Canadian Railway Ground Hazard Research Program: Applications of remote sensing techniques for managing rock slope instability

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27 October, 2017

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Canadian Railway Ground Hazard Research Program (RGHRP) - Overview

Program Objectives:

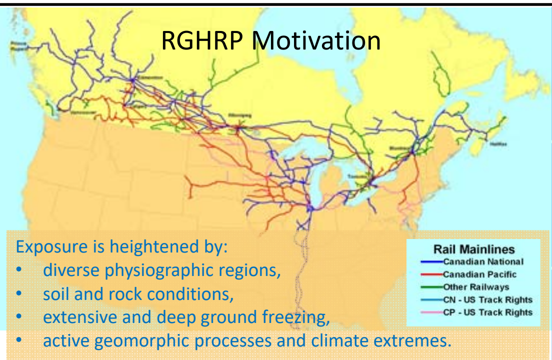
To develop risk management solutions to improve safety and reduce losses from railway ground hazards.

To meet the requirements for due diligence and standard-of-care under the Railway Safety Act, specifically Safety Management Systems.

To provide solutions such as:

- application of new methodologies for assessing hazards,
- development and refinement of new monitoring & detection technologies, and
- improvements to existing systems.

RGHRP Motivation

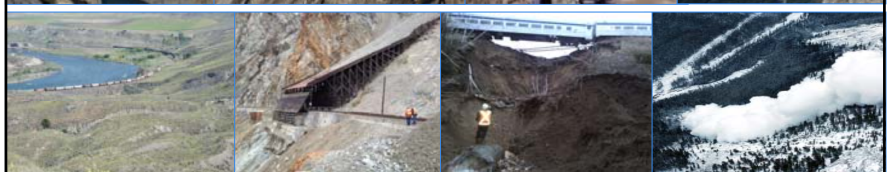


Exposure is heightened by:

- diverse physiographic regions,
- soil and rock conditions,
- extensive and deep ground freezing,
- active geomorphic processes and climate extremes.

RGHRP Motivation

Landslides, subsidence, hydraulic erosion, snow & ice result in unsafe track at the allowable train speed.



RGHRP Motivation

Railways are exposed to a wider variety and
higher frequency of ground hazards, and have a
higher exposure because of curvature and grade limitations.
RESULT! Complex and uncertain ground hazards present a
significant safety and operating risk to Canadian railways.

Project Team Leaders

NSERC CRSNG
University of Alberta
CN CP
Transport Canada Transports Canada

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RGHRP contributions

- Assessment and adoption of technologies for instrumentation, in collaboration with vendors and research teams – AccelArray, Geocubes, Microseismic, GPR, Acoustic waveguide, Resistivity, LiDAR, photogrammetry, UAV.
- Instrumentation installation and interpretation, and numerical simulation of complex mass movements, considering groundwater and geological models.
- Risk based assessment of ground hazards, including incident database development and analysis, probabilistic forecasting, evaluation of frequency / magnitude concepts, consideration of triggering activities.
- Development of practical guidelines for railway operation teams.
- Collaboration, training and information dissemination.

MEASURAND

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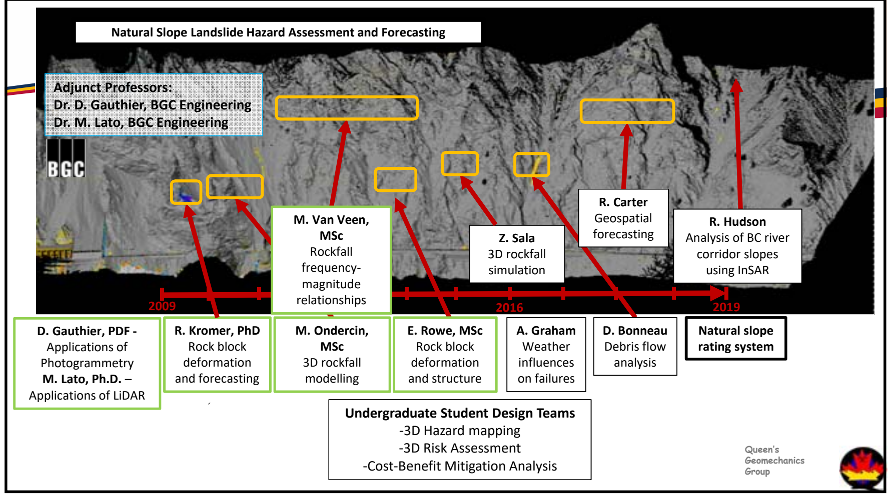

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Linear infrastructure adjacent to rock slopes

Linear infrastructure adjacent to rock slopes

Photo: courtesy of Tom Edwards

Rockfall event mitigation - Railways

Rock sheds

Tunnels

Slide detector fences and Ditches

Managing rock slope instability

- For large, natural slopes:
  - How do we identify which features may generate failing rocks, next?
  - How do we observe and measure the potential source zones / failure volume?
  - Can we forecast potential failure?
  - Once we have identified a potential source zone, what is the risk to infrastructure?

Case Study Site – White Canyon, British Columbia

White Canyon Study Site

Quartzofeldspathic Gneiss

Dioritic Intrusions

Tonalite Dykes

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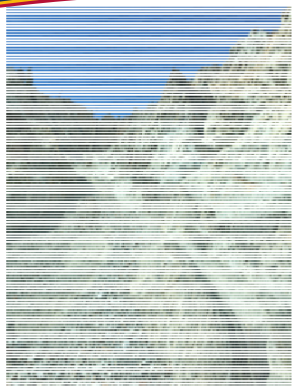
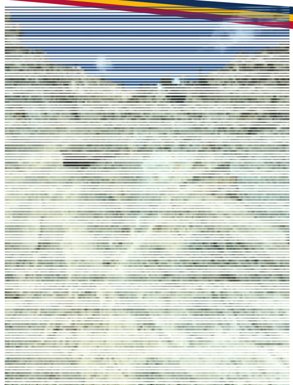
White Canyon Study Site





Active rockfall zone. Difficult to assess and monitor:

- Source of rockfalls, and
- Volume of debris in source zones.

