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Destruction of Luzon forearc basin from subduction to Taiwan arc–continent collision

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ABSTRACT

Along offshore to the east of southern Taiwan, different stages of subduction and collision occur simultaneously along strike of the convergent boundary. As a result, the evolution of the Luzon arc and its forearc basin can be studied from the younger subduction zone to the south to the collision zone to the north. Examining more than 8000 km of seismic lines, we analyzed the seismic stratigraphy of strata in a forearc basin and its successive basins in the collision zone, to study the processes related to arc collapse and forearc basin closure. The study area presents three evolutional stages: intra-oceanic subduction, initial arc–continent collision, and arc–continent collision. We divided 9 seismic sequences in the forearc basin and found older, sub-parallel basin-fill sequences (4–9) and younger, divergent sequences (1–3). Isochron maps of the sequences were used to interpret different deformation modes and their areal extends. On the arc side of the basin of the subduction and initial collision zones, we found relatively undisturbed strata, showing little arc deformation. On the trench side, the growth strata in sequences 1 through 3 are the result of recent tectonic wedging along the rear of the accretionary prism. Tectonic wedging and back-thrusts incorporate the forearc strata into the rear of the accretionary prism until they close the forearc basin at a region with a 2200 m basement relief. This relief is not caused by active deformation, as young flat forearc strata lap onto it and mark the transition from initial collision to collision where many growth strata to the north suggest abrupt increase in active arc basement deformation. The (1) deforming basement, (2) back-thrusts, and (3) other sedimentary processes affect the architecture of the successive basins in the collision zone until the arc is juxtaposed to the rear of the fold and thrust belt on land.

1. Introduction

Arc–continent collision processes are important elements for continental growth (e.g. McCourt et al., 1984; Jahn, 2004; Jahn et al., 2004; Brown et al., 2001). However, it is still not clear if an arc and its forearc will be preserved as a whole during collision processes. If not, what part will be preserved and why? In other word, we want to study how the arc deforms and gets accreted or eroded during the collision? In addition, we want to know how the forearc basin strata response to the deformation of the arc and the rear of the accretionary prism, as the subduction progresses into an arc–continent collision. Here we used a detailed seismic stratigraphic analysis to study the deformation in the forearc basin and its basement to better understand the evolution of Luzon Arc and its forearc basin as they collide with the Chinese Passive Margin near Taiwan.

2. Tectonic setting

Here we will discuss the subduction, initial collision, and collision regions found around offshore Taiwan and also their northern extension in onland regions. We will then discuss the southward propagation of the collision process due to the oblique collision in the Taiwan region.

The offshore Luzon arc (Fig. 1) is along the boundary between the Eurasian plate and Philippine Sea plate where the oceanic lithosphere of the South China Sea is subducting eastward beneath the Philippine Sea plate (Bowin et al., 1978) with a rate of about 8 cm/yr (e.g. Yu et al., 1995), forming the Manila trench, Taiwan accretionary prism, North Luzon Trough (forearc basin), and Luzon arc.

Going north at about 20°50′N, subduction changes into an initial arc–continent collision where the continent–ocean boundary of the Chinese passive margin enters into the trench (Reed et al., 1992). Further to the north, the progressively thicker continental crust of the Eurasian plate enters into the convergent boundary. As a result, the wedge grows wider, incorporating basement materials into the wedge (Chi et al., 2003), and the width of the forearc basin starts to decrease until it is closed at about 21°20′N where the arc basement rises dramatically.

