Topographic metrics and bedrock channels

Outline of this lecture

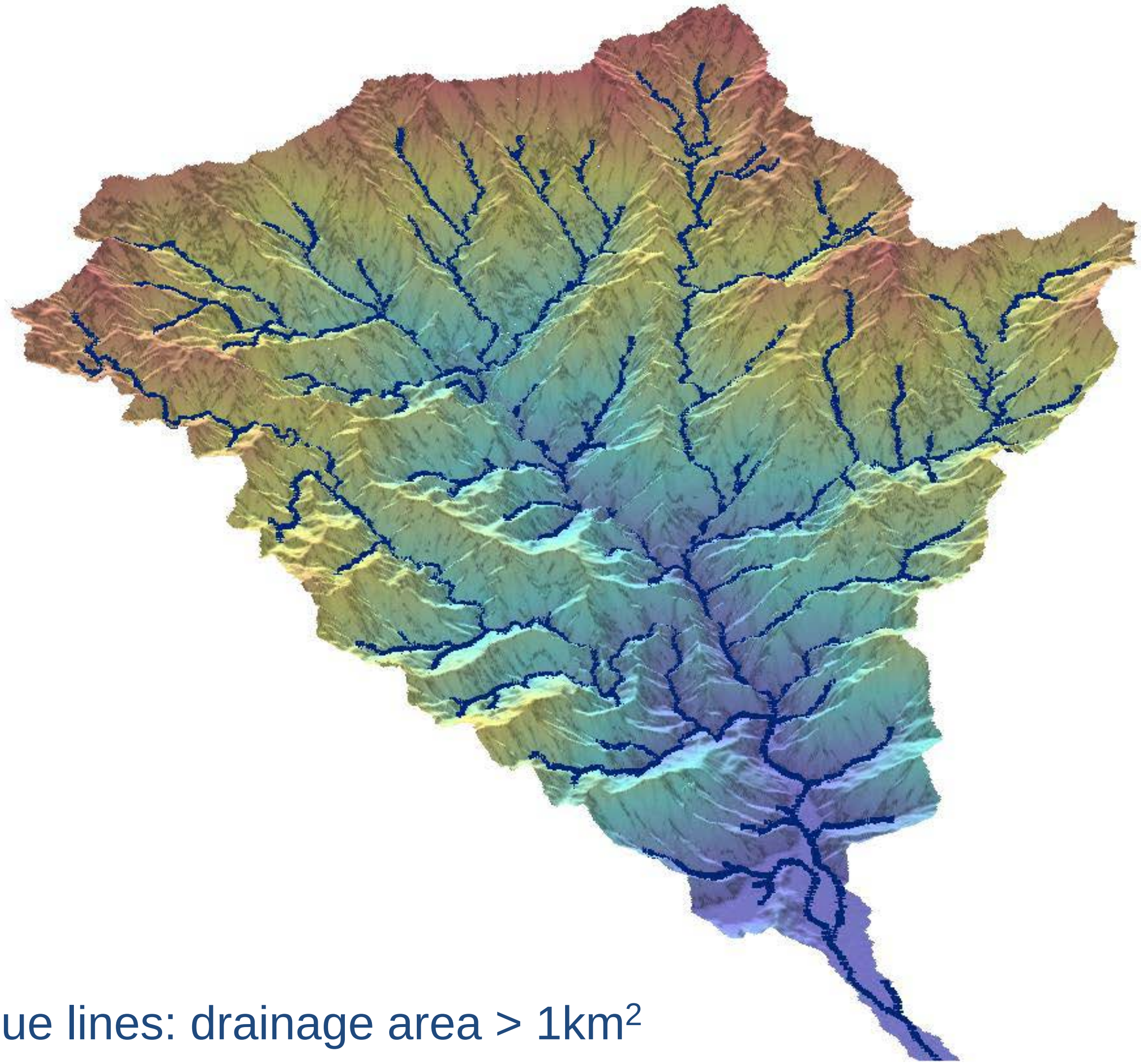
- Topographic metrics
- Fluvial scaling and slope-area relationships
- Channel steepness sensitivity to rock uplift

Topographic Metrics

- Many Topographic metrics have been proposed. We'll examine the three most common
  - Channel Steepness Index
  - Hillslope Gradients
  - Local Relief at Various Scales
  - Chi (Bodo lecture)
- What are the relationships among these?
- Which are most useful for gaging the influence of tectonics on topography?

--K. X Whipple

80-90% Relief is on Bedrock Channels



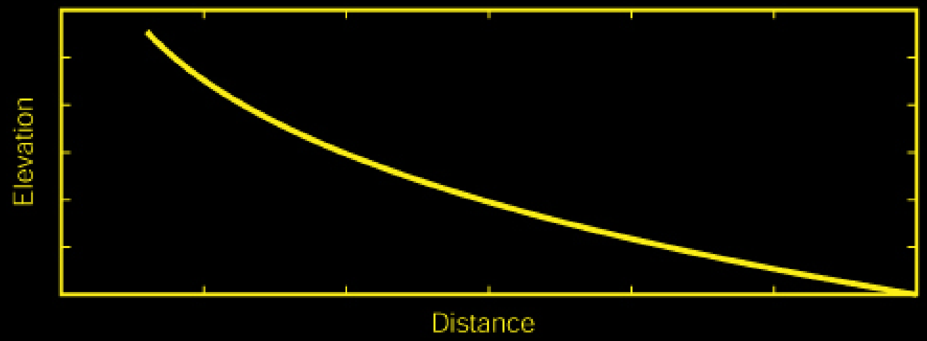
Blue lines: drainage area > 1km^2

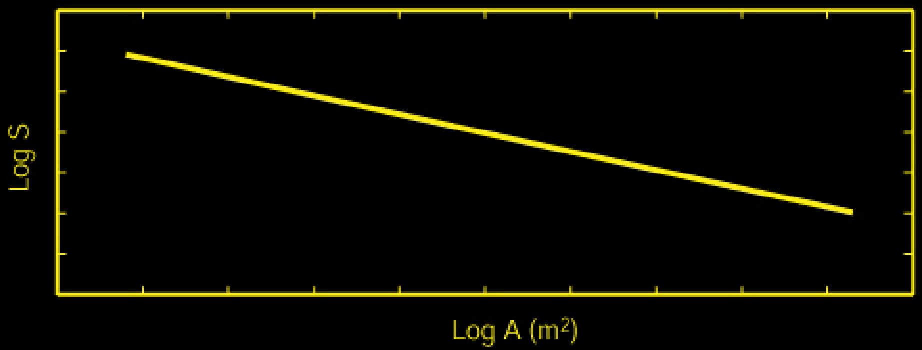
--K. X Whipple

Fluvial Scaling – Empirical Data

- Empirical data for well-adjusted fluvial systems around the globe yield the following scaling:

$$S = k_s A^{-\theta}$$

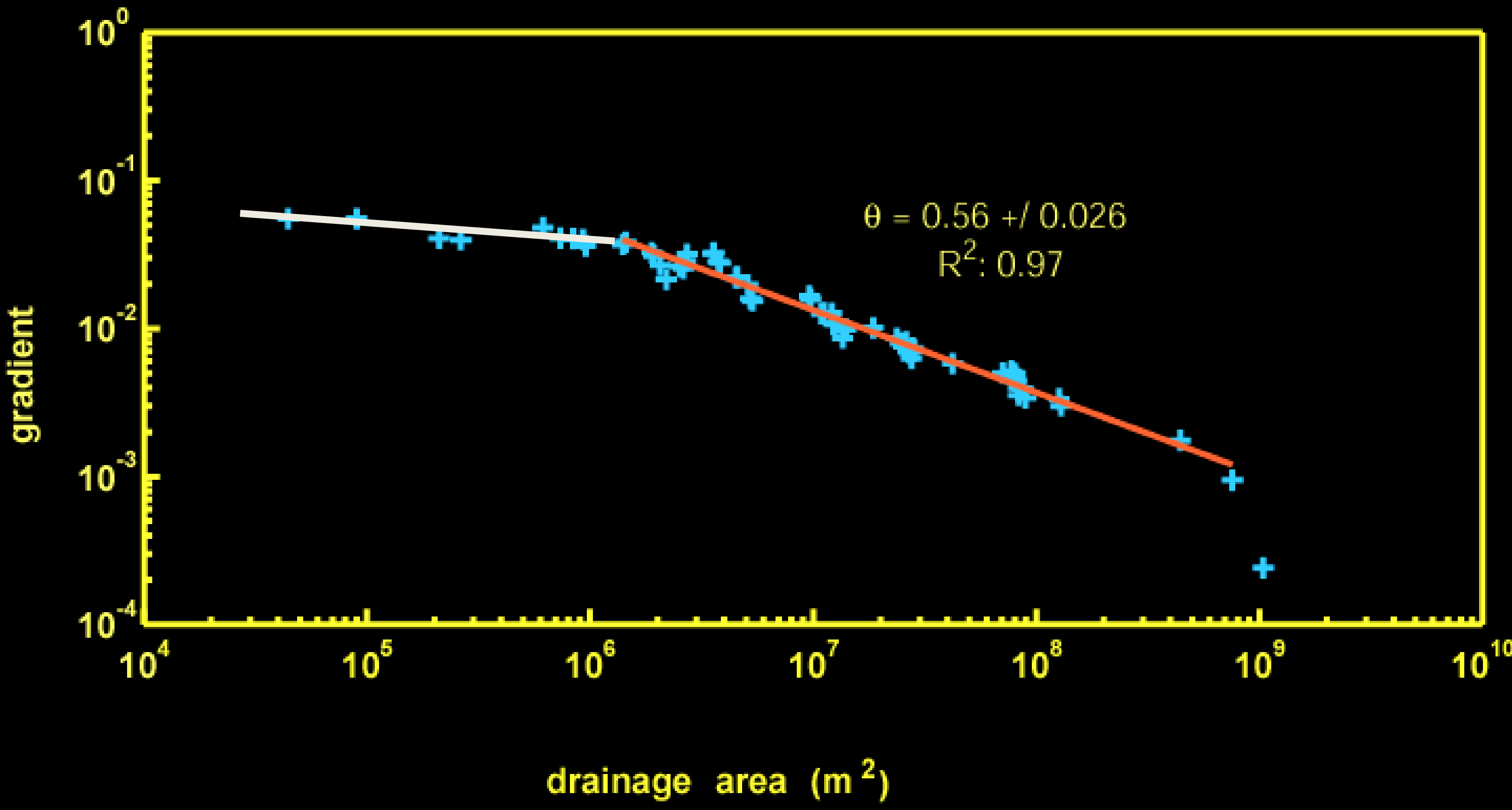




- Linear relationship between log(S) and log(A)
- **k_s is the channel steepness; θ is the concavity**

