# The September 2018 Naga landslide: Analysis and lessons learned

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- 20 September 2018, 05:53 AM
- Brgy. Tinaan, Naga City, Cebu
- 77 dead, 7 injured, 57 damaged houses, 8,252 people affected (NDRRMC, 2018)
- Affected barangays Mainit, Inoburan, Naalad, and Tinaan (including sitios Sindulan and Tagaytay)
- Damming in Pandan River
- Tension cracks reported at least 3 weeks before the landslide

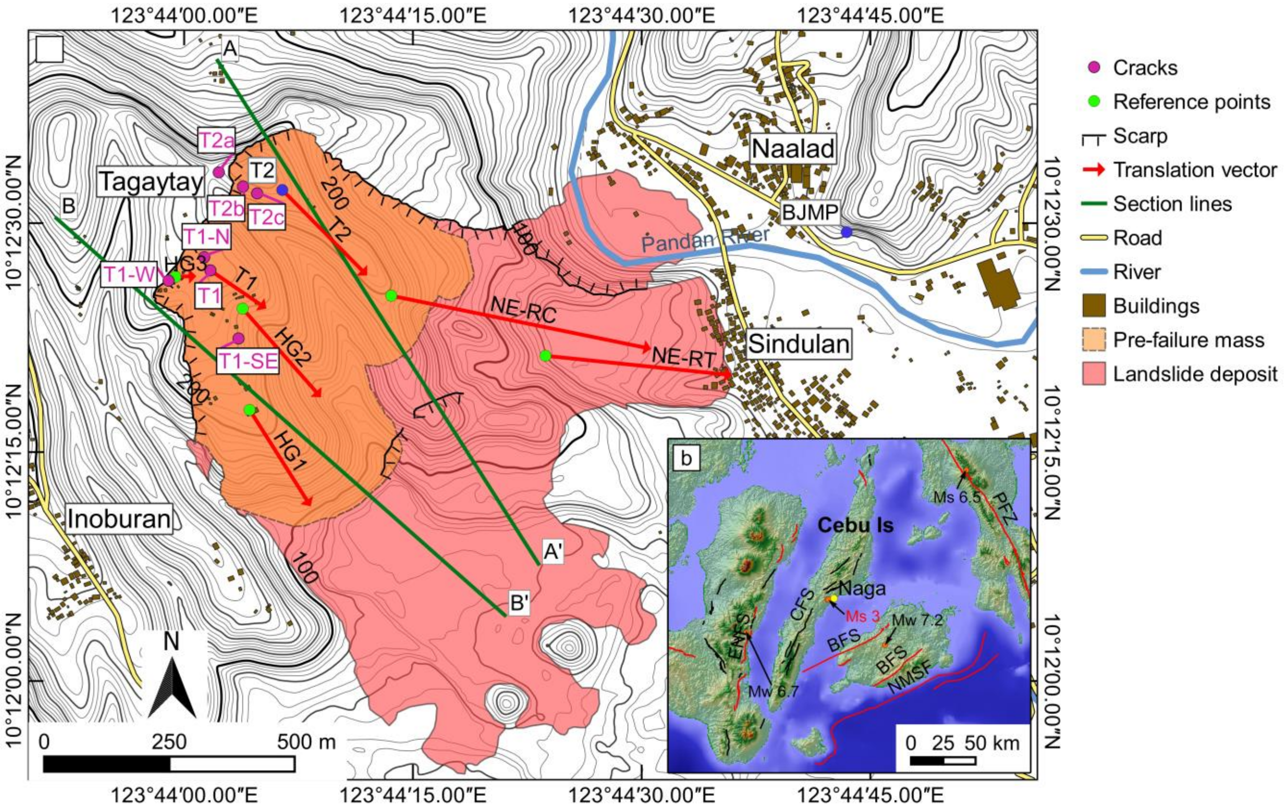
MGB-Region VII (2018)


Frames from the CCTV footage of BJMP

- Lasted for 67 s
- Landslide moved en masse and then split into two major directions

