Seeing the roots of mountains, imaging the crust of Tibet

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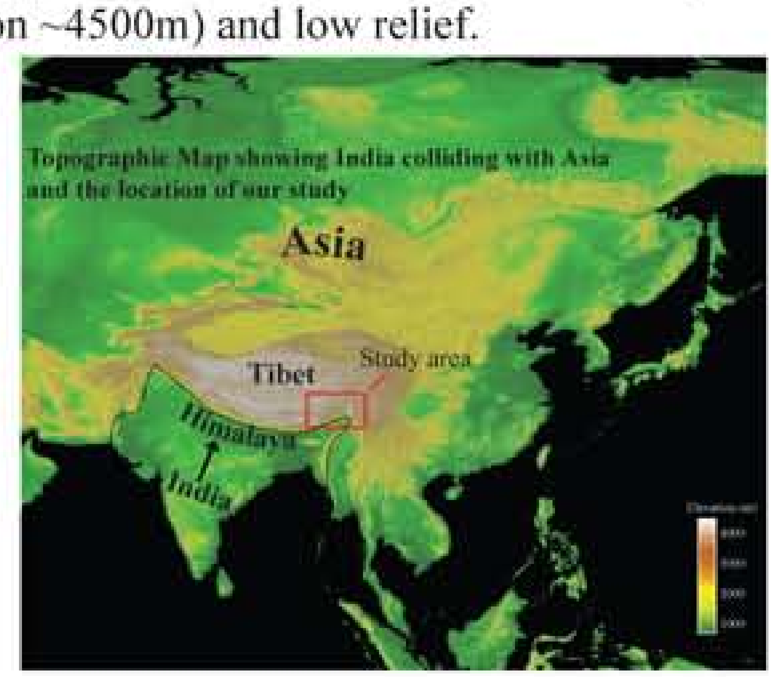
What happens when continents collide?

Using the Himalayan Mountains and Tibetan Plateau as a natural laboratory we are investigating:

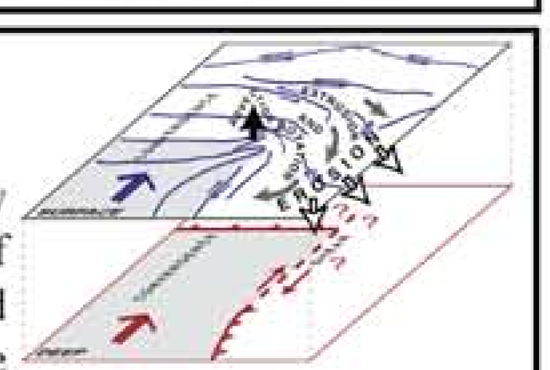
1) Why mountains are high
2) How rocks are modified during collisions
3) The role erosion plays in these processes



The Himalaya and Tibet provide an unique opportunity to study the process that are generating both extreme high relief mountains and high flat plateaus as they happen. The Himalaya and Tibetan Plateau developed with the onset of collision between the Indian and Eurasian plates ~50 million years ago and are continuing to evolve to this day. The Himalaya are a long (2,500 km) but narrow (~250 km) mountain range with extreme topographic relief and the highest mountains in the world (>8,000m), whereas Tibet is long (3000 km) and wide (up to 2000 km) with high elevation (average elevation ~4500m) and low relief.



What is happening below the surface?



This diagram shows how we observe the surface of Tibet deforming around the indenting corner of the Indian plate and the inferred structure and kinematics of the Indian plate in the subsurface. The goal of this study is to use seismology as a tool to directly image the subsurface architecture of the crust and mantle.

