



Lithospheric weakness and episodic reactivation of the Altyn Tagh Fault since the Early Cretaceous: Insights into stress transfer and Tibetan Plateau growth

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The mechanisms of stress transfer across continental plate interiors during continent-continent collision, as well as the timing and the style of far-field fault system responses, remain poorly constrained. The collision between the Indian subcontinent and what is now Tibet began in the Eocene and has involved still on-going north-south convergence throughout southern Tibet and the Himalayas, providing an exceptional natural laboratory for studying continental collision processes.

The Altyn Tagh Fault (ATF), a >1600-km-long lithospheric-scale strike-slip fault marking the northern boundary of the Tibetan Plateau, is a key structure for investigating how deformation propagated following the India-Asia collision. However, the timing of its (sinistral?) initiation remains uncertain, with proposed ages ranging from the Mesozoic to the Miocene. These uncertainties largely reflect the involved structural complexities and the difficulty of directly dating the fault's protracted brittle activity. To address this long-standing problem and to better understand the ATF's evolution and its role in the Plateau build-up, we conducted detailed structural investigations of two significant outcrops in the Old Aksay region (Gansu province). These exposures preserve a complex fault internal architecture containing numerous Brittle Structural Facies (BSFs), that is, distinct rock domains defined by characteristic fault rocks, mineralogy, textures, and kinematics. Repeated faulting at those outcrops localized deformation into weaker zones, creating thick foliated gouge layers, and along discrete slip surfaces, while lithons from earlier slip events were locally preserved. Their juxtaposition records the temporal and spatial evolution of the ATF, including its deformation mechanisms, physical conditions during initial faulting and subsequent reactivations. We combined multiscale structural analysis with multi-grain-size K-Ar dating of synkinematic illite separated from BSFs at both outcrops.

The results reveal a protracted, episodic faulting history from the Early Cretaceous (~115 Ma) to the Quaternary (~0.6 Ma), documenting at least five reactivation events. The earliest record at

~115 Ma suggests the ATF existed from before collision as a lithospheric weakness inherited from Mesozoic intracontinental deformation. Crucially, we identify an Early Eocene event (~56 Ma) that provides the first direct geochronological evidence for brittle deformation nearly synchronous with the initial India-Asia collision farther south, supporting models of rapid stress transfer to the northernmost plateau margin. A Late Oligocene reactivation at ~26 Ma coincides with rapid, widespread Miocene exhumation and sedimentation across northeastern Tibet. Late Pliocene (~3 Ma) and Middle Pleistocene (~0.6 Ma) events record continuing slip and deformation localization during progressive Plateau expansion.

This intricate >100 Myr archive demonstrates that long-lived lithospheric weaknesses can preserve deformation spanning multiple tectonic regimes. Beyond providing a robust temporal framework for the tectonic evolution of the northern Tibetan Plateau, our results highlight the efficiency of far-field stress transfer through rigid lithosphere even over very large distances, and establish a powerful methodological protocol for integrating geochronological records and structural investigations in intracontinental orogens worldwide.