Journal of Asian Earth Sciences 86 (2014) 1–11

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

# Strain modes within the forearc, arc and back-arc domains in the Izu (Japan) and Taiwan arc-continent collisional settings

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ARTICLE INFO

*Article history:*
Available online 20 August 2013

*Keywords:*
Arc-continent collision
Middle crust
Intra-oceanic slivering
Mantle decoupling
Forearc subduction
Luzon arc
IBM arc

ABSTRACT

In this study, I examine the strain modes of the forearc, arc and back-arc domains in arc-continent collisional settings leading to arc material subduction, delamination and/or accretion. The study focusses on two well-documented colliding island arcs: the Izu–Bonin–Mariana (IBM) arc in Japan and the Luzon arc in Taiwan, both carried by the Philippine Sea plate. Firstly, there is a body of evidence that both the IBM and the Luzon arcs were built on the same Late Jurassic to Early Cretaceous “proto-Philippine Sea Plate” crust. Their internal structure is thus more heterogeneous than expected from Paleogene or Neogene supposedly “intra-oceanic” island arcs. Secondly, those arc systems and proximal “back-arcs” have similar seismic characteristics attesting either for the presence of a middle crust with continental velocities and/or serpentinized uppermost mantle that facilitate crustal shortening/slivering and subsequent decoupling from the rest of the subducting plate. It is shown that the proximal back-arc domain (called “rear-arc” in case of paleoarc activity), overlying the mantle wedge and the subducting slab, may lose its strength if slab-derived hydration occur. Decoupling then occurs below the Moho. Arc delamination likely occurs in mid-crustal levels because middle-crust, heated by nearby magmatism, becomes weak. Accretion of arc material onto the upper plate depends on the characteristics of the arc itself and the geodynamic configuration. Most of the accreted material is probably underplated rather than frontally accreted.

## 1. Introduction

Modern collisions between a volcanic arc and a continent are common in southeast Asia: Luzon arc in Taiwan, Izu–Bonin and Kurile arcs in Japan, Sulu and Halmahera arcs in the Philippines, Sunda arc in Indonesia or Melanesian arc in Papua – New Guinea (Lallemand et al., 2001a). Many authors have examined the “land” expression of such collisions by studying the associated orogens (e.g., Brown and Huang, 2009; Brown et al., 2011; Mann et al., 2011), the arc being often considered as a (semi-)rigid indenter pushing forward the continental upper crustal layers (e.g., Suppe, 1981; Wu et al., 1997; Malavieille and Trullenque, 2009). Some proportion of arc material may be scraped off the subducting plate and add to the growing orogen (e.g., Taira et al., 1998; Arai et al., 2009).

In this study, I focus on the deformation of the subducting or colliding island arc from their initiation to the ultimate delamination/peeling or subduction. I do not describe onland outcrops of island arc slivers accreted to the overriding plate but rather examine the timing of the various deformation phases and the ingredients that control the localization of the arc deformation. Well-constrained examples of such processes are found on both eastern and western borders of the Philippine Sea Plate (PSP).

The collision of the Izu–Bonin–Mariana (IBM) Arc with central Japan has been carefully studied since the early eighties (e.g., Ogawa, 1983; Huchon and Kitazato, 1984; Soh et al., 1991; Taira et al., 1998; Mazzotti et al., 1999) but a new set of studies these last years has provided determining constraints on ongoing deep processes (e.g., Arai et al., 2009; Tamura et al., 2010; Tani et al., 2011). On the other side of the PSP, the Luzon Arc collides with Taiwan. Studies there were achieved later but again, efforts have been done these last two decades to better characterize the collision process, especially offshore (e.g., Wu et al., 1997; Teng et al., 2000; Lallemand et al., 2001b; Malavieille et al., 2002; Theunissen et al., 2012). Even if the geodynamic context differs from that in Japan, many similarities exist in these two situations and one may use the better knowledge of the IBM – Honshu collision to address questions in Taiwan, and vice versa.

The two cartoons in Fig. 1 illustrate the common points and main differences between the geodynamic contexts in Taiwan and in Japan. In Taiwan, the Miocene to present Luzon volcanic arc results from the subduction of the South China Sea (SCS) oceanic lithosphere, which belongs to the Eurasia plate (EP), beneath the PSP. That subduction system ends at the latitude of (northern)

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1367-9120/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jseaes.2013.07.043

Taiwan and is relayed by an orthogonal subduction of the PSP beneath EP, so that the Luzon arc that overrides the EP in the southern part of Taiwan, subducts beneath the same EP east of northern Taiwan. To summarize the tectonic situation, one may say that the Luzon arc first collides with the Taiwan orogen as a result of the continental nature of the subducting EP at the latitude of Taiwan north of the SCS, and then collides with and subducts beneath the EP east of northern Taiwan. The convergence rate between both plates averages 8 to 9 cm/yr in the collision area and the convergence azimuth is oblique to both plate boundaries (Seno et al., 1993). The emerging part of the deformed Luzon arc forms the Coastal Range east of Taiwan (about 150 × 10 km). In Japan, the Eocene to present IBM arc results from the subduction of the Pacific plate (PAC) oceanic lithosphere beneath the PSP. The IBM arc is carried down the Nankai subduction zone at a rate of about 4 cm/yr as it is part of the subducting PSP. The emerging part of the deformed IBM arc forms the Izu Peninsula and collision zone (ICZ) along the southern coast of central Honshu. It covers an area of about 100 × 40 km.

Despite variations in maturity, convergence rates and geometry of plate boundaries of both arc collision zones, we will see that their behavior is often similar in terms of deformation modes.