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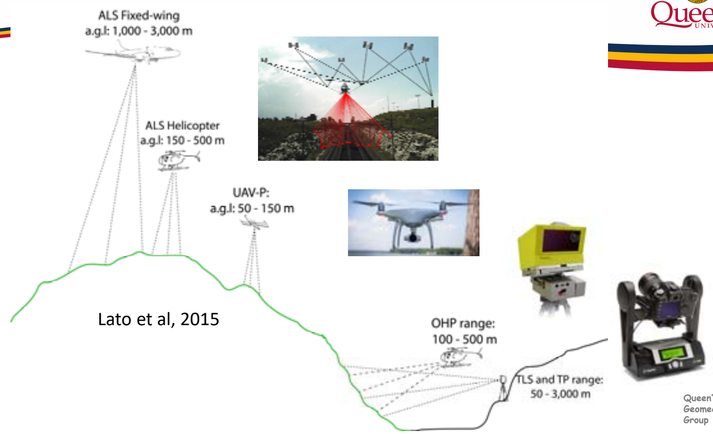
Remote Sensing techniques



Lato et al, 2015

Gigapan robotic head

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Overview of Methods Deployed at White Canyon

Terrestrial Laser Scanning (TLS)	Aerial Laser Scanning (ALS)	GigaPan Imaging	Terrestrial Photogrammetry	UAV Photogrammetry	Helicopter Photogrammetry	InSAR
[2012 – Present]	[Fall 2014; Fall 2015]	[2014 – Present]	[2014 – Present]	[August 2016]	[October 2016]	[March 2014 – June 2015]

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GigaPan Imaging

GigaPan

Gigapan example

van Veen et al, 2015, 2016 & 2017

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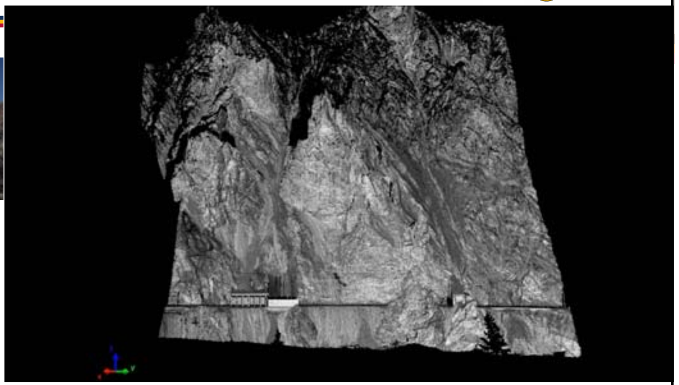
LiDAR Point Cloud



Ryan Kromer

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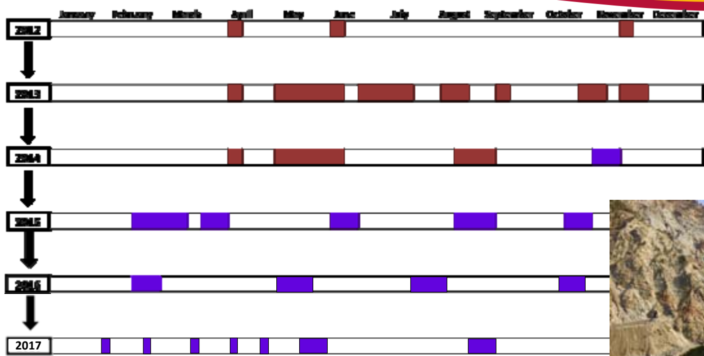
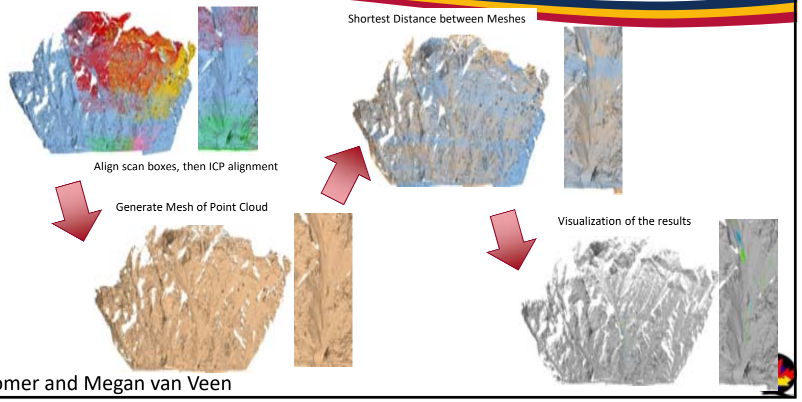
Available TLS Data



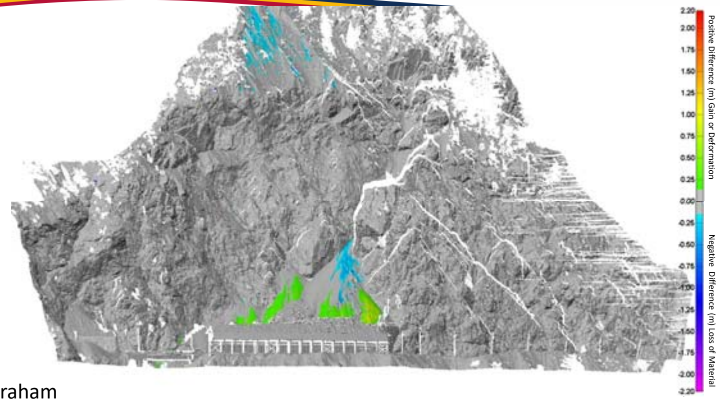
Steps to produce a Change Detection Map, between sequential scans



Ryan Kromer and Megan van Veen

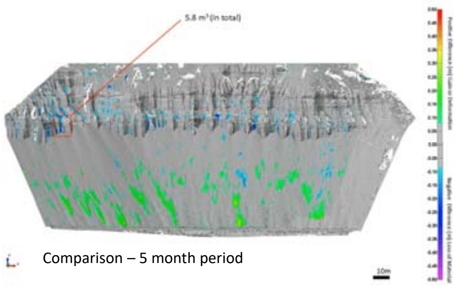
Ashcroft Mile 109.4

Comparison Dates: 2017-04-08 to 2017-05-23



Alex Graham

Change detection from 3-D models
Feature observation from GigaPan



Comparison – 5 month period

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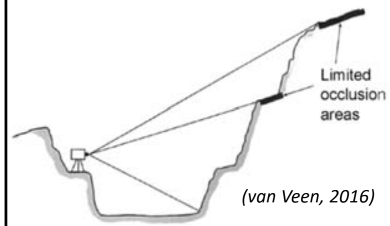
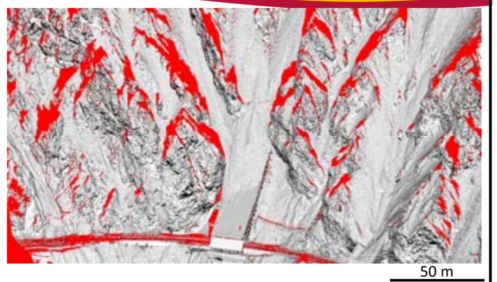
Occlusions in Terrestrial Laser Scanning



(van Veen, 2016)



