Understanding slope stability through remote sensing

mlato@bgcengineering.ca

Our ability as scientist and engineers to understand the mechanics of our environment is critical to developing practical solutions. This ability is compromised when working on landslides where information is traditionally limited to costly sporadic borehole mapping and instrumentation data, discrete surface measurements and observations, and interpolated geophysical data.
*Advances in remote sensing technologies have enabled us to **observe**, **interpret**, and **understand** the physical environment at previously unimaginable levels of detail.*

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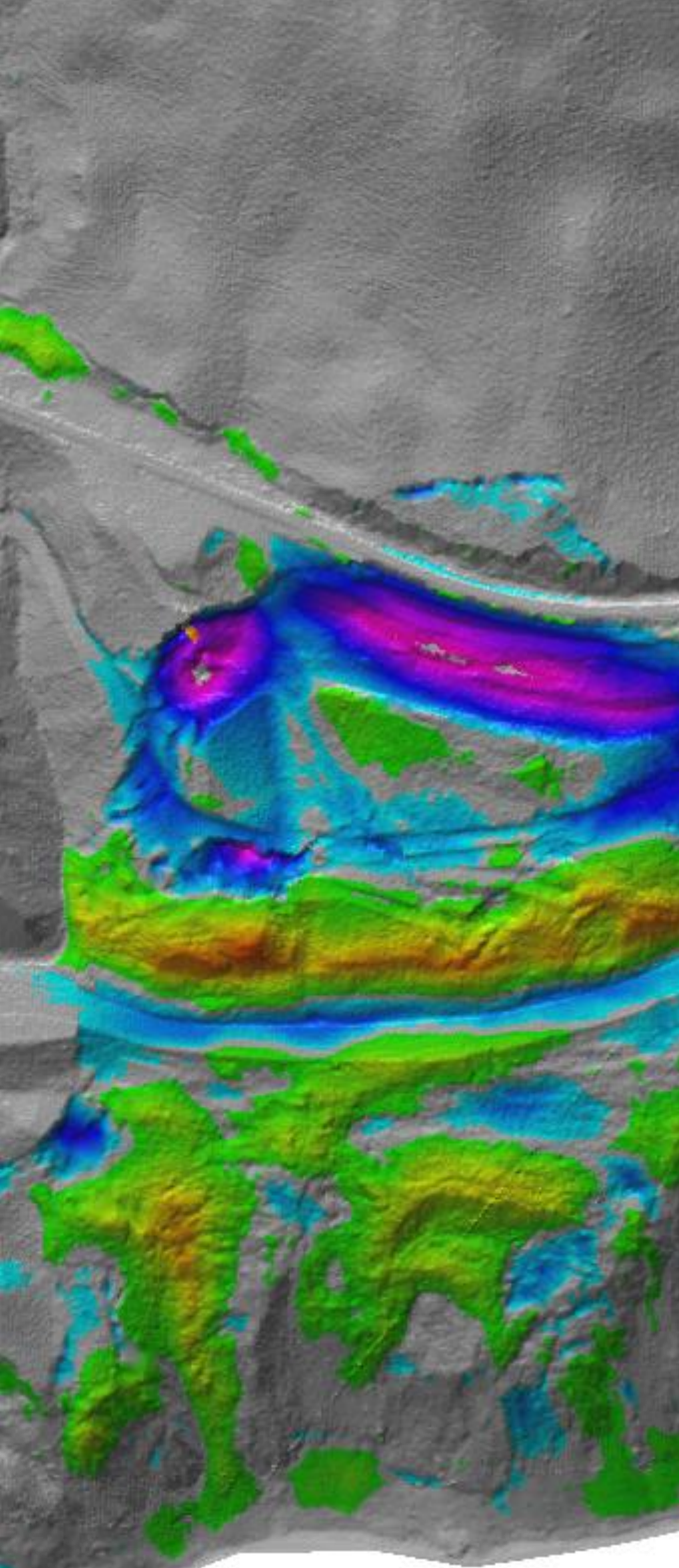
BGC

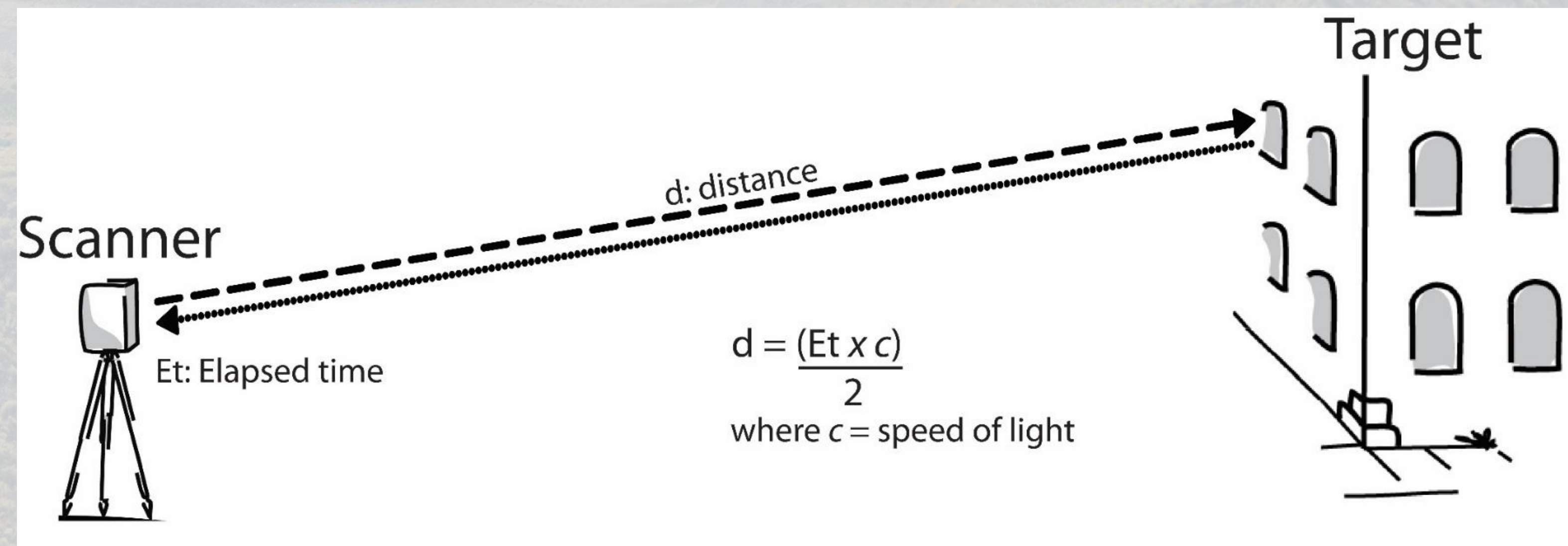


Understanding **Safety** **Accessibility** **Efficiency**

Technology, really nothing new

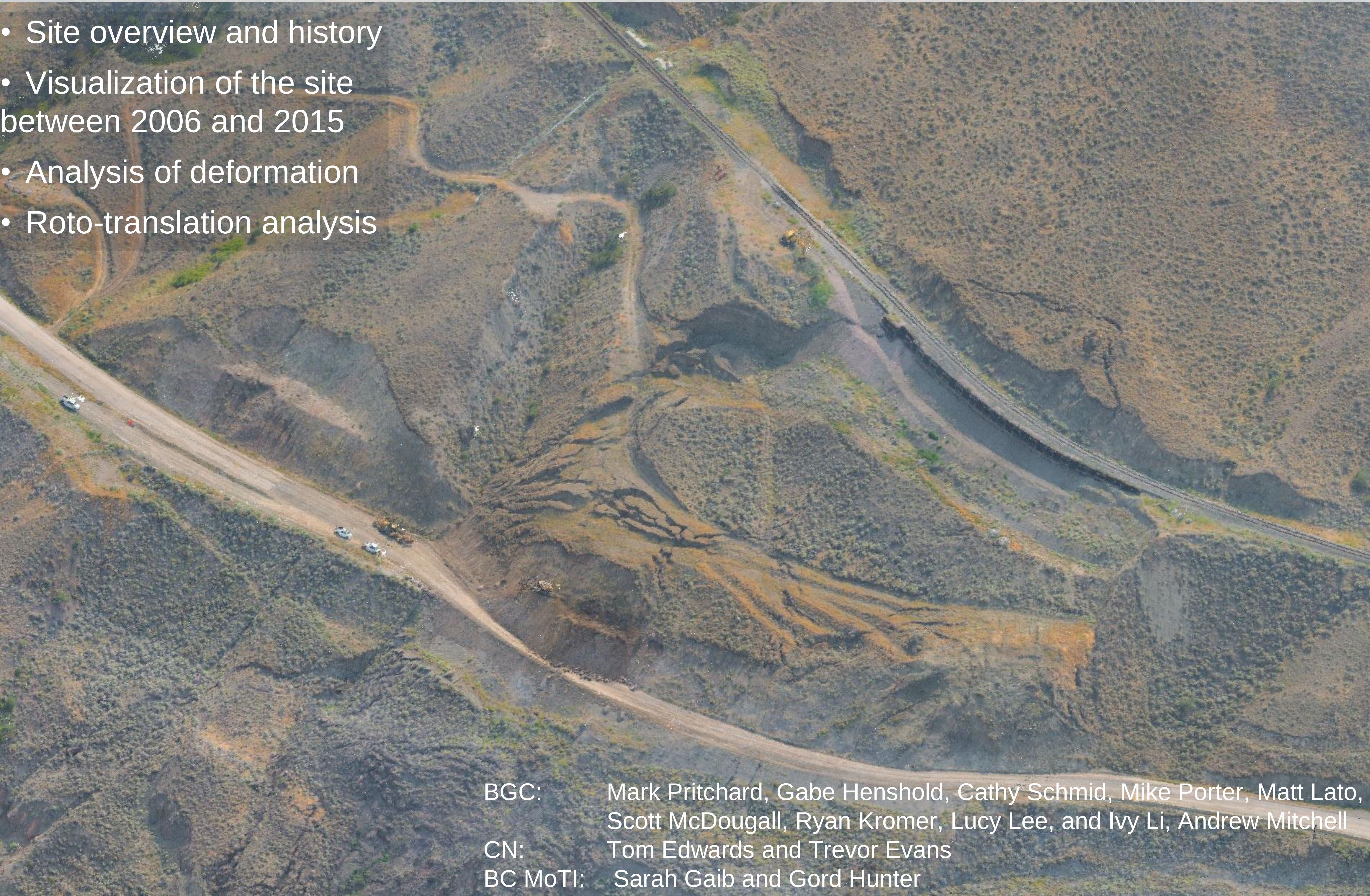
Unless you read The Economist, Jan 2nd to 8th 2016: A new remote sensing technology know as lidar can illuminate objects High up under the canopy and analyze them through reflected light

LiDAR: around since the 1960's
Significant advancements since the early 2000's



Photogrammetry: around since the 1840's
Significant advancements since the mid 2000's

