Geology, published online on 4 April 2013 as doi:10.1130/G34161.1

Geology

What drove continued continent-continent convergence after ocean closure? Insights from high-resolution seismic-reflection profiling across the Daba Shan in central China

Shuwen Dong, Rui Gao, An Yin, Tonglou Guo, Yueqiao Zhang, Jianmin Hu, Jianhua Li, Wei Shi and Qiusheng Li

Geology published online 4 April 2013;
doi: 10.1130/G34161.1

Notes

Geology, published online on 4 April 2013 as doi:10.1130/G34161.1

What drove continued continent-continent convergence after ocean closure? Insights from high-resolution seismic-reflection profiling across the Daba Shan in central China

Shuwen Dong[1]*, Rui Gao[2], An Yin[3], Tonglou Guo[4], Yueqiao Zhang[1], Jianmin Hu[1], Jianhua Li[1], Wei Shi[1], and Qiusheng Li[2]
[1]Institute of Geomechanics, Chinese Academy of Geological Sciences, 100081 Beijing, China
[2]Institute of Geology, Chinese Academy of Geological Sciences, 100037 Beijing, China
[3]Department of Earth and Space Sciences, University of California–Los Angeles, Los Angeles, California 90095, USA
[4]Southern Exploration and Development Division Company, Sinopec, Chengdu 610000, China

ABSTRACT

We conducted deep seismic-reflection surveying across the Jurassic Daba Shan thrust belt of central China to investigate how and why the continued convergence between north and south China lasted ~50 m.y. after the Triassic closure of their intervening oceans. Our study, together with surface geology, gravity surveying, and magnetic observations, indicates widespread occurrence of mafic plutons below the Daba Shan thrust belt. We propose that subduction of dominantly eclogitized mafic crust of northern south China provided the driving force for continued convergence between north and south China after ocean closure.

INTRODUCTION

Formation of the Jurassic Daba Shan thrust belt (Fig. 1) was related to either the continued convergence of north and south China after the Triassic closure of the Paleo-Tethys (Zhang et al., 2001; Ratschbacher et al., 2003; Dong et al., 2011) or far-field stresses induced by Jurassic collision of Neo-Tethys terranes along the southern margin of south China (e.g., Yin and Nie, 1996). The first model predicts southward propagation of deformation, whereas the second model requires reactivation of preexisting basement structures of south China. To test the two models, we acquired a 300 km seismic-reflection profile (Fig. 1). Our results support the continued convergence model, but are inconsistent with the far-field stress model.

REGIONAL GEOLOGY

The Daba Shan thrust belt consists of four zones (Fig. 1). Zone 1 displays Jurassic folds and thrusts locally reactivated due to kinematic linkage between faults along the western and northern margins of south China in the Cretaceous and Cenozoic (Meng et al., 2005; Richardson et al., 2008; Xu et al., 2010). Zone 2 is dominated by folds involving Permian–Jurassic strata (Shi et al., 2012). Zone 3 consists of imbricate thrusts and Paleozoic strata (Liu et al., 2006), whereas zone 4 is characterized by ductile shear zones,

