3rd Virtual Geoscience Conference Proceedings Volume

22-24 August 2018

Queen's University
Kingston, Canada

http://virtualoutcrop.com/vgc2018

Department of Geological Sciences and Geological Engineering 2018
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Individual contribution

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3rd Virtual Geoscience Conference 2018

Immersive Geoscience

VGC 2018

22-24 August 2018
Biosciences Complex
Queen's University
Kingston, Canada

Queen's University

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Immersive Geoscience

This year's conference comes at a time when new augmented reality (AR), mixed reality (MR) and virtual reality (VR) hardware are coming to market, including widely available smartphone powered options. Progress in VR, MR and AR technology is reducing the number of abstractions between the user and the computing environment and creating an intuitive and immersive way to interact with geoscience data. This emerging field allows for more rich and immersive learning experiences and allows complex 3-dimensional (3D) data to be easily communicated and understood by the stakeholders. Virtual reality and MR environments give students a rich and immersive learning experience. Recent advances in technology also allow multi-user, real-time interaction and collaboration. Learning in these environments is designed to mimic real world field trips, while integrating tools and activities beyond the possibilities of traditional fieldwork. This makes experiential learning in the geosciences more accessible and encourages observation and exploration by allowing fly throughs, sketching, data layering, and terrain manipulation. Users can now participate and explore data instead of simply seeing it on a map or computer monitor. This year's conference theme is *Immersive Geoscience*, covering the many exciting new developments in immersive visualization of geoscience data.

Virtual Geoscience Conference Series

The Virtual Geoscience Conference (VGC) series aim is to create an ongoing forum to discuss new developments in geomatics techniques and computer visualization in the geosciences. This allows researcher and industry members working in this niche area to discuss unique challenges and novel developments in the use and future perspectives of geomatics tools and computer visualization techniques applied to a wide range of geoscience applications. The first VGC conference, called *Vertical Geology* at that time, took place at the University of Lausanne in 2014. It came at a time of accelerated use of close range remote sensors to study vertical outcrops – those typically obscured or missing from conventional topographic maps and digital elevation data. The second conference in the series took place in Bergen in 2016 and included a broadening of the conference scope to include a wider variety of geoscience disciplines and an extension of the technical themes to include computer visualization.

Response

This year's conference received over 50 abstracts with a variety of geomatics, process simulation and computer visualization topics covering a range of geoscience disciplines. Key contributions to the conference included new algorithms, automated data processing pipelines, game engine simulations, AR and VR applications, HTML5 and web visualization, 3D data integration, monitoring natural hazards, characterization of caves, remote sensing used to optimize underground blasting, mapping of lava flows, monitoring landslides, and real-time data collection and visualization.

Presentation Formats

Three presentation types were available to authors, traditional oral and poster presentation types, and interactive presentations. Interactive presentations were first introduced at VGC 2016 with the aim to facilitate display of novel hardware and software, and to allow interaction with impressive geoscience datasets. The organizing committee was excited to continue this presentation format, supporting this year's theme of immersive geoscience. A total of five interactive sessions were offered to authors.

Acknowledgements

The organizing committee acknowledges support from the Virtual Outcrop Geology group for providing website support and the VGC steering committee for promoting and helping ensure the longevity of the conference series. This year's meeting would also not have been possible without the generous support and promotion from this year's sponsors. Administrative support from Lorna Dumond and Brenda Wood from the department of Geological Sciences and Geological Engineering and Queen's is also acknowledged. Finally, the VGC scientific committee is acknowledged for ensuring relevant and high quality scientific content at this year's conference.

Ryan Kromer
D. Jean Hutchinson
Matt Lato
Rob Harrap
Boyan Brodaric
August 2018

Committees

Conference Chair

Dr. Ryan Kromer, Colorado School of Mines, USA

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Dr. Tobias Kurz, Uni Research, Norway
Dr. Antonio Abellan, University of Leeds, UK
Holgar Kessler, British Geological Survey, UK
Dr. Sophie Viseur, Aix-Marseilles University, France

Practical Information

Conference Locations:

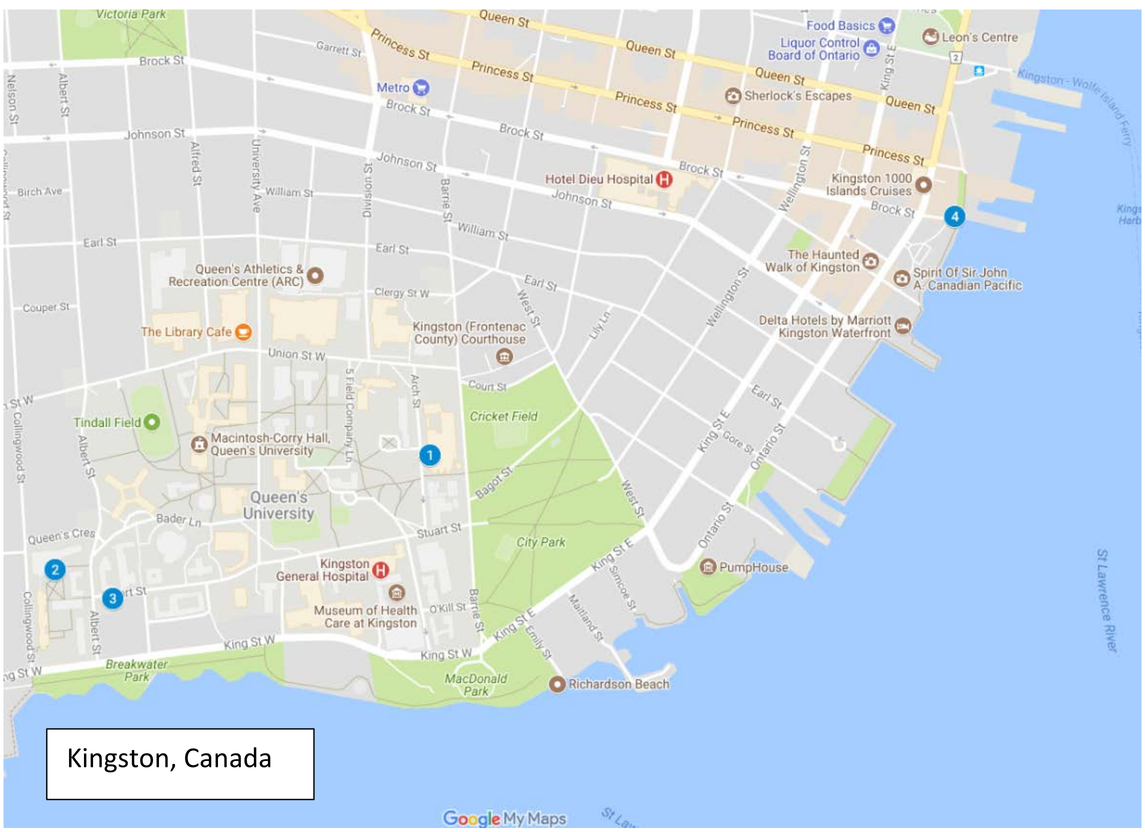
1. Conference Venue
   Biosciences Complex: 116 Barrie Street, Kingston

2. Leonard Hall – Lunch
   150 Queen's Crescent, Kingston

3. Smith House – On Campus Conference Accommodations
   222 Stuart Street, Kingston

4. Boat Cruise Departure

   Wharf at 1 Brock Street



Keynote Speakers

Keynote 1

Dr Nick Hedley,

Title of Talk: Mixed Reality Geoscience: Linking Worlds and Remixing Reality

Nick is an experienced interdisciplinary researcher of 3D geovisual interface technologies. He has designed, developed and applied virtual and mixed reality interface technologies for over 20 years. In addition to a rich portfolio of academic research, he has consulted for industry, science museums, media and motion picture companies, and international foundations, to develop geovisual interfaces and exhibits for professional geophysical practice, public education, science and government initiatives.

At the core of his work is the design, development and use of virtual and augmented reality interface technologies to view, explore and experience spatial visualizations and simulations in lab and everyday spaces. His team develops agile workflows, linking: 3D data capture, using UAV imaging and 3D laser scanning; 3D model production using photogrammetric and point cloud processing for regions from 2500 km^2 down to 10 cm^2; 3D spatial analyses and simulations at data resolutions down to sub-millimeter detail.

His portfolio includes: 3D capture of complex built and natural environments; 3D simulation of hazard dynamics; 3D ocean environments; risk intelligence capture and communication; marine debris; survey, simulation and visualization of glass sponge reefs; 3D visibility and privacy analysis; space-time visualization; archaeological reconstruction and visualization; award-winning 3D interfaces to visualize climate change futures (CLIVE); and planetary science.

Nick is the Director of the Spatial Interface Research Lab – a geovisual interface think tank – and a professor of geovisualization and spatial interface research in the Department of Geography at Simon Fraser University, Canada.

Keynote 2

Dr Joseph Wartman,

Title of Talk: Using Unmanned Aircraft Systems for Automated Assessment of Rockfall Hazards

Joseph directs the Natural Hazards Reconnaissance Facility (known as the "RAPID") at the University of Washington, where he is the H.R. Berg Professor of Civil and Environmental Engineering. A former editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering, he is the author of over 100 professional articles on geologic hazards. In addition to his technical publications, Wartman's essays and op-eds have appeared in the New York Times, the Seattle Times, and the Conversation, among other mainstream media venues. He is the recipient of several research honors awards including, most recently, the Geologic Society of America's Burwell Award in engineering geology. He earned his B.C.E. from Villanova University, and M.S., M.Eng., and Ph.D. degrees from the University of California, Berkeley.

Keynote 3:

Dr sc.nat. Regula Frauenfelder,

Title of Talk: The eye in the sky – Space- and Air-borne Monitoring of Infrastructure Deformation and Geohazards

Regula is a physical geographer currently working at the Norwegian Geotechnical Institute, a leading centre of research and consultancy in engineering geosciences. She earned her doctoral degree at the University of Zurich, in 2004. She has a wide background within remote sensing and geo-informatics with focus on natural hazards and, more recently, risk assessments. She has received several academic distinctions. Fields of expertise include spatial natural hazard analysis, ground deformation analyses with InSAR and object-based optical image analyses. Through her earlier positions, she gained a strong background in cryospheric science and research. She has over 15 years of experience as project manager of both R&D and consultancy projects, as well as with the preparation of scopes of work and tenders.

Keynote 4:

Dr Helen Reeves,

Title of Talk: Geoscientists' opportunities to apply virtual immersive tools in the managemnt of ground related hazards in cities

Helen Reeves is an engineering geologist with 19 years' post graduate experience in engineering geology research, with over 30 papers in engineering geological mapping, rock mass characterisation, geohazard mapping and geomechanics. She gained her undergraduate Geological Sciences degree from the University of Leeds and an MSc in Engineering Geology and a PhD from the University of Durham.

Currently, Helen is the Science Director for Engineering Geology & Infrastructure at the British Geological Survey (BGS) and leads the £3m annual NERC/BGS Engineering Geology research programme investigating the: processes and the spatial distribution of shallow geohazards in the UK (particularly landslides and subsidence); geotechnical & geophysical properties of the UK land mass and urban geoscience challenges in cities,

Helen is also Principal Investigator NERC/DFID funded grant 'LANDSLIP' (Landslide Multi-Hazard Risk Assessment, Preparedness and Early Warning in South Asia (NE/P000649, £2m, 2016-2020), Co-Investigator (CI) of EPSRC Assessing the Underworld (EPK021699, £5.8m, 2013-17) and CI of Newton-Ungku Omar Disaster Resilient Cities (EP/P01531X, £1.75m). She is the co-chair of the UK Natural Hazards Partnership Hazard Impact Model (HIM) working group; has contributed to the UK Government's Scientific Advisor Group for Emergencies during 2013-2014 winter storms; is an EU Civil Protection Mechanism Technical Expert; IAEG UK National Group President, an active committee member of the TRB standing committee on Engineering Geology (AFP10) and has contributed to a (US) National Research Council of the National Academies Committee on the "Underground Engineering for Sustainable Underground Development. Helen was awarded the Geological Society's Engineering Geology Group Award in 2015 and the Yorkshire Geological Society's Bisat Award in 2017.

Partners and Sponsors

BGC Engineering: *https://www.bgcengineering.ca*

BGC Engineering Inc. (BGC) is a consulting firm providing specialist services in applied earth sciences since 1990. Our practice, founded on an appreciation for the impacts of geology on engineered structures, is capable of addressing a broad spectrum of engineering and environmental issues related to development in challenging terrain. BGC's assignments vary from pre-feasibility level studies and routing evaluations to detailed design, construction inspection, contract management, and independent third-party review.

BGC is composed of over 400 professional engineers, geoscientists, technicians and support staff capable of providing a full range of geotechnical and hydrogeological investigation, design, and construction review services worldwide. BGC currently operates from eight Canadian offices in British Columbia, Alberta, Ontario, New Brunswick and Nova Scotia; two US offices in Colorado; and one South American office in Chile

UniResearch: *http://uni.no*

Uni Research is one of the leading research institutes in the Norwegian R&D sector. It was established in 2003 with owners the University of Bergen and Foundation for University Research in Bergen. The institute's main research themes are health, environment, climate, energy and social sciences. The VGC conference is organised by the Virtual Outcrop Geology Group within Uni Research CIPR, part of the institute's Geosciences division.

Virtual Outcrop Geology: *http://virtualoutcrop.com/*

The Virtual Outcrop Geology (VOG) Group is a collaboration between Uni Research CIPR and the University of Aberdeen, UK. Established in 2004, the group has pioneered the utilization of geological outcrop data using novel collection techniques such as laser scanning, photogrammetry and hyperspectral imaging. It has focused on new developments to process, visualize and extract information to fully exploit the methods in research and industry applications. These methods are becoming increasingly relevant to other disciplines, and the group has worked with projects in geoscience and energy research, mining, material recycling and cultural heritage.

Esri Canada: *https://esri.ca*

Esri Canada provides geographic information system (GIS) solutions that empower people in business, government and education to make informed and timely decisions by leveraging the power of mapping and spatial analytics. These solutions facilitate a successful digital transformation, enabling organizations to better manage their resources, plan their future and collaborate within and beyond their organization. Serving 12,000 organizations from 16 offices across Canada, the company is based in Toronto. In 2015, Esri Canada became a Gold Standard winner of Canada's Best Managed Companies. Learn more at esri.ca.

Geological Remote Sensing Group*: https://www.grsg.org.uk*

The Geological Remote Sensing Group (GRSG) is a special interest group of The Geological Society and the Remote Sensing and Photogrammetry Society, based in the UK but active internationally. The scope of the group covers all aspects of remote sensing for geological applications, and its membership includes geologists and remote sensing experts employed within industry, academia and government agencies. GRSG's activities are highly complementary to the scope of VGC.

IDS GeoRadar : *https://idsgeoradar.com*

IDS GeoRadar provides products and solutions for geophysical, mining, civil engineering, and security applications. Founded in 1980 as part of IDS Ingegneria dei Sistemi in Pisa, Italy, the company was recently acquired by Hexagon.

Through a continuous commitment to research and development, IDS GeoRadar provides professionals with innovative products using state-of-the-art technologies and novel solutions. Over the years, the company has pioneered radar technologies for civil applications as breakthrough products in this domain.

IDS GeoRadar develops products for a wide range of applications:

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- Civil Engineering
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- Geology and environment management
- Archaeology
- Forensics
- Landslide monitoring
- Mining Safety

GIM International: *https://www.gim-international.com*

GIM International, the independent and high-quality information source for the global geomatics industry, brings the latest insights and developments in both technology and management, including: topical overviews, news and developments, expert opinions, innovation updates, and more. The magazine is published monthly (i.e. 12 times a year) and is available on a subscription basis. A subscription to GIM International includes the weekly e-newsletter. GIM International is written for key decision-makers active in the international geomatics field and is targeted at commercial, academic and government professionals worldwide. Its readers are involved in land surveying, GIS, photogrammetry, remote sensing, LBS, Lidar, cartography, GPS/GNSS, cadastres, 3D city modelling, geo-databases and other geomatics-related activities.

Remote Sensing: *http://www.mdpi.com/journal/remotesensing*

Remote Sensing is now a prominent international journal of repute in the world of remote sensing and spatial sciences, as a pioneer and pathfinder in open access format. It has highly accomplished global remote sensing scientists on the editorial board and a dedicated team of associate editors. The journal emphasizes quality and novelty and has a rigorous peer-review process. It is now one of the top remote sensing journals with a significant Impact Factor, and a goal to become the best journal in remote sensing in the coming years.

Technical Programme

Wednesday 22nd August

6:00	8:00	Registration and Conference Icebreaker (Biosciences Atrium)

Thursday 23rd August

Time		Presenting Author	Title	Affiliation
7:30	8:15	Registration and Morning Coffee		
8:15	8:30	Ryan Kromer D. Jean Hutchinson	Conference Opening Remarks	Queen's University, Canada
Session Chair: Sophie Viseur				
8:30	9:00	Helen J Reeves	KEYNOTE: Geoscientists' opportunities to apply virtual immersive tools in the management of ground related	British Geological Survey, UK
9:00	9:15	Nick Rosser	Live web-based presentation of 3D coastal rockfall monitoring	Durham University, UK
9:15	9:30	Simon Buckley	Enhanced excursions: How virtual field trips complement existing geoscience field activities	Uni Research CIPR, Norway
9:30	9:45	Nicole Naumann	New ways of sharing outcrop data: the SAFARI database and 3D web viewer	Uni Research CIPR, Norway
9:45	10:00	Michel Jaboyedoff	Optimizing the use of 3D point clouds data for a better analysis and communication of 3D results	University of Lausanne, Switzerland
10:00	10:30	Coffee		
Session Chair: D. Jean Hutchinson				
10:30	10:45	Michael Hillier	Framework for modelling national scale 3D geological models	Geological Survey of Canada
10:45	11:00	Holger Kessler	The National Geoscience knowledge base at the British Geological Survey	British Geological Survey
11:00	11:15	Zac Sala	Game engine based modelling for rockfall back-analysis and simulation over time using a rockfall event database	Queen's University, Canada
11:15	11:30	Dave Gauthier	Karrat Fjord (Greenland) tsunamigenic landslide of 17 June 2017: Preliminary 3D Observations from SfM	BGC Engineering Inc., Canada
11:30	12:00	Nick Hedley	KEYNOTE: Mixed reality geoscience: Linking worlds and remixing reality	Simon Fraser University, Canada
12:00	1:30	Lunch		
Session Chair: Matt Lato				
1:30	1:45	Erik Vest Sørensen	3D mapping of lavas: insights into the volcanic and structural evolution of the Kap Dalton Graben, Blosseville Kyst, East Greenland	Geological Survey of Denmark and Greenland (GEUS)
1:45	2:00	Brett Carr	Investigating the emplacement and collapse of higher viscosity lava with structure-from-motion	Lamont-Doherty Earth Observatory, USA
2:00	2:15	Moritz Kirsch	Integration of terrestrial and aerial SfM photogrammetry and VNIR, SWIR and LWIR outcrop sensing for geological mapping	Helmholtz Institute Freiberg for Resource Technology, Germany
2:15	2:30	Doug Angus	Coupled thermo-hydro-mechanical and microseismic	ESG Solutions, Canada
2:30	2:45	Benoit Rivard	Alteration footprint of mineral deposits from spectral investigations of drill core and outcrops: Examples from	University of Alberta, Canada
2:45	3:00	Xiaodong Zhou	Real time core logging using corescan high resolution	Corescan Pty Ltd
3:00	3:05	Ryan Kromer	Introduction to poster and interactive sessions	