# Pre-failure deformation

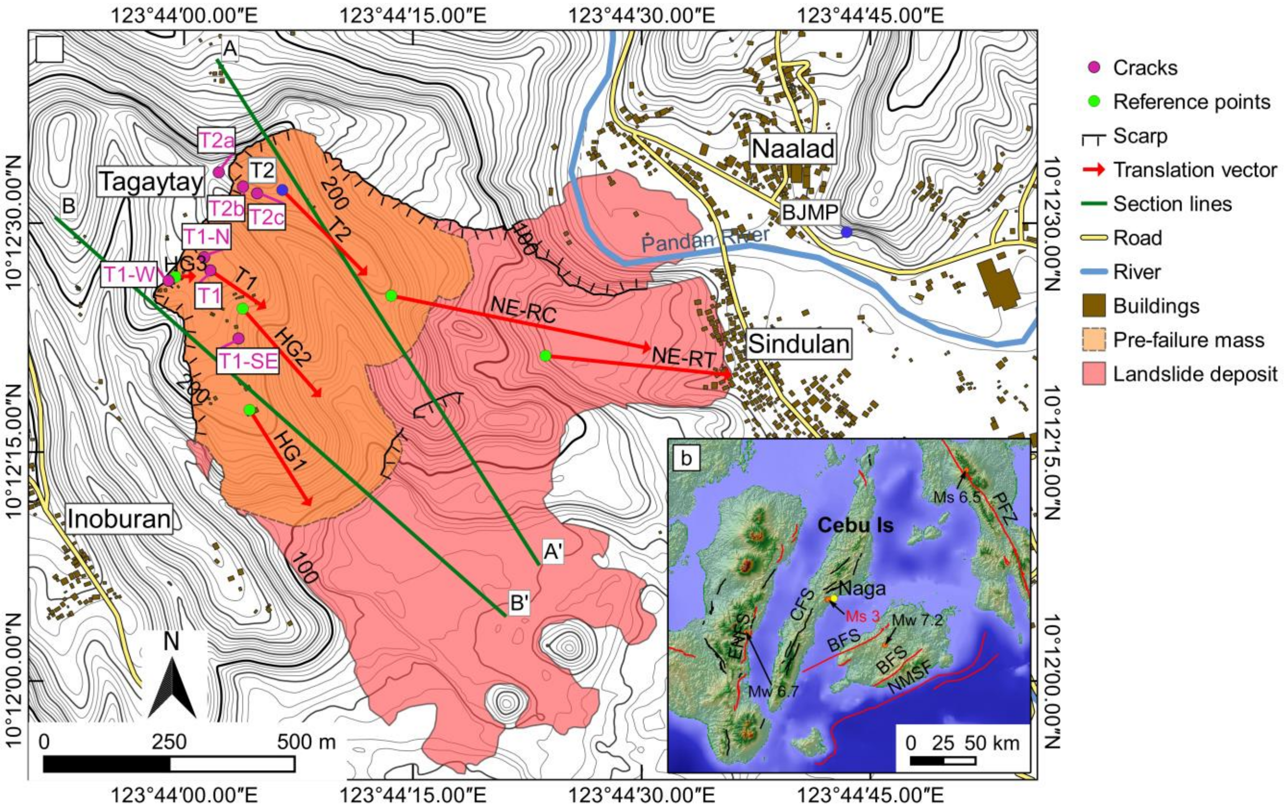
- 2007: intermittent ground cracks and rockfalls
- 2016: small tension cracks




| Tension cracks | Orientation | 29 August 2018 | | | 18 September 2018 | | | Mean net HD (cm) | Deformation rate (cm/day) |
|---|---|---|---|---|---|---|---|---|---|
| | | L (m) | HD (cm) | VD (cm) | L (m) | HD (cm) | VD (cm) | | |
| T1 | 35°, 80° SE | 45 | 8–10 | ~ 0 | Increased | 19–19.5 | 11–11.5 | 10.25 | 0.51 |
| T1-W | 10-20°, 90° | 1–1.5 | 1–3 | ~ 0 | 18–19 | 16–17 | Not reported | 14.5 | 0.73 |
| T1-SE | NW strike | 1–1.5 | < 1–3 | ~ 0 | | Not reported | | – | – |
| T1-N | 35°, 90° | | Not reported | | > 50 | 19–19.5 | 24–25 | 19.25 | – |
| T2a, T2b, T2c | 10-65°, 90° | 1–1.5 | 3–6 | ~ 0 | Increased | 14–14.5 | 3–6 | 9.75 | 0.49 |

# Pre-failure deformation

- Predominantly NE-trending cracks
- Progressive widening of cracks → tensional failure → shear strength reduction

