Earth and Planetary Science Letters 413 (2015) 144–157

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Mid-crustal detachment beneath western Tibet exhumed where conjugate Karakoram and Longmu–Gozha Co faults intersect

Nicholas J. Van Buer [a,*], Oliver Jagoutz [a], Rajeev Upadhyay [b], Marcel Guillong [c]

[a] Department of Earth, Atmospheric, and Planetary Sciences, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, United States
[b] Center of Advanced Study in Geology, Kumaun University, Nainital-263002, Uttarakhand, India
[c] Institute of Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25, NW CH 8092 Zürich, Switzerland

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 30 December 2014
Accepted 31 December 2014
Available online 21 January 2015
Editor: T.M. Harrison

Keywords:
metamorphic petrology
mechanical decoupling
geochronology
deformation
geologic map

ABSTRACT

Models for how shortening is accommodated in the India–Asia collision vary between an end member in which largely rigid blocks are extruded eastwards between lithospheric-scale strike-slip faults and an end member in which a hot, weak mid-crustal layer aids distributed deformation. Here the mode of crustal deformation is evaluated by studying the intersection of two main conjugate strike-slip faults at the west end of the Tibetan plateau. Our field mapping suggests that these faults, the right-lateral Karakoram fault and the left-lateral Longmu–Gozha Co fault, an eastward continuation of the Altyn Tagh fault, may be connected by a large-scale, east-dipping listric normal fault, exposing a wedge of mid-crustal rocks in its footwall. Pseudosection modeling of matrix and porphyroclast rim compositions from footwall metamorphic rocks yield late-syntectonic pressures of 640 ± 100 MPa and temperatures around $600 \pm 50\,^{\circ}$C. Extensive networks of narrow granitic dikes give U–Pb zircon ages as young as 13.7 ± 0.2 Ma, suggesting that footwall rocks remained hot until the late Miocene and were not exhumed until after this time. We infer >40 km heave across the Angmong fault, and suggest that it absorbs effectively all of the slip across the Longmu–Gozha Co fault (which it appears to truncate), so the Longmu–Gozha Co fault is seemingly confined to the upper crust. Similar mechanical decoupling likely occurs throughout the plateau, with strike-slip faulting in western Tibet limited to the upper, brittle part of the crust.

1. Introduction

Whether continent–continent collision zones are marked by plate-like tectonics or more pervasive strain largely depends on the properties of the middle and lower crust (Royden et al., 1997; Copley et al., 2011). In the archetypal India–Eurasia collision, one model emphasizes the importance of continuous deformation (England and Houseman, 1988), possibly aided by a weak, ductile mid-crustal layer beneath Tibet that allows decoupling between the upper crust and deeper parts of the lithosphere (Fig. 1B; Royden et al., 1997). This end-member model is supported by heat flow and geophysical data thought to indicate the presence of a hot (>600 °C), low-viscosity, mid-crustal layer (Alsdorf and Nelson, 1999; Wang, 2001; Mechie et al., 2004). Rare crustal xenoliths from Cenozoic alkaline volcanics also record high temperatures in the mid to lower Tibetan crust (Hacker et al., 2000).

Alternatively, it has been proposed that the Tibetan plateau behaves as a strong, rigid plate (Tapponnier et al., 1982), with an upper and lower crust that are mechanically coupled (Copley et al., 2011). In this model, substantial deformation is accommodated by lateral extrusion along lithospheric-scale conjugate strike-slip faults bounding the Tibetan plateau (Fig. 1A, Tapponnier et al., 2001). These two end-member crustal deformation models make specific predictions for the intersections of large-scale strike-slip faults (Fig. 1), which we evaluate in this paper using new field, petrologic, and geochronologic data.