3:05	3:20	Coffee		
3:20	4:20	Posters		
		Thomas Dewez	Mapping naturally occurring asbestos using combined spectral–geometric approaches	BRGM – French Geological Survey, France
		Raymond F. Kokaly	Mineral characterization using lab-, field-, and aircraft-based imaging spectrometers at Orange Hill porphyry Cu	U.S. Geological Survey, USA
		Brendan Hodge	Mapping the earth from pole to pole: Remote sensing of	UNAVCO Inc., USA
		Stephen Dankwa	3D visualization of sea surface temperature data :A technological tool	University of Electronic Science and Technology of China, China
		Jeffrey Moersch	Monitoring of dune migration rates and morphologic evolution with an unmanned aerial vehicle	University of Tennessee, USA
		Meron Gessesse	Enhancing UAV 3D orientation estimation using design of experiment and genetically optimized Kalman filter	Carleton University, Canada
		Charlotte Priddy	Virtual outcrop techniques as a means of generating quantifiable data in highly variable ephemeral fluvial systems: An example from the Kayenta formation, USA, for use in reservoir characterisation and modelling	Keele University, UK
		Bianca Wagner	Close-range sensing workflows in Structural Geology based on open-source/open-access solutions	University of Goettingen, Germany
		Josh Lambert	3D characterization of cave networks using photogrammetry, example from Longhorn Cavern,	University of Texas at Austin, USA
		Anette Eltner	Developing a low-cost camera gauge and an unmanned	TU Dresden, Germany
		Angus MacPhail	Mobile terrestrial photogrammetry	Queen's University, Canada
		Mathilde Desrues	Terresrial Laser Scanning time series analysis for landslide geometry and thickness inversion	University of Strasbourg, France
		Marc Janeras	Checking the complementarity of LiDAR / SfM terrain models derived from different platforms for rockfall projects	Cartographic and Geological Institute of Catalonia, Spain
		Alex Graham	Analysis of point cloud data to correlate geometric factors with rockfall pre-failure deformation patterns	Queen's University, Canada
		John Metzger	Analysis of point cloud data to correlate geometric factors	IDS Georadar, USA
		David Bonneau	A super-voxel approach for granular sediment analysis: initial results	Queen's University, Canada
		Paul-Mark DiFrancesco	Analysis of the 17 June 2017 Karrat Fjord landslide generated tsunami in western Greenland	Queen's University, Canada
4:20	5:15	Interactive Session and Reception		
		Alexandra Boghosian	Hololens visualization of the Ross Ice Shelf	Lamont-Doherty Earth Observatory
		Simon Buckley	Enhanced excursions: how virtual field trips complement existing geoscience field activities	Uni Research CIPR, Norway
		Owen Fernley	Electromagnetic modelling for the web: Building HTML5 visualizers in exploration geophysics	Lamontagne Geophysics Ltd., Canada
		Holger Kessler	Demonstration of GroundHog	British Geological Survey, UK
		Nick Rosser	Live web-based presentation of 3D coastal rockfall monitoring	Durham University, UK
5:15	5:30	Assemble for Historical Tour of Kingston		
5:30	6:45	Historical Tour of Kingston and Walk to Dinner Cruise		
6:45	7:10	Boarding Dinner Cruise Boat		
7:15	11:15	Boat Departs and Dinner Cruise		

Friday 24th August

Time		Presenting Author	Title	Affiliation
8:00	8:30	Registration and Morning Coffee		
Session Chair: Dave Gauthier				
8:30	9:00	Regula Frauenfelder	KEYNOTE: The eye in the sky – Space- and air-borne monitoring of infrastructure deformation and geohazards	Norwegian Geotechnical Institute, Norway
9:00	9:15	Luigi Parente	Precise change detection despite inaccurate camera calibration	Loughborough University, UK
9:15	9:30	Anette Eltner	Time-lapse SfM for 4D reconstruction	TU Dresden, Germany
9:30	9:45	Jennifer Day	Photogrammetric inspection system for underground hydroelectic infrastructure	University of New Brunswick, Canada
9:45	10:00	Laurent Froideval	An open-source method for georeferenced SfM 3D models of outcrops	Normandie Univ, France
10:00	10:30	Coffee		
Session Chair: Thomas Dewez				
10:30	10:45	Ioannis Vazaios	Discontinuity trace identification and rockmass assessment from TLS data	Queen's University, Canada
10:45	11:00	Sophie Viseur	3D models of fracture corridors : analysis of their internal connectivity and density variability	Aix-Marseille University, France
11:00	11:15	Raymond Kennedy	Physical modelling of retrogressive, sensitive clay landslides	Queen's University, Canada
11:15	11:30	Megan van Veen	Slope monitoring using TLS at the Site C project - Effectively presenting results	BGC Engineering Inc., Canada
11:30	12:00	Joseph Wartman	KEYNOTE: Using Unmanned Aircraft Systems for automated assessment of rockfall hazards	University of Washington, USA
12:00	1:30	Lunch		
Session Chair: Rob Harrap				
1:30	1:45	Mathilde Desrues	Gravitational unstabilities: an automatic pipeline for the analysis of time series of high frequency terrestrial	University of Strasbourg, France
1:45	2:00	Marc-Henri Derron	Infrared Thermal Imaging for rock slope investigation - Potential and issues	University of Lausanne, Switzerland
2:00	2:15	Jonathan D. Aubertin	LiDAR appliations to underground rock blasting optimization	K+S Windsor Salt, Canada
2:15	2:30	Thomas Dewez	From underground laser scans to 3D urban geological and geotechnical models	BRGM – French Geological Survey, France
2:30	2:45	Guido Venturini	How virtual can become real: The advantages of a good geological reference model	Schnabel-SWS, Canada
2:45	3:15	Coffee		
3:15	5:00	Panel Discussion		
		Mark Diederichs	Opening Discussion	Queen's University, Canada
		Ryan Kromer D. Jean Hutchinson	Panel discussion and closing remarks	Queen's University, Canada

Conference Contributions

Session 1

Chair: Sophie Viseur
Aix-Marseille University, France

Thursday 8:15 am – 10:00 am, 23rd August

Live web-based presentation of 3D coastal rockfall monitoring

Nick J. Rosser[1*], Jack Williams[1], Richard Jones[2],
& Max Wilkinson[2]

[1] Department of Geography, Science Labs, Durham University, South Rd, Durham, UK. DH1 3LE;
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[2] Geospatial Research Ltd., Harrison House, Hawthorn Terrace, Durham DH1 4EL

Key words: *Terrestrial laser scanning, realtime, rockfall*

We present a web-portal that displays near-real-time 3D data from constant 3D monitoring of rockfalls based on terrestrial laser scanning. Building on recent research on the development of algorithms that take advantage of the ability to detect small changes through time from high-frequency and high-resolution scanning, we present a platform that fully automates this workflow from data collection to dissemination. Our aim here is to make data, that can often be contentious, open and accessible to stakeholders.

Here we demonstrate the system using two monitoring installations on the NE UK coastline, where erosion is a pressing day-to-day issue for both the local government, but also for local communities who live on the coast. The first system is mains powered with fixed telecoms, mounted in a lighthouse at Whitby. The second is totally self-contained, housed in a custom box, with solar power and full 4G communications, and so can be deployed in any location (Fig. 2). Using data collected from these system, we consider specifically the case of storm events, which are suggested to dominate net erosion but are also causing increasing public concern. Our system allows the impacts of current conditions to captured and presented. To assess the role of storm impacts, we draw on an inventory rockfalls, gathered from March 2015 onwards to put current conditions into context (Fig. 1).

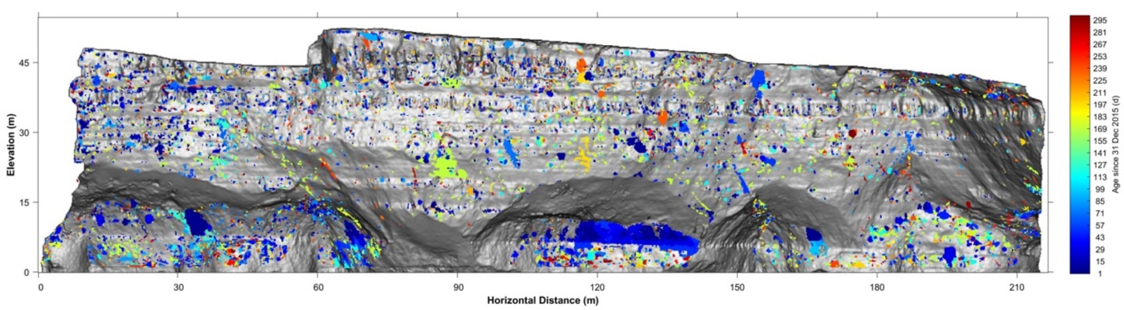

Figure 1: 9 months of near constant 3D monitoring of rockfall ay Whitby. Rockfall are colour by age of rockfall since the start of monitoring at a resolution of 1 hour.

We find that the occurrence of storms drives an increase in the rate of rockfall activity above baseline mass wasting. Storm events account for up to 10% of the total long-term recorded erosion, suggesting a direct link between rockfall and rainfall. Our database includes storms Eva and Frank, which resulted in widespread flooding across the UK in December 2015. An analysis of the relationship between individual rockfall timing and the passage of these rainfall events shows that up to 30% of the largest 1,000 rockfall occurred during periods of rainfall, and 60% occurred within 24 h of rainfall.

Figure 2. Add a figure with simple caption to help showcase the impact of your research.

Acknowledgements: The work is supported by Scarborough Borough Council.

References

WILLIAMS, J.G., ROSSER, N.J., HARDY, R.J., BRAIN, M.J., & AFANA, A.A. 2018. Optimising 4-D surface change detection: an approach for capturing rockfall magnitude–frequency, *Earth Surface Dynamics*, 6, 101-119.

Enhanced excursions: how virtual field trips complement existing geoscience field activities

Simon J. Buckley[1,2*], Nicole Naumann[1], Kari Ringdal[1], Benjamin Dolva[1], Bowei Tong[1], Joris Vanbiervliet[1], Tobias H. Kurz[1], John A. Howell[3]

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[2] Department of Earth Science, University of Bergen, P.O. Box 7803, N-5020 Bergen, Norway

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Key words: *3D modelling, visualisation, collaboration, multi-disciplinary, data fusion, education.*

Digital 3D capture of geoscience field localities is driving a paradigm shift in our approach to quantitative and qualitative analysis of the earth's surface and its processes. Techniques such as laser scanning and photogrammetry are applicable with shallow learning curves and high software automation, resulting in increased accessibility for geoscientists. Conventionally, 3D topographic modelling is the starting point for deriving quantitative measurements and interpretations for input to application-specific analysis. However, a further key benefit is using the high-resolution datasets as the basis for compiling diverse spatial and non-spatial data, for managing and communicating information about a field area. Examples are additional geospatial datasets, such as regional digital elevation models, aerial or satellite imagery, and topographic or geological maps, as well as field photos, cross sections, interpretations, logs, thematic maps (e.g. results of change detection, or classification using spectral imaging), overlays (BUCKLEY et al., 2013) and geophysical (e.g. ground-penetrating radar, seismic) datasets. Uniting these disparate data types in a common visual environment forms the basis for aiding interpretation and understanding, for educational purposes as well as to enhance collaboration between colleagues and disciplines (e.g. LECOMTE et al., 2016). Finally, such integrated geoscience datasets form the basis for virtual field excursions and fieldwork. Although long envisaged and investigated (e.g. STAINFIELD et al., 2000), current technological advances make virtual field trips increasingly realisable.

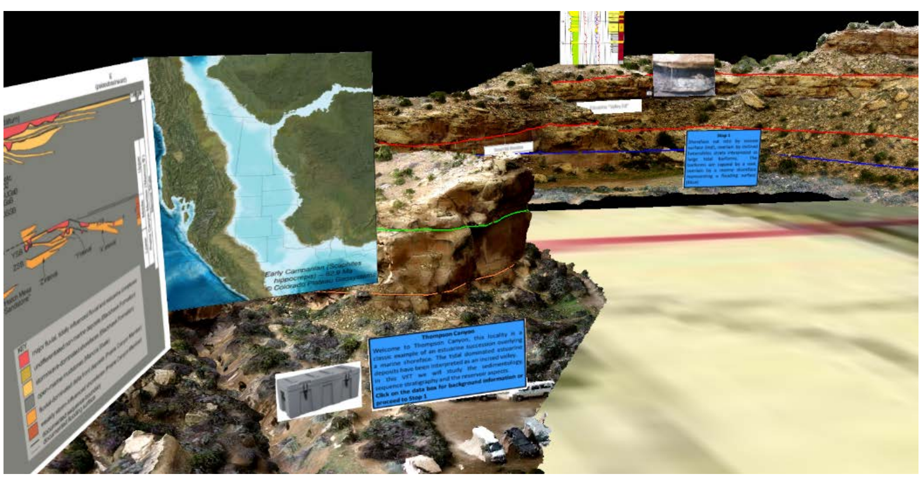

Figure 1: Virtual field trip of Thompson Canyon, Utah, USA, showing geological information located around 3D photogrammetric model.

In this contribution, we present ongoing work to develop virtual field trips of geoscience field areas, using case studies in outcrop geology. The key motivations and benefits of using virtual representations of the localities are discussed within the contexts of traditional fieldwork and excursions, remote education and training, and as resources for making field localities accessible to a wider audience. The field trips are developed by field leaders around three main procedures: data compilation (coordinate system unification and placement), animation and actions, and geological narrative (implementing elements of a traditional field guide), before being made available to participants. The presented solution is implemented on top of our in-house LIME software framework, allowing high performance real-time rendering of large datasets, together with flexible overlays using image panels. We present results from field localities where remoteness inherently restricts the number of participants who can physically take part in excursions to these areas. In summary, virtual field environments are a means to enhance rather than replace existing physical trips, as well as increasing inclusivity by bringing the experience of seeing field localities to a broader general audience.

Acknowledgements: Statoil ASA and the Research Council of Norway's (RCN) SkatteFUNN programme (project number 810837) have funded aspects of this work. Isabelle Lecomte, Ingrid Anell and Alvar Braathen are acknowledged for input on the case study, supported by the Trias North project (RCN Petromaks 2 grant 234152). In addition, an internal grant award from Uni Research CIPR was instrumental in enhancing the LIME software (http://virtualoutcrop.com/lime) during this research.

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New ways of sharing outcrop data: the SAFARI database and 3D web viewer

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Key words: *3D modelling, virtual outcrop, publishing, repository, query, reservoir modelling*

The SAFARI Project is a long-running research initiative to compile and interrogate a diverse range of data on geological outcrops for hydrocarbon exploration and production. The original project dates back to the late 1980s/early 1990s as an initiative to increase collaboration between Norwegian oil companies and academia, resulting in a quantitative outcrop analogue datasets for use in populating geocellular models. However, as there was no central database or storage space at that time, the acquired data were difficult to share and fell into disuse. In 2008, the SAFARI project was rejuvenated through joint industry and research council support, resulting in the development of a cloud-based, searchable repository of outcrop data, accessible today at http://SafariDB.com.

In addition to general descriptions for each geological outcrop, the SAFARI database stores detailed work carried out at a locality by individual researchers as studies, allowing multiple investigations and results, potentially by different geologists or groups, to be published. For each outcrop, the SAFARI database can include measurements, maps, field photos, logs, cross sections, interpretations, diagrams and figures, as well as high-resolution virtual outcrop datasets. Key to the database design is the ability to query the stored outcrops using a hierarchy of metadata (SAFARI standard) that each outcrop is tagged with, such as by geological age, basin type, depositional environment, sub-environment and down to the architectural element level. Users can run queries and plot statistical outputs for use in reservoir modelling, as well as use filters to browse and refine the list of stored outcrops. In addition, a wiki-style knowledge base provides a link between the numerical data and the underlying classification standard.

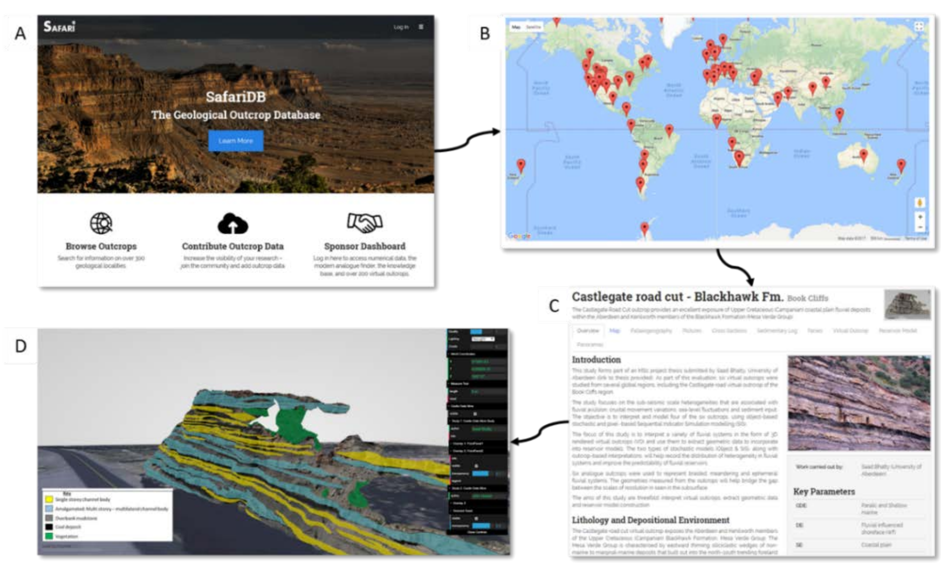

Figure 1: A) The SafariDB.com entry page; B) Browse or find outcrop locations from around the world; C) Read detailed and standardised description pages for each location; D) 3D virtual outcrop models in the SAFARI web viewer.

Central to the SAFARI database is a purpose-built 3D web viewer for viewing virtual outcrop models representing a stored outcrop section that has been acquired using laser scanning or photogrammetry. A key feature of the web viewer is that extremely large and detailed outcrop sections can be loaded, using a level of detail (LOD)-based data converter, which splits up the original 3D photorealistic models into tiles optimised for fast streaming over the Internet. The technical solution also allows ancillary data, such as georeferenced imagery, logs and field photos, to be stored and accessed together with the virtual outcrop model. Interpretations can also be overlain on the models as additional texture layers, and toggled interactively using a transparency slider. Furthermore, multiple interpretations can be stored as additional layers in a study, and multiple studies may be visible according to user access privileges. Thus, proprietary data co-exists seamlessly with public data on the same platform.

The contribution of this presentation is to highlight the status of the SAFARI database as a leading repository for geological outcrop data, especially virtual outcrops. A significant proportion of SafariDB is being made public with the aim of offering the database as a public resource for the wider geological community to share the wealth of data that are now being collected. Users will be able to upload models and interpretations, tagged with metadata that will be fully searchable, significantly increasing the uptake and usage of these new and exciting technologies.

Acknowledgements: The authors acknowledge the continuous support and funding of companies of the FORCE consortium (AkerBP, BP, ConocoPhillips, DEA Norge, Eni Norge, INEOS, Lundin Norway, Neptune Energy, Point Resources, Repsol, Statoil ASA, Spirit Energy, Suncor, Total and VNG Norge), the Norwegian Petroleum Directorate and the Research Council of Norway (VOM2MPS, project number 234111).

Optimizing the use of 3D point clouds data for a better analysis and communication of 3D results

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Key words: *LiDAR, photogrammetry, point cloud, communication*

The large increase of 3D point clouds (3DPC) production and availability, improved greatly the characterization of the earth's surface. They are mostly produced by structure from motion (SfM) as well as terrestrial (TLS) or airborne (ALS) laser scanner. Nevertheless, if the 3DCP are often well exploited for modelling or analysis, they are often not well used for imaging results or communication. Some software such as CLOUDCOMPARE (GIRARDEAU-MONTAUT, 2011) provide tools to enhance the quality of images. We aim here to show how to optimally use the imaging to highlight 3D data and associated results. The challenge is to keep in the virtual image the properties of the nature that are captured by 3DCP, because the additional data immerge in this virtual world must "reflect reality".

Figure 1: Yosemite Valley image based on the ALS surface model and terrain model.

First the relevant type of projection mainly axonometric of perspective must be chosen. Perspective appears the best for communicating. Applying shading to the 3DPC is the most important to give a 3D perception of the scene, it is the basic tool to provides depth in the image (BONAVENTURA et al., 2017). Then, colorizing the point cloud helps to better understand its different elements, helping their differentiation. It is often more realistic to colorize the vegetation, which must be either selected by automatic tools (BRODU & LAGUE, 2011) or manually identified. In many case the digital surface model (DSM) coupled with digital terrain model (DTM) allows to represent forest. But to enhance the quality several filters can be used. For instance, coupling Eye Dome Lighting (EDL) (GIRARDEAU-MONTAUT, 2006), Direct lighting / hill shading (BOUCHENY, 2009; BURROUGH et al., 2015), Ambient occlusion (TARINI et al., 2006) and colours permits to obtain images very close to reality (Fig. 1). The depth of field is also a tool to focus on an aspect of an image. Further colour schemes can also be adapted to the 3D such as the Coltop Scheme (JABOYEDOFF *et al*., 2007), which merge slope and aspect in one colour attribute.

The goal is often to include results and modelled data within a scenery to facilitate their understanding and interpretation related to the local context. for example, it is rather easy to include rockfall trajectories with an ALS/TLS based 3D terrain model. Then, the presence of vegetation or simple landscape features allows a better interpretation of the modelled rockfall trajectories related to the surrounding area. It is more difficult to use SfM point clouds for modelling slope mass movements and visualizing their results because of artifacts created by vegetation which can be hard to separate from the ground. In that case, the 3D model based on the photos used to build the model can look realistic, but might gives a false impression of highly detailed model. It is recommended to use artificial shading based on the terrain orientation instead of photo's textures in that case to make sure that artifacts are visible, and can then be removed.

There remains a lot to do in 3DPC treatments and representation, especially because the real 3D modelling exploiting the full 3D resolution and related 3D surfaces is not really developed up to now. Rockfall modelling is nowadays an exception (NOËL *et al.*, 2016; Fig. 2).