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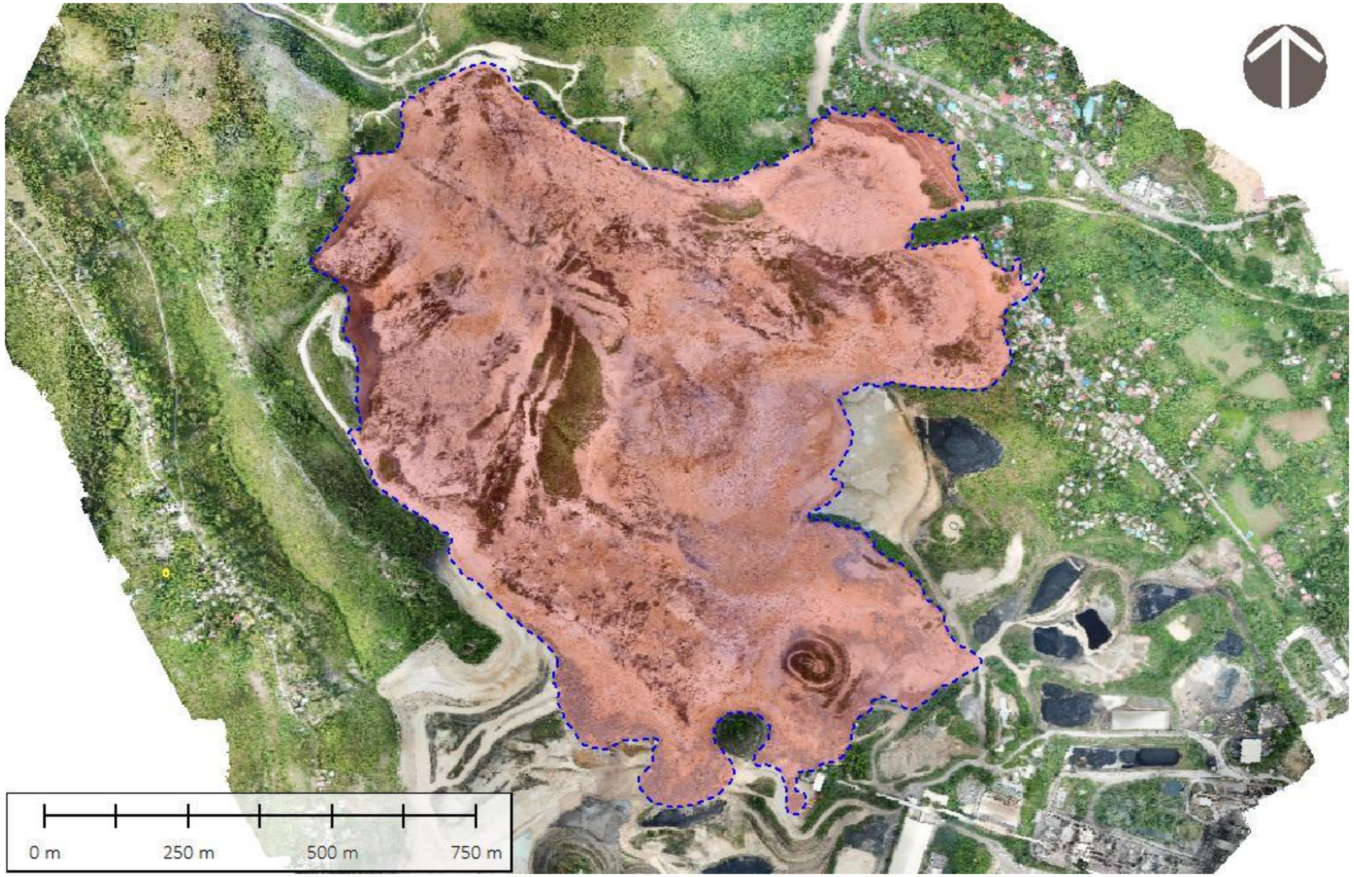
# General description of the landslide

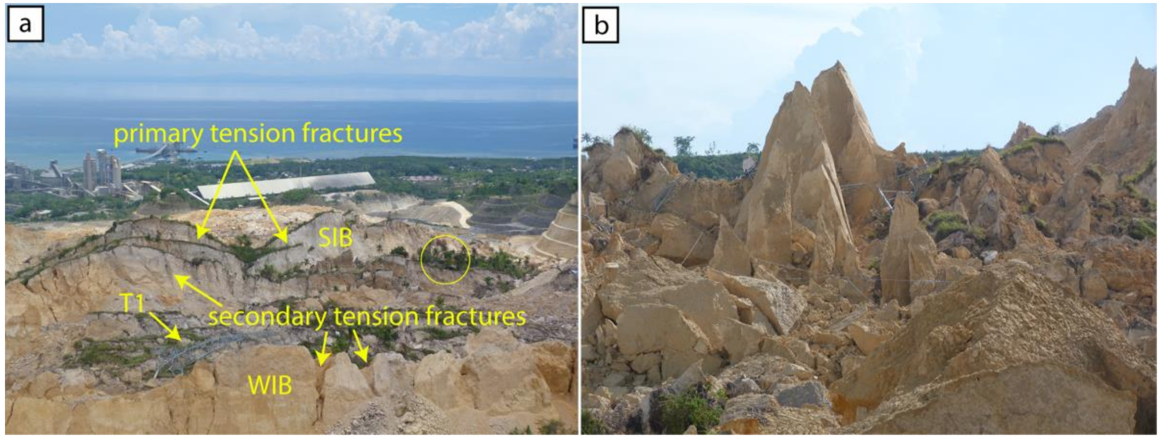
- Area: ~$9.5 \times 10^5$ $m^2$ (~95 ha)
- Volume: ~27 M $m^3$
- Velocity: 0.63–7.91 m/s (very rapid to extremely rapid)
- Runout: 1.34 km
- Head scarp: 480-m-long, ~50-m-high, 55–75° steep
- Underlain by limestones of the Plio-Pleistocene Carcar Formation
    - Thinly to thickly bedded calcarenites and calcirudites
    - Gently SE-dipping (low-angle) and daylighting
    - Poorly cemented and very porous

