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INTRODUCTION TO A SPECIAL SECTION
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Special Section:
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Key Points:
- We summarize and report new data sets, observations, and modeling results of the eastern Tibet during the last decade.
- All these contributions will provide new insights into the geodynamics of the eastern Tibet.
- We further highlight a number of outstanding questions that remain to be addressed.

Correspondence to:
H. Zhang,
huiping@ies.ac.cn

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Ten Years After the Wenchuan Earthquake: New Insights Into the Geodynamics of the Eastern Tibet

Huiping Zhang[1,2], Eric Kirby[3,1], Haibing Li[4], Kristen Cook[5], and Peizhen Zhang[2,6]

[1]State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, Beijing, China, [2]Guangdong Provincial Key Laboratory of Geodynamics and Geohazards, Guangzhou, China, [3]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA, [4]Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China, [5]GFZ German Research Centre for Geosciences, Potsdam, Germany, [6]School of Earth Science and Geological Engineering, Sun Yat-sen University, Guangzhou, China

Abstract In 2008, the *Mw* 7.9 Wenchuan earthquake killed >80,000 and injured more than 370,000 people in the province of Sichuan, China. About 5 years later, *Mw* 6.6 Lushan earthquake occurred on 20 April 2013, only ~90 km further south. More recently, in 2017, a third event, *Mw* 6.5 Jiuzhaigou earthquake, occurred ~250 km north of the Wenchuan earthquake epicenter. These events were all along the Longmen Shan thrust belt in eastern Tibet. The questions posed by these events still reverberate in the Chinese and international geoscience communities. In this special section, we summarize and report new data sets, observations, and modeling results of the eastern Tibet during the last decade. It covers the tectonics of eastern Tibet, the seismology, and the surface response of the earthquake. All these contributions will provide new insights into the geodynamics of the eastern Tibet. We further highlight a number of outstanding questions that remain to be addressed.

1. Introduction

In the past decade and a half, a series of earthquakes have occurred along the eastern margin of the Tibetan Plateau, in Sichuan Province, China. In May 2008, the *Mw* 7.9 Wenchuan earthquake ruptured multiple strands of the imbricate Longmen Shan thrust belt, killing >80,000 people and injuring more than 370,000. Five years later, in 2013, the *Mw* 6.6 Lushan ruptured a southern segment of the same thrust system. More recently, in 2017, a third event occurred ~250 km north of the Wenchuan earthquake epicenter. This *Mw* 6.5 Jiuzhaigou earthquake occurred along a little-known extension of the Huya fault to the east of the Min Shan and resulted in additional damage and casualties. These events provide new insights into long-standing questions regarding the structural and tectonic evolution of this part of the Tibetan Plateau.

The Longmen Shan, a mountain range ~500 km long and 30–50 km wide, marks a steep topographic transition from the eastern Tibetan Plateau with elevations ~4,000 m to the foreland of the Sichuan Basin at ~500 m above sea level (Clark & Royden, 2000; Kirby et al., 2003, 2008). Mountain summits in the southwest part of the Longmen Shan reach elevations in excess of 7,000 m, and the transition to the foreland region represents one of the steepest margins of the plateau (Clark & Royden, 2000). The degree to which this sharp gradient in topography and crustal thickness (e.g., Robert et al., 2010) is a relict of Mesozoic orogeny and crustal thickening (e.g., Dirks et al., 1994) and the degree to which it reflects mountain building in Cenozoic time (Hubbard & Shaw, 2009) remain a first-order question. Similarly, the degree to which active structures in the seismogenic crust reflect the superposition of the present-day stress field on inherited crustal anisotropy is not well understood. Finally, the physical state and rheologic properties of the middle and lower crust in eastern Tibet and whether such crust is capable of lateral flow (e.g., Burchfiel et al., 2008) remain a vigorous debate.