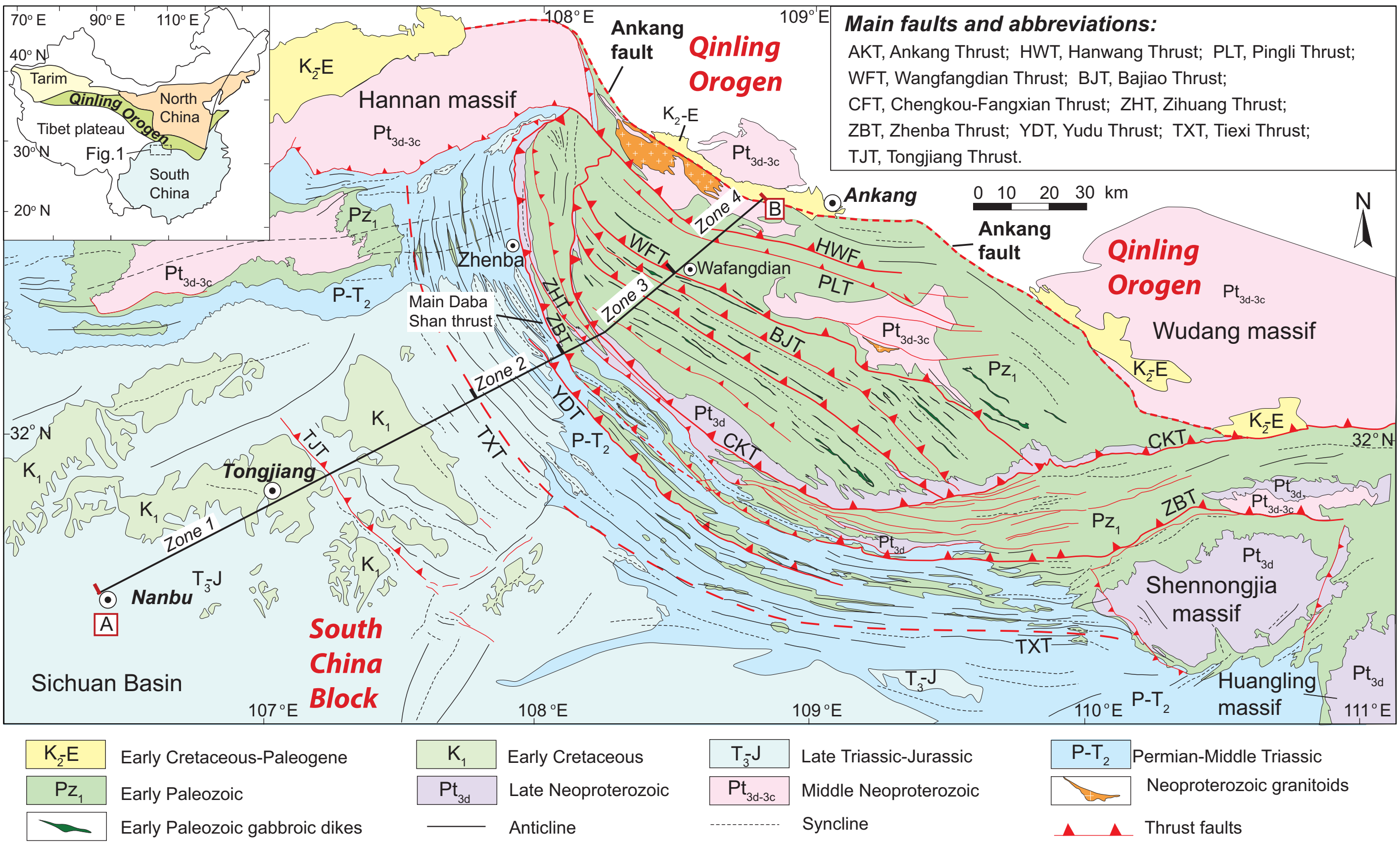

Figure 1. Simplified geologic map of Daba Shan (China) and location of seismic profile A–B shown in Figure 2A. Also indicated are major structural zones mentioned in text. Qinling orogen in inset map separates North and South China blocks. Ductile Ankang thrust marks boundary between Qinling orogen and Daba Shan thrust belt.

*E-mail: swdong@cags.ac.cn.

pervasive cleavage formation, low- to high-grade metapelite, and Neoproterozoic metabasite and metagranitoids (740–790 Ma) (Li et al., 2012). East-trending Ordovician gabbroic dikes occur widely in zones 3 and 4 (Luo and Duan-Mu, 2001; Dong et al., 2011). The Ankang fault between the Daba Shan and the Qinling orogen (Zhang et al., 2001) was reactivated in the Cenozoic (Ratschbacher et al., 2003) (Fig. 1).

DABA SHAN SEISMIC-REFLECTION PROFILE

A 300-km-long reflection seismic profile was obtained (Figs. 1 and 2A). Data acquisition and data processing methods and an uninterpreted high-resolution seismic profile can be found in the GSA Data Repository[1].

