Forum Reply

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Appalachian-style multi-terrane Wilson cycle model for the assembly of South China

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We welcome the opportunity to respond to the Comments by Shu et al. (2018) and Faure et al. (2018), and to further discuss and develop our ideas. We thank Cees van Staal for discussions on this Reply.

The authors of the two Comments have been collaborators and co-authors on South China and hold the view that the Early Paleozoic (Wuyi-Yunkai/Kwangsian) orogeny was an intraplate/intracontinental orogeny.

Early Paleozoic Sedimentation

The Cambrian-Ordovician sedimentary rocks in South China show "a progressive facies evolution within a single southeastward deepening basin" (Faure et al., 2018) and "show a passive continental margin setting" (Shu et al., 2018). The sedimentary sequence thickens southeastward and *paleocurrent directions point northwestward* (e.g., Shu et al., 2014). These are inconsistent with an intraplate orogenic model in which an intracontinental rift basin was opened and closed within South China (e.g., Shu et al., 2015). Instead, the data suggest that at least the upper part of the basin was likely a foreland basin formed due to tectonic loading from the east, consistent with our interpretation that the Yangtze-Greater West Cathaysia continent was the lower plate in a southeastward subduction setting (Lin et al., 2018, our figures 6C and 6D).

The angular unconformity at the base of the Devonian in West Cathaysia is a manifestation of the Early Paleozoic orogeny. Further to the west (foreland in our model), the angular unconformity becomes a disconformity and eventually a conformity on the Yangtze craton. No such a transition from angular unconformity to conformity has been observed toward the east in South China. This is again inconsistent with the symmetric intraplate orogenic model of Shu et al. (2015) for the opening and closure of a rift basin within South China.

As part of their intraplate orogenic model, Shu et al. (2015, their figure 11D) invoke a westward "underthrusting or subduction" (beneath Cathaysia) of a "suspected East China Sea block" as the mechanism to close the basin. The above discussion indicates that it is more likely that the basin was closed due to collision with a terrane from the east, as we have proposed (see below for further discussion).

Early Paleozoic Structural Vergence

According to Shu et al. (2015), early Paleozoic structures are doubly vergent: northwest-vergent in the western part of West Cathaysia and further west (our foreland), and southeast-vergent in the eastern part of West Cathaysia (our hinterland). As acknowledged by Shu et al. (2015, p. 1616), "doubly vergent thrusting does not provide a unique argument for an intraplate orogenic setting of Cathaysia in the Early Paleozoic". In fact, doubly vergent thrusting is not uncommon in collisional and accretionary orogens; e.g., in the Alps and the Canadian Appalachians.

Early Paleozoic Metamorphism, Magmatism and Orogeny

Yao et al. (2017) and Lin et al. (2018) documented metamorphic zircon of both Neoproterozoic and early Proterozoic ages in West Cathaysia. It is generally accepted that the upper amphibolite to granulite/eclogite facies metamorphism (>1 GPa in metapelite) documented by Zhao and Cawood (1999) and others is early Paleozoic in age. Shu et al. (2018) have evidently misrepresented Yao et al. (2017) by implying that their ca. 860 Ma metamorphic age is the age of the high-pressure (HP) metamorphism, as Yao et al. (2017, p. 7) explicitly state that "conditions of metamorphism at this time are unknown as textural relations between the [zircon] rim ages and the metamorphic mineral assemblages are not preserved and the other rims within the same samples yield early Paleozoic ages around 440–430 Ma". This misrepresentation is puzzling, as Shu and Yao coauthored both papers.

The HP metamorphism cannot be readily explained by an intraplate orogenic model. The "intracontinental subduction" model as depicted in Faure et al.'s (2009) figure 8 requires a "subduction zone" to be initiated in the middle of a continent, and one side of the continent to be "subducted" steeply to a great depth beneath the other. This process is unlikely as it contradicts physics, since continental crust is too buoyant to initiate subduction within it and accommodate the deep subduction required by the metamorphic record, and it is not corroborated by any convincing evidence in modern or ancient analogues. In addition, subduction of a part of a continent under another part is unlikely to be at such a high angle and would lead to significant crustal thickening and uplift of the upper plate, for which there is no evidence. The model of Faure et al. (2009, their figure 8) is also inconsistent with northwest-vergent structures in the western part of West Cathaysia described above.

We have proposed that the Early Paleozoic orogeny is a result of collision of South China with a proposed terrane (PT) to the east. In our model, West Cathaysia was the lower plate and experienced high-grade and HP metamorphism (Lin et al., 2018, our figure 6D). The presence of syn- to post-tectonic S-type granites in West Cathaysia is consistent with our model, as such granites are common in collisional/accretionary orogens. We believe that subduction, collision, and post-collisional heating provide a better mechanism for burial, thickening, and partial melting of the crust than the intraplate orogenic model. S-type granites formed by either process are not expected to show any prominent "belt-type" geometry.

As a refinement to the model of Lin et al. (2018), we suggest here that the 460–420 Ma (Late Ordovician–Silurian) high-grade and HP metamorphism and magmatism were related to the Cambrian-Ordovician subduction and collision discussed above, based on the sedimentary record (Fig. 1). The time lag between subduction-onset of collision and peak metamorphism-magmatism could equate with the time needed to heat up the under-thrusted cold crust as a result of thermal relaxation of depressed isotherms. England and Richardson (1977) demonstrated that conductive heating of large slabs of under-thrusted cold crust is a slow process, and heating up to upper amphibolite and granulite conditions may take tens of millions of years. This refined model implies that the 460–420 Ma Early Paleozoic orogeny in South China could be directly related to Gondwana assembly. The big time lag implies a long-lasting collision and can be explained by collision of a large promontory on the down-going plate, a topic we will explore separately.