The different rheological models for the deformation of the Tibetan crust can be tested, as they make detailed predictions for what happens at the intersections of large-scale, plateau-bounding strike-slip faults. For example, in the North American Basin and Range province, where the presence of a weak lower crust is well established, strike-slip faults of the Death Valley fault system, the Panamint Valley fault, and the conjugate Garlock fault are connected by large-scale normal fault systems (Burchfiel et al., 1989; Serpa and Pavlis, 1996). The presence of a weak mid-crustal layer below the upper crust deflects the normal and strike-slip faults into a subhorizontal detachment system, allowing for large-scale displacement of the upper crust with respect to the lower crust

* Correspondence to: Department of Geological Sciences, California State Polytechnic University, 3801 W Temple Ave, Pomona, CA 91768, United States.
E-mail address: njvanbuer@csupomona.edu (N.J. Van Buer).

http://dx.doi.org/10.1016/j.epsl.2014.12.053
0012-821X/

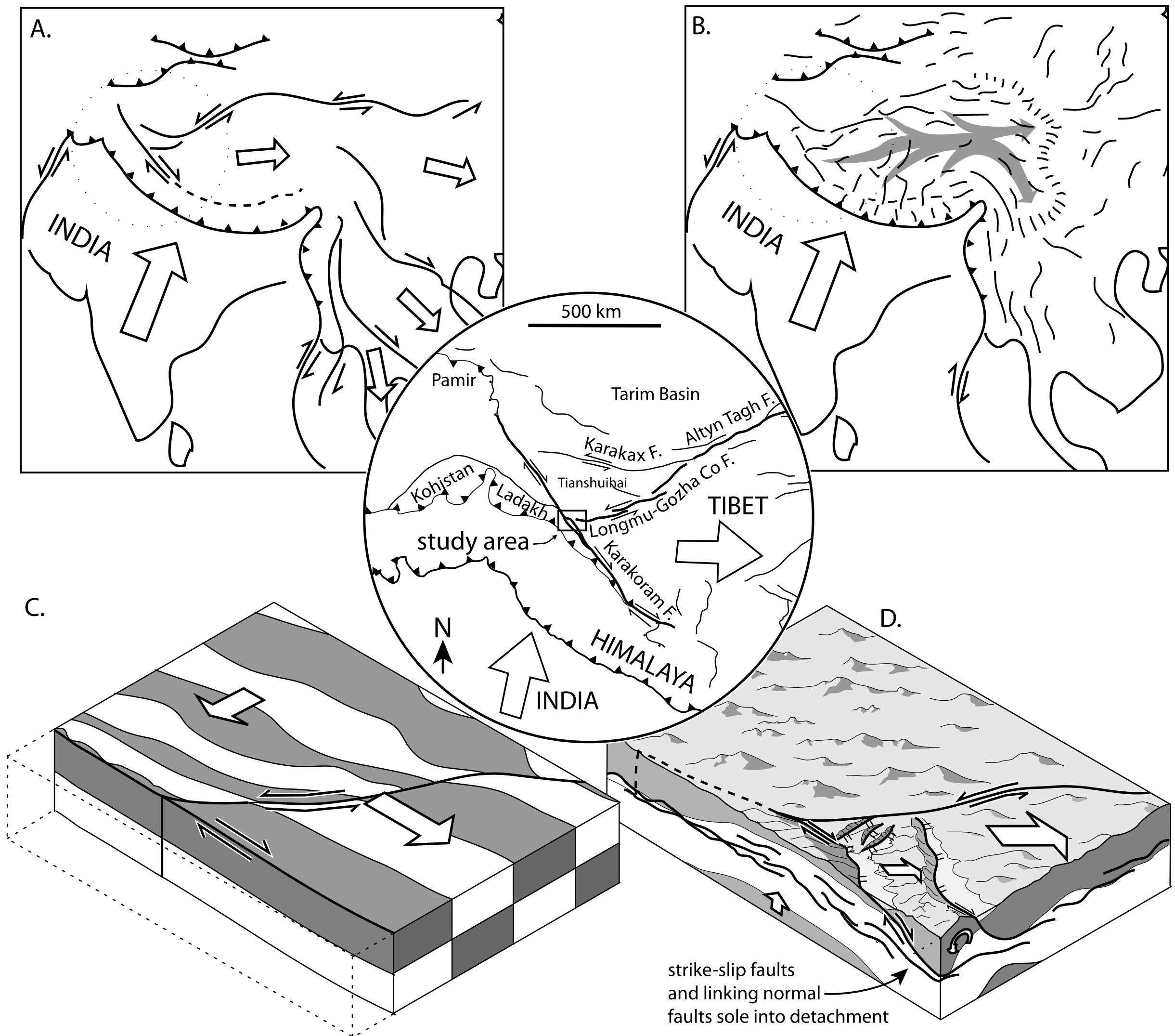

Fig. 1. A. In one end-member model for the India–Asia collision, the whole Tibetan crust behaves as a relatively coherent unit, causing deformation to be concentrated on lithospheric-scale faults, mostly concentrated around the edges of the plateau. Central inset shows mapped faults near western Tibet. B. In the other end-member, a weak middle crust facilitates distributed deformation throughout the plateau as it flows eastwards. Minor faulting related to that deformation is distributed throughout the plateau. C, D. These panels compare the predicted outcomes of the two end-member models on a conjugate fault junction. The block diagrams are oriented to mimic the approximate orientation of the junction between the right-lateral Karakoram fault (parallel to the left edge of the block diagrams) and the left-lateral Longmu–Gozha Co fault (cutting across the center of the blocks). C is based on the analog model PA1 of Peltzer and Tapponnier (1988). Stress is distributed throughout the vertically integrated crust, allowing the extruded block to remain largely intact while strain in concentrated along its margins by shear weakening. Significant deformation is limited to the area where the two blocks straddling the