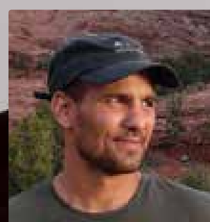
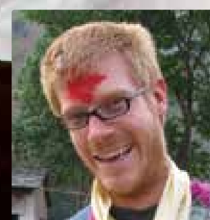
Comprehending the Himalaya

Cracking the code on the complexities of mountain building, **Professor Kelin Whipple** is leading novel, field-based research into climate and tectonics, using the Bhutan Himalaya as a field study





What are the primary goals of your research in the Bhutan Himalaya?

Mountain building is a competition between tectonic rock uplift and erosion. Our main goal is to decipher the roles of climate and tectonic rock uplift in the construction of the mountainous landscapes of the Bhutan Himalaya. Surprisingly, tectonics and climate can influence how the landscape forms in similar ways, so part of our project involves developing the ability to distinguish between the two processes. Specifically, we seek to determine whether, and at what rate, the mid-latitudes of Bhutan have been uplifted relative to the Indo-Gangetic plains to the south and to quantify the role of long-term climate change (over millions of years) in this surface uplift.

Why study the Bhutan Himalaya in particular?

The Bhutan Himalaya presents an excellent opportunity to quantify the relative roles of climate and tectonics in mountain building. Bhutan's topography is distinct from the rest of the Himalaya in that there is essentially no physiographic Lesser Himalaya. The more rugged and steep Higher Himalayan mountains rise directly out of the Indo-Gangetic plains. Terrain similar to the Lesser Himalaya is instead perched at ~3,000 m above deep, rugged canyons in the mid-latitudes of Bhutan (see Figure 1). We are investigating how and when this came to pass.

What fundamental questions about climate, topography, erosion, and tectonics underlie your research in Bhutan?

Fundamentally, our research strives to quantify the interrelationships among rock uplift (tectonics), topography, climate, and erosion rates. We then use these relationships to develop methods for deciphering tectonic and climatic histories from modern topography and the pattern of erosion rates in space and time. A key question in Bhutan is whether the relationship between mean annual rainfall and erosion rate is sufficiently strong to support the hypothesis (first proposed by Associate Professor Djordje Grujic of Dalhousie University) that the unusual topography results from the development of the rain shadow cast by the Shillong Plateau ~200 km to the southeast. In addition, we also ask whether the topography and spatiotemporal patterns of erosion require a tectonic driver.

What challenges do you face in this study?

Obtaining appropriate samples from the right locations within the rugged, mountainous, topography of the Kingdom of Bhutan is a great challenge. To be most valuable, samples must be collected from specific locations chosen on the basis of detailed analyses of topographic and climatic conditions; obtaining these samples is time-consuming, expensive, and at times rather adventurous. There are also challenges in data interpretation as there is significant and inherent uncertainty in the erosion rates, and climate change on glacial timescales can cause rates measured at the millennial timescale to differ from long-term mean rates. Fortunately, this can be assessed through comparison with longer-term estimates and does not greatly impact the spatial pattern of erosion rates in the unglaciated catchments we sample, which is of crucial importance to our study.

What results have you obtained so far?

We have already learned a lot, though final interpretations must wait for all of the data to be processed. To date, we have discovered that:

- Millennial-scale erosion rates document that Bhutan is indeed in a state of increasing relief – the canyons surrounding the low-relief benches perched at ~3000 m in the mid-latitudes of Bhutan are getting deeper
- Differences in mean annual rainfall have a measurable effect on millennial-scale erosion rates, but the magnitude of this effect appears to be insufficient for a climate change ~6 million years ago to have triggered the ongoing phase of relief production, as had been hypothesised
- A change in tectonics, possibly associated with the uplift of the Shillong Plateau southeast of Bhutan, appears to be required to explain the interesting topography of Bhutan

As your research is multidisciplinary in nature, do you work with other specialists in fields outside of your own?

This research definitely requires collaboration among scientists with a range of expertise. Within our team on this specific project we combine expertise in bedrock channels and long-term landscape evolution (myself and Byron Adams) with expertise in measuring erosion rates and surface ages using cosmogenic nuclides (Arjun Heimsath and Adams), with expertise in mapping geologic structure (Adams). Importantly, our study is complementary to a concurrent study of the structure and thermal evolution of the Bhutan Himalaya (conducted by Kip Hodges and Adams – ASU) that adds critical information on erosion rates averaged over millions of years. In addition, we are collaborating with Todd Ehlers from Universität Tübingen, Germany, on the interpretation of erosion rates and topographic relief recorded in the thermal histories of apatites and zircons using a numerical model.

