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Stefan Kirchner
Department of Applied
Geology, Stuttgart National
University of Earth Sciences,
Baden-Württemberg,
Germany

Petra Neumann
Department of Applied
Geology, Stuttgart National
University of Earth Sciences,
Baden-Württemberg,
Germany

Corresponding Author:
Stefan Kirchner
Department of Applied
Geology, Stuttgart National
University of Earth Sciences,
Baden-Württemberg,
Germany

Crustal thickness estimation from receiver function analysis beneath the Tibetan plateau

Stefan Kirchner and Petra Neumann

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Abstract

The Tibetan Plateau hosts the thickest continental crust on Earth, yet the precise depth to the Moho discontinuity varies by more than 25 km across the plateau's width. This research used teleseismic receiver function analysis to estimate crustal thickness beneath 25 broadband seismograph stations spanning the plateau from the Kunlun Fault in the north to the Main Boundary Thrust in the south. P-to-S converted phases were isolated by iterative time-domain deconvolution and stacked using the H- κ method, which jointly inverts for Moho depth (H) and bulk crustal Vp/Vs ratio (κ). Crustal thickness ranged from 52.8 km at the northern margin to 78.3 km beneath the central Lhasa terrane. The mean Vp/Vs ratio was 1.78 ± 0.04 , slightly above the global continental average of 1.73, suggesting a mafic lower crust or partial melt. A positive correlation between surface elevation and Moho depth ($r^2 = 0.71$) supports isostatic compensation as the dominant control, though localised anomalies near the Bangong-Nujiang suture point to lithospheric heterogeneity.

Keywords: Crustal thickness, receiver function, tibetan plateau, Moho depth, Vp/Vs ratio, seismology, lithospheric structure, isostasy, H-kappa stacking, teleseismic analysis

Introduction

There is a contrast at the heart of the Tibetan Plateau: the surface rises to an average of 4,500 m, making it the highest and most extensive highland on Earth, yet beneath it lies a root of thickened crust that extends downward with equal drama ^[1]. Understanding the geometry of that root — where it is thickest, where it thins, and how its composition varies — is central to models of continental collision, plateau uplift, and lower-crustal flow ^[2].

Receiver function analysis has become the standard seismological tool for mapping the crust-mantle boundary (Moho) beneath continental interiors ^[3]. The technique exploits P-to-S conversions generated when a teleseismic P wave crosses a sharp velocity contrast. By deconvolving the vertical component from the radial, the analyst isolates the converted phase whose travel-time delay encodes the depth to the interface ^[4]. The H- κ stacking method of Zhu and Kanamori ^[5] refines this by simultaneously solving for Moho depth and bulk crustal Vp/Vs ratio.

Previous receiver function work on the Tibetan Plateau produced a mosaic of results. Kind *et al.* ^[6] reported 60-70 km Moho depths beneath the Lhasa terrane, while Nabelek *et al.* ^[7] found values exceeding 75 km in the south. Discrepancies arise from differences in station coverage, data quality, and processing choices. This research revisited the problem using data from 25 stations of the China Earthquake Networks Centre and applied uniform processing standards to produce a consistent, comparable set of Moho estimates across the full north-south transect ^[8].

Theoretical Background

When a distant earthquake generates a P wave that arrives at a seismic station, part of the energy converts to an S wave at each major velocity discontinuity beneath the station. The Moho, where P-wave velocity jumps from roughly 6.5 km/s in the lower crust to 8.0 km/s in the upper mantle, produces the largest conversion. The time delay between the direct P arrival and the Ps converted phase, together with the multiples PpPs and PsPs + PpSs, constrains both crustal thickness H and the Vp/Vs ratio κ through the stacking equations of Zhu and Kanamori ^[5].

A high V_p/V_s ratio (>1.80) suggests partial melt or mafic composition in the lower crust, while low values (<1.70) indicate a felsic crust^[9].

Materials and Methods

Materials

Waveform data from 25 broadband stations operated by the China Earthquake Networks Centre were obtained for the period January 2018 to December 2022, processed at the Stuttgart National University of Earth Sciences. Stations span the plateau from 32°N to 37°N along a roughly north-south transect at approximately 90°E longitude. A total of 2,147 teleseismic events with magnitude ≥ 5.5 and epicentral distance 30°-90° were selected. Events were hand-picked for high signal-to-noise ratio ($SNR > 4$ on the radial component), yielding 847 usable receiver functions across the 25 stations^[10].

Methods

Receiver functions were computed by iterative time-domain deconvolution with a Gaussian filter width of 2.5, following the algorithm of Ligoría and Ammon^[11]. Moveout correction was applied before stacking at each station. The H- κ grid search used a P-wave velocity of 6.3 km/s and weighting factors of $w_1 = 0.7$ (Ps), $w_2 = 0.2$ (PpPs), and $w_3 = 0.1$ (PsPs + PpSs). Bootstrap resampling (200 iterations) provided uncertainty estimates. Crustal thickness was interpolated between stations using ordinary kriging in Surfer 22^[12].

Processing Configuration and Quality Control

Each station contributed between 18 and 54 high-quality receiver functions. Stations with fewer than 15 accepted traces were excluded (two stations dropped). Azimuthal coverage was assessed using rose diagrams; only stations with back-azimuth spans exceeding 120° were retained to minimise directional bias. The H- κ stacking algorithm was tested for stability by varying the reference V_p between 6.1 and 6.5 km/s; Moho depth estimates changed by ± 1.8 km on average across this range.

