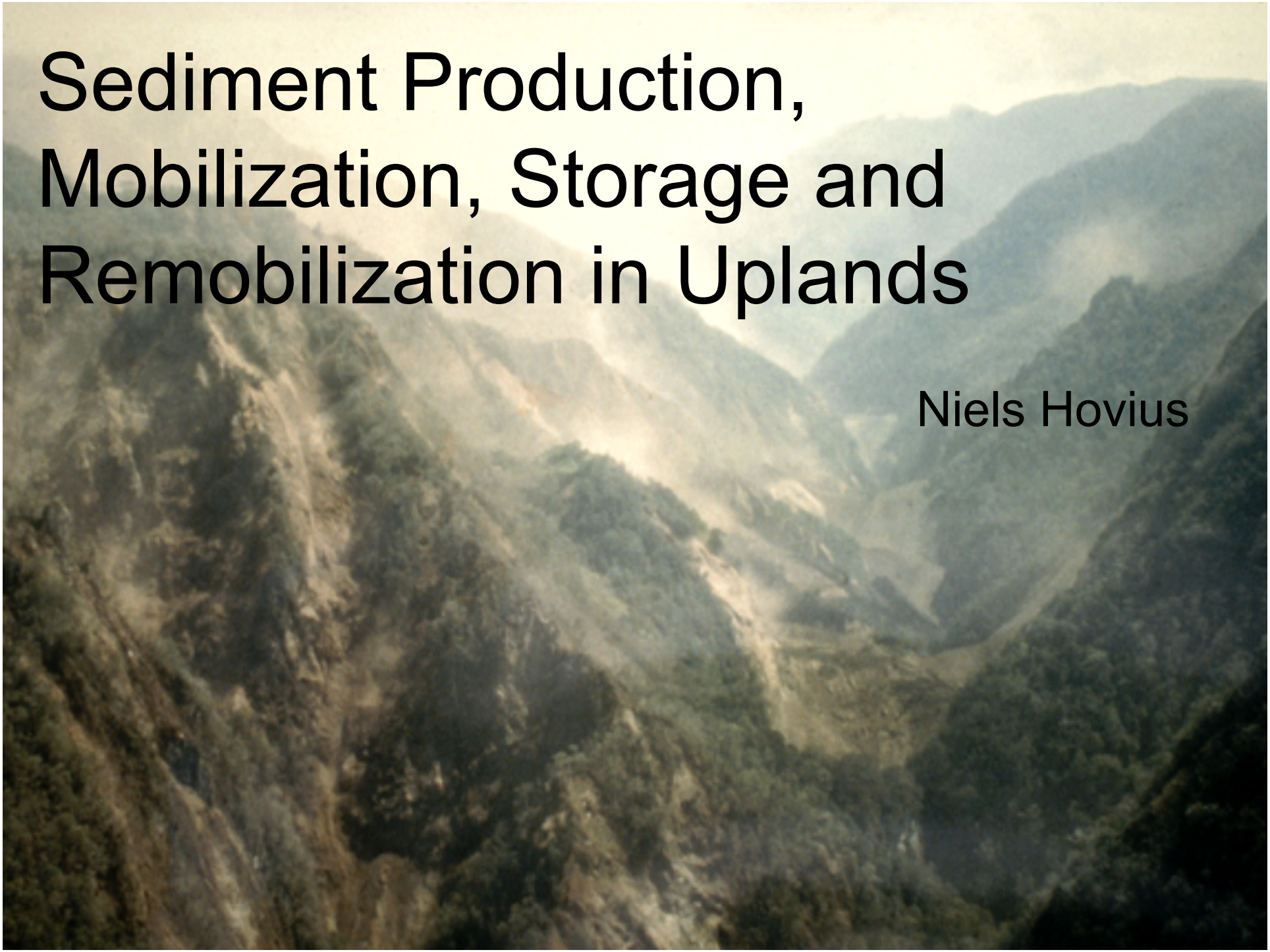
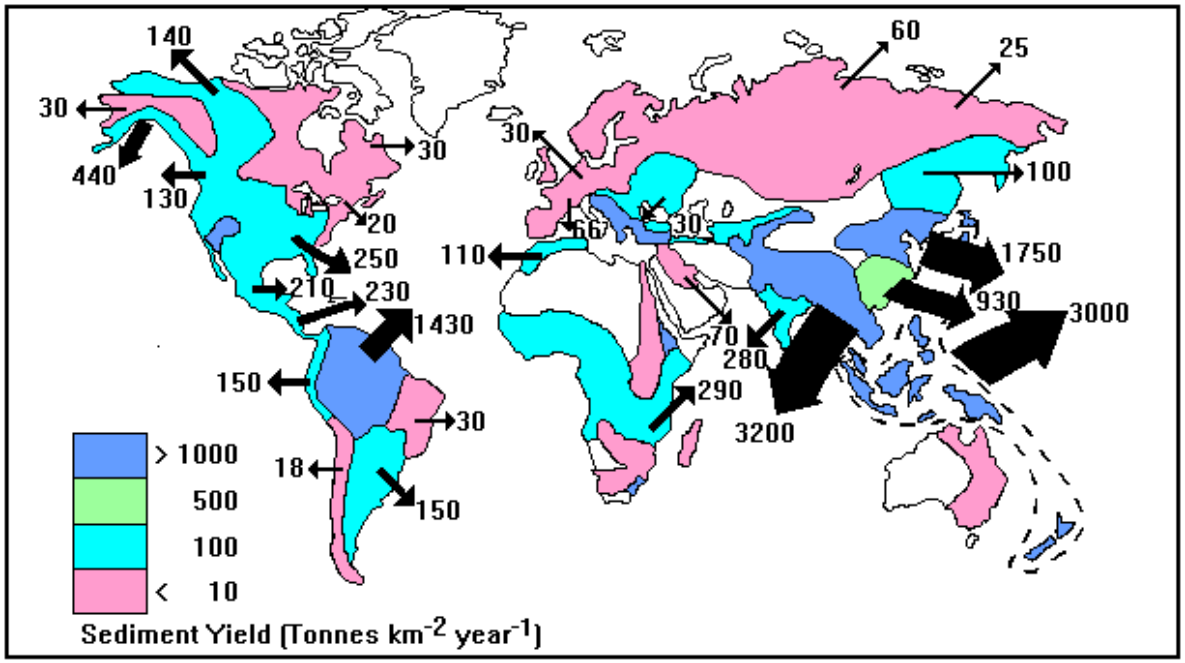


Sediment Production, Mobilization, Storage and Remobilization in Uplands

Niels Hovius

GLOBAL SEDIMENT YIELD



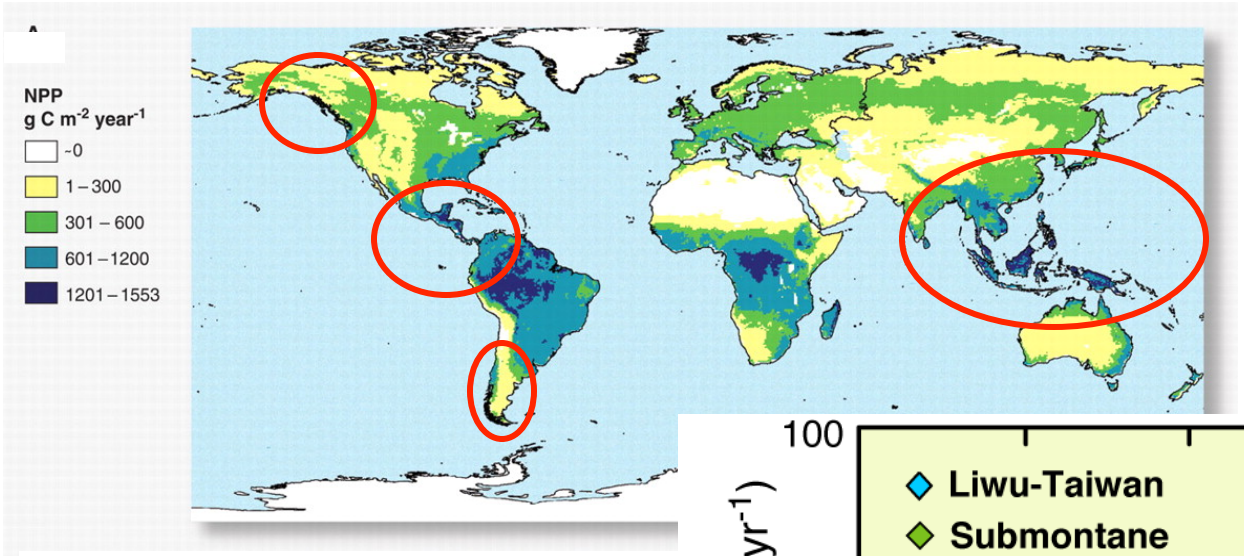
Global pattern of sediment yield, with river output of sediment to the oceans (tonnes x10^6)

Milliman and Meade, 1983

Controls: elevation, relief, etc. are proxies for:

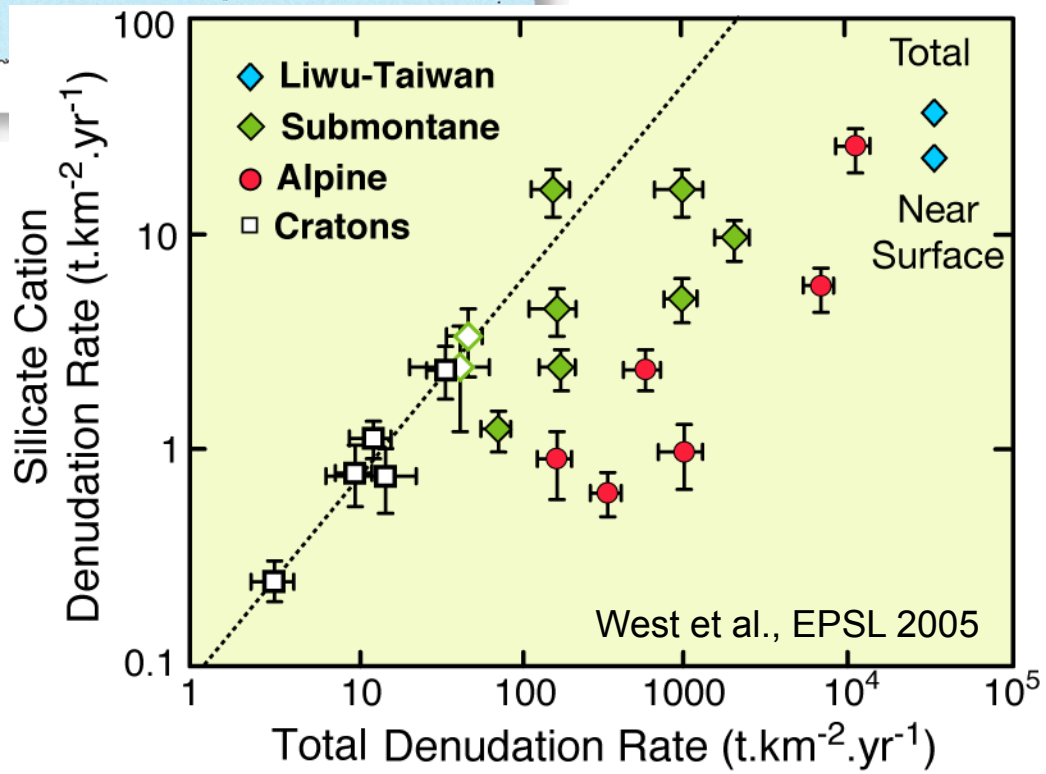
Convergence/divergence rate, modulated by ambient climate.