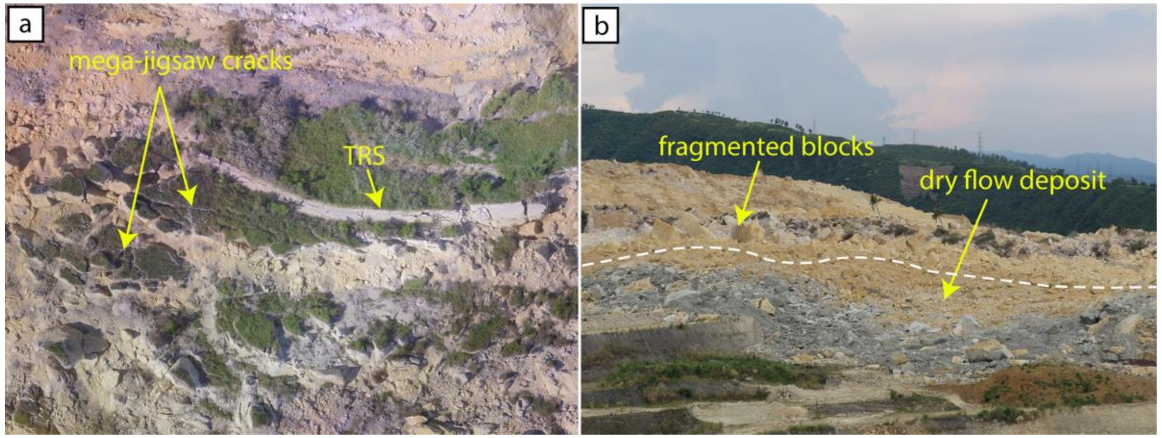



Post-landslide orthomosaic from Ariel Lazarte

# Mechanism: evidence from deposits

- Successive detachment of multiple blocks along a series of tension cracks
- Primary and secondary tension fractures
- Slab-like and wedge-like blocks
- Landslide deposit facies: intact blocks, fragmented blocks, dry flow deposits, rockfall deposits, collapsed blocks → variable processes within a single landslide
- Most blocks retained their upright positions → predominant translational mechanism