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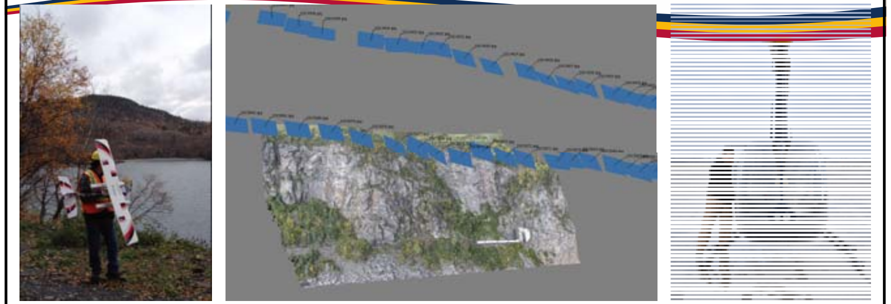
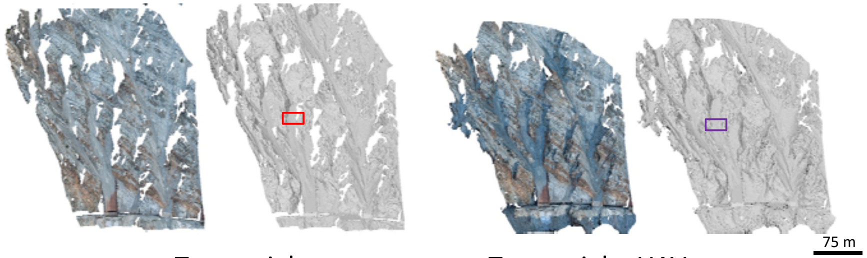
Photogrammetry



Photogrammetry revolutionized by Structure From Motion processing – Agisoft PhotoScan

Gauthier et al, 2015

Photogrammetry

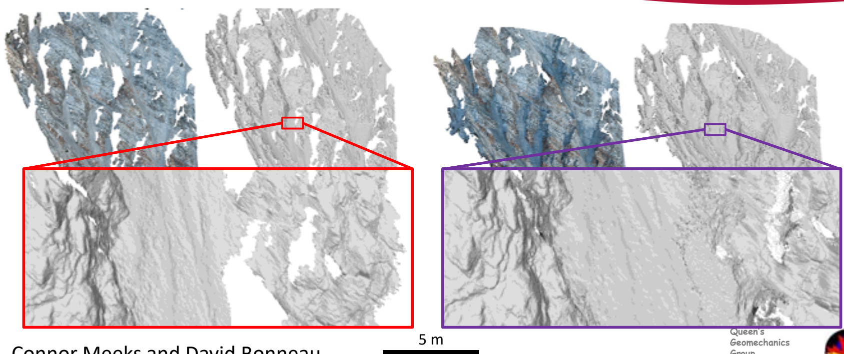


Terrestrial

Terrestrial + UAV

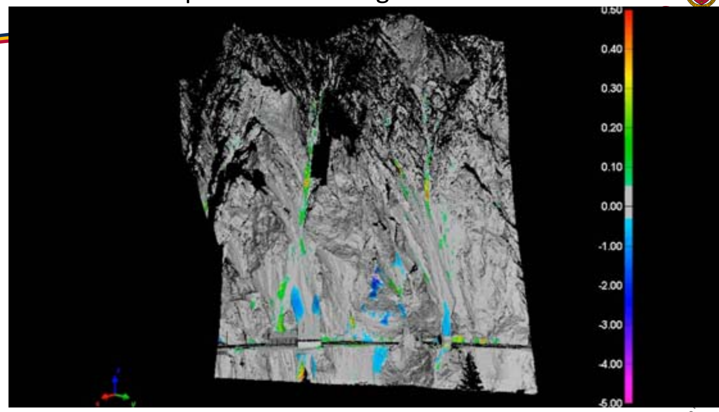
Connor Meeks and David Bonneau

Photogrammetry



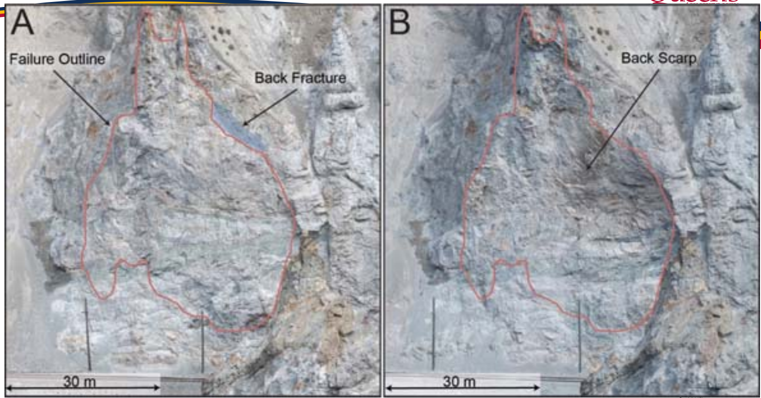
Connor Meeks and David Bonneau

Active rock slope – LiDAR change detection



Matt Lato

Rock slope failure case history



2600 m³ failure June 2013

29

2600 m³ failure

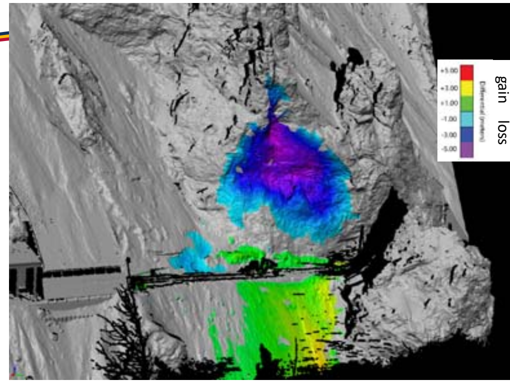


Photo by Tom Edwards

Dave Gauthier

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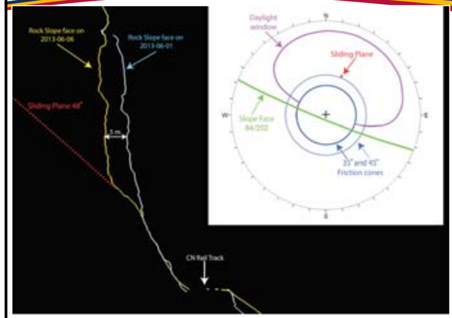
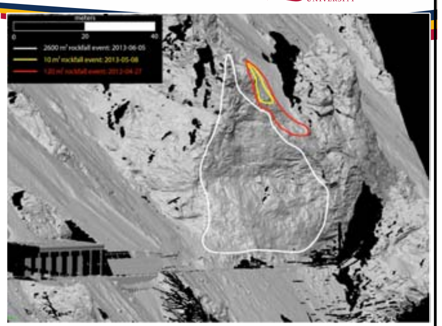
Structural Analysis of Failure