NET PRIMARY PRODUCTIVITY, ORGANIC MATTER

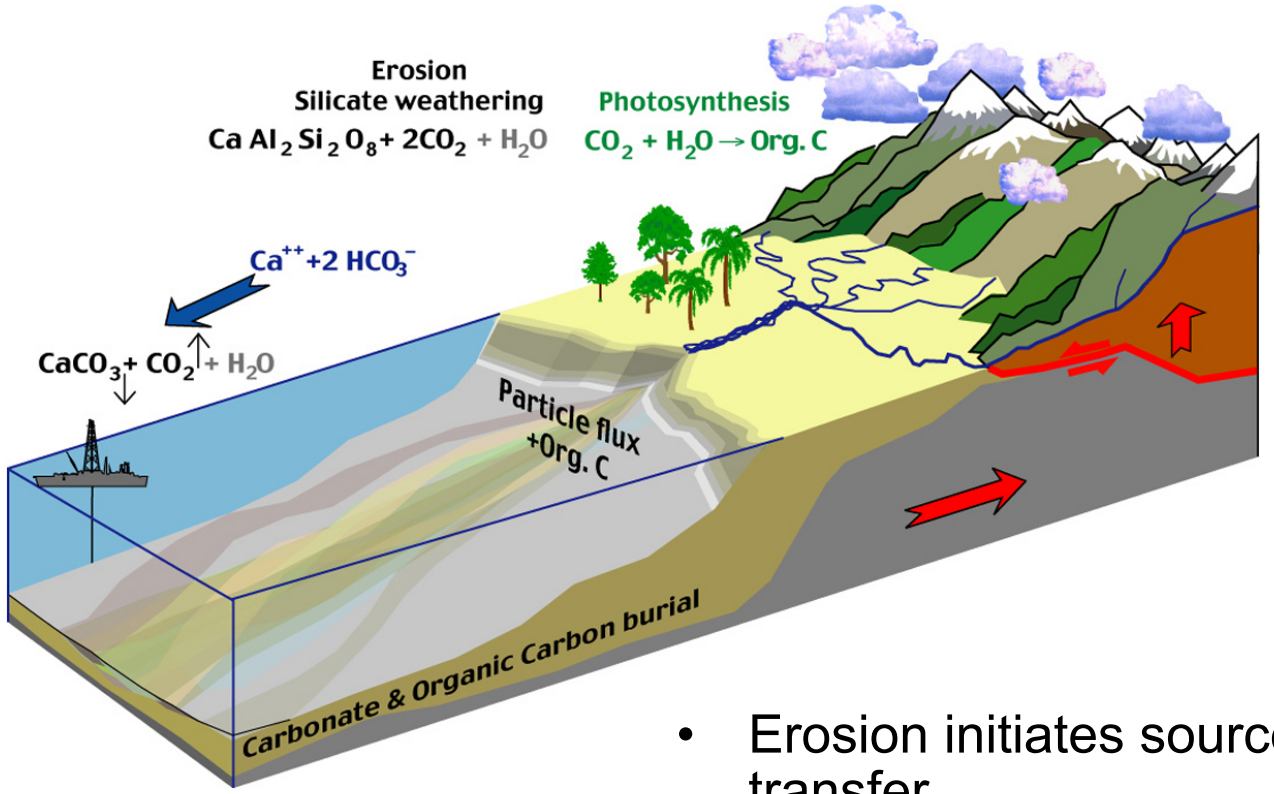


Bowman et al.,
Science 2009

SILICATE WEATHERING

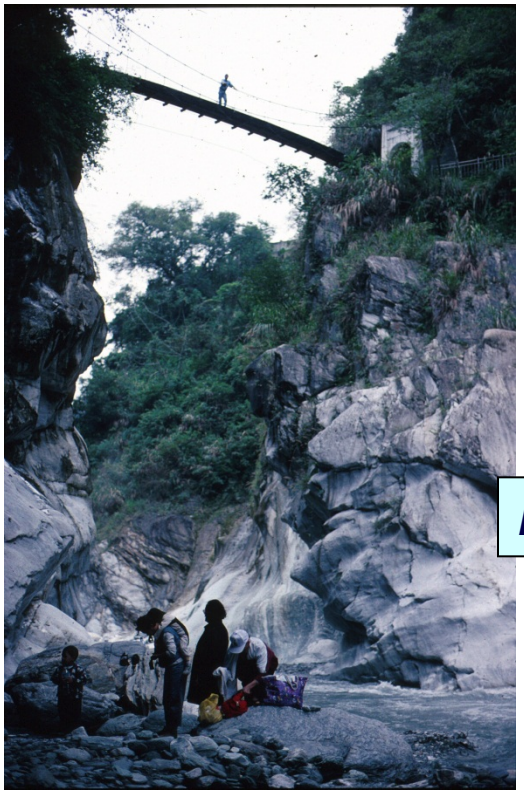


CONTINENTAL EROSION AND CARBON CYCLING



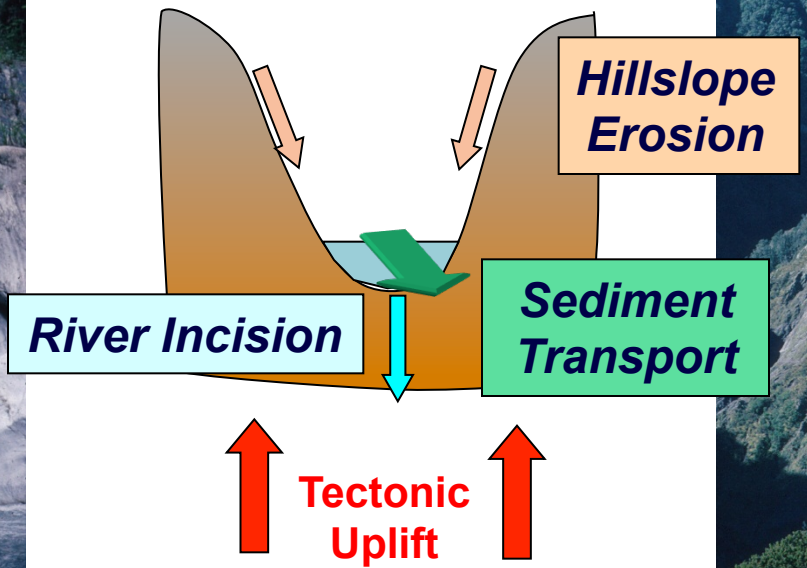
- Erosion initiates source to sink transfer.
- Erosional refreshing of rock surfaces optimizes chemical weathering.
- Erosion processes harvest biogenic carbon.

DOMINANT EROSION PROCESSES



Fluvial Bedrock Incision

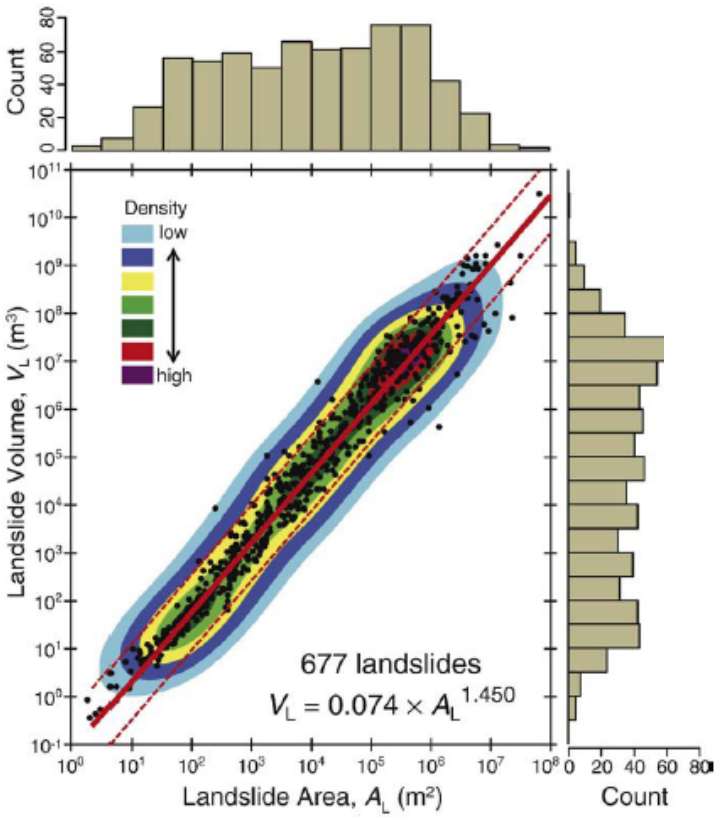
- Drives down base level
- Undercuts valley sides