Understanding mountain **building**

A group at **Arizona State University** is using a unique approach to test hypotheses pertaining to Bhutan Himalayan evolution, providing clarity to the often conflicting influence of climate and tectonics on topography

ALTHOUGH RESEARCH INTO collisional mountain belts has been carried out extensively over the past five decades, scientists have not been able to reach consensus on how climatic and tectonic processes affect topography, or how these processes interrelate. The Himalaya are an archetypal collision belt formed by the ongoing impingement of the Indian subcontinent into Asia. In an attempt to test provocative notions that climate can control tectonics and mountain building, research has begun in the Bhutan Himalaya, a less studied part of the orogen where circumstances of geological evolution afford an opportunity to study the interconnections among climate, topography, erosion and tectonics.

THE BHUTAN HIMALAYA

Characterised by several isolated low-relief topographic benches, 20-40 km wide, at an elevation of around 3,000 m and separated by deep canyons, Bhutan exhibits some of the most rugged topography in the Himalaya (see figure overleaf). This unique physiography is a puzzle that represents an excellent opportunity to explore hypotheses surrounding the interplay of climate, tectonics and topography.

Led by Professor Kelin Whipple, co-PI Dr Arjun Heimsath and PhD student Byron Adams at Arizona State University (ASU), researchers are currently investigating the evolution of the landscapes of Bhutan to determine the proximal cause for the pronounced changes in erosion rate required to form the perched low-relief topographic benches. Such changes in erosion rates are indicative of a change in tectonic activity, climate, or both. Transient landscape characteristics, such as these – especially in terms of erosion rate patterns – provide a framework from which to determine the drivers of change. The ASU team's research focuses on basin-averaged millennial-scale erosion rates combined with thermochronology data; allowing them to discriminate between climate and tectonic-driven models in Bhutan and test hypotheses regarding the fundamental underlying relationships among climate, erosion rate, topography and tectonics.

THEORY-GUIDED SAMPLING STRATEGY

Whipple's group is employing a novel, integrative and interdisciplinary approach that builds upon understanding developed over the last 15 years about the evolution of bedrock river channels and their role in sculpting mountainous topography. He explains: "Most important to our study is the recognition that the temporal history of rock uplift and climate is often recorded in the topography and spatial distribution of erosion rates across a landscape. A good example of this is the dramatic change in elevations associated with currently or previously active faults in Bhutan. We can use the spatial distribution of erosion rates averaged over the last few thousand years to infer the history of changes in erosion rates and relief production over the last few million years".

Using theory to guide sampling strategy is a critical aspect of what Whipple's group is doing. The millennial-scale erosion rates are determined by measuring cosmogenic nuclide concentrations in river sands from basins selected based on

POST-6 MA TECTONIC EVOLUTION OF THE BHUTAN HIMALAYA

OBJECTIVES

- To explore the proposition that Bhutan's landforms represent a pronounced change in erosion rate and possibly tectonics; and tackle fundamental problems in the understanding of mountain building
- To determine basin-averaged millennial-scale erosion rates from the concentration of cosmogenic radionuclides within river sands covering a wide range of mean annual precipitation, river channel steepness and basin relief
- To discriminate between climate and tectonic-driven models in Bhutan and test hypotheses regarding the relationships between climate, erosion rate, topography and tectonics
- To share findings in a meaningful way that better informs decisions in land use management and hazard mitigation

KEY COLLABORATORS

Kip Hodges, Arizona State University, USA

Todd Ehlers, Universitat Tubingen, Germany

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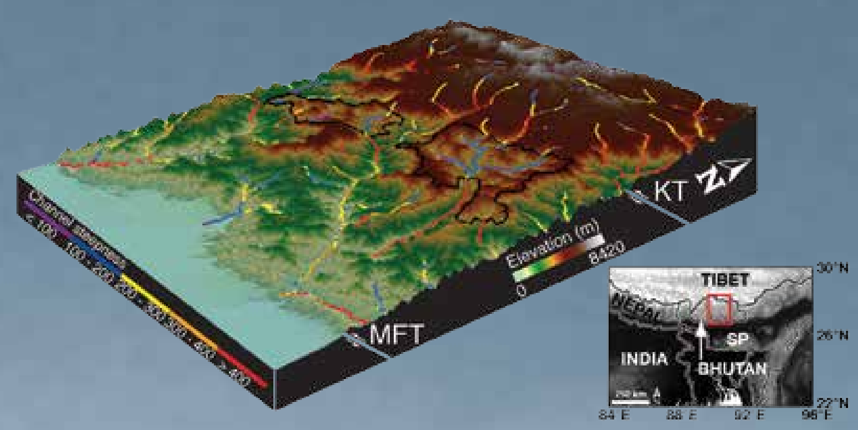
KELIN WHIPPLE focuses on the linkages among topography, climate, erosion rate, and tectonics. Active projects encompass the physics of bedrock channel erosion, reach-scale dynamics of bedrock channel evolution, and neotectonic studies of active deformation.

