

# Stability of the gravel-sand transition of the Ganga Plains recorded in Siwalik stratigraphy; implications for extreme floods

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@laura\_quick



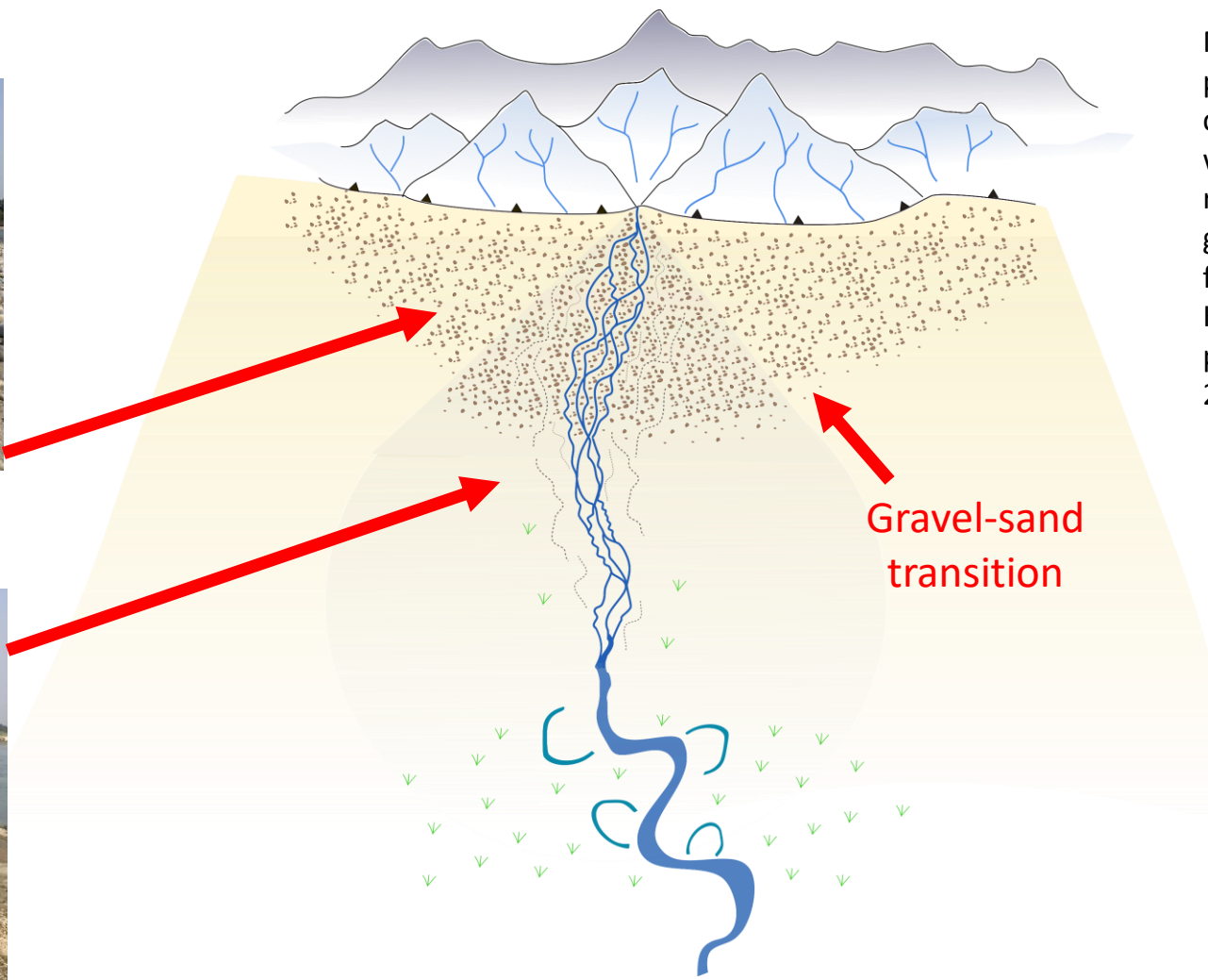
# Gravel-sand transitions

The gravel-sand transition is a geomorphic feature observed in all mountain-fed and smaller foothill-fed Himalayan rivers. It is characterised by an abrupt downstream reduction in grain size from gravel to sand and is often associated with a break in channel gradient, which suggests it has been a relatively stable feature over the last few thousands of years (Dingle et al., 2016). In the Indo-Gangetic Plain the gravel-sand transition ranges from 10 to 30 km downstream from the mountain front (Dubille and Lavé, 2015; Dingle et al., 2016).