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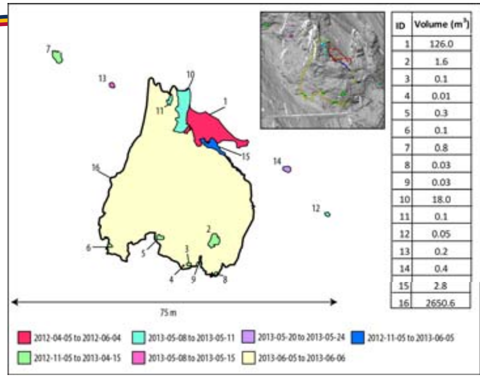
Rockfall History



ID	Volume (m³)
1	126.0
2	1.6
3	0.1
4	0.01
5	0.3
6	0.1
7	0.8
8	0.03
9	0.03
10	18.0
11	0.1
12	0.05
13	0.2
14	0.4
15	2.8
16	2650.6

Ryan Kromer

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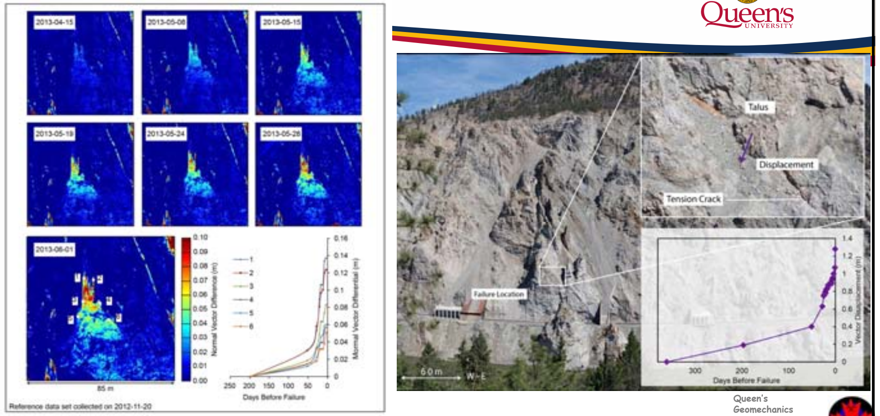
Identifying Rock Slope Failure Precursors



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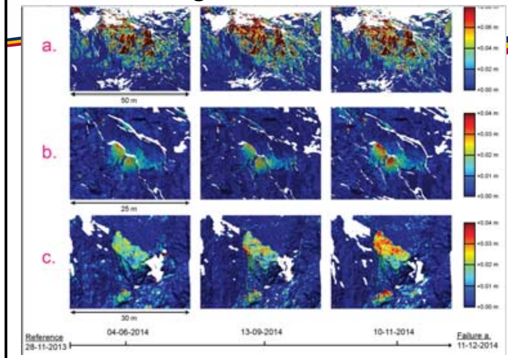
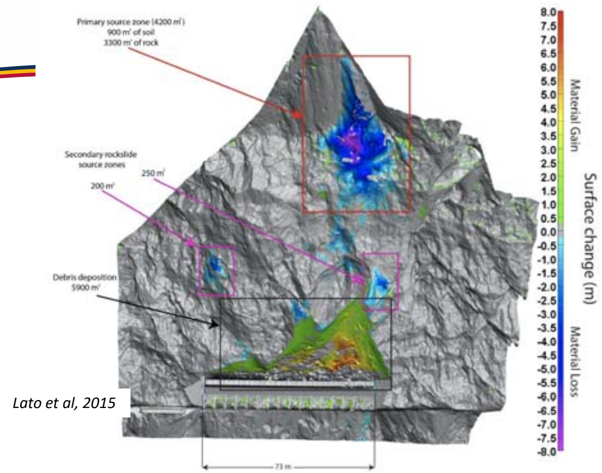
Forecasting Failure



Kromer et al, 2016

Dec 11, 2014



Lato et al, 2015

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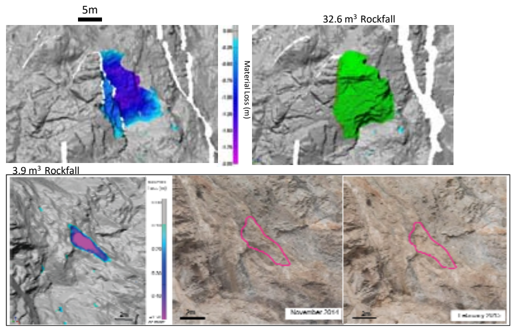
Rockfall Database Development

Data Collection → Processing → Analysis



Rockfall Database

- Scan Interval (time)
- Rockfall location
- Rockfall magnitude
- Expected/observed structure and failure mechanism
- Source zone lithology
- Rock quality estimate (GSI)

From LiDAR

From Photos

van Veen et al, 2017

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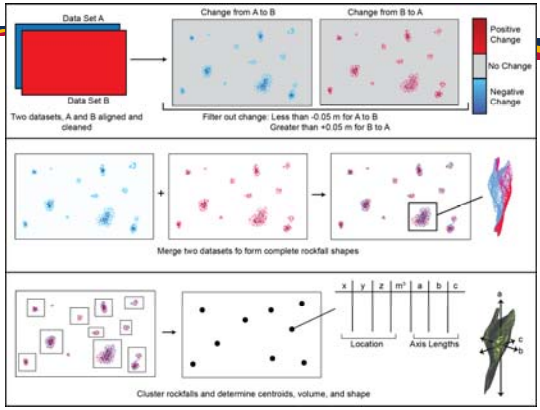
Extracting rockfall data



Megan van Veen

Based on methods from Carrea et al. (2014), Tonini & Abellán (2014) and Janeras et al. (2015)

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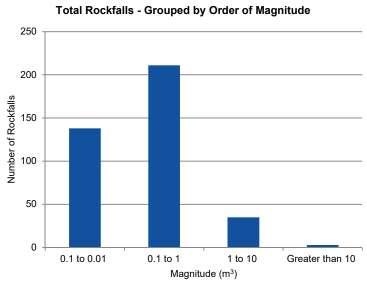
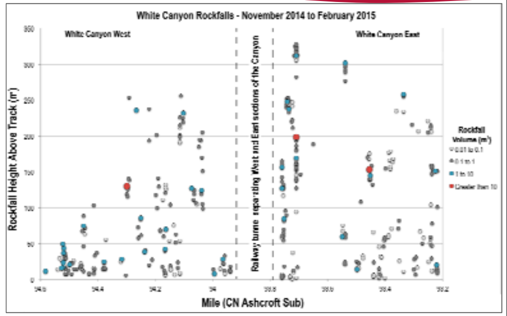
Data Analysis - Volume





