Marine and Petroleum Geology 96 (2018) 331–347

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Stratigraphic modeling of the Western Taiwan foreland basin: Sediment flux from a growing mountain range and tectonic implications

Stefan Nagel[a], Didier Granjeon[b], Sean Willett[a], Andrew Tien-Shun Lin[c], Sébastien Castelltort[d,*]

[a] Department of Earth Sciences, ETH Zürich, Sonneggstrasse 5, 8092, Zürich, Switzerland
[b] IFP Energies Nouvelles, Rueil-Malmaison, Paris, France
[c] Department of Earth Sciences, National Central University, 300 Jungha Road, Chungli, Taoyuan 101, Taiwan
[d] Department of Earth Sciences, University of Geneva, Rue des Maraichers 13, 1205, Geneva, Switzerland

ARTICLE INFO

Keywords:
Taiwan
Foreland basin
Tectonic sedimentology
Arc-continent collision
Stratigraphic modeling
Erosion
Sedimentation

ABSTRACT

Sediment flux signals from source to sink in foreland basins preserve a record of tectonics, sea level and climate through erosion and sedimentation. However, longitudinal sediment transport often occurs in foreland basins, thus removing part of the orogenic material flux from foreland basin records. Here we use mass balance calculation and stratigraphic simulations of sediment fluxes for the Taiwan orogen to provide an order of magnitude estimate of how much orogenic material may bypass a foreland basin. Our results indicate a significant, potentially more than 50%, mismatch between sediment volume currently preserved in the basin and the amount of material presumably eroded from the orogen since the onset of collision in Taiwan. This suggests either a significant overestimation of average erosion rates over the period concerned with orogenic development of Taiwan, or it supports previous paleogeographic work suggesting that longitudinal sediment transport in the paleo-Taiwan Strait served as a major bypass conduit of importance for the establishment of a steady state orogen. We identify candidate submarine topography in the South China Sea that may preserve Taiwan's missing erosional mass.

1. Introduction

Sediment fluxes within foreland basins exert a primary control on basin architecture involving interactions between tectonics, sea level and climate through erosion and sedimentation (e.g., Allen et al., 2013; Castelltort et al., 2015; Flemings and Jordan, 1989; Posamentier and Allen, 1993). The orogenic history of many ancient basins has been reconstructed with help of sedimentary records, such as in the Alps (Garzanti et al., 2004; Lihou and Allen, 1996), Pyrenees (Puigdefàbregas et al., 1992; Vergés and Burbank, 1996), or Himalayas (Garzanti et al., 2005; White et al., 2002), but it is still not well known how much of the orogenic history is eventually preserved and how tectonics, facies and sediment supply to basins are linked (Castelltort et al., 2015; Romans et al., 2016).

The western foreland basin in Taiwan (Fig. 1A) is a particularly suitable place to study interactions between tectonics and sediment fluxes because it is very young (5–6 Ma) and still very active (modern seismicity and extreme climate conditions). In this basin, southwestward ongoing oblique collision between the Luzon volcanic arc and the continental shelf of Eurasia (OCT: Ocean-Continent Transition in Fig. 1A) makes it possible to record the full evolution of basin deformation (e.g., Suppe, 1981; Covey, 1984; Lin et al., 2003) and provides an opportunity to connect tectonics and depositional processes at different stages of the basin's evolution. The western foreland of Taiwan is the historical basin where the classical foreland filling sequence was first described by Covey (1984, 1986). Indeed, the basin evolved from an early underfilled stage with relatively deep-water sedimentation (now observable in the modern setting in the South of the orogen) to a late balanced-filled stage, where shallow marine environments persist until today (most of modern Taiwan Strait, Covey, 1984), despite the enormous amount of sediment supplied to the ocean by the rising Taiwan mountains (Milliman and Kao, 2005; Milliman and Syvitski, 1992). In that sense, Taiwan orogen is emblematic of the distinct classical evolutionary stages (underfill to overfill, flysch to molasse) that characterize many ancient foreland basin systems such as in the Molasse basin of the Alps (Allen et al., 1991), the Bradanic Trough in the Apennines (Tropeano et al., 2002), the Solomon Sea in Papua New Guinea (Silver et al., 1991) or the South-Pyrenenan foreland basin (Puigdefabregas and Souquet, 1986). As a consequence of the oblique collision, the basin records a time-transgressive southwestward oriented migration of facies belts (e.g., Covey, 1984; Chen et al., 2001a, 2001b; Nagel et al., 2013) and sediment depocenters