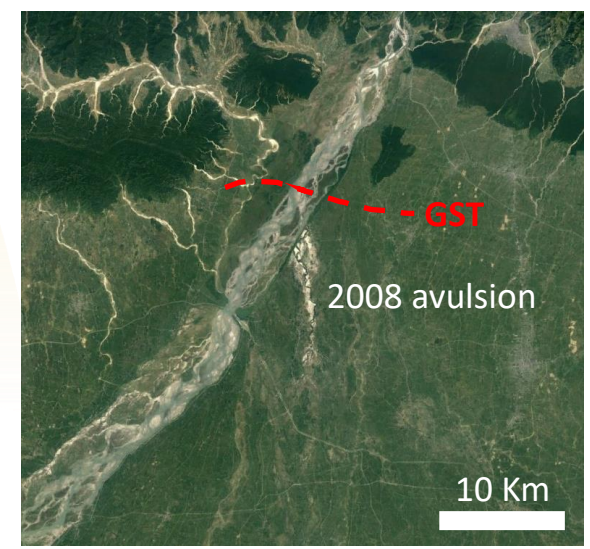
GRAVEL BED



SAND BED

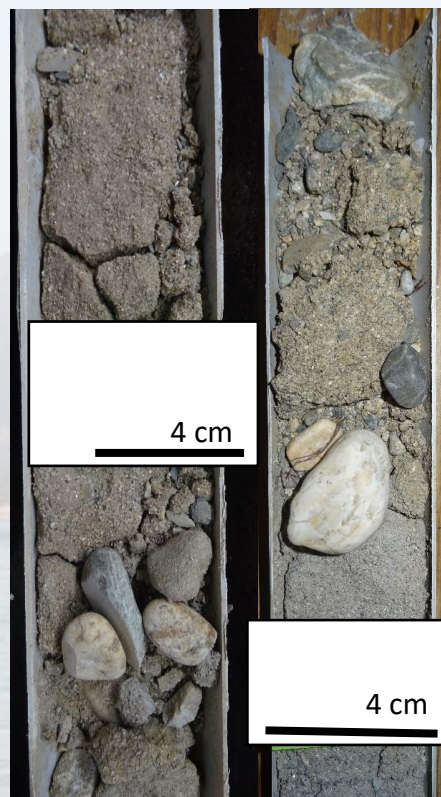
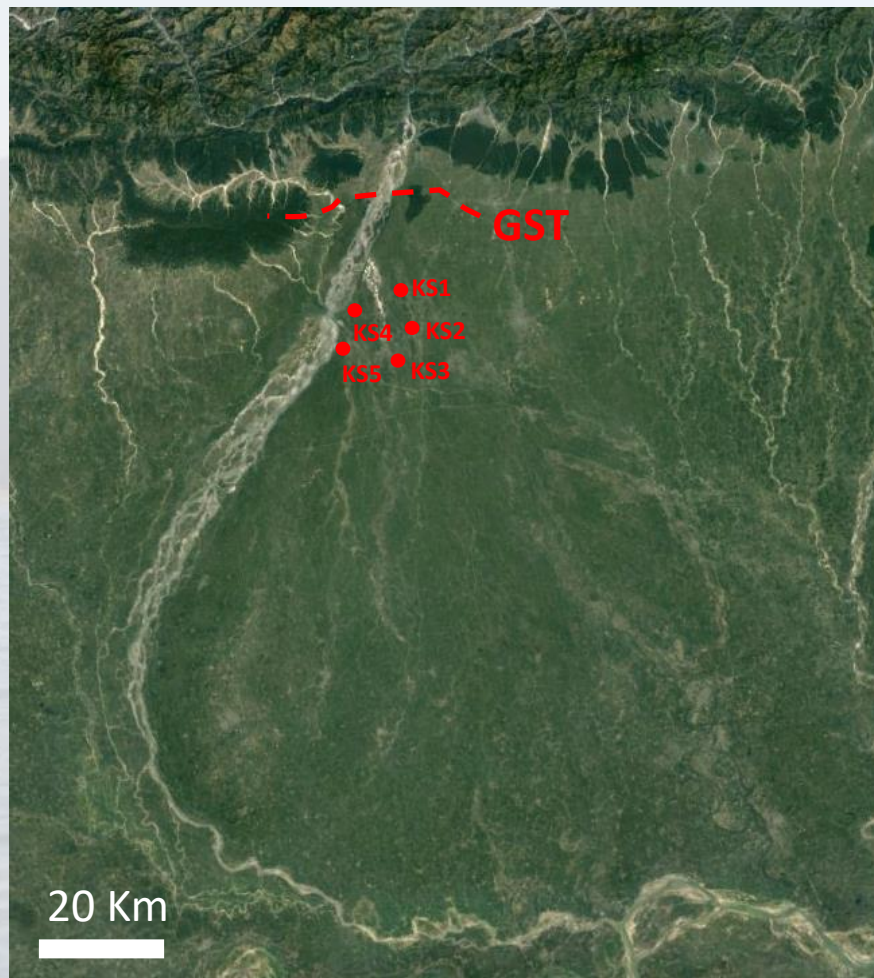