Fountain Slide: An Overview



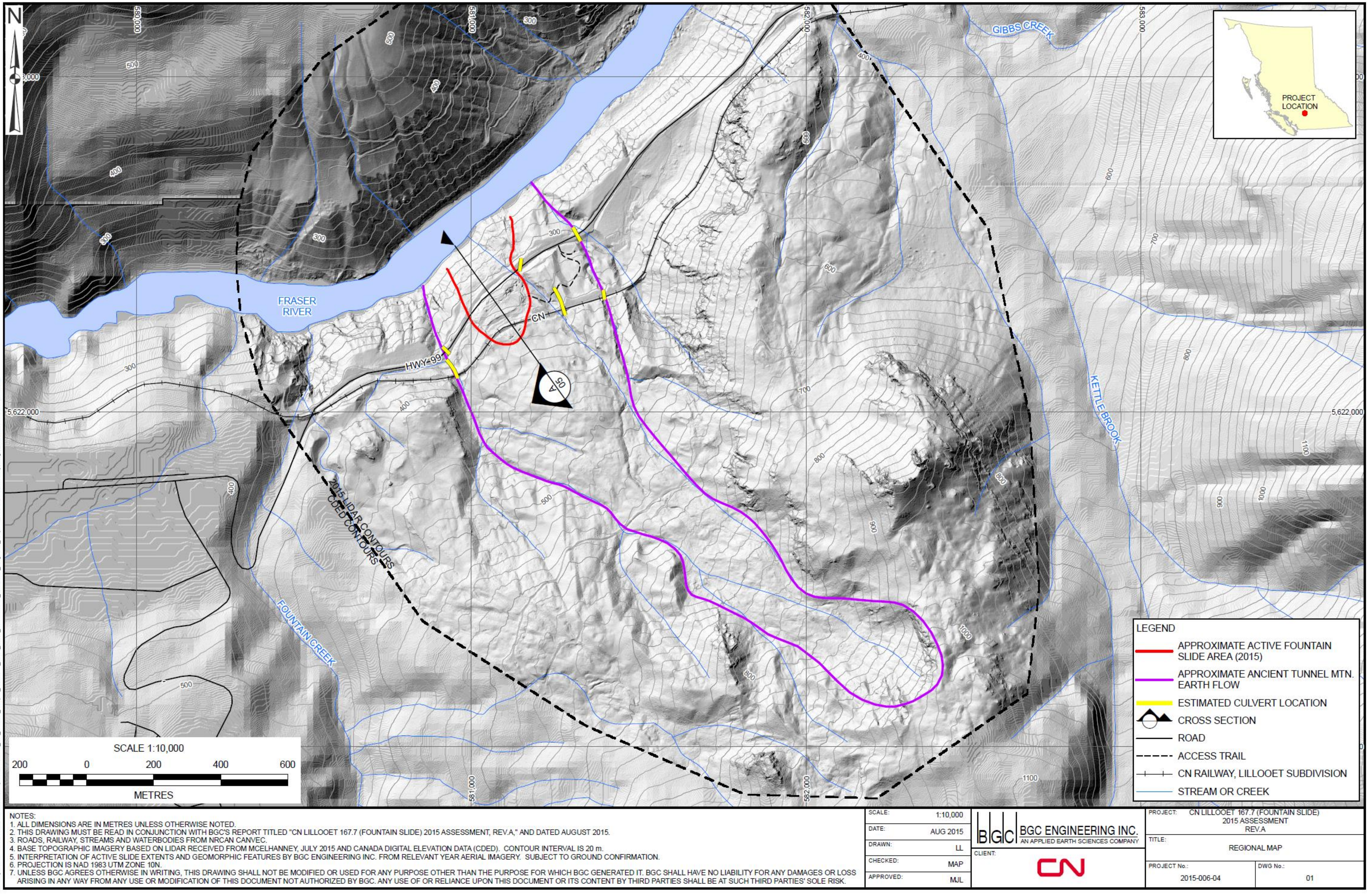
- Site overview and history
- Visualization of the site between 2006 and 2015
- Analysis of deformation
- Roto-translation analysis

BGC: Mark Pritchard, Gabe Henshold, Cathy Schmid, Mike Porter, Matt Lato, Scott McDougall, Ryan Kromer, Lucy Lee, and Ivy Li, Andrew Mitchell

CN: Tom Edwards and Trevor Evans

BC MoTI: Sarah Gaib and Gord Hunter

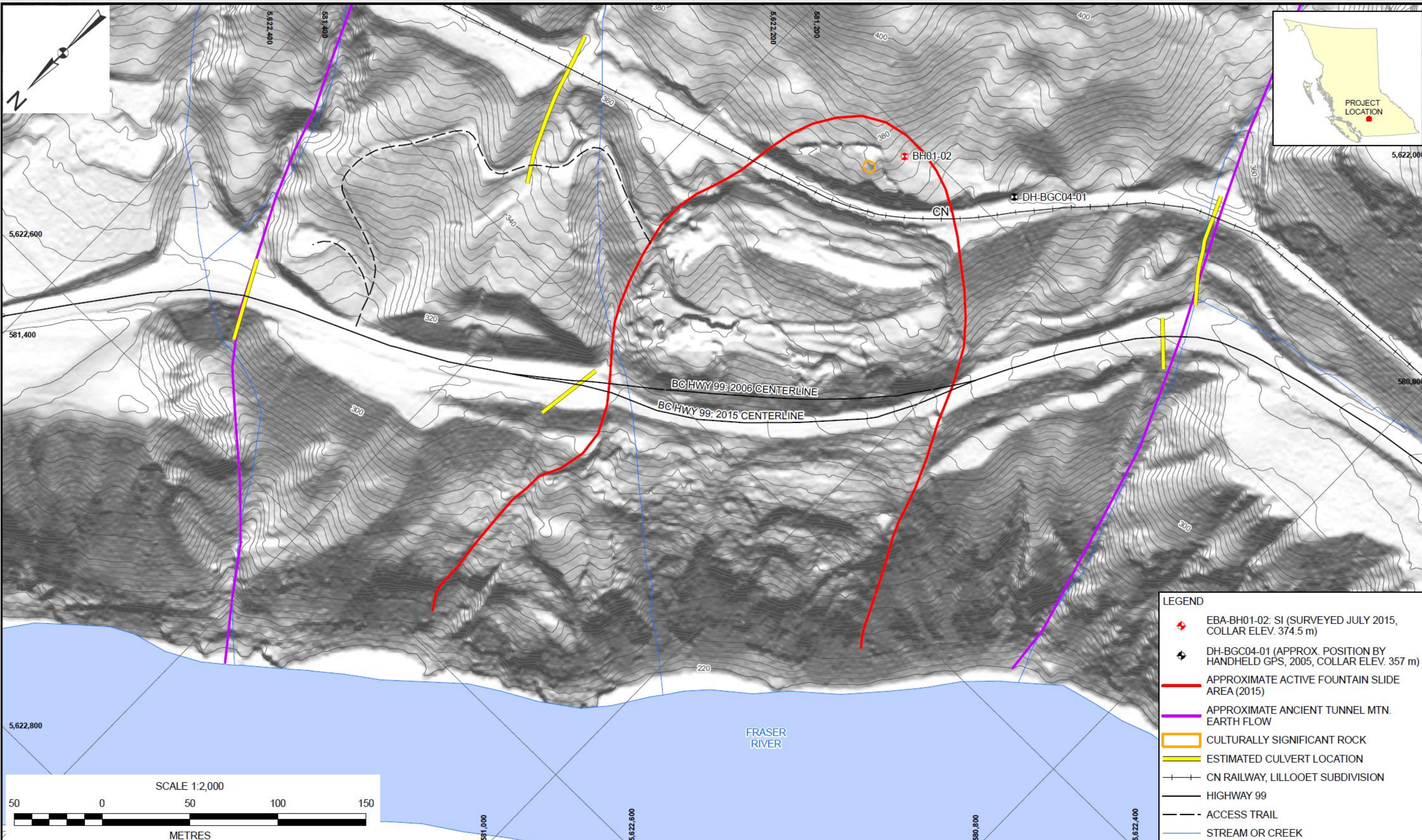
Overview


FRASER RIVER
CN
HWY 99
GIBBS CREEK
KETTLE BROOK
FOUNTAIN CREEK
2015 LIDAR CONTOURS
CDED CONTOURS
PROJECT LOCATION
LEGEND
APPROXIMATE ACTIVE FOUNTAIN SLIDE AREA (2015)
APPROXIMATE ANCIENT TUNNEL MTN. EARTH FLOW
ESTIMATED CULVERT LOCATION
CROSS SECTION
ROAD
ACCESS TRAIL
CN RAILWAY, LILLOOET SUBDIVISION
STREAM OR CREEK
SCALE 1:10,000
200 0 200 400 600
METRES
NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT, REV.A," AND DATED AUGUST 2015.
3. ROADS, RAILWAY, STREAMS AND WATERBODIES FROM NRCAN CANVEC.
4. BASE TOPOGRAPHIC IMAGERY BASED ON LIDAR RECEIVED FROM MCELHANNEY, JULY 2015 AND CANADA DIGITAL ELEVATION DATA (CDED). CONTOUR INTERVAL IS 20 m.
5. INTERPRETATION OF ACTIVE SLIDE EXTENTS AND GEOMORPHIC FEATURES BY BGC ENGINEERING INC. FROM RELEVANT YEAR AERIAL IMAGERY. SUBJECT TO GROUND CONFIRMATION.
6. PROJECTION IS NAD 1983 UTM ZONE 10N.
7. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.
SCALE: 1:10,000
DATE: AUG 2015
DRAWN: LL
CHECKED: MAP
APPROVED: MJL
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
CLIENT:
PROJECT: CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT REV.A
TITLE: REGIONAL MAP
PROJECT No.: 2015-006-04
DWG No.: 01

2012-2015 Events

- Fall of 2013 – accelerated movement noted above the CN rail line
- BGC completed LiDAR change detection for CN and oversaw geotechnical drilling of a single borehole in the inner ditch and installation of a slope inclinometer casing and 3 v.w. piezometers
  - September 14-16, 2015 Drilling and Instrument Installation
  - 38.4 m deep hole using a sonic rig
  - Shear surface between 17-18 m bgs (elevation 343-342 m)
  - Movement rate of ~6 mm/day

Overview



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3. ROADS, RAILWAY, STREAMS AND WATERBODIES FROM NRCAN CANVEC.
4. BASE TOPOGRAPHIC DATA BASED ON 2015 LIDAR RECEIVED FROM MCELHANNEY, JULY 2015. CONTOUR INTERVAL IS 2 m.
5. INTERPRETATION OF ACTIVE SLIDE EXTENTS AND GEOMORPHIC FEATURES BY BGC ENGINEERING INC. FROM RELEVANT YEAR AERIAL IMAGERY. SUBJECT TO GROUND CONFIRMATION.
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SCALE:	1:2,000
DATE:	AUG 2015
DRAWN:	LL
CHECKED:	MAP
APPROVED:	MJL

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: CN

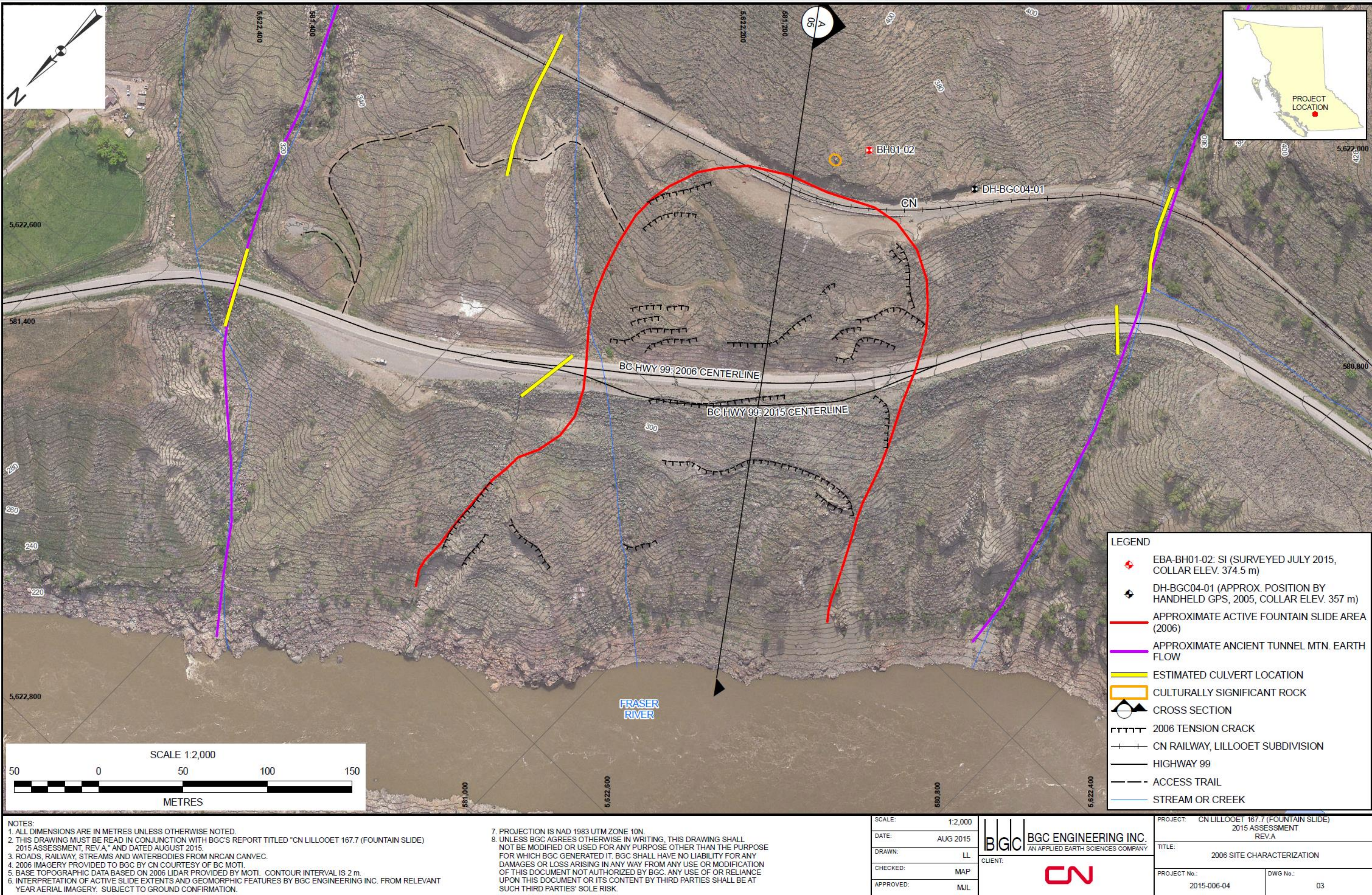
PROJECT: CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT REV.A

