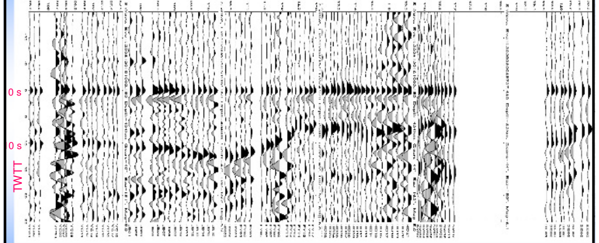
The Moho after 100+ Years of Research: What, Where, When, & Why Do We Care?

– *P*-wave reflection profile over ~1,000 km
– What obvious features do you see?



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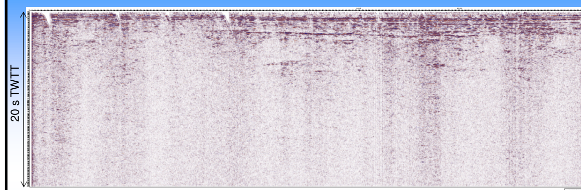
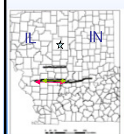
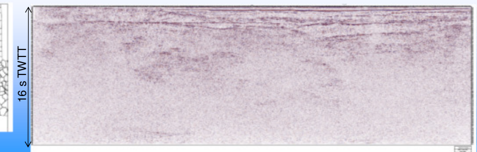
Chunquan Yu & Robert van der Hilst, MIT
Tai-Lin Tseng, National Taiwan University
Chi-yuen Wang, University of California, Berkeley

Where is the Moho? Is This a Big Problem?



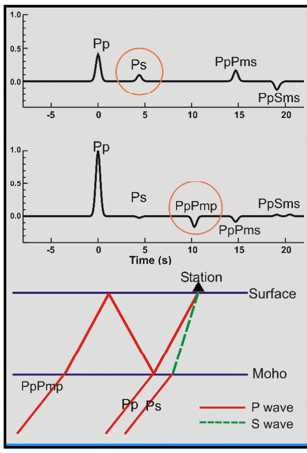
COCORP Profile, 153 km





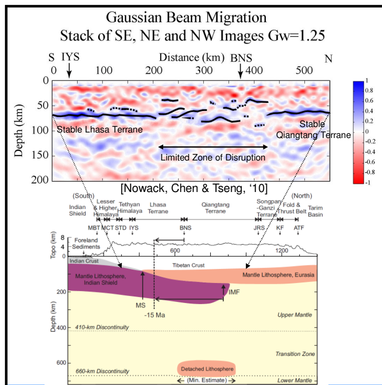
[Courtesy of J. McBride & H. Leetaru]

Reprocessed Industrial Data, 122 km



"Receiver Functions"

- Illumination from below by distant earthquakes
  - Source powerful enough to probe deep into the mantle
- Transmitted wavefields
  - *P-SV* or *SV-P* conversions
  - Information is in the coda
    - One man's noise is the other's signal [Aki & Richards, '80]
- Forward scattering
  - [e.g., Bostock et al., '01]
  - Imaging condition: Match
    - Back-propagation of scattered wavefield
    - Incident wavefield

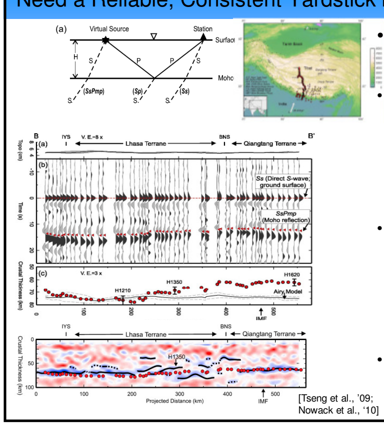


- Some Details
  - Grids @ 1 km x 1 km
  - 2-D background model

Regional Variations of Moho

- Gaussian beam migration
  - Impedance contrasts (from scattered wavefields)
  - No smoothing
  - Interpretation by multi-frequency analysis (Gw 2.3)
- Two Stable terranes w/ sharp Moho
  - Strong mantle
  - cf. Crust under pure shear!
- Zone of disruption: How thick is the crust?
- Moho is NOT always a simple interface
  - More details are not always helpful…