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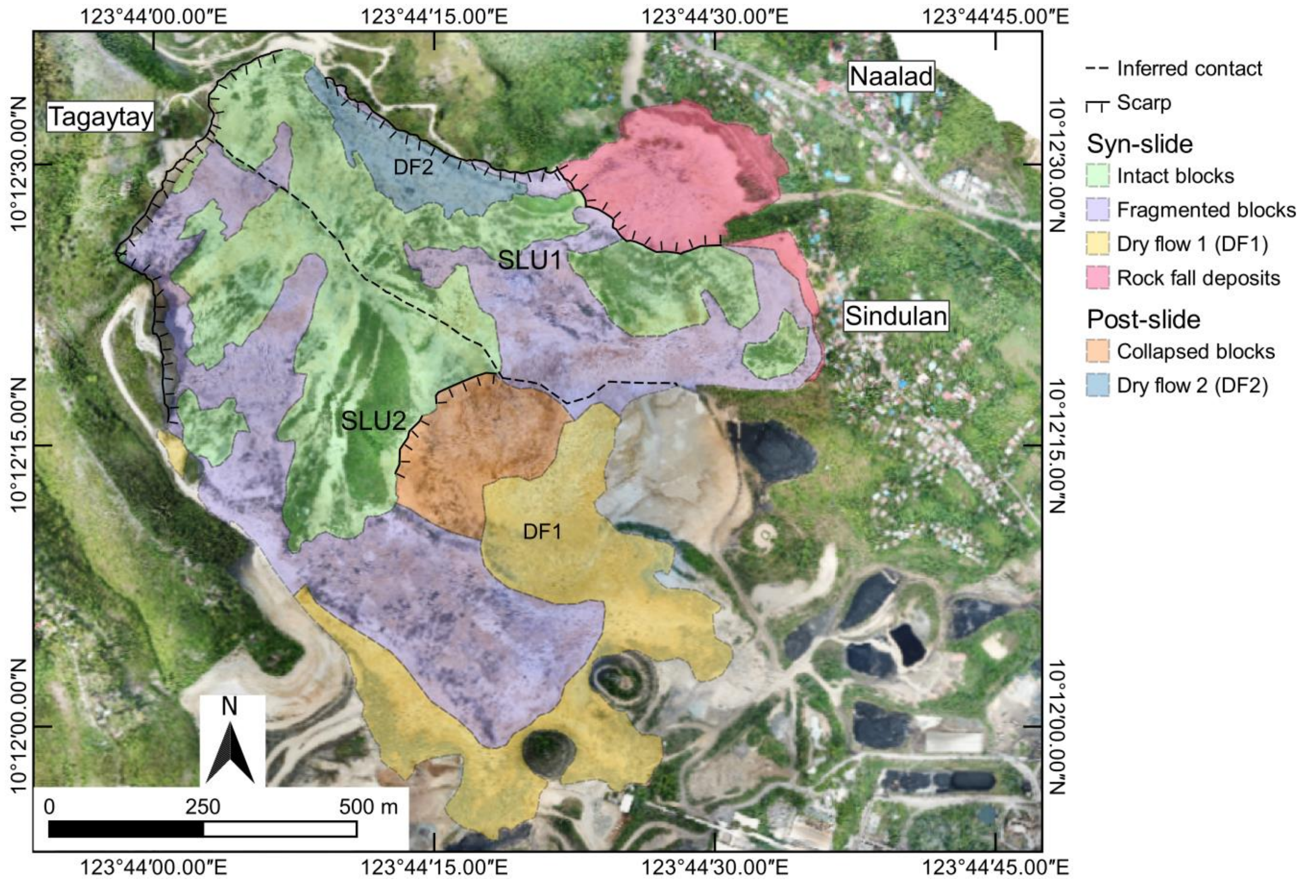
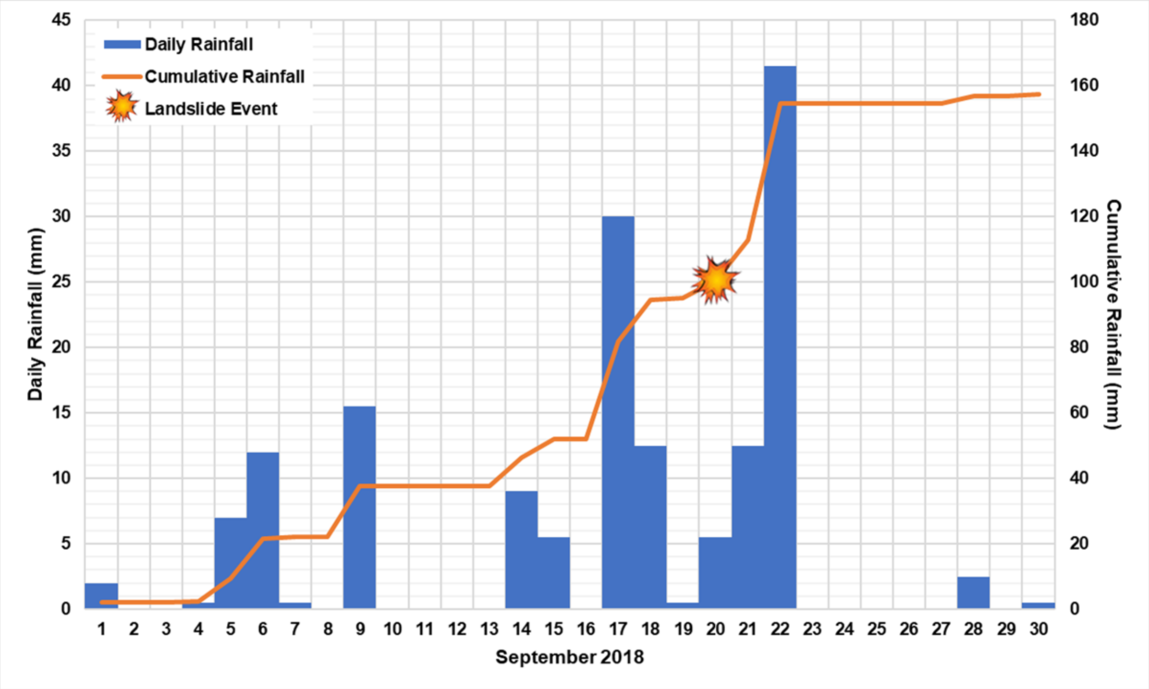


# How does the 2018 Naga landslide fare against the 2006 Guinsaugon landslide?



| | 2006 Guinsaugon (Catane et al., 2007, 2008) | 2018 Naga |
|---|---|---|
| Area | 3.2 $km^2$ | 9.5 $km^2$ |
| Volume | 14–18 M $m^3$ | 27 M $m^3$ |
| Maximum velocity | 120–130 m/s | 7.9 m/s |
| Runout | 4.1 km | 1.34 km |
| Mechanism | rockslide-debris avalanche | translational block slide |