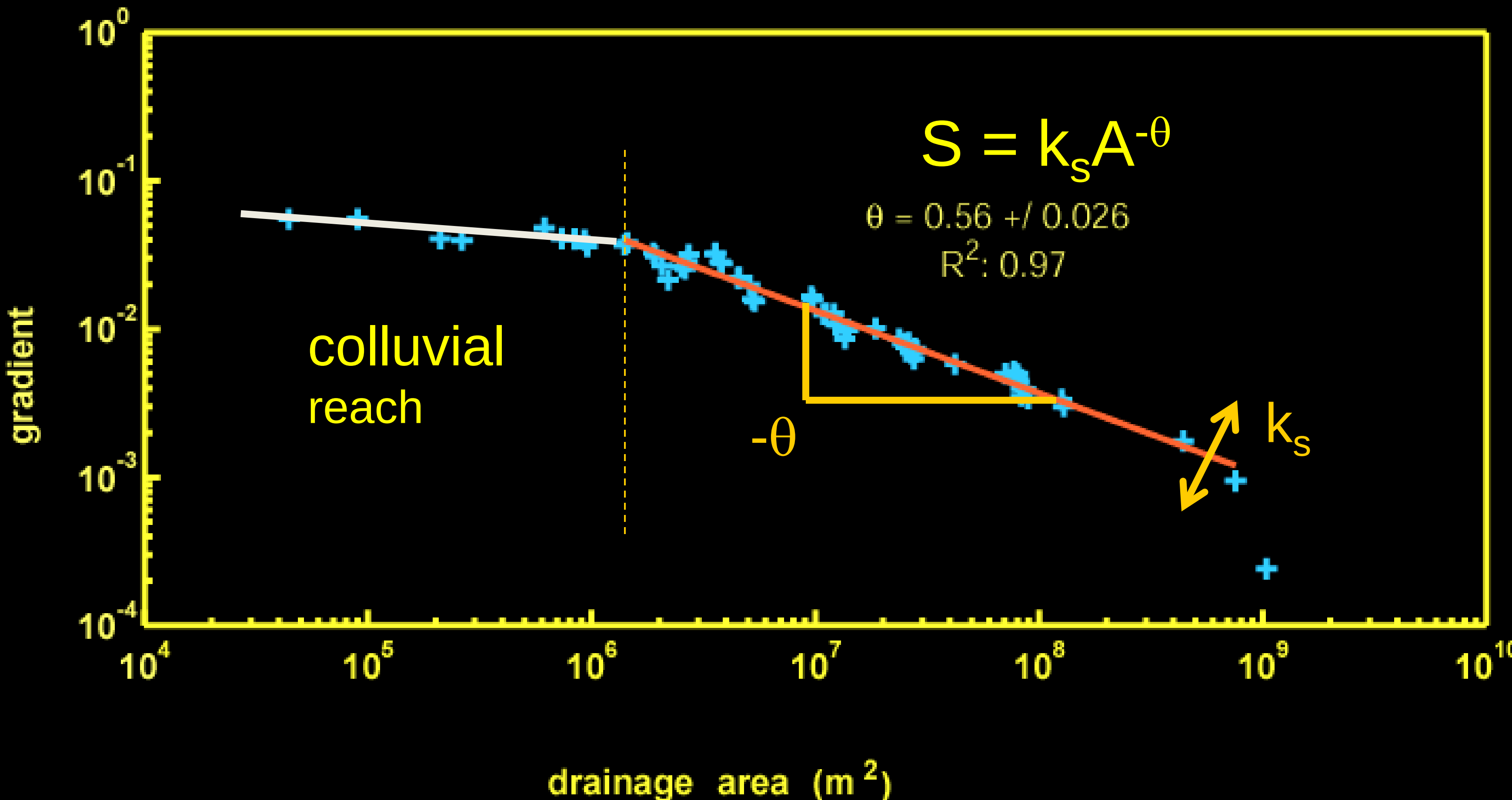
--K. X Whipple

Flint's Law: Mixed Bedrock-Alluvial Stream (Appalachians, VA)



--K. X Whipple

Flint's Law: Mixed Bedrock-Alluvial Stream (Appalachians, VA)