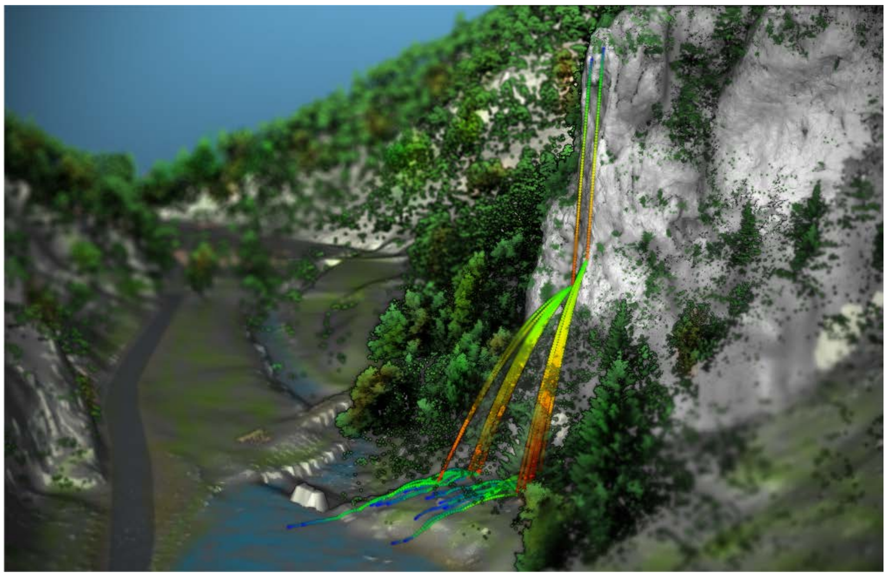

Figure 2. Example of rockfall modelling included in an artificially colorized cloud point.

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Session 2

Chair: D. Jean Hutchinson
Queen's University, Canada

Thursday 10:30 am – 12:00 pm, 23rd August

Framework for modelling national scale 3D geological models

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Key words: *Hierarchical 3D visualization, geoscience, big data*

National geological models are increasingly being developed to help address a variety of continental and global issues such as those related to climate, water, or hazards. However, their nascent development is highlighting many scientific and technological challenges, primarily related to the construction and maintenance of very large 3D models. These are manifest technologically as gaps in modeling methods, related to sparse data and regional interpretation, as well as infrastructure gaps related to the handling of massive data volumes that overwhelm present commercial modeling systems. To overcome this infrastructure gap, new approaches are taken here for the storage, management, viewing and dissemination of a national geological 3D model for Canada, ranging from the surface to the deep subsurface (~46km). The infrastructure is comprised of several components: geometry data model, hierarchical data structure, geospatial database, visualization software, and an upcoming web portal. To represent the wide variety of possible geometries for 3D geological models (points, curves, surface meshes, structured and unstructured 3D grids) the open source VTK (Visualization Tool Kit) data model is adopted. Interactive visualization of a massive 3D model is accomplished by 3D tiling, in which 3D model components are inserted into an octree-based hierarchical data structure that partitions the data into blocks with different resolutions and sizes, limiting viewing to relevant data. The evolving national 3D geology model is stored in an open source database, PostgreSQL, which contrasts with prevalent file-based modeling systems. It is visualized directly from this database using customizations of the Paraview and ParaviewWeb software, for both desktop and forthcoming web-based environments. Ongoing tests on desktop system have shown this environment to scale effectively for the expected data volumes, indicating this approach is promising as a national 3D geological modeling infrastructure.

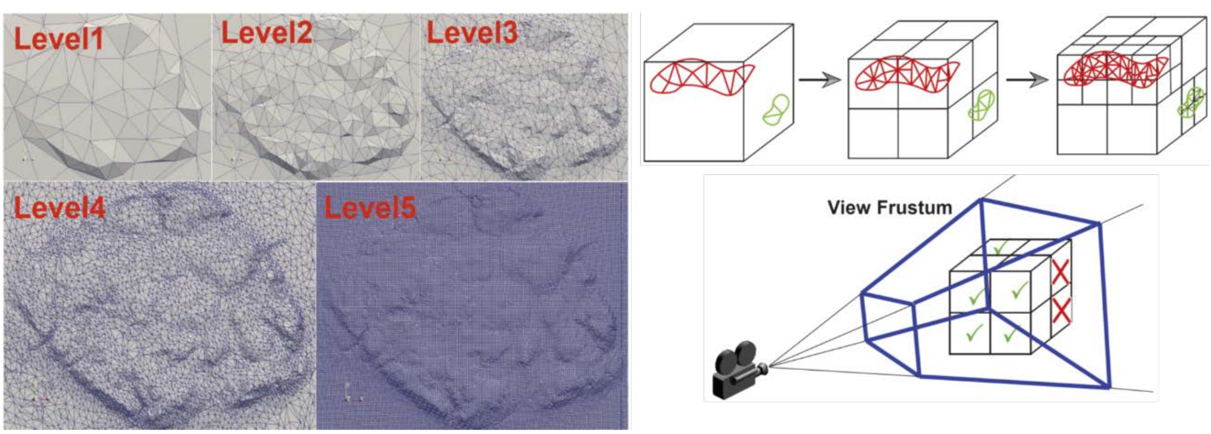

Figure 1: Hierarchical data structure for 3D visualization of big data.

The National Geoscience Knowledge Base at the British Geological Survey

Holger Kessler[1]

[1] *British Geological Survey, Nottingham, United Kingdom*

This presentation will present a historic perspective on the development of a digital national geological knowledgebase at the world's oldest geological survey (Fig. 1). It will describe the period of digitisation, the formation of a corporate database infrastructure, the systematic collection of borehole information, the evolution of the national geological model as well as the development of webservices, apps and software to deliver the outputs to stakeholders. Particular emphasis will be placed on how BGS interfaces and interacts with in industry with the advent of Building Information Modelling (BIM). The increasing need for crowd-sourced information and how national organisations will deal with the diversity of information received will conclude the presentation.

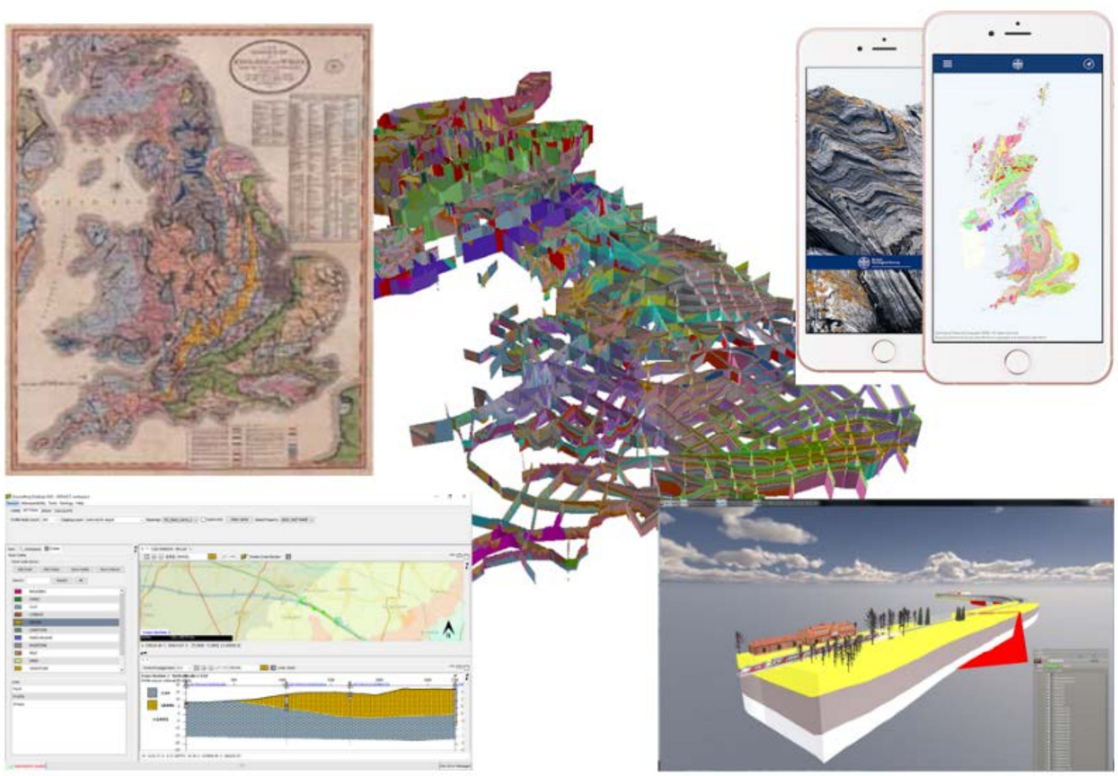

Figure 1: Digital national geological knowledgebase at the world's oldest geological survey

Game Engine Based Modelling for Rockfall Back-Analysis and Simulation Over Time Using a Rockfall Event Database

Zac Sala[1] & D. Jean Hutchinson[1]
[1] *Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Canada*

Key words: *Rockfall, LiDAR, Photogrammetry, Unity Game Engine, Blender*

The rockfall process involves the conditioning, detachment, and downslope movement of material from rock outcroppings. Rockfall represents a major hazard along natural and engineered slopes, having the potential to damage nearby infrastructure, and cause injury or loss of life. As a hazard it is especially common in mountainous environments, where weathering and erosion rates are high, and space limitations result in the construction of infrastructure adjacent to steep rock slopes.

In order to mitigate against the consequences of rockfall and ensure public safety, it is important that we can properly identify potential failures, as well as assess the potential spatial extent with which rockfall debris is likely to impact. The delineation of likely rockfall runout based on identified source zones is a necessary input for the effective design and placement of mitigation. Rockfall runout assessment is commonly completed using numerical methods which attempt to model the physical collision between simulated slope and rockfall objects in 2D, 2.5D, or 3D. To date, a number of different rockfall modelling programs exist, each approaching the problem differently in terms of geometry (2D, 2.5D, 3D), physics (lumped mass, hybrid, rigidbody) and resolution. As part of the Railway Ground Hazard Research Program (RGHRP), a rockfall modelling technique which uses the Unity3D game engine was originally developed by ONDERCIN (2016) with ongoing work on the technique focusing on calibration and additional functionality. The use of game engine technology for rockfall modelling offers a number of key benefits such as: support for fully 3D high-resolution topography (<10cm); dynamic rigidbody physics for custom mesh shapes including bouncing, sliding, and rolling; continuous collision detection between multiple rigid bodies simultaneously; ant the connection of rigid bodies together through breakable links. On top of this Unity3D is a well-documented development platform which is regularly updated and supported by a community with millions of users.

The work presented here focuses on the application of this rockfall modelling technique to the back-analysis of rockfall from a database of events which has been continuously built since 2014 for field sites in south central British Columbia. The database was constructed based on change detection results from point clouds collected using terrestrial laser scanning (TLS) (VAN VEEN. 2016). Cases from the back-analysis will be presented (Figure 1), comparing rockfall deposition simulated in Unity (Figure 2) to measured accumulations of rockfall debris from change detection analysis. Additionally, a simulation of rockfall occurrence for a section of slope over time will be tested, with size, frequency, and source locations based on relationships extractedfrom the rockfall database, and collision parameters based on the back-analysis of representative events.

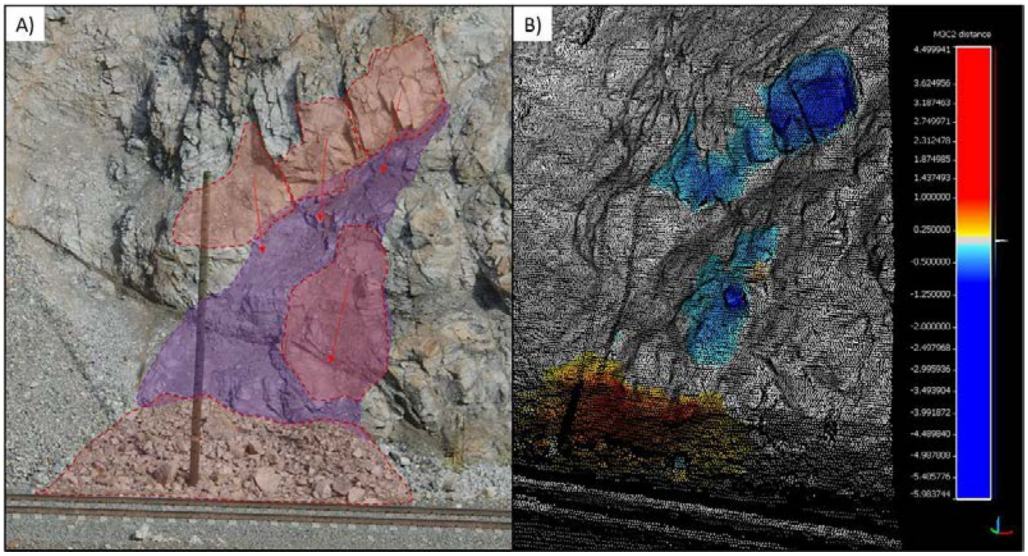

Figure 1: Showing annotated imagery (A) and change detection results (B) for a rockfall event which took place between October 7th and 9th 2016. The event involves two distinct areas of loss, with the lower slope loss interpreted here to be the result of impact from the downslope movement of rockfall material from the upper slope source. The accumulation of rockfall material from both events can be seen in the adjacent track side debris pile.

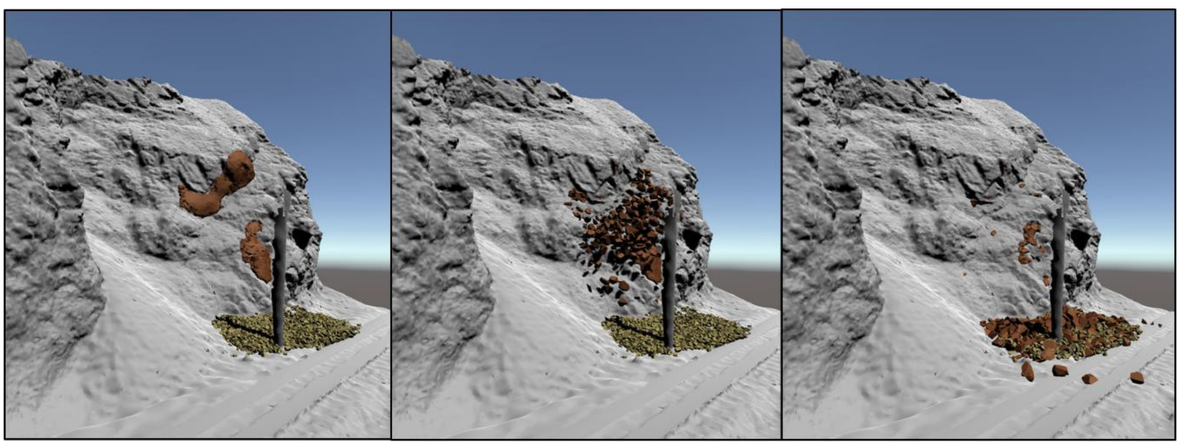

Figure 2: An example rockfall simulation produced using the Unity game engine for the October 2016 rockfall event.

Acknowledgements: This research was supported by the Canadian Railway Ground Hazard Research Program (CN Rail, CP Rail, Transport Canada, Geological Survey of Canada).

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Karrat Fjord (Greenland) tsunamigenic landslide of 17 June 2017: Preliminary 3D Observations from SfM

Dave Gauthier[1], Scott A. Anderson[2], Hermann M. Fritz[3], Thomas Giachetti[4]

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[2]*BGC Engineering Inc., Golden, CO 80401, USA*
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On 17 June 2017 a landslide-generated tsunami reached the village of Nuugaatsiaq, Greenland, leaving four persons missing and presumed dead. Here we present a preliminary high-resolution analysis of the tsunamigenic landslide scar based on SfM from oblique aerial photographs taken during a post-failure reconnaissance helicopter overflight. Through a 3D quantitative comparison with a pre-failure satellite-derived DEM we estimate that approximately 58 million cubic meters of rock and colluvium (talus) was mobilized during the landslide, 45 million cubic meters of which reached the fjord, resulting in a destructive tsunami. We classify this event as a 'tsunamigenic extremely rapid rock avalanche', which likely released along a pre-existing metamorphic fabric, bounded laterally by slope-scale faults, which were identified in the 3D model. This application highlights the utility of helicopter-based SfM for rapid response to geohazard events, and for subsequent analyses.

Session 3

Chair: Matt Lato
BGC Engineering Inc., Canada

Thursday 1:30 pm – 3:05 pm, 23rd August

3D mapping of lavas: insights into the volcanic and structural evolution of the Kap Dalton Graben, Blosseville Kyst, East Greenland

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Key words: p*hotogrammetry, 3D-mapping, stereo-images*

Digital photogrammetry enables the geologist to, so to speak, bring the outcrop into the laboratory where the geology can be analysed in three dimensions. In this study we use digital photogrammetry combined with fieldwork to establish the lava stratigraphy of the Igtertivâ and Skrænterne Formations on Kap Dalton, Central East Greenland and to analyse the structure of the area.

The area is part a c. 65.000 km^2 large Palaeogene lava plateau (PEDERSEN *et al*., 1997) formed along the Blosseville Kyst (68° N to 70°30´N) as the result of continental breakup in the vicinity of the ancestral Iceland hotspot. Evidence of the late magmatic (post-breakup) volcanic activity (50-47 Ma), is only found in a few places along the East Greenland rifted margin. One such place is Kap Dalton and the area is therefore important for the understanding of the late stage volcanic evolution and transition to sedimentation (Bopladsdalen and Krabbedalen Formations) as well as the subsequent graben-formation.

We here use oblique stereo-images collected in 2008 with a calibrated handheld digital camera from a helicopter during approximately 20 min of flight time. The images were prepared for stereoscopic 3D feature mapping using a combination of the commercial photogrammetry software packages SocetSet from BAE Systems, 3D Stereo Blend from Anchorlab and Bingo-F Bundle Adjustment software. Using digital photogrammetry, the area can be investigated following the principles, that whatever can be seen in the images can be mapped and quantified in three dimensions.

By careful photogrammetric mapping of lava flows and faults we are able measure their structural orientation (strike and dip) as well as true thickness of the individual lava flows. This is used to show that lavas of the Igtertivâ and upper Skrænterne formations were formed at a slow pace, allowing time for erosion of lava top zones and formation of intra-basaltic sediments, in a subaerial environment with occasional marine incursions. After the formation of the Igtertivâ Formation the youngest parts of the formation was removed by erosion and a discontinuity was formed between the Igtertivâ Formation and an overlying 30 m thick volcaniclastic succession that includes the base of Bopladsdalen Formation. Lavas overlying the volcaniclastic succession document the existence of a previous unknown volcanic event in the area of Kap Dalton, post-dating the Igtertivâ Formation and that an unconformity is present between Bopladsdalen and Krabbedalen Formations.

Structural observations within the graben suggest that the graben evolved asymmetrically. Throw along the master faults is varied and that the main part of the graben can be viewed either as a large eroded horst or a block that have moved by strike-slip movement. The graben at Kap Dalton formed after the formation of the Igtertivâ Formation and overlying volcaniclastic succession, possibly in the course of separating Jan Mayen from Greenland.

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Investigating the emplacement and collapse of higher viscosity lava with structure-from-motion photogrammetry

Brett B. Carr[1*], Amanda Clarke[2], J Ramón Arrowsmith[2], Loÿc Vanderkluysen[3], & Einat Lev[1]

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[2] *School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA*

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Key words: *Volcanology, lava flow, photogrammetry, structure-from-motion, natural hazards, UAVs*

Volcanoes erupting intermediate to rhyolitic lava are frequently active and commonly found along subductions zones. This higher viscosity lava can form thick lava flows or domes which are often unstable and collapse, generating deadly pyroclastic flows. Despite the higher viscosity, lava flows from these eruptions can be highly mobile, extending up to 10 km from their source (KERR & LYMAN, 2007), increasing the reach of potential hazards. In contrast to relatively short-lived explosive eruptions also common at these volcanoes, effusive flow- or dome-forming eruptions can persist for over a century (WOLPERT *et al.*, 2016), presenting a long-term hazard to nearby populations.

To study how lava flows and domes grow and collapse, we apply structure-from-motion photogrammetry to measure the topography of the erupted lava at Sinabung Volcano, Sumatra, Indonesia. After over a millennium of inactivity, Sinabung began erupting in 2010 and a persistent effusive eruption of andesite lava began in late 2013 (NAKADA *et al.*, 2018). A 2.9 km long lava flow was emplaced in 2014, and since 2015 a lava dome has been active at the summit, producing frequent pyroclastic flows and small explosions.

