Cenozoic crustal shortening and plateau uplift within the Hoh Xil Basin, north-central Tibetan Plateau: Implications for causal mechanisms of plateau evolution

Lydia M. Staisch*, Nathan A. Niemi, Marin K. Clark, Chang Hong

Motivation

The central Tibetan Plateau was deformed, and possibly uplifted to near-modern elevations, prior to the Indo-Asian collision, analogous to the modern Altiplano-Puna Plateau in South America[12,13] (Fig. 1). Today, the Tibetan Plateau is roughly double the width of the pre-collisional deformation belt and the majority of post-collisional plateau expansion took place in the north.

Outstanding Questions:

How and when was crustal shortening accommodated in northern Tibet?

How does the timing and magnitude of shortening compare with paleoelevation and modern values of crustal thickness?

What causal mechanisms for plateau uplift are consistent with our data?

Timing of Deformation

"Ar/Ar" GEOCHRONOLOGY

Sampling

We collected variable deformed volcanic rocks from the FTTB for geochronology (Fig. 2).

Results

The deformed rhyolite is 33.48 ± 0.24 Ma (Fig. 3).

Interpretation

Ar/Ar ages indicate that north-south shortening of the FTTB ceased between ~34 and 27 Ma.

THERMOCRONOLOGY

Modeling

We modeled apatite (U-Th)/He ages and apatite fission-track length distributions from samples collected from the FTTB (Fig. 2) using HeFTY.[14]

Results

The onset of rapid cooling occurred by 45 ± 48 Ma, followed by slow cooling in the Oligocene (Fig. 4).

Interpretation

Shortening and exhumation of the FTTB initiated in the mid-Eocene, soon after the onset of Indo-Asian collision, and continued into the Oligocene.

FAULT GOUGE DATING

Methods

We dated two thrust faults from the FTTB (Fig. 2). Fault gouge ages obtained by polytype analysis and 40Ar/39Ar dating of clay-sized gouge aliquots and linear best fit using Bayesian regression techniques.

Results

Both fault gouge samples provide a faulting age of 44 - 45 Ma (Fig. 5).

Interpretation

We interpret the data to suggest that the south-directed thrust faults within the FTTB were active in mid-Eocene time.

Magnitude of Deformation

Methods

We constructed a geologic cross section across the FTTB (Figs. 2 and 6), based on field observations, isopach data[15], and new and existing geologic mapping[16-18]. We line and area balanced the cross section to derive the amount of shortening and estimated uncertainties based on hanging wall cut-offs, depth to decollement, and stratigraphic thicknesses[19-20].

Results

We derive a shortening estimate of 40.26 ± 10.03 km (28.0 ± 7.2%).

Isostatic Uplift

Methods

We calculate the isostatic uplift for ~28% pure shear to test whether shortening can account for modern crustal (65-70 km) and lithospheric (130-150 km) thicknesses and for Miocene paleoelevations (3.4-4.2 km).

Results

Measured upper crustal shortening cannot account for Miocene elevations or modern crustal thickness (Fig. 7b).

Interpretation

Other mechanisms of crustal thickening and surface uplift are necessary to build the northern plateau, such as lower crustal flow[21-23], uniform lithospheric thickening[24], and possibly mantle root loss[25] (Fig. 7c).

Isostatic calculations for proposed mechanisms for additional thickening and uplift are all compatible with a reasonable initial crustal and lithospheric thickness (Fig. 7d).

Conclusions

Crustal shortening across northern Tibet

Crustal shortening initiated nearly synchronously across the northern plateau at ~50 Ma onset of Indo-Asian collision.

Surface uplift

Uplift due to Eocene-Oligocene crustal shortening in the Hoh Xil Basin cannot reproduce high elevation and thick crust.

Paleoelevation and palynological data suggest high elevation was attained after the Oligocene, suggesting that additional uplift and crustal thickening occurred in the absence of upper crustal shortening.

Acknowledgments

This work was supported by NSF Continental Dynamics grants EAR-0083711 and EAR-1211434 to MKC and NAN and on NSF Graduate Research Fellowship awarded to LMS. We also acknowledge NSF grant 4920120434 (to An Zhang) which supported both our Chinese colleagues at the Institute for Earth Environment and our joint fieldwork in Tibet.

References

[10] Authigenic age
[12] Crustal thickening only
[13] Crustal thickening and/or uplift mechanisms explored in calculations of isostatic compensation. In plots (b-f), step isostatic calculations on the isochron, step and results of surface uplift are outlined by arrows. Plateau surface elevation was modeled as a thick, 35 km pure shear crust on an elastic and plastic lithosphere. Calculations are outlined in red. Initial crustal and lithospheric thicknesses are outlined in purple. Surface conditions following detachment of modern elevation at a depth of 100 km were used in all models.
[14] Proportion detrital illite
[15] Detrital age
[16] Crustal thickening only
[17] Crustal thickening and/or uplift mechanisms explored in calculations of isostatic compensation. In plots (b-f), step isostatic calculations on the isochron, step and results of surface uplift are outlined by arrows. Plateau surface elevation was modeled as a thick, 35 km pure shear crust on an elastic and plastic lithosphere. Calculations are outlined in red. Initial crustal and lithospheric thicknesses are outlined in purple. Surface conditions following detachment of modern elevation at a depth of 100 km were used in all models.
[18] Proportion detrital illite
[19] Detrital age
[20] Crustal thickening only
[21] Crustal thickening and/or uplift mechanisms explored in calculations of isostatic compensation. In plots (b-f), step isostatic calculations on the isochron, step and results of surface uplift are outlined by arrows. Plateau surface elevation was modeled as a thick, 35 km pure shear crust on an elastic and plastic lithosphere. Calculations are outlined in red. Initial crustal and lithospheric thicknesses are outlined in purple. Surface conditions following detachment of modern elevation at a depth of 100 km were used in all models.
[22] Proportion detrital illite
[23] Detrital age
[24] Crustal thickening only
[25] Crustal thickening and/or uplift mechanisms explored in calculations of isostatic compensation. In plots (b-f), step isostatic calculations on the isochron, step and results of surface uplift are outlined by arrows. Plateau surface elevation was modeled as a thick, 35 km pure shear crust on an elastic and plastic lithosphere. Calculations are outlined in red. Initial crustal and lithospheric thicknesses are outlined in purple. Surface conditions following detachment of modern elevation at a depth of 100 km were used in all models.