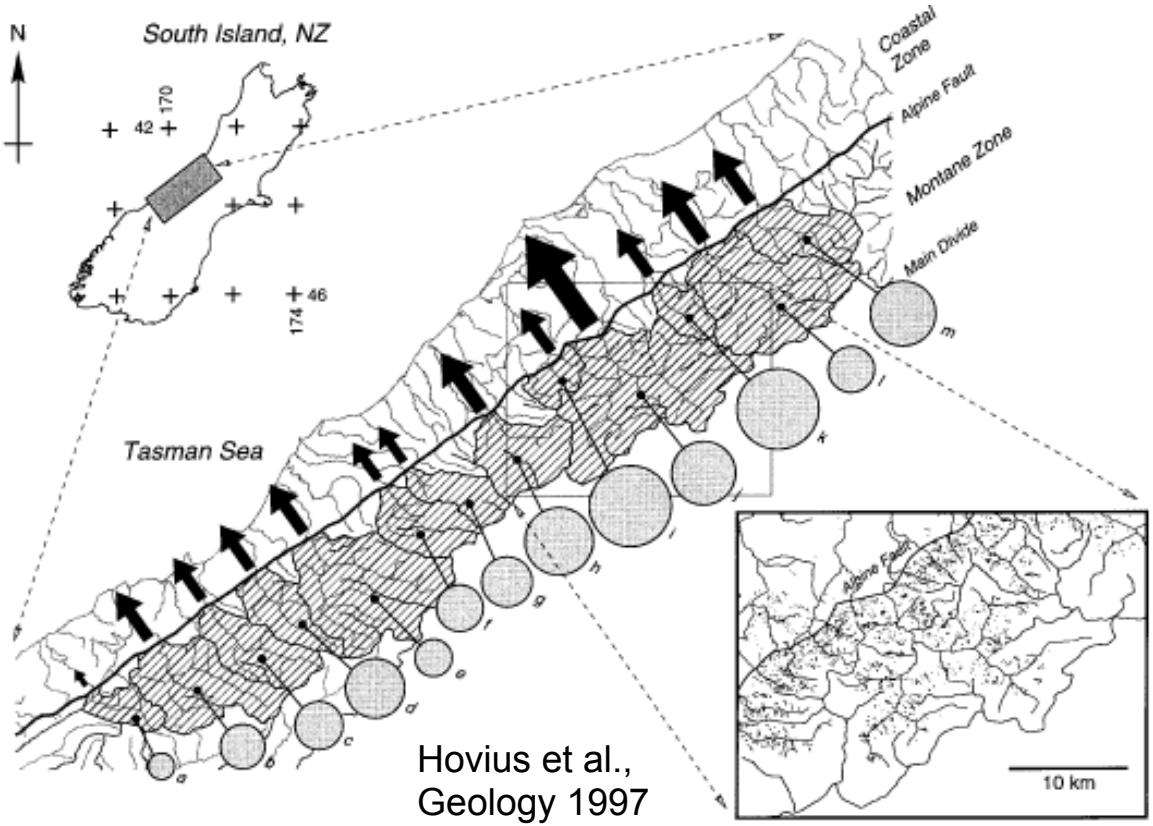
Bedrock Landsliding

- Lowers landscape
- Tools for river cutting

LANDSLIDE-DRIVEN SEDIMENT FLUX



Guzzetti et al., EPSL 2009

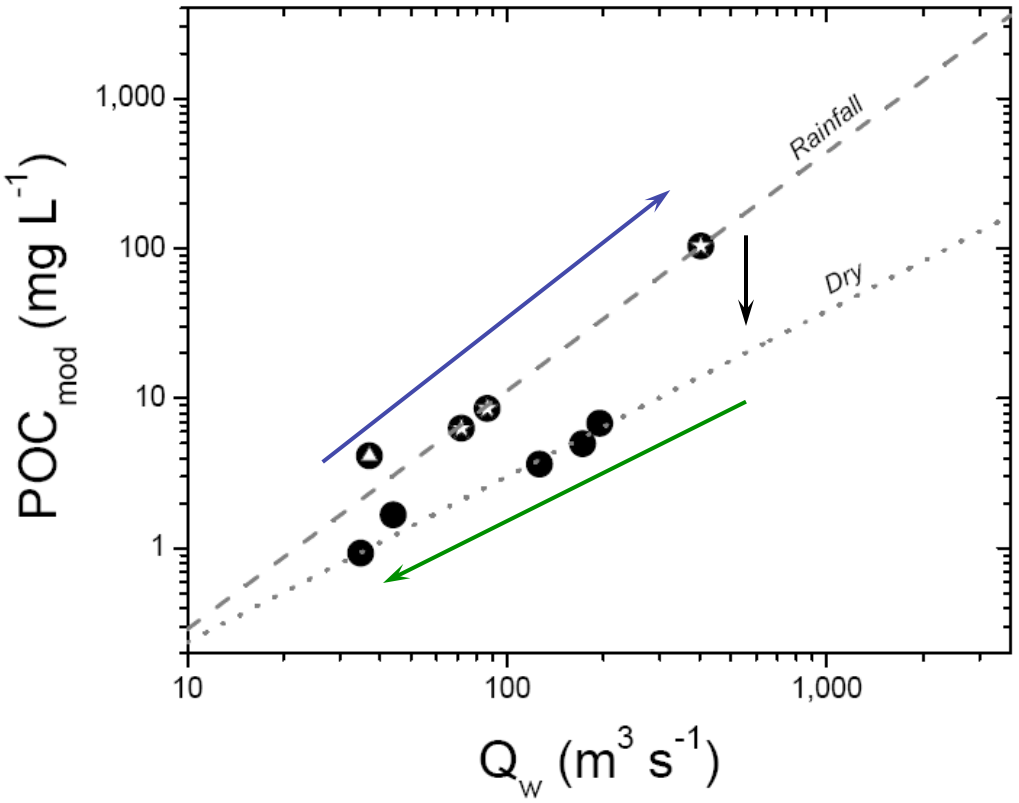


Hovius et al., Geology 1997

NZ: Landslide sediment flux = Tectonic flux

Landslide area ~ volume scaling underconstrained at local level.

WASH AND WASTE



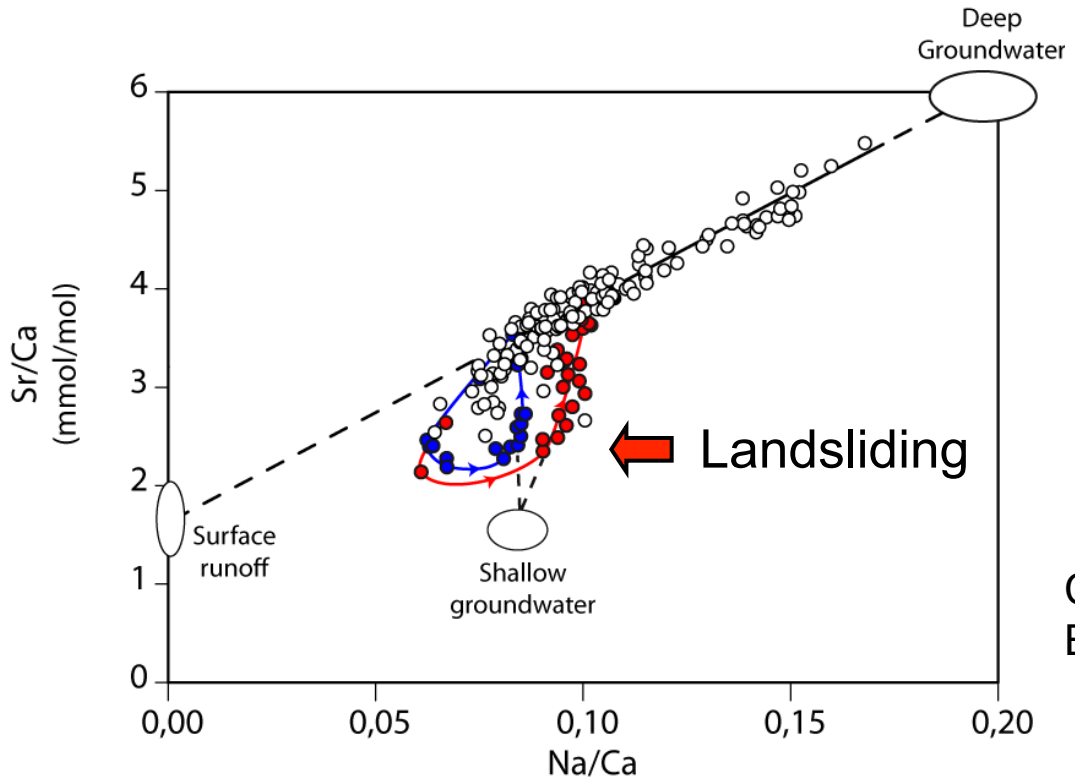
Sediment in channel is only source during dry intervals: landslide lags and alluvium.

Landslides contribute new sediment during rainstorms, but with the same composition.

Runoff during rainfall mobilizes litter and soil to boost the POC_{mod} concentration.

Hilton et al., Nature Geoscience, 2008

THREE WATER SOURCES AND WEATHERING SITES



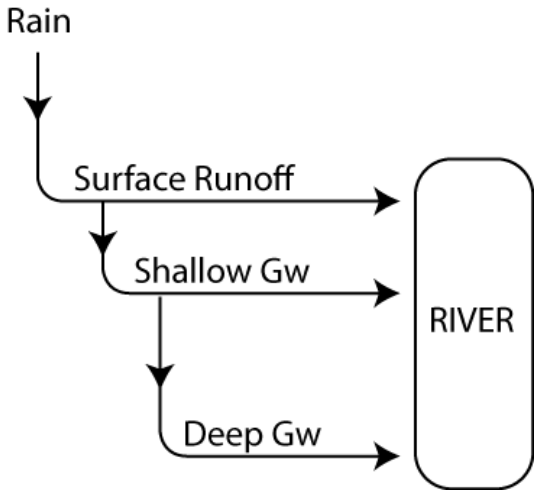
Calmels et al.,
EPSL 2011

No or moderate rain: river water is mix of surface runoff and deep recharge.
Surface runoff dominated by carbonate weathering.
Deep groundwater has increased load from silicate weathering.

Typhoon precipitation systematically flushes shallow groundwater.
Reservoir with distinct chemistry. Landslide-triggering rainfall.

WEATHERING FLUXES

2002-2008: 190 samples



	10^6 mol/yr					10^3 mol/km^2/yr
	Deep Weathering	Shallow Weathering	Surface Weathering	Rain	Total River	Total River
Na	93	56	47	16	212	490
Ca	156	-2190	4396	65	2428	5580
Mg	453	-130	350	20	692	1590
K	23	-311	430	7	149	340
Si	-16	-29	239	0	194	450
SO_4	847	-849	1488	33	1519	3490

Surface:

Carbonate weathering.

Shallow subsurface:

Carbonate deposition.
Clay mineral formation.
Uptake by vegetation.
Silicate dissolution.

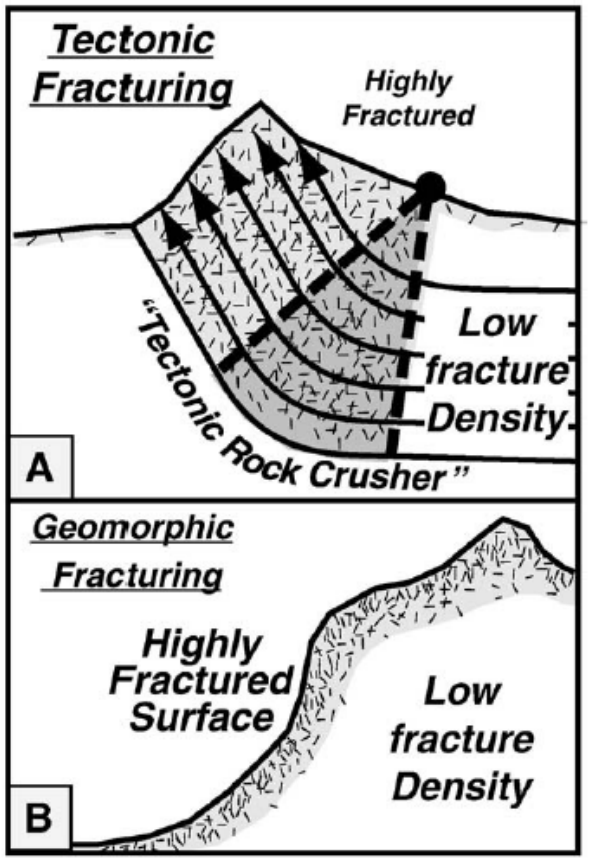
Deep subsurface:

Net weathering environment driven by sulphuric acid

Sulphuric acid is major weathering agent.

Calmels et al., EPSL 2011

FRACTURED ROCK

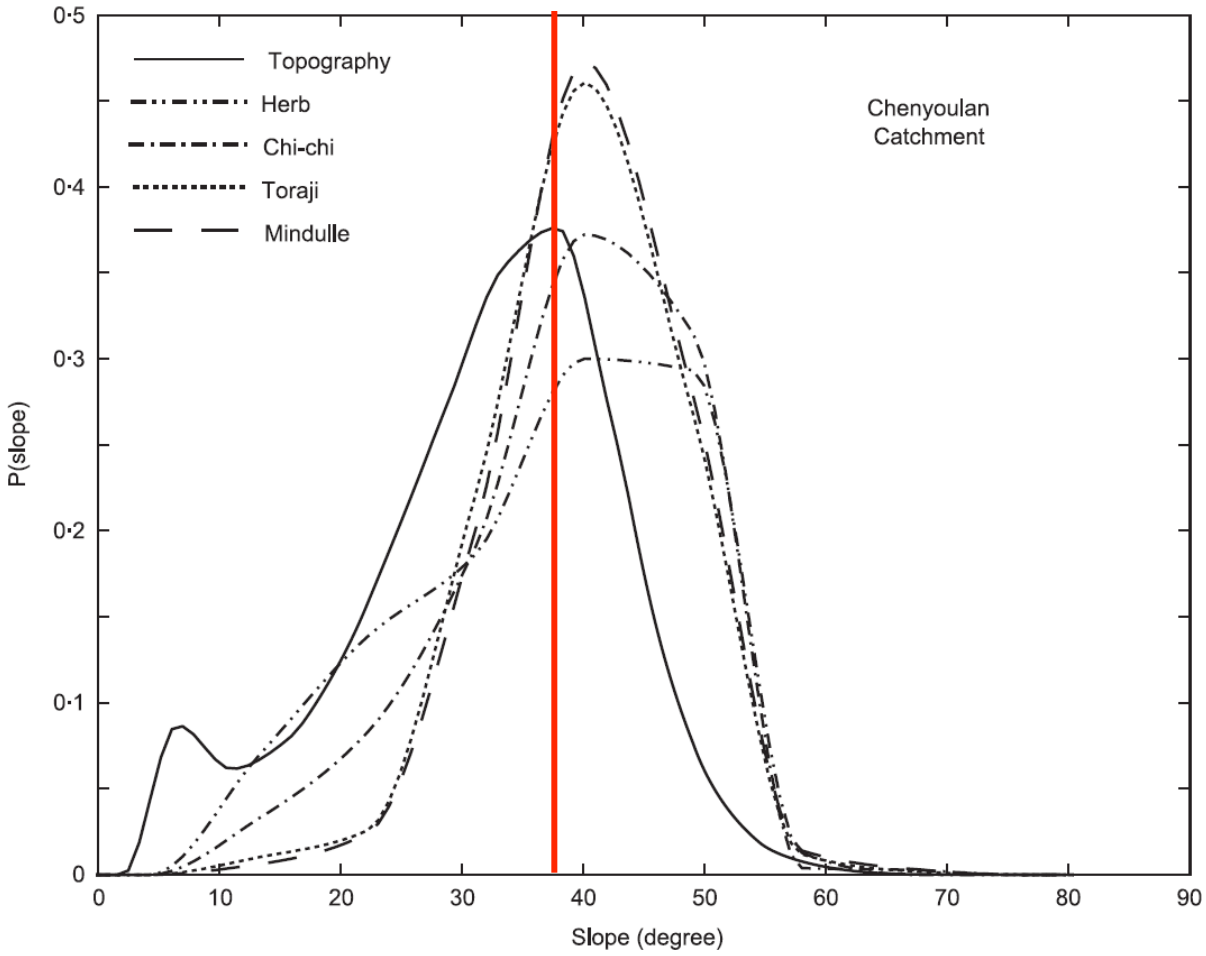


Molnar et al., JGR 2007

Clarke & Burbank, EPSL 2010

Extensive, deep fracture network hosts significant weathering, and reduces strength of bedrock.