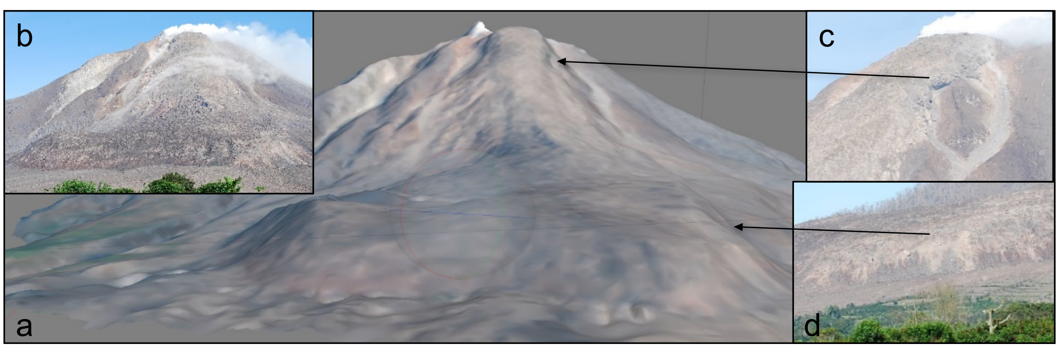

Figure 1: Photogrammetric model of Sinabung (a). A photo used to make the model is shown in (b). Areas of active and observable change in the flow include a gravitationally unstable region of the upper flank (c) and a slow advancing breakout region near the flow front (d)

We created multiple photogrammetric models (Fig. 1) of Sinabung using ground-based photographs from a DSLR and an iPhone 5 during a two-week field campaign in September 2014. We find that while model resolution directly correlates to the resolution of the photographs, the greatest source of error is image clarity-an iPhone-derived model can be better than a DSLR-derived model if the iPhone photos are from a day with better viewing conditions. We difference digital elevation models (DEMs) derived from our models from a pre-eruption DEM to calculate the lava flow volume to be $1.03 \pm 0.14 \times 10^8$ m^3 (~0.1 km^3) (Fig. 2) (CARR *et al.*, 2018). This leads to an estimated time-averaged discharge rate of 4.8 ± 0.6 m^3 s^{-1}. We difference DEMs created from photographs taken 4 days apart to identify relatively high topographic change in zones along the flow front and on the upper flank (Fig. 1). These changes can be explained by active advance of lava in isolated regions along the flow front and by the collapse of material on the upper flank. Large collapses of these upper flank instabilities in October 2014 and June 2015 were caused by lava overtopping ridges that had initially confined the flow (Fig. 2b).

We are returning to Sinabung in June 2018 to continue our photogrammetric monitoring and will use a drone equipped with both visual and thermal cameras to image the active lava dome. We aim to measure dome volume and effusion rate, as well as identify developing areas of instability. By identifying these unstable areas, we will begin to understand the processes driving how and where they form and potentially anticipate the size and likelihood of future collapses. This presentation will discuss our findings based on field work in 2014 and include the first presentation of initial results from 2018 field work.

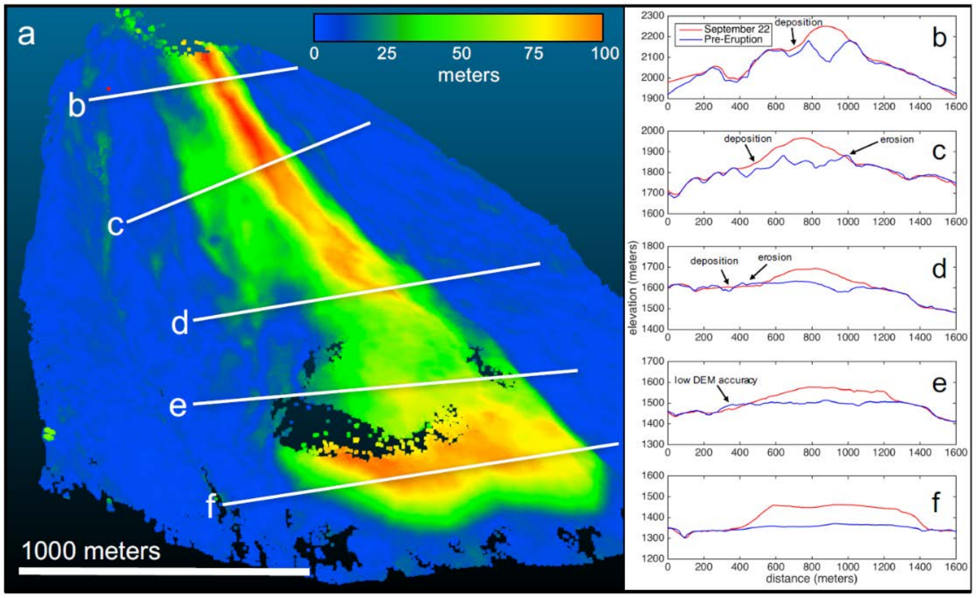

Figure 2: A thickness map of the Sinabung lava flow is shown in (a). White lines show the trace of the profiles across the flow shown in (b-f). White scale bar in (a) refers to distance scale. Color scale bar in (a) refers to flow thickness.

Acknowledgements: This work was previously funded in part by summer PhD student research fellowships awarded by the School of Earth and Space Exploration (SESE) and funded by a Graduate College University Block Grant at Arizona State University. This work is currently funded by NSF EAR PF Award #1725768. The Badan Informasi Geospasial and the Center for Volcanology and Geological Hazard Management in Indonesia generously shared data and resources used in this study. This work is enhanced by a memorandum of understanding between SESE and the Department of Geologic Engineering at Universitas Gadjah Mada in Yogyakarta, Java, Indonesia.

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Integration of terrestrial and aerial SfM photogrammetry and VNIR, SWIR and LWIR outcrop sensing for geological mapping

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Key words: *outcrop sensing, hyperspectral imaging, photogrammetry, UAV, short-wave infrared, long wave infrared*

Virtual outcrop models and hyperspectral imaging are powerful geological tools in their own right. In combination, however, these datasets allow the evaluation of material properties in 3D space and thus provide a valuable asset to any modern geological field campaign. Previous studies have successfully fused hyperspectral data, commonly in the visible to near-infrared (VNIR) and short-wave infrared (SWIR) range, with terrestrial LiDAR (TLS) data. In order to overcome some of the limitations of this approach such as the data gaps caused by the occlusion effect occurring in TLS data and the indistinctiveness of many rock-forming silicates in the VNIR–SWIR spectral range, we describe an integrated workflow to produce a geometrically and spectrally accurate combination of Structure-from-Motion (SfM) point clouds and hyperspectral VNIR, SWIR and long-wave infrared (LWIR) datacubes. The added value of this combination is twofold: (1) Due to the varying image acquisition angles, ground- and drone-based, high resolution SfM point clouds are less influenced by occlusion and thus are well suited for, e.g., structural geological analysis. Moreover, SfM point clouds are versatile in that, once calculated, they can serve as a basis for fusion with many spectral datasets with different spectral ranges, sensor positions and acquisition times. (2) Hyperspectral LWIR imaging adds a complement to hyperspectral VNIR and SWIR data in the field of mineral mapping, since the molecular vibrations of many rock-forming minerals have characteristic resonant frequencies in the LWIR part of the electromagnetic spectrum.

In this contribution, we demonstrate a novel acquisition, processing and interpretation workflow for the combination of ground- or drone-based photogrammetric and hyperspectral VNIR, SWIR and LWIR data on the example of the Naundorf gravel quarry in Saxony (Germany), which features sulfide-rich hydrothermal zones in a granitoid host. The data are processed using spectroscopic (e.g., feature matching) and machine learning algorithms to generate meaningful 2.5 D maps. We validate the remote sensing data with thin section analysis, laboratory X-ray diffraction and as well as point spectrometer data. The combination of ground- or drone-based photogrammetric and hyperspectral VNIR, SWIR and LWIR imaging provides a means for safer and more efficient ground surveys as well as a better, mathematically sound, sampling strategy for further structural, geochemical and petrological investigations.

Coupled thermo-hydro-mechanical and microseismic modelling for predicting the post-closure evolution of a geological disposal facility for radioactive waste excavation damage zone

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Key words: *Radioactive waste disposal, 3D microseismic modelling, interactive figures.*

Microseismic modelling and monitoring is used to understand fracture initiation and propagation for mine-induced and producing reservoir-induced microseismicity applications. We investigate the potential for using microseismic monitoring of fracture initiation and propagation during construction, closure and post-closure of a deep geological radioactive waste facility. We investigate microseismicity based on modelling material failure and fracture propagation in a coupled thermo-hydro-mechanical simulation. The 3D model is of a circular tunnel in anisotropic lower strength sedimentary rock. The mechanical constitutive model incorporates elastic anisotropy, material hardening and softening, and tensile, shear and shear-enhanced compaction failure. The loading simulates tunnel excavation, bentonite backfilling, bentonite swelling pressure and thermal expansion. The results are analysed in terms of spatial and temporal variations in the distribution of material failure. We observe expected material failure sensitive to material anisotropy and in-situ stress during tunnel excavation. Slip occurs post-closure because of increasing pore pressure as the thermal expansion of the fluid is three times greater than the rock mass.

We evaluate the associated moment tensor mechanisms based on the eigen-solution of the differential stress tensor to estimate the pseudo scalar seismic moment of failure, with the assumption that failure is not aseismic. We use explicitly modelled fracture propagation to group failure events spatially and temporally. For comparison of methods, we additionally evaluate the actual seismic moment based on the fracture propagation and shear modulus. The shear events display a pseudo scalar seismic moment distribution varying over two orders of magnitude. Overall, the results from the study indicate that it may be possible to monitor the post-closure excavation damage zone evolution in lower strength sedimentary rock using microseismic monitoring.

We analyse the density of microseismic event points whilst applying constraints to determine the spatial and temporal distribution of events and magnitudes. We present an accessible analysis using interactive figures with graphical user interfaces. We explore the current methods for publishing interactive figures. And present a case for journals to include interactive figures within the online publication document and methods for integrating the interactive documents with static versions.

Alteration footprint of mineral deposits from spectral investigations of drill core and outcrops: Examples from Canadian mines

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Key words: *Hyperspectral, alteration, mine wall, mineralogy*

Hyperspectral imaging for proximal sensing in mine settings is a field of applied imaging spectroscopy that is rapidly expanding. This study reports on the use of shortwave infrared hyperspectral imagery acquired in mine settings to map the abundance and distribution of key alteration minerals, and in some instances their compositional variability. We present imagery of mine walls (cm to dm pixels) acquired at a range of standoff distances from tens to hundreds of meters. A gold mine and a copper mine are used as primary geological settings. From the former we show the use of mine wall spectral imagery for mapping lithologic assemblages and the transition between proximal and medial alteration as seen in white mica chemistry. In the specific mine example used, the white mica chemistry can be shown to relate to ore grade in drill core on the basis of assays. Observations derived from mine wall imagery are also compared to that derived from spectral imagery of drill core that were acquired at much higher spatial resolution (sub-millimeter pixels). For the copper mine setting, the use of mine wall imagery is shown for the characterization of alteration domains and links to known structures (e.g. faults). We also discuss the potential use of such imagery for ore characterization, here in the context of the presence of clays, as it relates to geometallurgy and ore processing. Lastly in examples of this study where changes in mineral chemistry are inferred from the detailed characterization of mineral absorption features, we discuss the importance of wavelength calibration. For this purpose, measurements obtained in the laboratory and in the field for the same geological medium are compared.

Real time Core Logging Using Corescan High Resolution Hyperspectral Core Imaging Data, Alturas, Chile

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Key words: *Corescan, hyperspectral core imaging, mineral exploration, real time core logging*

Alturas is a semi-concealed, diatreme complex related high sulfidation deposit, located in the highly endowed El Indio belt, Chile. It is the most recent discovery made by Barrick, with an inferred resource of 211 Mt at 1.0 g/t gold.

Through close collaboration with industry and rapid innovation driven by the field needs, Corescan high resolution hyperspectral core imaging technology was successfully implemented for real-time logging, for the first time in the industry, in the advanced drilling program at Alturas during the 2014-2015 drilling campaign.

The use of Corescan real time logging at Alturas allowed increased logging efficiency, consistency, more informed real time decision mapping, and fast tracked a high-quality 3D alteration model for resource estimation. Real time Corescan semi-quantitative VNIR-SWIR mineralogy coupled with texture characteristics reveals not only the spatial distribution pattern but also empowers exploration geologists with new insight on alteration paragenesis, at the time of logging.

Furthermore, with the use of high resolution satellite technology such as Worldview-3, new knowledge of ore system derived from Corescan data at hand sample-core hole and deposit scales can be readily applied to map surface alteration at district and regional scales, and equally if not more importantly, to guide field follow-ups.

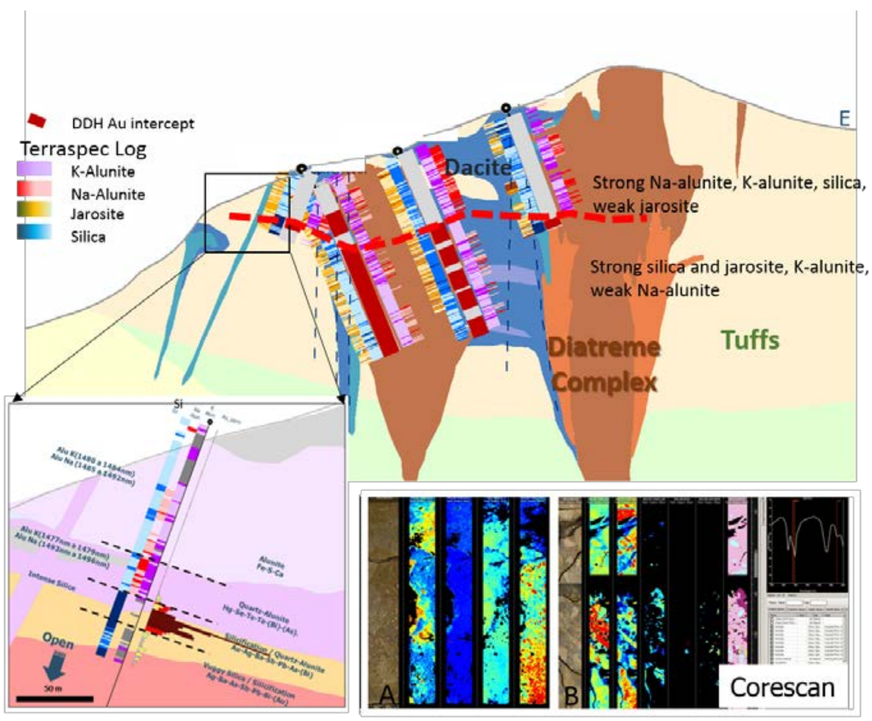

Figure 1: Alturas preliminary section (as of June 2013), showing geology, alteration and Terraspec alunite composition zoning in relation to mineralization. Lower right, Corescan semi-quantitative VNIR-SWIR mineralogy coupled with texture characteristics provides new insight on alteration paragenesis.

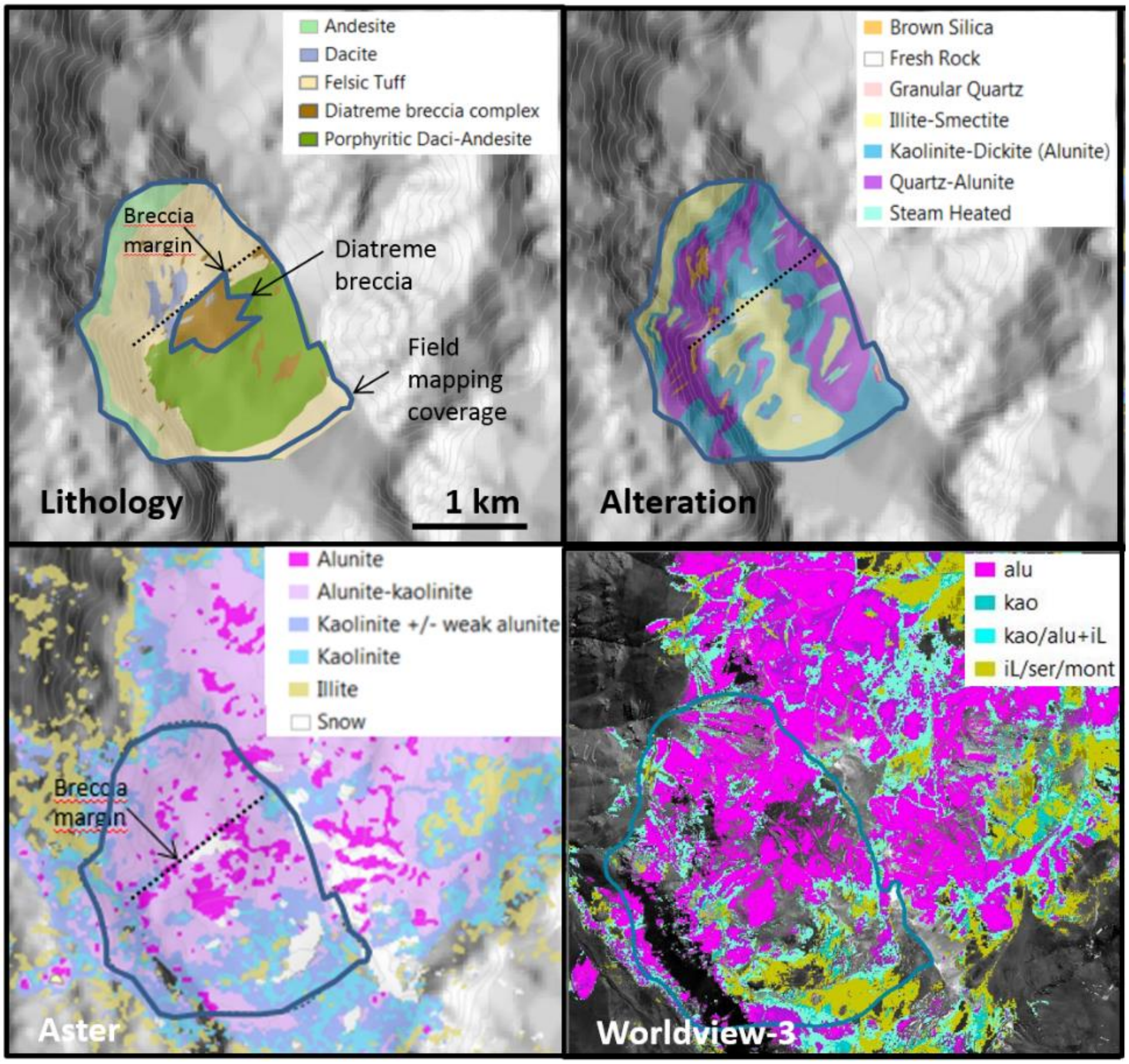

Figure 2. Alturas surface geology and alteration maps, derived from Worldview-3 (lower right) and Aster (lower left) satellite data.

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Session 4

Poster Session

Thursday 3:20 pm – 4:20 pm, 23rd August

Mapping naturally occurring asbestos using combined spectral–geometric approaches

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Key words: *3D outcrop modelling, hyperspectral imaging, data fusion, naturally occurring asbestos*

Asbestos is a common term for a group of fibrous minerals (mainly fibrous serpentine and amphibole) employed in the past in building materials, but now heavily regulated in the context of renovation and construction environments. However, asbestos is also found in the natural environment, most commonly as cleavage fragments caused by mechanical stress being applied to source rocks containing non-asbestiform minerals (e.g. HARPER 2008, LEE et al. 2008). This naturally occurring asbestos (NOA) is found in soils and geological bedrock, which may be disturbed by human activity, or through exposure during heavy construction processes, such as during quarrying or development of infrastructure projects (e.g. BUCK *et al.*, 2013, LABAGNARA *et al.*, 2013). In this context, the occurrence and dangers associated with NOA is less recognised and regulated in fewer countries, and only a few countries (USA, France, Italy) have started to issue more restrictive regulations (e.g. VAN GOSEN, 2007). Such regulations require representative sampling and subsequent laboratory analysis to be carried out, which can be challenging during short site inspections, due to the natural variation of petrology and mineralogy. State-of-the-art remote sensing techniques have the potential to assist representative sampling and identify hazardous minerals in exposed geology (e.g. BUCKLEY *et al.*, 2013, KURZ *et al.*, 2013, SWAYZE *et al.*, 2009).

In this contribution, we present a case study applying topographic 3D modelling (photogrammetry) and spectral measurement (spectroscopy and hyperspectral imaging) to assess the potential of synergistic approaches to mapping NOA on a recently excavated road cut. This exposure, located close to the village of Sande, Western Norway, comprises banded leucocratic gneisses with intercalations of mafic rocks in boudinage form. Ferro-actinolite fibres are observed within fractured bounding and layer interfaces. To assess the potential of spectral methods for NOA mapping, outcrop hyperspectral imaging is combined with field and laboratory spectroscopy.