The closure of the North Luzon Trough marks the transition from initial collision to collision. Here, the Huatung Ridge is formed along the rear of the accretionary prism (Lundberg et al., 1997; Chen and Nakamura, 1998). This bathymetric high creates basin-filled sequences in the Southern Longitudinal Trough receiving detritus

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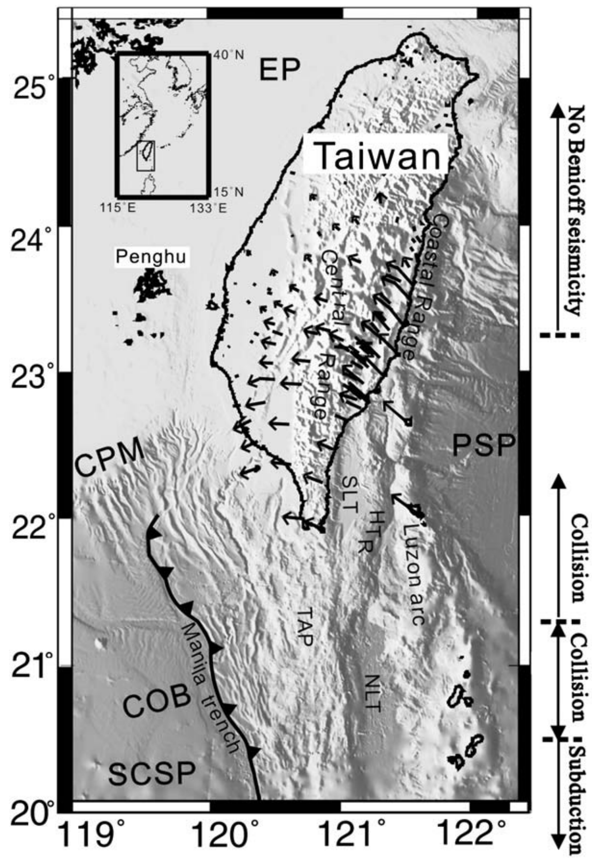

Fig. 1. Location map of Taiwan and regional tectonic setting. Here the oceanic South China Sea plate (SCSP) of the Eurasian plate (EP) is subducting southeastward at a rate of about 85 mm/year under the Philippine Sea plate (PSP) along the Manila trench forming the Taiwan accretionary prism (TAP), North Luzon Trough (NLT)—the forearc basin, and Luzon arc. The subduction changes into an initial arc–continent collision where the continent–ocean-boundary (COB) of the Chinese passive margin (CPM) enters into the trench. As a result, the accretionary prism grows larger. The initial collision changes into collision area where forearc basin is closed and the backthrusts form the Huatung Ridge (HTR), and its piggyback basin (the Southern Longitudinal Trough, SLT). Finally, the Luzon arc is juxtaposed next to the Central Range, a fold and thrust belt that is the northern extension of Taiwan accretionary prism. The Benioff seismicity associated with Luzon arc disappears abruptly north of 23°20′N. The arrows show the GPS relative motions with respect to the island of Penghu sitting on the stable Chinese continent.

from southeastern Taiwan. During the collision process, the forearc basin and its basement are consumed until the Luzon volcanic arc is juxtaposed next to the fold and thrust belt of Taiwan onland in the mature collision zone (Lundberg et al., 1997; Cheng et al., 1998). By introducing shortening in the forearc basin basement in their sandbox models, Malavieille and Trullenque (2009) have successfully reproduced the shallow morphology and deformation in this region.

It is still not clear what happens to the consumed forearc basin basement. Several models have been proposed to explain the missing forearc basin basement. Based on compiled field studies, Teng (1990) proposes that part of the basement has been uplifted and exhumed as a response to the detachment of the slab. On the other hand, analog and numerical modeling suggests that a slice of forearc basement is subducted underneath the Luzon arc along an east-dipping lithospheric fault and can subduct a slice of forearc basement underneath the Luzon arc operating north of 21°30′N based on offshore seismicity data (Chemenda et al., 1997; Tang and Chemenda, 2000; Chemenda et al., 2001). This hypothesis is consistent with results from 2D traveltime inversions of both ocean bottom and onland seismic data (McIntosh et al., 2005) which have imaged a detached forearc block bounded by a steep east-dipping boundary fault illuminated by seismicity.