LIMIT LANDSCAPE



Lin et al., ESPL, 2008

Modal slope of topography: 37°

Landslides oversample slopes >35°- 40°.

Landslides undersample Slopes <35°- 40°.

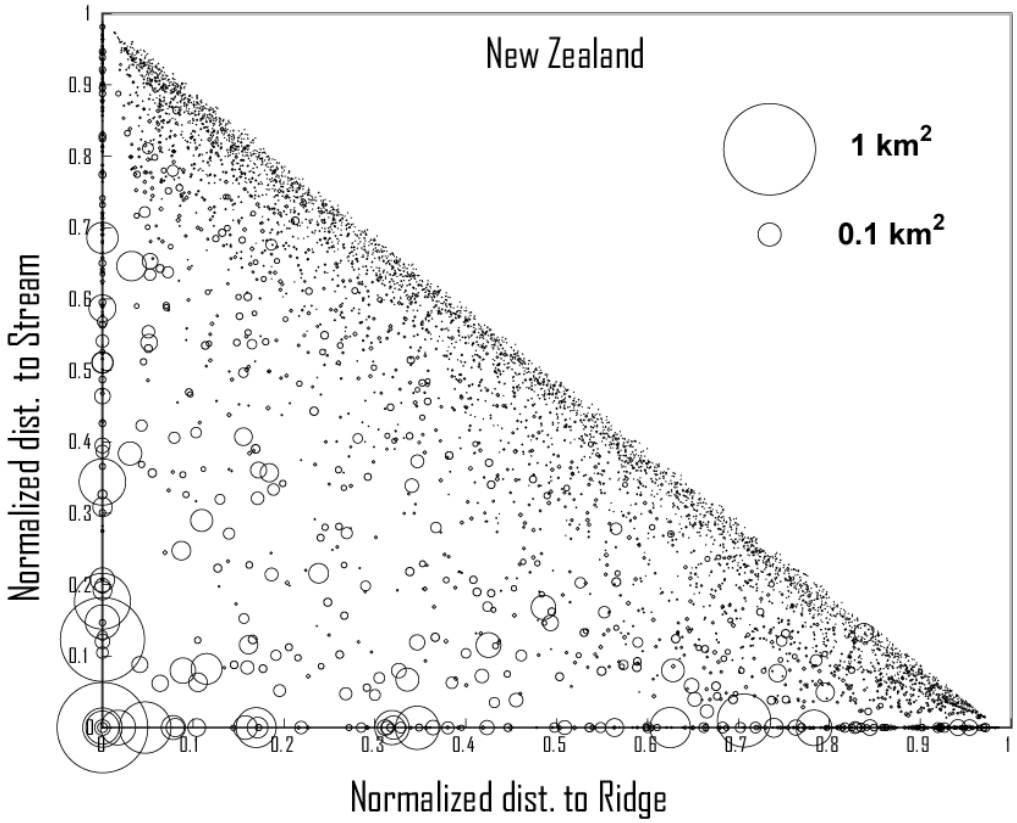
Landslides remove the steepest topographic elements.

Modal slope of topography is critical slope of substrate.

~ angle of internal friction

LOCATION OF LANDSLIDES ON SLOPES

Southern Alps, New Zealand
Rainfall Induced Landslides



Landslide distribution:

Upper quarter: 24%

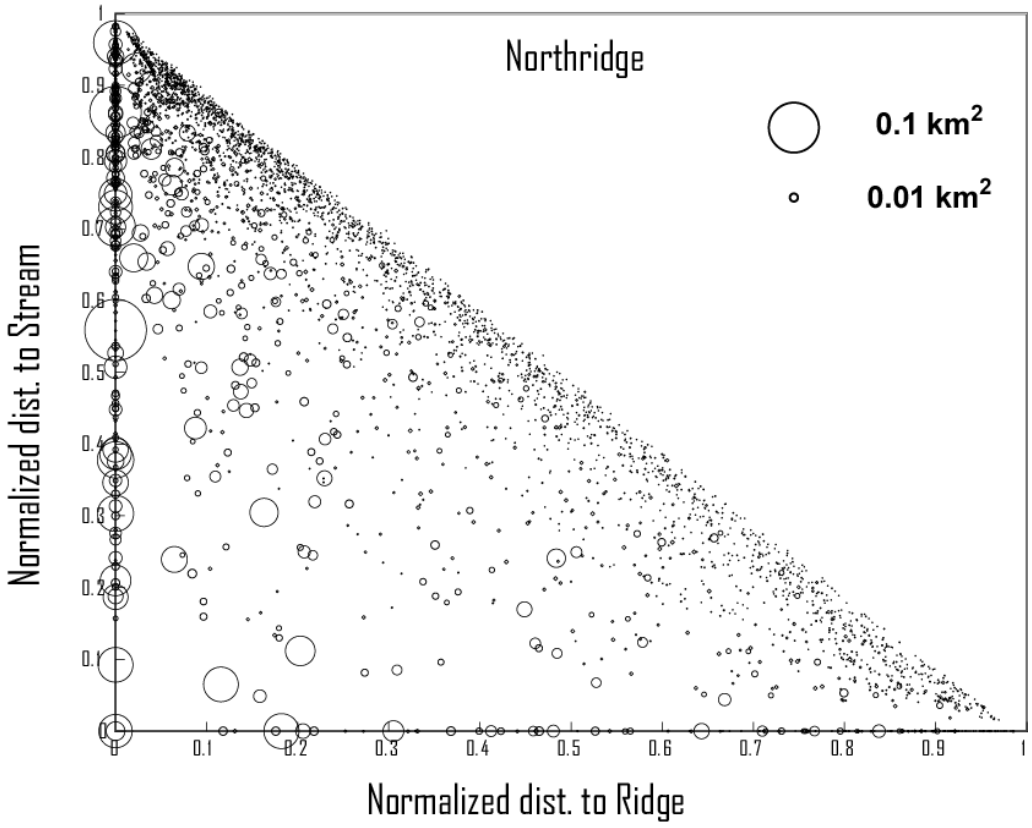
Lower quarter: 28%

Meunier et al., EPSL 2008

- Landslides evenly distributed across slopes
- Large landslides initiate at edges in topography

LOCATION OF LANDSLIDES ON SLOPES

Northridge, California
Earthquake Induced Landslides



- Landslides cluster on ridge crests
- Large landslides high on slopes

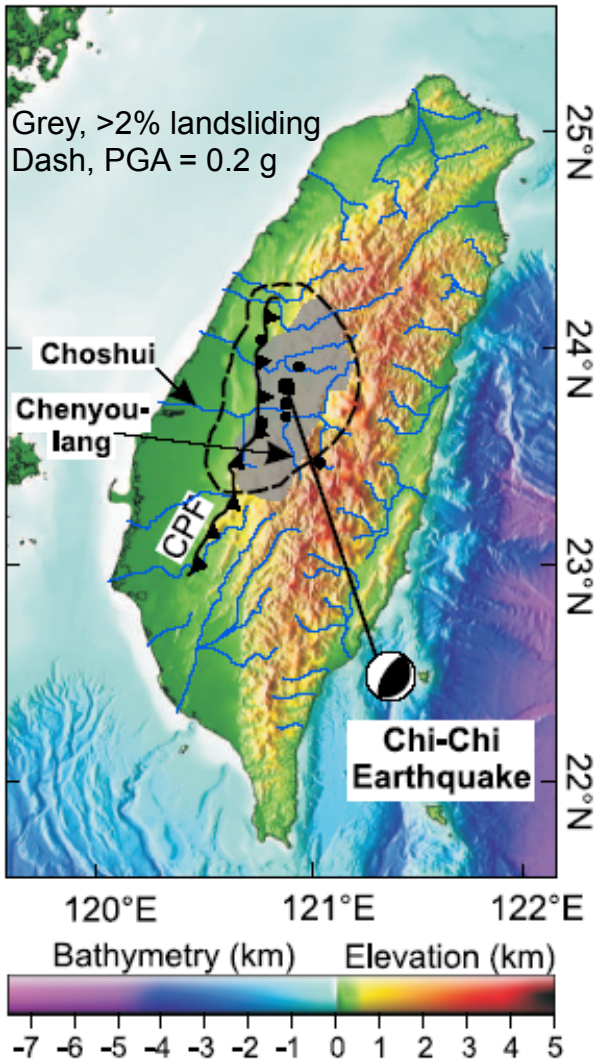
Landslide distribution:

Upper quarter: 56%

Lower quarter: 11%

Meunier et al., EPSL 2008

CHI-CHI, TAIWAN 1999



- M_w 7.6 earthquake; D = 8 km; 100 km long rupture
- Measured ground accelerations ~1 g; triggered >20,000 landslides
- Subsequent typhoons triggered >50,000 landslides

Dadson et al., Geology 2004.

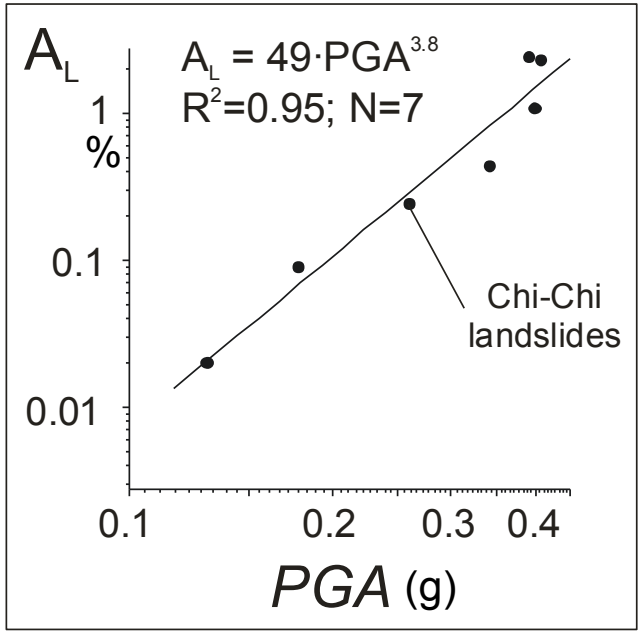
REGIONAL LANDSLIDE PATTERNS

Wave attenuation :

$$A_{(R)} \propto \frac{A_0}{R} e^{-\frac{\pi . f}{v}\frac{R}{Q}}$$

Geometric spreading

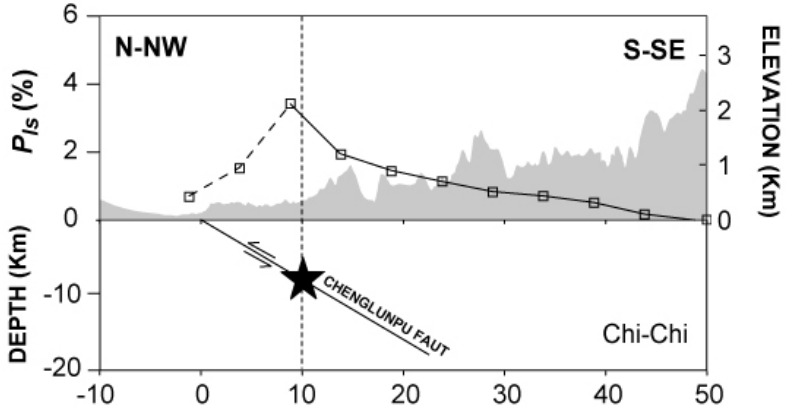
Quality factors :
Qi Anelasticity term
Qs Scattering term



General pattern:

Landslide density ~ peak ground acceleration

- Landslide intensity highest at epicentre, unless no topography.
- Exponential decay of landslide intensity away from epicentre.