Shallow Structures (<~20 km)

A regional unconformity at a depth of ~12 km is below zones 1, 2, and 3 (Fig. 2A). Based on regional stratigraphy (Shi et al., 2012), we assign the unconformity at the base of Neoproterozoic strata. Below the unconformity, subhorizontal and gently tilted reflectors are surrounded by a pervasively transparent region (Fig. 2A). At the northern end of zone 1, the dip of a sequence of south-dipping reflectors decreases upward, displaying half-graben geometry. The reflectors are on top of the transparent region in the north and are truncated by the transparent region in the south (Fig. 2A). We interpret the transparent region to represent crystalline basement and the tilted reflectors to represent growth strata in a half-graben. The origin of other finely laminated regions in the seismic profile is less clear as their boundaries are less well defined; they may either be bounded by normal faults or intruded by plutons. We tentatively interpret them to represent fault-bounded rift basins.

Gently folded reflectors at depths of 0–8 km in zones 1 and 2 are truncated by the Main Daba Shan thrust (Zhenba thrust), which extends to a depth of ~27 km and dips at ~14° (Fig. 2A). A sequence of north-dipping reflectors above the thrust truncates a group of south-dipping reflectors above, displaying a hanging-wall thrust-ramp relationship (Fig. 2C). Several low-angle thrusts evidenced by their truncations of layered reflectors extend continuously from zones 3 and 4 to below the southernmost Qinling (Fig. 2C).