Many rivers of the Indo-Gangetic Plain are prone to abrupt switching of channel courses causing devastating floods over some of the world's poorest and most densely populated regions. Recent work has identified the gravel-sand transition as an avulsion node for the channels; notably the avulsion of the Kosi River in 2008 occurred in close proximity to its gravel-sand transition (Sinha, 2009).

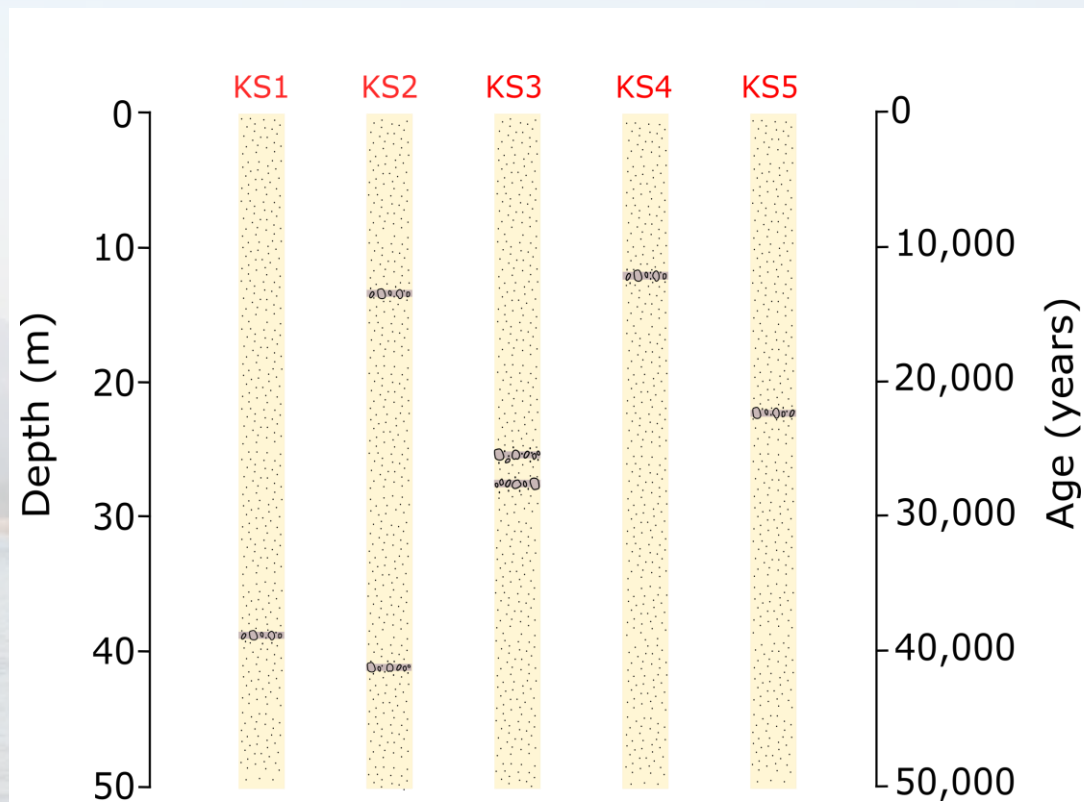