Meunier et al., GRL 2007

POST-SEISMIC HILLSLOPE RESPONSE

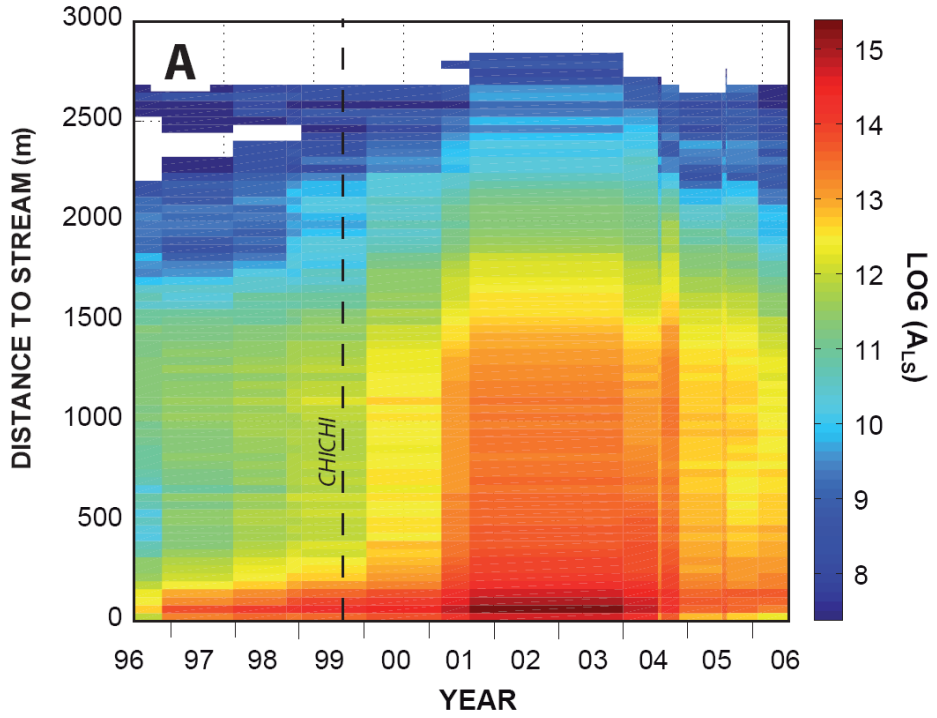
Landslide rate increased due to seismic weakening of substrate.

Weak materials removed during typhoons.

Typhoons trigger disproportionate number of landslides.

Rate of landsliding decreases.

Landsliding migrates down slope.



Chenyoulan River:

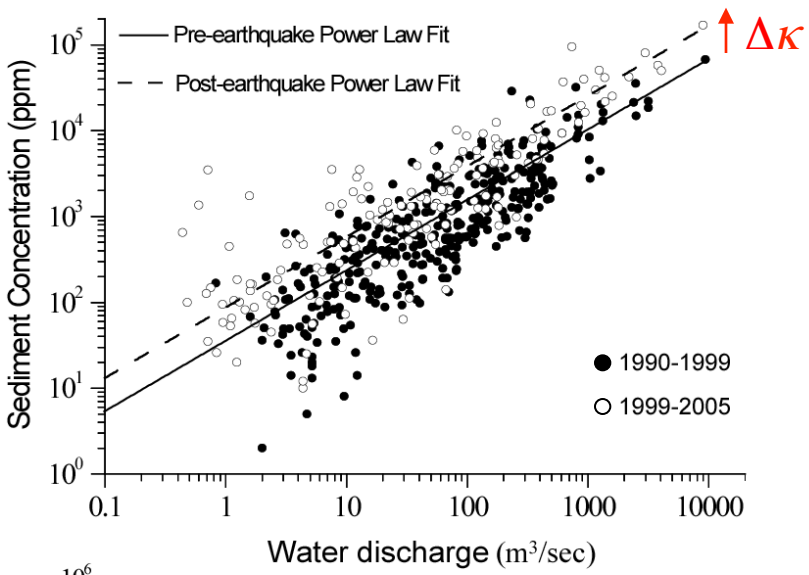
Before earthquake: 8,123 landslides (31.5 km^2), low on hillslopes.

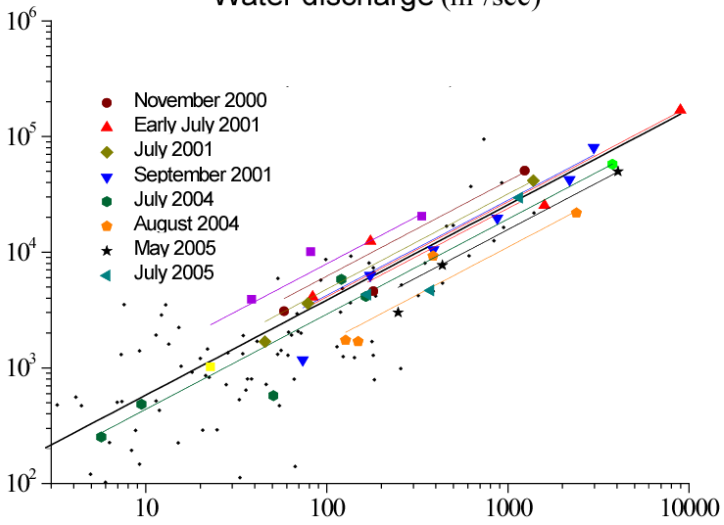
During earthquake: 3,800 landslides (16 km^2), topographic site effect.

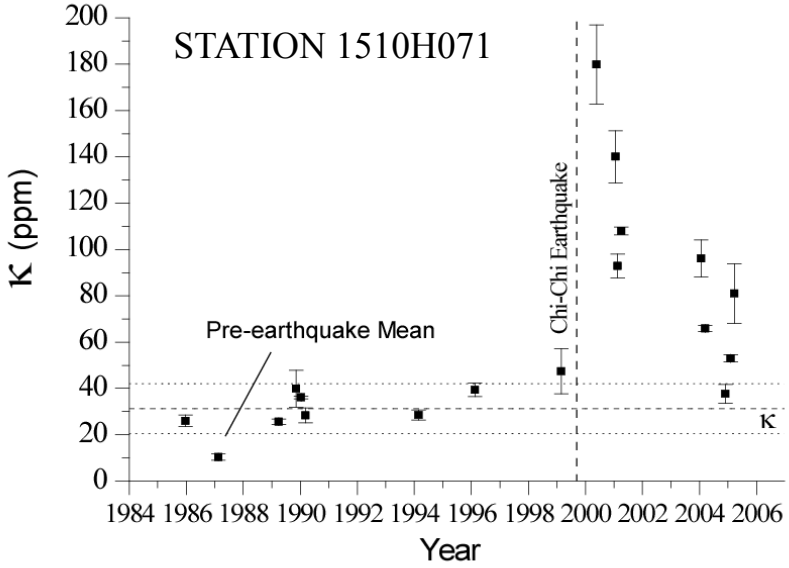
After earthquake: 48,370 landslides (221 km^2), co-seismic pattern.

Hovius et al., EPSL 2011

POST-SEISMIC FLUVIAL RESPONSE TIME







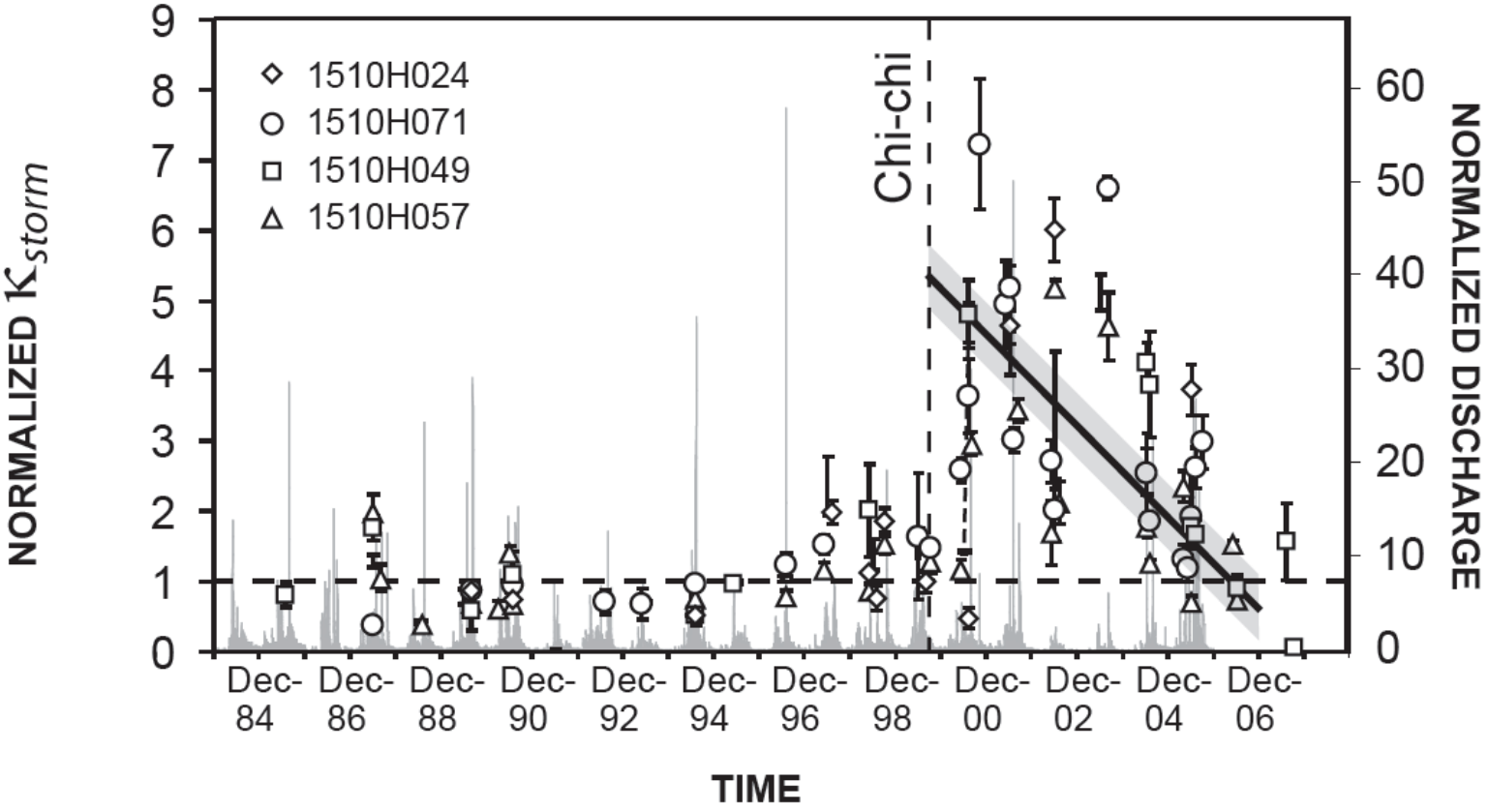
$$C = \kappa Q_w^{b}$$

κ is sediment concentration at unit water discharge.

