Seismic Characteristics of the Transition from Debris Flow to Hyperconcentrated Flow, Tahoma Creek, Washington

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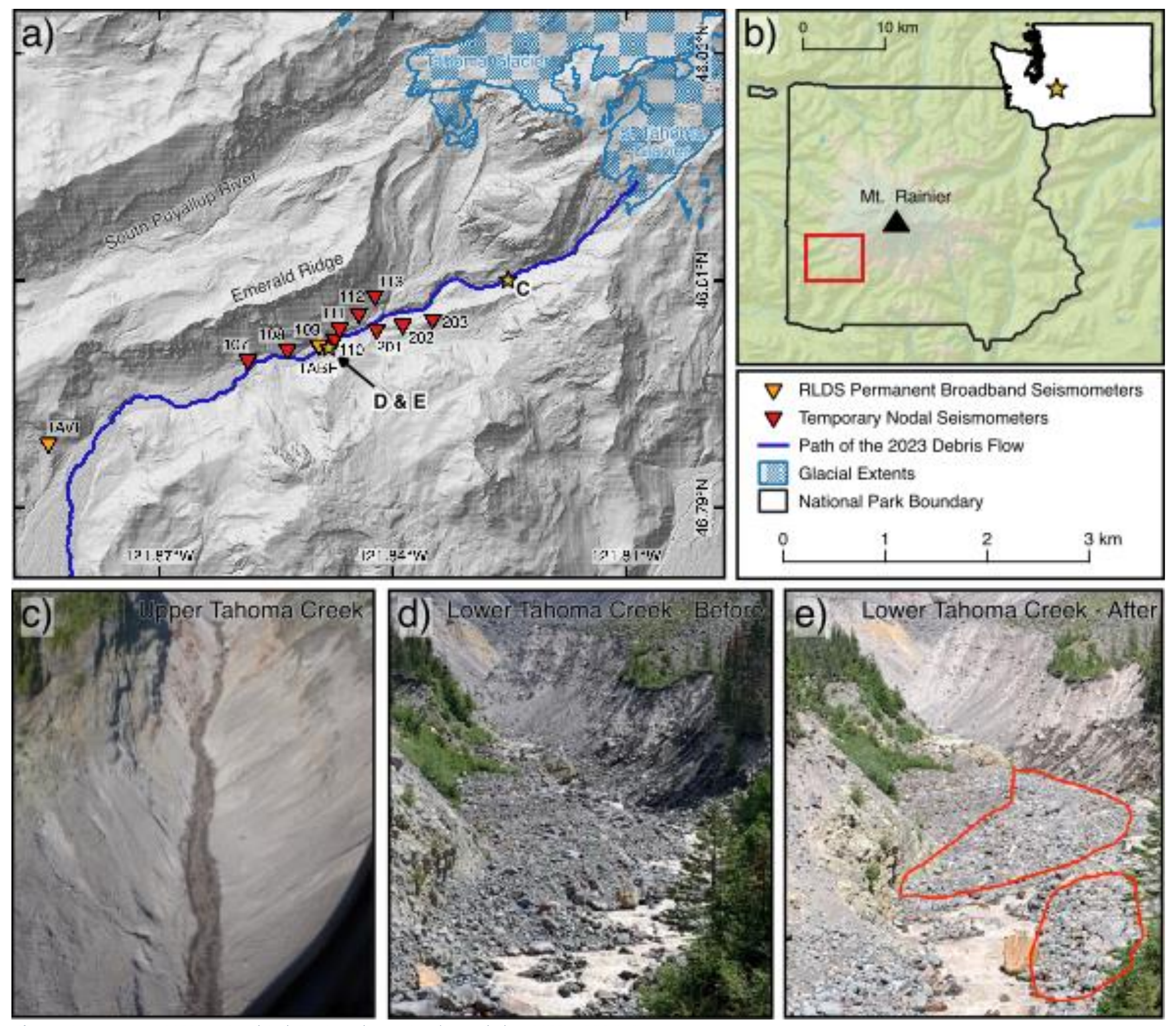
Study Area: Debris Flows in Tahoma Creek

Tahoma Creek (a) sits on the SW flank of Mount Rainier (b) in Washington, USA. Over 60 documented debris flows have occurred in Tahoma Creek since 1926. This debris flow originated from a suspected glacial outburst on South Tahoma Glacier on August 15, 2023.