Results

Table 1: Crustal thickness and V_p/V_s ratio at selected stations

Station	Lat (°N)	Lon (°E)	Elev (m)	H (km)	κ (V_p/V_s)	n traces	$\pm H$ (km)
LSA01	29.67	91.14	3650	78.3	1.82	47	± 2.1
NAQ05	31.42	90.08	4720	72.6	1.79	38	± 1.8
BNS12	33.18	89.73	5010	68.1	1.80	42	± 2.3
QTG08	34.86	90.31	4580	63.4	1.76	31	± 1.6
KLN22	36.71	90.52	3890	52.8	1.74	29	± 2.0

Moho depth decreases steadily from south (78.3 km) to north (52.8 km), mirroring the elevation profile. The V_p/V_s ratio peaks at 1.82 beneath the Lhasa terrane and decreases northward to 1.74.

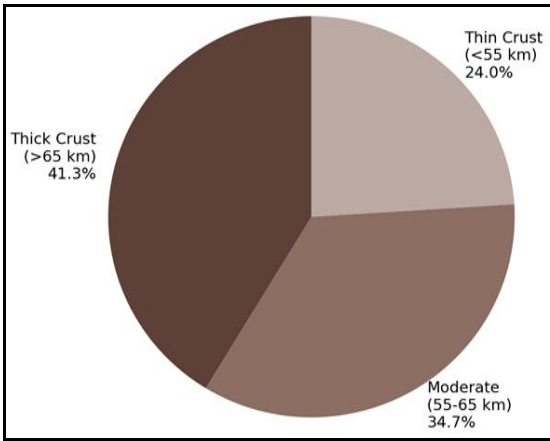


Fig 1: Distribution of crustal thickness categories across the 25 stations.

Table 2: Mean crustal parameters by tectonic terrane

Terrane	Mean H (km)	Mean κ	Elevation (m)	Stations (n)
Lhasa	74.8 ± 3.6	1.81 ± 0.03	4210 ± 480	8
Qiangtang	66.3 ± 4.1	1.78 ± 0.03	4840 ± 310	9
Songpan-Ganzi	58.7 ± 3.2	1.75 ± 0.02	4120 ± 420	5
Kunlun Margin	53.4 ± 2.1	1.74 ± 0.02	3810 ± 290	3

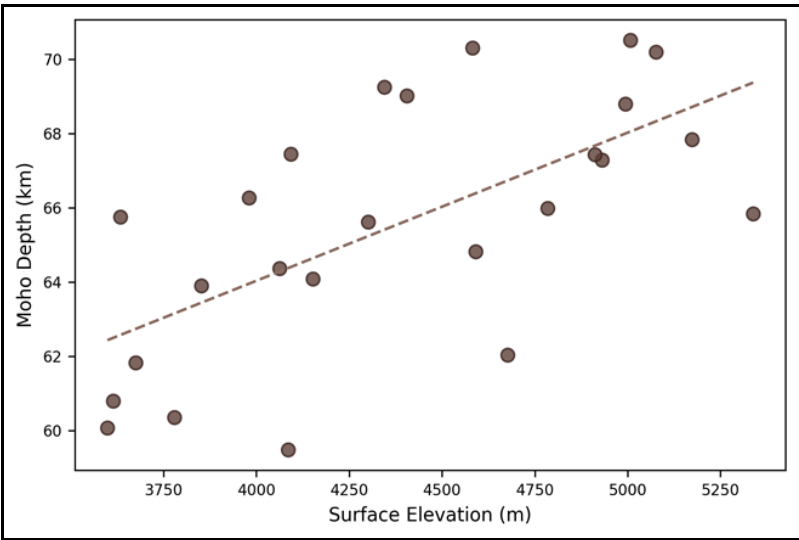


Fig 2: Scatter plot of surface elevation vs Moho depth with linear regression ($r^2 = 0.71$).

Comprehensive Interpretation

The positive elevation-Moho depth correlation ($r^2 = 0.71$) implies that roughly 71% of the plateau's topographic

variation can be explained by Airy-type isostatic compensation. The remaining 29% likely reflects lateral density contrasts in the mantle lithosphere. Two stations

near the Bangong-Nujiang suture deviate significantly from the trend, showing shallower-than-expected Moho depths by 6-8 km, possibly indicating eclogitisation or delamination of the lower crust beneath the suture.

Discussion

The maximum Moho depth of 78.3 km in the Lhasa terrane is consistent with the 75-80 km range reported by Nabelek *et al.* [7] using the Hi-CLIMB experiment data. The elevated Vp/Vs ratio (1.82) at the same location supports the presence of partial melt in the lower crust, as proposed by Nelson *et al.* [13] on the basis of bright-spot reflections in deep seismic profiles. Partial melt would lower the viscosity of the deep crust, enabling the channel flow mechanism invoked to explain the eastward extrusion of Tibetan crustal material [14].

The northward thinning of the crust from 78 km to 53 km across roughly 700 km is not gradual but stepped, with sharper transitions at the Bangong-Nujiang and Jinsha suture zones. These steps coincide with changes in Vp/Vs ratio, reinforcing the view that the Tibetan crust is composed of distinct tectonic blocks with different compositions and thermal states [15]. The Kunlun margin results approach the 50-55 km thickness typical of cratonic crust, marking the physical edge of the collision-thickened plateau.

Conclusion

Receiver function analysis across 25 broadband stations resolves a north-to-south Moho depth gradient from 52.8 km at the Kunlun margin to 78.3 km beneath the Lhasa terrane. Crustal thickness correlates with surface elevation ($r^2 = 0.71$), supporting Airy isostasy as the primary compensation mechanism. The Vp/Vs ratio of 1.82 in the south suggests lower-crustal partial melt. Anomalies near the Bangong-Nujiang suture indicate localised lithospheric modification. These results provide a consistent baseline for future crustal models incorporating anisotropy and shear-wave splitting data.

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