387 rockfalls between 0.01 and 20.5 m^3, over 3.5 months

van Veen et al, 2017

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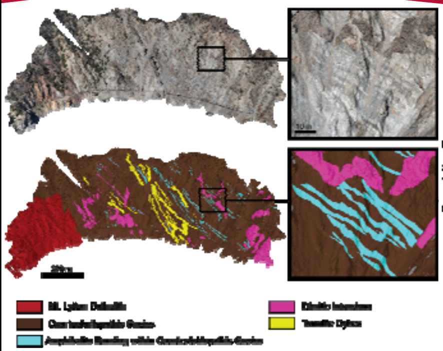
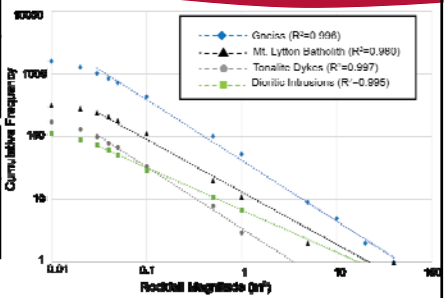
Data Analysis - Lithology





van Veen et al, 2017

(van Veen 2016)

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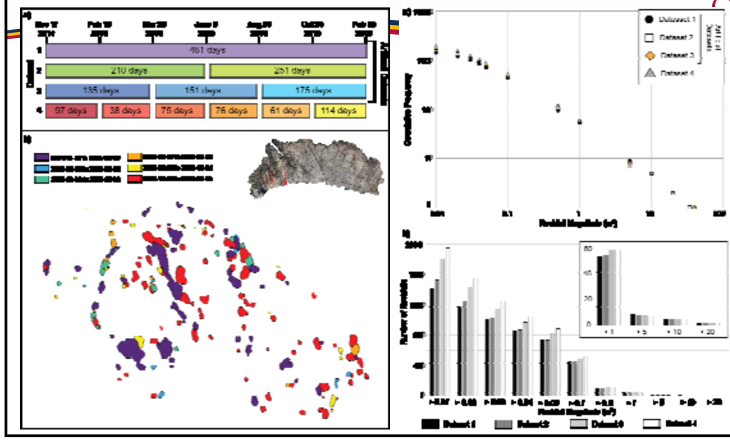
Effects of Scan Interval on FM Curves



Longer elapsed time between surveys: Multiple individual rockfalls are recorded as a single cluster; and Location and volume becomes less accurate

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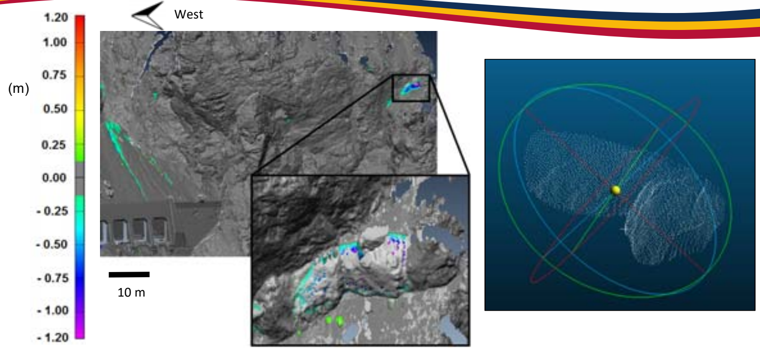
Rockfall Block Deformation Analysis

Queen's University



Rowe et al, 2016

Ashcroft Mile 80.8 to 81.2 (Goldpan) – Section 2
Comparison Dates:
2015-10-27 to 2016-02-15

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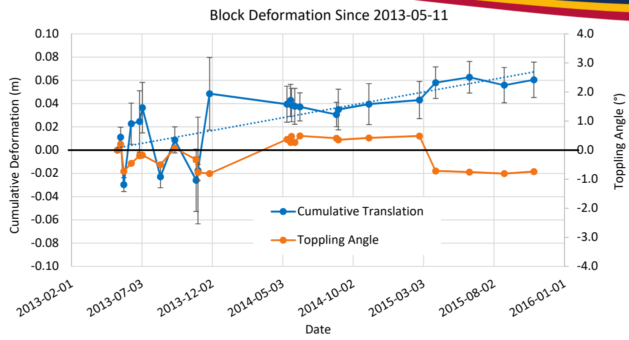
Rockfall Block Deformation Analysis

Queen's University



Rowe et al, 2016

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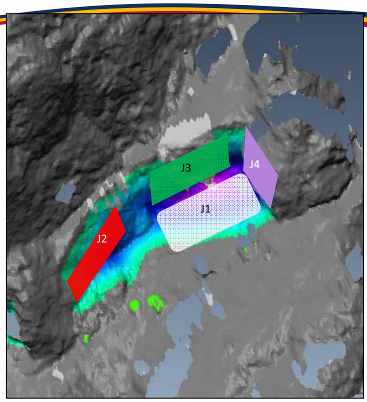
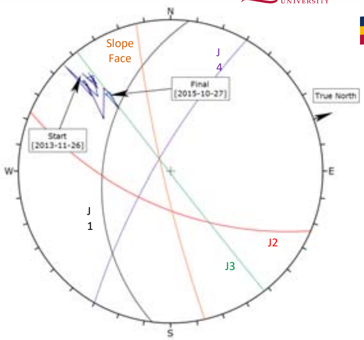
Rockfall Block Structural Analysis

Queen's University





Rowe et al, 2016

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Rockfall Block Structural Analysis

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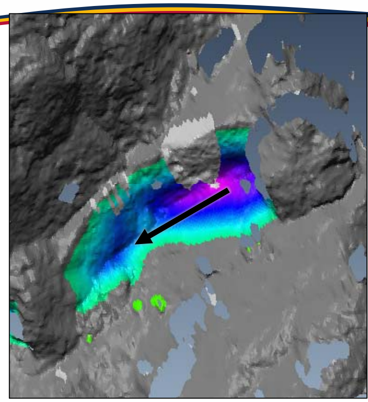

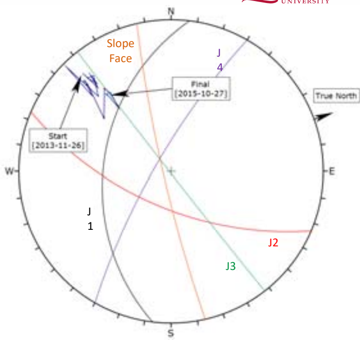

Rowe et al, 2016

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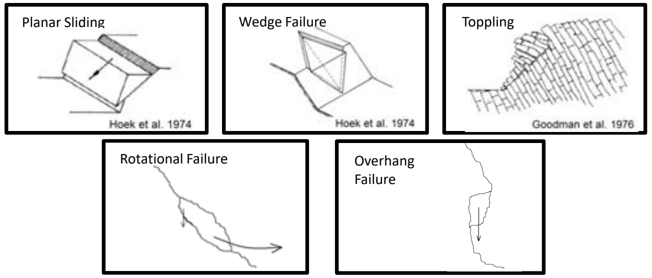
Determining warning thresholds for different failure mechanisms