# How stable is the gravel-sand transition?

Subsurface data from the Kosi mega-fan in eastern Nepal reveals 10-40 Ka gravels located ~30 km downstream from the current gravel-sand transition. The implication is that this key geomorphic boundary can periodically prograde considerably further into the Ganga Plains.



Core ~40 km from mountain front



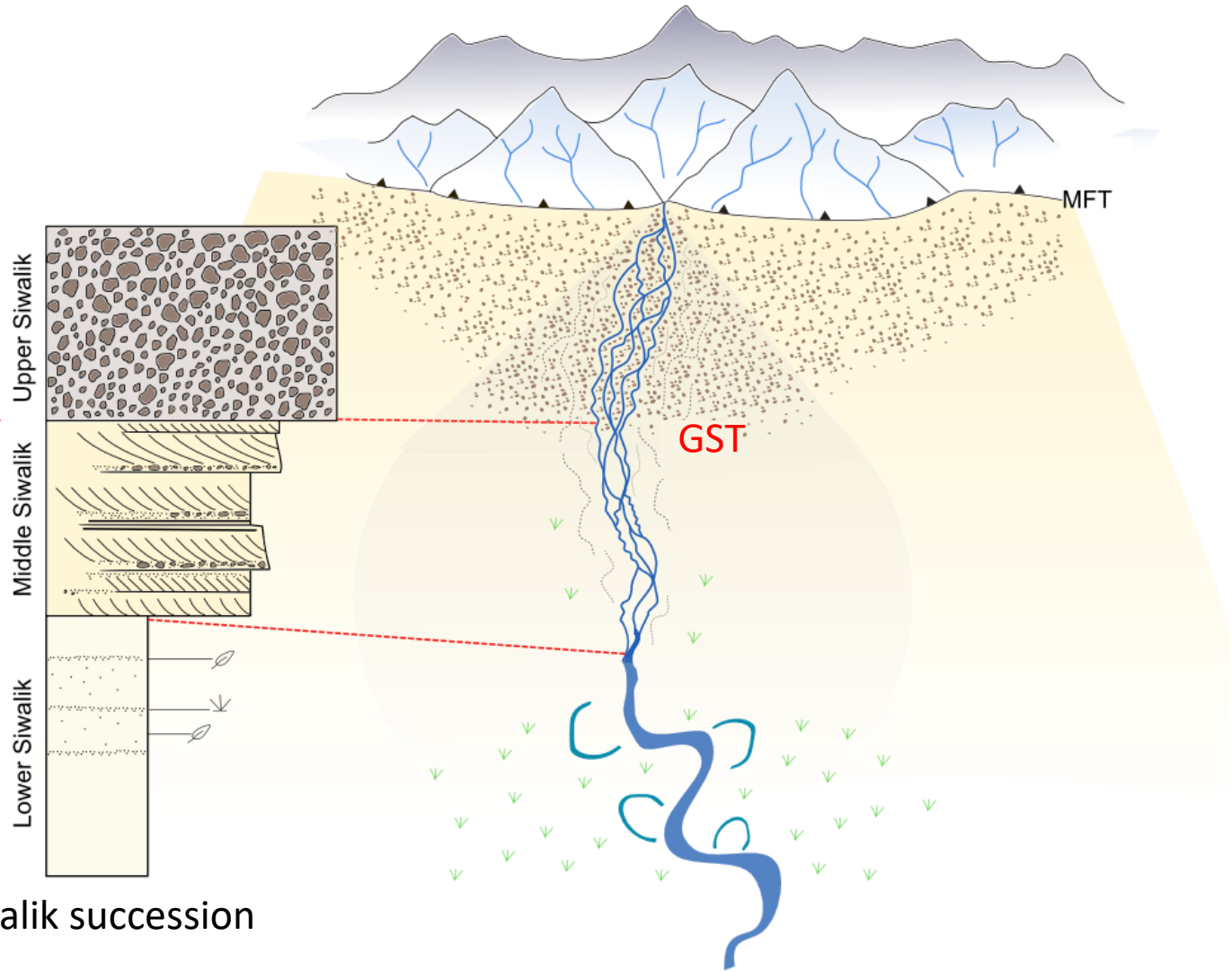
Rare punctuated gravel pulses have been observed in the Kosi mega fan core (Sinha et al., 2014).

