Journal of Asian Earth Sciences 62 (2013) 180–204

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

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

Sedimentology and foreland basin paleogeography during Taiwan arc continent collision

Stefan Nagel [a,*], Sébastien Castelltort [a,b], Andreas Wetzel [c], Sean D. Willett [a], Frédéric Mouthereau [e], Andrew T. Lin [d]

[a] Department of Earth Sciences, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland
[b] Department of Earth Sciences and Environment, University of Geneva, Rue des Maraîchers 13, 1205 Genève, Switzerland
[c] Geological–Paleontological Institute, University of Basel, Bernoullistrasse 32, 4056 Basel, Switzerland
[d] Department of Earth Sciences, National Central University, 300 Jungda Road, Chungli, Taoyuan 101, Taiwan
[e] Université Pierre et Marie Curie, ISTEP, UMR 71934, Place Jussieu, 75252 Paris Cedex 05, France

ARTICLE INFO

Article history:
Received 9 March 2012
Received in revised form 20 August 2012
Accepted 3 September 2012
Available online 19 September 2012

Keywords:
Foreland basin
Taiwan
Paleogeography
Lithofacies
Sedimentary environment
Oblique collision

ABSTRACT

The Western foreland basin in Taiwan originated through the oblique collision between the Luzon volcanic arc and the Asian passive margin. Crustal flexure adjacent to the growing orogenic load created a subsiding foreland basin. The sedimentary record reveals progressively changing sedimentary environments influenced by the orogen approaching from the East. Based on sedimentary facies distribution at five key stratigraphic horizons, paleogeographic maps were constructed. The maps highlight the complicated basin-wide dynamics of sediment dispersal within an evolving foreland basin.

The basin physiography changed very little from the middle Miocene (∼12.5 Ma) to the late Pliocene (∼3 Ma). The transition from a passive margin to foreland basin setting in the late Pliocene (∼3 Ma), during deposition of the mud-dominated Chinshui Shale, is dominantly marked by a deepening and widening of the main depositional basin. These finer grained Taiwan derived sediments clearly indicate increased subsidence, though water depths remain relatively shallow, and sedimentation associated with the approach of the growing orogen to the East.

In the late Pleistocene as the shallow marine wedge ahead of the growing orogen propagated southward, the proximal parts of the basin evolved into a wedge-top setting introducing deformation and sedimentation in the distal basin. Despite high Pleistocene to modern erosion/sedimentation rates, shallow marine facies persist, as the basin remains open to the South and longitudinal transport is sufficient to prevent it from becoming overfilled or even fully terrestrial.

Our paleoenvironmental and paleogeographical reconstructions constrain southward propagation rates in the range of 5–20 km/Myr from 2 Ma to 0.5 Ma, and 106–120 km/Myr between late Pleistocene and present (0.5–0 Ma). The initial rates are not synchronous with the migration of the sediment depocenters highlighting the complexity of sediment distribution and accumulation in evolving foreland basins.

1. Introduction

Foreland basins are mechanically coupled to orogens and store in their sedimentary archives most of the history of mountain building (Beaumont, 1981). The relationship between the tectonic evolution of a mountain range and sedimentation in its foreland has been extensively analyzed in different convergent basin systems around the world, e.g. Taiwan (Covey, 1984b; Teng, 1990), the Pyrenees (Burbank et al., 1992; Puigdefàbregas and Souquet, 1986), the European Alps (Allen et al., 1991) and the Himalayas (Burbank et al., 1988).