k_s is a general morphometric index:
No dependence on basin shape

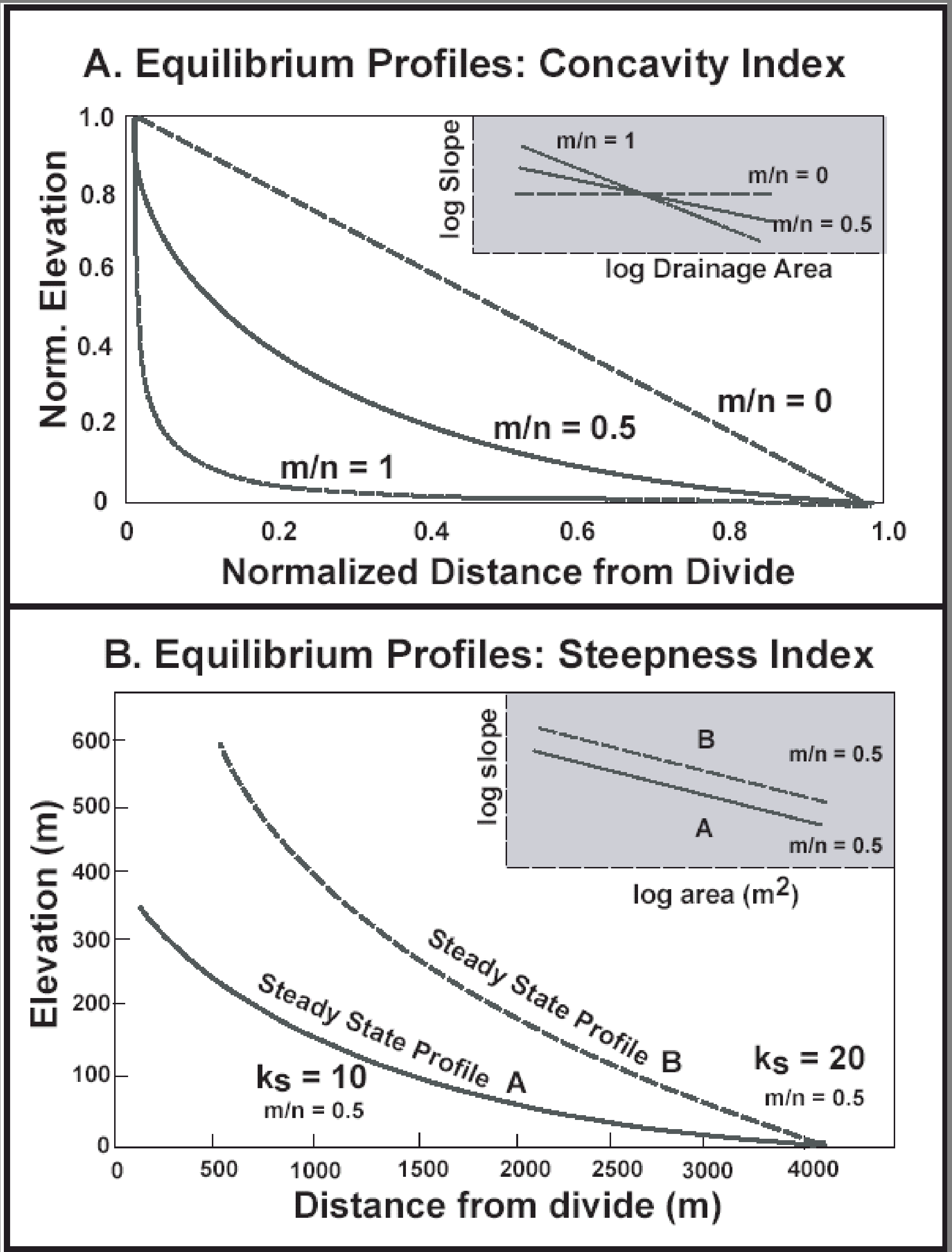
--K. X Whipple

Duvall, Kirby, and Burbank, 2004, JGR-ES

U = Rock Uplift Rate

Concavity (θ)
invariant with U

Steepness (Ks)
varies with U



$\theta = m/n$

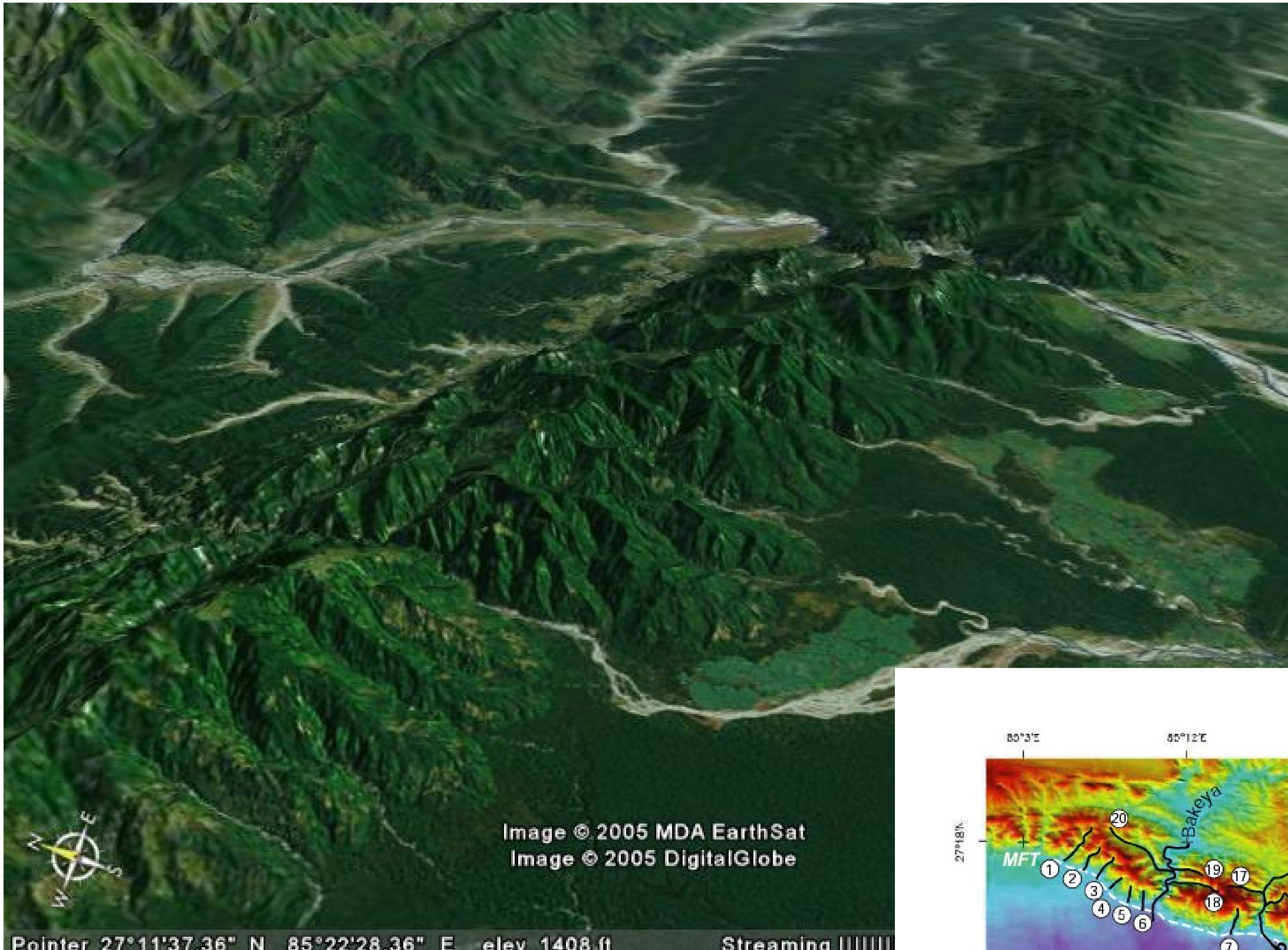
$S = k_s A^{-\theta}$

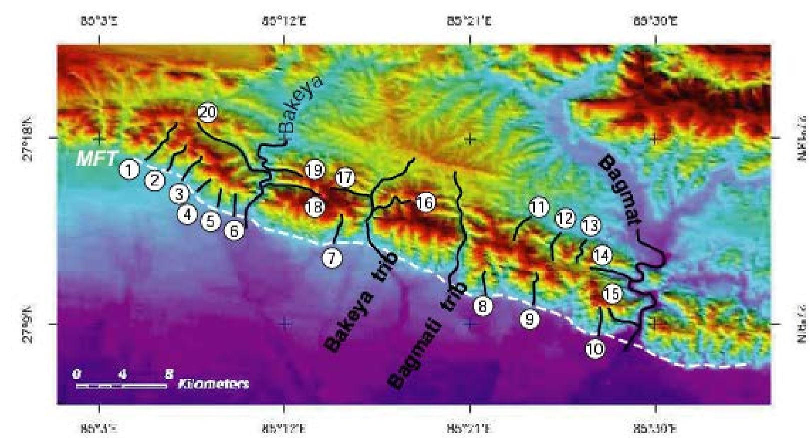
k_s

--K. X Whipple

Siwalik Hills, Nepal

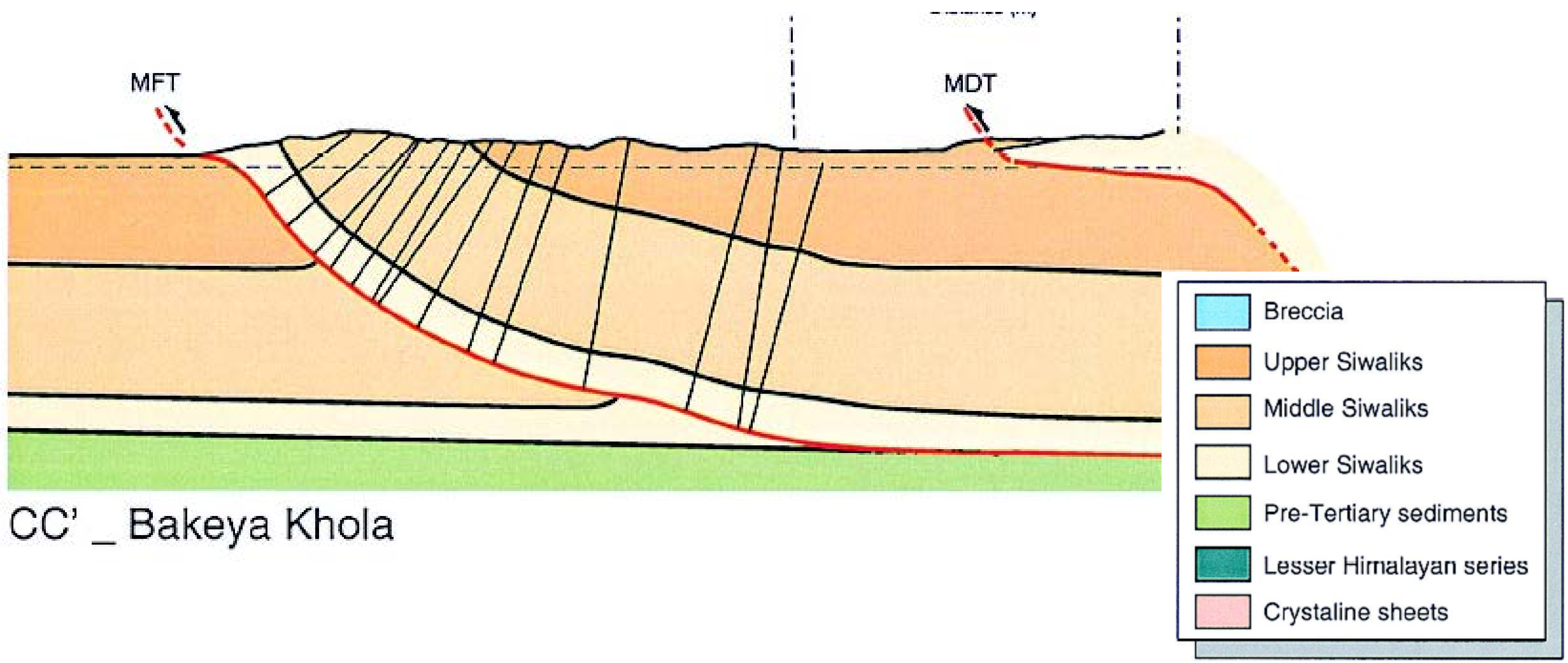
--K. X Whipple





Active folding of fluvial terraces across the Siwaliks Hills, Himalayas of central Nepal

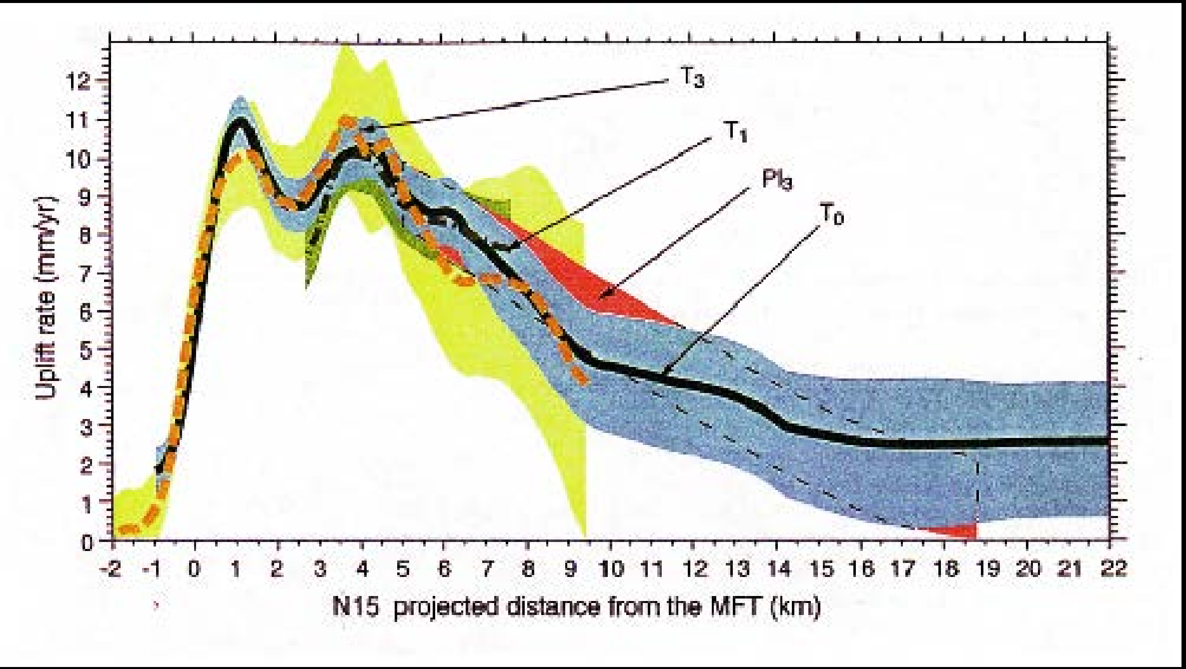
J. Lavé[1] and J. P. Avouac
Laboratoire de Géophysique, Commissariat à l'Energie Atomique, Bruyères-Le-Châtel, France



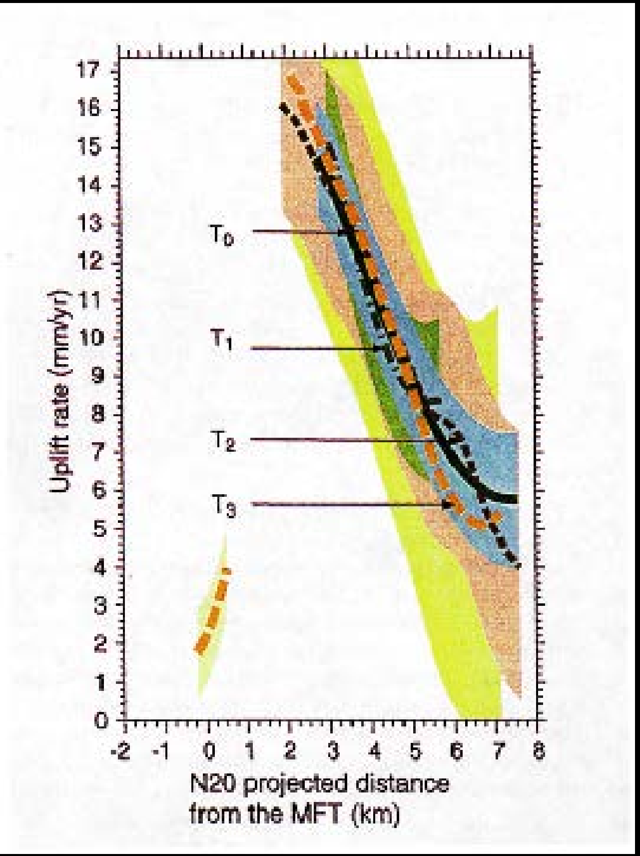
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. B3, PAGES 5735–5770, MARCH 10, 2000