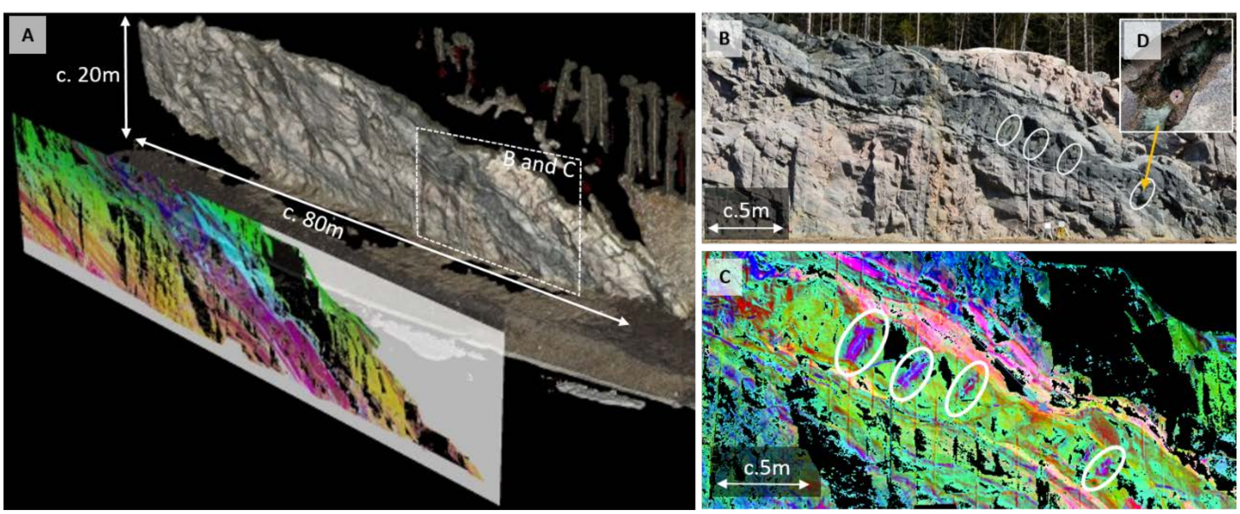

Figure 1: A) 3D photorealistic digital outcrop model from Sande road cut integrated with hyperspectral imagery. B) Fractures (marked by white ellipses) within the mafic rocks with natural asbestos mineralisation, C) Hyperspectral variation map indicates different mineralogy associated with the fractures in the mafic rocks. D) Ferro-actinolite found in the pockets associated with the fractures within the mafic rocks (scale: coin size = 25mm).

Acknowledgements: The authors are grateful to Institut Carnot BRGM for the RADIOGEOM mobility grant supporting aspects of this work. Statens Vegvesen is thanked for allowing site access to the case study area. In addition, an internal grant award from Uni Research CIPR was used to enhance the LIME software (http://virtualoutcrop.com/lime) during this research.

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Mineral characterization using lab-, field-, and aircraft-based imaging spectrometers at Orange Hill porphyry Cu deposit in Alaska

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[1]U.S. Geological Survey, [2]University of Alaska Fairbanks, [3]Flemish Institute for Technological Research

Imaging spectrometer data has been applied at mid-latitudes to assist mineral exploration efforts for certain deposit types, including porphyry Cu, volcanogenic massive sulfide, orogenic Au, epithermal, and iron oxide Cu-Au deposits. The technology is less frequently applied at higher latitudes where data collection and analysis are more difficult due to short collection seasons and low-angle solar illumination. We examined data from imaging spectrometer acquisitions in the lab, in the field, and from an aircraft, to assess the use of the technology as an aid to regional mineral exploration efforts in remote parts of Alaska. At the regional scale, HyMap™ airborne imaging spectrometer data were collected in July, 2014, over the Orange Hill and Bond Creek porphyry Cu deposits at 6 m pixel size. Exposed rocks cropping out on a hillside of the Orange Hill Cu-Mo-Au mineralized zone was then scanned in July, 2015, using a field-based HySpex™ spectrometer at 30 cm pixel size. Corescan™ and HySpex laboratory-based imaging spectrometers were used to collect hyperspectral images with as fine as 24 μm pixel size on selected hand samples and thin section billets. Mineral identifications made using the laboratory imaging spectrometer data were supported by X-ray diffraction and electron microprobe analyses. Comparing mineral information derived from imaging spectrometer data acquired with different spatial and spectral resolutions, we find consistency in identifications of spectrally dominant minerals, including white mica, chlorite, clays, and gypsum. Variations in the wavelength position of white mica 2200 nm Al-OH absorption seen at the airborne scale were also observed in finer-scale field and laboratory imaging, with wavelength positions spanning the 2199 to 2207 nm range. The relatively longer wavelength micas are associated with porphyry formation and are distinct from mica in plutonic and volcanic arc rocks not affected by magmatic-hydrothermal fluids. The results demonstrate imaging spectroscopy can assist mineral exploration in exposed mountainous terrain in Alaska.

Mapping the Earth from Pole to Pole: Remote sensing of snow, ice and rock with UAS and TLS

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Keywords: *UAS, terrestrial LiDAR, photogrammetry, geodetic imaging, Antarctica, Arctic, Alpine*

UNAVCO, a university-governed non-profit supported by the U.S. National Science Foundation (NSF), provides Unmanned Aerial Systems (UAS) and Terrestrial Laser Scanning (TLS) support to geoscience researchers. We maintain a pool of small unmanned aerial systems, terrestrial laser scanners, and supporting field equipment (e.g., GPS systems, ground control, communications equipment), software, and staff trained in best practices for operation of these systems. UNAVCO UAS staff have FAA certification for sUAS operation within the National Airspace and in Antarctica. This combined expertise in GPS, TLS, and UAS remote sensing technology allows UNAVCO to support a wide range of geoscience research applications.

UNAVCO's experience with TLS began in ~2008, and we presently support 35-50 projects per year. We operate a pool of eight Riegl and Leica TLS systems. The most recent acquisition is an ultra long-range Riegl VZ-6000 scanner capable of collecting data at ranges of up to 6km. More recently, UNAVCO has expanded our geodetic imaging program to incorporate UAS. In addition to small consumer-grade UAS (e.g., DJI Phantom 4 Pro), we've recently acquired a heavy payload DJI Matrice 600 to expand our capabilities for geoscience research. In addition to high-resolution aerial imagery, advanced payloads for thermal IR, radiation, and multispectral remote sensing data are now possible with our pool of UAS. These new instruments will allow remote sensing data collection over larger areas, at longer range, and in previously inaccessible locations. UNAVCO also maintains an online archive for the imaging data we collect; presently there are approximately 90 high-resolution three-dimensional datasets of rock outcrops, glaciers, rivers beds, caves, buildings, and archaeological objects, amongst others. UNAVCO also provides training for use of these technologies in research, including field acquisition and data processing and analysis. We have an active educational program developing curriculum resources for integration of TLS and UAS technology and data into undergraduate education.

This presentation will showcase results from our TLS and UAS operations in high latitude and high altitude locations. Technical and logistical challenges of work in harsh polar and alpine environments are significant. We have adapted our workflow for reliable field operations in technical terrain and adverse weather. Results from these field surveys will be highlighted.

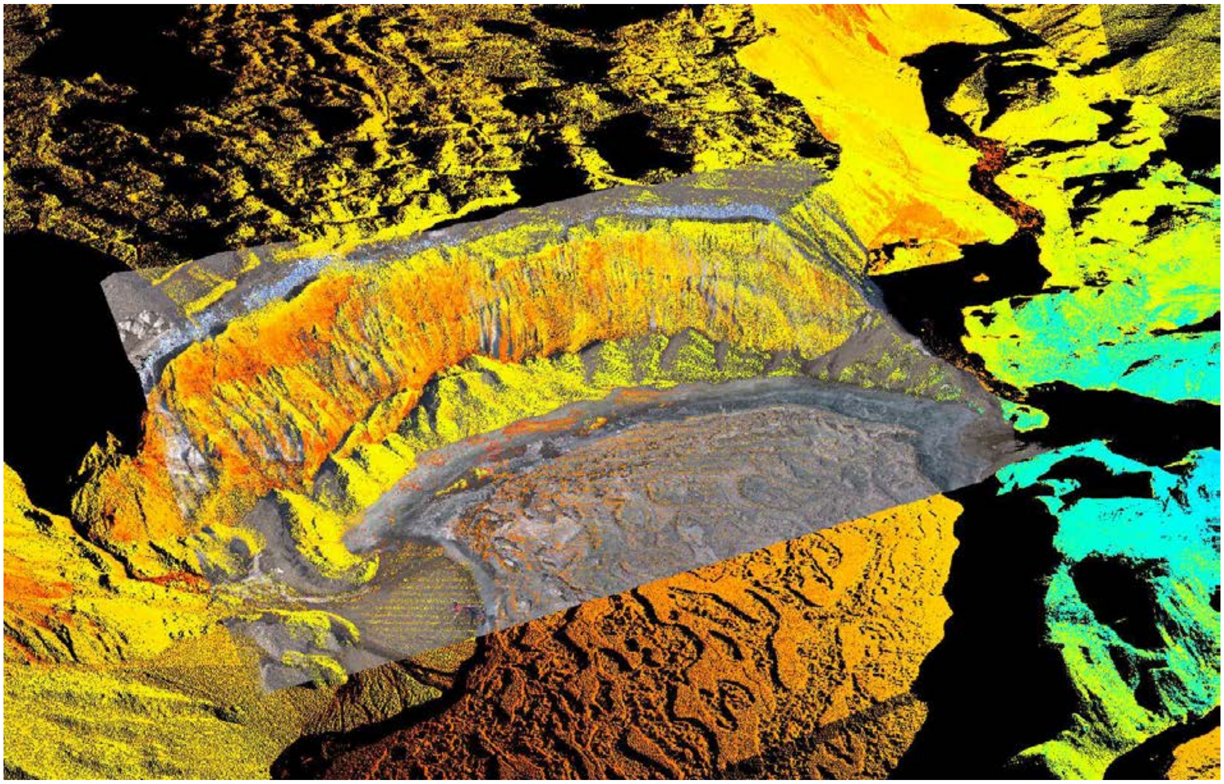

Figure 1. The image shows a thermokarst debris-covered ice cliff, frozen lake ice, and stream delta near McMurdo Dry Valleys, Antarctica. A TLS derived intensity-classified point-cloud is overlain by a UAS acquired visible-image point-cloud. Rapid retreat of the ice cliff is measured by surface change detection using these disparate remote sensing data sources. The UAS data was collected with GPS ground control in less than one hour. The TLS data collection time was over four times longer with GPS ground control.

Acknowledgments: U.S. National Science Foundation, United States Antarctic Program

3D Visualization of Sea Surface Temperature Data: A Technological Tool

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Keywords: *3D Visualization, Volume rendering, pattern, ParaView, Sea Surface Temperature*

The capability to visualize, analyze and interacting with objects that matters, is of importance to the Geoscience community and to other fields across the globe nowadays. 3D visualization is a sole technology to provide a visual content and interpretation inany capacity to human understanding and vision. As a result, 3D visualization is a subject of importance in processing sea surface temperature data and that is why there is the need for the implementation of computer systems of 3D visualization software for sea surface temperature data. This current research paper used ParaView as a 3D visualization technology tool to implement a three-dimensional space using a 3d sea surface temperature dataset, by creating a file reader in a Pipeline Browser and loading the variable Sea Surface Temperature (SST) in the variable properties pane and finally displaying an interpretation 3D object onto the RenderView for interaction. This current paper has applied 3D visualization technology to the field of ocean surface temperature data processing and used an efficient volume rendering technique to visualize the sea surface temperature in a three-dimensional space which is good and effective for human vision and interpretation. This methodology has gone a long way to improve the efficiency and provide a vivid interpretation to sea surface temperature data visualization. The most significant aspect of this research paper is to provide the importance of 3D visualization and how ParaView as a 3D technology tool had assisted in visualizing a 3D sea surface temperature data in a three-dimensional interpretation.

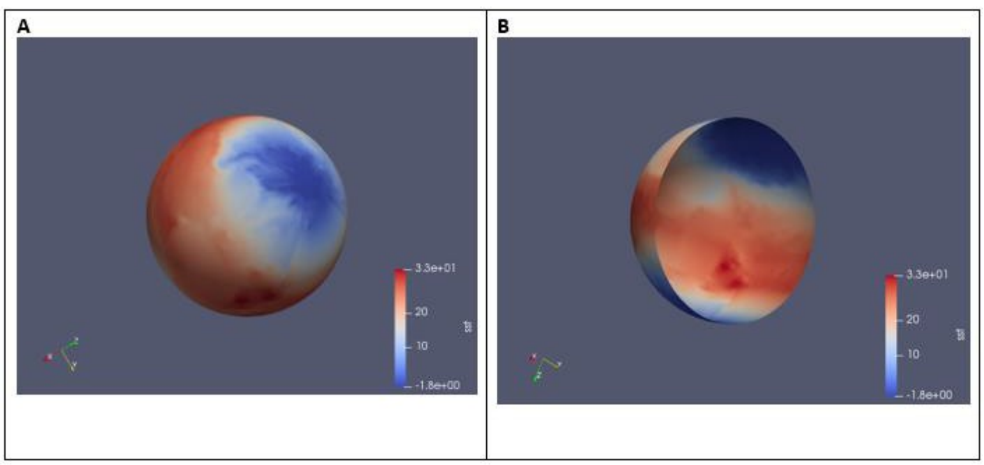

Figure 1. Shows the volume rendering of the SST. A represents the surface of the SST in the rendering mode whiles B represents the clipping of the SST or the cross-sectional view.

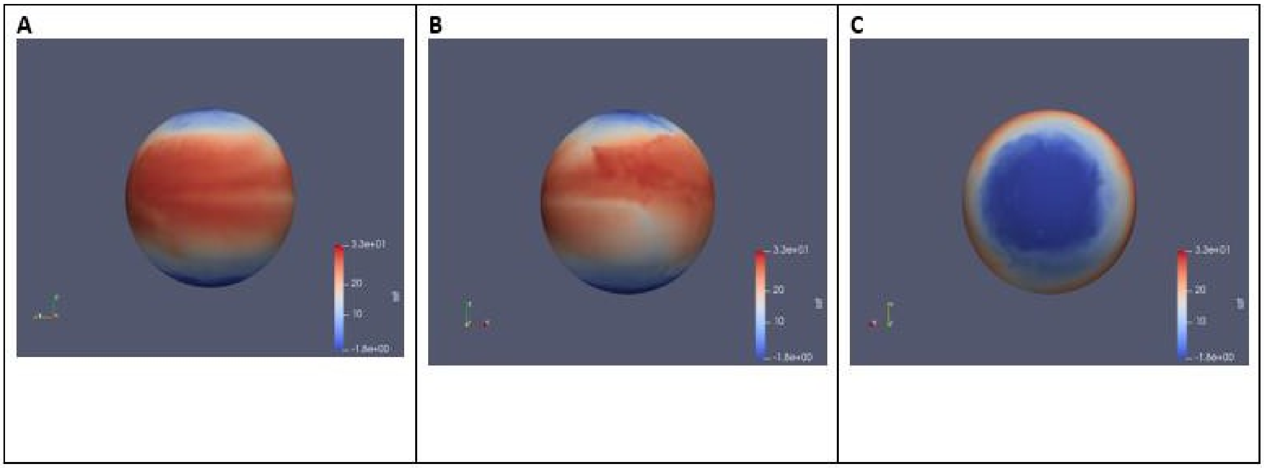

Figure 2. Shows the various views from the SST visualisation, A is the view on the X-Axis, B is the view on the Y-Axis and C is the view on the Z-Axis, and all in the positive direction.

Monitoring of Dune Migration Rates and Morphologic Evolution with an Unmanned Aerial Vehicle

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Cameron McCarty[1]
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Key words: *Dune migration, Dune morphology, Unmanned Aerial Vehicle*

Background: The barchan dune field near the southwestern shore of the Salton Sea in southern California is a classic locality that has been used for many dune investigations (e.g., LONG & SHARP, 1964; PELLETIER, 2013). Recent migration rates for the Salton Sea dunes have been calculated as values ranging from ~3-43 m yr-1 (PELLETIER, 2013). To date, morphological studies of these dunes have made use of aerial photographs from manned aircraft (e.g., LONG & SHARP, 1964), aerial Light Detection and Ranging (LiDAR) (e.g., PELLETIER, 2013, HOOSE *et al*., 2014), and terrestrial laser scanning (TLS) (e.g., PELLETIER, 2013, HOOSE *et al*., 2014]. Investigations using satellite images at similar locations have been performed as well (e.g., NECSOIU *et al*., 2009). Unmanned Aerial Vehicles (UAVs) are starting to see use in many remote sensing applications because of their low cost and logistical ease of deployment, and the high spatial resolution of the acquired data. These factors make UAVs particularly useful for acquiring high spatial and high temporal resolution data or images for detection of morphological changes (HUGENHOLTZ et al., 2013; CLARK, 2017). We have acquired a UAV image data set over the Salton Sea dunes, with images taken before and after a short, but strong wind event, and once again a year later. The closely-spaced times of acquisition of the data bracketing the strong wind event make this a unique data set for understanding the migration and evolution of dunes in response to a single wind event, and the images collected a year later show the cumulative effect of multiple wind events.

Data: Images were acquired during flights over the dune field with a DJI Phantom 4 Pro UAV. Flights were performed on 03 March 2017, 06 March 2017, and 24 February 2018. Each flight was performed at an altitude of 60 m, resulting in a ground sampling distance of 1.88 cm. On each flight day, approximately 1600 images of the dune field were acquired with frame overlaps of 80% in both directions, covering an area of approximately 0.5 km^2. Between the times of the two 2017 flight days, on 05 March 2017, nearby weather stations registered a significant wind event, with winds coming from the west at speeds exceeding the saltation threshold for a duration of approximately 16 hours.

Methods: The images for each flight were processed using structure from motion algorithms to produce orthophotomosaics and digital surface models (DSMs) of the study area for each flight day. These data products were registered to each other using fixed ground control tie points to enable change detection analysis. The registered DSMs were differenced from each other in order to identify areas of erosion and deposition and investigate morphological changes.

Results: Figure 1 shows the changes detected by differencing the two DSMs made from images acquired before and after the wind event in early March, 2017. The expected pattern of erosion on the windward side and deposition on the leeward side of the dunes is present, however there are localized amounts of deposition on windward sides near the crest of the dunes. This is consistent with deposition on the downwind side of the crest due to flow expansion before separating at the brink. The calculated average depth of erosion and deposition from the wind event is 32 cm ± 20 cm and 30 cm ± 20 cm, respectively. Average hourly rates of slip face migration during the wind event (assuming 16 hours of activity) for the four dunes labeled in Figure 1 ranged from 0.9 cm hr-1 (Dune D) to 5.3 cm hr-1 (Dune B). A similar change detection analysis using the UAV images acquired in late February, 2018, is underway. Preliminary results indicate annual migration rates for the same dunes ranging from 16 m/yr (Dune D) to 29 m/yr (Dune B). This implies that between 34 and 106 wind events of the magnitude of the one observed on 05 March 2017, would be necessary to account for the total annual migration

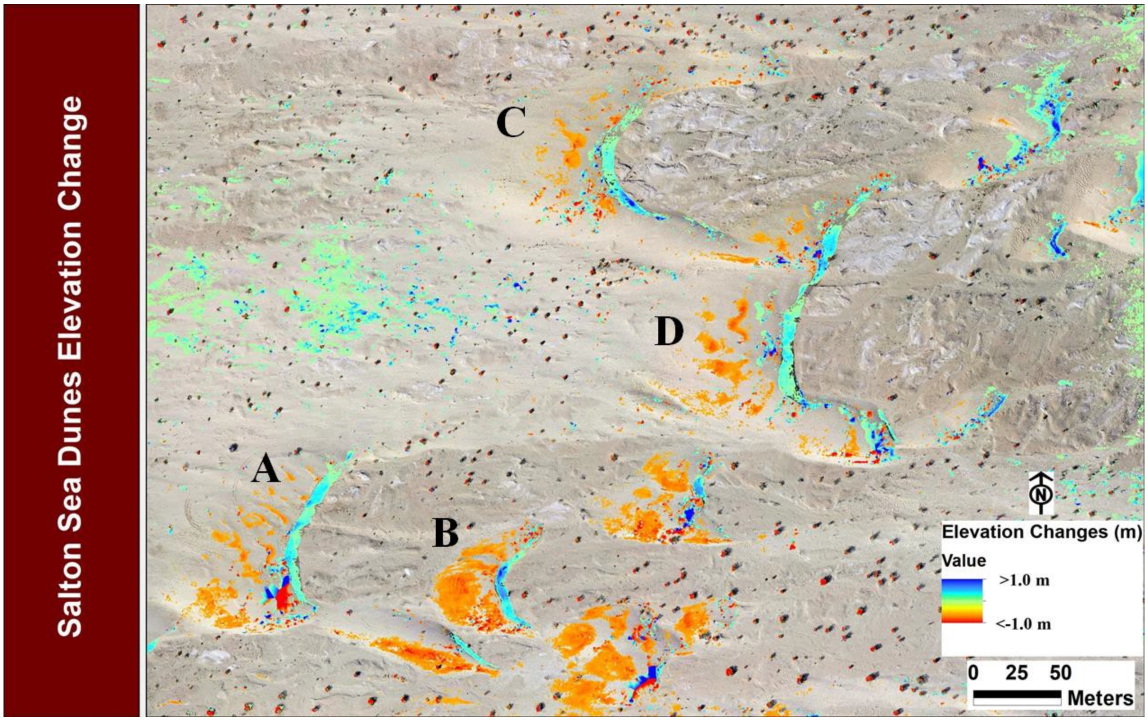

Figure 1: Elevation changes from a single wind event on March 5th, 2017, calculated from UAV data overlaid on the March 3rd, 2017, orthophotomosaic. Values within ±20 cm of 0 cm have been masked out due to uncertainties in the analysis. Red colors indicate erosion, while blue colors indicate deposition.