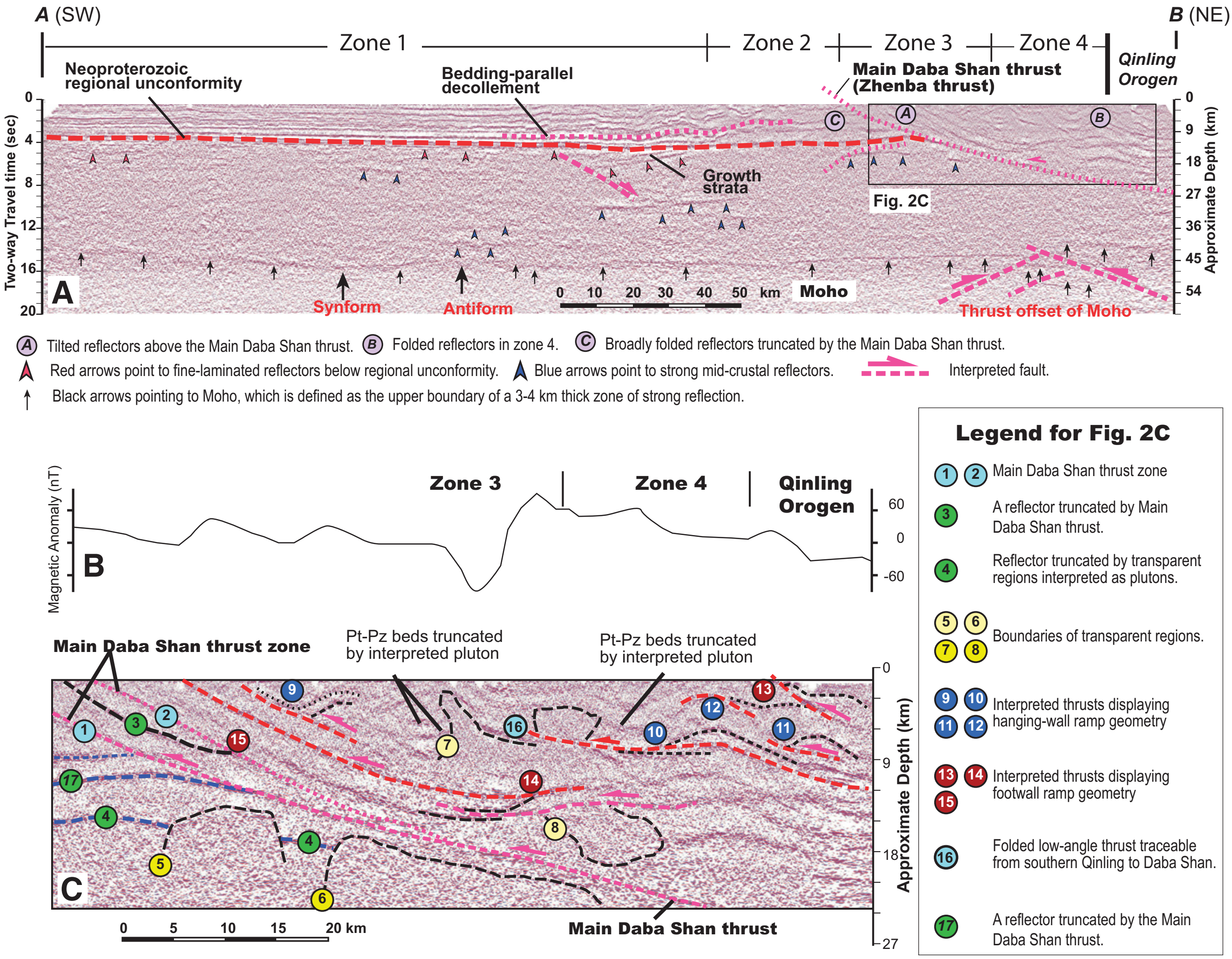

Figure 2. A: Seismic profile (see Fig. 1 for location) and labels of main geologic features discussed in text. Uninterpreted high-resolution seismic profile can be found in Data Repository (see footnote 1) for comparison. Thrusts below Daba Shan and southernmost Qinling are bounded below by north-dipping Main Daba Shan thrust. This basal thrust can be recognized by truncation of layered reflectors and its high reflectivity. B: Magnetic anomaly across Daba Shan (from Zhang et al., 2009). C: Close-up view of seismic profile (see Fig. 2A for location). Thrusts can be identified by their cutoff relationships and correlation with surface geology. Several low-angle thrusts in middle crust can be traced continuously from zones 3 and 4 to below southernmost Qinling orogen. Also shown are transparent regions with their boundaries truncating layered reflectors (see text for details). Pt-Pz—Proterozoic–Paleozoic.

[1]GSA Data Repository item 2013185, data-collection and data-processing methods, and a high-resolution seismic profile, is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Deep Structures (>~20 km)

Thin (2–5 km) zones of subhorizontal reflectors in the middle and lower crust may be interpreted as shear zones or sills. As the reflectors do not link with upper crustal faults and are directly below the interpreted rift basins, we suggest that they represent sills emplaced during synrift extension.

The Moho is defined as the top surface of a continuous zone (3–4 km thick) of strong reflection below a transparent to weakly reflected lower crust (Fig. 1). It displays wavy geometry in the south and is offset by thrust shear zones in the north (Fig. 2A). There are no obvious links between Moho-offset faults and upper crustal structures.

Mafic Plutons in the Seismic Profile

A gently north dipping reflector below the interpreted Neoproterozoic unconformity at depths of 16–20 km in zone 2 is truncated by two seismically transparent regions (Fig. 2C). Transparent patches are also observed below zones 3 and 4 in the seismic profile that truncate reflectors representing Proterozoic–Paleozoic strata, based on their correlation to surface geology (Dong et al., 2011; Shi et al., 2012). The transparent regions could have been an artifact of seismic-wave diffraction over sharp fold hinges, but this is inconsistent with broad folds seen in the field and above the seismic profile. As the transparent regions are located below widely occurring gabbroic dikes (Luo and Duan-Mu, 2001), they likely represent mafic intrusions emplaced during dike formation. This interpretation is supported by the high gravity and magnetic anomalies in the same region where the transparent regions are imaged in our seismic profile (Li and Ding, 2007; Zhang et al., 2009) (Fig. 2B).