Further to the north onland, the Luzon arc extends into Coastal Range that consists of Miocene arc-related volcanic rocks unconformably overlain by sediments. To the west, the Taiwan fold and thrust belt, some of which is composed of continental units from the Chinese passive margin corresponds to the northern extension of the offshore Taiwan accretionary prism (Kim et al., 2005). As the Luzon arc approaches the Taiwan and Chinese passive margin, the volcanism ceases (Lo et al., 1994), but still exhibits remnant magmatic activities based on fission track dating and helium isotopic data of gas samples onland (Yang et al., 2003). The cessation of the volcanism is probably related to the over-thrust of the arc onto the passive margin on a major east-dipping listric fault as inferred from Carena et al. (2002). Based on paleomagnetic data, Lee et al. (1991) found a clockwise rotation, in map view, of the segmented Coastal Range as the arc rode onto the passive margin. However, the boundaries of each segment are still unknown. Lithological and field studies in the intra-arc regions onland found evidence of the arc which uplifted, subsided, and then again uplifted to its current position on land (Dorsey, 1992; Huang et al., 2006). There is no major forearc basin strata found onland. Convergent processes are still on-going, as slab earthquakes illuminate a clear east-dipping Benioff zone east of the Coastal Range. However, this seismic zone disappears abruptly north of 23.3°N.

Although the timing of initial collision is still under debate, Teng (1990) proposed that it probably began in the late middle Miocene and is currently propagating southward toward the modern subduction zone of offshore Taiwan at a rate of 55 to 120 mm/yr (Suppe, 1984; Lundberg et al., 1997; Byrne and Crepsi, 1997).

Due to the oblique collision in Taiwan region, different stages of the collision occurred simultaneously along the strike of the convergent boundary. The evolution of the arc and its forearc basin can be studied by constructing a series of cross sections, oriented east–west, through the subduction zone in the south to the more mature collision zone on Taiwan in the north (Suppe, 1984; Huang et al., 2006). Because of the oblique collision, the evolution of the Luzon arc can be studied not only by looking at the exposure on land, but also by analyzing offshore transects south of its current location. Similar concepts have been applied to study the evolution of the Taiwan accretionary prism (Chi et al., 2003; Chi and Dreger, 2004). Their results show progressive basement-involved deformation and exhumation in the accretionary prism from subduction to collision. Next we will use marine

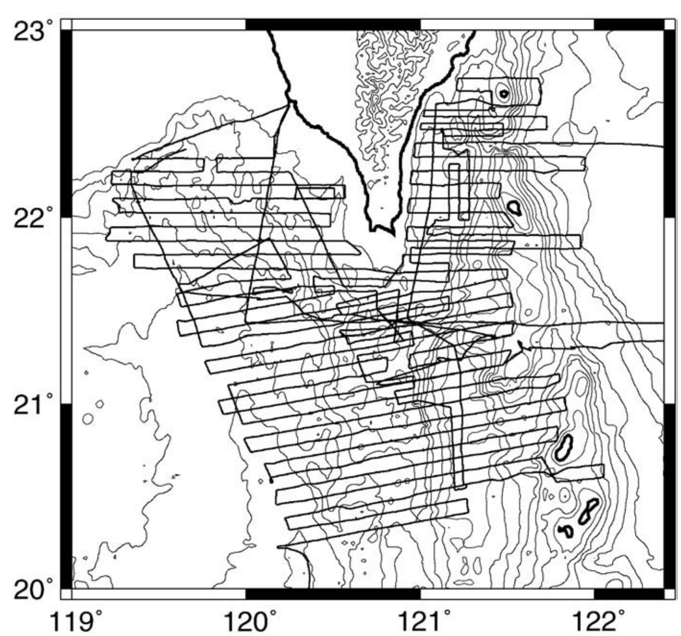

Fig. 2. Track chart of R/V *Moana Wave* cruise. We derive the seismic stratigraphy of the forearc basin using this dense dataset.