## 2. Recent advances in understanding the IBM arc and the ICZ in Japan

### 2.1. IBM arc origin and age

Based on studies of forearc oceanic rocks, supposed to have formed as a result of subduction initiation stage along a former fracture zone (Stern and Bloomer, 1992), the inception of the IBM arc has been dated at 51–52 Ma (Ishizuka et al., 2011). Lallemand (1998) argued that an Early Eocene age is a minimum since the forearc rocks that have been sampled might have formed after subduction began, particularly if they did not formed in the former forearc (Deschamps and Lallemand, 2003). Indeed, IBM is an erosional margin with rates of forearc consumption of several kilometers per million years (von Huene and Scholl, 1991; Lallemand, 1995), and it may be that the oldest arc rocks have been consumed by subduction. Furthermore, the presence of Mesozoic continental crust in the Mariana forearc basement was suspected by Azéma and Blanchet (1982) after leg DSDP 60 when they discovered Late Jurassic–Early Cretaceous reworked pebbles in a volcanic matrix. More recently, Ishizuka et al. (2012) have described Jurassic basaltic pillow lavas with Indian Ocean MORB affinities in the Bonin forearc suggesting that Mesozoic crust constitutes the basement of the IBM arc. To summarize, most of the arc consists in a volcanic ridge that began to form in Early Eocene or earlier but there are striking evidences that part of the arc basement is inherited from a "proto-PSP" that is composed of older (Jurassic to Cretaceous detrital zircons), non-oceanic, possibly continental crust (Tani et al., 2012).

### 2.2. IBM arc seismic and petrological structure

The oldest arc sequences mostly consist of tholeiitic basalts (Tamura et al., 2010). These Eo-Oligocene basaltic and rhyolitic rocks are exposed both in the forearc of the main actual IBM arc (sometimes in association with boninites) and along the Palau-Kyushu Ridge (Figs. 1 and 2) which is the remnant part of the pre-Miocene IBM arc rifted during the Miocene spreading of the Shikoku and Parece-Vela basins (e.g., Karig, 1971). This Eo-Oligocene arc was emplaced over a zone about 200 km wide across the present IBM arc (Suyehiro et al., 1996) to which the Palau-Kyushu Ridge must be added to restore the original arc. Based on seismic velocities, the crustal thickness varies from 20 to 30 km beneath the arc showing undulations with wavelengths of about

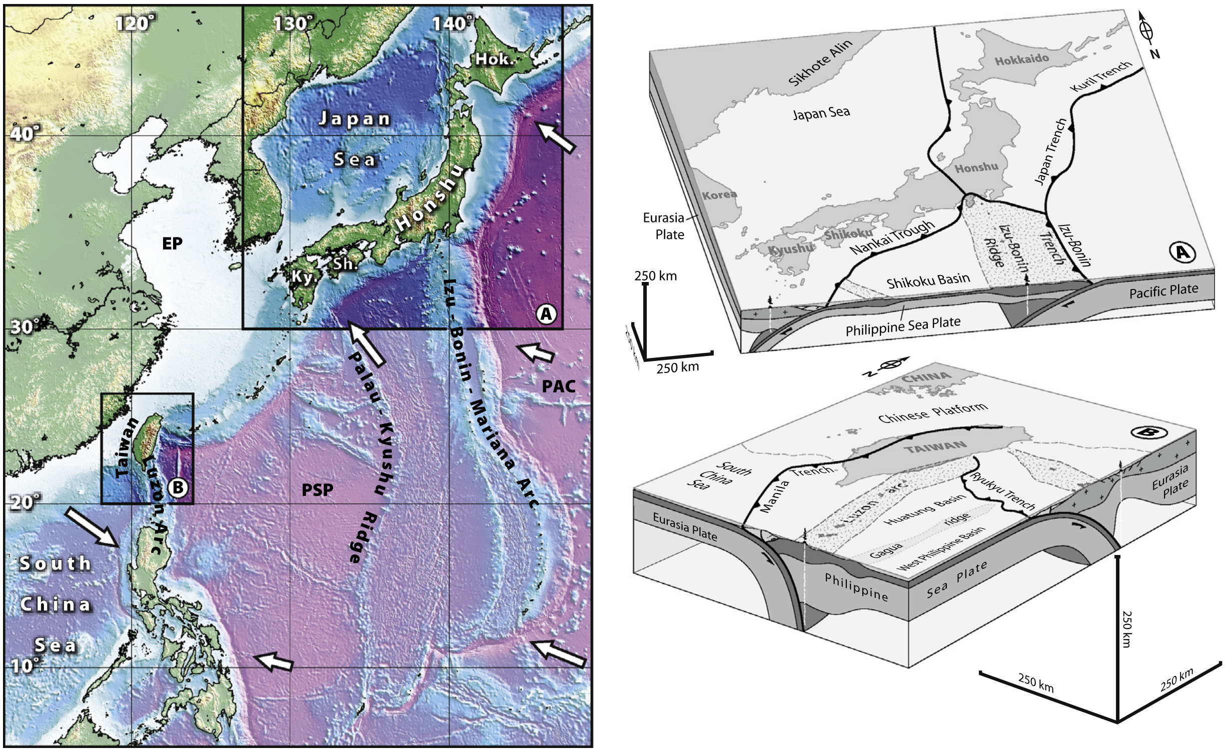

**Fig. 1.** Map showing the northern part of the Philippine Sea Plate with main features and location of the two perspective views of the Luzon and Izu–Bonin arc collision zones. Note that the scales of each diagram is different even if horizontal and vertical proportions are similar. EP = Eurasia Plate; PSP = Philippine Sea Plate; PAC = Pacific Plate; Ky. = Kyushu; Sh. = Shikoku; and Hok. = Hokkaido.