In the upper stretches of the Tahoma Creek channel (c), this event acted as a classic debris flow. In the mid and lower stretches of the channel (d & e), we see evidence of large deposits, indicating that the flow transitioned to a hyperconcentrated flow as the channel widened from 10 $\pm$ 1 m to 48 $\pm$ 4 m.



Photos: Scott Beason, 2023, National Park Service; Alex Iezzi and Wes Thelen, 2023, USGS CVO

Debris Flows vs. Hyperconcentrated Flows

Debris flows and hyperconcentrated flows exist on a spectrum of sedimented flow types, although the transition between them is not always clear.

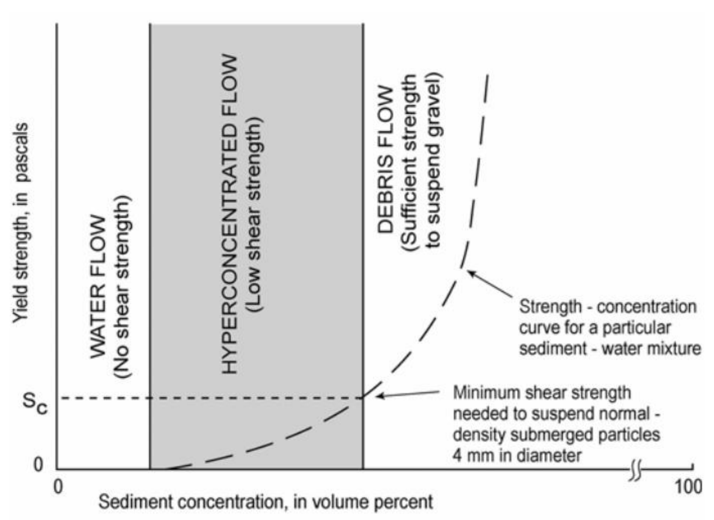


Figure (above) from: Pierson, T. C., 2005, Hyperconcentrated flow – transitional process between water flow and debris flow, in Jakob, M. & O. Hungr, *Debris-flow Hazards and Related Phenomena,* Praxis Springer, Berlin.

Sediment Concentration by Volume
The concentration of sediment by volume is the primary classification tool for distinguishing hyperconcentrated flows (20-60%) from debris flows (>60%).[1,2]

Rheological Criteria
Both flow types are non-Newtonian. Debris flows have sufficient yield strength for gravel-sized particles to be suspended in the mixture.[1,3,4]

Flow Deposits
Debris flow deposits are generally poorly sorted with inverse grading. Hyperconcentrated flows, have normal grading and are stratified.[5]