extruded block are zippered together. D is based on the model of Burchfiel et al. (1989), for the Death Valley/Garlock conjugate fault system. In this case, extrusion between the right-lateral/normal oblique faults in the foreground and the left-lateral fault cutting across the center is accommodated by large-offset, low-angle normal faults that root into the middle crust.

(Fig. 1D; Wernicke et al., 1988; Burchfiel et al., 1989; Lister and Davis, 1989). In the case of a more rigid crust, analog models indicate that lithospheric strike-slip faults might intersect without loss of vertical integrity of the crust, with most of the deformation accommodated by horizontal shortening where the two strike-slip faults zipper together behind the extruding block (Fig. 1C; Peltzer and Tapponnier, 1988). In this case, significant normal faulting would not be expected, and listric faulting within the crust would be precluded by the presence of a strong middle crust (Fig. 1C).

Even though it has been documented that normal faults play an important kinematic role in minor conjugate strike-slip zones within the Tibetan plateau (Taylor et al., 2003), the intersections of major plateau-bounding strike-slip faults have not been studied. To constrain how the evolution of the Tibetan crust and plateau fits between the two end-member rheological models, we present a detailed study of the intersection of two of the most important plateau-bounding strike-slip faults in western Tibet. We mapped in detail the intersection between the right-lateral Karakoram fault (KKF) and the left-lateral Longmu–Gozha Co fault (LGF), an eastward continuation of the Altyn Tagh fault (Figs. 1, 2).

2. Field relationships

2.1. West end of the Longmu–Gozha Co fault

Geologic mapping, via fieldwork where accessible, and also using ASTER and Landsat imagery processed via principal component analysis, suggests that the KKF and LGF are linked by a set of north–south-striking, east-dipping faults in the Chang Chenmo Range, which we refer to as the Angmong fault system (Fig. 2). In the next section, we argue that these faults represent a major normal fault system. Between the Angmong fault system and the Altyn Tagh fault, the LGF strikes about N 80° E. Along the transect of Matte et al. (1996), the LGF separates Mesozoic slate,