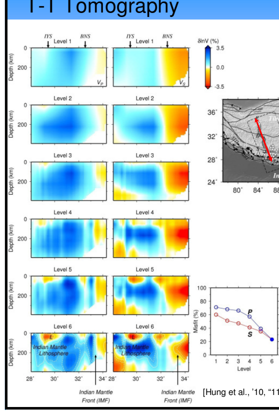
Need a Reliable, Consistent Yardstick for Crustal Thickness



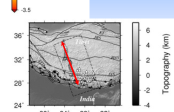
[Tseng et al., '09; Nowack et al., '10]

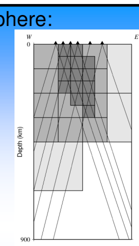
- Virtual Deep Seismic Sounding (VDSS)
- Wide-angle reflection from *SsPmp*
  - Virtual source
    - Deep-penetrating
  - Large signal
  - Physically averaged position of crust-mantle transition
- Gradual, northward thinning of crust
  - Deviation from Airy isostasy starts near S. end of disrupted Moho
  - Up to ~12 km difference
  - ~2 km in residual topography!
- Thermal or dynamic support from the mantle

Current Configuration of Colliding Lithosphere: T-T Tomography



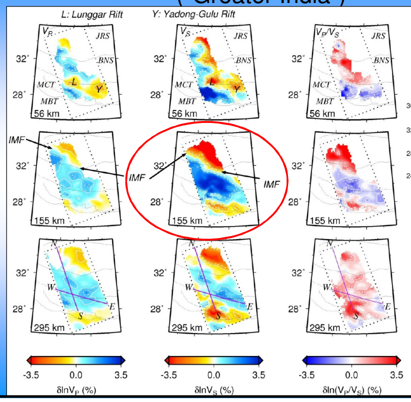
[Hung et al., '10, '11]

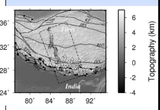




- Finite-frequency ("banana-doughnut") kernels (effects of wave-front healing)
- New, multi-scale expansion of model space
  - Data adaptive, no *a priori* smoothing
- Mantle: Sub-horizontal, high-speed anomaly
  - Interpreted as underthrust Indian mantle lithosphere
  - IMF emerge early in the expansion, appearing already at level-1 (longest wavelength)

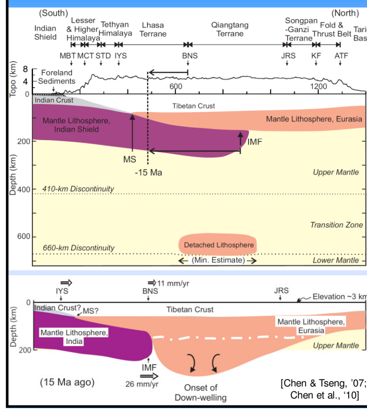
Regional Extent of Indian Mantle Lithosphere (“Greater India”)





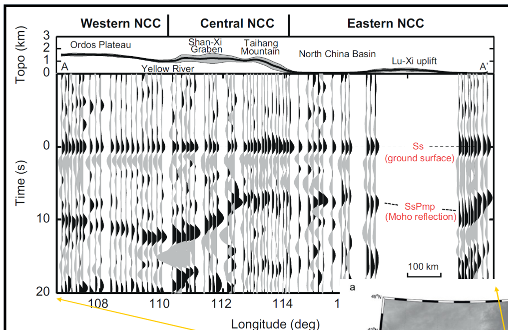
[Hung et al., '10, '11]

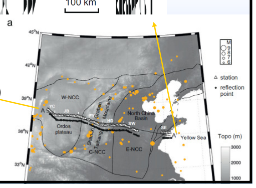
Reconstruction of LM to -15 Ma



[Chen & Tseng, '07; Chen et al., '10]