DISCUSSION

Mode of Lithospheric Deformation

The lack of reactivated basement structures below the Neoproterozoic unconformity is inconsistent with the far-field stress model (Fig. 2A). In contrast, the presence of folded thrusts in the north and unfolded thrusts in the south of the Daba Shan thrust belt (Fig. 2) requires that shortening had propagated southward, consistent with the continued convergence model of Zhang et al. (2001). It is possible that the transmission of the far-field stress was accomplished by motion along a north-striking right-slip system in western south China that was linked with the east-trending Jurassic Daba Shan thrust belt (Wang et al., 2003). However, such a fault pattern can also be explained by the continued northward indentation of south China into north China as envisioned by Zhang et al. (2001).

Mode of Lithospheric Deformation

The Moho in the seismic profile is either folded or offset by thrusts (Fig. 2A). Its wavy geometry may have originated from compositional variation of the lower crust and upper mantle or deformation predating the flat Neoproterozoic unconformity. However, as the Moho is offset by thrusts directly below the Main Daba Shan thrust, which is the most dominant structure in the Daba Shan, the simplest interpretation is that Moho deformation occurred during Jurassic Daba Shan thrusting. As the Neoproterozoic unconformity and mid-crustal flat reflectors are not folded, upper mantle deformation may have been accommodated by a subhorizontal décollement in the lower crust (i.e., the strain accommodation zone in Fig. 3). Taken together, Jurassic deformation of the Daba Shan was accommodated by the development of a crustal-scale thrust wedge above and distributed shortening in the lower crust and upper mantle below.

Driving Mechanisms of Continued Continental Convergence

Although our new seismic data favor the continued convergence model, its dynamic cause is poorly understood as the Paleo-Tethys was closed in the latest Triassic (ca. 210 Ma) while Daba Shan thrusting remained active until the Late Jurassic (ca. 165 Ma). Based on surface geology, seismic imaging from this study, and the existing gravity and magnetic data, the Daba Shan thrust wedge appears to consist of abundant Ordovician mafic plutons. Their emplacement may be related to the early Paleozoic formation of a passive continental margin in northern south China. As a result, one would expect that the proportion of mafic intrusions increases northward across the margin. The northern crust of south China dominated in mafic intrusions was probably dragged down to the Paleo-Tethys subduction zone during the terminal stage of ocean closure. Consequently, eclogitization of the dominantly mafic crust may have facilitated the prolonged continental convergence in the Jurassic, leading to Jurassic thrusting in the Daba Shan.

TECTONIC EVOLUTION

The interpreted Precambrian rift basins (Fig. 3) may have been developed at 800–700 Ma coeval with bimodal volcanism in northern south China and the Daba Shan (Ling et al., 2008; Li et al., 2012) (Fig. 4). Subsequent rifting of north Qinling away from north China in the Neoproterozoic was followed by separation of south Qinling from south China in the early Paleozoic (Fig. 4) (Dong et al., 2011). Associated with early Paleozoic rifting was the emplacement of Ordovician mafic sills into the