Acknowledgments

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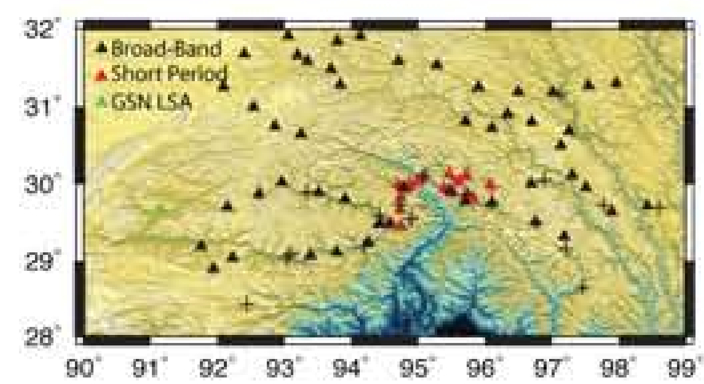
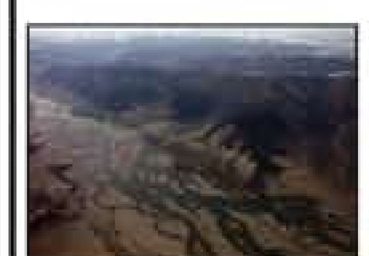
Study Area: southeast Tibet

To image the subsurface structure of southeast Tibet we installed 70 seismometer in September 2003 and operated them until November 2004. The instruments were on loan to us from the Incorporated Research Institutions for Seismology (IRIS). Below is a map of station locations and topography. Photos are included to emphasize the extreme variability in landscape across the study region.