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Enhancing UAV 3D Orientation Estimation using Design of Experiment and Genetically Optimized Kalman Filter

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Key words: *Attitude and Heading Reference Systems (AHRS), UAV, Genetic Algorithm, Design of Experiment*

3D orientation estimation is of great importance in several geomatics applications. It is a key component in the navigation and control of Unmanned Aerial Vehicles (UAV). 3D orientation estimation is performed by Attitude heading reference systems (AHRS) (DENTI *et al.*, 2010). AHRS consists of inertial measurement unit (IMU) and basic sensor-fusion firmware to estimate the attitude and heading of a platform. Attitude and heading are critical to determining the control loop's feedback parameters for UAVs. Some advanced UAVs may include *gimballed* platforms that can rotate independently from the UAV platform as seen in Figure 1. To direct the gimballed platforms to a certain orientation, a robust and accurate AHRS is needed.

Figure 1: UAV Quad-copter with gimballed camera platform

AHRS utilize Kalman Filters (KF) as an efficient method to estimate the state of a stochastic system by minimizing the mean of the squared errors related with the integration of accelerometers, gyroscopes, magnetometers and GPS (if available). However, the stability and accuracy of KF is dependent on accurate knowledge of sensor noise covariance (Q matrix) and measurement noise covariance (R matrix). Although KF parameters can be partially approximated by Allan Variance method (EL-SHEIMY, HOU, & NIU, 2008), in practice, the resulting parameter need further optimization. Since there is no closed-form solution for this problem, this further optimization is commonly performed by a trial- and-error approach.

This work proposes a systematic procedure for optimizing KF parameters using Genetic Algorithms (GA) and the Design of Experiments (DoE). GA is an optimization tool that takes advantage of the concept of natural genetics to solve optimization problems. The GA maps a set of individual objects into a new set of population with the aim of finding an approximately good solution to the system by genetically breeding the set of individuals over a series of iterations. To accelerate the GA performance, we propose the utilization of DoE technique. We used DoE technique to determine the most sensitive parameters in the AHRS design and interactive effects of different parameters. Then, to accelerate the GA performance, we use DoE to direct the GA operators to the most significant parameters. Simulation and real experiments have been carried out and the optimized KF parameters have been used on a real AHRS platform showing significantly enhanced, robust and accurate 3D orientation estimation performance. The overall system block diagram is shown in Figure 2.

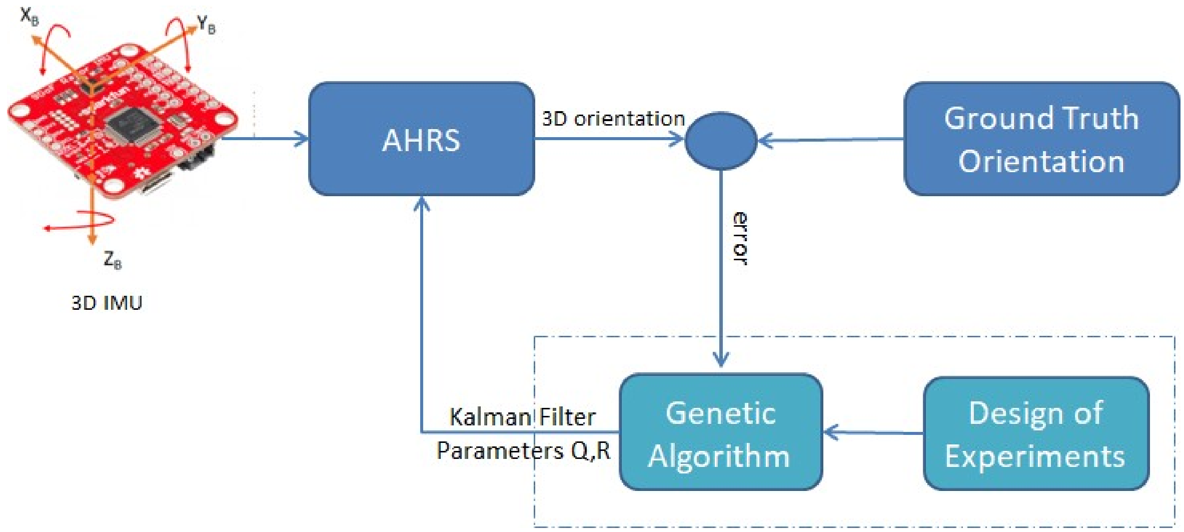

Figure 2. Block diagram of the proposed method

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Virtual Outcrop Techniques as a Means of Generating Quantifiable Data in Highly Variable Ephemeral Fluvial Systems: An Example from the Kayenta Formation, USA, for use in Reservoir Characterisation and Modelling

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Key words: *Photogrammetry, geoscience, reservoir characterisation*

Outcrop analogue studies are a useful technique and have long been recognised as a valued guide for prediction of subsurface architectural elements and provide realistic geology to static models. With recent advancements in technology, virtual outcrops are now relatively simple to generate and gather statistically relevant data for use in reservoir characterisation and modelling.

This work examines the exceptional exposure of three-dimensional outcrops from the mixed ephemeral fluvial and aeolian Lower Jurassic Kayenta Formation, western USA, to determine the proximal to distal, temporal and spatial distributions and interactions within these environments. Exposure is often in the form of large vertical to stepped cliffs (Figure 1), and is highly variable both laterally and vertically, this makes traditional sedimentary logging techniques difficult to conduct and not representative of the sedimentary system as a whole.

Figure 1: High resolution outcrop photograph demonstrating the degree of variability of the ephemeral fluvial system within Kayenta Formation, taken near Uravan, CO.

Digital field capture photogrammetric techniques have been used on multiple field sites from proximal to distal to examine and record in detail the spatial interaction, geometry and dimensions of architectural elements and facies distributions of the ephemeral fluvial and aeolian environments. This data, coupled with the sedimentary logs, have been used to develop quantified three-dimensional facies models of sedimentary interactions between elements of these environments. Statistically relevant data on element dimensions have been used to generate quantifiable reservoir models based on geobody thickness to width

ratios, extracted from three-dimensional photogrammetric models using geological visualisation and interpretation software (VRGS).

Structural measurements of beds, polylines and geobodies can be extracted within the software (Figure 2). Mapping of geobodies, such as, fluvial channels, can allow for accurate measurements of the channel width and heights by incorporating sedimentological data, such as palaeocurrents. This allows for accurate reconstruction of channel bodies regardless of the orientation of preservation, which can give overestimated ratios.

These quantifiable models can then be applied and tested for robustness against similar geological settings, with the photogrammetry and statistical analysis of the geobodies aiding in the three-dimensional reconstruction where limited data is available. This provides valuable information for subsurface application for enhanced reservoir characterisation in complex mixed aeolian-fluvial systems, such as the Permian Leman Sandstone of the Southern North Sea, UK.

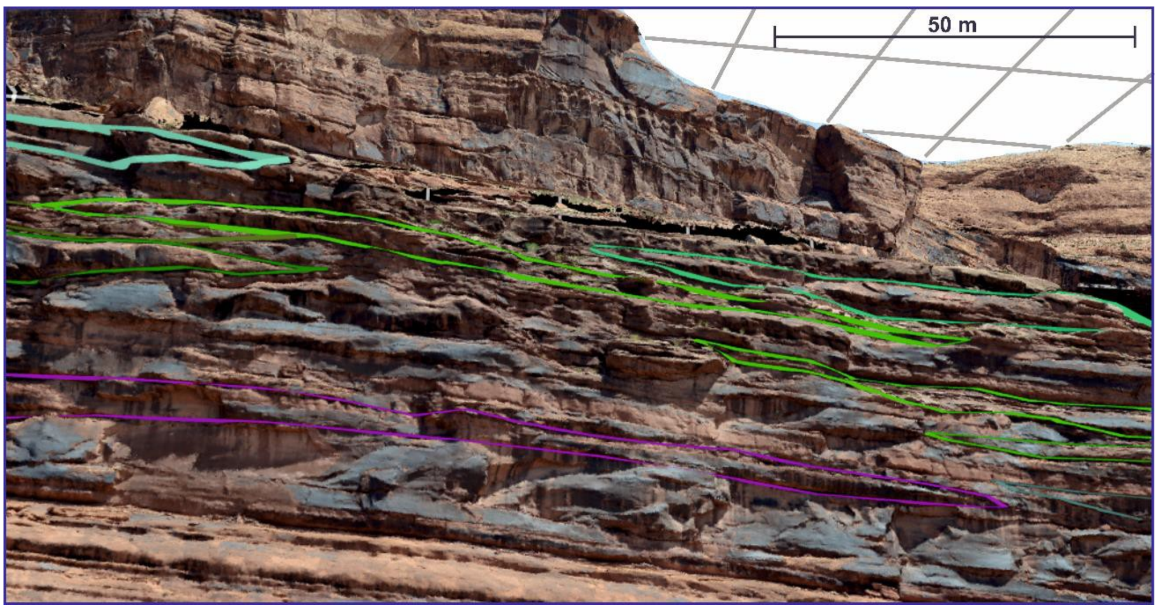

Figure 2: Screen capture of a three-dimensional photogrammetric model being analysed in VRGS for geobody identification.

Acknowledgements: This project is funded partially by the NERC CDT in Oil and Gas. Many thanks to David Hodgetts (Manchester University) for permission to use VRGS.

Close-range sensing workflows in Structural Geology based on open-source/open-access solutions

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Key words: *Structural Geology, DOM, workflow, open-source*

In Structural Geology, many projects start with intensive field-based data acquisition campaigns, which might be performed in quite different types of natural or artificial outcrops. For some years, this field work has been substantially influenced and transformed by various close-range sensing techniques that allow the field geologist to create a digital outcrop model (DOM) and to take along plenty of geometrical and spectral information about the outcropping rocks.

In general, DOMs can be utilized for outcrop visualisation, documentation, manual outcrop analysis ("point-picking"), extraction of spectral data and/or semi-automatic extraction of geometric data. Within a structural investigation DOMs might be deployed for fold analysis, fault analysis, extraction of fracture networks, fracture roughness estimation, detection of neotectonic activities or digitisation of geological features for 3D-models of various scales resulting in a large number of analysing techniques.

Latter might be carried out on point clouds or meshes (with or without spectral information) and may differ in pre-processing and processing steps as well as in software solution. Therefore, the analysing structural geologist faces various tools, data formats, file types, operations and outcomes. Our investigation focus on the compilation of useful, transparent, sustainable and comparable workflows or "pipelines", which can be executed by open-source/open-access solutions.

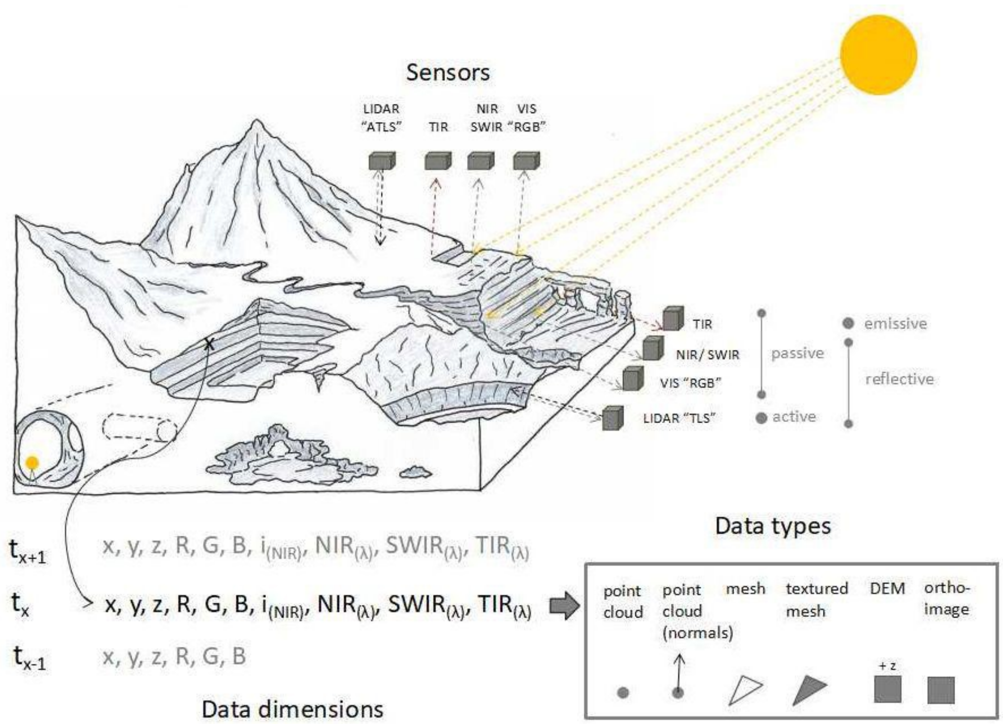

Figure 1: Schematic sketch illustrating typical geological outcrops (horizontal, vertical or mixed) and applicable aerial and terrestrial sensor types as well as resulting data dimensions and data types of digital outcrop models (DOMs)

3D Characterization of Cave Networks using Photogrammetry, Example from Longhorn Cavern, Central Texas

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Keywords: *photogrammetry, cave, geoscience*

Digital outcrop models (DOM) have been a valuable tool in geologic modeling over the past ten years. LiDAR generated data has been a critical tool in the creation of data for visualization in geologic studies. With the advancement of photogrammetry software processes, we are now able to deliver comparable three-dimensional models at a fraction of the cost of a LiDAR survey while maintaining the accuracy to a high degree depending on the resolution of the data set. In this study we duplicated the workflow of imaging outcrops in 3D and applied it to a new setting, a cave network. The modeled cave system is Longhorn Caverns is in Burnet, Texas (30.684504, - 98.350292), which is developed in the Lower Ordovician Ellenburger Group near the edge of the Llano Uplift in Central Texas.

This project was constructed by assembling a dataset of thousands of overlapping images of the Longhorn Caverns cave system. In Longhorn Caverns, the rooms and passages are expansive enough to allow a person to traverse the network freely and capture overlapping images of the cave walls, ceilings, and floor at all angles with a digital single-lens reflex (DSLR) camera and a wide angle lens. The completed dataset constituted approximately 6000 individual images that were used to construct the photogrammetric model that characterizes over ~750 meters of cave passage.

A Leica Disto X310 survey instrument, a combination of a laser distance meter, compass, and clinometer with modified firmware for the specific use in caving, was used to collect survey data in the cave system. This instrument measures distances along with inclination to establish control points in the cave. We collected a GPS point outside of the cave and established that reading as the first control point. We were able to then measure from that initial control point and work through the cave collecting data and establishing GPS derived ground control with 70 control points.

All images were processed within Agisoft Photoscan Professional software package. In addition to the construction of the model, GPS-derived control points were registered with the images at an average of ~50 image projections per control point. This enables the photogrammetry model to be geographically referenced in virtual space and further data analysis can take place on the model in relation to its real world attributes and coordinates.

Accurate 3D representation of caves allows for extracting critical morphometric parameters that can be subsequently used for geostatistical modeling of karst network. These parameters include, orientation and dimension of cave tunnels and rooms, spatial distribution and pattern of cave elements. The ability to accurately represent karst or paleokarst network in 3D is important for both hydrogeology and reservoir characterization.

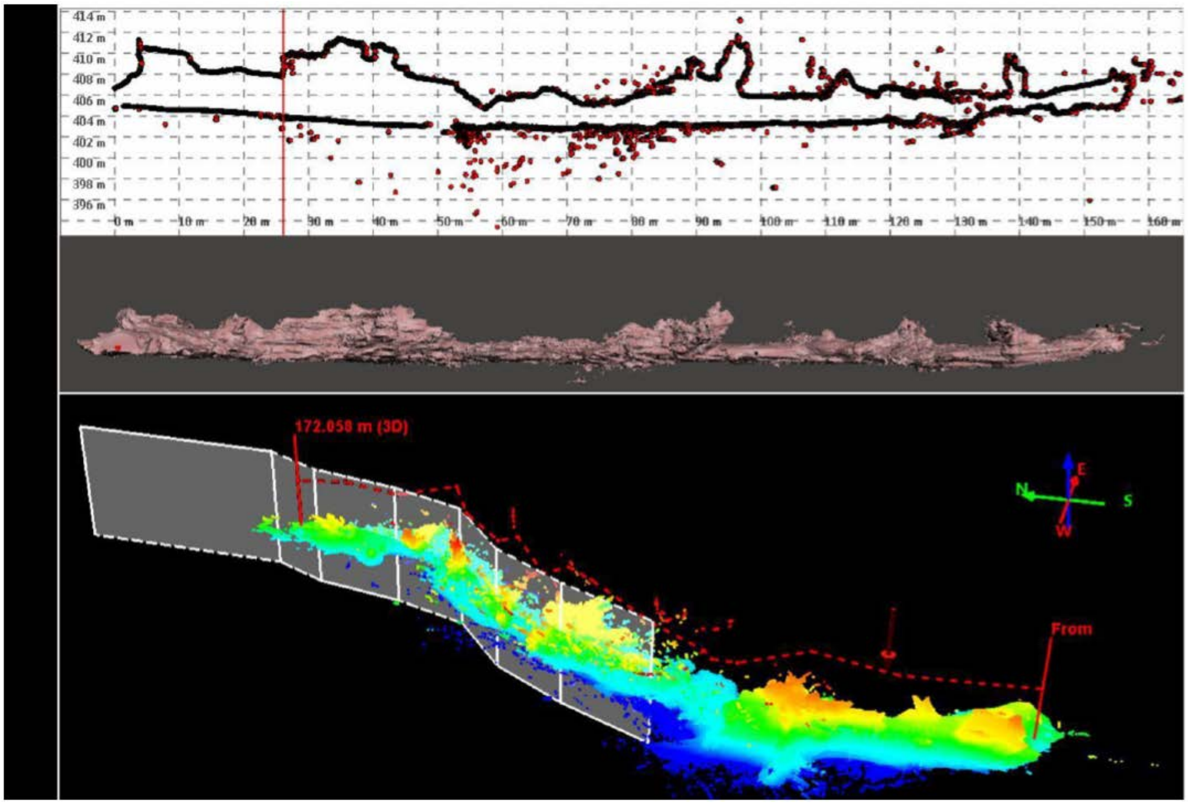

Figure 1: Portion of cave model with vertical slice taken

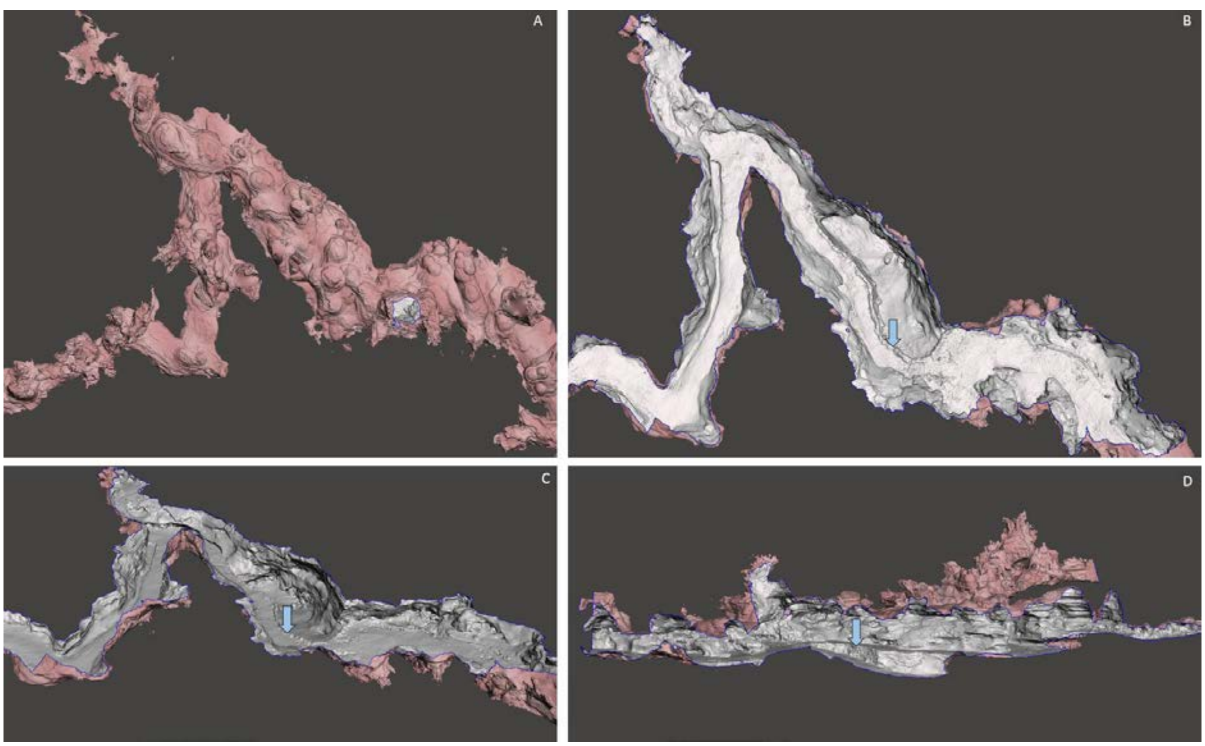

Figure 2. Mesh section of Longhorn Cavern

Developing a low-cost camera gauge and an unmanned water vehicle to measure hydro-morphological parameters

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Key words: *water level detection, particle tracking velocimetry, unmanned water vehicle, mobile LiDAR*

Extreme events, i.e. flash floods, in small and medium scaled catchments evolve rapidly after intense rainfall. In the research project EXTRUSO new models are developed to describe and predict these flood events. The models depend on high resolution input data, i.e. a dense monitoring network for hydrological parameters and high resolution digital terrain models (DTMs) for geomorphological parameters. Small scale catchments are mostly ungauged, stressing the necessity for densifying the hydro- geomorphological observations.