$$\Delta\kappa = \kappa_{post} - \kappa_{pre}$$

Hovius et al., EPSL 2011

POST-SEISMIC RESPONSE TIME

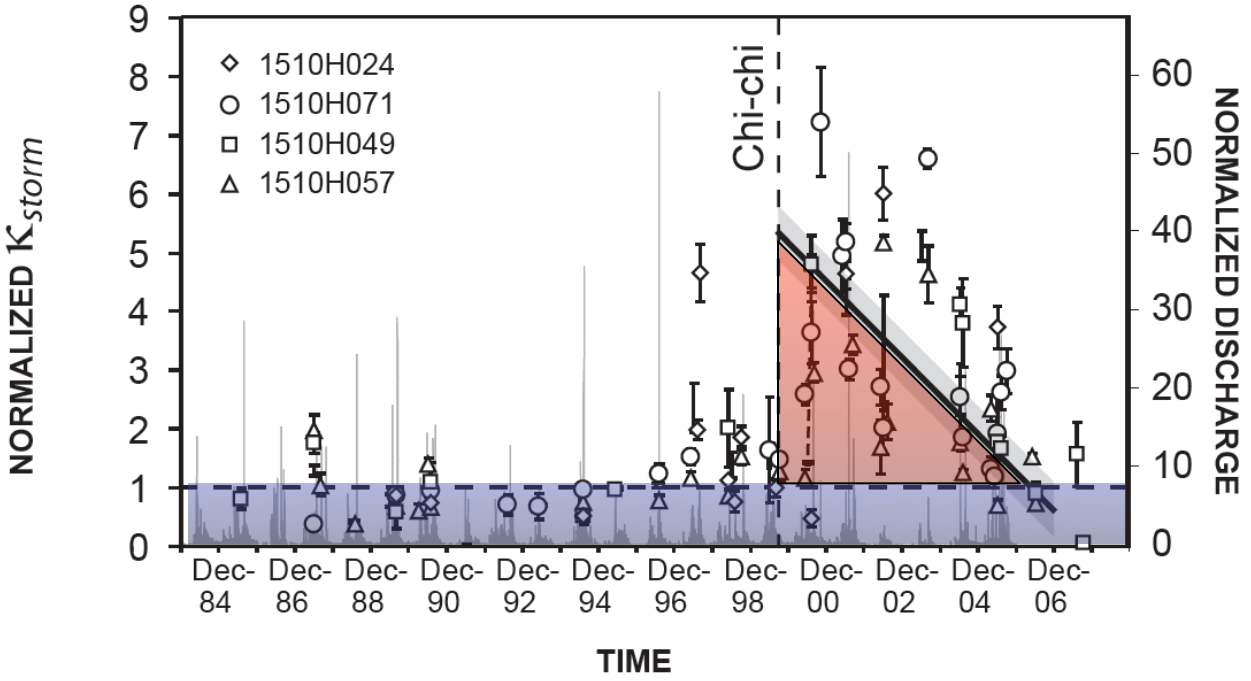


Fluvial response time: 6 ± 0.8 years (1σ).

Linear fit: R^2 = 0.54

Hovius et al., EPSL 2011

EXCESS SEDIMENT REMOVAL



At mountain front:

Excess suspended load - typhoon floods: 206 ± 50 Mt

other discharges: 34 ± 10 Mt

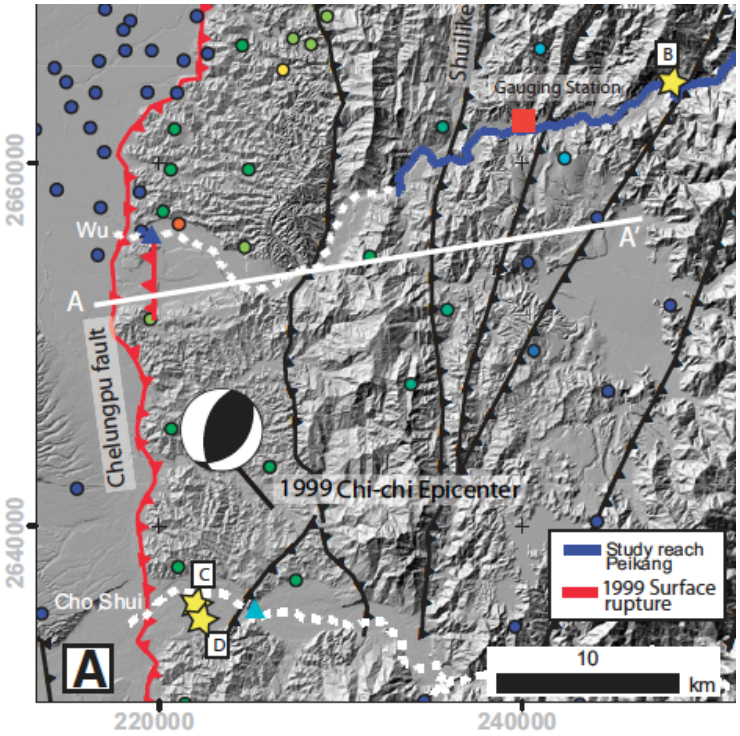
+ Bedload: 30% TOTAL excess: 320 ± 80 Mt

Expected total sediment transport: 520 ± 20 Mt

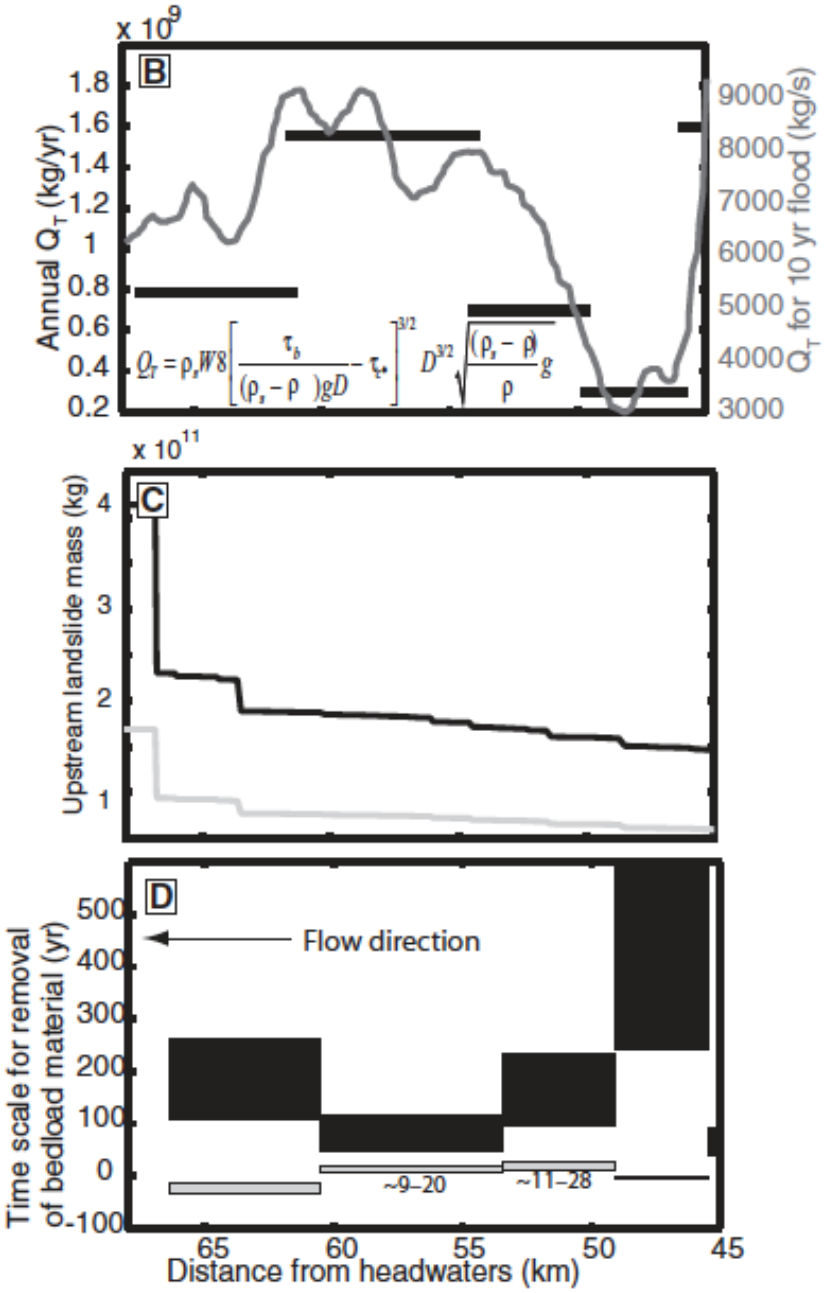
Hovius et al., EPSL 2011

BEDLOAD RESPONSE

Yanites et al., Geology 2010



Bedrock channels are over-loaded with landslide debris: Aggradation up to >10m. Removal 100-500 yr.

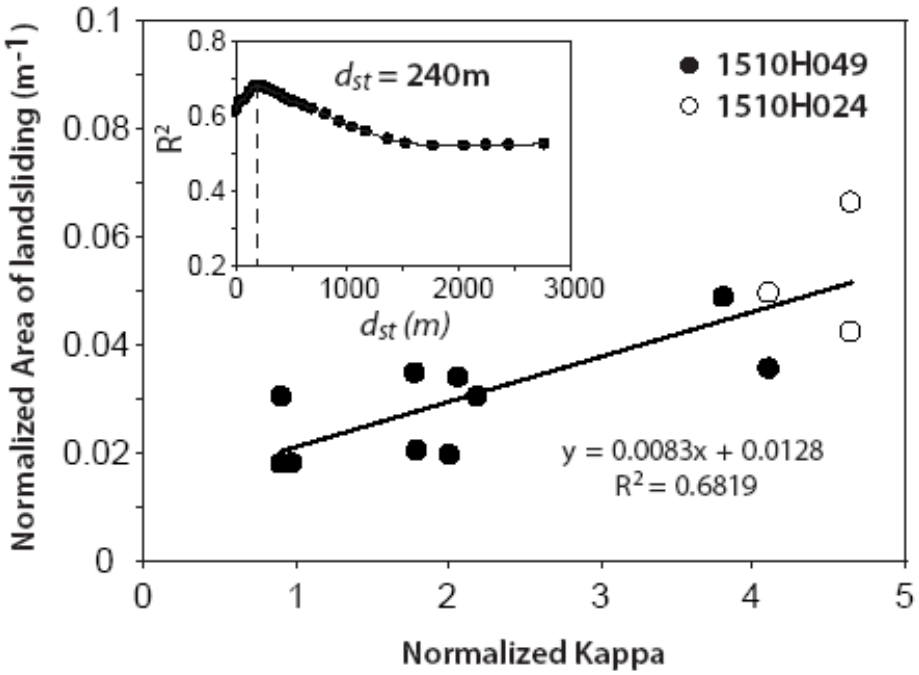


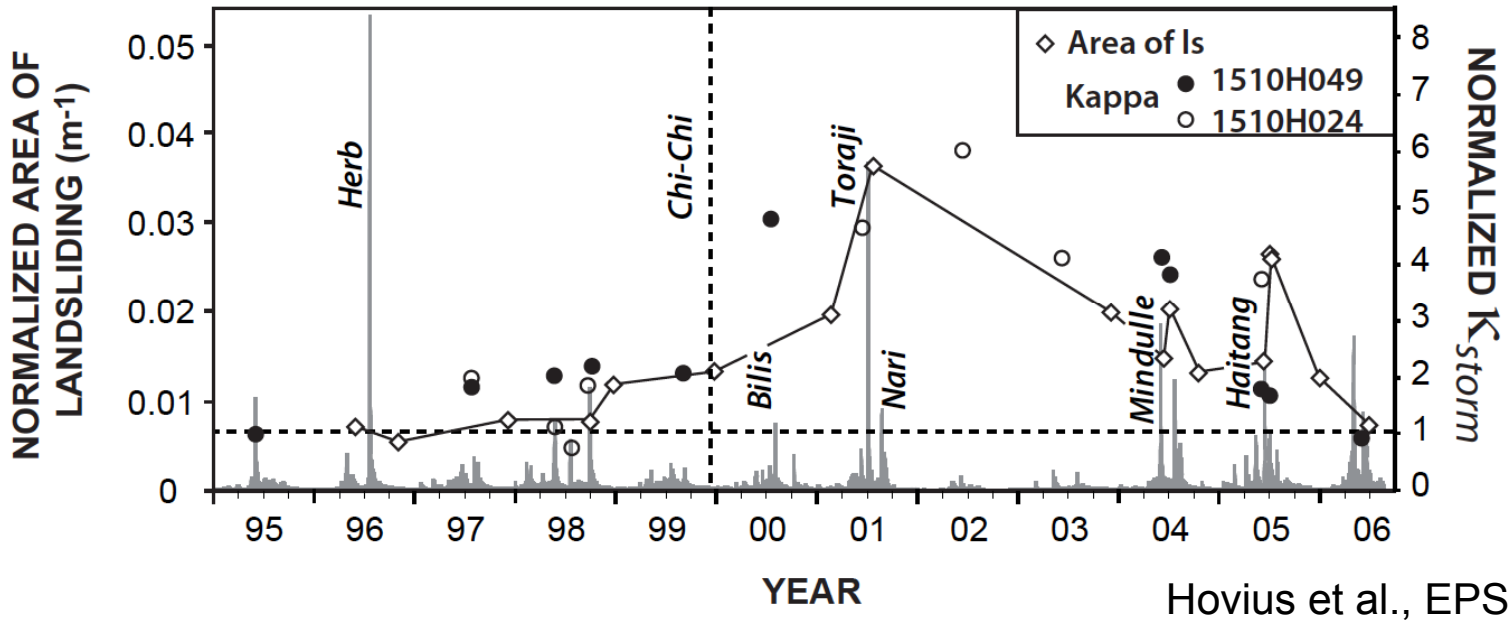
HILLSLOPE-CHANNEL COUPLING

Lower hillslopes and channels are effectively coupled.