# Long-term record of gravel-sand transition mobility



A longer term record ( $>10^6$  yrs) of gravel-sand transition mobility is recorded in the stratigraphic record of the Miocene fluvial Siwalik Group, which is exhumed as a series of thrust fault blocks at the Himalayan mountain front. The Siwalik Group is formed of fluvial sediment which were deposited by rivers similar to those found in the Indo-Gangetic Plain today.

Gravel-sand transition

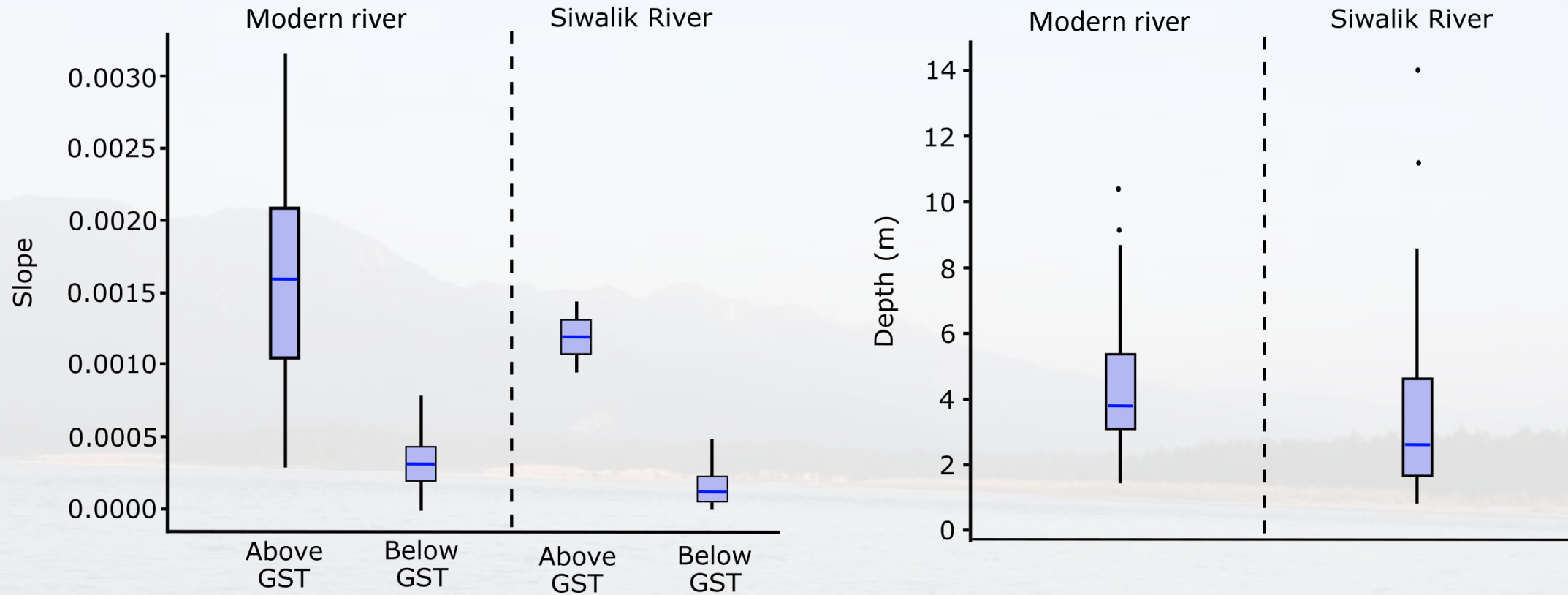


Siwalik succession

The Siwalik succession is divided into three lithofacies units that coarsens upwards from siltstones and sandstones to coarse conglomerates. The units are termed the Lower, Middle and Upper Siwaliks respectively and reflect the current depositional environments found on the Ganga Plains.