Recent seismic events in eastern Tibet provide a new perspective on these first-order questions, and a remarkable wealth of new observations has been acquired in the years since the Wenchuan earthquake. This special section provides a retrospective compilation of manuscripts that collectively refine our understanding of the geological evolution, crustal structure, and seismic potential of the Longmen Shan thrust belt. The collection of contributions includes 18 papers published in *Tectonics* and 8 papers published in *JGR-Solid Earth*. These contributions address a range of topics from the geologic evolution, active tectonics, and stress state of eastern

Tibet; seismology of the 2008 Wenchuan earthquake; the response of surface processes and erosion following the earthquake; new geophysical images of the crustal architecture; and geodynamic modeling of deformation in eastern Tibet.

2. Geologic Evolution of the Longmen Shan and Adjacent Regions

Much of the high, flat part of eastern Tibet to the northwest of the Longmen Shan is underlain by the Songpan-Garze terrane (Clark et al., 2006), which consists predominately of thick middle and upper Triassic flysch deposits (Burchfiel et al., 1995). The fault system along the Longmen Shan initially developed during Mesozoic convergence between the North China Block, South China Block, and the Songpan-Garze basin (Burchfiel et al., 1995; Cook et al., 2013). Triassic shortening structures involving metamorphic rocks are unconformably overlain by Lower to Middle Jurassic strata (Burchfiel et al., 1995). Structural analyses and $^{40}Ar/^{39}Ar$ geochronology by Yan et al. (2018) and available mapping results across the northern Longmen Shan revealed that the southward foreland fold-and-thrust propagation took place between 237 and 180 Ma, indicating that the Longmen Shan thrust belt was first built in the Early Mesozoic by the southward progressive deformation of the foreland belt of the southwest Qinling orogenic belt.

New structural and thermobarometric data presented by Airaghi et al. (2018) provide new insight into the structural and metamorphic evolution of the Mesozoic orogen. Their contribution provided a comprehensive data set of the paleotemperatures and P-T estimates for low-grade metamorphic domains. In the central Longmen Shan, two Early Mesozoic metamorphic jumps were observed across the Wenchuan and Beichuan faults, respectively, attesting to differential burial and exhumation histories across major fault systems. In the southern Longmen Shan, rocks experienced greenschist facies metamorphism in the Late Cretaceous; peak conditions were reached at circa 80–60 Ma in the basement, circa 55–33 Ma in the cover, and circa 50 Ma after the greenschist facies metamorphic overprint observed in the central Longmen Shan (ca. 150–120 Ma). The observed differences in metamorphic history suggest that present-day fault segmentation along the central and southern Longmen Shan reflects antecedent conditions that were established during Mesozoic mountain building.

Cenozoic deformation in eastern Tibet is characterized by southeast directed overthrusting and involved reactivation of Mesozoic fabrics and structures (Burchfiel et al., 1995, 2008). Deconvolving the history of slip along the Longmen Shan thrust belt is very challenging, and significant uncertainty still remains regarding the magnitude of Cenozoic displacement. Early thermochronologic studies revealed significant cooling in Miocene time (Arne et al., 1997; Kirby et al., 2002). However, more recently, Wang et al. (2012) demonstrated, using a suite of low-temperature thermochronometers, that the central Longmen Shan experienced two phases of rapid exhumation, one that began in Oligocene time (~30–25 Ma) and a second phase in the late Miocene (~15 Ma to present). Although the spatial extent of Oligocene exhumation remains poorly known, exhumation starting at circa 35–30 Ma has also been observed along the continuation of the Longmen Shan thrust belt, ~300 km to the southwest (Zhang et al., 2016). Writing in the present special section, Cao et al. (2019) report new evidence of late Oligocene to early Miocene tectonic exhumation from the Yalong-Yulong thrust belt. New apatite fission track and (U-Th)/He thermochronology samples from the Jianchuan basin in the hanging wall of the Yulong thrust showed 2.3–3.2 km rapid exhumation between ~28 and ~20 Ma. The approximate synchronicity of exhumation along the Yalong-Yulong and Longmen Shan thrust systems indicates that widespread crustal shortening and thickening took place in eastern Tibet during the late Oligocene to early Miocene.

