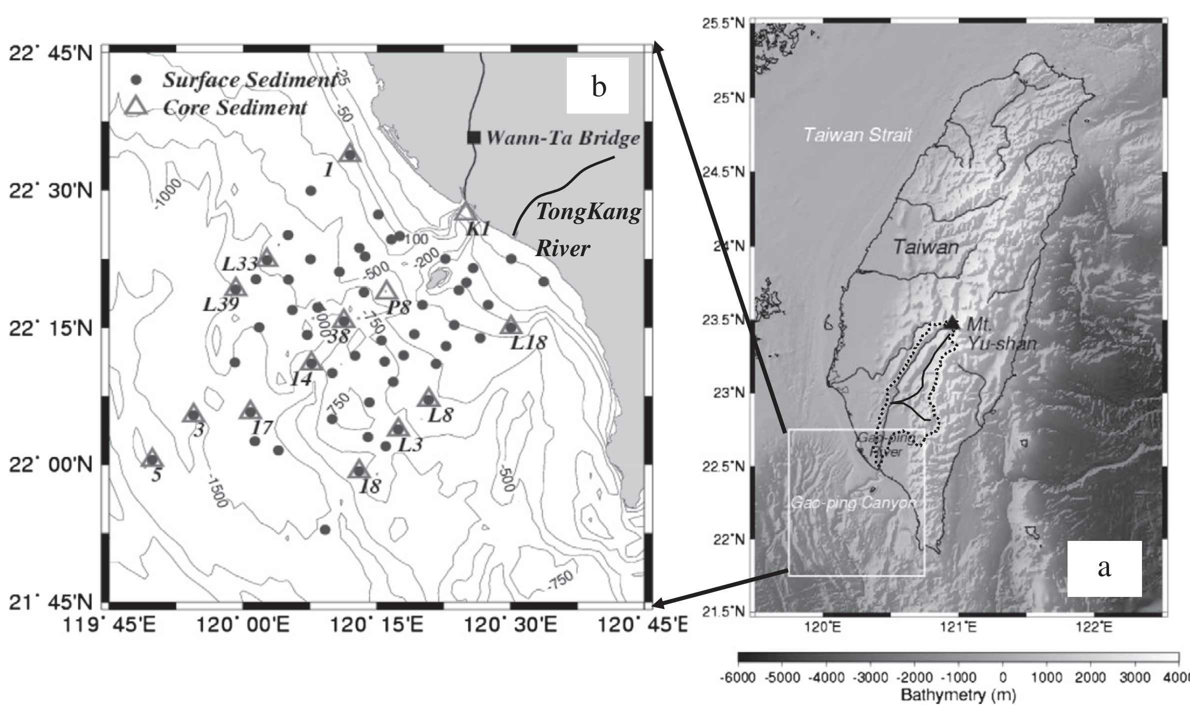

Fig. 1. Map showing the Gaoping River's drainage basin (marked with dotted line) and the study area off southwestern Taiwan (a), and sampling locations in the lower reaches of the GP River (Wann-Ta Bridge) and numerous sediment sampling sites (b).