Lengthscale: ~0.25 km.

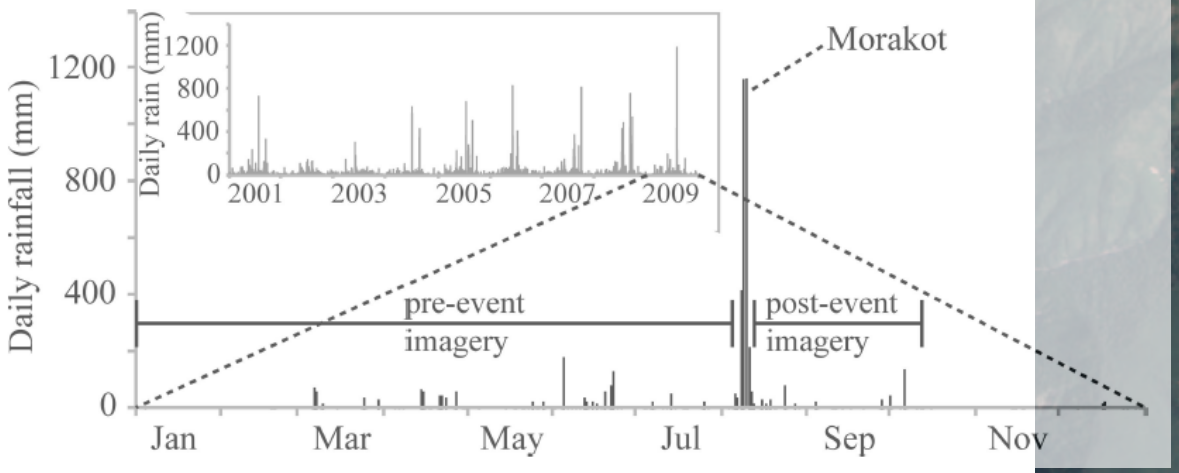
Fluvial response records landscape response.

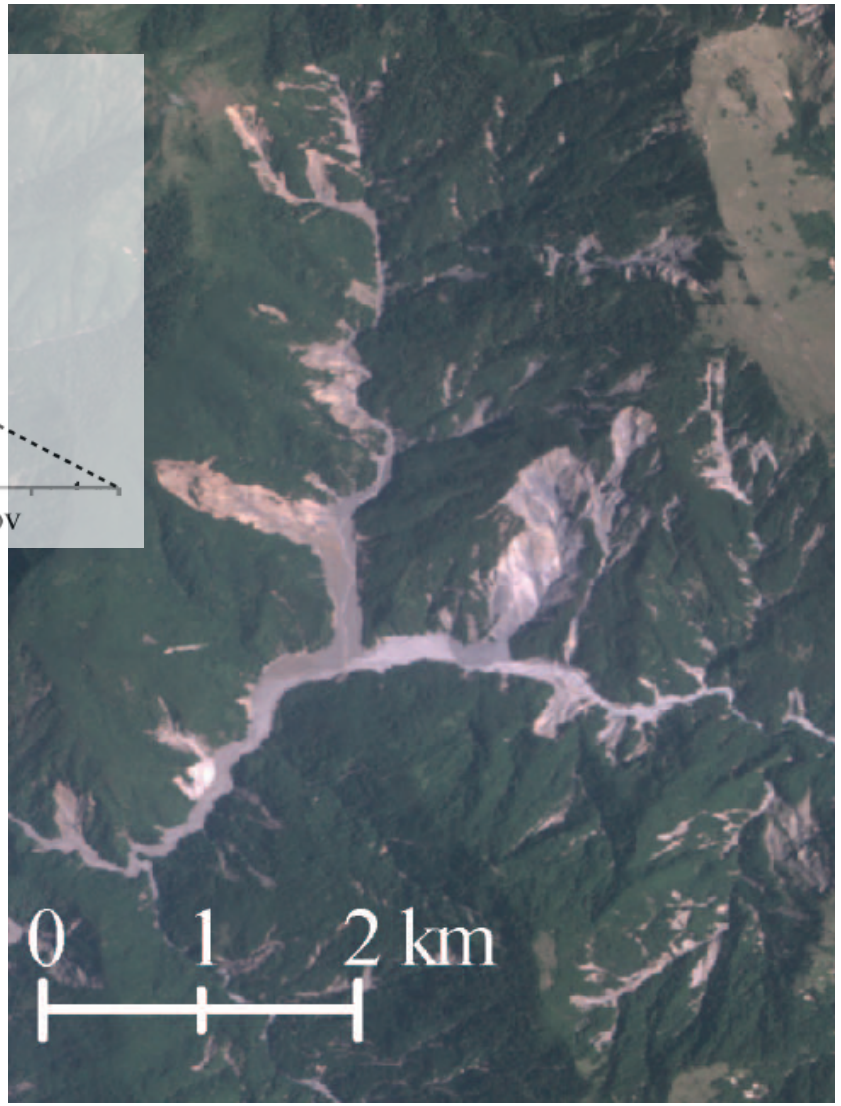




Hovius et al., EPSL 2011

HILLSLOPE-CHANNEL COUPLING





Typhoon Morakot, 2009:
Up to 3m precipitation in 3 days.

Landslide density >3%

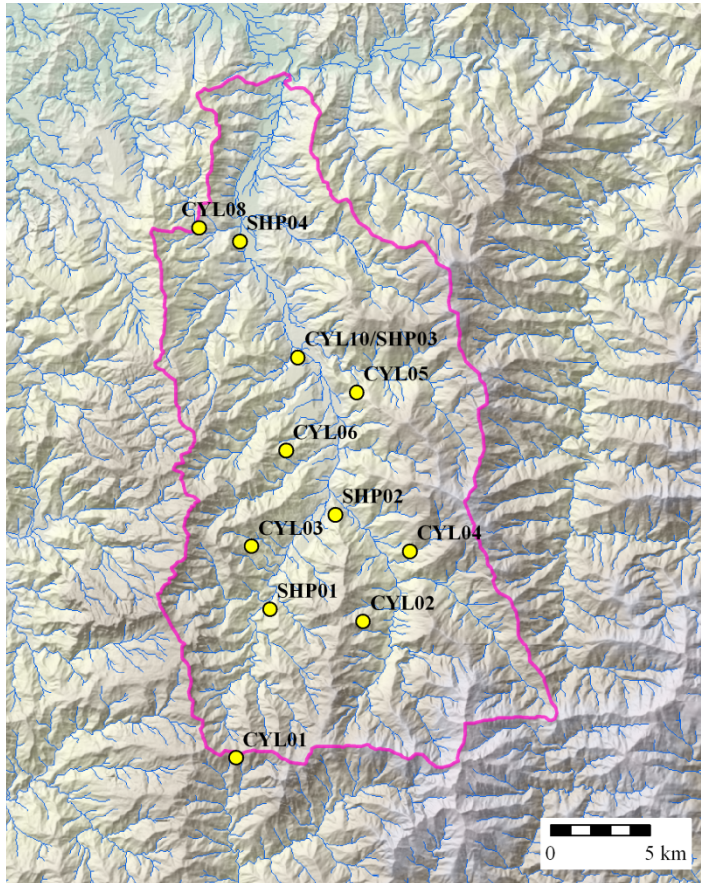
Hillslope-channel coupling
Up to 100%

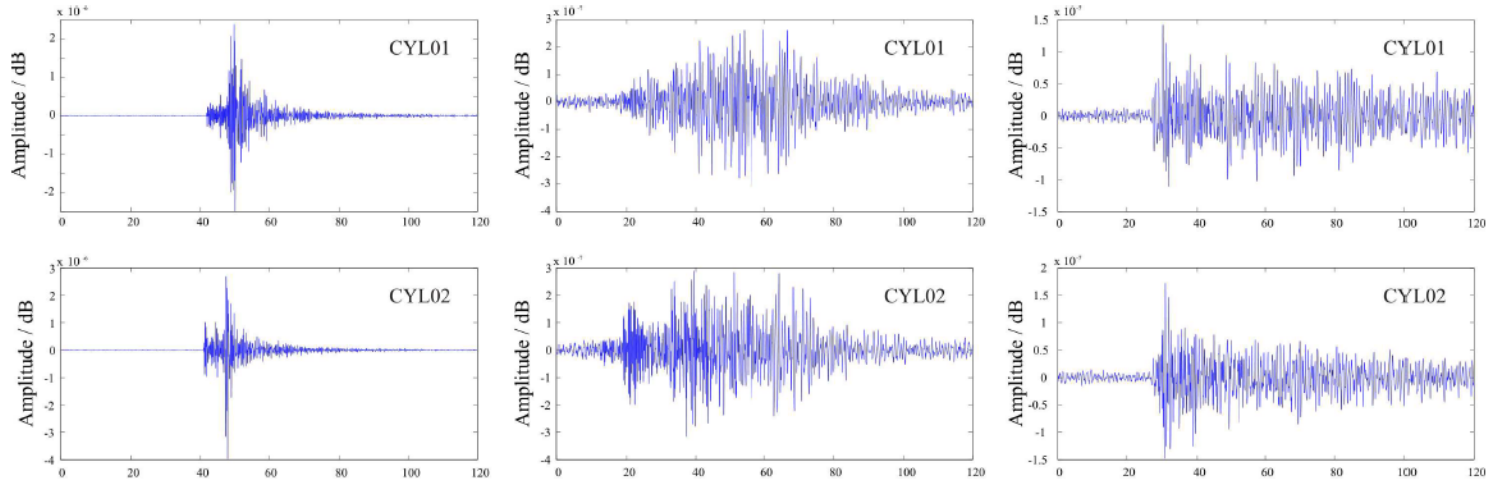
West et al., 2011

SEISMIC SIGNALS OF SURFACE PROCESSES

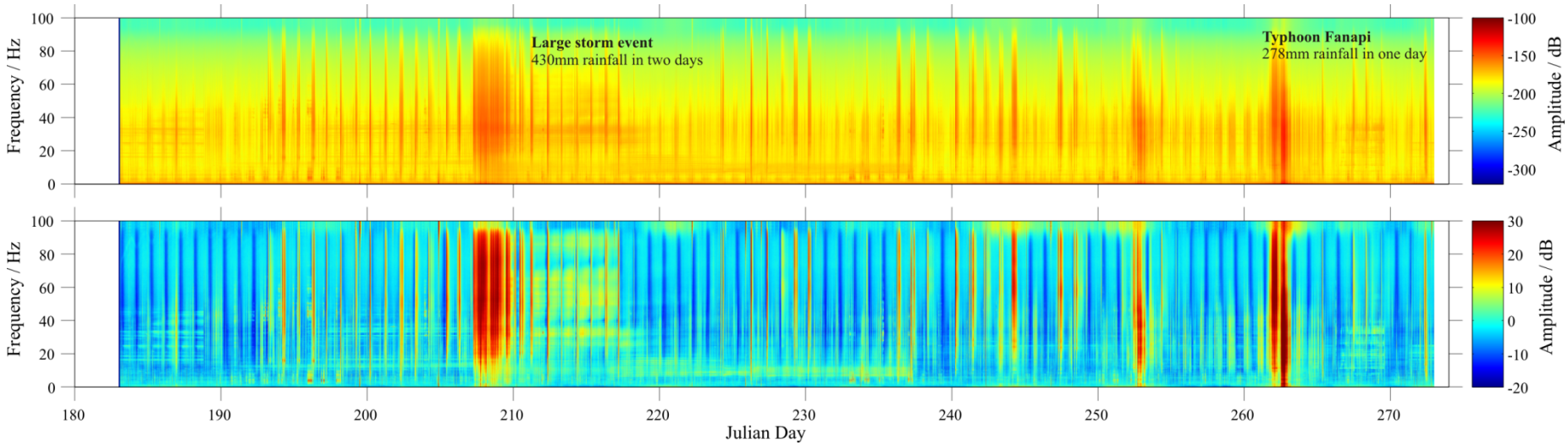
Geomorphological processes generate seismic signals, distinct from earthquakes, that can be used to determine the nature, location and timing of the event.