Compared with the relatively limited evidence for Oligocene exhumation, evidence for widespread exhumation and cooling is abundant along the eastern margin of the Tibetan Plateau. Writing in this special section, Tian et al. (2018) present new thermochronologic data from along the Min Shan, the mountain range defining the topographic margin of the plateau north of the Longmen Shan. New thermochronologic samples across the Minjiang and Huya faults exhibit diachronous ages across these fault systems, with younger ages in their hanging walls than footwalls (Tian et al., 2018). Inference of thermal histories from age-elevation sample distribution and kinetic models suggests that differential exhumation started in late Miocene time (~10 Ma), consistent with evidence for late Miocene exhumation elsewhere in eastern Tibet.

South of the Min Shan, several north-south striking thrusts are present within the Sichuan Basin. New work suggests that some of these structures have been reactivated along northeast striking preexisting faults (Li, Zhang, et al., 2018). Subsurface structural architecture determined by seismic reflection profiles, borehole data, and field investigations led Li, Zhang, et al. (2018) to suggest an origin of the oblique thrusting and strain partitioning under a regional east-west compressional stress. Using the records of fault activity and growth strata in the late Pliocene and Quaternary foreland sediments, as well as the coseismic rupture style of the Wenchuan earthquake, Li, Zhang, et al. (2018) place bounds on the timing and amount of crustal shortening since ~5–2 Ma. These ages are younger than thermochronologic constraints on the cooling and exhumation along the Longmen Shan and suggest the possibility that deformation has propagated into the Sichuan Basin relatively recently.

Wang et al. (2018) also report new results from the southeast regions of the plateau margin, southwest of the Longmen Shan, along two continental scale shear zones for apatite and zircon (U-Th)/He thermochronology. Interestingly, these results also reveal a similar but younger two-stage exhumation than that of the Longmen Shan thrust belt. Combined with insightful analysis of the longitudinal profiles of the Salween River, Wang, Zhang, et al. (2018) identified a first rapid and prominent cooling event in the middle Miocene followed by a second, lower magnitude cooling event in the late Miocene to early Pliocene. These pulses of deformation are consistent with a possible late Cenozoic ~60–80° clockwise rotation observed along the adjacent northern Sibumasu and Simao regions, as shown by the available and new paleomagnetic data (Li, Van Hinsbergen, et al., 2018).

Several contributions address the geodynamic consequences of erosional unloading of the steep plateau margin. Over geologic timescales, fluvial incision and associated erosional unloading will drive isostatic rebound of the flexural upper crust. Tan et al. (2018) explored how this process may impact fault activity along the Longmen Shan. The authors modeled topographic stresses on the faults that ruptured during the 2008 Wenchuan earthquake and found that stress changes due to spatial differences in topography and fluvial incision may explain coseismic slip partitioning during rupture. A second contribution explores erosion by landslides over several earthquake cycles. G. Li et al. (2019) designed a two-dimensional surface displacement field model over a full earthquake cycle accounting for coseismic deformation, postseismic relaxation, landslide erosion, and erosion-induced isostatic compensation. Not surprisingly, they found that the ratio between the landslide erosion and uplift is mostly sensitive to parameters related to landslide volumes and moderately sensitive to the effective elastic thickness of lithosphere. They concluded that the long-term average seismic volume balance for eastern Tibet and the topography following the earthquakes is more constructed rather than destructed. Finally, a related paper estimated the contribution of isostatic rebound due to coseismic landslide erosion (Ren et al., 2018). Considering that tectonic uplift along the Longmen Shan thrust belt likely initiated between 15 and 10 Ma ago, these authors estimated ~550–1,300 m total isostatic rebound if the earthquake-induced landslide erosion occurred repeatedly in a similar manner to the Wenchuan earthquake (Ren et al., 2018).