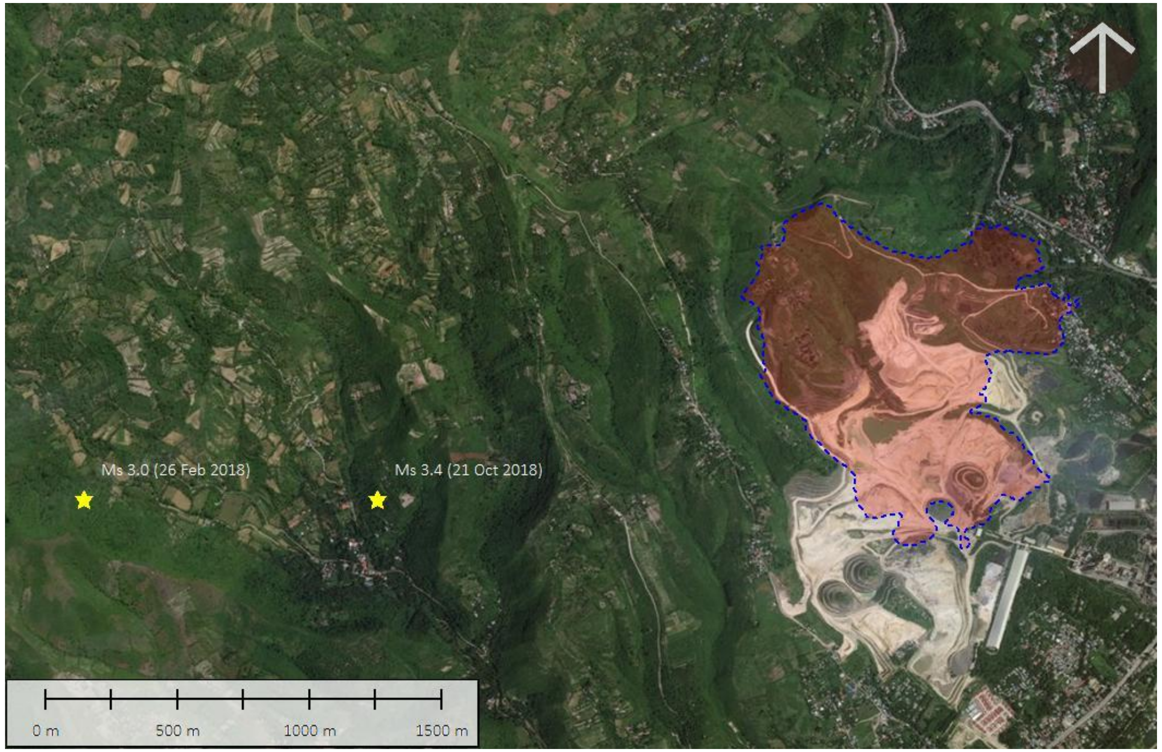
# What could have triggered the landslide?




Rainfall data from DOST-ASTI rain gauge located 900 m NW of the landslide

- 15 September: Typhoon Ompong made landfall in Cagayan about 900 km NNW of Naga City
- 17 September: 30 mm maximum daily rainfall
- 20 September, 04:00-05:45 AM: 4.5 mm instantaneous rainfall
- 1-20 September: 99.5 mm cumulative rainfall
- Far below the global threshold of 100 mm/day
- Rainfall is unlikely to have triggered the landslide

# What could have triggered the landslide?




- 26 February 2018, 06:36 AM
  - Ms 3.0 shallow (32 km) earthquake about 2.8 km SW of the landslide
  - No reports of earthquake intensity and landslide precursors
- No earthquakes immediately prior or during the landslide
- 21 October 2018, 07:04 PM
  - Ms 3.4 shallow (10 km) earthquake about 1.8 km SW of the landslide
  - PEIS IV was reported
  - No reports of landslide reactivation
- Earthquake is unlikely to have triggered the landslide

