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Indentation-induced tearing of a subducting continent: Evidence from the Tan–Lu Fault Zone, East China

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ABSTRACT

Vertical tearing of oceanic slabs has been well documented at subduction zones. It remains unclear whether a subducting continent can tear vertically. Origin of the continental-scale Tan–Lu Fault Zone (TLFZ) in East China provides an example of the vertical tearing of the subducting continent at the convergent stage. The Dabie and Sulu orogens between the North China Plate (NCP) and the Yangtze Plate (YZP) are left-laterally offset about 400 km along the NE-striking TLFZ, but the fault zone terminates abruptly at the southeastern corner of the Dabie Orogen, suggesting unique origin of the fault zone. We present structural evidence to show that the TLFZ initiated as a sinistral fault zone that is exposed in ductile shear belts just to the east of the Dabie Orogen. Our muscovite $^{40}Ar/^{39}Ar$ dating results, coupled with existing age data, indicate that the TLFZ formed at 240–230 Ma (Middle Triassic), when the YZP continental crust was subducted beneath the NCP along both the Dabie and Sulu sutures. We also show that SE-directed extrusion of the subducted crust in the Dabie Orogen occurred during 230–209 Ma (Late Triassic) and overprinted contractional deformation in the TLFZ to the southeast of the Dabie Orogen. Syn-collisional folds and thrusts in the YZP, to the east of the TLFZ, exhibit evidence for large-scale dragging by the sinistral fault zone, whereas those in the NCP to the west are perpendicular to the TLFZ without obvious evidence for drag. Combining these lines of evidence with published data on the tectonic evolution of the two orogenic belts, we propose an indentation-induced continent-tearing model for the origin of the TLFZ. We suggest that the present southern boundary of the NCP represents its original shape, with a promontory in front of the Dabie Orogen. At the oceanic subduction stage, the overriding NCP promontory led to vertical tearing of the subducting oceanic plate along the TLFZ, which formed the eastern boundary of the promontory. Once the rigid NCP indenter collided with the passive YZP along the Dabie Orogen, the oceanic slab tear propagated into the YZP lithosphere, resulting in long-distance, low-angle subduction of the YZP underneath the NCP indenter and NNE-ward, horizontal motion of the torn YZP east of the TLFZ until the final collision at the Sulu Orogen. Thus, the indentation induced the vertical tearing of the subducting YZP along the TLFZ.

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1. Introduction

Continental collision can result in the indenting of a rigid continent into a soft continent (England and Houseman, 1986; Houseman and England, 1986, 1993; Robl and Stüwe, 2005; Doglioni et al., 2007). Examples of continental indenters with higher viscosity include the Indian plate in the India–Asia collision zone and the Adriatic plate in the European Alps collision zone (Tapponnier et al., 1982; Ciancaleoni and Marquer, 2008; Garzanti and Malusà, 2008; Schattner, 2010). The Asian and European plates in front of the indenters behaved as soft continents that developed arcuate deformed belts (England and Houseman, 1986; Doglioni et al., 2007; Rosenberg et al., 2007; Dumont et al., 2011; Malusà et al., 2011, 2015). It remains unclear whether an indented continent with lower viscosity can tear vertically during the indentation. Vertically torn oceanic slabs are well documented at convergent plate boundaries (Doglioni et al., 1994, 2001; Lallemand et al., 1997; Govers and Wortel, 2005; Miller et al., 2005; D'Orazio et al., 2007; Rosenbaum et al., 2008; Agostini et al., 2010; Hale et al., 2010; Kennett and Furumura, 2010; Özbakır et al., 2013; de Sigoyer et al., 2014; Karaoğlu and Helvacı, 2014; van Benthem et al., 2014), and are known as Subduction–Transform Edge Propagator (STEP) faults (Govers and Wortel, 2005). Vertical slab tears commonly occur during subduction rollback (Doglioni et al., 1994; Govers and Wortel, 2005; Mason et al., 2010; Özbakır et al., 2013; de Sigoyer et al., 2014; Karaoğlu and Helvacı, 2014), and the key trigger for tearing of the slab is variation in the relative slab motion velocities along the strike of a subduction system (Govers and Wortel, 2005; Rosenbaum et al., 2008; Rosenbaum and Piana Agostinetti, 2015). Passive continent subduction may follow oceanic lithosphere subduction during continent–continent collision, because of the possible pull exerted by the subducted oceanic slab (Riguzzi et al., 2010). Three-dimensional numerical models suggest that a 40-km-thick continental crust adjoining a large ocean can be pulled downwards by the oceanic plate and subducted to depths of >200 km (van Hunen and Allen, 2011). The effective viscosity of average continental lithosphere is estimated to be at least an order of magnitude smaller than that of oceanic lithosphere (Gordon, 2000). It can therefore be inferred that vertical tearing of a subducting oceanic slab may propagate into the attached, subducting continent. The Tan–Lu Fault Zone (TLFZ) in East China provides an opportunity to test this inference.