3. Active Faults and Earthquake Sequence

The 2008 *Mw* 7.9 Wenchuan earthquake and subsequent events inspired renewed interest in the seismogenic potential of faults in the Longmen Shan region. Convergent and right-lateral deformation along the eastern margin has been largely accomplished along three fault systems, namely, from northwest to southeast, the Wenchuan-Maoxian (Pingwu-Qingchuan) fault, Yingxiu-Beichuan fault, and Guanxian-Anxian fault (Burchfiel et al., 1995; Densmore et al., 2007; Kirby et al., 2000, 2003).

The 2008 *Mw* 7.9 Wenchuan earthquake ruptured along the Guanxian-Anxian fault and the Yingxiu-Beichuan fault (Densmore et al., 2007; Zhang et al., 2010). Except for the ~70 km rupture along the Guanxian fault, the coseismic rupture extended ~270 km northeastward along the Yingxiu-Beichuan fault, but it propagated only about 20 km southwestward from the epicenter (Zhang et al., 2010). Fundamental debate still exists regarding the geometry and depth extent of these seismogenic faults. Geologic and geodetic constraints suggest that the structures are listric reverse faults that transect the upper crust at relatively high angle, yet seismic reflection data reveal low to moderate angle reflectors interpreted to represent thrust faults. Using seismic data recorded by a dense temporary seismic array, Yin et al. (2018) relocated aftershocks during the first 7 days after the mainshock and suggested that aftershocks were associated with high-angle listric faults that rooted into a shallowly dipping plane at ~20 km depth. This listric fault geometry was later confirmed by the Wenchuan earthquake Fault Scientific Drilling project, which was designed to look into the coseismic Yingxiu-Beichuan fault structures (Li et al., 2013). Adding to this body of work, Wang et al. (2019) found that the Yingxiu-Beichuan fault had a very long history of slip with a listric reverse fault geometry and its accumulated crustal shortening has been responsible for the uplift of the Longmen Shan. In the third pilot borehole of the Wenchuan earthquake Fault Scientific Drilling project, the same research group (He et al., 2018) also found evidence for aseismic creep facilitated by phyllosilicate minerals and pressure solution on the Guanxian-Anxian fault plane. They further suggested that the fault may exhibit depth-dependent behavior, creeping at shallow crustal levels, as a possible explanation for the Wenchuan earthquake rupture mechanism.

Additional contributions in this special section address the question of Quaternary activity along other fault systems adjacent to the Longmen Shan. Near the transition from the Longmen Shan into the interior plateau, the Pingwu-Qingchuan fault connects to the southwest with the Wenchuan-Maoxian fault, and it is the most northwest fault in the Longmen Shan thrust belt. Because the coseismic Wenchuan earthquake rupture propagated from the Yingxiu-Beichuan fault toward the Pingwu-Qingchuan, whether the Qingchuan fault could host previous large earthquakes or not and its future seismic potential is in critical need of study. Liang et al. (2018) conducted field investigations and paleoseismic trenching on this fault segment and found very minor dextral strike-slip but extension fractures along the Qingchuan fault since the late Quaternary. Formation of the extensional structures was then argued to be a secondary coseismic effect due to the earthquakes on the Beichuan-Yingxiu fault. The recent activities along the Qingchuan fault might have been hampered due to the differential Quaternary uplift and stress release along the Min Shan, as revealed by Tian et al. (2018) and Kirby et al. (2000).

To the south of the Longmen Shan thrust belt, the Daliang Shan fault connects continuously with the Xianshuihe fault but with a low slip rate and scarce strong earthquakes. To assess seismic hazard, Sun et al. (2019) excavated four trenches along the south Daliang Shan fault and discovered six and thirteen events on the two splay faults. The seismic energy accumulated on the Daliang Shan fault was further suggested to be equivalent to an $M \approx 7.6$ event in eastern Tibet.