An approach is presented using a low-cost camera based tool to measure water levels and flow velocities to derive discharge. Thereby, image processing is performed to automatically retrieve water lines in images, besides manual image measurements, considering the temporal signature of the water surface. Afterwards, the image information is projected into object space to estimate the actual water level. Flow velocities at the water surface are estimated using particle tracking velocimetry considering least square matching.

To measure the river topography, a remote controlled multi-sensor-platform, i.e. an unmanned water vehicle (UWV), is presented, that enables the acquisition of high resolution DTMs of the river banks. Additionally, the UWV is equipped with an echo sounder to measure the river bathymetry. An in-house calibration workflow is developed to calculate the relative orientation between a LiDAR, a 360°camera and the IMU.

Results reveal that the introduced camera gauge allows for the estimation of water levels with sub-cm accuracy. Due to the implementation of a low-cost system, significant densification of hydrometric stations in ungauged catchments is possible. The new boat-based multi-sensor-platform enables the acquisition of point clouds with cm-accuracy. Photogrammetric methods can provide detailed information about the terrain and its hydrological response and therefore be an important supplement for hydrological modelling.

Mobile Terrestrial Photogrammetry

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Key words: *Photogrammetry, change detection, rockfall hazards*

Ontario has over 16,500 km of provincial highways, many of which are subject to rockfall hazards associated with slopes and rock cuts adjacent to the roadways. The recurrent nature of rockfall hazards necessitates frequent monitoring and a method of prioritization for remedial efforts. To date within Ontario this has been carried out effectively by the application of the Ontario Rockfall Hazard Rating System (RHRON) which acts to quantify hazard at a given site, estimate the cost of remediation, and provides a basis for comparison between sites. However, this method relies on on-site manual measurements being taken, exposing employees to some measure of traffic and rockfall hazard. In addition, manual measurements of the rock face itself are limited to portions of the face which can be quickly and safely accessed. In order to minimize the risk to employees, decrease the time required, and increase spatial coverage, mobile terrestrial photogrammetry was employed to generate 3D models. Using this technique, photographs are gathered at highway speed along a pre-planned survey route and used as inputs to photogrammetric models. While the use of terrestrial photogrammetry to complement site investigations is well established, performing surveys from a mobile platform allows users to increase spatial coverage per time period while limiting exposure. Analysis of individual models permits input data for the RHRON system to be measured, in addition to enabling identification of unstable blocks for kinematic analysis. By collecting multi-temporal data, users are also able to detect changes over time, identify prevalent rock fall source and accumulation zones, and better assess the effects of previously employed remedial actions. A review of the methodology and results for several rock cuts monitored in the Eastern region of Ontario will be presented.

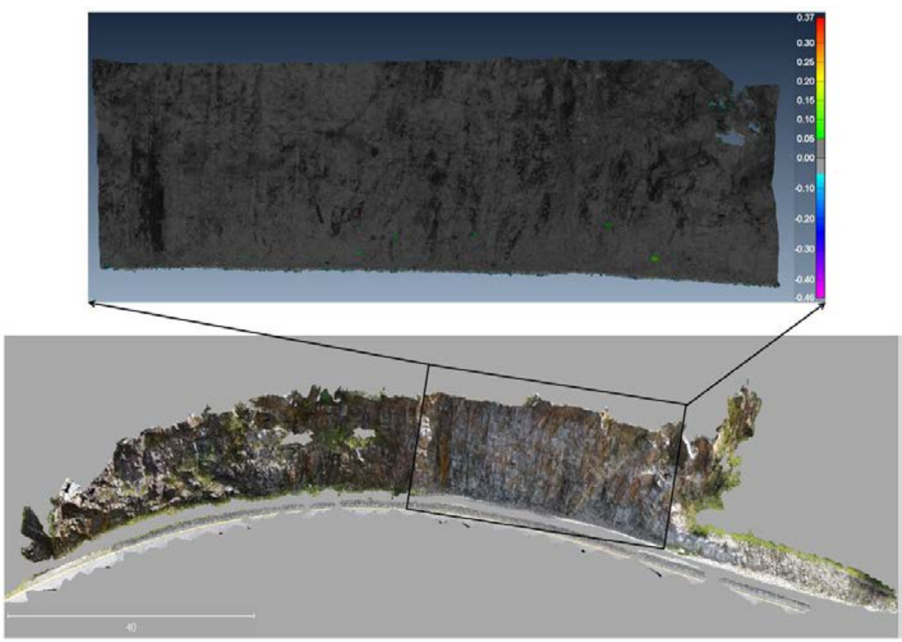

Figure 1: Photogrammetric model and associated change detection map created with images taken at highway speed.

Figure 2: ARAN 7000 Vehicle owned and operated by the MTO. The end goal of research is to attach a camera rig to a mobile vehicle allowing automated network level data acquisition for rockfall prone highway corridors.

Acknowledgments: BGC, Railway Ground Hazard Research Project (RGHRP), Ministry of Transportation of Ontario (MTO)

Terrestrial Laser Scanning time series analysis for landslide geometry and thickness inversion

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Key words: *Landslide, Terrestrial Laser Scanning, Monitoring, Automated registration, Displacement analysis Thickness inversion*

We present a complete Terrestrial Laser Scanning (TLS) analysis system applied to the Pas de l'Ours-Aiguilles landslide (Fig. 1). The unstable area has a width of 1 km and a length of 600m, associated with rockfalls, mudflows and significant deformation of the road located at the base of the slope. The site has been instrumented with a permanent Optech ILRIS TLS system for 6 months allowing for acquisition of almost 200 scans. Considering the amount of data, an automated procedure was developed to process the data and inspect landslide activity. We developed a three-stepped data processing workflow from the acquisition to the estimation of the landslide volume.

Point cloud processing scripts were developed in C++ and are mainly based on PCL (RUSU & COUSINS, 2011), PDAL and GDAL libraries. A filtering and registration pipeline (KROMER *et al.*, 2017) was first implemented to check point cloud consistency, reject unusable files, filter noise and unwanted areas, and to finely align all point clouds to obtain a consistent dataset over the period of acquisition. The pipeline was designed to be adjustable and usable for various use cases, as it is user-configurable and internally adaptive to the input dataset resolutions. The registration step is insensitive to vegetation, which avoids time consuming vegetation filtering. Nevertheless, an optional pipeline can be activated to clean point clouds and compile Digital Surface Models (DSMs). The pipelines were parallelized with OpenMP in order to speed up the entire dataset computation. A second module handles the registered scans and outputs the 3D displacement fields, for each component. The TLS-derived displacement fields are compared to surface displacements measured by a permanent ground-based InSAR installed on the site. Finally, the third module takes the displacement field as input data for the inversion of landslide thickness using the strategy initially proposed by BOOTH *et al.* (2013) and adapted to long time series. The tool allows the estimation of landslide geometry and volume according to the depth inversion.

The workflow provides an efficient way to manage TLS point cloud datasets for the analysis of mass movements. It can be set up either for near-real-time monitoring situations or for post-acquisition processing.

Figure 1: Lower part of the Pas de l'Ours landslide seen from the instrumentation area (permanent LiDAR and GB-InSAR).

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Checking the complementarity of LiDAR / SfM terrain models derived from different platforms for rockfall projects

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Key words: *Lidar, photogrammetry, RPAS, rockfall*

A rockfall risk mitigation plan in Montserrat Massif (Catalonia, NE of Spain) is currently being carried out. The challenges posed by this singular place of natural and cultural heritage, where hazard and exposure meet, require research work beyond the strict protection projects. Several terrain models obtained from different technologies (Table 1) have been tested for the ongoing rockfall hazard analysis (JANERAS *et al.*, 2017a).

Table 1: List of the different type of terrain models available for the risk mitigation plan in Montserrat.

	Sensor	Platform	Coverage
LiDAR	LiDAR	Airborne (plane)	Most part of the mountain
	LiDAR	Terrestrial	Rock walls above hotel facilities
SfM Photogrammetry	PENTA camera	Airborne (plane)	Sanctuary and monastery area
	Onboard camera	RPAS / drone	Rock blocks, locally
	Handy camera	Helicopter	Rock walls under surveillance
	Handy camera	Terrestrial	Sparse

ICGC has his own planes to deal with the official cartographic mission in Catalonia, on which airborne LiDAR and PENTA camera (SOLER *et al.*, 2016) are mounted and operated. At the start of the mitigation plan, a terrain elevation model (TEM) was obtained with airborne LiDAR for the main part of the Montserrat Massif at 1x1m scale, and a test with the PENTA device (airborne oblique cam set) was performed at the area of most interest. Additionally, at several places other type of surveys has been done with specific purposes, combining other techniques based on LiDAR and photogrammetric sensors mounted on different platforms. The return of experience of these tests will be done, regarding its applicability to both stability and propagation analyses (JANERAS *et al.*, 2017b).

For instance, in the Devil's Castle rock formation a sufficiently detailed 3D model is obtained by the PENTA survey. But its characteristic ceiling is not well reproduced. The model is improved by the addition of some terrestrial images. Moreover, to perform the stabilization projects of large blocks at the cliff behind the buildings, a terrestrial LiDAR survey was performed. To complete the upper and rear parts of the rock needles a mixed model was build adding the data of airborne LiDAR (JANERAS et al., 2004). Finally, other blocks and rock faces of interest have offered the possibility to cross-check the photogrammetric models of PENTA as reference, and those obtained by structure from motion (SfM) techniques applied to image series coming from RPAS/drone and helicopter surveys (BUILL *et al.*, 2016).

Acknowledgements: The geological risk mitigation plan in Montserrat is supported by the Catalan Government and includes a research line of work on the geomechanical behaviour of this rock mass leading to instabilities. Some tools required for this plan demand also to perform some tests in geomatics innovation, like exposed.

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Analysis of point cloud data to correlate geometric factors with rockfall pre-failure deformation patterns

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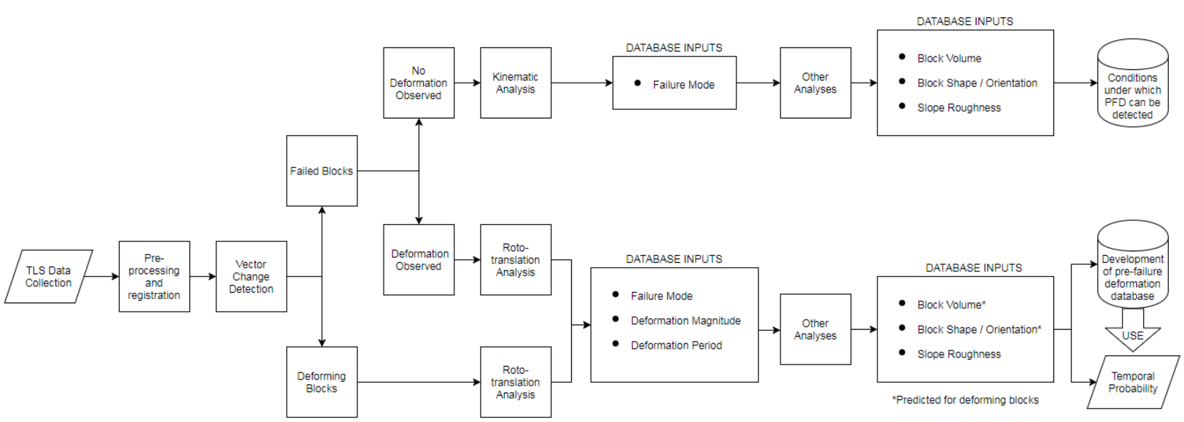
Key words: *Lidar, rockfall, geohazards, monitoring, forecasting*

Rockfalls are a common hazard along transportation corridors in Western Canada, threatening both infrastructure and human safety. Knowledge of the location and approximate timing of potential rockfalls would enable mitigatory actions to be taken if necessary. As early as hundreds of days before failure, some rockfalls exhibit centimeter-scale movements which are measurable via change detection methods which utilize point cloud data from repeated terrestrial laser scanning (TLS). Characterization of pre-failure deformation magnitude and duration and associating these trends with various other slope characteristics for past rockfalls can enable case-history-based empirical temporal forecasting for future events (Figure 1). This enables hazard ranking of potential rockfalls based on predicted volume and current state of deformation and estimated time-to-failure ranges. As the database containing past rockfalls and their characteristics grows, more accurate probability estimates can be achieved. Identification of which characteristics have the greatest impact on a potential rockfall's pre-failure deformation trends, especially whether it is present at detectable levels, is important for streamlining the population of the database, constraining failure probability estimates, and identifying conditions under which forecasting is possible. Deformation trends for past rockfall events are assessed using a best-fit roto-translation method, which involves successive fitting of a rock block mesh to past scans and conversion of the required rigid-body transformation matrices to translation, topple, and tilt angle values (OPPIKOFER et al., 2009). Geometric characteristics which may affect rock deformation patterns that can be obtained from point cloud analysis include, but are not limited to: block shape, block orientation, slope angle, block volume to back scarp surface area ratio, and slope roughness. This study will investigate the effects that various combinations of these characteristics have on both pre-failure deformation duration and magnitude at various survey sites in the Ashcroft subdivision of CN Rail Western Canada.

Figure 1: A workflow showing the development and usage of a pre-failure deformation database for rockfall prediction



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Coastal Area Dynamics, Traffic Corridor Event Safety, and Management Support Creating Sectoral Change

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Key words: *Natural Hazards, rockfalls, landslides, coastal erosion*

In late 2016, through early 2017, across the Pacific Northwest and California, a series of ongoing oceanic and climate influenced events resulted in serial landslides of varying magnitudes across the region. We highlight a series of events, their impact, the challenges created, our application of available and new technology tools, and most importantly, the actual description of the engagement process with geologists, geotechnical engineers, contractor staff, local, regional, and state agency planning and management officials.

We describe a series of events including the deployment of four (4) terrestrial InSAR systems all producing 24/7 data with analysis and reporting on a daily basis to three separate DOT Districts' geology, engineering, and contractor teams.

We describe the intimate daily data process, and it's very important outcome – two tables and a Response Level Protocol – action elements not before made available, based on near real-time data that allowed all work to continue in any weather, as regular local failures continued, and as the pressure rose from communities facing economic and infrastructure debacles. Project managers shared this information at the highest levels to serve as a foundation for the measures taken. Dynamic and short term attainable goals were planned and executed to return access and carriage through these affected areas.

A Super-Voxel Approach for Granular Sediment Analysis: Initial Results

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Key words: *Granulometry, voxels, SfM-MVS photogrammetry*

Granulometry, or the measurement of the size distribution in a collection of grains, has been a subject of research in a variety of fields. Characterizing the size and shape of grains can provide insight into a variety of geomorphological processes and assist in the optimization of operations, such as blasting.

Quantifying blast fragmentation, block size distributions on talus slopes or reach-scale variations in grain size along a river requires a rapid, accurate and repeatable measurement technique. Physical tests, such as sieving or the Wolman pebble count, although well-established, are limited in their ability to provide high resolution information of grain size due to the time-consuming nature of physical sampling. Furthermore, these methods are destructive, which hinders repeated surveys and potentially exposes engineers to rockfall hazards if working on talus slopes.

Remote sensing techniques have been presented to overcome the issues highlighted above. Image analysis related to blasting and fragmentation of rock piles has been a subject of research since the 1980's (THURLEY, 2002). However, there are several known issues with 2-Dimensional (2D) image analysis techniques such as: no direct measure of scale, perspective distortion, uneven lighting conditions, excessive shadowing, color and texture variation in the material, and inability to distinguish overlapped particles and non-overlapped particles (THURLEY, 2002).

2.5-Dimensional (2.5D) techniques have also been introduced to overcome the issues associated with 2D methods. Three main methods have been identified and include:

1. Relationship between D_{50} and the standard deviation of elevation (σ_z) from a Digital Elevation Model (PEARSON *et al.*, 2017)
2. Localized standard deviation of elevation (effective roughness equivalent) (HERITAGE & MILAN, 2009)
3. Deviation of a point from a plane that was fit to all points inside a user-set radius (WOODGET & AUSTRUMS, 2017)

Through a series of laboratory and patch-scale tests, PEARSON *et al.* (2017) investigate the use of surface roughness metrics (2.5D methods) as a proxy for grain size in high resolution topographic surveys. They examined the effects of: precision limitations with Structure-from-Motion Multi-View-Stereo (SfM-MVS) photogrammetry datasets, particle roughness, particle shape, imbrication, sorting effects and form roughness. From their experiments, they conclude that the use of surface roughness as a proxy for D_{50} is not recommended for poorly sorted material.

Recently, BONNEAU & HUTCHINSON (2018) have demonstrated that semi-supervised machine learning can be used to identify particles 25 cm in diameter on a talus slope in terrestrial laser scans (TLS). Using this methodology, they were able to identify sorting mechanisms which have been observed in flows of granular material on talus slopes. Furthermore, this study illustrates that particle sizes can be measured on a talus slope without having to expose workers/researchers to potential rockfall hazards originating from the cliff above the talus slope.

In this work, we continue to build on 3-Dimensional (3D) analysis techniques and present a fully 3D segmentation and classification algorithm, which takes full advantage of the 3D point cloud geometry acquired from remote sensing techniques such as SfM-MVS photogrammetry and both terrestrial (TLS) and aerial laser scanning (ALS). The aim is to segment and classify a 3D point cloud into detectable grains for subsequent analysis.

Acknowledgements: SNC-Lavalin is gratefully acknowledged for providing the sieved aggregate used in this study. Melanie Coombs and Brodie Shannon are acknowledged for their assistance in the laboratory testing. This research was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery and Accelerator grants held by D. Jean Hutchinson and by the Canadian Railway Ground Hazards Research Program (CN Rail, CP Rail, Transport Canada, Geological Survey of Canada). Support was also provided to David A. Bonneau by the NSERC's Graduate Scholarship Program.

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Analysis of the 17 June 2017 Karrat Fjord Landslide Generated Tsunami in Western Greenland

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[2] *BGC Engineering, Kingston, Canada*

Key words: *Landslide, tsunami, back analysis, forward modelling*

On 17 June 2017 a 50 million cubic meter rockslide fell into Karrat Fjord (Western Greenland) at a height of over 1000 meters. The impact of the material generated a tsunami wave which propagated 30km and inundated the remote community of Nuugaatsiaq, killing 4 of its 85 inhabitants. Presented is a back analysis model of the June 2017 event and a forward model of a hazardous failure adjacent to the June 2017 landslide scar, in efforts to access the risk for the remote community of Nuugaatsiaq.

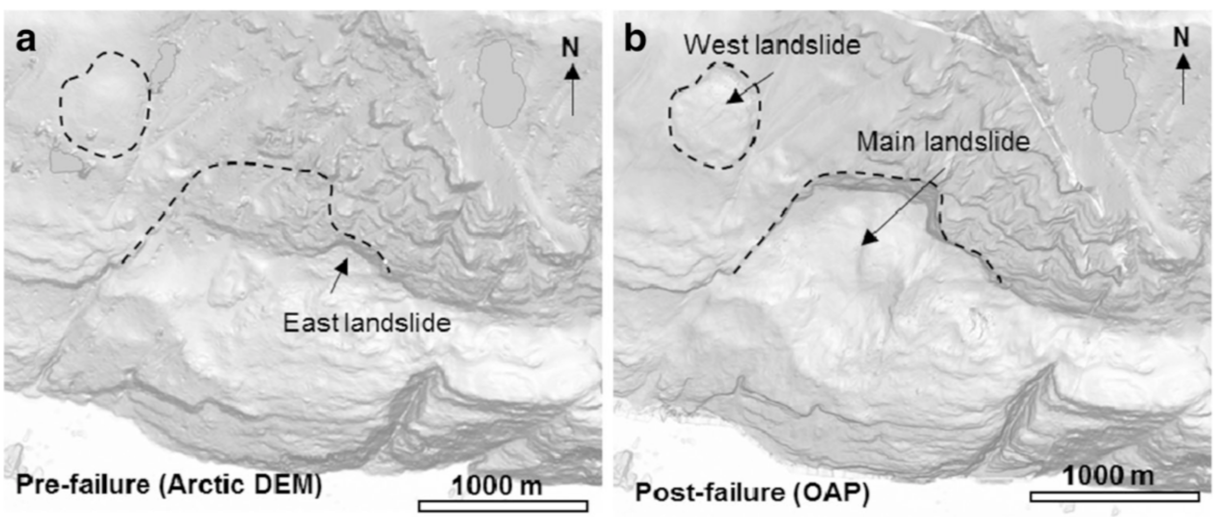

Figure 1: Pre and post DEM of the June 2017 Karrat Fjord landslide from GAUTHIER et al., 2017.