--K. X Whipple

Bagmati Transect



Bakeya Transect

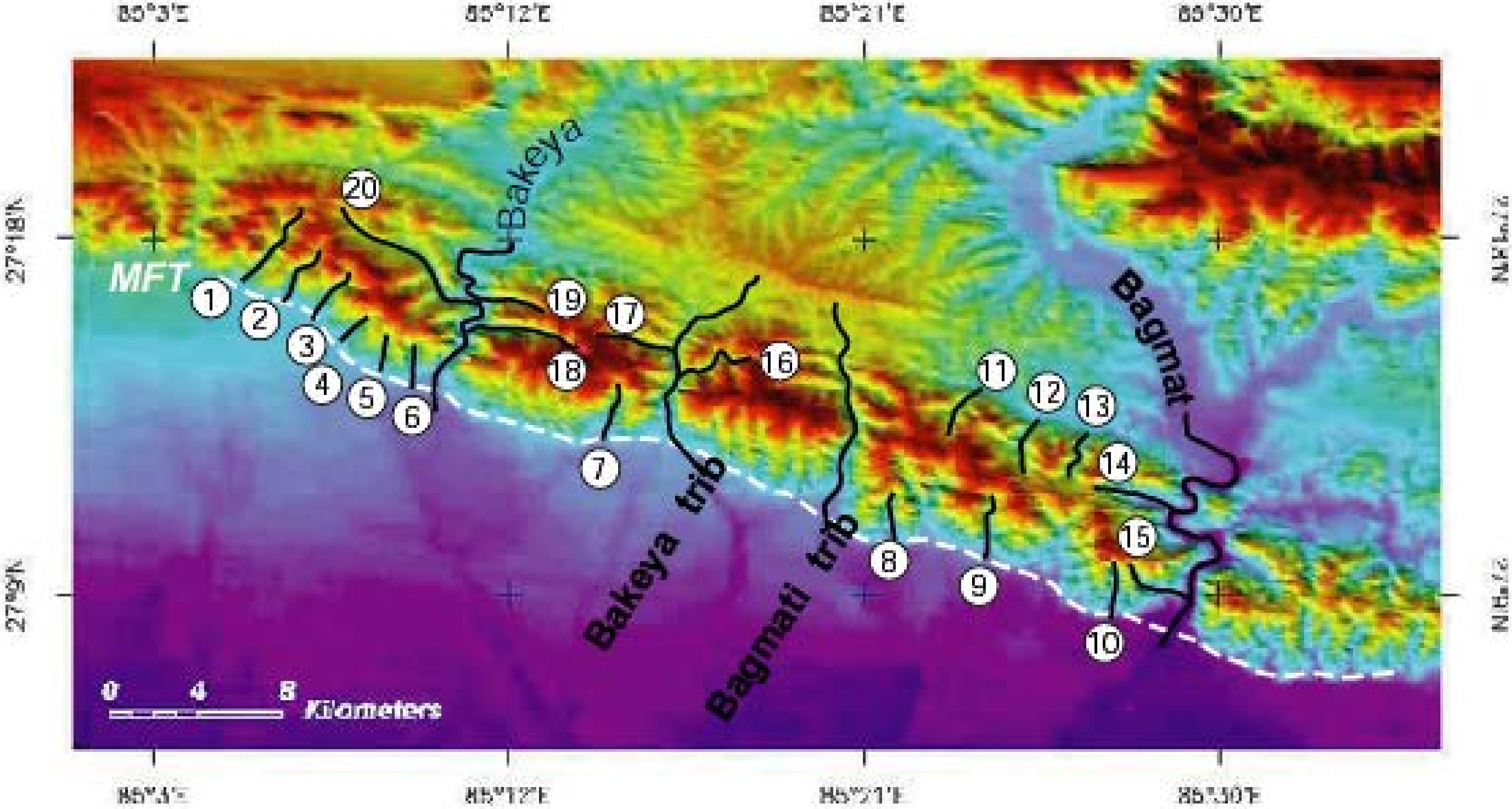


Data from Lave and Avouac, 2000, JGR

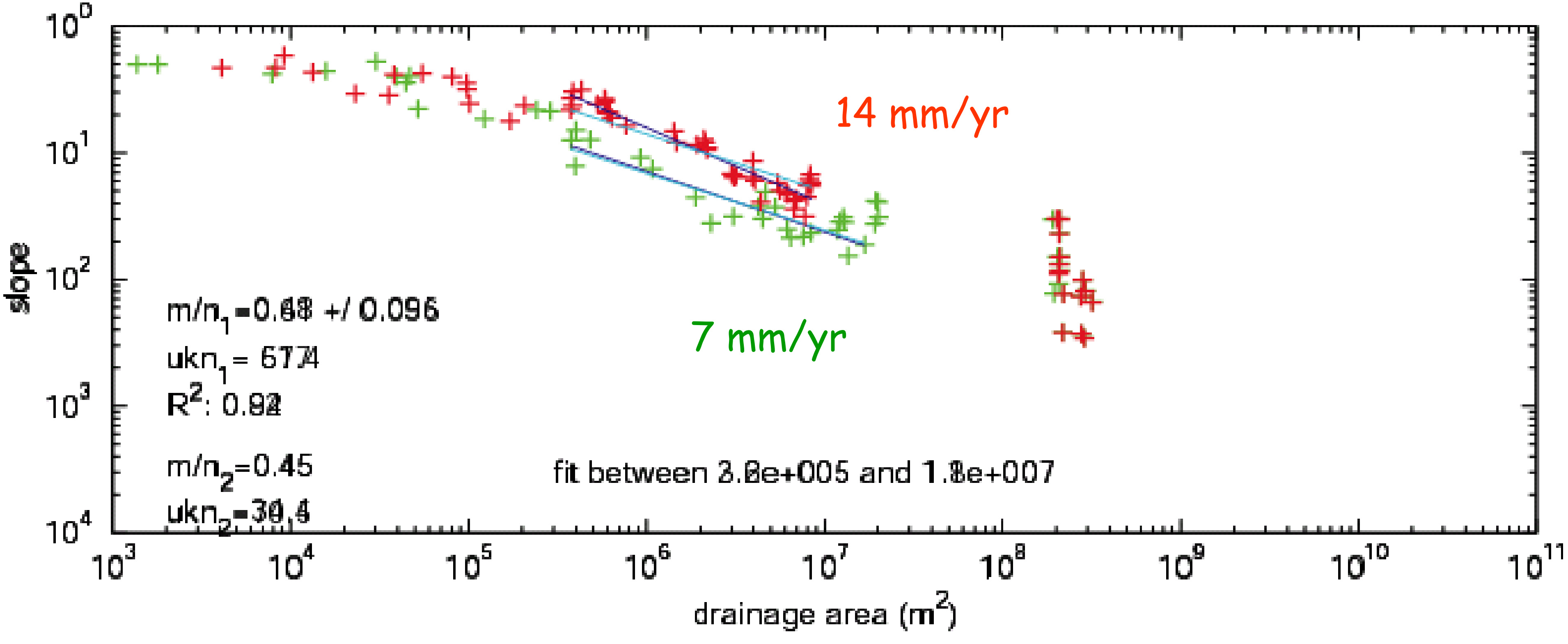
--K. X Whipple

Siwalik Hills Anticline
Himalaya Foreland, Nepal

--K. X Whipple



Strike-Parallel: Normal, uniform concavity