4. Stress State of Eastern Tibet

The present state of stress in the crust along the eastern Tibetan Plateau remains a frontier of research. Understanding the relationships between fault activity, stress in the shallow crust and deformation in the deep crust and mantle can provide insight into the geodynamics of the region. To estimate driving forces of deformation in eastern Tibet, Yang et al. (2018) conducted teleseismic shear wave splitting measurements and measured seismic anisotropy. Combining these results with estimates of maximum compressive stress in the upper crust from focal mechanisms of recent earthquakes, these authors found that the induced anisotropy mainly resulted from alignment of fault fabrics by strong shearing along strike-slip faults, while the widespread stress rotations and systemic angular difference between the upper crustal stress field and seismic anisotropy suggest the decoupling of upper crustal deformation from middle and lower crust (Yang et al., 2018).

Many studies have proposed that large earthquakes on the fault will cause changes in the regional stress field (e.g., Yi et al., 2012). Tectonic loading due to large earthquakes along one fault is expected to affect the other nearby faults. To investigate stress evolution due to interaction on different faults and the long-term temporal pattern of seismicity, Luo and Liu (2018) analyzed stress changes on major active faults due to coseismic displacement and postseismic viscoelastic stress relaxation in eastern Tibet. By combining a three-dimensional viscoelastoplastic finite element model with a geodynamic model, together with available geodetic data, they found that only 9 of the 28 large earthquakes since 1327 Common Era. ruptured along fault segments where the Coulomb stress was decreased by preceding events. But interestingly, when considering the interseismic tectonic loading and rate of stress accumulation, they identified that the Coulomb stress on the Yinxiu-Beichuan fault had increased before the 2008 event. Luo and Liu (2018) finally calculated the interseismic stressing rates for most of the active faults and pointed out high seismic potential along the Xianshuihe and Anninghe faults, which are connected with the Daliang Shan fault, as presented here in the special section by Sun et al. (2019).

In a similar contribution, Liu, Dong, et al. (2018) focused on the stress interaction among the Xianshuihe fault and different faults along the Longmen Shan thrust belt. By analyzing 14 large earthquakes ($M \geq 6.5$)

from 1725 Common Era. until the Wenchuan earthquake, Liu, Dong, et al. (2018) calculated stress for different faults and suggested that stress contrasts were consistent with tectonic loading over ~20–160 years. They suggest an interseismic stressing rate of 1300 Pa/a, 2.4–6.5 times larger than the estimation by Luo and Liu (2018) in this special section. Liu, Dong, et al. (2018) conclude that recent seismic events cast a stress shadow near the southwest part of the Longmen Shan thrust belt. This stress shadow is suggested to have acted as a barrier that prevented the Wenchuan earthquake rupture from effectively propagating toward the southwest and may have led to an ~60 km long seismic gap between the Wenchuan and the Lushan events.

The question of remote triggering is also raised regarding the 2017 *Mw* 6.5 Jiuzhaigou earthquake. The location of the Jiuzhaigou event (33.20°N, 103.82°E) is ~250 km to the north of the epicenter of 2008 *Mw* 7.9 Wenchuan earthquake and occurred along a little-known fault system. Jia et al. (2018) investigated spatial and temporal variations in seismicity rate in the Jiuzhaigou region. They discovered that there was a decrease of background seismicity around the epicenter of the Jiuzhaigou earthquake immediately after the occurrence of the 2008 *Mw* 7.9 Wenchuan earthquake. Along with calculation of the static and viscoelastic stress changes, these authors conclude that the 2017 Jiuzhaigou earthquake was delayed by the Wenchuan earthquake. Moreover, they suggest that nearby active faults are still capable of future large-magnitude earthquakes, consistent with the numerical modeling results by Luo and Liu (2018) in this special section.