* Corresponding author.
E-mail address: sebastien.castelltort@unige.ch (S. Castelltort).

https://doi.org/10.1016/j.marpetgeo.2018.05.034
Received 11 August 2017; Received in revised form 18 May 2018; Accepted 31 May 2018

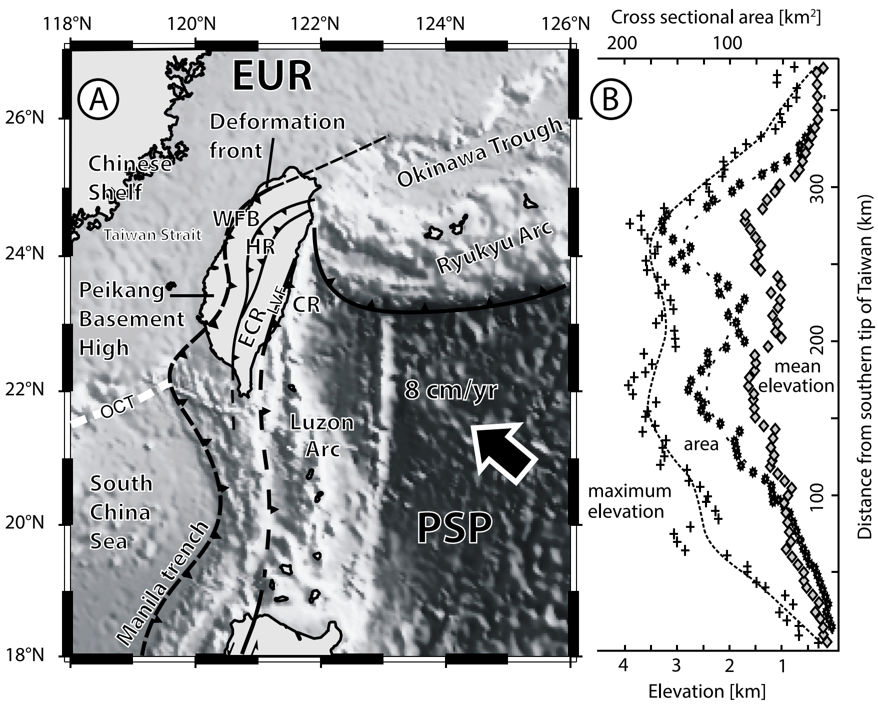

Fig. 1. Geodynamic context of the collision in Taiwan and along-strike morphology. A) The plate context and main structural units in Taiwan. Note the overall obliquity between the Luzon Arc - Manila Trench system and the Eurasian margin (OCT). PSP: Philippine Sea Plate; EUR: Eurasian Plate; WF: western Foothills; HR: Hsüehshan Range; ECR: Eastern Central Range; LVF: Longitudinal Valley Fault; CR: Coastal Range; OCT: Ocean–Continent Transition. B) Longitudinal evolution of maximum elevation, mean elevation and cross-sectional area of the orogen (modified after Stolar et al., 2007, Suppe, 1981). The "plateau" of all three parameters displayed by the central segment of the orogen suggests that the mountain belt has reached a constant size and height despite the longer collisional history in the North compared to the South. Based on this assumption, Suppe (1981) among others have suggested that the orogen is at steady state, i.e. has reached a critical size for which tectonic influx of material is in overall balance with erosion. Decreasing elevation in the North is due to mountain range collapse associated with propagation of the extensional regime of the Okinawa Through. In the South, the orogen is still growing, has not reached steady state, hence the tapering elevation and decreasing width.