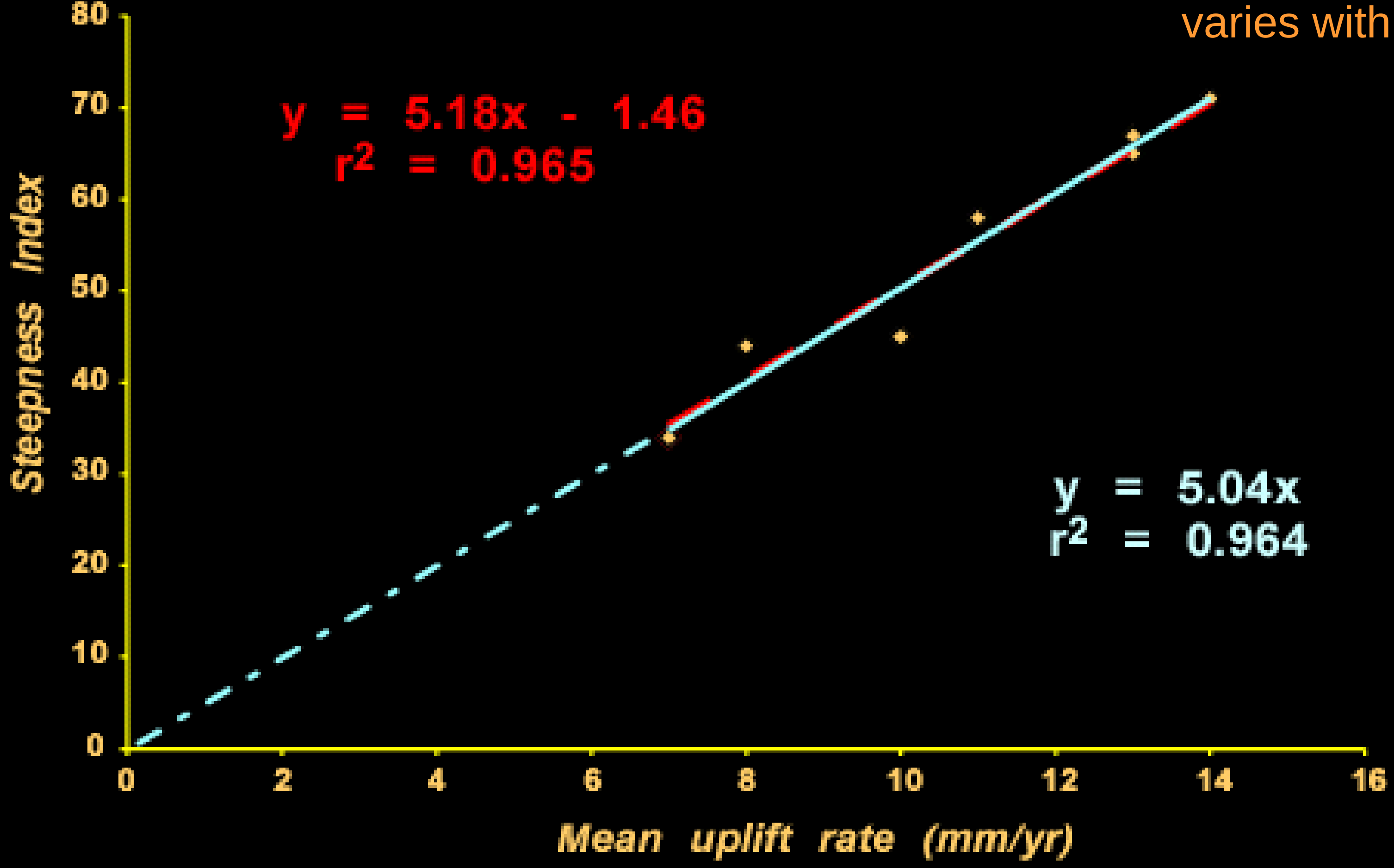


Strike-Parallel: Steepness varies with U

--K. X Whipple

Siwalik Hills, Nepal

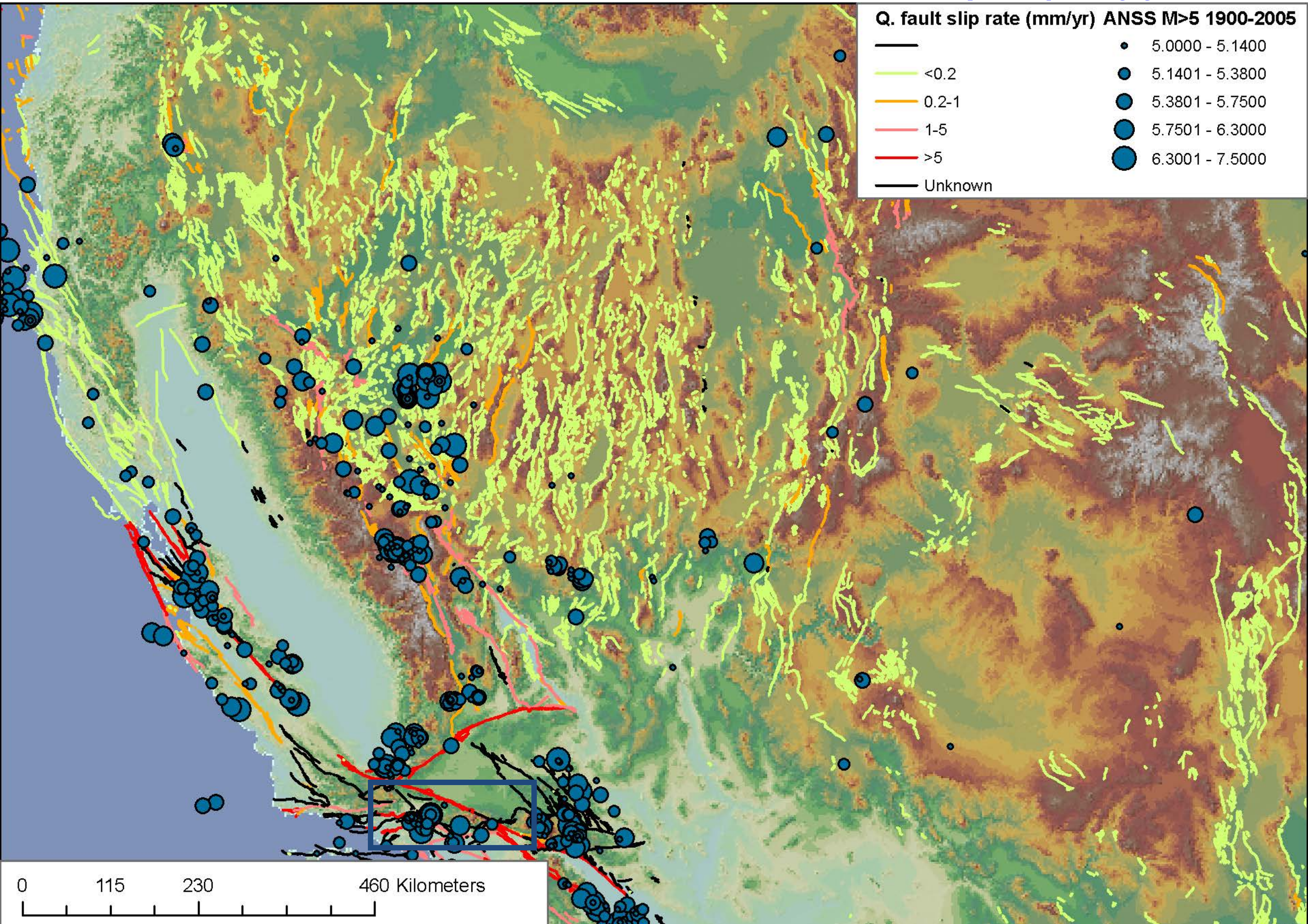
Steepness (Ks) varies with U



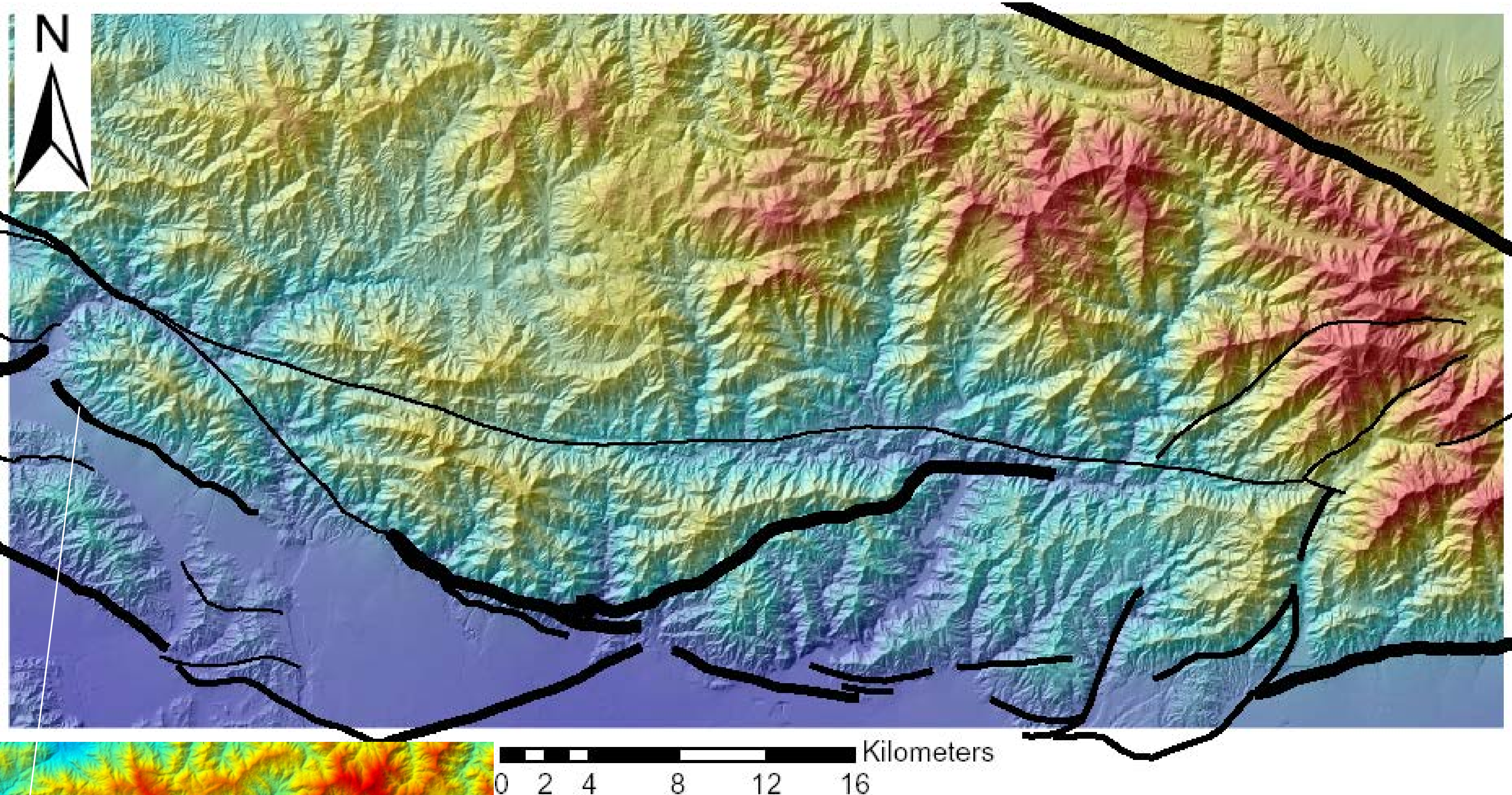
Tectonic Geomorphology of the San Gabriel Mountains