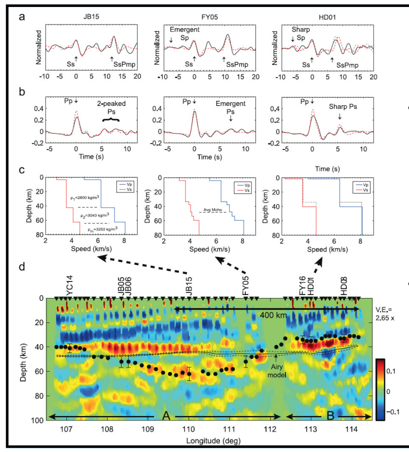
- 30 – 15 Ma
  - IM advanced beneath Lhasa terrane
  - IMF impinged upon S. edge of Qiangtang terrane
- Rayleigh-Taylor instability
  - Thermal Rayleigh #
  - $Ra = g\alpha(\Delta T)h^3/\kappa\nu$
  - Convective removal of thickened root
    - Making space for IMF
- 15 Ma – present
  - Indian mantle lithosphere advanced N. beyond BNS
  - Detached mantle lithosphere resting above the lower mantle
  - Elevation of Qiangtang terrane was only 3 km





- VDSS across N. China Craton (~1,200 km)
- Large variations in crustal thickness
- Unexpected from Airy isostasy & previous work

[Yu, Chen, Ning, et al., EPSL '12]

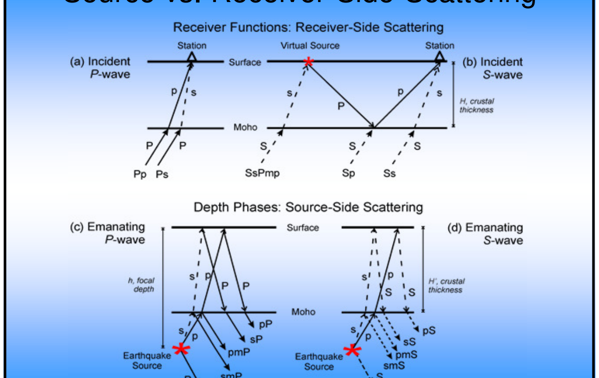


Best of both Views

- RF: Moho highly variable in nature
  - Sharp
  - Transitional
  - Distinct lower crust below Conrad
    - Mistaken as the Moho
  - “Input” for heat flow analysis
  - “Missing” lower crust for Archean cratons?
- VDSS: insensitive to details
  - Self-consistent way of measuring & comparing crustal thickness
  - Reliable
    - Large signal
    - Wide coverage

[Yu, Chen, Ning, et al., EPSL '12]

Source vs. Receiver-Side Scattering

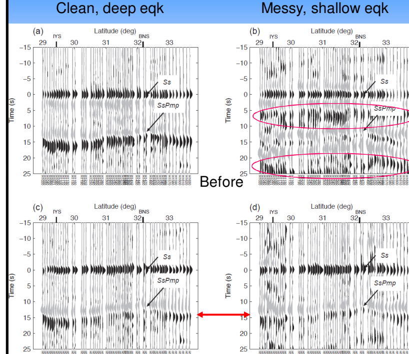


[Chen et al., Tectonophys. '13]

New Development: Using All Sources of Illumination

Clean, deep eqk

Messy, shallow eqk



After (PMA-Decon)

- Depp eqks are the best sources
  - No interferences among phases of interests
  - Rich in high-frequency contents by avoiding going through highly attenuative upper mantle twice
  - Limited quantity of data
  - Poor azimuthal coverage & move-out analysis (e.g., no selective detection)
- All strong sources are good!
  - Particle motion analysis and subsequent deconvolution
  - Verified by synthetic seismograms
  - Validated by Hi-CLIMB data

[Yu, Chen, van der Hilst, GJI, '13]

Conclusions

- Large-scale, subhorizontal underthrusting of cratonic lithosphere hides, but not necessarily destroys, cratons
  - Current collision not recycling cratonic crust into the mantle
- Two case studies of crustal thickness based on new method
  - Large deviations from Airy isostasy
  - Contrasting tectonic settings
    - Tibet: Gradual, northward thinning of crust → delicate balance between crustal isostasy and thermal buoyancy of the mantle
    - Ordos: Mafic lower crust beneath the Conrad discontinuity → Pratt isostasy → proxy of starting materials for lower crust foundering
  - Moho can be a dynamic feature (e.g., re-lamination, tectonic disturbance)
- VDSS to complement global map of crustal thickness
  - With a single, consistent & reliable yardstick
    - Improved coverage & resolution
  - Current volume of continental crust
  - Crustal isostasy
  - Dynamic topography due to mantle convection
  - Interpretation of heat flow data
  - Crustal corrections for seismic investigations of the deep interior

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