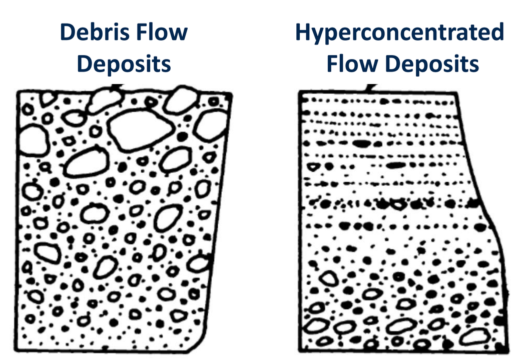
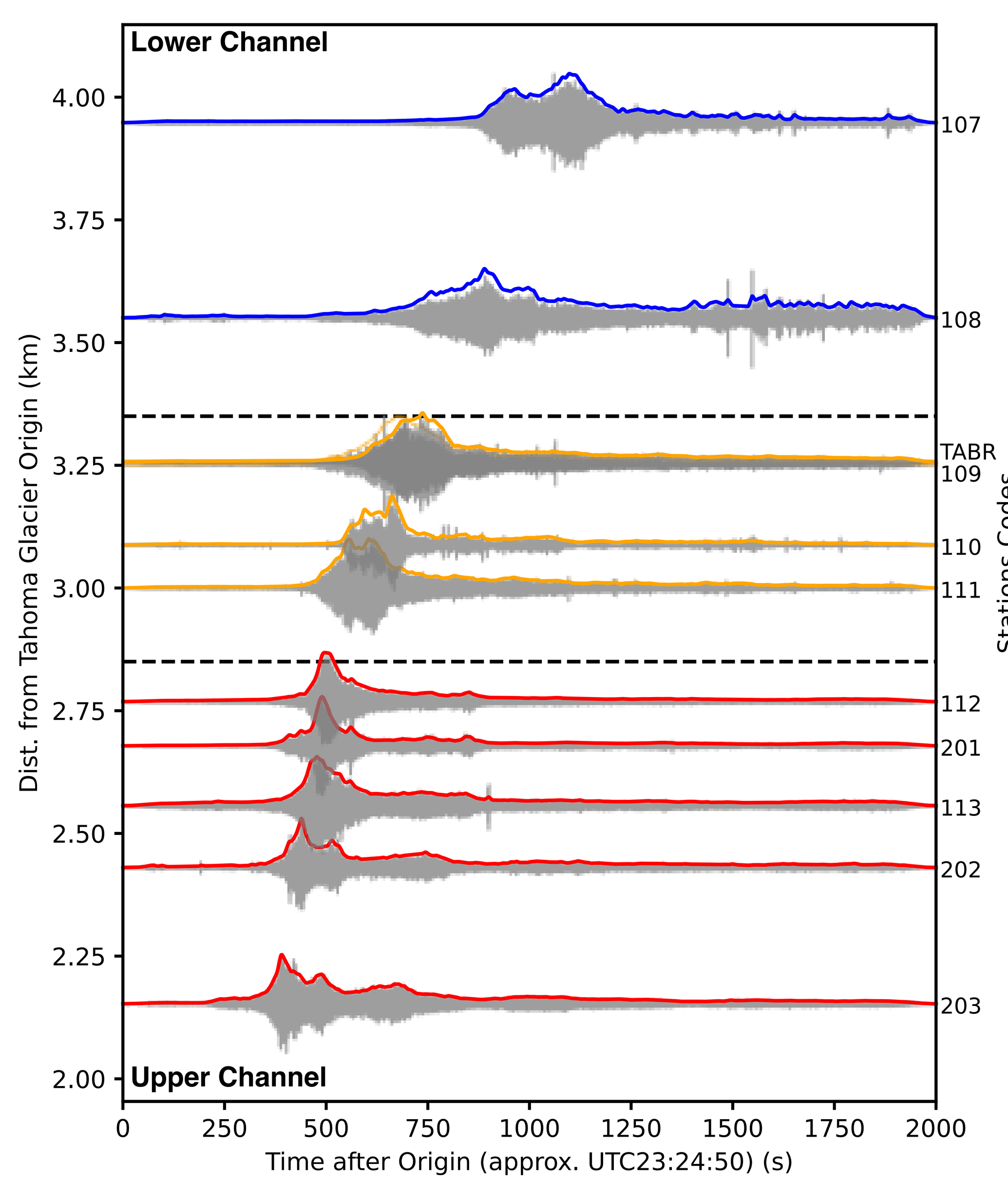