http://qfaults.cr.usgs.gov

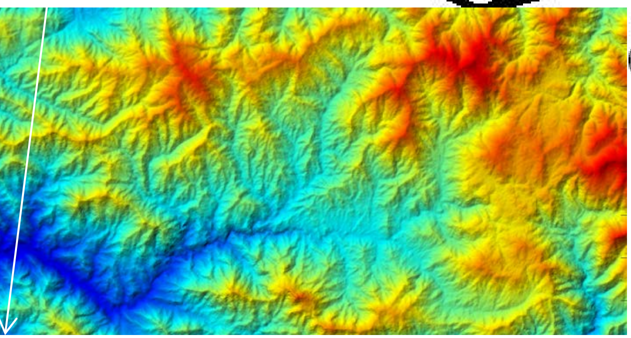
http://earthquake.usgs.gov/anss/



Shaded Relief with Color = Elevation

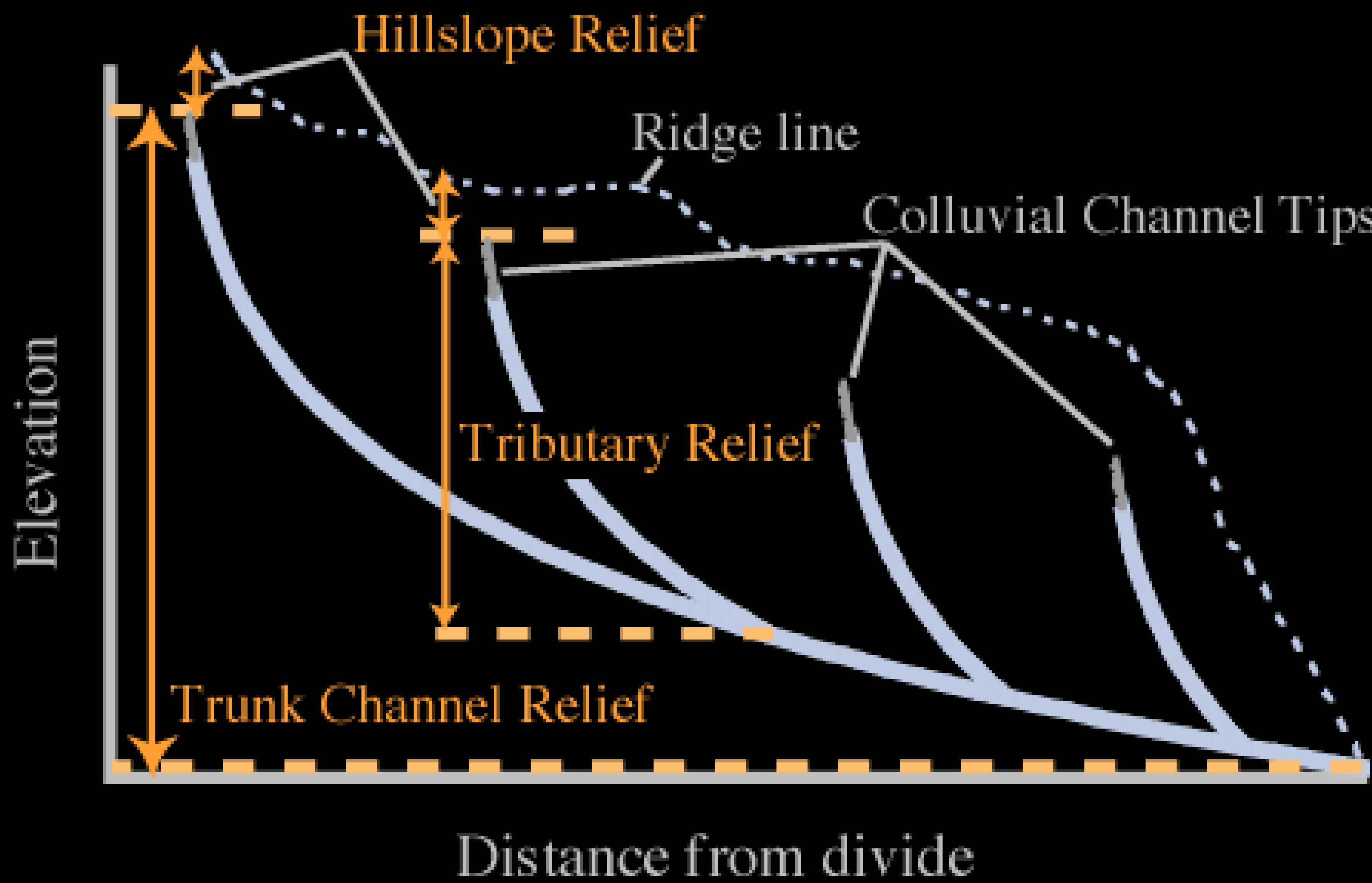


Active Faults
Thickness = Most Recent Known Slip



srtm_bigtujunga30m_utm11.tif

--K. X Whipple

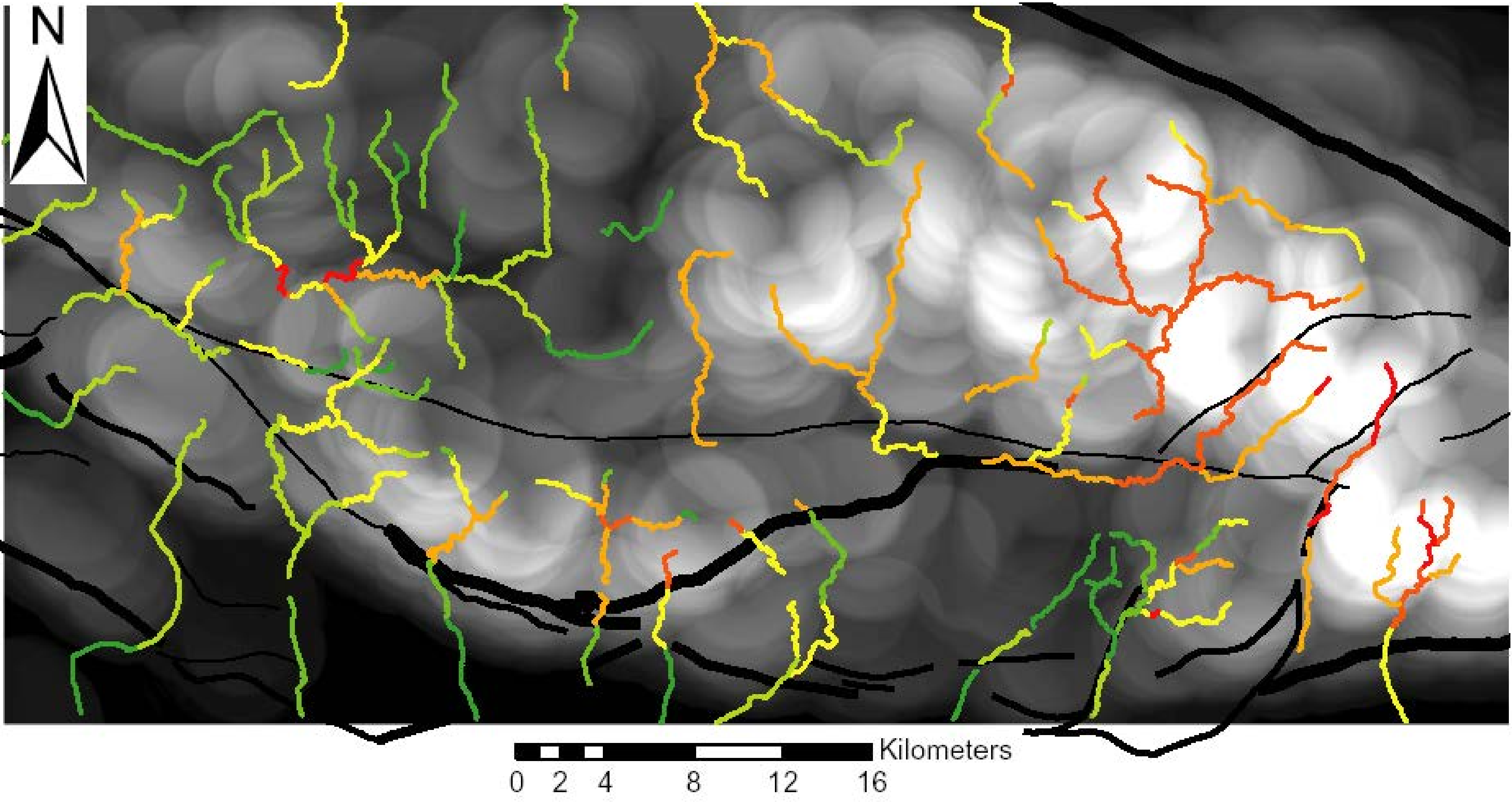


Beware: Many authors use “hillslope relief” and “local relief” (measured over up to 5km radius) as interchangeable

--K. X Whipple

Streams by Normalized Steepness Index

Local Relief (r = 2.5km)



Note: abrupt steepness breaks across active faults, no break where inactive/slow

--K. X Whipple

Geological Society of America
Special Paper 398
2006

Tectonics from topography: Procedures, promise, and pitfalls

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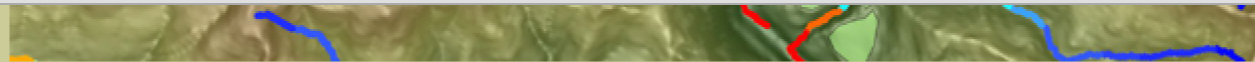
ABSTRACT

Empirical observations from fluvial systems across the globe reveal a consistent power-law scaling between channel slope and contributing drainage area. Theoretical arguments for both detachment- and transport-limited erosion regimes suggest that rock uplift rate should exert first-order control on this scaling. Here we describe in detail a method for exploiting this relationship, in which topographic indices of longitudinal profile shape and character are derived from digital topographic data. The stream profile data can then be used to delineate breaks in scaling that may be associated with tectonic boundaries. The description of the method is followed by three case studies from varied tectonic settings. The case studies illustrate the power of stream profile analysis in delineating spatial patterns of, and in some cases, temporal changes in, rock uplift rate. Owing to an incomplete understanding of river response to rock uplift, the method remains primarily a qualitative tool for neotectonic investigations; we conclude with a discussion of research needs that must be met before we can extract quantitative information about tectonics directly from topography.

geomorphtools.org

geomorphtools.org/Tools/StPro/StPro.htm

Introduction to the I... | Franklin & Marshall ... | Tectonic Geomorph... | GLG362/598--Geom... | About Underwood ...



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Stream Profiler

- **Tool Description**
  - This tool allows users to extract river profiles from DEM data and analyze the steepness index and concavity of one or more channels. It operates using ArcGIS 9.X or 10.X and MATLAB r14 more recent (requiring Matlab's Statistics Toolbox).
- **Tool Codes**
  - ArcGIS 9.X .dll file and MATLAB codes here.
  - ArcGIS10.X .dll files and MATLAB codes are here.
    - Installation instructions are below and are here.
    - (we are working on revisions for Arc10.1)
    - Do not unzip with built-in windows decompress. This corrupts the DLL for some reason. WinRaR and 7zip are known to work fine.
    - Install directions are in install_uninstall_notes.txt
    - Matlab Codes are unchanged from previous version
    - A few improvements (tutorial is still for the 9.X version):
      - Append files on import works better – you don't get multiple copies of the merged shapefile loading up in arcmap
      - Hot links to pop up the matlab output figures now work on the merged shapefile, so you can click any channel with the lightning strike and view the channel profile and fits you may have done.
      - A few error catches have been added to warn users if

The old way. Now we use TopoToolbox!

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journal homepage: www.elsevier.com/locate/jsg

Review

Expression of active tectonics in erosional landscapes

Eric Kirby[a,b,*], Kelin X. Whipple[c]

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[c] *School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA*

Channel steepness considerations

"By evaluating slope-area regressions using a reference concavity index (θ_{ref}), one can determine a normalized steepness index (k_{sn}) that allows effective comparison of profiles of streams with greatly varying drainage area" (Wobus, et al., 2006)

$$S = k_{sn} A^{-\theta_{\mathrm{ref}}}$$

Stream-power family of incision models

$$E = K A^{m} S^{n}$$

(*E* is erosion rate, *K* is a generalized rate constant, *A* is drainage area, and *S* is local slope)