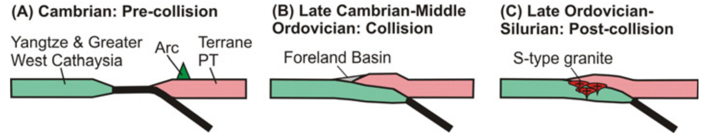

Figure 1. Schematic diagrams showing a refined model for Early Paleozoic orogeny in South China (modified from figure 6C-D of Lin et al., 2018). In this model, the Late Ordovician-Silurian high-grade high-pressure metamorphism and magmatism were related to the Cambrian-Middle Ordovician subduction and collision and the resulting burial and crustal thickening.

The Chencai Complex has been proposed by others (e.g., Zhao et al., 2015) to be an early Paleozoic accretionary complex. However, the validity of our model does not depend on this interpretation. Evidence for Neoproterozoic magmatism and early Paleozoic metamorphism provided by Shu et al. (2018), if correct, supports our inclusion of the complex in West Cathaysia.

Post-Collisional Rifting

It is generally accepted that South China is a microcontinent that rifted away from Gondwana. This happened in the late Paleozoic (Metcalfe, 2011), as in our model. In fact, regardless of which Early Paleozoic orogenic model is more likely, the orogen must have been much longer and significantly wider initially than what is preserved in southern China; the rest must have moved away, through rifting and/or strike-slip motion. This needs to be considered in any tectonic interpretation of the orogen. It implies that a lack of evidence in South China for the closure of an early Paleozoic ocean (such as an arc or ophiolitic mélange) is not a sufficient argument against a subduction-collision origin or for an intraplate orogenic origin for the Early Paleozoic orogen. In addition, some oceans closed by subduction didn't generate arcs (e.g., the Alps), and ophiolites and mélanges are not preserved in many ancient orogens.

West and East Cathaysia Terranes and Northwest Fujian Fault

West and East Cathaysia have distinct geological histories (see Lin et al., 2018, our figures 2, 3, and 4; see also Fig. 2). They are separated by the Northwest Fujian Fault (NWFF). Evidence is extensive that West and East Cathaysia are two terranes that were not amalgamated until the Mesozoic, and is inconsistent with Faure et al.'s (2018) assertion that "the entire Cathaysia was a single continent".

We did provide/discuss the location, kinematics and timing of the NWFF (e.g., our figures 3 and 5). Quantifying displacement along a regional-scale strike-slip fault is rarely possible due to lack of adequate markers. It is illogical for Faure et al. (2018) to argue against large strike-slip motion along the NWFF based on their work on another fault, even if the two had been kinematically related.

Triassic Indosinian Orogeny and East Cathaysia

We agree that the Triassic Indosinian orogeny in West Cathaysia and further west was mostly an intraplate response to the collisions to both northern and southern South China. The southern part of West Cathaysia was intensely tectonically overprinted during the Indosinian collision, as in the Yunkai area (Fig. 2).

The spatial distribution of Triassic metamorphic zircon (Fig. 2) supports our interpretation that East Cathaysia (with metamorphic pressure up to ~1 GPa in the Wuyishan area) originated from an Indosinian orogen to the south through strike-slip motion along the NWFF.

Fuchuan Ophiolite

Ophiolites preserved in ancient orogens are allochthonous and form part of suture zones. We consider the Northeast Jiangxi fault, the boundary between the Jiuling and Huaiyu terranes, as a suture zone, not a single fault. The Fuchuan ophiolite could be a part of this suture zone or a remnant of the backarc basin associated with the Jiuling terrane.

Concluding Remarks

Science is advanced by proposing and testing new hypotheses. Being open-minded is always a good idea and "thinking outside the box" can be useful, especially for South China where major controversies persist. The multi-terrane accretion-collision Wilson cycle model we proposed reconciles the seemingly contradictory evidence for multiple aspects of South China in a single coherent model, and represents a brand-new perspective. We propose here that the Late Ordovician-Silurian tectono-metamorphism and magmatism (the Early Paleozoic Wuyi-Yunkai/Kwangsian orogeny) in South China resulted from the Cambrian-Middle Ordovician subduction and onset of collision. Testing our model will enhance our understanding of South China, as well as the configuration of Gondwana and Rodinia.

We predict that with more work, more terranes and more accretionary/collisional events will be recognized in South China.

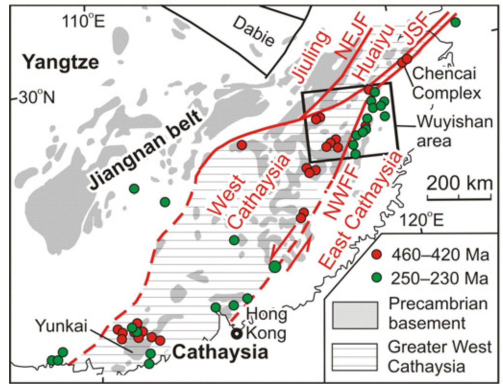

Figure 2. Distribution of early Paleozoic and early Mezozoic metamorphic zircon U-Pb ages in eastern South China (compiled from Lin et al., 2018; and Wang et al., 2013). NEJF—Northeast Jiangxi fault; JSF—Jiangshan-Shaoxing fault; NWFF—Northwest Fujian fault.

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