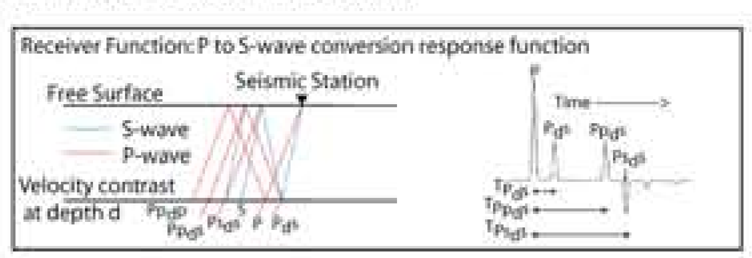




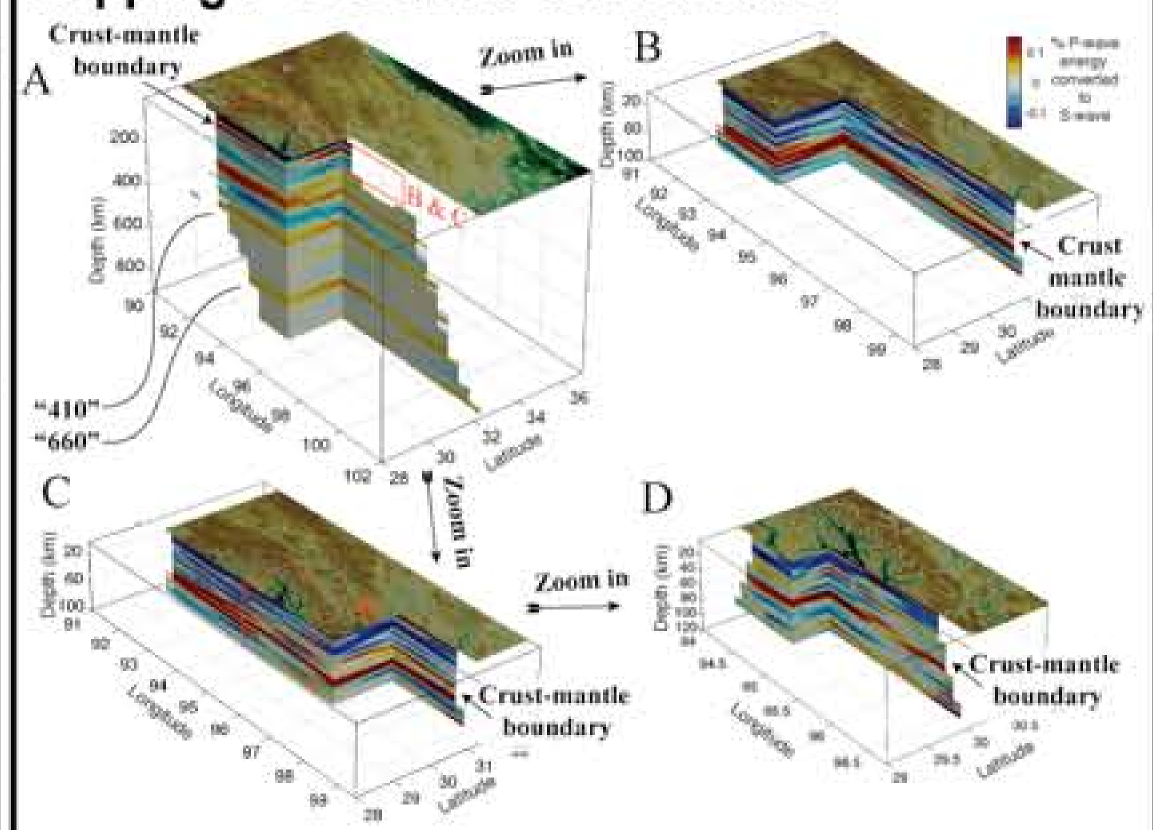



Imaging the subsurface

Seismology is the study of elastic and sound waves in the earth. They are generated by either natural (ie earthquake) or man-made sources (ie explosion). The seismic wave field is composed of pressure (P) and shear (S) waves. These waves travel at different velocities and can be used to identify subsurface structures. In this study we will use P-waves that convert energy into S-waves at seismic velocity contrasts. To identify these arrivals we will construct an Earth response function for the composite P-to-S converted waves that reverberate below the surface. The response function and corresponding wave field are shown below.

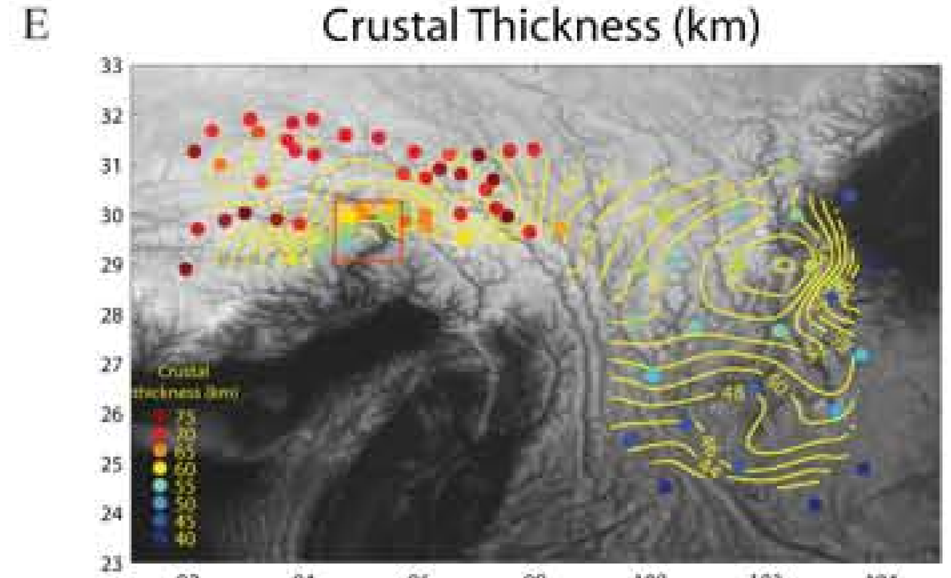


Mapping P to S-wave conversions



These images represent the response of the Earth beneath southeast Tibet for converting P-wave energy to S-waves. The images are constructed by mapping the P-to-S response functions along the paths of the incoming seismic waves from 140 earthquakes, magnitude 5.5 mb and greater. The top surface of the volume is elevation; the 3-d cross sections are amount of P-wave energy converted to S-wave. **Fig A** shows the response of the Earth down to 900 km depth. The crust - mantle boundary is observed at roughly 70 km and solid-state phase transformations are seen at 410 and 660 km depth. The strong contrast mapped at ~200km is the reverberated phase in the crust. **Fig B & C** are zoomed in versions of Fig A. Two different cross sections are shown to show lateral variability in crust. **Fig D** is higher resolution model constructed using the denser short period network (red triangles) located at the end of the Himalaya. **Fig E** shows the thickness of the crust in reference to the surface topography. Station locations are shown and are color coded to thickness of crust at that location. Data from another experiment run to the southeast of ours has been added to the map.