The gravel-sand transition is recorded as the contact between the Middle and Upper Siwaliks

# Can we compare ancient and modern river systems of the Indo-Gangetic plain?



Based on sedimentological analysis we believe that that ancient Siwalik rivers have comparable channel slope and channel depth to the modern rivers of the Indo-Gangetic Plain.

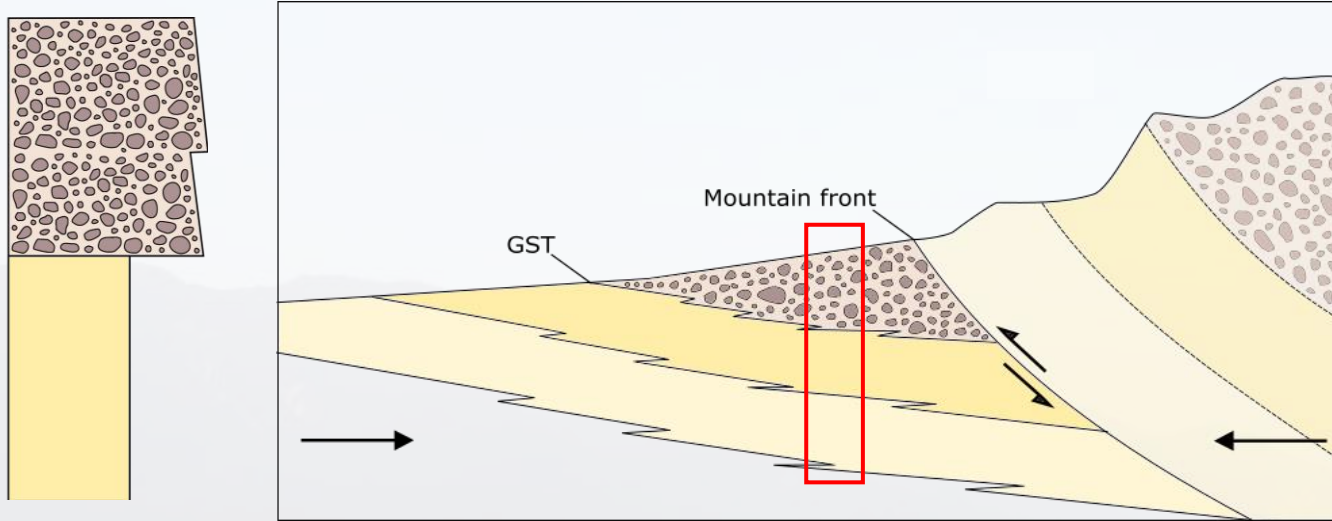
\* modern channel slope is extracted from a SRTM DEM. Ancient Siwalik slope is calculated using sediment  $D_{50}$ , and stratigraphic bed thickness (Paola and Mohrig, 1996; Ganti, 2019)

\*\* modern channel depth has been extracted from published ADCP cross sections from Ganga Plain rivers (Sonkar et al, 2019; Dingle et al, 2020). Ancient Siwalik channel depth is estimated from stratigraphic bed thickness.