Development study:
Chenyuoluan Chi, Taiwan





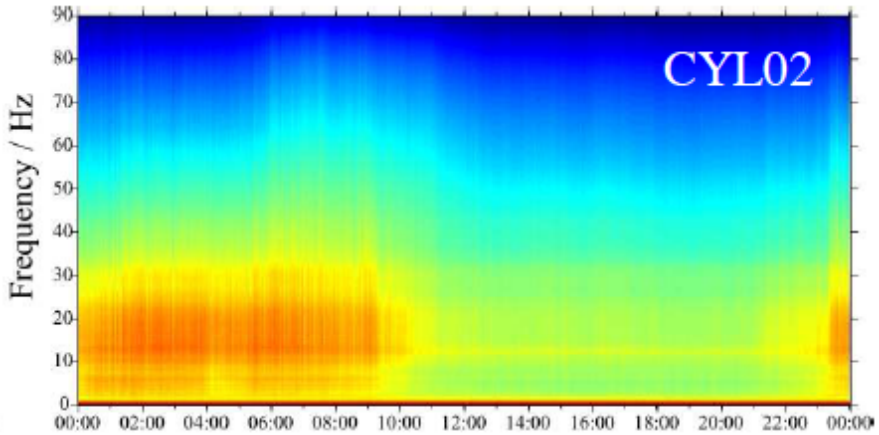
EROSION NOISE, TYPHOON SEASON 2010



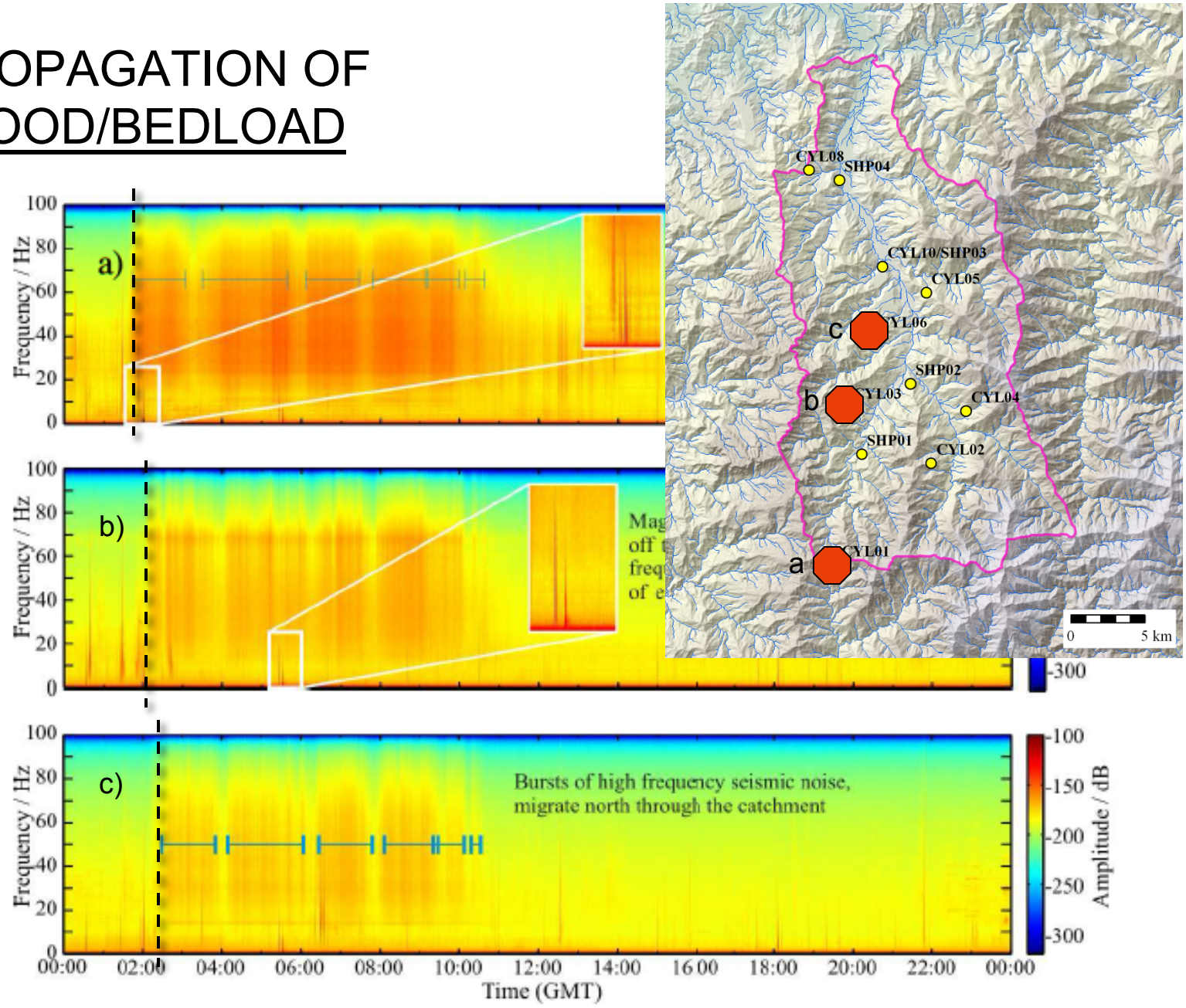
Record is combination of seismic, anthropogenic and geomorphic signals.

Average human activity removed.

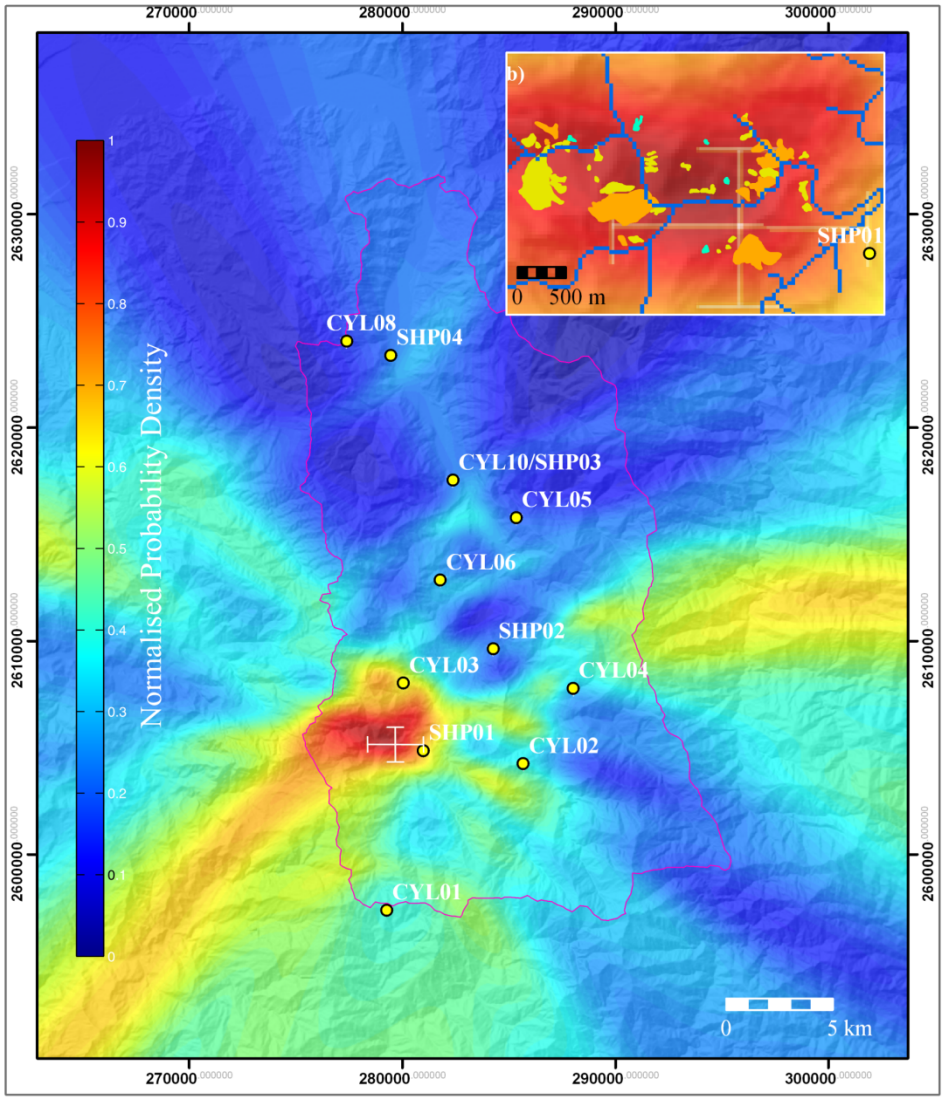
Earthquakes isolated

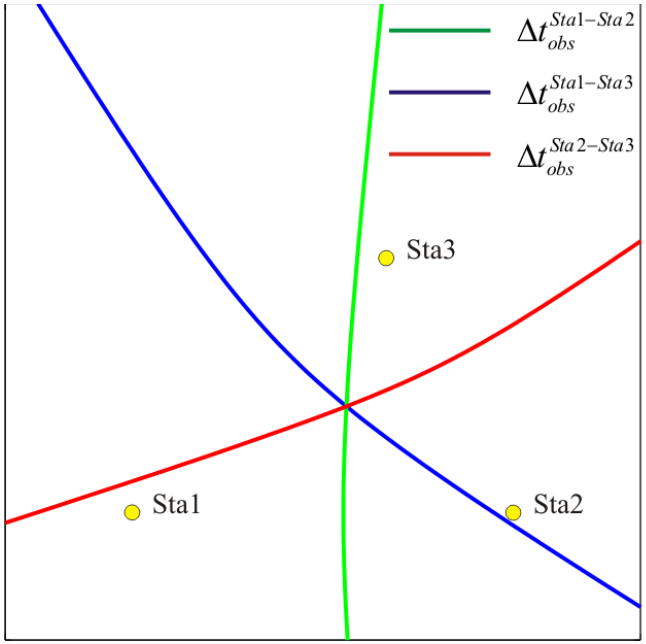


PROPAGATION OF FLOOD/BEDLOAD



LOCATION, TIMING OF GEOMORPHIC EVENTS





Fresh landslide/debris flow

Existing geomorphic structure, active

Existing geomorphic structure, inactive at image resolution