The Western foreland basin in Taiwan preserves an exceptionally detailed record of the Miocene–Pliocene–Pleistocene collision, exhumation and erosion of a young and active orogen (Fig. 1). The foreland basin infill comprises a 7–9 km thick succession of pre-orogenic and syn-orogenic Cenozoic strata (Lin and Watts, 2002; Lin et al., 2003; Yu and Chou, 2001). Geological and geophysical evidences suggest that part of this succession consists of siliciclastic facies that reflect the basin development from an early underfilled stage to a late steady-state stage. According to Covey (1986), mass balance calculations indicate a mismatch between sediment volume currently preserved in the basin and the amount of expected material eroded from the orogen since the onset of collision (based on an erosion rate of 5.5 km/Ma and a southward orogen area development since 3 Ma). Thus Covey (1986) suggested

* Corresponding author. Tel.: +41 446322365.
E-mail address: stefan.nagel@erdw.ethz.ch (S. Nagel).

1367-9120/$ - see front matter
http://dx.doi.org/10.1016/j.jseaes.2012.09.001

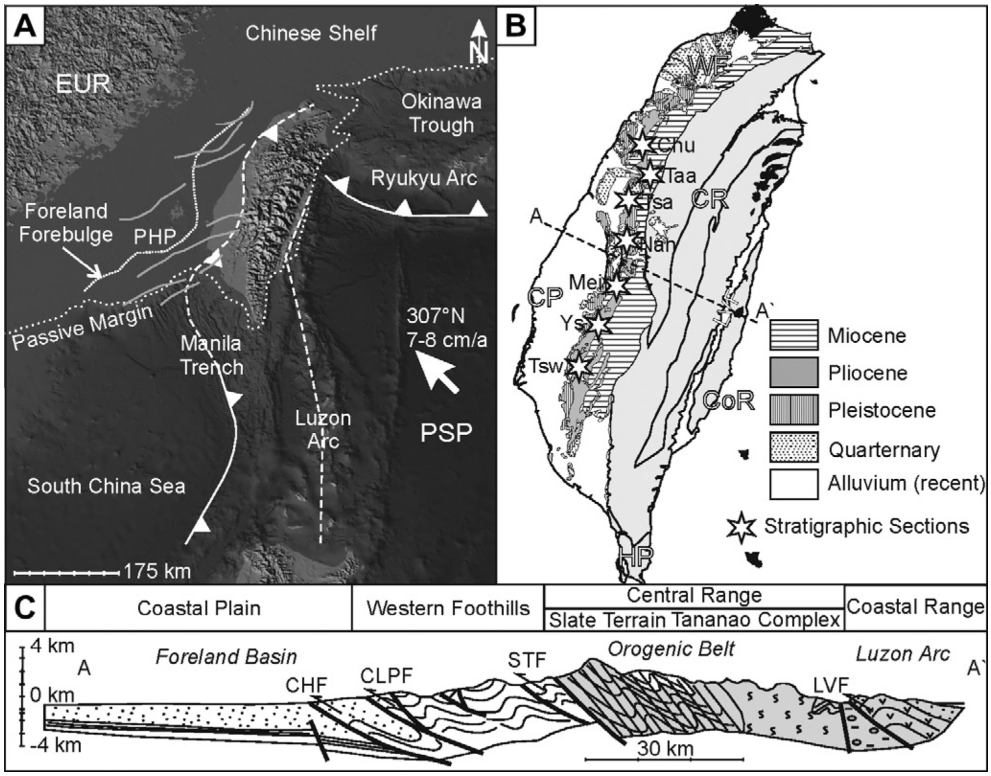

Fig. 1. (A) Plate tectonic configuration of the Taiwan area. The collision zone in Taiwan is divided into three main domains: Ryukyu arc-trench system and the associated Okinawa trough, an extensional basin as a result of the collision and subduction of the Philippine Sea plate; Luzon volcanic arc and Manila trench in the south; pre-collisional Eurasian continental shelf break. EUR = Eurasian continental plate, PSP = Philippine sea plate, PM = 200 m isobath (= recent shelf break), FF = foreland forebulge (Lin et al., 2003), PHP = Peikang High, (B) Geological provinces (Ho, 1988) and measured stratigraphic sections, CP = Coastal Plain, WF = Western Foothills, CR = Central Range, CoR = Coastal Range, HP = Hengchun Peninsula, LVF = Longitudinal Valley Fault, Chu = Chuhuangkeng, Taa = Taan River, Tsa = Tsaohuchi River, Nan = Nantou, Mei = Meishan, Ys = Yunshuichi, Tsw = Tsengwenchi and (C) Schematic cross section of Taiwan, CHF = Changhua fault, CLPF = Chelungpu fault, STF = Shuangtung fault (Teng, 1990).

that marine and fluvial processes "were efficient at transporting some of the debris out of the foreland basin, creating a basin of steady state size", which essentially resulted in maintaining shallow marine environment in the foredeep.