More than 300 $M_L \geq 4.0$ aftershocks occurred after the mainshock of the 2008 *Mw* 7.9 Wenchuan earthquake until 8 September 2010. Lin et al. (2018) analyzed the broadband waveforms for these events and used 160 events to invert seismic moment tensors. Considerable variations were observed with a mixture of mainly reverse and strike-slip mechanisms and a small number of normal events. The variability of aftershock mechanisms was argued to be an indication of stress reorganization on numerous small secondary faults. Furthermore, Wang et al. (2018) investigated the generation of the seismic gap between the Wenchuan and Lushan ruptures by analyzing the microearthquakes along the Longmen Shan and adjacent regions from May to December 2015. Interestingly, these authors found that these small events tend to concentrate at different depths on both sides of the seismic gap; thus, they speculated that the gap might have served as a transition zone between the source regions of the Wenchuan and Lushan events. They further argued that the small seismic events are most likely modulated by seasonal water storage in the shallow crust (Wang, Liang, et al., 2018).

5. Deep Structure and Geodynamics

The geodynamic mechanism(s) for plateau uplift and lateral expansion in eastern Tibet has been the subject of considerable research and remains controversial, with some workers proposing thickening by lateral flow in the lower crust (Clark & Royden, 2000; Royden et al., 1997, 2008), extrusion of rigid blocks (Molnar & Tapponnier, 1975), and deformation distributed throughout the lithosphere (Bendick & Flesch, 2007; Copley, 2008). In addition to constraints from near-surface geologic observations, knowledge of the deep crust, mantle structure, and the geodynamics is essential to resolving this question. A full understanding of the evolution of eastern Tibet requires large-scale and high-resolution imaging of the crustal and upper mantle structure underneath the plateau and the adjacent tectonic domains.

Several crustal scale or even deeper cross sections across the Longmen Shan thrust belt have been previously provided from both controlled-source and passive-source seismic experiments. All of these experiments showed that the Moho varies from ~40 km beneath the Sichuan basin to ~60–65 km beneath the eastern Tibetan plateau. To better understand the spatial pattern for the structure of the crust and mantle across the Longmen Shan thrust belt, Qian et al. (2018) deployed an array of 80 broadband seismic stations across the region. Seismic imaging using *P* wave receiver functions along six profiles revealed complex along-strike variation of the Moho geometry, similar to the along-strike metamorphic segmentation reported in this special section (Airaghi et al., 2018). The Moho deepening is relatively smooth in the northeast part of the Longmen Shan, but in the central and southwest regions, the Moho deepens abruptly and may even be duplicated. In contrast to previous studies, these authors find a low-velocity layer at the base of the crust beneath the Sichuan basin, which they argued is similar to structures along the northern margin of the Tibetan Plateau against the Qaidam basin (Karplus et al., 2011).

To evaluate lithospheric architecture over a broader region beyond the Longmen Shan thrust belt, Zhang et al. (2018) acquired ~74 k high-quality *S* wave traveltime residuals from teleseismic waveforms of ~600 earthquakes recorded by the ChinArray seismic network and obtained a new higher-resolution larger-scale 3-D shear wave velocity model. The variation of their shear wave velocity structures in the crust and upper mantle revealed pronounced regional heterogeneities, including particularly clear velocity contrast boundaries along the eastern Tibet margin. One of the most interesting findings is that the distribution of different tectonic domains is consistent with the imaged zones of low velocity and high velocity at depths of 10 to 100 km. This prominent feature of regional heterogeneities led them to conclude that deformation of eastern Tibet is primarily governed by these heterogeneities and characterized by horizontal shortening and vertical stretching (the authors' "push-squeeze mechanism"). Additionally, Zhang et al. (2018) reinforced previous results that relatively rigid blocks surrounding the plateau constrain the deformation of the plateau interior (e.g., Cook & Royden, 2008).