Kirby and Whipple, 2012

Channel steepness considerations

At steady state, by definition the channel erosion rate is equal to the uplift rate of rock ($E = U$), and the steady-state channel gradient(S_e) is

$$S_e = (U/K)^{1/n} A^{-m/n}$$

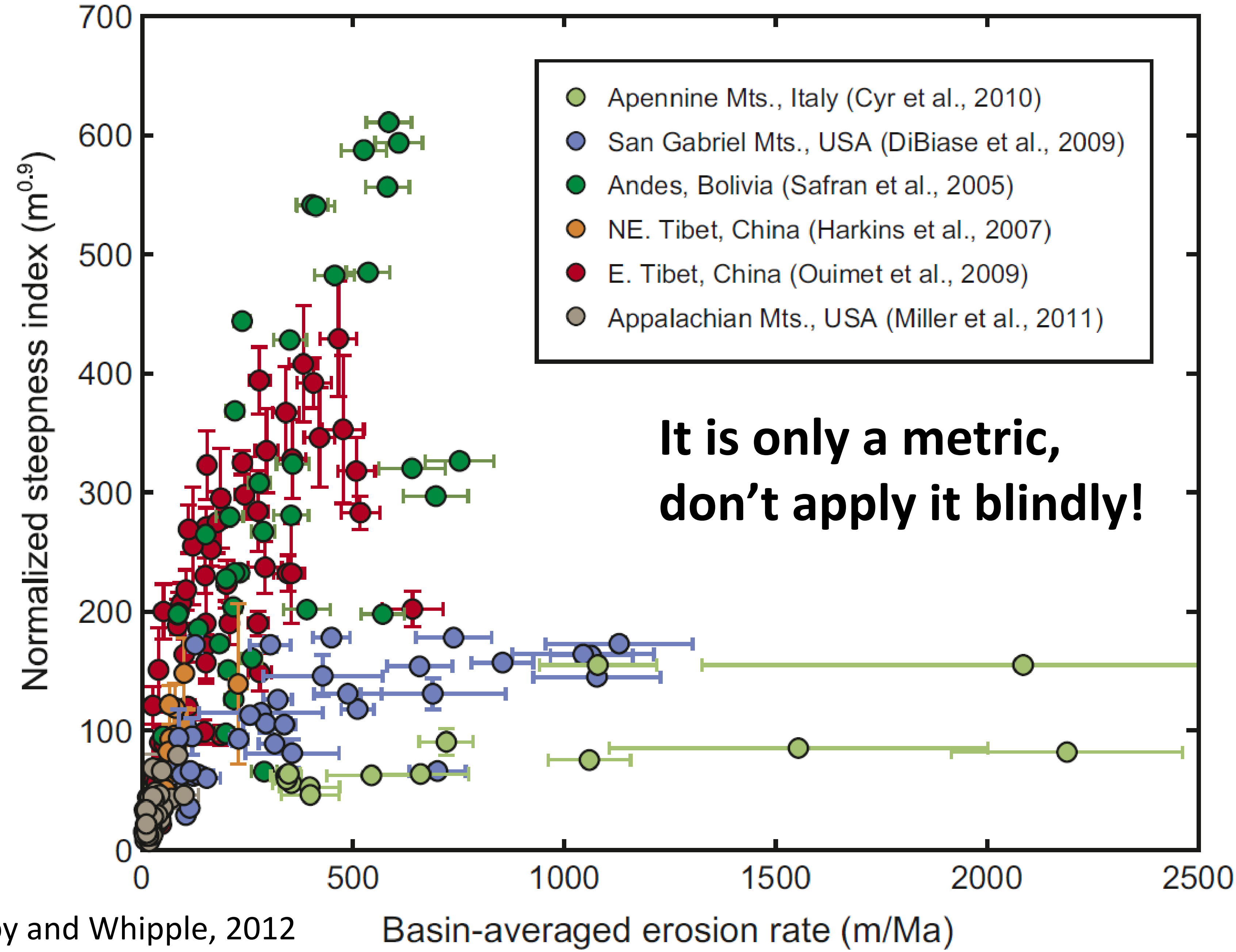
Recall:

$$S = k_{sn} A^{-\theta_{\mathrm{ref}}}$$

predicts $\theta \sim ½$, consistent with observations for well-graded channels with uniform K and U ($0.4 < \theta < 0.6$)

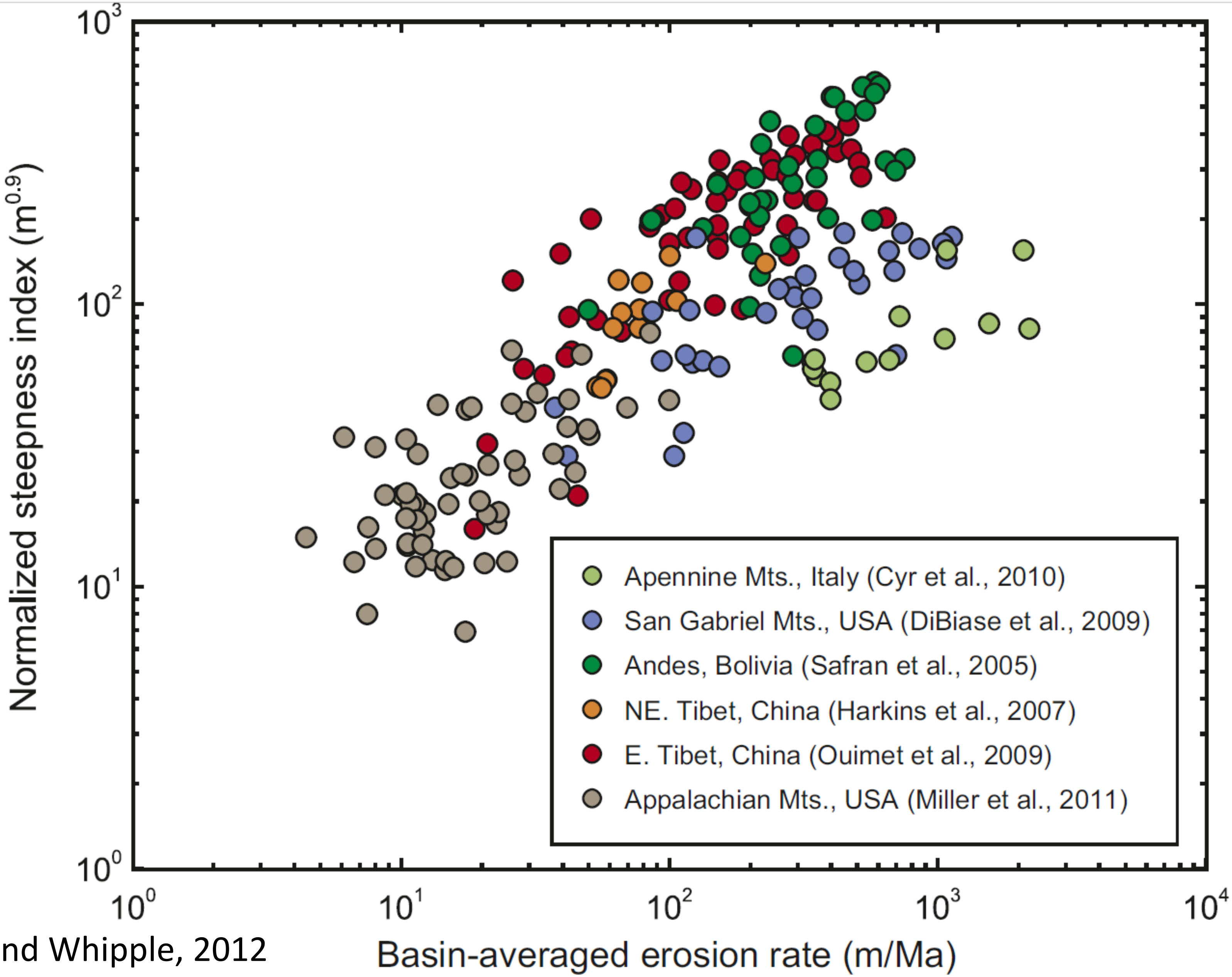
And thus we assume, $K_{sn} \sim U^p$ (rock uplift rate) all other things (like climate, vegetation, and rock resistance to erosion, [that is K], being roughly equal)

Kirby and Whipple, 2012



It is only a metric, don't apply it blindly!