# How can Siwalik stratigraphy record the stability of the gravel-sand transition?

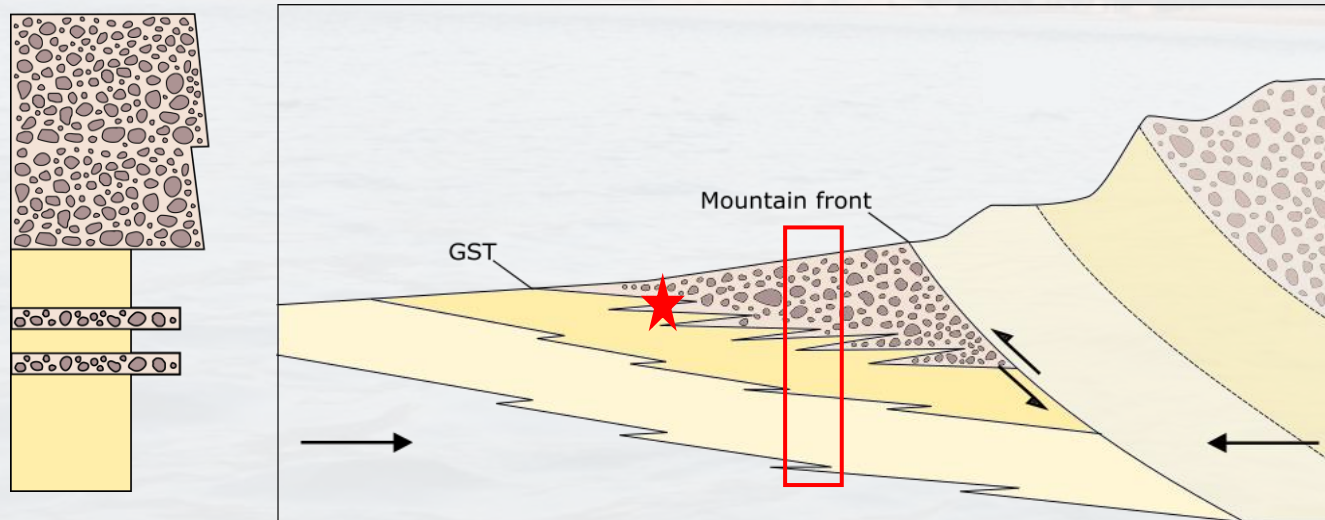


## Stable gravel-sand transition



A stable gravel-sand transition would appear as a sharp contact between the Middle and Upper Siwaliks

## Mobile gravel-sand transition



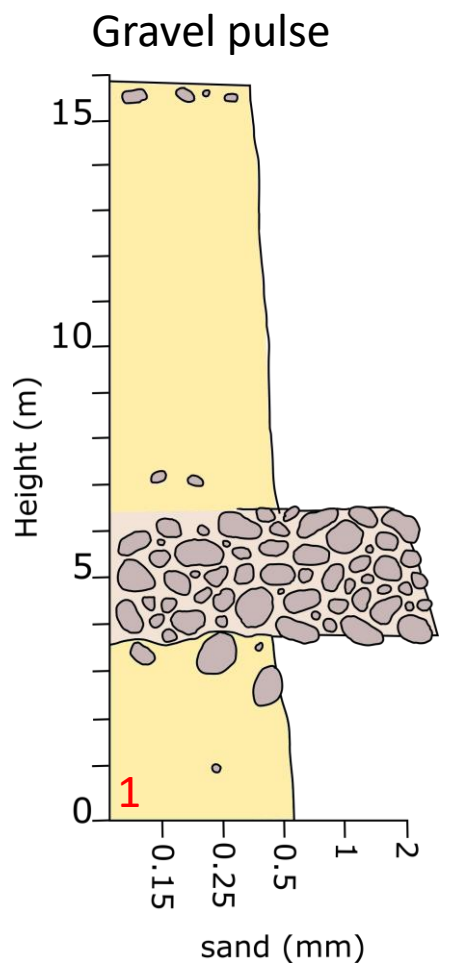
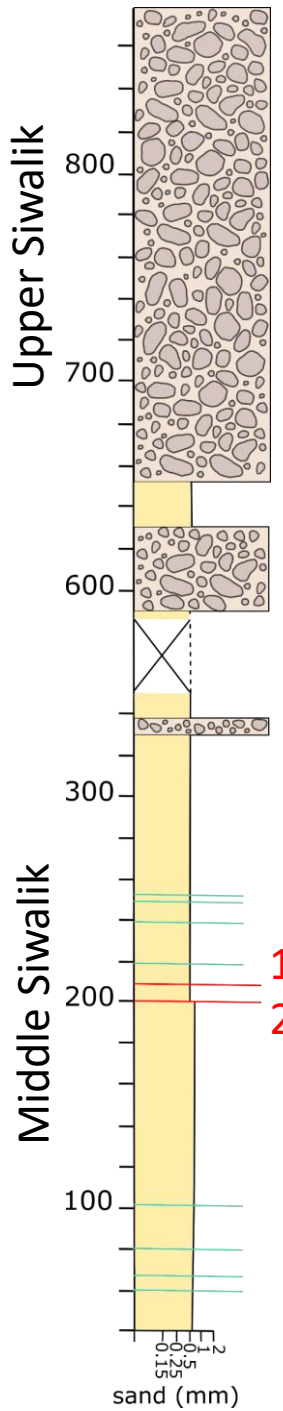
A mobile gravel-sand transition would record gravel pulses below the Middle to Upper Siwalik contact