TITLE: FOUNTAIN SLIDE SITE PLAN

PROJECT No.: 2015-006-04

DWG No.: 02

Overview


PROJECT LOCATION
BH01-02
DH-BGC04-01
CN
BC HWY 99: 2006 CENTERLINE
BC HWY 99: 2015 CENTERLINE
FRASER RIVER
SCALE 1:2,000
50 0 50 100 150
METRES
LEGEND
EBA-BH01-02: SI (SURVEYED JULY 2015, COLLAR ELEV. 374.5 m)
DH-BGC04-01 (APPROX. POSITION BY HANDHELD GPS, 2005, COLLAR ELEV. 357 m)
APPROXIMATE ACTIVE FOUNTAIN SLIDE AREA (2006)
APPROXIMATE ANCIENT TUNNEL MTN. EARTH FLOW
ESTIMATED CULVERT LOCATION
CULTURALLY SIGNIFICANT ROCK
CROSS SECTION
2006 TENSION CRACK
CN RAILWAY, LILLOOET SUBDIVISION
HIGHWAY 99
ACCESS TRAIL
STREAM OR CREEK
NOTES:
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3. ROADS, RAILWAY, STREAMS AND WATERBODIES FROM NRCAN CANVEC.
4. 2006 IMAGERY PROVIDED TO BGC BY CN COURTESY OF BC MOTI.
5. BASE TOPOGRAPHIC DATA BASED ON 2006 LIDAR PROVIDED BY MOTI. CONTOUR INTERVAL IS 2 m.
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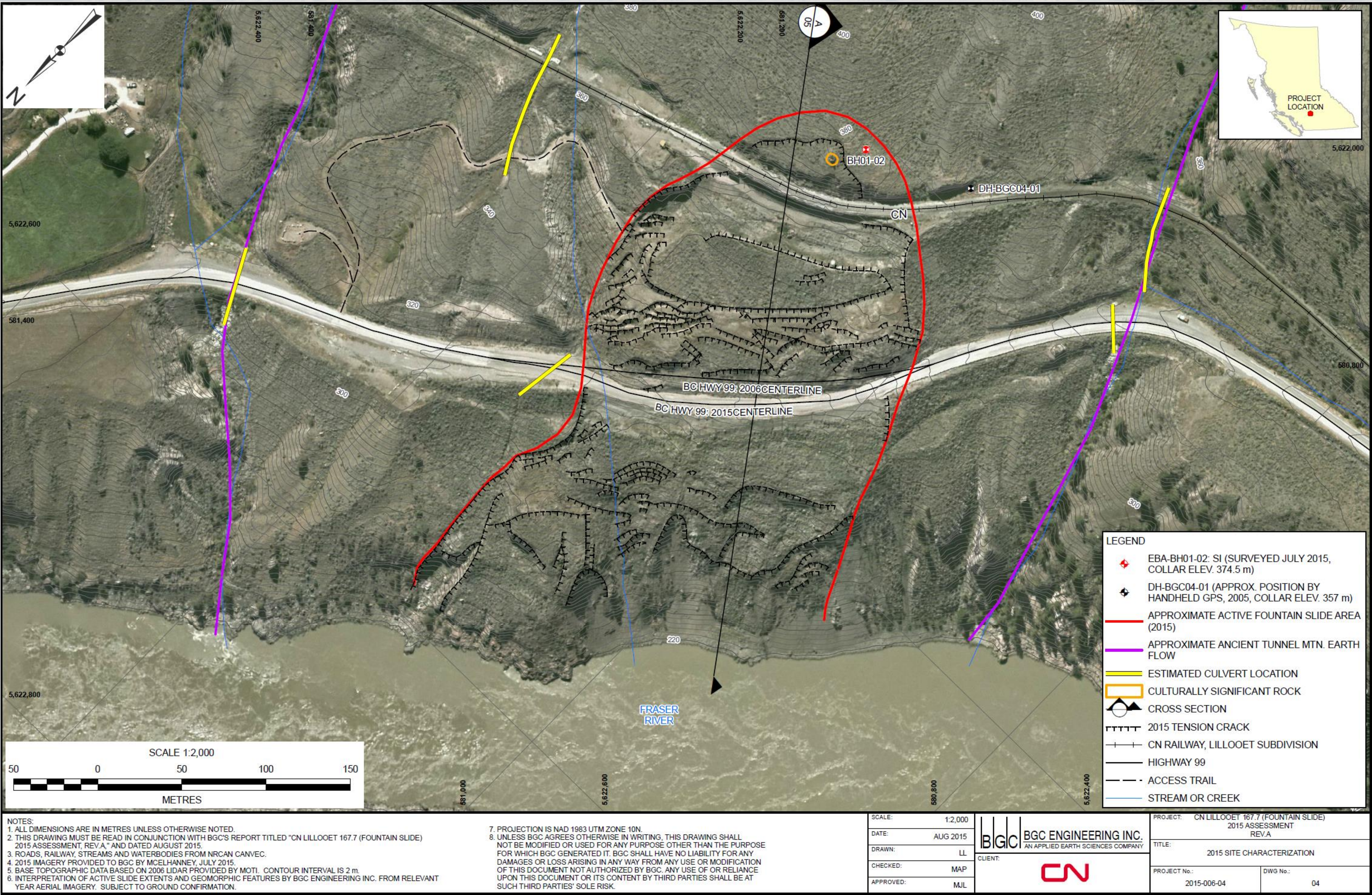
SCALE: 1:2,000
DATE: AUG 2015
DRAWN: LL
CHECKED: MAP
APPROVED: MJL
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
CLIENT:
PROJECT: CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT REV.A
TITLE: 2006 SITE CHARACTERIZATION
PROJECT No.: 2015-006-04
DWG No.: 03

Overview


BH01-02
DH-BGC04-01
CN
BC HWY 99: 2006CENTERLINE
BC HWY 99: 2015CENTERLINE
FRASER RIVER
PROJECT LOCATION
A
05
SCALE 1:2,000
50 0 50 100 150
METRES
LEGEND
EBA-BH01-02: SI (SURVEYED JULY 2015, COLLAR ELEV. 374.5 m)
DH-BGC04-01 (APPROX. POSITION BY HANDHELD GPS, 2005, COLLAR ELEV. 357 m)
APPROXIMATE ACTIVE FOUNTAIN SLIDE AREA (2015)
APPROXIMATE ANCIENT TUNNEL MTN. EARTH FLOW
ESTIMATED CULVERT LOCATION
CULTURALLY SIGNIFICANT ROCK
CROSS SECTION
2015 TENSION CRACK
CN RAILWAY, LILLOOET SUBDIVISION
HIGHWAY 99
ACCESS TRAIL
STREAM OR CREEK
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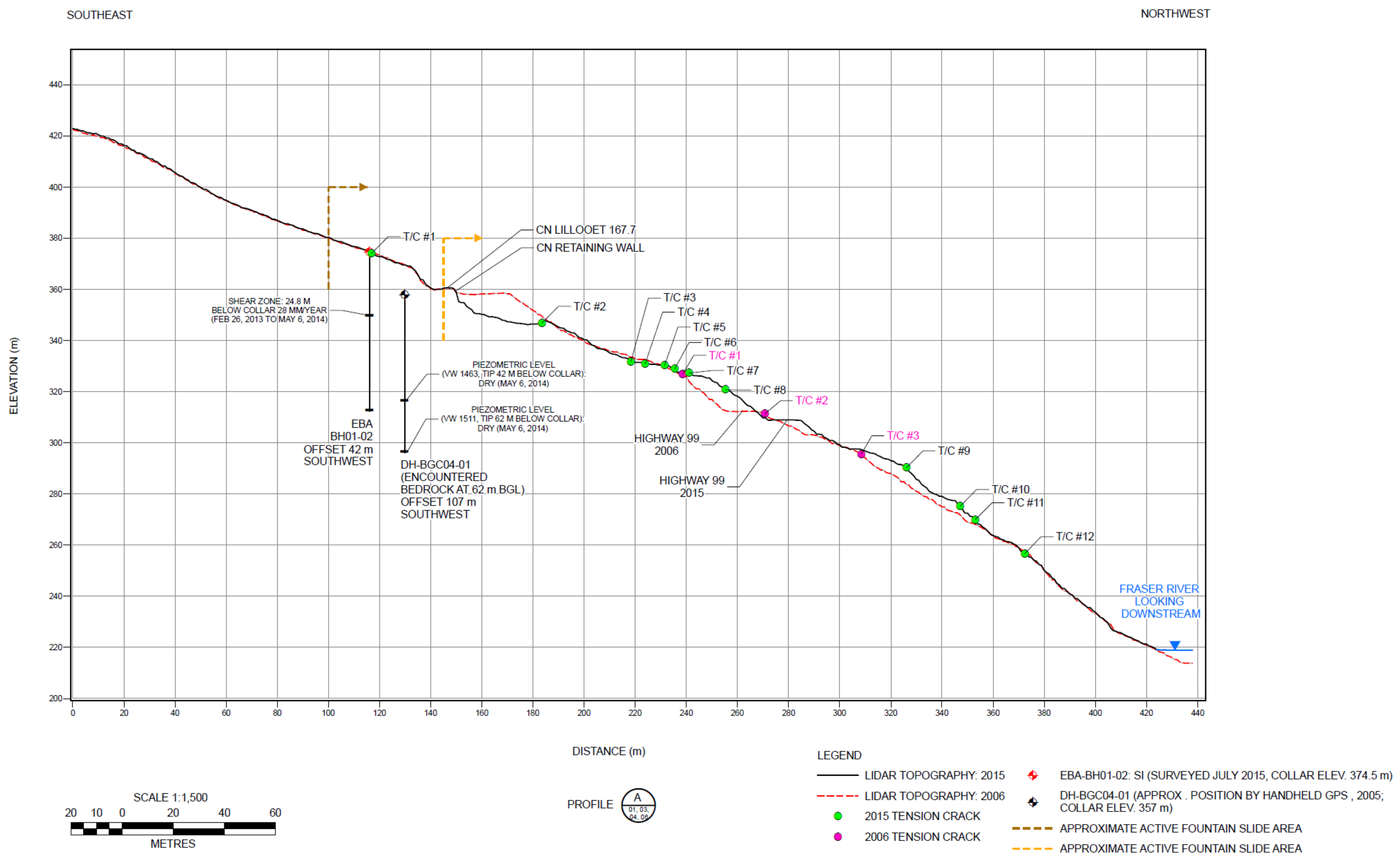
SCALE: 1:2,000
DATE: AUG 2015
DRAWN: LL
CHECKED: MAP
APPROVED: MJL
BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY
CLIENT:
CN
PROJECT: CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT REV.A
TITLE: 2015 SITE CHARACTERIZATION
PROJECT No.: 2015-006-04
DWG No.: 04

Profile Analysis



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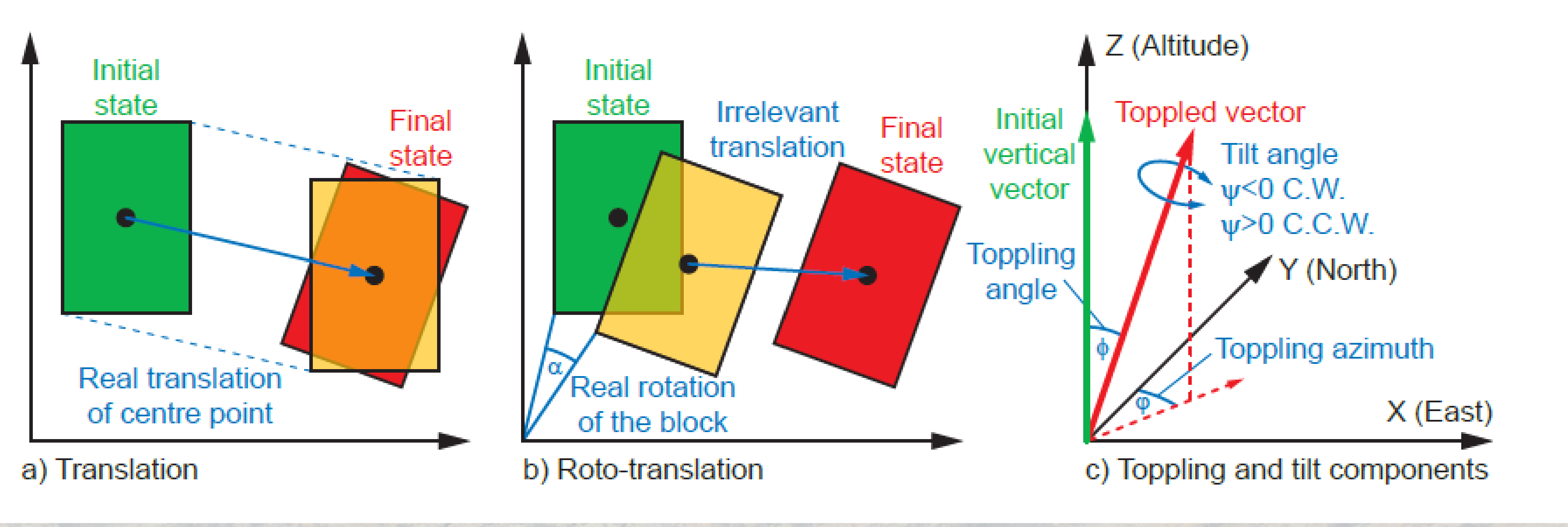
SCALE: 1:1,500	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY	PROJECT: CN LILLOOET 167.7 (FOUNTAIN SLIDE) 2015 ASSESSMENT REV.A		
DATE: AUG 2015		TITLE: PROFILE A-A'		
DRAWN: LL	CLIENT: CN	PROJECT No.: 2015-006-04	DWG No.: 05	
CHECKED: MAP				
APPROVED: MJL				