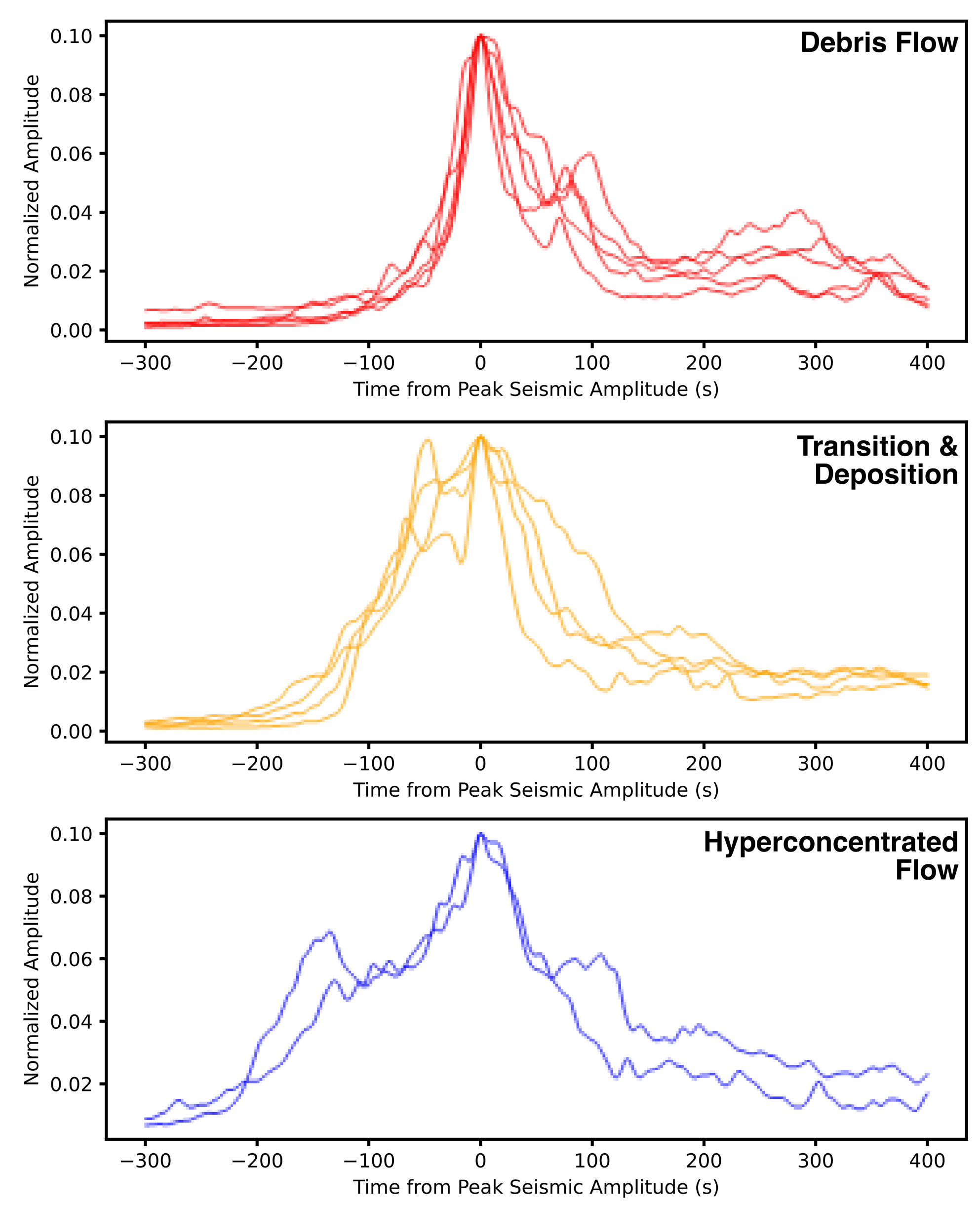