The continental-scale left-lateral TLFZ strikes generally NE–SW for about 2400 km (Fig. 1), but has an unusual southern termination and displacement change along strike. The fault zone separates the Dabie and Sulu orogens by about 400 km, but terminates abruptly at the southeastern corner of the Dabie Orogen. The northern boundary of the North China Plate (NCP, also referred to as the North China Craton) is located ~800 km north of the Sulu Orogen, and is sinistrally displaced only ~150 km along the TLFZ (inset in Fig. 1; Zhu et al., 2005). The abrupt termination and discordant displacements exclude the possibility that the TLFZ originated as a post-orogenic strike-slip fault zone, as suggested by Xu et al. (1987); Xu and Zhu (1994) and Leech and Webb (2013), because the post-orogenic fault zone would extend further to the south of the Dabir Orogen and show roughly consistent displacements for both the two orogens and the northern boundary of the NCP. It is widely accepted that the TLFZ initiated during the Middle Triassic collision of the NCP and Yangtze Plate (YZP) along the Dabie and Sulu orogens (Li et al., 1993; Rowley et al., 1997; Hacker et al., 2000; Faure et al., 2003), although the mechanism by which it initiated remains controversial. Several syn-collisional models have been proposed, in which the fault is interpreted to be developed either as a syn-exhumation transform fault (Fig. 2a; Okay and Şengör, 1992), an indenter boundary (Fig. 2b; Yin and Nie, 1993), a tear fault triggered by upper crust overthrusting in the Sulu Orogen (Fig. 2c; Li, 1994; Lin, 1995; Chang, 1996), or a rotated suture line during collision between the NCP and YZP (Fig. 2d; Gilder et al., 1999). The fault has also been explained in terms of a post-collisional orocline model (Fig. 2e; Wang et al., 2003) and as a syn-subduction transform fault or slab tear (Fig. 2f; Zhu et al., 2009).

Constraining the structural features and timing of the initial TLFZ is crucial for understanding its origin, but neither of these points have been well constrained because the fault is often overprinted by younger structures (Wang, 2006; Zhu et al., 2010) and covered by Early Cretaceous to Paleogene rift basins (Fig. 1; Zhu et al., 2010; G. Zhu et al., 2012). Lin et al. (2005) proposed that no syn-collisional strike-slip ductile shear belt exists in the southern Zhangbaling TLFZ (Fig. 1). In contrast, Zhang et al. (2007) argued that the southern Zhangbaling TLFZ was deformed by the Tan–Lu syn-collisional ductile shear zone along an obliquely convergent zone between the NCP and YZP, whereas the northern Zhangbaling TLFZ represents a 240–235 Ma ($^{40}Ar/^{39}Ar$ muscovite ages) top-to-the-south detachment zone that coupled deeper ductile shear with shallower brittle deformation. The NE-striking sinistral ductile shear belts on the western margin of the Sulu Orogen and the eastern margin of the Dabie Orogen yield $^{40}Ar/^{39}Ar$ muscovite ages of 221–181 Ma (Zhu et al., 2009), which were interpreted as recording syn-collisional sinistral faulting (Zhu et al., 2009). However, their overprinting on the exhumed ultrahigh-pressure rocks of the orogenic belts suggest that they developed post-exhumation. Structures in the low-grade metamorphic rocks of the Zhangbaling Group, exposed just east of the Dabie Orogen, have received little attention.

This work is focused on the southern segment of the TLFZ. We analyzed the TLFZ in five different areas (see location in Fig. 1) and present structural and geochronological evidence to show that the TLFZ originated as a Middle Triassic sinistral fault zone. The initial structures are locally preserved on the western margin of the YZP and have been overprinted by younger deformation. We integrate the structural and geochronological data with constraints on the collisional development of the NCP and YZP, as well as syn-collisional, marginal structures. On this basis, we propose that the TLFZ developed along the lateral boundary of an indenter that was located in the NCP, and that the indentation led to syn-collisional vertical tearing of the subducted YZP.