Rotation-Translation Analysis

Rigid body deformation analysis
Track blocks through space and time



Characterization and monitoring of the Åknes rockslide using terrestrial laser scanning

T. Oppikofer[1], M. Jaboyedoff[1], L. Blikra[2,3], M.-H. Derron[3], and R. Metzger[1]

[1]Institute of Geomatics and Analysis of Risk (IGAR), University of Lausanne, Switzerland
[2]Åknes/Tafjord Project, Stranda, Norway
[3]Geological Survey of Norway (NGU), Trondheim, Norway

Received: 7 January 2009 – Revised: 5 June 2009 – Accepted: 5 June 2009 – Published: 26 June 2009

Monserrat, O., and Crosetto, M.: Deformation measurement using terrestrial laser scanning data and least squares 3-D surface matching, ISPRS J. Photogramm., 63, 142–154, 2008.

CN Ashcroft MP 109.4

Forecasting rock fall…words that were banished from my vocabulary

Queen's: Ryan Kromer, Jean Hutchinson
BGC: Matt Lato, Dave Gauthier, Mark Pritchard
CN: Tom Edwards and Trevor Evans

Can we forecast rock fall location, volume and time?

- **Hypothesis, part 1:** Rock fall slope failures have precursor deformation

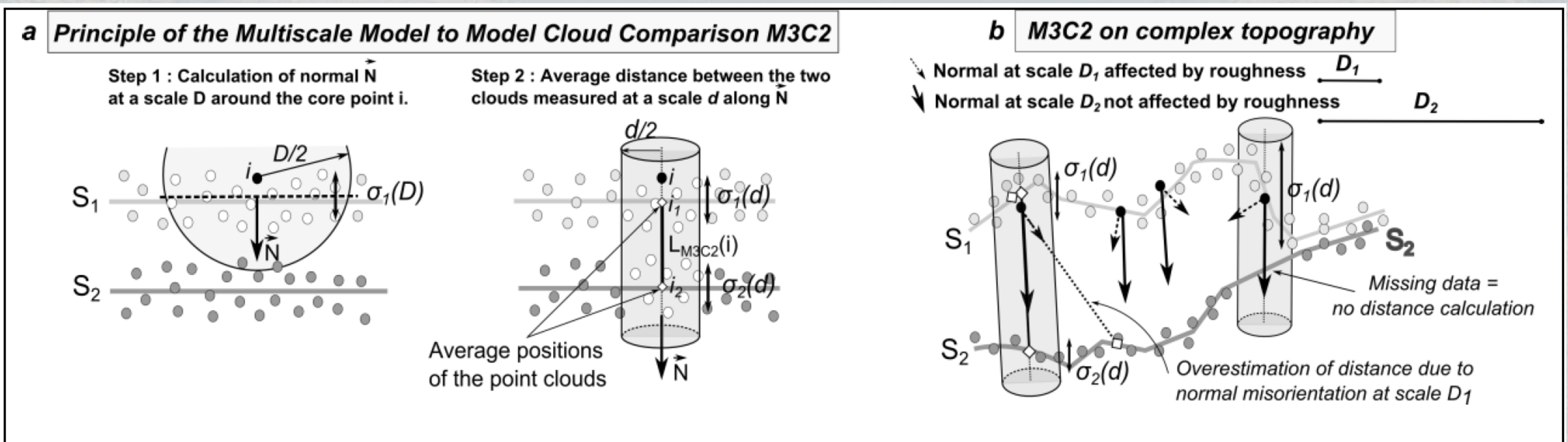
- **Hypothesis, part 2:** Rock fall source zones and volumes can be predicted (months) prior to failure

Project Test Site: Ashcroft MP 109.4

- 200 km from Vancouver, 50 km north of Hope on the Trans Canada (Jackass Mountain)
- Numerous rock fall failures
  - 50k m^3 rock fall Closed the railway for 4 days in December 2012
- TLS data collection began in December 2013

Project Test Site: Ashcroft MP 109.4

- Filtered change detection algorithm proposed by: Lague et al. (2013)



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Accurate 3D comparison of complex topography with terrestrial laser scanner : application to the Rangitikei canyon (N-Z)

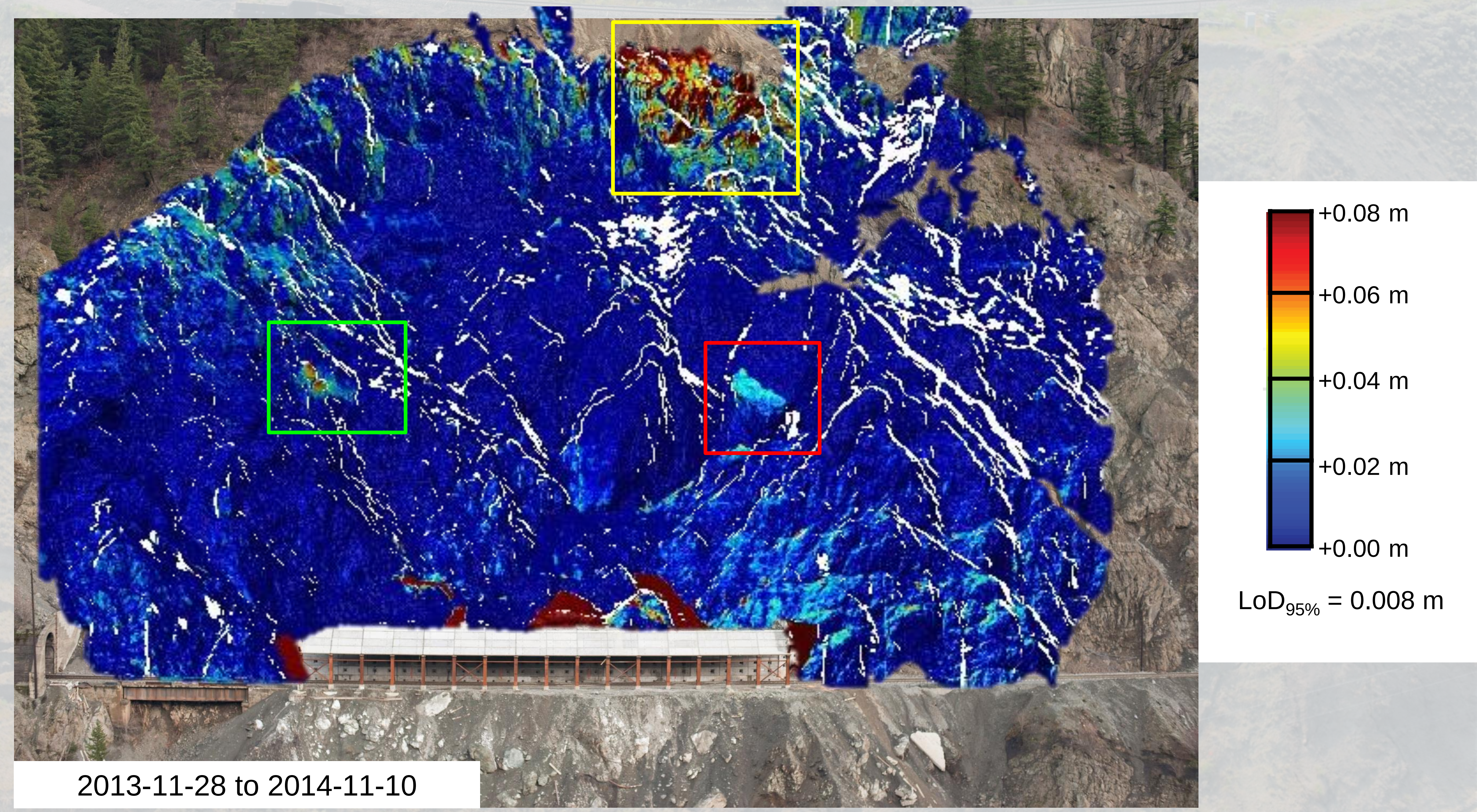
Dimitri Lague[1,2], Nicolas Brodu[3], Jérôme Leroux[1]

1: Géosciences Rennes, Université Rennes 1, CNRS, Campus de Beaulieu, 35042 Rennes, France. Email: Dimitri.Lague@univ-rennes1.fr, tel: +33 2 2323 56 53, fax: +33 2 2323

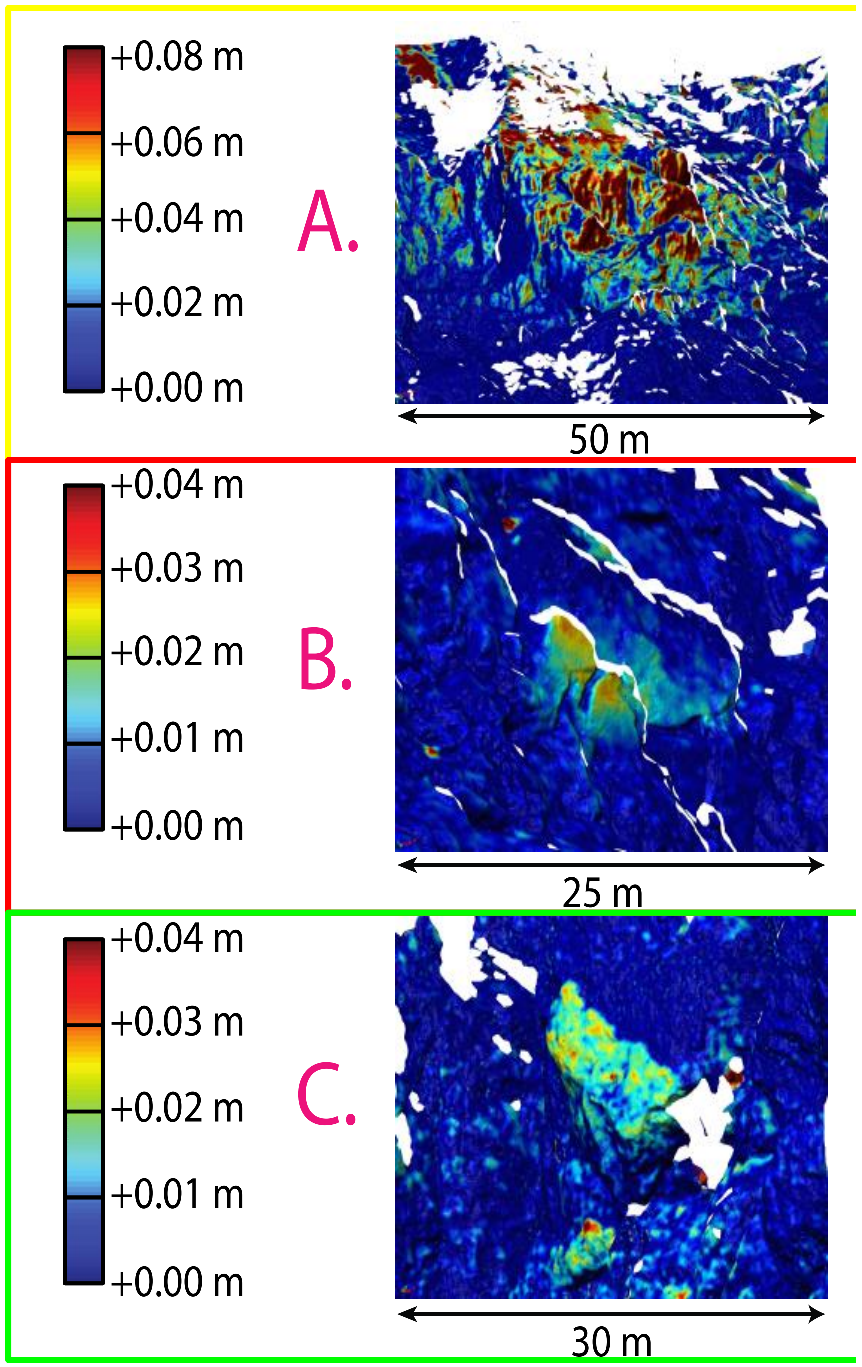
2: Dpt of Geological Sciences, University of Canterbury, Christchurch, New-Zealand.