Figure (right) from: Sohn, Y.K., Rhee, C.W., and B. C. Kim, 1999, Debris Flow and Hyperconcentrated Flood-Flow Deposits [sic] Central Korea, *Journal of Geology*, 107, 1, 111-132.

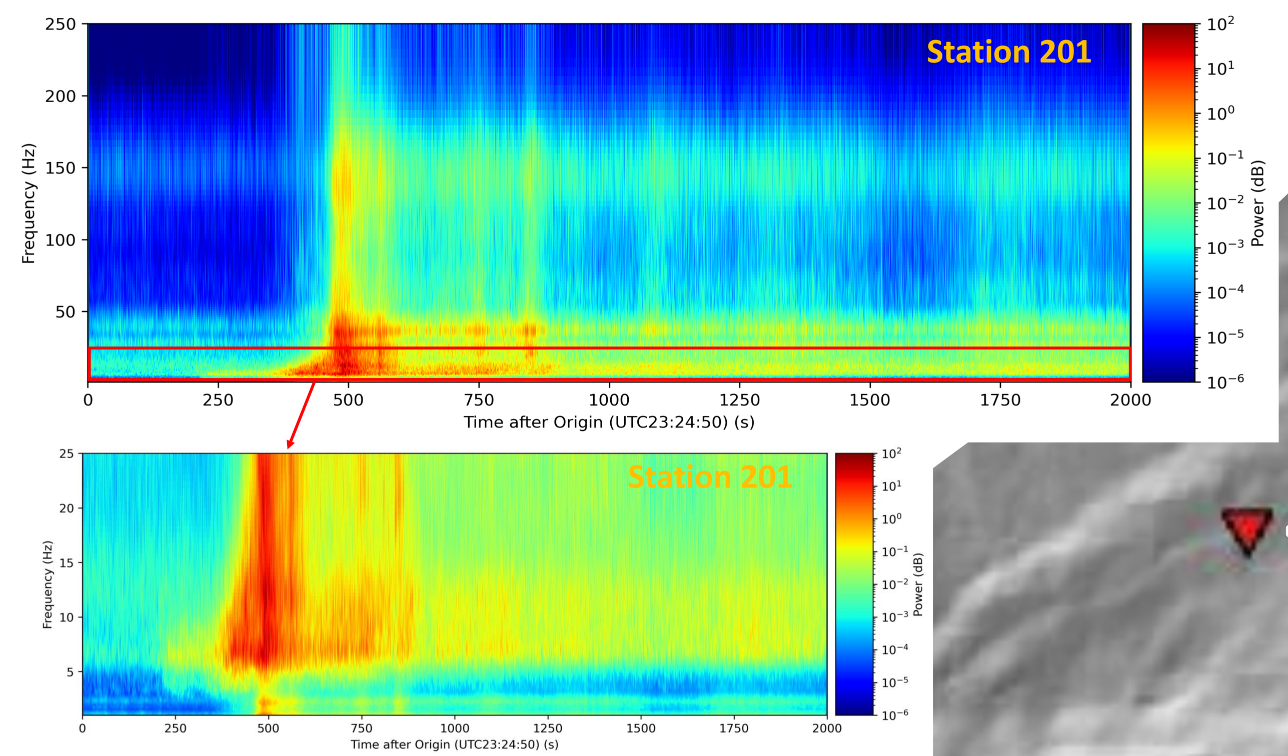
What are the seismic characteristics of the various flow states as the flow moves down the channel?

Waveform envelopes (below) illustrate the progression of the flow. We have classified the recordings into three groups: debris flow (red), transitional depositional state (yellow), and hyperconcentrated flow (blue). The approximate locations of the transitions between flow states (black dashed lines) occur between Stations 112 and 111 for the transition from debris flow to deposition and Stations 109/TABR and Station 108 for the transition from deposition to hyperconcentrated flow.