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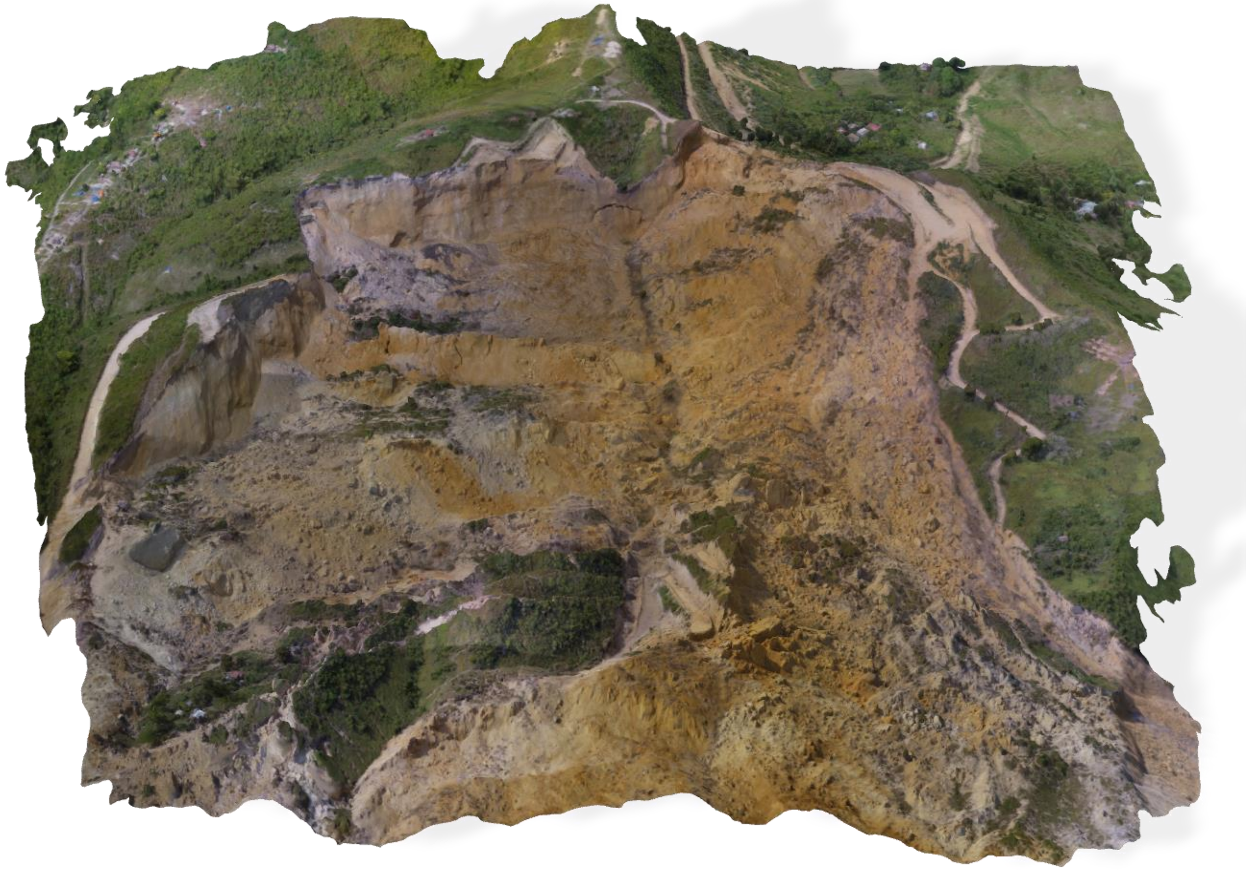
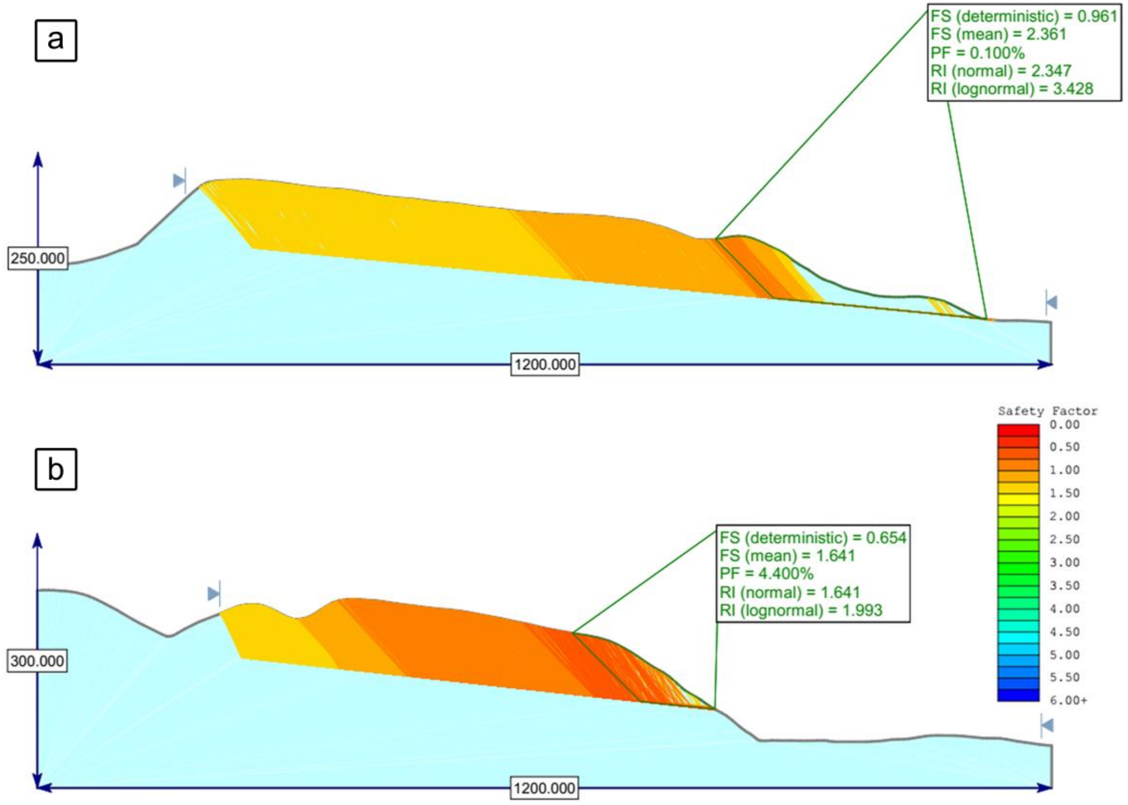