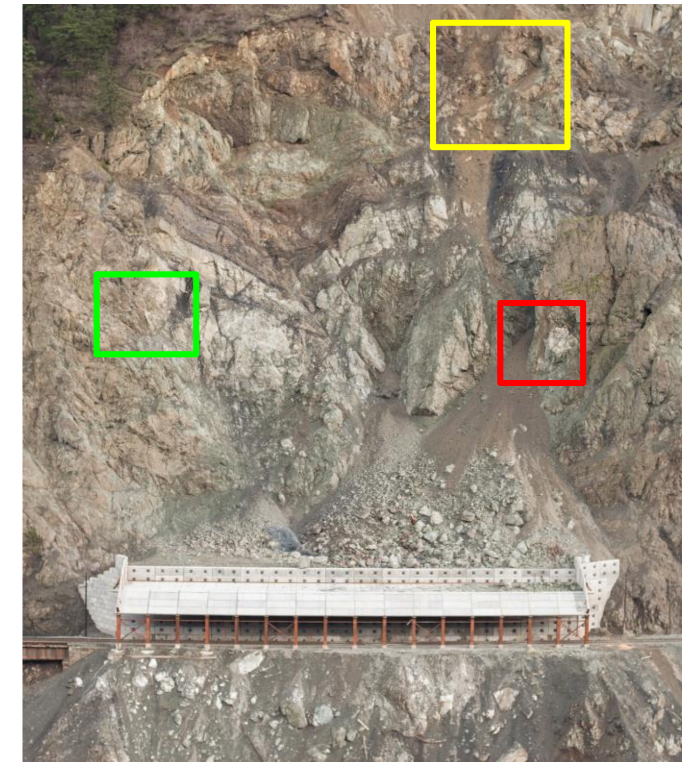
3: Institut de Physique de Rennes, Université Rennes 1, CNRS, Campus de Beaulieu, 35042 Rennes, France.

After eight months of monitoring



Temporal Analysis

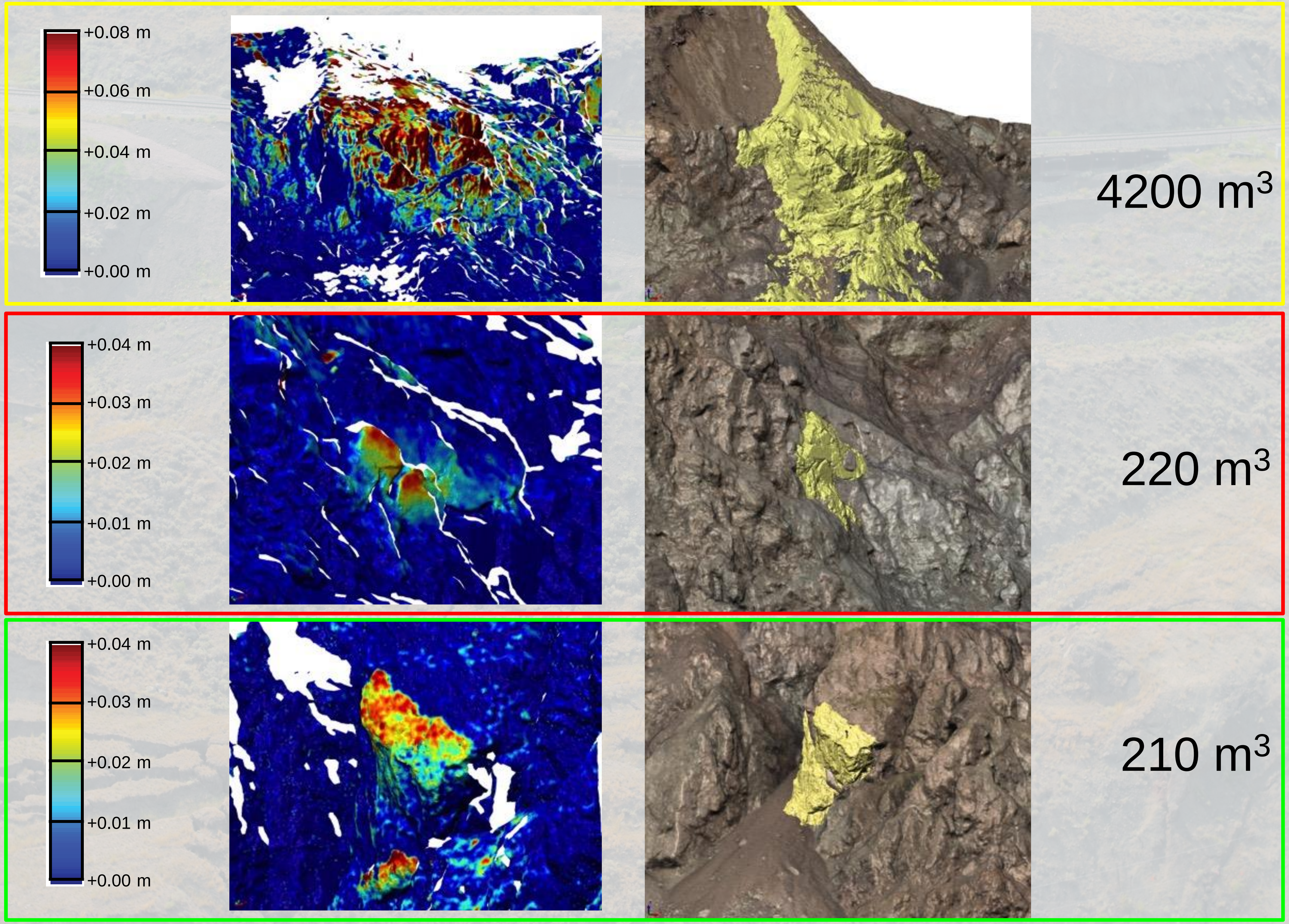




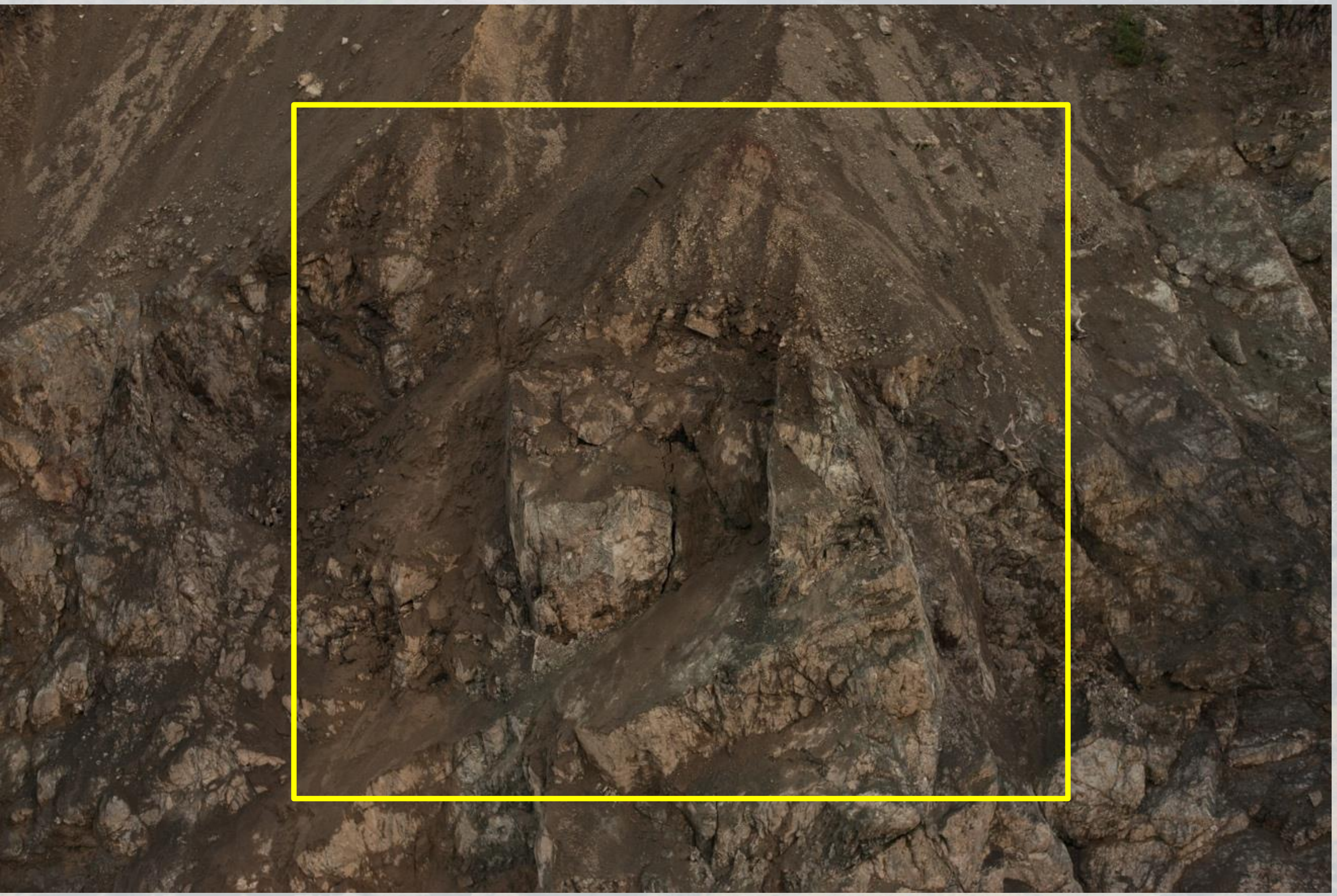
Early Warning

- June 2014: first signs of rock block deformation were detected
- September 2014: deformation was confirmed, signs of advancement were identified
- September 2014: Estimated volumes and locations of source zones provided to CN
- December 2014: Failure of three identified source zones

Post Failure Assessment



Failure Event



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Conclusions

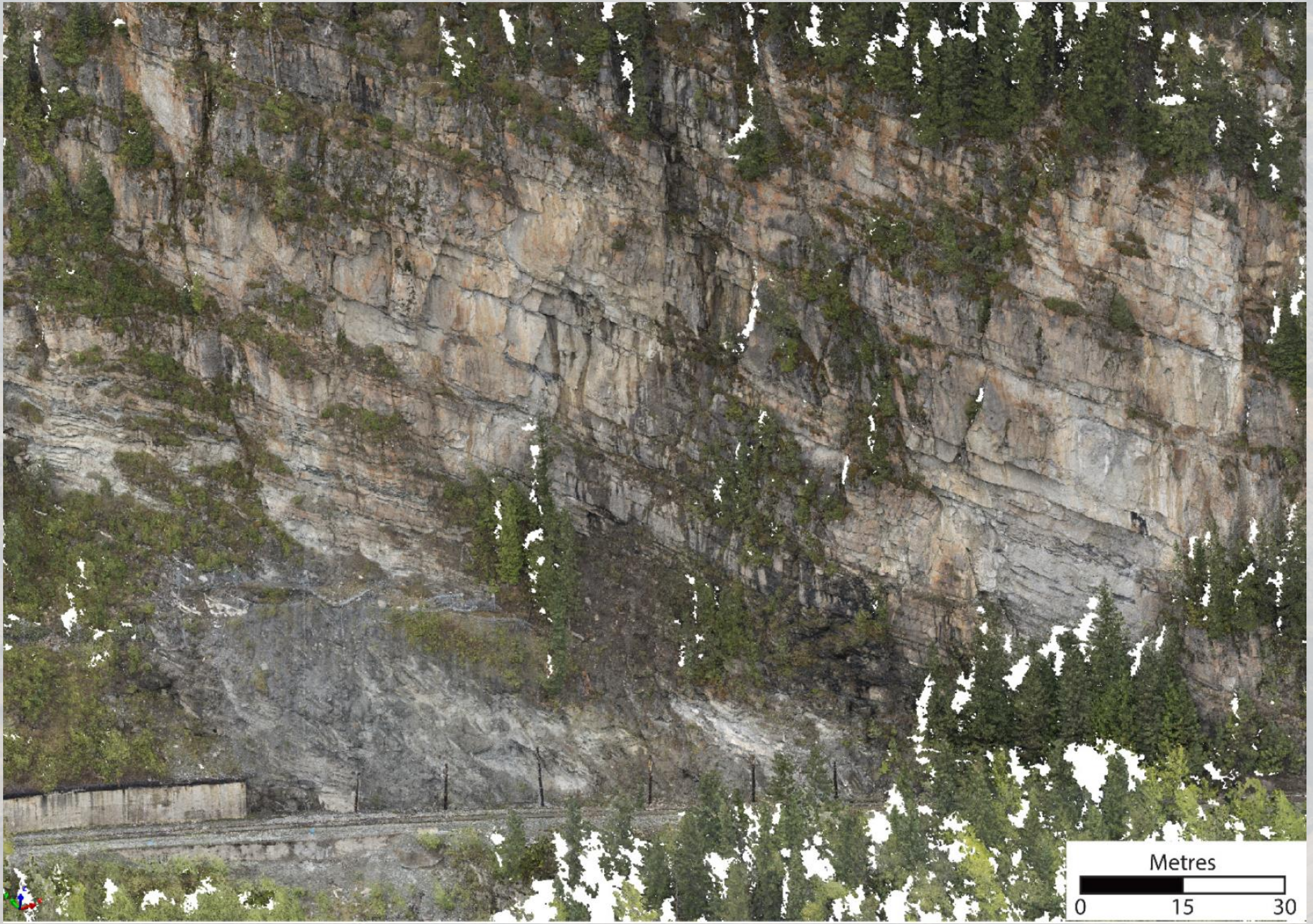
- Using terrestrial LiDAR without ground control sub-cm level deformation can be mapped
- Rock fall failures with traditionally undetectable pre-failure deformation can be detected
- We have numerous (>20) case studies of this technique ranging from $1 m^3$ to $5000 m^3$ failures
- New developments by Ryan Kromer are demonstrating $LoD_{95\%}$ at 2 mm

