Earth and Planetary Science Letters 487 (2018) 179–189

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Present-day crustal deformation and strain transfer in northeastern Tibetan Plateau

Yuhang Li [a,b,*], Mian Liu [b,c], Qingliang Wang [a], Duxin Cui [a]

[a] *Second Monitoring and Application Center, China Earthquake Administration, Xi'an, China*
[b] *Department of Geological Science, University of Missouri, Columbia, MO, USA*
[c] *Laboratory of Computational Geodynamics, Chinese Academy of Sciences, Beijing, China*

ARTICLE INFO

Article history:
Received 11 October 2017
Received in revised form 18 January 2018
Accepted 25 January 2018
Available online xxxx
Editor: A. Yin

Keywords:
Tibetan Plateau
extrusion tectonics
GPS
leveling
strain partition

ABSTRACT

The three-dimensional present-day crustal deformation and strain partitioning in northeastern Tibetan Plateau are analyzed using available GPS and precise leveling data. We used the multi-scale wavelet method to analyze strain rates, and the elastic block model to estimate slip rates on the major faults and internal strain within each block. Our results show that shear strain is strongly localized along major strike-slip faults, as expected in the tectonic extrusion model. However, extrusion ends and transfers to crustal contraction near the eastern margin of the Tibetan Plateau. The strain transfer is abrupt along the Haiyuan Fault and diffusive along the East Kunlun Fault. Crustal contraction is spatially correlated with active uplifting. The present-day strain is concentrated along major fault zones; however, within many terranes bounded by these faults, intra-block strain is detectable. Terranes having high intra-block strain rates also show strong seismicity. On average the Ordos and Sichuan blocks show no intra-block strain, but localized strain on the southwestern corner of the Ordos block indicates tectonic encroachment.

1. Introduction

The collision of the Indian and Eurasian plates in the past ∼50 Ma has led to the formation of the Tibetan Plateau (Molnar and Tapponnier, 1975; Yin and Harrison, 2000). How was the plate convergence absorbed, and how has the Tibetan Plateau grown in time and space, remain uncertain. The collision caused contraction and thickening of the crust to form today's high-standing Tibetan Plateau, but it remands debated as whether crustal thickening has been achieved by pure shear of the lithosphere (England and Houseman, 1986) or by large-scale lateral flow in the lower crust (Clark and Royden, 2000). Others have argued that the collision is mainly accommodated by lateral extrusion of Asian lithosphere along major strike-slip faults (Tapponnier et al., 1982), based on evidence of large offsets and fast slip along many of the E–W trending strike-slip faults that bound the Tibetan Plateau and its internal terranes. However, pure lateral extrusion does not build a plateau, so we need to understand how the lateral extrusion is related to crustal contraction (Zheng et al., 2013a).

The spatiotemporal patterns of crustal deformation in the Tibetan Plateau, and slip rates of the major Tibetan faults, should provide the primary constraints of these competing processes. However, establishing the geological history of the growth of the Tibetan Plateau has been challenging (Yin and Harrison, 2000; Wang et al., 2014). On the other hand, space-based geodesy has provided detailed information of the present-day crustal deformation in the Tibetan Plateau, especially in its northeastern region (Zheng et al., 2013a; Gan et al., 2007). Furthermore, high precision leveling data from two dense networks established since the 1970s in eastern and northeastern Tibetan Plateau have become available in recent years (Liang et al., 2013; Hao et al., 2014), providing additional constraints on the vertical motions.

Northeastern Tibetan Plateau is a region of active plateau growth, as indicated by the intense seismicity (Fig. 1) and late Cenozoic deformation (Zheng et al., 2013a; Wang et al., 2014; Duvall and Clark, 2010). The present-day crustal deformation in northeastern Tibetan Plateau thus bears the keys to understanding the rise and growth of the Tibetan Plateau. In this study, we analyze the available GPS and precise-leveling data from northeastern Tibetan Plateau to address the following questions: 1) How is crustal extrusion along major strike-slip faults related to contraction and uplift? 2) Is the horizontal and vertical crustal motion correlated with each other? and 3) How are the various terrenes in northeastern Tibetan Plateau deforming today?

* Corresponding author.
E-mail address: liyuhangdz@163.com (Y. Li).