(Simoes and Avouac, 2006), similar to other oblique collisions such as in Papua New Guinea (Abbott et al., 1994; Silver et al., 1991), but the details of the geometry of the initial collision at the scale of Taiwan are still ambiguous and several models have been proposed. Whereas some models favor an arc-continent collision (Huang et al., 2006; Suppe, 1984, 1988; Teng, 1990), others suggested a two stage collision of an exotic block with the Eurasian continental margin and a second collision of Luzon volcanic arc with the passive margin (Lu and Hsü, 1992), or an arc-arc collision between Luzon volcanic arc and a paleo-Ryukyu arc system extending to the west of Taiwan (Seno and Kawanishi, 2009; Sibuet and Hsu, 1997; Sibuet et al., 1995), or even that collision may have happened synchronously along the margin at the scale of Taiwan (within a larger scale context of obliquity between EUR and PSP, Fig. 1A, Castelltort et al., 2011; Lee et al., 2015).

From an orogenic point of view, Taiwan has been proposed as a possible illustration of topographic steady state in a critical orogenic wedge because it shows an approximately constant width of 90 km (Suppe, 1981; Stolar et al., 2007) and elevations and cross-sectional area plateau in the central segment of the belt (Fig. 1B). Indeed, if it was not at steady state, the orogen should be wider in the North where collision started earlier, and progressively narrower southwards. Instead the cylindrical shape of the orogen suggests that it has reached a critical size and slope. As a consequence, Taiwan orogen has been taken as an emblematic example of a steady state orogen in which erosional processes are able to balance uplift rates. As a note of caution some authors have explained that while the idea of steady state generally applies at large-scale in Taiwan, high-frequency climate oscillations linked to orbital climate shifts may well prevent the establishment of pure steady state at all scales (e.g., Whipple, 2001). Additionally, the Western foredeep itself also eventually reached a steady state size where accommodation space stayed constant despite the large sediment fluxes from Taiwan mountains (Covey, 1984, 1986). Therefore Covey (1986) suggested that sediment bypass out of the basin must have been an important factor that balanced accommodation space and sediment supply, maintaining the basin shallow marine, and preventing it from becoming overfilled or even fully terrestrial.

The aim of this paper is to test, within the frame given by tectonic (plate boundaries configuration and timing, basin evolution) and geomorphic (steady state, erosion and sediment supply rates) constraints exposed above, the plausibility and magnitude of sediment bypass and to discuss implications for understanding foreland basins architecture within a well constrained source-to-sink setting. To do this, we use 3D stratigraphic simulations with different tectonic scenarios and we try to compare them with seismic lines from the Taiwan Strait to evaluate the match between simulations and observations. These simulations show how different tectonic settings control the stratigraphic evolution of the foreland basin, and allow to quantify sediment budget for the source-to-sink system. Results emphasize a significant mismatch between preserved volumes in the foreland with respect to volumes predicted given inferred erosion rates and topographic development. We discuss the implications of these contradictions for the importance of longitudinal sediment transport in foreland basins.

2. General setting and background

2.1. Geology and tectonics

The Taiwan mountains, rising almost 4 km above sea level, formed by collision between Philippine Sea plate and Eurasian continent shelf (Figs. 1A and 2). Arc volcanism associated with subduction below the Philippine sea plate ceased between 6 Ma and 3 Ma, when the arc resisted subduction and collided with the Asian passive margin to form an initial accretionary wedge (Huang et al., 2006; Yang et al., 1995). In most recent studies, arc-continent collision is estimated to have initiated in late Pliocene (Nagel et al., 2013; see discussion below). This is based on observing a continuous sandstone provenance shift and increasing illite crystallinity, interpreted to represent progressive unroofing and recycling of the metamorphic orogenic belt (Dorsey and Lundberg, 1988; Nagel et al., 2013). Oblique collision between the N-S trending Luzon volcanic arc and the NE-SW trending passive margin resulted in southwest propagating collision (e.g., Nagel et al., 2013; Simoes and Avouac, 2006; Suppe, 1981; Teng, 1990), with modern collision point presently located offshore SW Taiwan (Lin et al., 2008; Yu and Huang, 2009). Today, the southernmost tip of Taiwan, which exhibits transient landscape features (Giletycz et al., 2015), represents the youngest relief associated with the emerging orogen. Oceanic lithosphere in the South China Sea is currently being subducted below the Philippine sea plate along the Manila Trench (Fig. 1A) whereas the