CN Albreda MP 55.3 (Robson Valley)

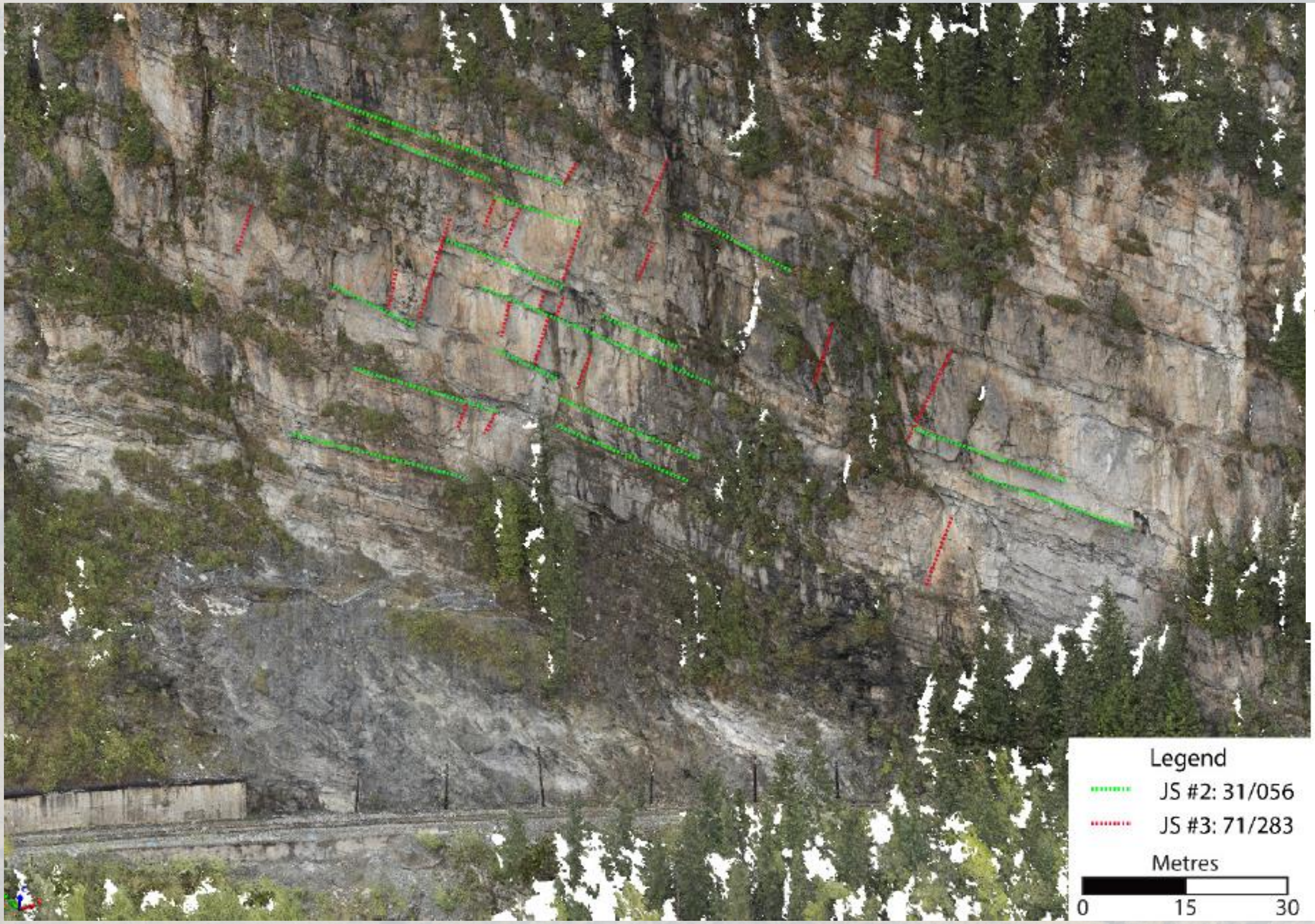
Understanding rock fall potential
for designing mitigation

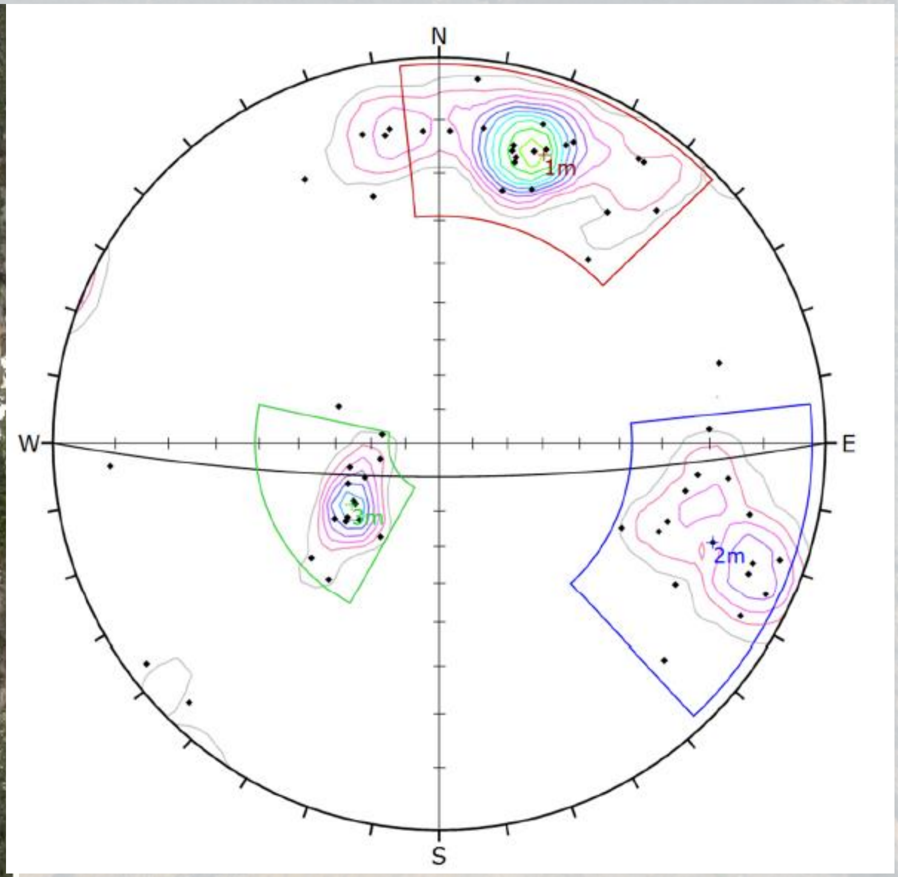
Pre-BGC: Matt Lato, Dave Gauthier, Mark Diederichs, Jean Hutchinson
CN: Tom Edwards and Trevor Evans