ARJUN HEIMSATH is a geomorphologist whose main interests are in quantifying the rates and processes of erosion in hilly and mountainous landscapes. These rates and processes are coupled by examination of the feedbacks driven by tectonic, climatic, and anthropogenic forcing.

BYRON ADAMS is a tectonic geomorphologist whose primary interests lie within the broad spectrum of surface processes and tectonics, as well as their interactions with climate.

School of Earth & Space Exploration
ARIZONA STATE UNIVERSITY



Perspective image of Bhutan topography with low-relief, high-elevation benches outlined in black, river traces colored by channel steepness, and major thrust faults shown schematically in cross section (KT – Kakhtang Thrust; MFT – Main Frontal Thrust). Inset map shows context and location of Shillong Plateau (SP).

analysis of topography in the context of landscape evolution theory. One useful topographic metric, channel steepness, is calculated for segments of river channels and makes it possible to observe changes in the gradient of a river without being biased by the magnitude of its drainage area. Previous research has shown that there is a positive relationship between channel steepness and erosion rates. The group is complementing these short-term erosion rates with longer-term estimates based on the thermal histories experienced by bedrock samples. These samples are interpreted in a model that tracks the cooling of rocks associated with erosion across spatially and temporally evolving topographic relief.

CENTRAL HYPOTHESES

There are three overarching hypotheses for the origin of the Bhutanese low-relief surfaces that the group are interested in. The first is a climate-based hypothesis, which contends that a rain shadow cast by the Shillong Plateau, south of the Himalaya, was the cause of decline in erosion efficiency, driving surface uplift. The second is a tectonic-based hypothesis, which suggests that an increase in rock uplift rate is driving surface uplift. The third hypothesis allows a hybrid of the previous two. To test these hypotheses, the group combines new and existing low-temperature thermochronology data with basin average erosion rates. The thermochronology data demonstrate cooling ages from 7-2 million years ago and provide insight into the exhumation histories of the low-relief landscapes and adjacent canyons. In addition, they have selected 55 basins across Bhutan that capture the influence of a wide range of relief and mean annual precipitation on erosion rates. When plotted against modelled predictions, the erosion rates should allow the team to reject one or more of the hypotheses.

The preliminary data gleaned from samples collected in the relatively dry interior of Bhutan imply a relatively low erosion efficiency (similar to the eastern margin of the Tibetan Plateau), which may reflect the influence of the Shillong Plateau rain shadow. However, analysis of all the samples is ongoing and the group plans to broaden the samples to encompass a wide range in annual precipitation, a decision that will be critical to determine the strength of this climatic influence.

TACKLING FUNDAMENTAL PROBLEMS

Only when the analyses of all the samples are complete will the researchers have enough data to estimate the timing of the onset of surface uplift; to quantitatively assess the magnitude of the climatic influence on erosion rates in Bhutan; and definitively determine whether a tectonic driver is required to explain the landscapes. In addition, results from an ongoing, complementary study also being conducted at ASU on the thermal and structural history of the Bhutan Himalaya will be required to define the longer-term history of erosion rates. Many recent models of mountain building in collision settings make predictions about the distribution of fault activity and its relation to patterns of climate and erosion. The team's broad sample collection scheme will allow for examination of erosion and uplift patterns across Bhutan in both space and time to determine if model predictions are correct.

Whipple hopes that the methods his group is developing will prove very useful in the estimation of seismic hazard potential. "Our method can provide a cheap and rapid assessment of the rates and patterns of tectonic rock uplift in remote areas. Previous work in Sichuan, China, successfully anticipated the location and extent of active rock uplift associated with the devastating magnitude 7.9 Earthquake on the 12 May 2008. We need to do all we can to anticipate seismic hazards along the densely populated Himalayan front." In addition, Whipple's research will produce maps of erosion rates and thus sediment loads in Bhutan's rivers – information that will help the National Environmental Commission of Bhutan, with whom they are collaborating closely, to better assess seismic and landslide hazards, manage sedimentation, soil erosion and the extraction of natural resources, and to better anticipate landscape response to climate change, all of which are pressing concerns to the population of this region.