Numerous tectonic and sedimentary studies have addressed the progressive arc-continent collision (Barrier and Angelier, 1986; Chang and Chi, 1983; Chemenda et al., 2001; Covey, 1984a; Lin et al., 2003; Mouthereau et al., 2001; Sibuet and Hsu, 1997; Stephan et al., 1986; Suppe, 1981; Teng, 1990; Wang, 1987; Yu, 1993). Based on linear margin geometries Suppe (1981) first proposed that due to the obliquity between the PSP-EUR motion and the orientation of the Asian margin, the collision propagated southward at an average rate of 90 km/Myr with respect to the Luzon volcanic arc. In support of southward propagation of the collision, lithofacies analysis of the foreland basin filling shows a gradual southward deepening (Covey, 1984b), and rapid subsidence in the Southwestern part of the basin at 0.98 Ma (Hong, 1997), later than in the North (late Pliocene to early Pleistocene). In addition, isopach maps of the synorogenic series (Shaw, 1996) are indicative of a southward migration of the main foreland depocenters from late Miocene (6.5 Ma, e.g. Kueichulin fm.) to Pleistocene (1.1 Ma, e.g. Toukoshan fm.), however at an average rate of 31 + 10/−5 km/Myr (Shaw, 1996; Simoes and Avouac, 2006) much smaller than the predicted ~90 km/Myr.

This paper addresses how the southward propagation of the orogen is recorded in the sedimentary landscape evolution of the foreland basin of Taiwan. One major objective is to derive paleogeographic maps of the foreland basin at key time horizons in order to bring new constraints on the evolution of the southern propagation.

A detailed sedimentological and ichnological study of seven representative sedimentary sections in combination with literature data allows to distinguish sixteen facies grouped into seven facies associations. The sedimentary data form the base to propose a new facies model which incorporates modern data on waves from the Taiwan Strait as a means to calibrate paleobathymetry. Five facies maps were build for time slices at 12.5 ± 1.0 Ma, 5.5 ± 0.5 Ma, 3.5 ± 0.5 Ma, 2.0 ± 0.2 Ma and 0.5 ± 0.15 Ma.

These maps document the progressive shallowing of the Taiwan Strait with time as well as the progressive westward and southward migration of the coastline. The relatively slow (5–20 km/Myr) southward migration of the coastline is in agreement with depocenter migration, which demonstrates the strong control by mountain building and the related sediment dispersal system in this foreland basin on the distribution of paleoenvironments. These results add new constraints to kinematic models of plate collision in this area.

2. Geological and stratigraphic setting

The island of Taiwan is located at the plate boundary between the Eurasian plate (EUR) and the Philippine Sea plate (PSP, Fig. 1A). The PSP-EUR relative convergence velocity is of the order of 70–80 km/Myr (Seno et al., 1993) and leads to subduction of PSP beneath EUR along the Ryukyu arc trench system and opening of the Okinawa Trough backarc basin in the Northeast (Ku et al., 2009). The South China Sea is subducted along the Manila Trench, below PSP, in the West and South, which is accompanied by volcanism in the Luzon Arc. Collision of the Luzon volcanic arc (belonging to the PSP) with the EUR passive margin forms the Taiwan Mountains.

The geology of Taiwan is subdivided into four major tectonic-stratigraphic elements (Fig. 1B): The Coastal Plain (CP), the Western Foothills (WF), the Central Range (CR, Hsüehshan Range and