CN Albreda MP 55.3

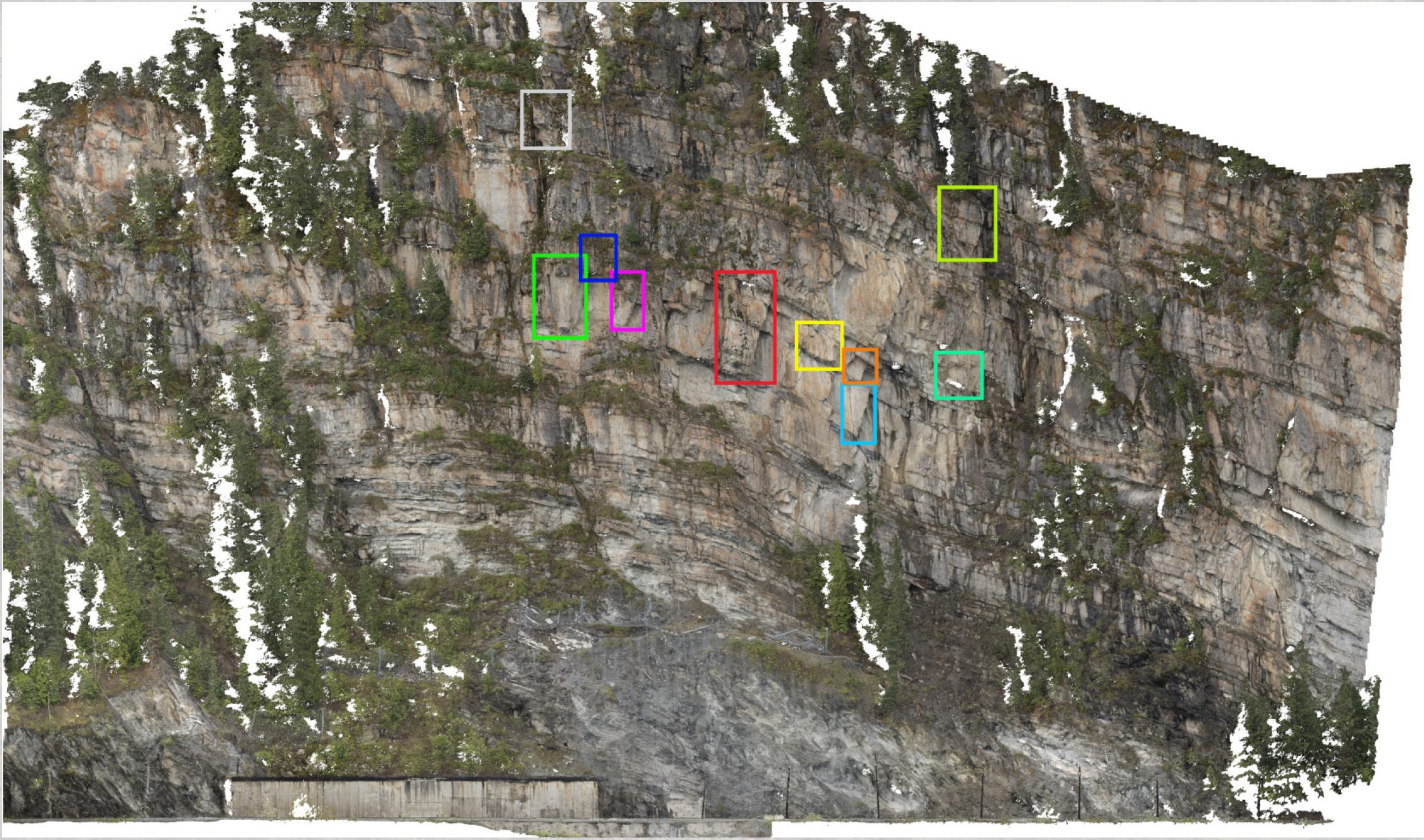


CN Albreda MP 55.3: Kinematics

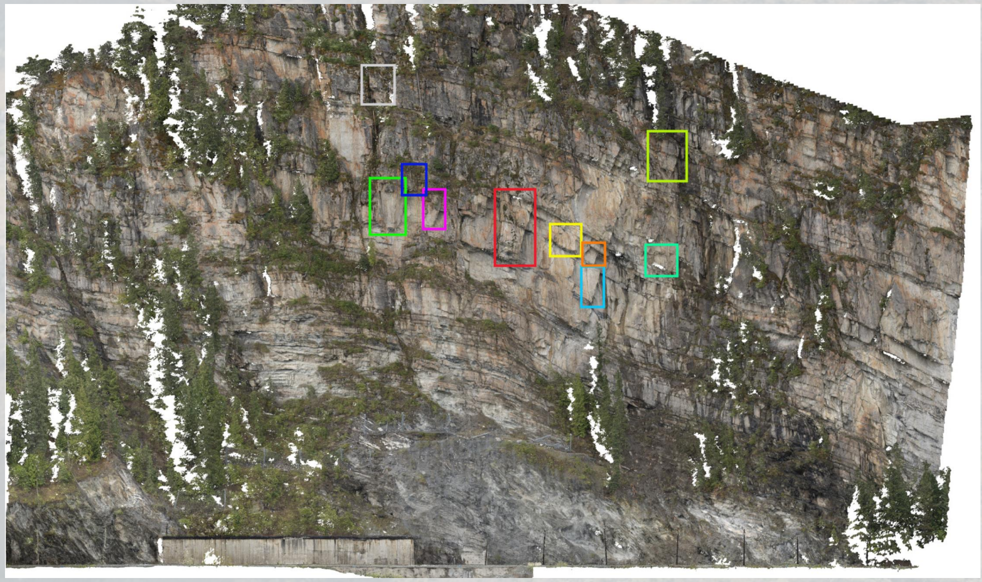


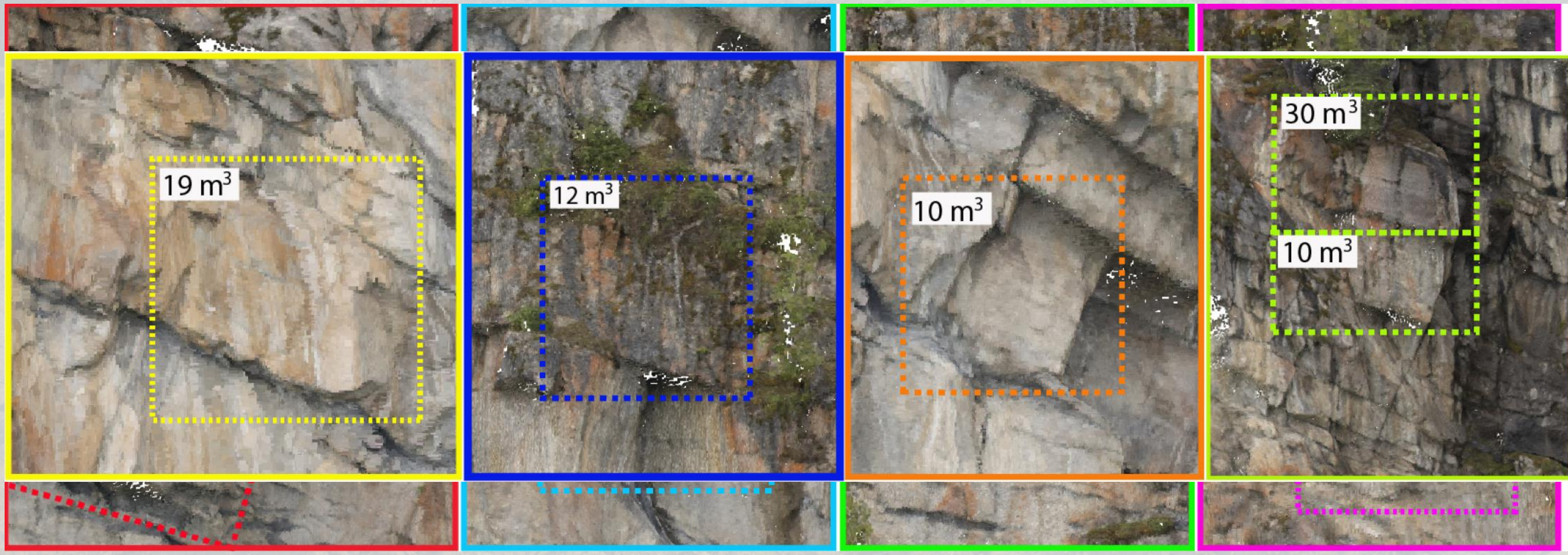


CN Albreda MP 55.3: The 'big-blocks'



CN Albreda MP 55.3: The ‘big-blocks’





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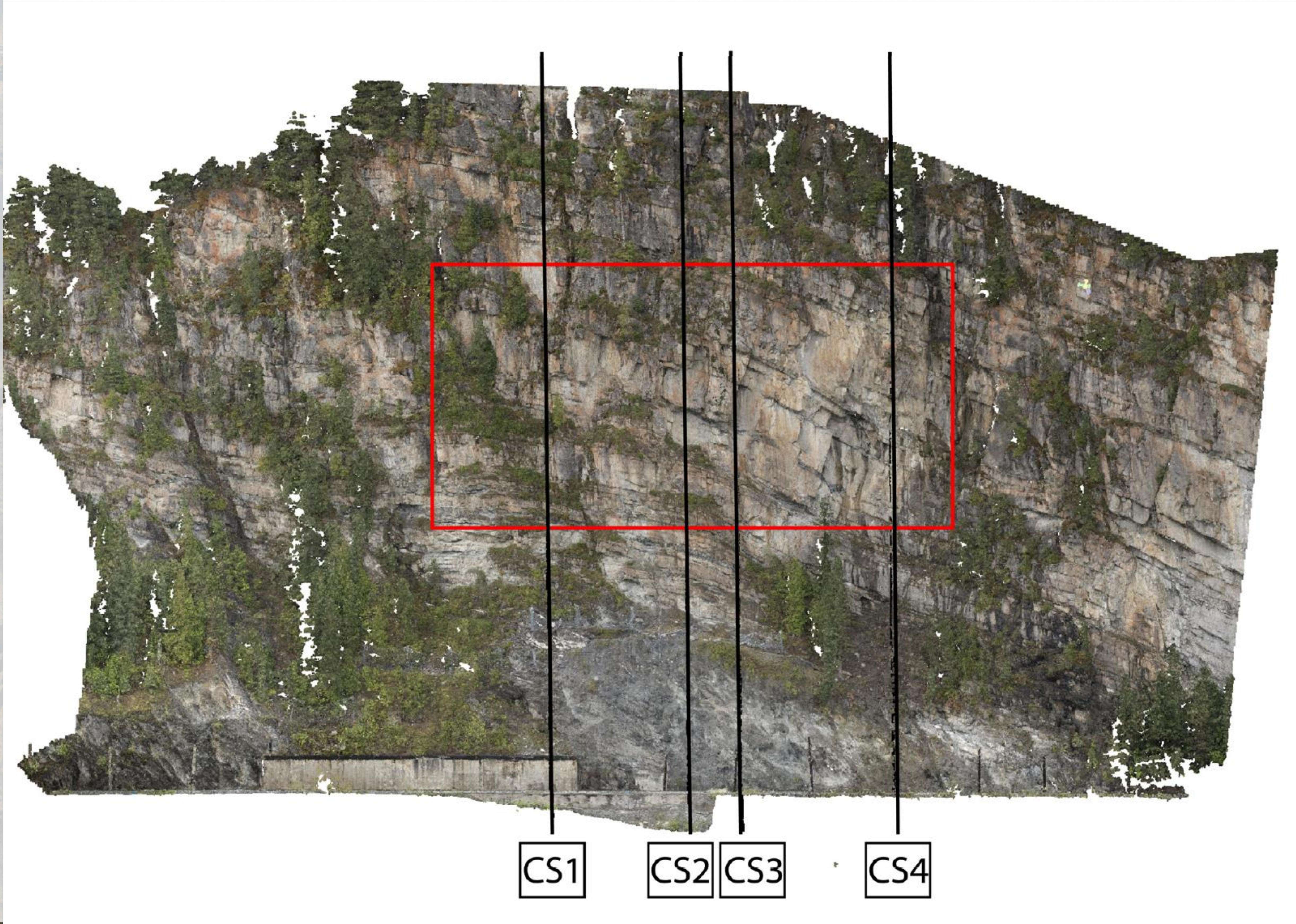
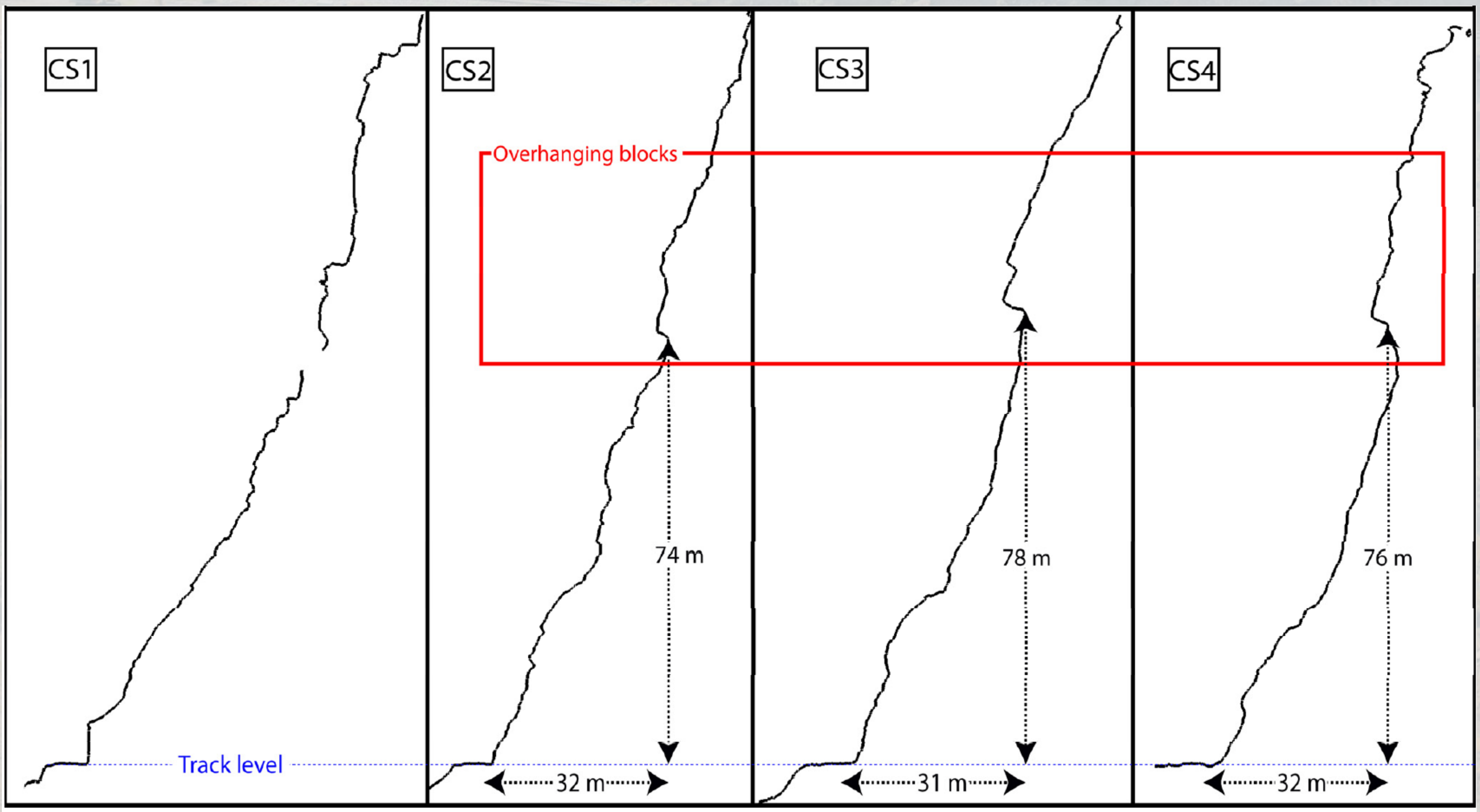
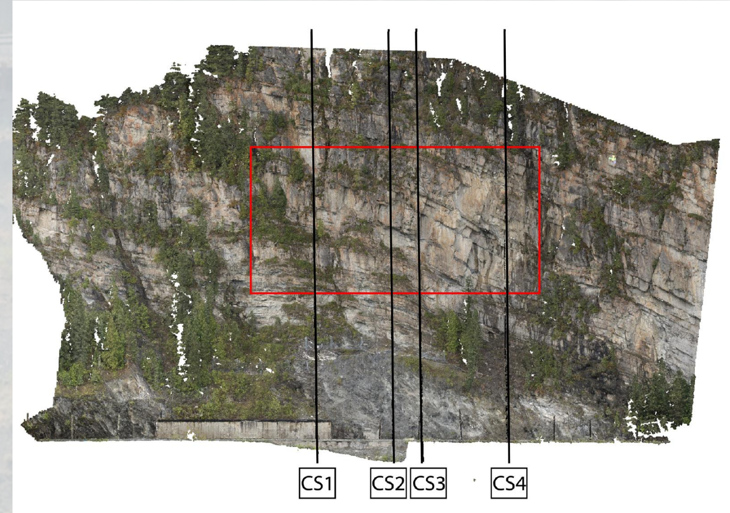
CN Albreda MP 55.3: Source Zones