Writing also in this special section, Sun and Liu (2018) further highlight the significance of the regional heterogeneities in different regions of the plateau. Using a suite of two-dimensional viscoplastic finite element models, Sun and Liu (2018) succeeded to reproduce the major features of the two types of plateau margins with different rheologic contrasts between the plateau and the bounding blocks. Their results suggest that (1) major lateral growth of the plateau mainly occurred northeastward, where numerous terranes with relatively weak mantle lithosphere were prone to incorporation into the plateau; (2) the lateral growth of the plateau has been restricted and confined by the adjacent blocks with a strong mantle lithosphere, such as the Sichuan Basin. These margins, in turn, localized strain and occurrence of large earthquakes. The Wenchuan, Lushan, and Jiuzhaigou earthquakes are the perfect examples due to this style of localized deformation in the eastern Tibet.

To answer the question of why the seismic gap between the Wenchuan and Lushan earthquakes persisted between two large events, Liu, Liang, et al. (2018) deployed a dense seismic array to conduct joint inversion of dispersion curves and receiver functions. Their study yielded a velocity structure with very high resolution of ~20 km and revealed a low-velocity zone and thickened crust beneath this seismic gap, which they argued for an origin of partial melting that could explain the aseismic behavior.

This first-order rheologic contrast between the plateau and the Sichuan Basin, highlighted both by Zhang et al. (2018) and Sun and Liu (2018) in this special section, explains steeper topographic gradients and localized strain accumulation along this plateau margin. At a more regional scale, there also exist local heterogeneities due to lithologic variations in the shallow crust. Qiao et al. (2018) noticed the potential role of the relatively rigid crust of the Emeishan Large Igneous Province in southeastern Tibet. They used ambient noise tomography to invert waveform data from 73 broadband stations for a 3-D shear wave velocity model of the crust and uppermost mantle. The inner zone of the Emeishan Large Igneous Province was found to be relatively rigid with a higher velocity than that in the surrounding areas, and the authors infer that these heterogeneities guided the flow of crust from the central plateau into two channels. In addition, synthesis of available deformation histories, these authors propose a two-phase transport model in SE Tibet involving (1) rigid block extrusion between the right-lateral Sagaing Fault and left-lateral Red River Fault during the early Oligocene-early Miocene and (2) a mode of rigid block extrusion and material channel flow in the middle-lower crust from the late Miocene to the present. This two-phase pulsed deformation is consistent with low-temperature thermochronology observations from the Longmen Shan thrust belt (Wang et al., 2012), the Yalong thrust belt (Zhang et al., 2016), and the Jianchuan Basin (Cao et al., 2019 in this special section), suggesting early Oligocene construction of the eastern margin and a late acceleration of exhumation and uplift during the late Miocene.

6. Concluding Remarks

The collection of papers in this special section represents a diverse suite of the most recent results pertaining to the tectonic evolution of eastern Tibet and adjacent regions. Although we do not expect all of the questions to be answered by the contributions herein, we emphasize that the new data and results presented here deepen our understanding of how this region of the plateau continues to evolve. The papers in this special section also highlight a number of outstanding questions that remain to be addressed. Those include the following. (1) Deconvolving the relative contributions of Mesozoic and Cenozoic deformation to the modern crustal thickness and elevation in eastern Tibet is hampered by limited records of sedimentation in the adjacent basins and by significant overprinting of the different stages of deformation. The degree to which

Mesozoic orogenic events preconditioned the region and continue to localize active deformation remains a first-order question. (2) Geodynamic drivers for two phases of Cenozoic exhumation and mountain building still need to be explored. These may reflect either distinct stages of plateau growth or may be a consequence of the interaction between tectonics and climate during the late Cenozoic. (3) The coevolution of topography, erosion in both coseismic events and throughout interseismic periods, and the stress state of the crust remain an outstanding question in active orogens worldwide. (4) The degree to which active structures, both along the Longmen Shan thrust belt and within the Sichuan Basin, pose future seismic hazards to the highly populated regions adjacent to eastern Tibet is a societally pressing question. Further studies that integrate paleoseismic histories with stress loading will be critical to anticipate such hazards. (5) Finally, the role of rheologic contrasts in the lithosphere and how they modulate and localize deformation remain essential questions that bear on both the accumulation of permanent deformation and earthquake generation and rupture propagation.

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