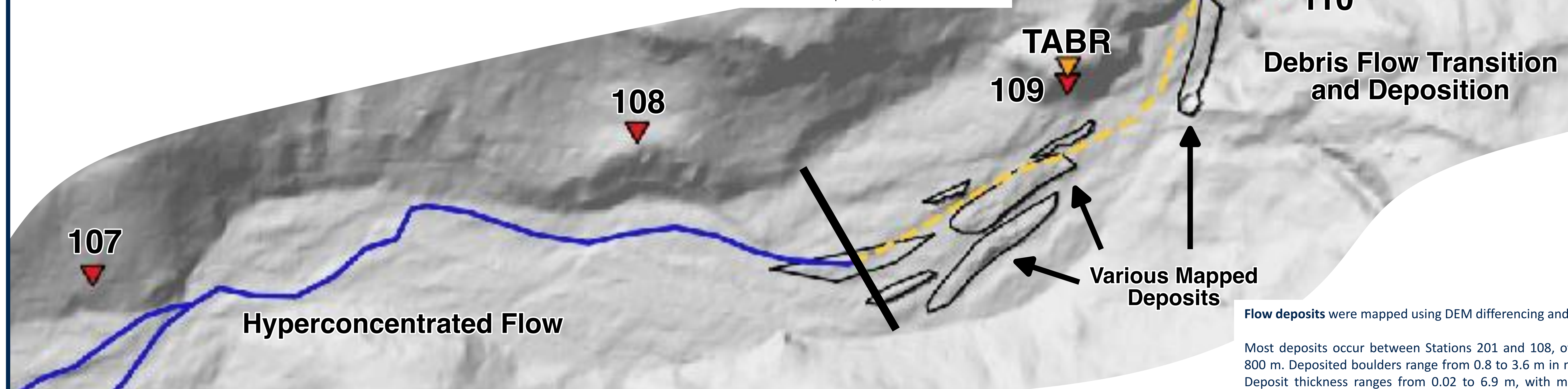




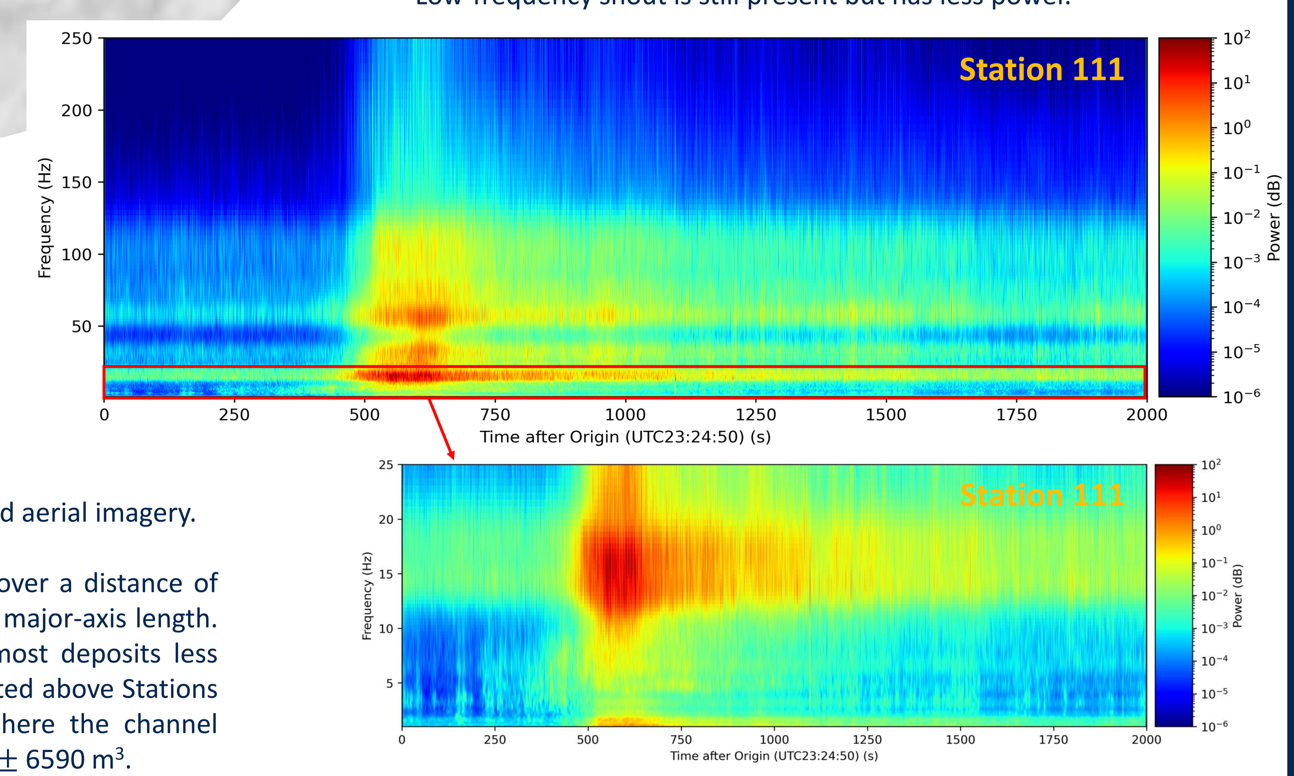
Spectrograms show significant changes in spectral content as the flow progresses down the channel. We show three example spectrograms from Stations 201, 111, and 108.