Emily Rowe

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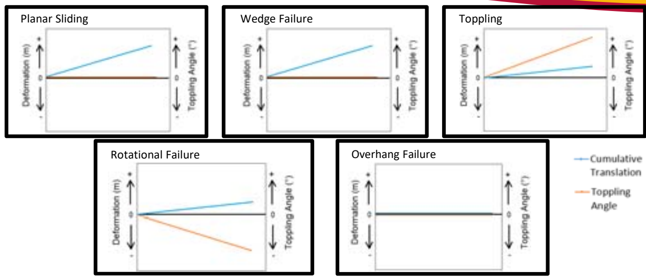
Conceptual failure mechanism behaviour



Rowe et al, 2016

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Modelling Rockfalls using Game Engines

- Fully 3D
- Built-in physics
  - NVIDIA PhysX Engine
  - Robust collision detection
  - Rigidbody dynamics
- Intuitive development environment
  - Pre-existing 3D coordinate system
  - Realistic visualization through lighting and texture
  - Modular and object-oriented
  - Fully scriptable (C# or JavaScript)
- Regularly updated
  - Freely available
  - Supported by large community of developers

Made with unity

Zac Sala

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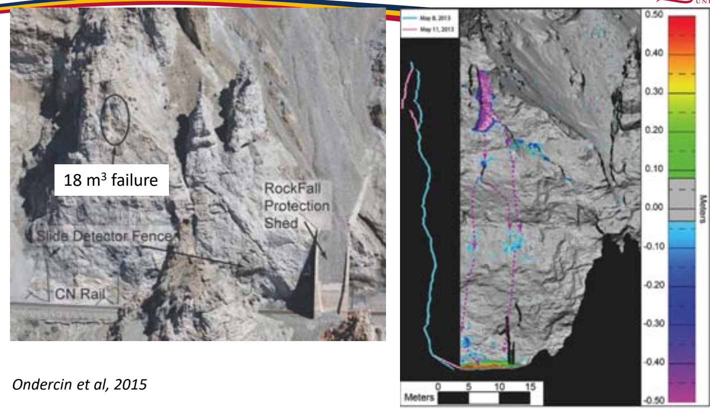
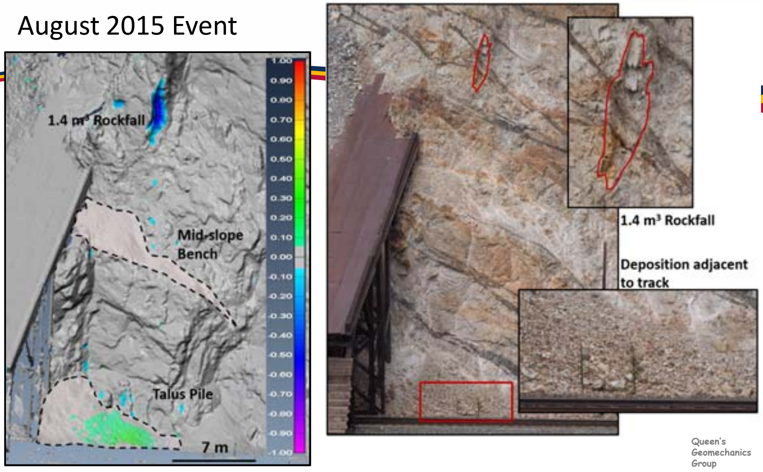
Calibration of rockfall simulation via path analysis



Ondercin et al, 2015

August 2015 Event



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Incorporating True Shape

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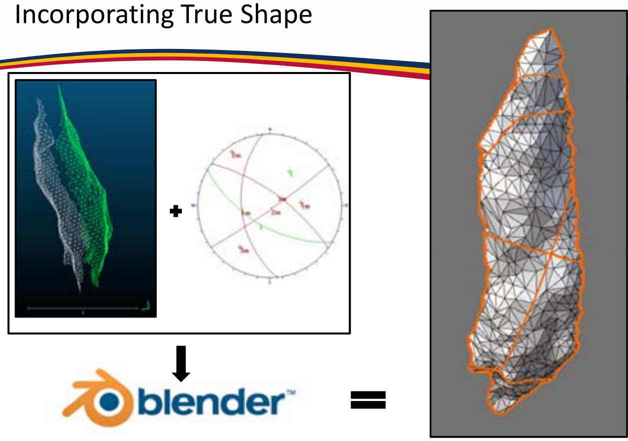

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Real Time Terrestrial Monitoring

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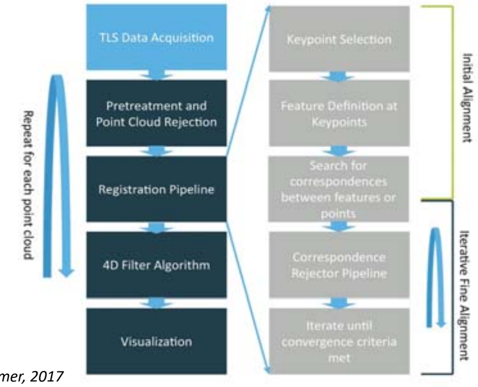

Kromer, 2017

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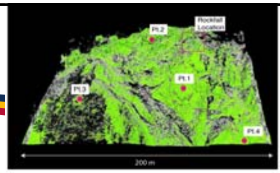
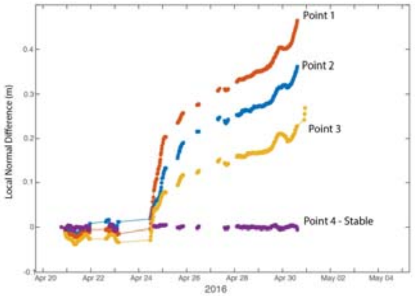
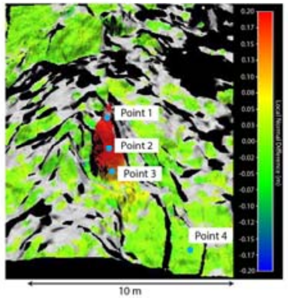
Real Time Terrestrial Monitoring