https://doi.org/10.1016/j.epsl.2018.01.024
0012-821X/

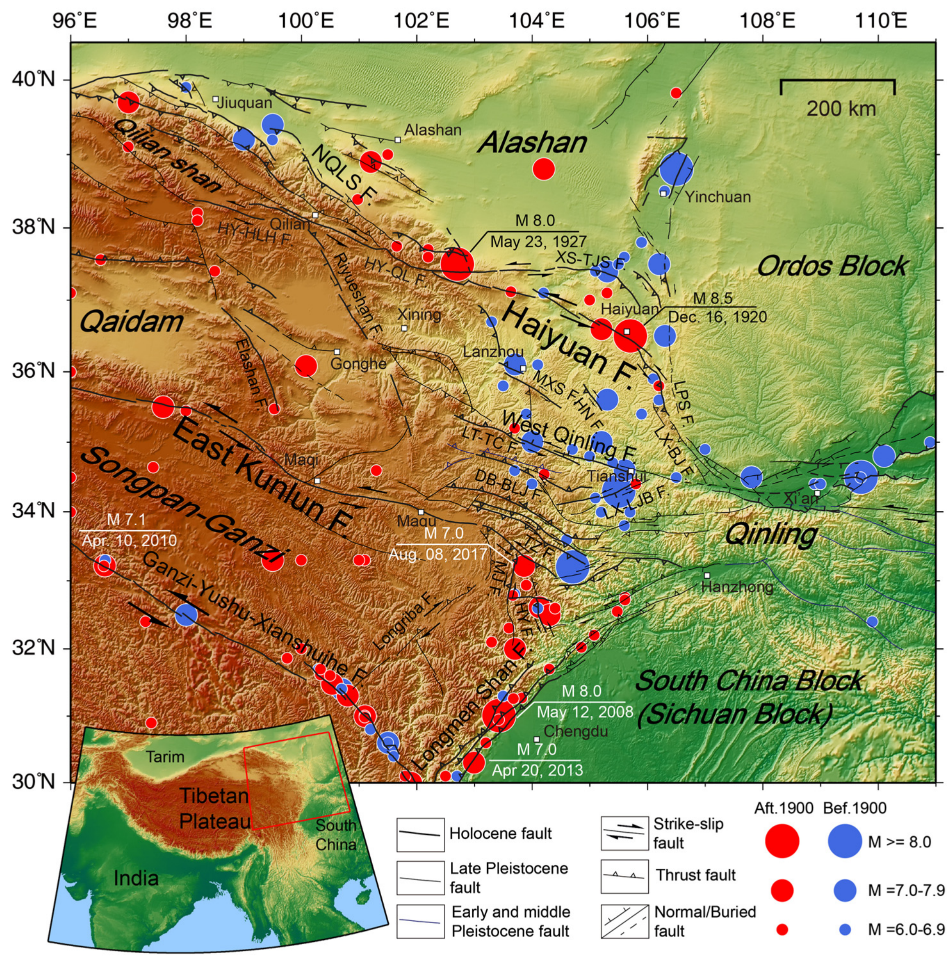

Fig. 1. Topographic relief, major faults (lines), and earthquake epicenters (circles) of northeastern Tibetan Plateau. NQLS F., the north of Qilian Shan Fault; XS-TJS F., the Xiangshan–Tianjingshan Fault; LPS F., the Liupan Shan Fault; LX-BJ F., the Longxian–Baoji Fault; MXS F., the Maxianshan Fault; HN F., the Huining Fault; LT-TC F., the Lintan–Tanchang Fault; DB-BLJ F., the Diebu–Bailongjiang Fault; TZ F., the Tazang Fault; MJ F., the Minjiang Fault; HY F., the Huya Fault; LX-LJB F., the Lixian–Luojiabu Fault; HY-HLH F., the Halahu segment of Haiyuan Fault; HY-QL F., the Qilian segment of Haiyuan Fault. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Tectonic background

The Tibetan Plateau consists of many terranes with different history and lithology, separated by a complex system of faults. These internal heterogeneities have a strong impact on the Cenozoic deformation history and strain distribution (Yin, 2010). To understand how these terranes and faults reacted to the Indo-Asian collision and influenced the present-day strain distribution, we briefly summarize here the geological background of major terranes and faults in northeastern Tibetan Plateau.

2.1. Major terranes

In this paper, northeastern Tibetan Plateau is loosely defined as the region north of the Ganzi–Yushu–Xianshuihe Fault and east of the Qaidam block (Fig. 1). Its southern part is the Songpan–Ganzi terrane (Fig. 1), which developed from a Paleozoic oceanic crust and is characterized by a thick sequence of Triassic strata of deep marine deposits (Yin and Harrison, 2000). Seismological studies show low velocities and high attenuation in the crust and upper mantle under the northern and eastern parts of the Songpan–Ganzi terrane (Zhang et al., 2011).

The Qaidam terrane (basin) (Fig. 1) is a low-relief, strong block developed on the Tarim-North China Proterozoic cratonic basement. Formation of the Qaidam basin started in early-middle Eocene (Yin et al., 2008), or in the middle Miocene to Pliocene as the deformation front jumped from the Eastern Kunlun Range to the Qilian Shan region (Metivier et al., 1998). In comparison with the Songpan–Ganzi terrane, under the Qaidam terrane the lower crust and upper mantle have higher seismic velocity (Mechie et al., 2012).

Further north is the Qilian Shan terrane, the northern margin of the Tibetan Plateau, which is bounded by the Alashan platform to the north (Fig. 1). As an orogeny of Ordovician continent–continent collision, the Qilian Shan experienced significant Cenozoic crustal shortening and folding (Metivier et al., 1998; Yuan et al., 2013; Tapponnier et al., 1990; Duvall et al., 2010). The folding and thrusting in this part of the plateau has partially accommodated the left-lateral crustal motion along the Altyn Tagh Fault by transferring left-lateral strike-slip motion to oblique thrusting (Zheng et al., 2013a; Tapponnier et al., 1990; Zheng et al., 2010).

Between the Songpan–Ganzi and Qilian Shan terranes and the bounding Ordos and Sichuan blocks is a transition zone consisting of numerous smaller terranes, each with a complex tectonic history. The West Qinling block is adjacent to the northeastern part of the Songpan–Ganzi terrane, between the Tazang and West Qinling faults. It experienced strong crustal contraction during the late Cenozoic (Zheng et al., 2013a). In contrast, the Longxi block, located between the West Qinling Fault and the Haiyuan Fault, has had much weaker Cenozoic deformation (Wang et al., 2012).

Northeastern Tibetan Plateau is bounded by the Alashan block to the north, the Ordos block to the east, and the Sichuan block