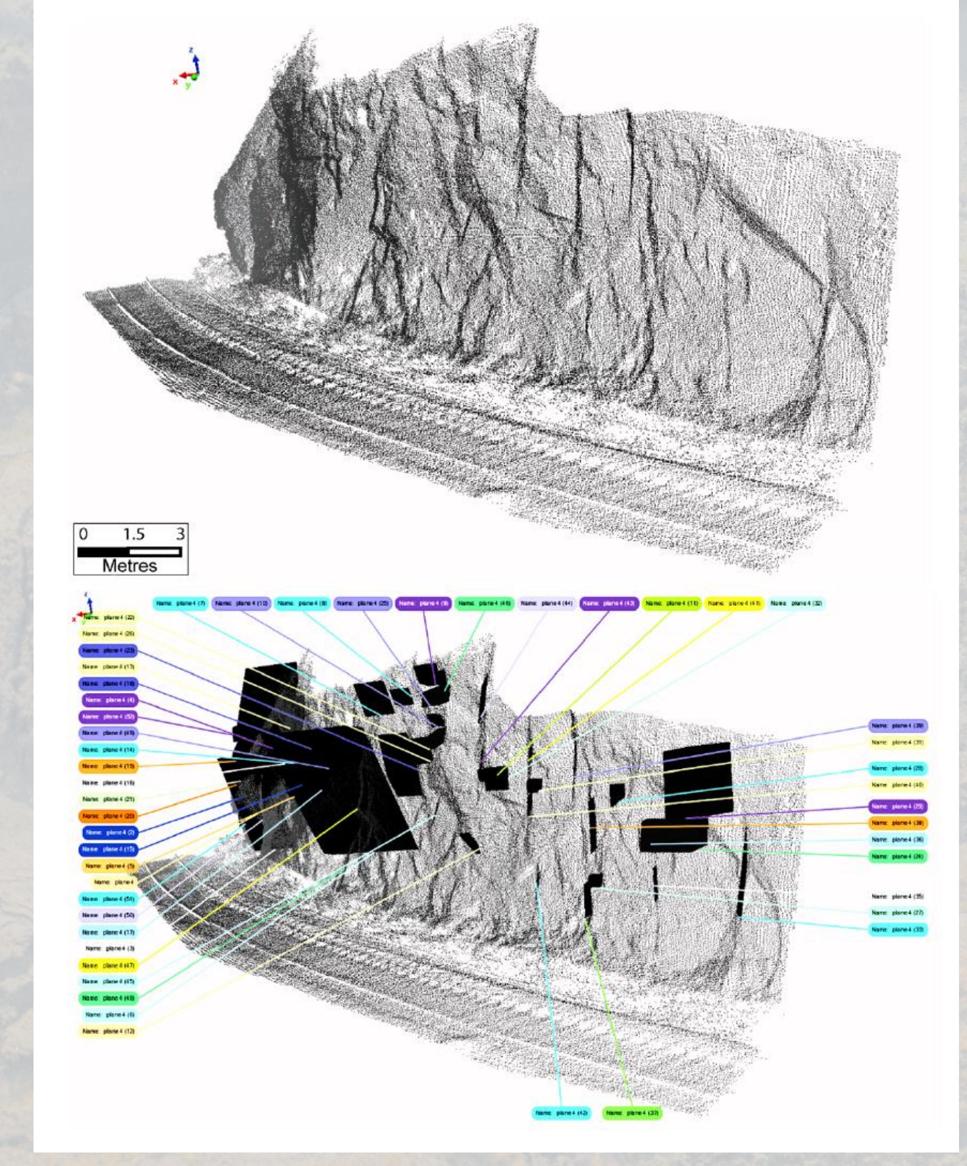
CN Albreda MP 55.3: Source Zones



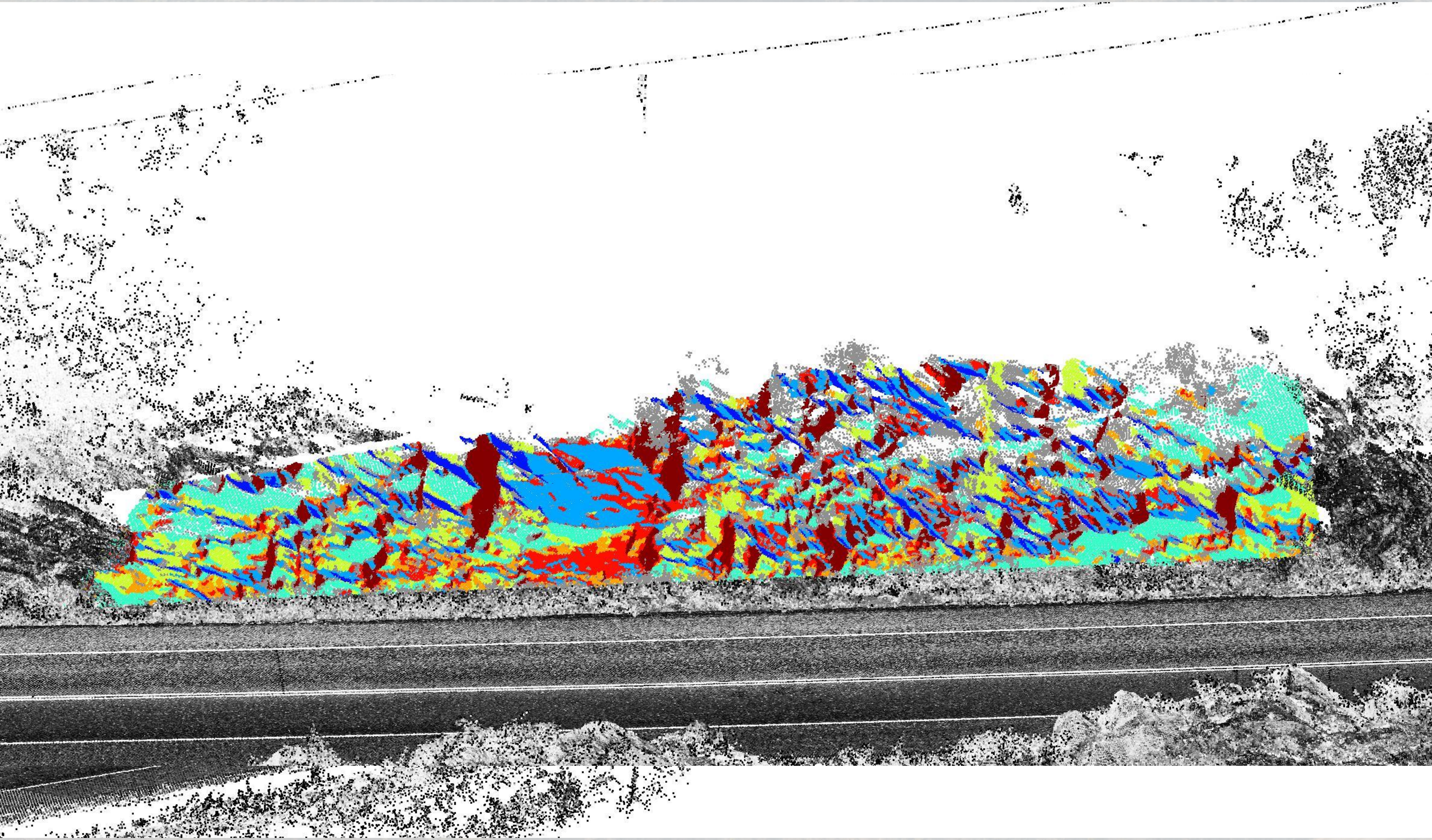


One Last Example…back in 2008

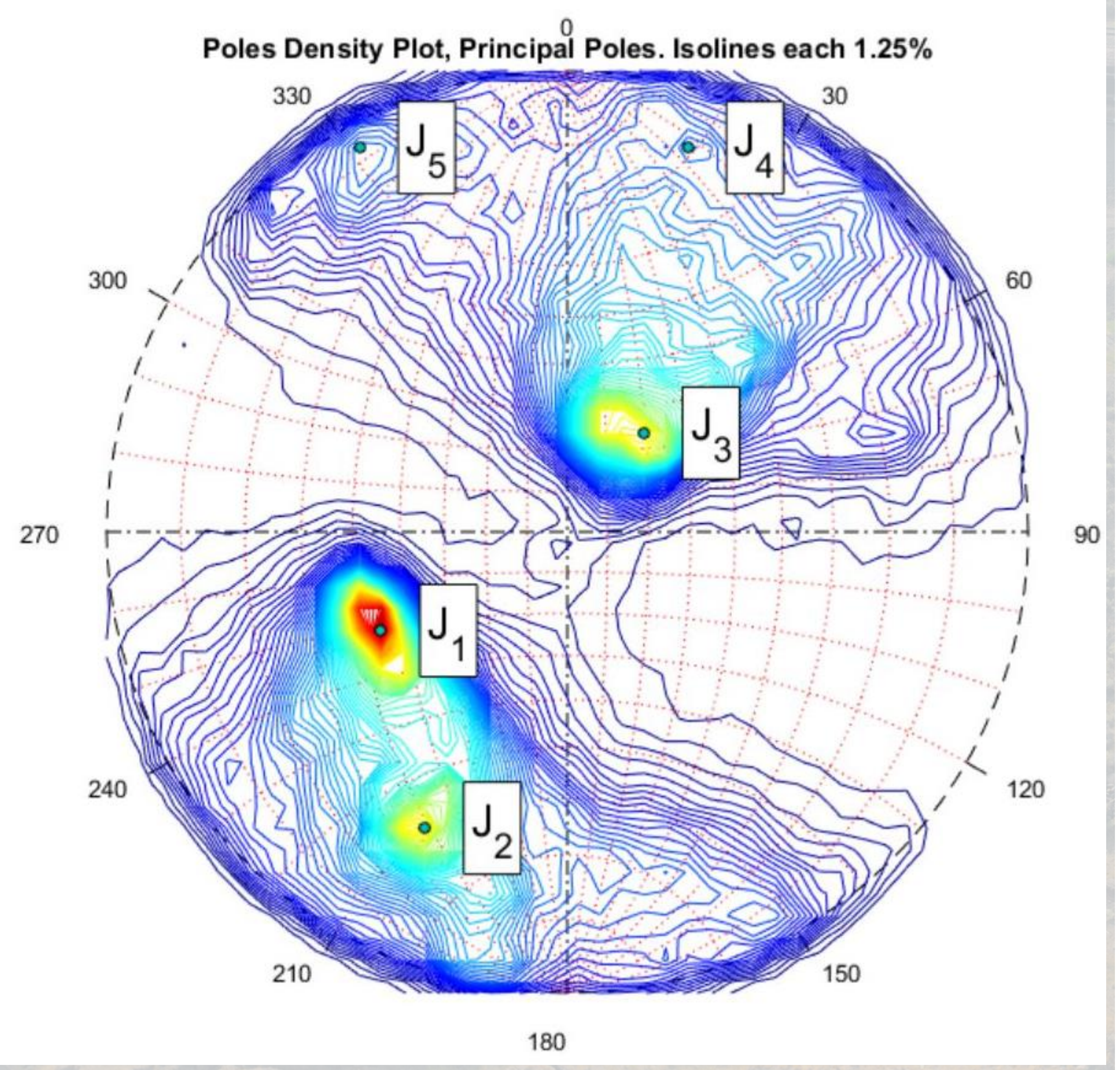
Lato M., Hutchinson D.J., Diederichs M.S., Ball D., and Harrap R. (2009)
“Engineered monitoring of rockfall hazards along transportation corridors: using mobile terrestrial Lidar”
Nat. Hazards Earth Syst. Sci., 9, 935–946



One Last Example…now…my Ph.D has been replaced with by a MatLab program…



One Last Example...now



Conclusions

- Remote Sensing processing capabilities are changing how we are able to visualize and understand active earth processes
- The knowledge we gain from remote sensing can fill in traditional 'data gaps' and allow us to provide better solutions to complex earth science challenges
- New techniques and algorithms allow us to collect, process, and gain understanding faster, with less bias, and in traditionally hard to access locations
- **At the end of the day:** it allows us to be better engineers through the knowledge the data can provide

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