★ Punctuated gravel pulses

# How are gravel pulses recorded in the Siwalik rock record?

A Siwalik section in Dehradun (northwest India) was logged to better understand the mobility of the gravel-sand transition through time. Two significant gravel pulses have been identified below the Middle – Upper Siwalik contact (red lines on summary log).

First order calculations using convergent velocities, stratigraphic thickness and sediment accumulation rates suggest that these gravel pulses likely existed between 7 – 26 km in front of the gravel-sand transition.



Example of thick gravel pulse (~ 2m gravel with 9m of sand on top - see log left) with an erosive base.  $D_{50}$  grain size of the two gravel pulses are 52 mm and 45 mm.



Example of thin gravel layer with an erosive base (blue lines on summary log). These thin gravel layers are similar to those found in the Kosi mega fan core.

## What sort of event can push the gravel pulses beyond the gravel-sand transition?

Significant gravel pulses have been identified directly below the Middle to Upper Siwalik contact which suggest that the gravel-sand transition is indeed mobile and can episodically prograde far into the plains. However, what sort of event could push the gravel pulses up to 27 km downstream of the gravel-sand transition?

Using the Meyer-Peter-Muller equation:

Example event in geological record:

River depth = 11 m (2 m gravel below 9 m sand)

River width = 350 m

$D_{50}$  = 45 mm

$$q_b = 8 \sqrt{(s - 1) g d_{50}^3 (\theta - \theta_c)^{3/2}}$$

Using traditional bedload transport approach, such as the MPM equation, the threshold of motion is estimated to occur at velocity,  $u \geq \sim 3$  m/s, or a discharge  $\sim 11,500$  m<sup>3</sup>/s. At this rate, it would take  $\sim 1$  year of a sustained discharge to transport the gravel 10 km downstream of the GST. If the velocity increased to 7 m/s, for example, representing a discharge of 26 000 m<sup>3</sup>/s, this time would reduce to 3.5 days.

Since 1960, the biggest discharge in the Karnali river, Nepal's second largest river, was recorded in the 2014 flood, with a peak discharge  $\sim 21,000$  m<sup>3</sup>/s lasting 4-5 hours. Clearly the 3.5 day flood from the above calculation far exceeds the duration of recent big flood events recorded in Himalayan rivers.

**So what cascade of events could have caused these gravel pulses?**



# Ongoing work

- How do hyper-concentrated water-sediment flows affect the rate of bedload transport in extreme events?
- Use Modified bedload transport equations which account for unsteady flows of extreme events (e.g. Cao et al, 2011).
- Numerical modelling of cascade events which combine increases in sediment load (e.g. landslides) with extreme discharge events.
- Finally, uncertainty analysis of extreme events which could produce gravel pulses in the Siwalik rock record.

# Concluding Remarks

- Miocene rivers recorded in the Siwalik rock record have similar characteristics to those found in the Indo-Gangetic Plain today. This allows us to use the Siwalik rock record to provide examples of possible future extreme events in the region.
- Using the stratigraphic record we have identified gravel pulses which episodically prograde far into the plains (up to 27 km in front of the gravel-sand transition).
- Preliminary calculations suggest that a big event is needed to push gravels far beyond the gravel-sand transition.