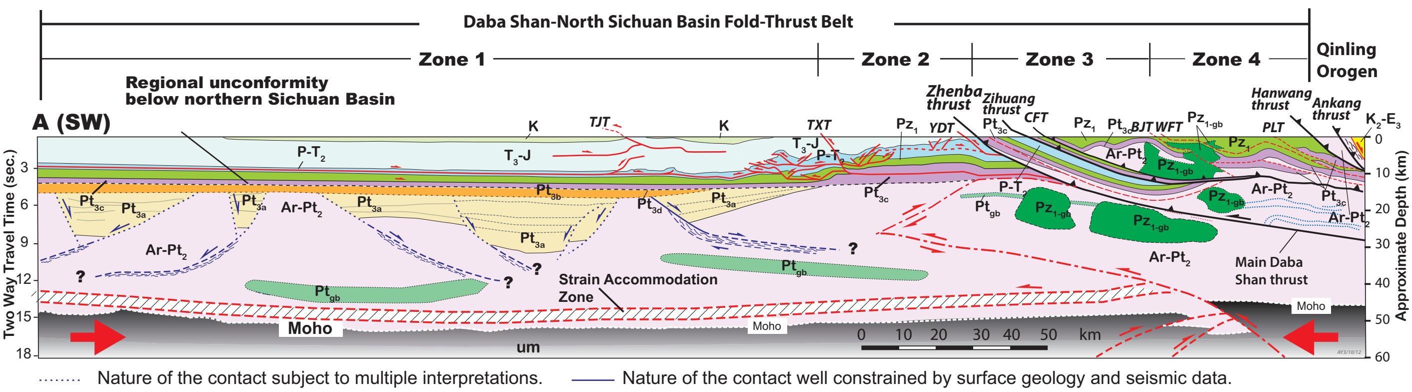

Figure 3. Interpreted cross section of Daba Shan thrust belt (China). Following steps were taken for constructing the section: (1) identifying thrust cutoffs and tracing major marker reflectors, (2) establishing matching offsets across faults, (3) correlating faults in seismic profile with surface geology, (4) extrapolating stratigraphic units from surface geology, and (5) checking overall consistency of seismic and surface data and bed-length and/or fault-slip balances. As interpreted structures are nonunique, we use solid and dashed lines to indicate relative strength of our interpretations (see map symbols for explanation). PLT—Pingli thrust; WFT—Wafangdian thrust; BJT— Bajiao thrust; CFT—Chengkuo-Fangxian thrust; ZHT—Zihuang thrust; YDT—Yudu thrust; TXT—Tiexi thrust; TJT—Tongjiang thrust. Lithologic units: K_2-E_3—Late Cretaceous to Paleogene strata; K_1—Early Cretaceous strata; T_3-J—Late Triassic to Jurassic strata; P-T_2—Permian to Middle Triassic strata; Pz_1—early Paleozoic strata; Pt_{3d}—unit d of Neoproterozoic strata; Pt_{3c}—unit c of Neoproterozoic strata; Pt_{3b}—unit b of Neoproterozoic strata; Pt_{3a}—unit a of Neoproterozoic strata; Ar-Pt_2—Archean to Mesoproterozoic basement rocks; um—upper mantle rocks; $Pz_{1\text{-}gb}$—Paleozoic gabbroic intrusion; Pt_{gb}—Proterozoic gabbroic intrusion.