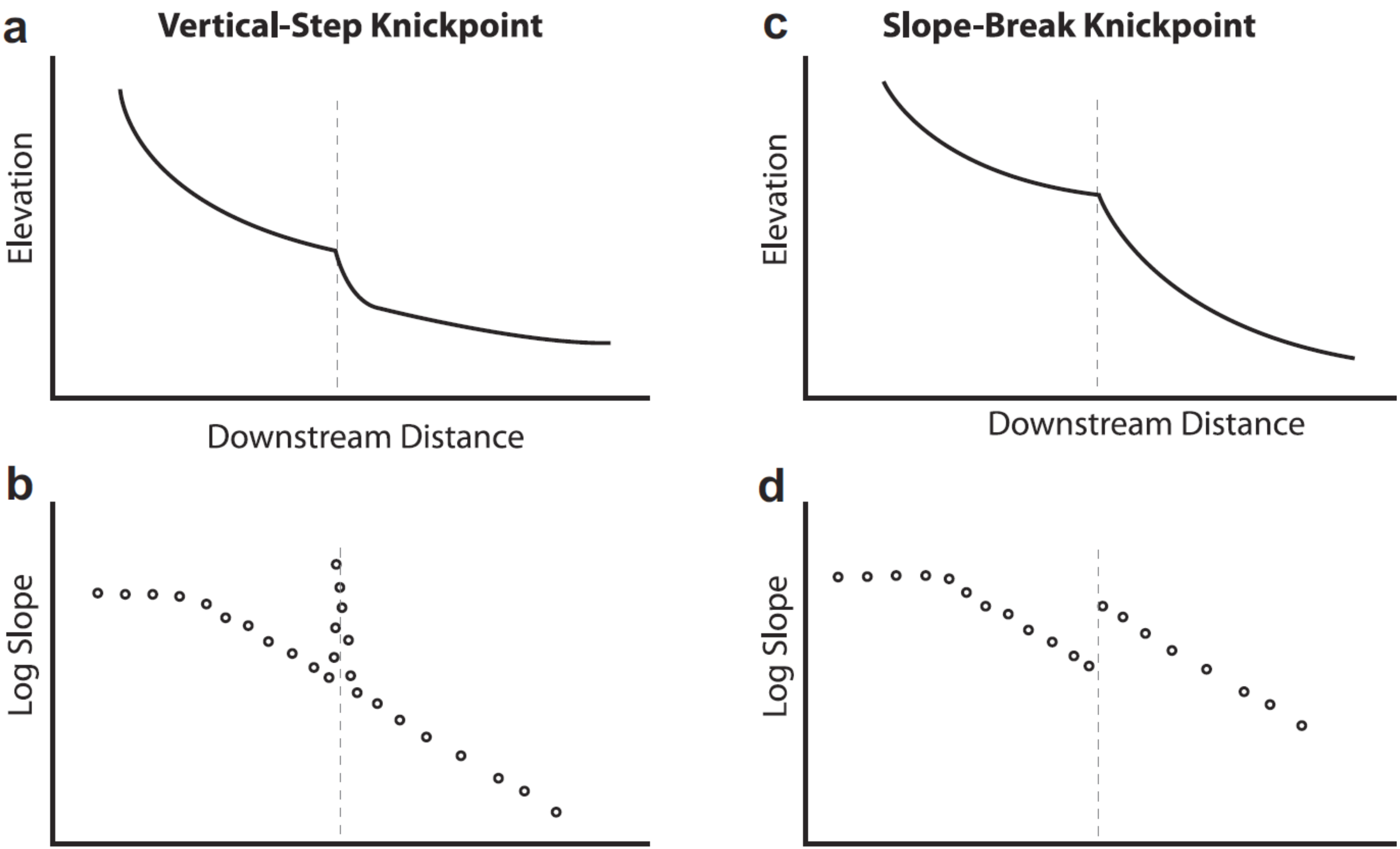
Kirby and Whipple, 2012



Kirby and Whipple, 2012

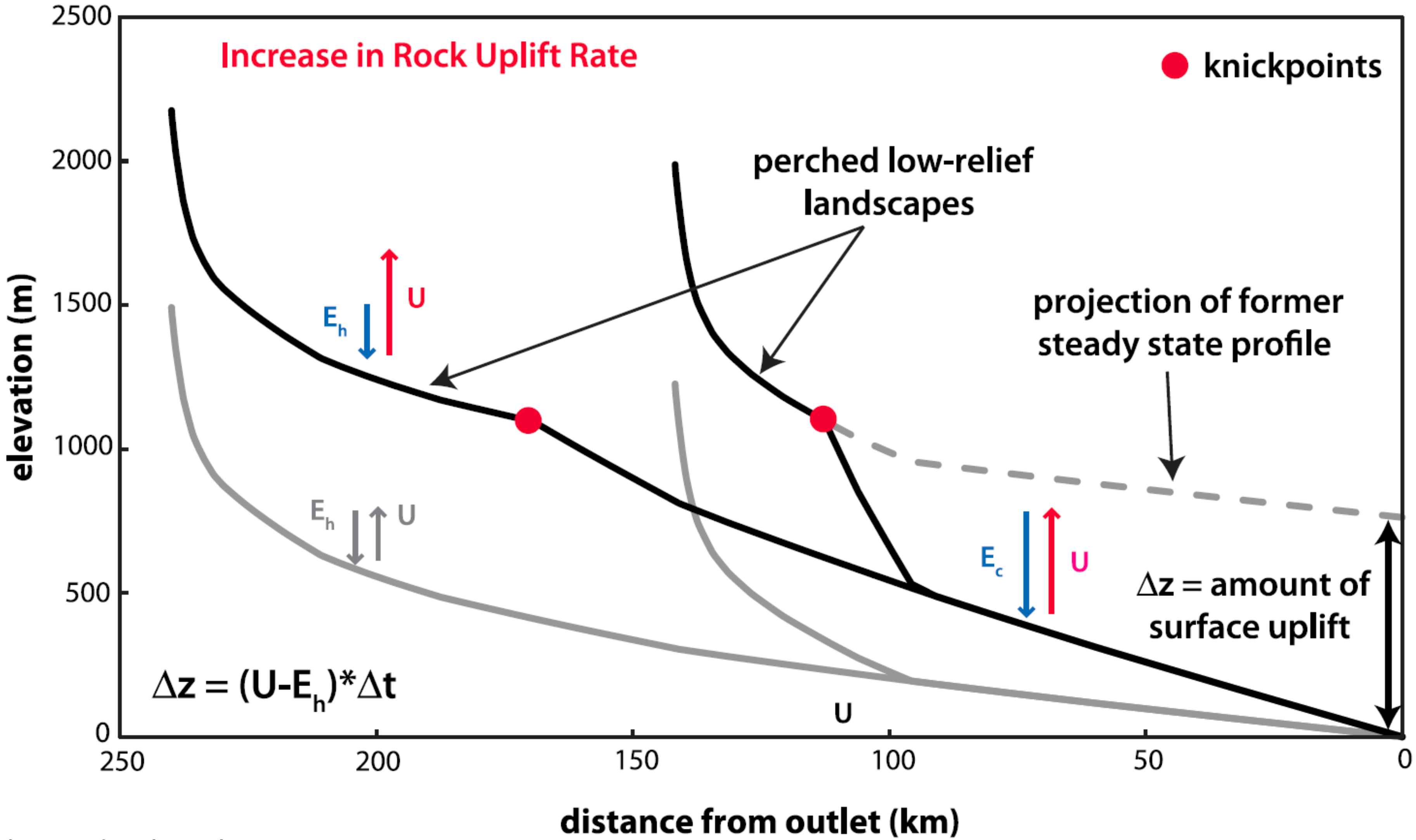
Transient channel response and knickpoints

Migrating boundaries between downstream region adjusting to new forcing (e.g., baselevel drop) and upstream region adjusted to prior state



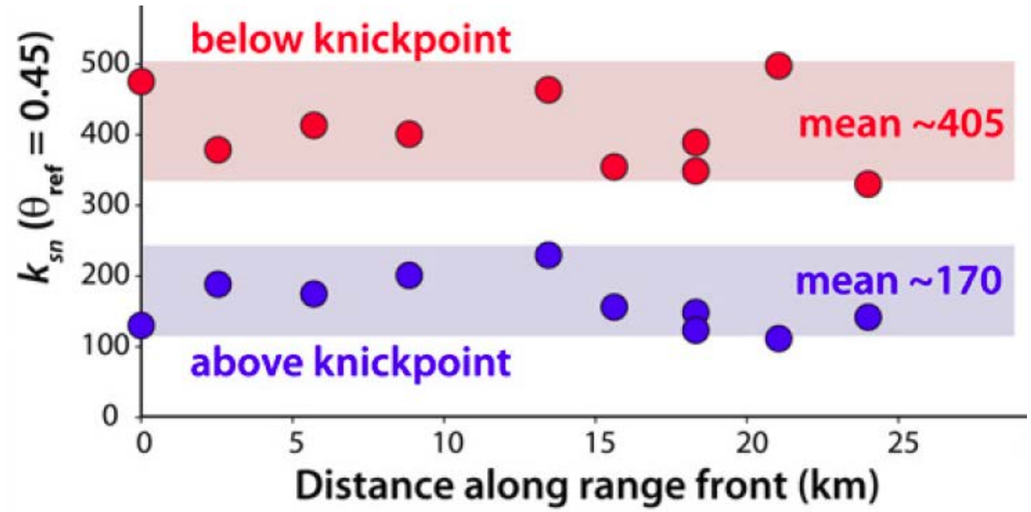
Kirby and Whipple, 2012 Log Area

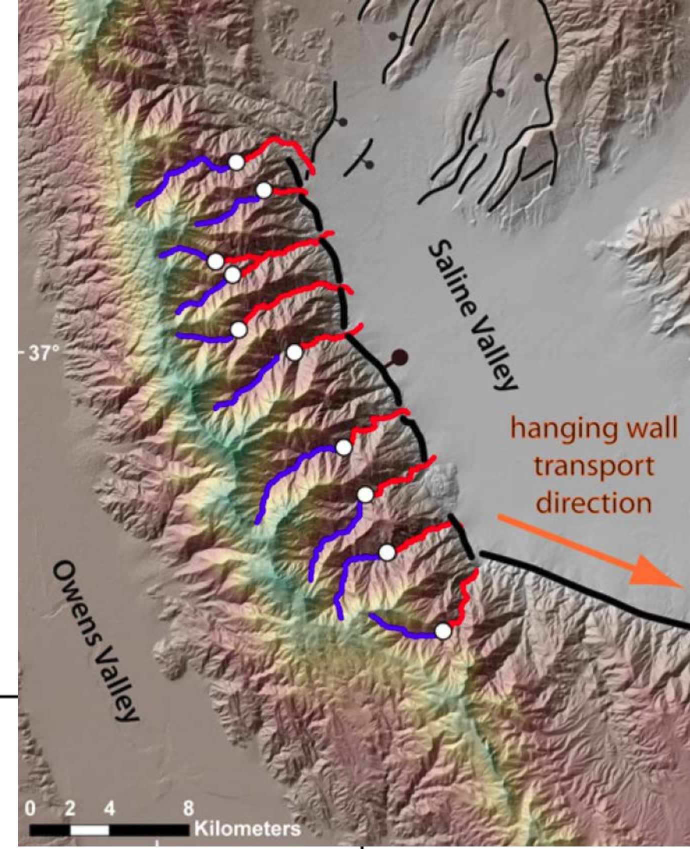
Interpretation of transient profiles

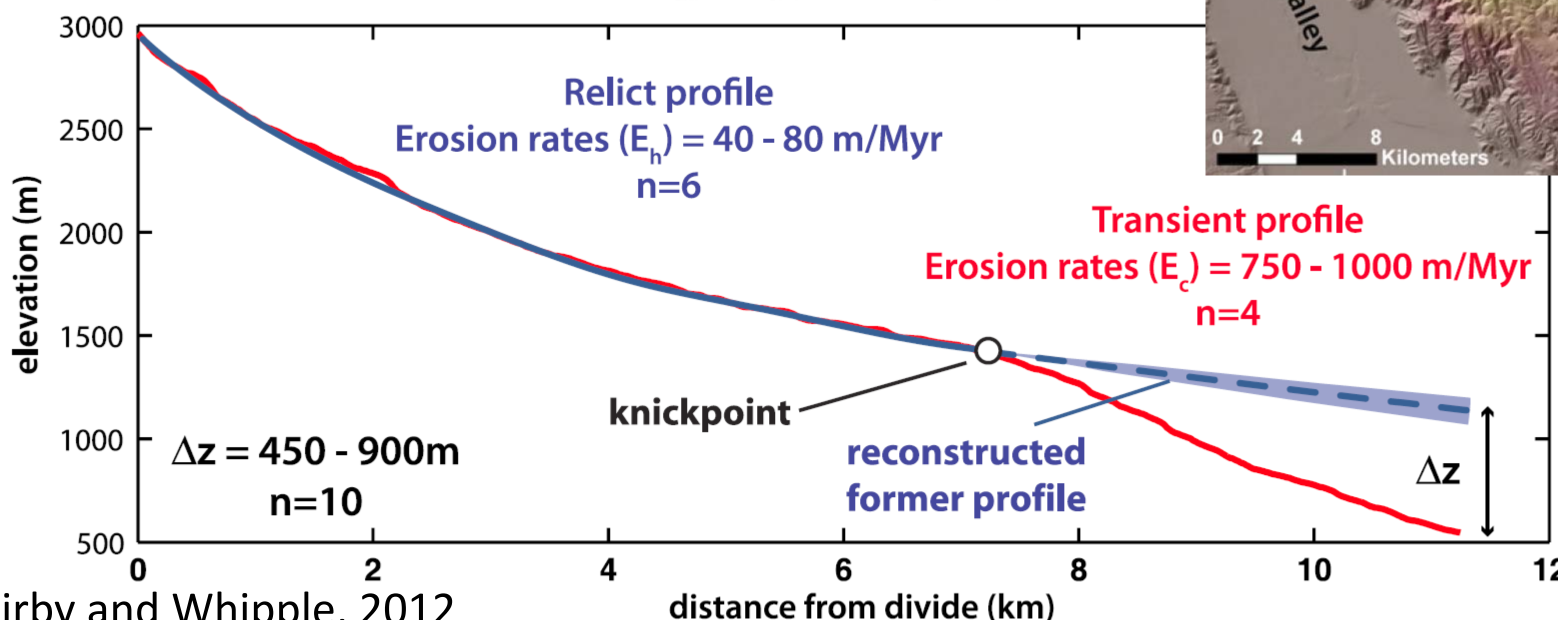


Kirby and Whipple, 2012

Saline Valley, California example







Implies change in fault throw rate

Kirby and Whipple, 2012