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Eocene Age Shortening Deformation in Northern Tibet: Implications Models of Plateau Growth

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Present - day orography of the Tibetan Plateau is largely attributed to the collision and ongoing convergence between India and Eurasia during the past ~ 50 million years. While most models of plateau formation consider a south to north progression of faulting, recent studies in northern Tibet show that thrust faulting and basin formation commenced at or soon after collision began. Early deformation was likely widespread reaching from the central to northern perimeter of the plateau. The distal or far-- - extent of the plateau is likely set by the contrast between weaker, more easily deformed accreted terranes and island arcs that make up the Eurasian margin, and stronger lithospheric fragments that underlie the Tarim Basin and the north China craton. Regardless of their geodynamic origin, Eocene age thrust faults in northern Tibet imply that the northern margin has remained stationary while the intervening region deforms where the emerging plateau grows narrower and presumably higher.

Many studies show that southern Tibet experienced large magnitude shortening in Cretaceous time related to oceanic subduction (e.g. Kapp et al., 2007), but did not deform extensively following continental collision (e.g. Coward et al., 1988). Instead, ca. 50 Ma deformation was widespread across the northern plateau, which arises from new evidence from stratigraphy and thermochronometry studies (Clark et al., 2010; Bally et al., 1986; Dupont - Nivet et al., 2004; Wang et al., 2008; Yin et al., 2002; Fang et al., 2003; Studnicki - Gizbert, 2008; Spurlin et al., 2005), and is further supported by new data presented here. This deformation occurred on major thrust and reverse faults that accommodate north - south or NNE - SSW directed fault motion. These fault systems extend for tens to hundreds of kilometers along strike and occur from the Qiangtang terrane to areas north of the Kunlun suture and within the Qilian Shan.

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The Hoh Xil basin, located near the boundary between the Qiangtang and Songpan Garze terranes, accommodated up to 6 km of terrestrial sediment shed northward from the central Qiangtang terrane. The age of these strata, the Fenghuoshan Group, are constrained by new geochrononlogy, biostratigraphy, and revised magnetostratigraphic data to have been deposited between 83 and 51 Ma (Staisch et al., submitted), placing the northern limit of pre - collisional deformation near the central Qiangtang terrane. Unconformable relationships between the Fenghuoshan Group and the overlying Late Eocene – Oligocene Tuotuohe and Yaxicuo groups indicate that tectonic deformation had expanded northward into the Hoh Xil Basin by late Eocene time. Steeply tilted ~33 Ma rhyolitic lava flows interbedded within the Tuotuohe Group indicate that active deformation continued into at least early Oligocene time.

Tectonic quiescence has persisted across the central Hoh Xil Basin since late Oligocene – early Miocene time. Undeformed lacustrine sediments of Miocene age (Wudaoling Gr.) overlie the moderately deformed Yaxicuo Gr. and more strongly deformed Paleocene age Fenguoshan Group (Staisch et al., submitted). Steeply dipping strata of the Fenguoshan Gr. are capped by undeformed basalt flows dated at ca. 27 Ma, which provides an upper limit on shortening deformation of the central Hoh Xil Basin. In the western Hoh Xil basin, north - south striking grabens cross - cut east - west striking folded and faulted Cenozoic (?) strata. New field observations from the western Hoh Xil Basin show Cenozoic (?) red beds faulted down on Triassic flysch deposits within the only recognized graben system in northern Tibet, currently of unknown age.

Pliocene to recent deformation in northern Tibet has long been recognized (e.g. Meyer et al., 1998). The highest fault slip rates occur on the Altyn Tagh and Kunlun strike-- - slip faults with crustal shortening, and presumably crustal thickening, occurring in an area between these major faults.

Active deformation south of the Qilian Shan appears to be concentrated in young sedimentary basins within the Qaidam Basin and upon the high plateau, south of the Qaidam Basin. The Kumkuli Basin (~ 4.8 km elev) within the plateau contains Oligocene and Miocene fluvial to lacustrine sediments dated with pollen and ostracod paleontology (Xinjiang Geologic Survey). Large‐scale isoclinal folds indicate post‐Pliocene crustal shortening in excess of ~23% estimated from reconstructed cross‐sections. Folded Quaternary fan surfaces indicate active faulting. 36Cl cosmogenic radionuclide dating from abandoned fan surfaces suggests rapid fold growth rates in excess of 2 mm/yr.

Commonly cited models suggest that when two continental plates collide, the resulting orogenic plateau should grow outward in time (e.g. Tapponnier et al., 2001; England and Houseman, 1988; Royden, 1996). That is, deformation and topography first develop at the collisional plate boundary and then an incipient plateau grows wider as topographic gradients favor deformation at greater distances because the continental lithosphere is weak enough to respond to these gravitationally derived stresses. However, localized faulting at the distal margin of the plateau from roughly Eocene time to the present suggests that the perimeter of the orogen remains relatively stationary during the ~ 2500 km of northward motion of India since collision.

A stationary perimeter in northern Tibet has geodynamic consequences related to the post--‐collisional decrease in convergence rates calculated from marine magnetic anomalies (e.g. Molnar and Stock, 2009). Using a stationary boundary, exponentially decreasing convergence rates predicts a constant contractional strain rate of 6.3×10^{-16} s^{-1} across the plateau, which is in good agreement with recently published plate motions and modern geodetic velocities (Clark, 2012). For viscous rheologies, constant bulk strain rate implies that ongoing convergence is resisted by constant average stress (constant force), likely derived from an intact, high‐viscosity mantle lithosphere beneath the plateau. The viscous resistance of the mantle lithosphere implies a previously unrecognized link between continental rheology and plate motions. If viscous resistance is a common condition to orogens, then orogen width rather than height may play a critical role in interpreting past plate motions. As such, orogen width can be evaluated from the geologic record of fault timing, which is advantageous over discrepant interpretations of past elevation from proxy records. Such models have potential impact for understanding the dynamics of plate motions at convergent continental margins.

Key words: Eocene, thrust faulting, deformation, fault gouge dating, thermochronometry, plate reconstructions

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