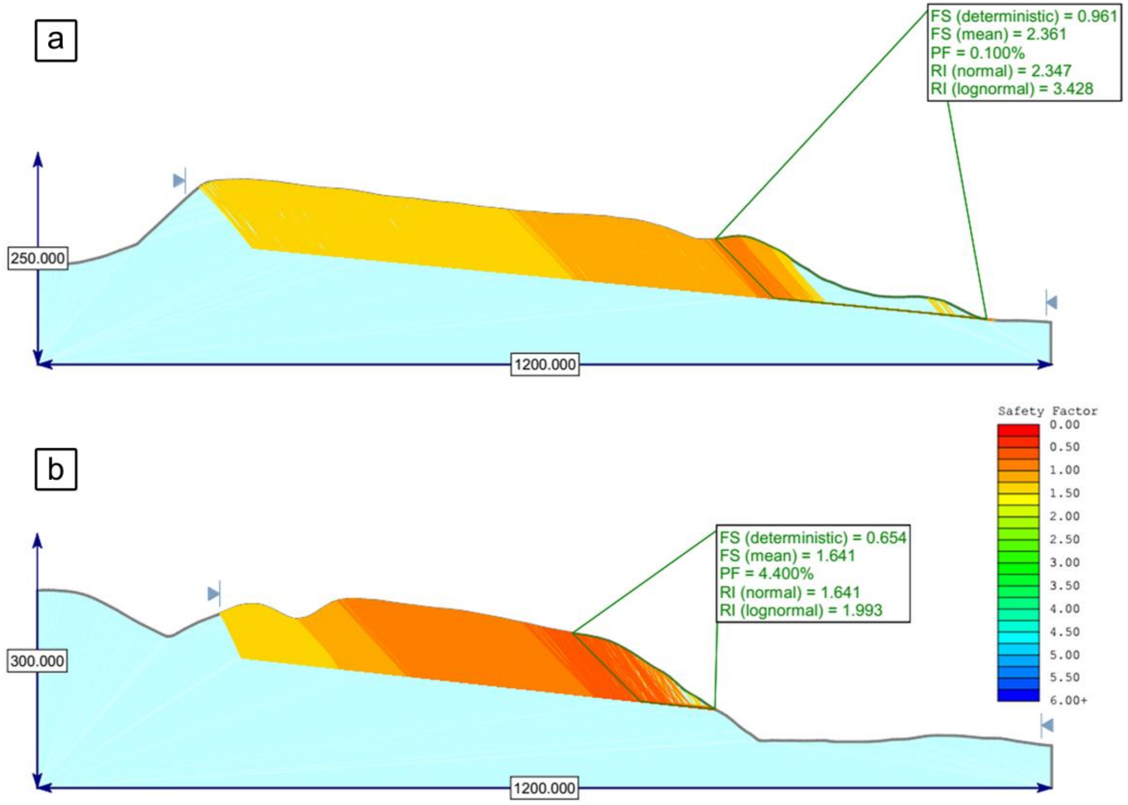
- Steep cut slopes associated with extraction activities
  - Change the load distribution on potential slip surfaces
  - Change the hydrologic conditions of the slope
  - Expose potential slip surfaces
  - Withdraw support at the toe
- Investigate the effect of cut slopes through probabilistic slope stability analyses

# Preliminary slope stability analyses




- 2D limit equilibrium analyses
  - Daylighting bedding planes as potential slip surfaces
  - Assumptions: homogenous material, unsaturated condition
  - Estimated material strength parameters:
    - Unit weight = 17–23 kN/$m^3$
    - Intact UCS = 5–25 MPa
    - GSI = 36–54
    - Intact rock constant = 5–15
    - Disturbance factor = 1.0

# Preliminary slope stability analyses




- 2D limit equilibrium analyses
  - Factors of safety:
    - (a) 0.969–3.96
    - (b) 0.668–2.798
- Slopes may already be marginally stable
- Additional removal of support by extraction activities → increase in shear stress
- Further exposure of potential slip surfaces from cut slopes → decrease in shear strength

# Conclusions

- The September 2018 Naga landslide is a low-angle translational block slide
- Rainfall and earthquake are unlikely to have triggered the landslide
- Cut slopes were marginally stable along a low-angle slip surface even at unsaturated conditions
- There is no immediate direct trigger to the landslide
- Eventual failure can be due to progressive weakening of the slope or further disturbance of the slope

# Lessons learned

- Development of tension cracks at least 3 weeks before the landslide provided reasonable lead time to issue an early warning
- This prompted the timely evacuation of the residents of Tagaytay, where the tension cracks were located
- However, most of the casualties came from Sindulan and Naalad at the distal end of the landslide because of the lack of information on potential landslide runout
- There should have been fewer casualties if the volume and runout were anticipated
- Modelling of possible landslide runout must be part of any landslide investigation

# Lessons learned

- Review cut slope designs and extraction methods
- In any extraction activities, full-time monitoring by geologists and geotechnical engineers is essential

# *Thank you!*