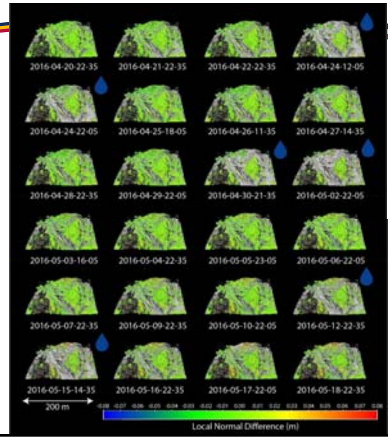


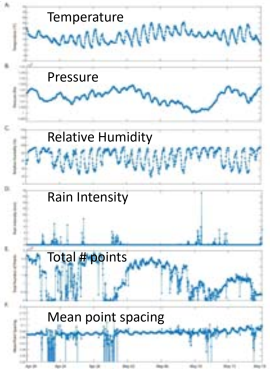




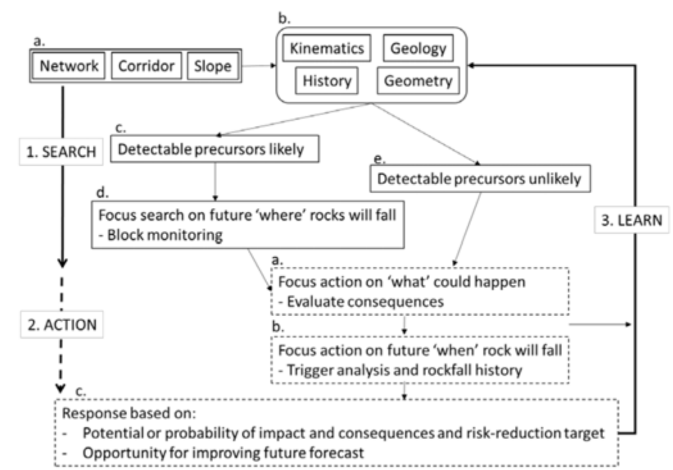
Kromer et al, 2017

Real Time Terrestrial Monitoring

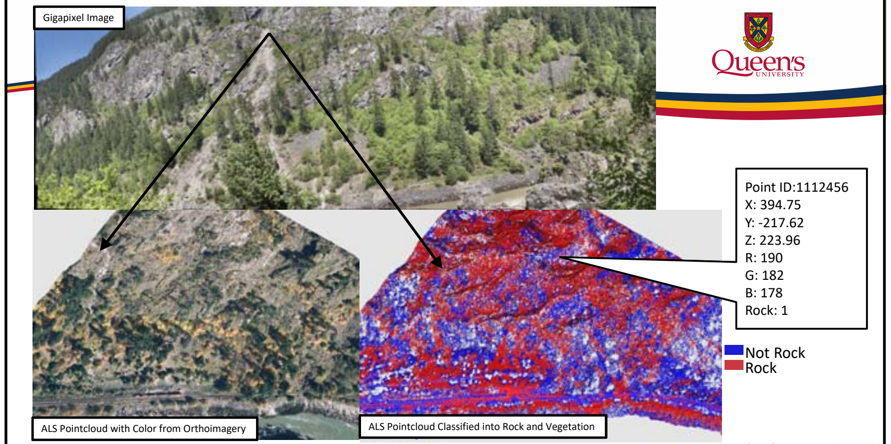




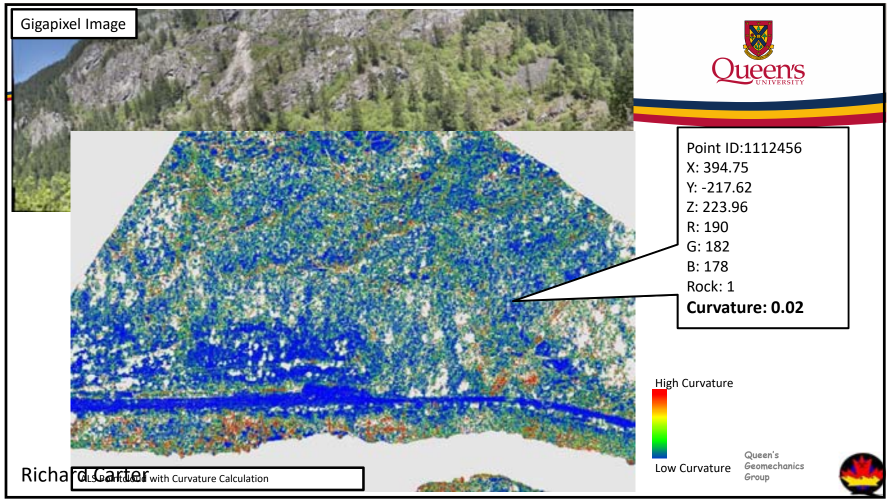
Kromer et al, 2017

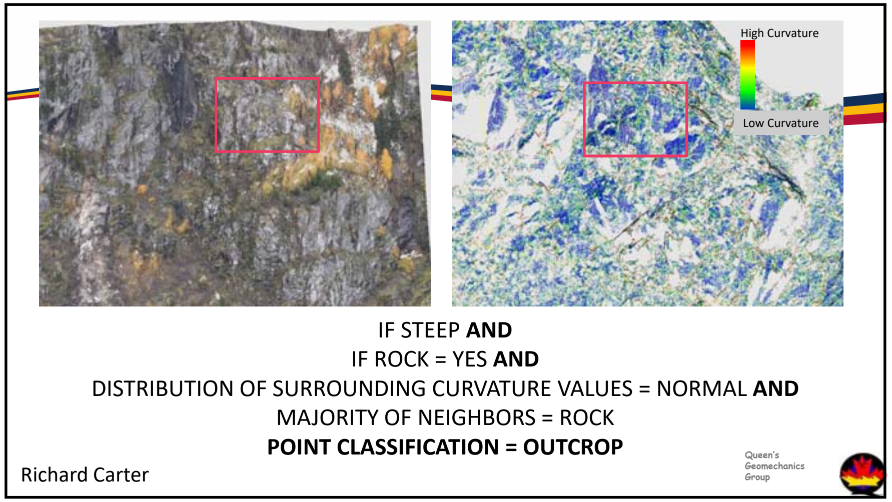


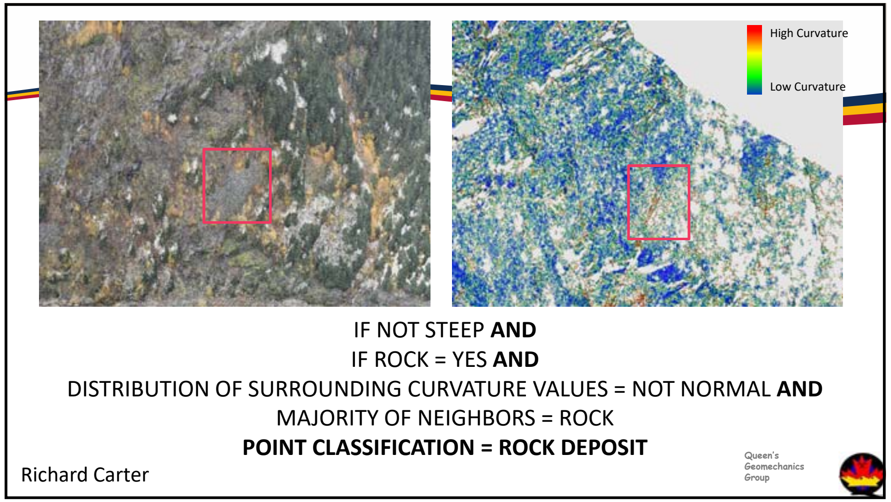
Gauthier, Strouth and Hutchinson, 2017

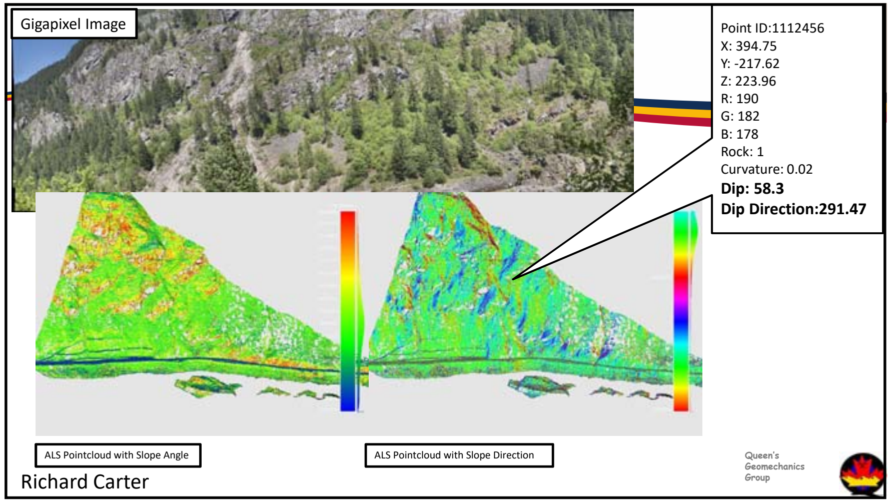


Richard Carter


Gigapixel Image
Queen's University
Point ID:1112456
X: 394.75
Y: -217.62
Z: 223.96
R: 190
G: 182
B: 178
Rock: 1
Curvature: 0.02
High Curvature
Low Curvature
ALS Pointcloud with Curvature Calculation
Richard Carter
Queen's Geomechanics Group


High Curvature
Low Curvature
IF STEEP AND
IF ROCK = YES AND
DISTRIBUTION OF SURROUNDING CURVATURE VALUES = NORMAL AND
MAJORITY OF NEIGHBORS = ROCK
POINT CLASSIFICATION = OUTCROP
Richard Carter
Queen's Geomechanics Group


High Curvature
Low Curvature
IF NOT STEEP AND
IF ROCK = YES AND
DISTRIBUTION OF SURROUNDING CURVATURE VALUES = NOT NORMAL AND
MAJORITY OF NEIGHBORS = ROCK
POINT CLASSIFICATION = ROCK DEPOSIT
Richard Carter
Queen's Geomechanics Group


Gigapixel Image
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Y: -217.62
Z: 223.96
R: 190
G: 182
B: 178
Rock: 1
Curvature: 0.02
Dip: 58.3
Dip Direction:291.47
ALS Pointcloud with Slope Angle
ALS Pointcloud with Slope Direction
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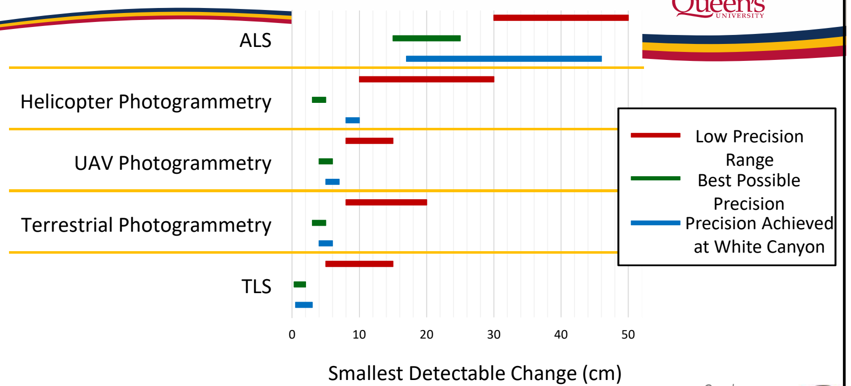
Conclusions

- Remotely sensed detailed 3-D geometrical models are superb data sets for slope stability analysis, particularly if:
  - Models taken from multiple vantage points are available,
  - Time sequential models can be compared.
- RS techniques are more versatile than ever before, due to:
  - High rate of acquisition of detailed data,