Debris flow spectrograms show:
- Signal in low frequencies (10-20 Hz)
- The leading edge (snout) of the signal in low frequencies (larger material),
- Wider frequency ranges that coincide with the main body arrival.

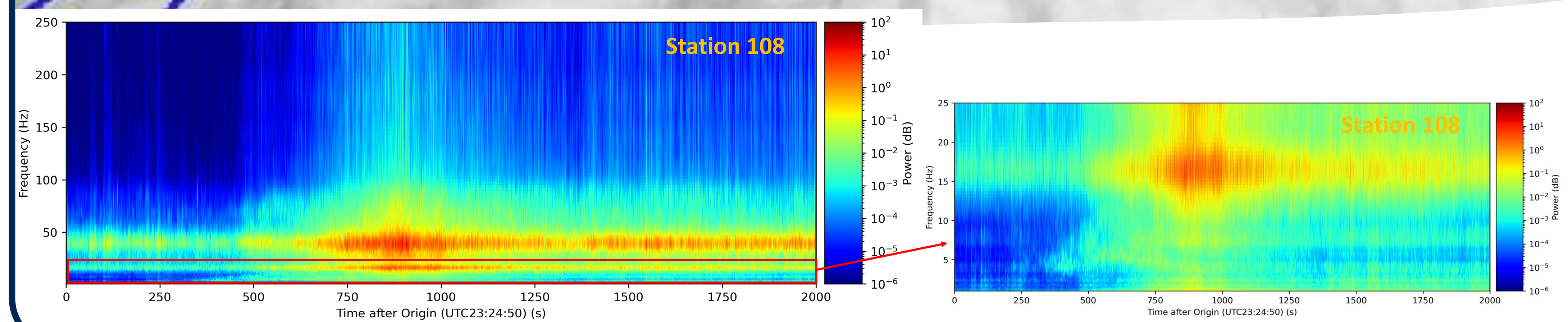


Spectrograms over the depositional interval show:
- Loss of low-frequency signal (<10 Hz),
- Narrowing of the activated frequency range both at low and high intervals,
- Low-frequency snout is still present but has less power.



Flow deposits were mapped using DEM differencing and aerial imagery.

Most deposits occur between Stations 201 and 108, over a distance of 800 m. Deposited boulders range from 0.8 to 3.6 m in major-axis length. Deposit thickness ranges from 0.02 to 6.9 m, with most deposits less than 0.2 m in thickness. Most material (79%) is deposited above Stations 109 and TABR, with 54.2% of material deposited where the channel initially widens. Deposit volume is estimated at 24,800 $\pm$ 6590 m^3.



Hyperconcentrated flow spectrograms show:
- Significantly reduced signal <25 Hz and no signal below 15 Hz,
- Reduced high frequency signal above 50 Hz,
- Elongated and featureless main body arrival with no leading snout.

3 Key Points

1. Near-field seismic recordings can be used to determine when a debris flow transitions to a hyperconcentrated flow.
2. Debris flow recordings have a sharp signal arrival, a defined low-frequency leading snout, and a wide range of frequency signal content in the main body of the flow.
3. Hyperconcentrated flow signals have an elongated onset and an elongated, featureless main body with limited low- and high-frequency content.

References:
1. Pierson, T. C., 2005, Hyperconcentrated flow – transitional process between water flow and debris flow, in Jakob, M. & O. Hungr, *Debris-flow Hazards and Related Phenomena,* Praxis Springer, Berlin.
2. Beverage, J. P., and J. K. Cutherbertson, 1964, Hyperconcentrations of Suspended Sediment, *Journal of Hydraulics Division,* **90**, 6, 117-128.
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5. Sohn, Y. K., Rhee, C. W., and B. C. Kim, 1999, Debris Flow and Hyperconcentrated Flood-Flow Deposits in an Alluvial Fan, Northwestern Part of the Cretaceous Yongdong Basin, Central Korea, *Journal of Geology,* **107**, 1, 111-132.