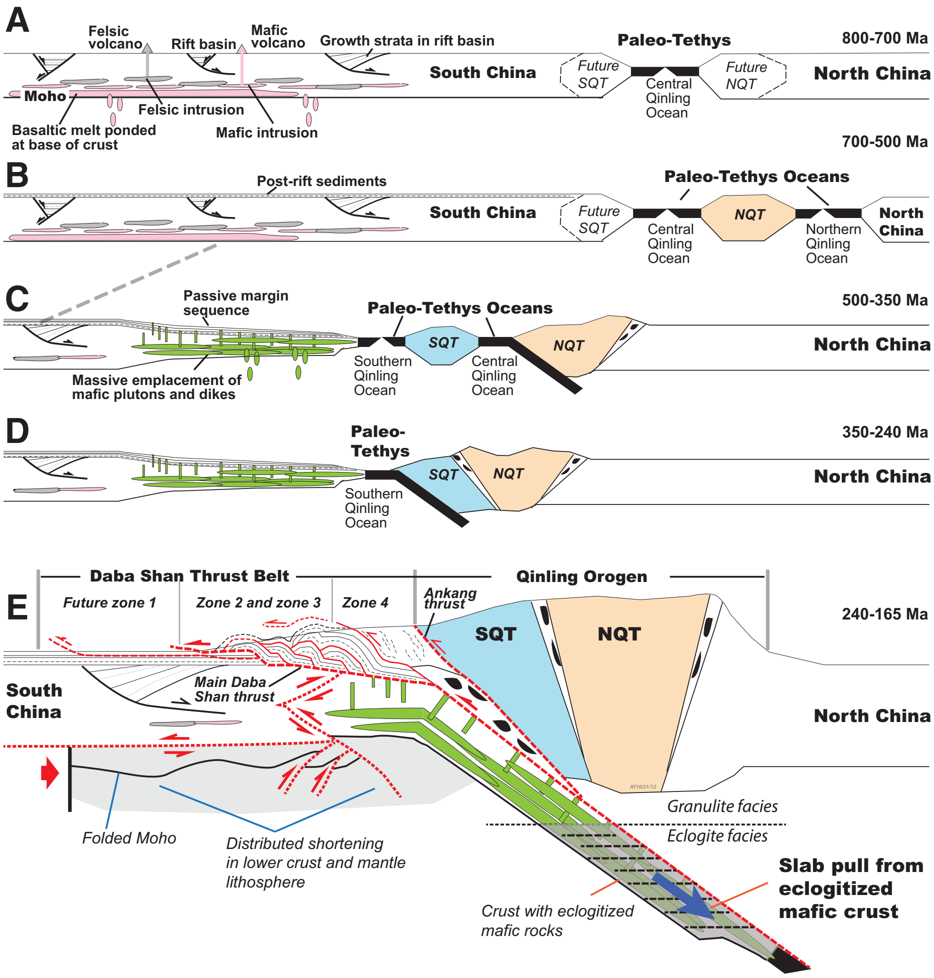

Figure 4. Tectonic evolution of Daba Shan thrust belt (China). A: 800–700 Ma. Formation of rift basins and coeval bimodal igneous activity across south China. North and south China are separated by central Qinling Ocean. SQT—southern Qinling terrane; NQT—northern Qinling terrane. B: 700–500 Ma. Rifting of north Qinling from north China and opening of northern Qinling Ocean. C: 500–350 Ma. Rifting of south Qinling from south China and opening of southern Qinling Ocean in early Paleozoic that was associated with emplacement of mafic sills; collision of north Qinling and north China and collision between north and south Qinling in Devonian. D: Continued opening and subduction of southern Qinling Ocean. E: 240–165 Ma. Closure of Paleo-Tethys by collision of south China and Qinling orogen.

crust of the newly developed passive margin in northern south China. Collision of north Qinling and north China and the collision of north and south Qinling occurred in the Devonian (Zhang et al., 1997). The Paleo-Tethys was completely closed in the latest Triassic (Yin and Nie, 1993) (Fig. 4). The continued Jurassic convergence of north and south China was driven by slab pull of subducted south China that has a dominantly eclogitized mafic crust (Fig. 4).

ACKNOWLEDGMENTS

This study was financed jointly by SinoPec (grants YPH08021, YPH08022, YPH08023) and SinoProbe (grant 08-01). We thank Mou Shuling, Cai Xiyuan, Jin Zhijun, Ma Yongsheng, Qian Ji, and Zhang Yonggang for their support. We also thank Sun Shu and Li Tingdong for constructive discussions and encouragement. Yin's work on Asian tectonics has been supported by the Tectonics Program of the U.S. National Science Foundation.

REFERENCES CITED

Dong, Y.P., Zhang, G.W., Neubauer, F., Liu, X.M., Genser, J., and Hauzenberger, C., 2011, Tectonic evolution of the Qinling orogen, China: Review and synthesis: Journal of Asian Earth Sciences, v. 41, p. 213–237, doi:10.1016/j.jseaes.2011.03.002.

Li, J.H., Zhang, Y.Q., Xu, X.B., Dong, S.W., and Li, T.D., 2012, Zircon U-Pb LA-ICP-MS dating of Fenghuangshan pluton in northern Daba mountains and its implications for tectonic settings: Geological Review, v. 58, p. 581–593.

Li, Z.K., and Ding, Y.Y., 2007, A tentative discussion on characteristics of the Daba Mountain nappe structure: Geophysical and Geochemical Exploration, v. 31, p. 495–498.

Ling, W.L., Ren, B.F., Duan, R.C., Liu, X.M., Mao, X.W., Peng, L.H., Liu, Z.X., Cheng, J.P., and Yang, H.M., 2008, Timing of the Wudangshan and Yaolinghe volcanic sequences and mafic sills in South Qinling: U-Pb zircon geochronology and tectonic implication: Chinese Science Bulletin, v. 53, p. 2192–2199, doi:10.1007/s11434-008-0269-6.