  - New techniques to build data sets, through intelligent and selective alignment processes,
  - Software packages readily available to work with data, and
  - Visualization tools to display the data easily.

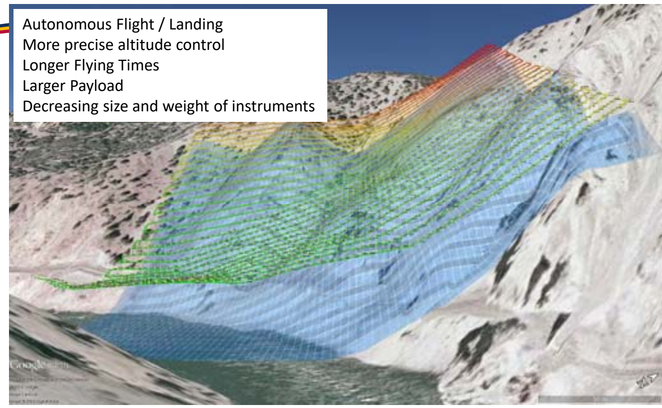
Conclusions

- Repeated scans of rock slopes allow:
  - Detection of very small, precursor changes, not sufficient to damage infrastructure, but as indicators of larger scale failure potential.
  - Detection of sub-cm scale deformation, permitting analysis of deformation rates over time, and type of movement whether accelerating, stick-slip, or steady state.
  - Forecast of impending rock slope failure.
  - Identification of rock slope failures at a wide range of volumes for analysis and for calibration data sets for new generation rockfall modelling.

Potential Precision by Method



Next steps – data collection



Next Steps

- Development of data processing methods to permit increasingly precise and accurate interpretation – underway by R. Kromer.
- Definition of appropriate methods, and frequency of scans, depending upon requirements: general review of rock slope instability or detailed geomorphological analysis – underway by A. Graham for rockfalls and D. Bonneau for debris channels.
- Expand change detection capabilities to larger scales, other forms of remote sensing, including aerial LiDAR – underway by R. Carter; and satellite based – underway by R. Hudson.
- Move towards pro-active rock slope risk management via monitoring and calibrated modelling – underway by Z. Sala.
- Detailed analysis of weather and climate impacts on frequency and magnitude of failure.

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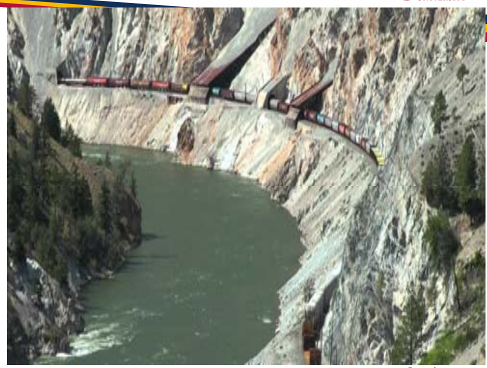
Thank you for your attention



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