E



Why gravity doesn't pull mountains down

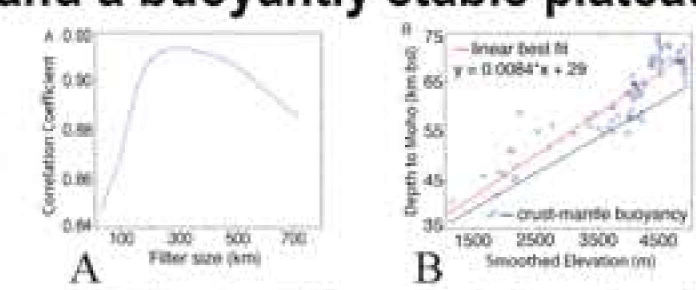
Just as ice floats on water because it is less dense, the less dense crust of the earth floats on the mantle. These items float because when an object is placed in a fluid it can only displace a mass equal to the fluid before the pressure of the fluid pushes the object up balancing the force of gravity. If we add mass to the top of the floating object the object will sink until a volume of fluid has been displaced that equals the new mass. Thus if we add material, such as mountain to the top of the crust, the base of the crust will sink deeper, creating a root to compensate for the extra mass.

Strength of mantle

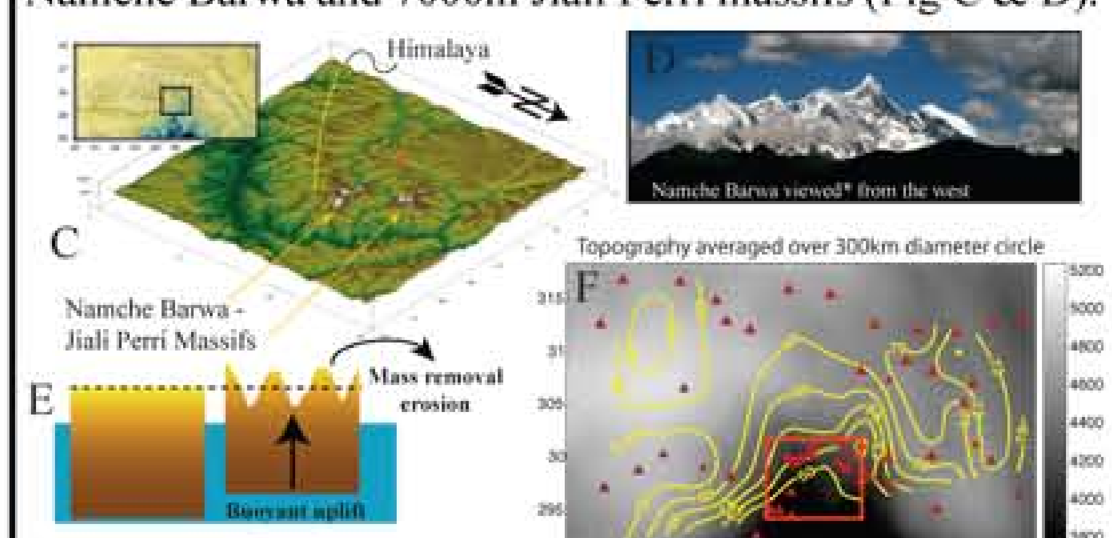
We know from seismology that the mantle is a solid not a fluid - but we also know from plate tectonics that it also behaves like a fluid over long periods of time. By measuring the wavelength over which the crustal root responds to applied loads from short wave length features such as individual mountains to long wave length features such as plateaus we can begin to understand where the forces are generated that hold high elevated features up.

High mountains and a buoyantly stable plateau

If we average the surface topography at long wavelengths a strong correlation is seen between elevation and crustal thickness (Fig A). This correlation closely matches models for a crust buoyantly supported by the mantle (Fig B). Suggesting that long wavelength (100's km) topographic highs are supported by a buoyant crust while short-wavelength (10's km) structures are not.



One example in our study area of short wavelength topography not being supported by a deep crustal root is the ~8000m Namche Barwa and 7000m Jiali Perri massifs (Fig C & D).



It is theorized that these peaks obtain their anomalous height due to a positive feedback with erosion. As erosion removes mass from the system the crust weights less and buoyantly moves up (Fig E). The effect the incised river valleys has on the region is seen when topography is smoothed over 300 km (Fig F). Lending support to erosion causing high peaks theory, the long wavelength elevation is lower in the same areas as the thinner crust and high peaks of Namche Barwa and Jiali Perri (red box Fig F and Fig E previous section).