Liu, S.G., Li, Z.W., and Liu, S., 2006, Formation and evolution of Dabashan foreland basin and fold-and-thrust belt, Sichuan, China: Beijing, Geological Publishing House, 248 p.

Luo, K.L., and Duan-Mu, H.S., 2001, Timing of early Paleozoic igneous rocks in the Daba Mountains: Regional Geology of China, v. 20, no. 3, p. 262–266.

Meng, Q.R., Wang, E., and Hu, J.M., 2005, Mesozoic sedimentary evolution of the northwest Sichuan basin: Implication for continued clockwise rotation of the South China block: Geological Society of America Bulletin, v. 117, p. 396–410, doi:10.1130/B25407.1.

Ratschbacher, L., Hacker, B.R., Calvert, A., Webb, L.E., Grimmer, J.C., McWilliams, M.O., Ireland, T., Dong, S.W., and Hu, J.M., 2003, Tectonics of the Qinling (central China): Tectonostratigraphy, geochronology and deformation history: Tectonophysics, v. 366, p. 1–53, doi:10.1016/S0040-1951(03)00053-2.

Richardson, N.J., Densmore, A.L., Seward, D., Fowler, A., Wipf, M., Ellis, M.A., Li, Y., and Zhang, Y., 2008, Extraordinary denudation in the Sichuan Basin: Insights from low-temperature thermochronology adjacent to the eastern margin of the Tibetan Plateau: Journal of Geophysical Research, v. 113, p. 1–23, doi:10.1029/2006JB004739.

Shi, W., and 13 others, 2012, Intra-continental Dabashan orocline, southwestern Qinling, central China: Journal of Asian Earth Sciences, v. 46, p. 20–38, doi:10.1016/j.jseaes.2011.10.005.

Wang, E., Meng, Q., Burchfiel, B.C., and Zhang, G., 2003, Mesozoic large-scale lateral extrusion, rotation, and uplift of the Tongbai-Dabie Shan in east China: Geology, v. 31, p. 307–310, doi:10.1130/0091-7613(2003)031<0307:MLSLER>2.0.CO;2.

Xu, C.H., Zhou, Z.Y., Chang, Y., and Francois, G., 2010, Genesis of Daba arcuate structural belt related to adjacent basement upheavals: Constraints from fission-track and (U–Th)/He thermochronology: Science China, v. 53, p. 1634–1646, doi:10.1007/s11430-010-4112-y.

Yin, A., and Nie, S., 1993, An indentation model for the North and South China collision and the development of the Tan-Lu and Honam fault systems, eastern Asia: Tectonics, v. 12, p. 801–813, doi:10.1029/93TC00313.

Yin, A., and Nie, S., 1996, A Phanerozoic palinspastic reconstruction of China and its neighboring regions, *in* Yin, A., and Harrison, T.M., eds., The tectonic evolution of Asia: Cambridge, UK, Cambridge University Press, p. 442–485.

Zhang, G.W., Dong, Y.P., and Yao, A.P., 1997, The crustal compositions, structures and tectonic evolution of the Qinling orogenic belt: Geology of Shanxi, v. 15, no. 2, p. 1–14.

Zhang, G.W., Zhang, B.R., Yuan, X.C., and Xiao, Q.H., 2001, Qinling orogenic belt and continental dynamics: Beijing, Science Press, p. 1–855.

Zhang, Y., Dong, Y.P., Li, T.G., Yang, M.S., Cheng, S.Y., and Wang, Y.P., 2009, Magnetic anomaly analysis of the Dabashan fault and its tectonic implications: Progress in Geophysics, v. 24, p. 1267–1274, doi:10.3969/j.issn.1004-2903.2009.04.015.

Manuscript received 22 October 2012
Revised manuscript received 14 January 2013
Manuscript accepted 17 January 2013

Printed in USA