Figure 1 shows the rock slope in 2015 and in 2017 following the failure. The bedrock consist of foliation which gives the tendency to fail in a planar fashion. The section east of the main landslide scar was chosen to be forward modeled, as its potentially large catastrophic failure was thought to govern the risk.

A landslide runout model (DAN-W) was used in conjunction with a wave propagation model (Delft3D) to simulate the June 2017 event. The landslide model was constructed using 5-m pre and 2-m post DEM profiles extracted through the landslide area using ArcMap. The wave propagation model space was constructed using coarse IBCAO 500-m bathymetry data. The rheological parameters within the landslide model were adjusted until a correct runup of 5-m was output from the June 2017 model. An intermediate momentum transfer calculation was used, in which the amplitude of the initial solitary wave is calculated given the landslide thickness, velocity, angle of entry, and depth of water (TAKE & MULLIGAN 2017). Empirical wave runup calculations were used to compare the Delft3D wave height output to the 5-m runup measurements taken at Nuugaatsiaq following the June 2017 event (HUGHES, 2004). Figure 2 shows the D3lft3D wave propagation output from the June 2017 model.

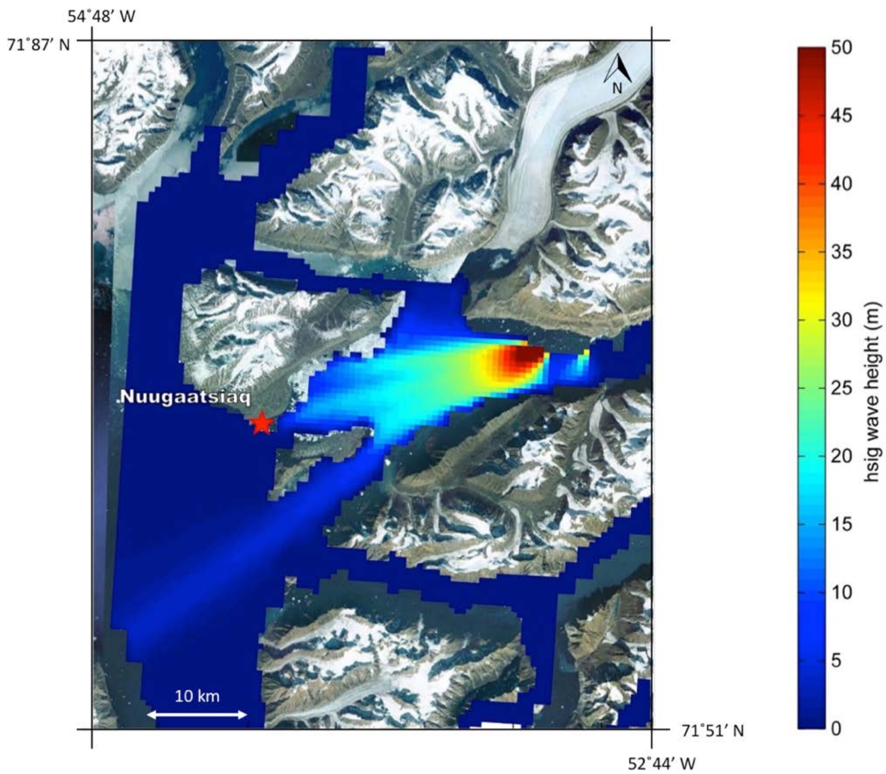

Figure 2: The D3LFT 3D wave propagation output for the June 2017 Karrat Fjord landslide generated tsunami event.

Following the calibration of the June 2017 landslide generated tsunami model, the potential failure of the eastern section was modeled. The model reached the upper limit wave height likely governed by the wave breaking criterion, which was used moving forward with the risk analysis of Nuugaatsiaq.

Further analysis is required to understand the hazards in the rock slope area, and further modeling should be investigated with finer bathymetry data sets to understand the propagation of waves throughout the fjord.

Acknowledgements: Much thanks to Dave Gauthier of BGC Engineering for his mentorship and expertise in natural hazards, risk analysis, and risk mitigation. Thank you to Dr. Andy Take and Dr. Ryan Mulligan of the Queen's Civil Engineering Department for their resources and experience in landslide and wave propagation modelling. We would also like to thank Alex Baumgard and Garrett Miller of BGC Engineering for their additional support on the project. Lastly, we would like to express our gratitude to GAUTHIER *et al*. for the use of their data.

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Session 5

Interactive Session

Thursday 4:20 pm – 5:15 pm, 23rd August

1. Alexandra Boghosian– Hololens visualization of the Ross Ice Shelf

2. Simon Buckley– Enhanced excursions: how virtual field trips complement existing geoscience field activities (Session 1)

3. Own Fernley– Electromagnetic modelling for web: Building HTML5 visualizers in exploration geophysics

4. Holger Kessler – Demonstration of GroundHog (Session 2)

5. Nick Rosser– Live web-based presentation of 3D coastal rockfall monitoring (Session 1)

Hololens visualization of the Ross Ice Shelf

Alexandra Boghosian[1], Peter Richards[2], Martin J. Pratt[3], Jonathan Kingslake[1], Robin E. Bell[1]

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[2] Columbia University, Department of Computer Science, New York, NY, United States
[3] Washington University in St Louis, Department of Earth and Planetary Sciences, St. Louis, MO, United States

The ROSETTA Ice project has been flying over the Ross Ice Shelf in Antarctica to map the area over the last three years. The IcePod has been deployed as part of the ROSETTA project to comprehensively map the ice shelf from top to bottom. The ROSETTA datasets map the ice shelf surface, internal structure, and ice shelf base with lidar, visible and IR cameras, and radar, as well as the underlying ocean floor with a gravimeter and magnetrometer. Due to the high volume of data collected on each flight, visualizing the ROSETTA data can be challenging.

Using the Microsoft Hololens, we create the first augmented reality visualization of the interior of Antarctica's ice by combining pre-existing ice surface and bed topography digital elevation models with ROSETTA radar echograms. Data from the ROSETTA project are collected by flying in a grid pattern, and radar echograms are often reviewed line-by-line, where viewers need to match features across tracks. Like other stratigraphic data, ice-penetrating radar data are represented with a fence diagram. However, advances in 3D imaging and augmented reality allow us to visualize data in cross-section more easily, putting the data in proper geographic context and allowing the user to interact with the data more intuitively.

We take the ice surface and bed DEM to build a map of Antarctica that the user can translate, rotate, and walk around. Using voice activation, the user can zoom in on the Ross Ice Shelf, where she can look beneath the ice shelf surface to "step through" the radar echograms in their collected locations. This preliminary product is encouraging and supports the use of the Hololens in visualizing the multiple instrument datasets from the ROSETTA project.

Electromagnetic Modelling for the Web: Building HTML5 visualizers in Exploration Geophysics

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Key words: *visualizer, 3D, modelling, HTML5, webGL*

Recent developments in web technology have enabled a viable cross-platform alternative to traditional desktop applications in geoscience software. Lamontagne Geophysics Ltd is completing an ecosystem of geoscience modelling and survey design tools that leverage this technology to provide an accessible means to explore electromagnetic data. The tools employ scalable vector graphics (SVG) to plot data and survey designs in high quality printable format, while the use of webGL has enabled the visualization of virtual geological scenes in 3D (Fig. 1). Although most calculations are performed directly in the browser, we export models to a server running a modelling engine for more computationally intensive processing. These models are saved as an editable JSON file, however optimization for larger datasets will be necessary. By presenting these tools, we demonstrate how web-based technology is ready for the challenges inherent in visualizing and modelling problems in exploration geophysics and geoscience in general.

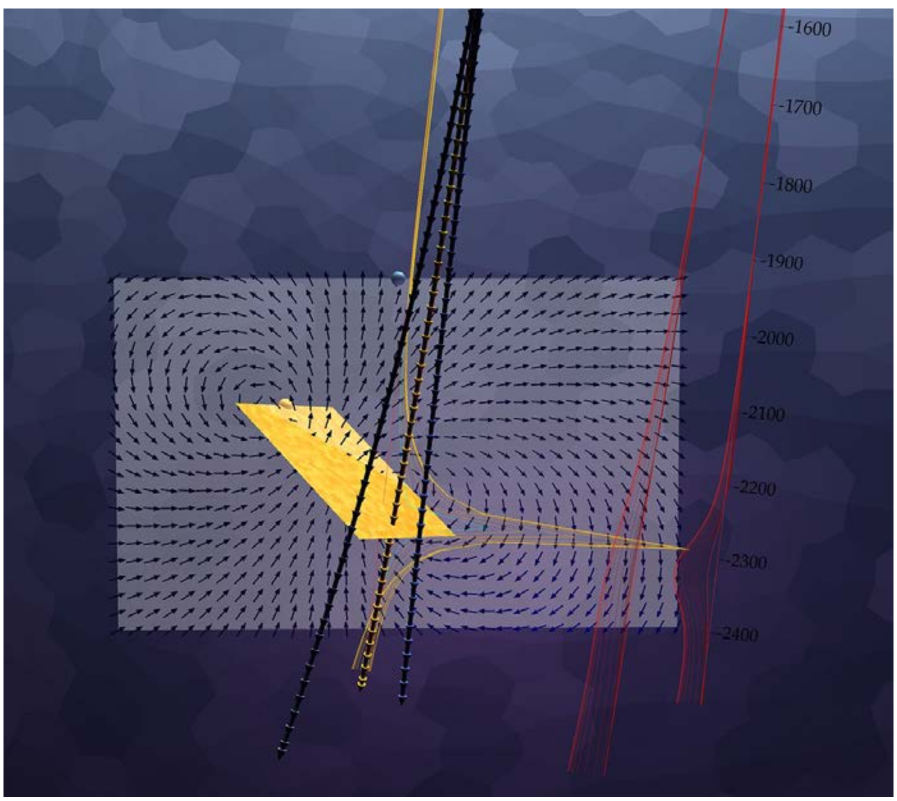

Figure 1: A 3D Scene of an electromagnetic model rendered in the browser using webGL. A large curved mesh is the backdrop for a conductive plate. A vector plane indicates the direction of the secondary field, three boreholes display the modelled EM response at depth (w-component,in-hole anomaly highlighted).

Session 6

Chair: Dave Gauthier
BGC Engineering Inc., Canada

Friday 8:30 am – 10:00 am, 24th August

Precise change detection despite inaccurate camera calibration

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Key words: *Close range photogrammetry, Structure-from-Motion (SfM), camera calibration, 3D reconstruction, surface comparison, displacement monitoring*

The Structure-from-Motion (SfM) workflow (SNAVELY *et al.*, 2006) is a photogrammetric technique which provides a valuable option for a range of monitoring applications using low cost systems. Inexpensive non-metric passive sensors such as single lens reflex (SLR) cameras, fully automated photogrammetric software and capabilities comparable to Terrestrial Laser Scanner (TLS), support the increasing use of this technique. However, some critical factors can affect the quality of the 3D scene generated (MOSBRUCKER *et al.*, 2017) introducing constraints and limitations. Specifically, camera calibration remains a critical control on the accuracy of derived data.

A consumer-grade digital camera system based upon four fixed cameras has been evaluated, including the impact of inaccurately determined camera geometry. This was achieved through both laboratory experiments (LE) and by field verification (FV). For the LE a scaled model of a steep vegetation-free slope was built at Loughborough University (Fig.1a). Critical factors investigated included camera calibration, network configuration and number of images processed. FV was conducted at the Spittles cliffs (Lyme Regis, England) to test the system on a real site and at larger scale (Fig.1b). This unstable cliff, mainly composed of Greensand that rests on Lower Lias clays with interbedded limestone layers (MAY, 2003), represents an ideal site for detecting small geomorphic change.

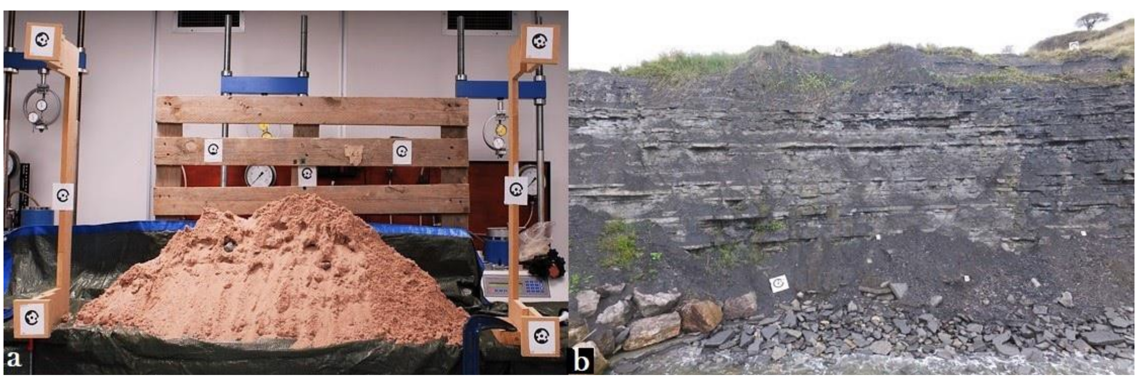

Figure 1: a) Lab experimentation: the slope was composed of sharp sand and was 1.5m long, 0.5m wide, 0.5m high and with a gradient of 60°. b) A section (25x20m) of an unstable sea cliff was selected for field verification.

During the LE, image acquisition was carried out using four DSLR cameras (Nikon D80) with a convergent geometry and mounted on tripods placed ~2m from the artificial slope. Tests were conducted with both, cameras in fixed and unfixed locations. After a first photo acquisition (Epoch1), a second set of images (Epoch2) was obtained after excavating three small localised holes on the slope surface. The general methodological approach involved using the SfM-MVS workflow to generate dense point clouds corresponding to the different epochs and estimating distances between closest points to obtain local displacements in 3D. Photogrammetric processing was implemented in PhotoModeler (www.photomodeler.com), whilst CloudCompare (www.danielgm.net/cc/) was used for change analysis. Distances were calculated with the multiscale model-to-model cloud comparison (M3C2) algorithm (LAGUE *et al.*, 2013). On both study sites use of only four frames produced high density point clouds and 3D surface change were successfully detected for both LE (Fig.2a) and FV (Fig.2b). On the FV, displacements due to removal of targets, footprints in loose scree, small collapses, talus erosion and

presence of vegetation were identified. Results demonstrate a significant improvement using a fixed camera system when compared to an unfixed configuration. As expected, a pre-calibrated camera model produced the most accurate result. Using this calibration option with a fixed camera configuration and comparing Epoch1 and Epoch2, a standard deviation of 0.3mm and mean distance of 0.01mm was produced. Interestingly, a 20% wrong lens model produced similar results (standard deviation=0.8 mm; mean distance=0.01 mm), suggesting a significant reduction in systematic errors if fixed cameras are adopted.

This investigation demonstrates the potential of developing an automated near-real time monitoring system that exploits a fixed camera configuration. The next stage of the research project will develop a variable frequency monitoring approach and latest results and progress will be presented also.

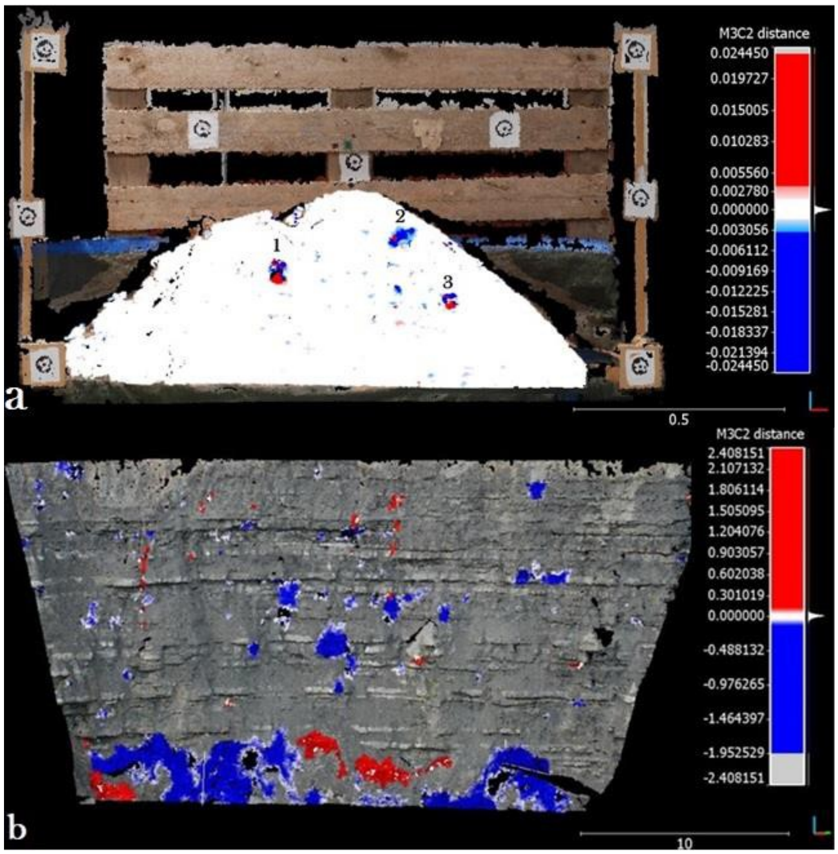

Figure 2. Example of the generated 3D point cloud for both LE (a) and FV (b). Multi-temporal comparisons obtained with the M3C2 algorithm and represented with colour scale histograms, shown capabilities to detect geomorphic changes (Blue – erosion; Red – deposition; White/point cloud – no change).

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Time-lapse SfM for 4D reconstruction

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Marcus Schindewolf[4]

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Key words: *4D monitoring, soil erosion, SfM-photogrammetry, time-lapse*

Time-lapse cameras enable fascinating visual insights into earth surface processes only by compressing time. Their applications in geosciences helps to document and analyze processes in high temporal resolution. Due to rapid developments in computer vision and photogrammetry an array of multiple cameras allows for 3D surface reconstruction of any area of interest. Installing a time-lapse system with a multi-angle camera setup can thus enable repeated calculation of point cloud differences. The main benefits of such a setup lie in the continuous 4D monitoring of geomorphic processes.

Two case studies are presented where 4D reconstruction is performed to observe the impact of heavy rainfall events on rill forming and sheet erosion: (1) a thunderstorm event that was captured at a field with a temporal resolution of 15 seconds and (2) a rainfall simulation that was observed at plot scale with a temporal resolution of 10 seconds.

A workflow for automatic data generation is presented, comprising the following steps: a) data collection, b) camera calibration and subsequent image correction to consider a significantly lower amount of images of the scene and thus lower redundancy for parameter estimation, c) template matching to automatically identify ground control points in each image to account for camera movements, d) 3D reconstruction of each acquisition interval, c) and finally applying temporal filtering to the resulting surface change models to correct random noise and to increase the reliability of the measurement of signals of change with low intensity.

Results reveal significant surface changes during the events, measured with mm- to cm-accuracy. Ripple and pool sequences were identified in both case studies. Additionally, roughness changes and hydrostatic effects are apparent along the temporal domain at the plot scale. Besides the continuous visual identification of processes, the study allowed for the derivation of mass fluxes in the research areas. Furthermore, observations can serve as validation data for event based erosion modelling. Future perspectives include using smart micro-computers.

Photogrammetric Inspection System for Underground Hydroelectric Infrastructure

D. Cody Bradley[1*], Lloyd M. Waugh[2], Jennifer J. Day[3], & Glendon Hanscom[4]
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[4] *New Brunswick Power, Fredericton, Canada*

Key words: *Photogrammetry, hydroelectric, tunnel, liner inspection, generating station*

A photogrammetric inspection system has been developed to accurately document the visual and spatial condition of underground hydroelectric infrastructure. The system consists of three main components: data acquisition, data modelling, and model delivery. A robotic data acquisition system incorporating micro controllers, wireless technology and photography equipment including lighting was designed, fabricated, tested, and refined to automate data capture. BRADLEY *et al.* (2018) describe the data acquisition system in detail. The data modelling workflow permits processing of large scale models in excess of 5,000 images. The resulting models are compatible with CAD software. They can also be delivered in a custom interface developed to facilitate visualization of 3D models and incorporate inspection specific tools. The main features of the interface include intuitive interaction with large scale models on a standard laptop computer, quick navigation, distance measurement, and a split screen mode that allows two models to be navigated synchronized for comparison purposes. Different model textures can also be applied to enhance visualization, including high resolution imagery, a wireframe, and a shaded mesh.

The photogrammetric inspection system was utilized to document the 7.5 m diameter and 822 m long concrete lined section of the Grand Falls Generating Station intake tunnel in New Brunswick. The resulting model has a visual resolution of 2 mm and a spatial accuracy of 5 mm, which is the root mean square error between the model and traditional survey check points (Figure 1). The traditional method used to inspect the Grand Falls intake tunnel is by visual observations. The size and location of observed deterioration are estimated by standing on the invert of the tunnel with only a flashlight for illumination and are documented in spreadsheet form. The photogrammetric model accurately documents deterioration throughout the entire tunnel.

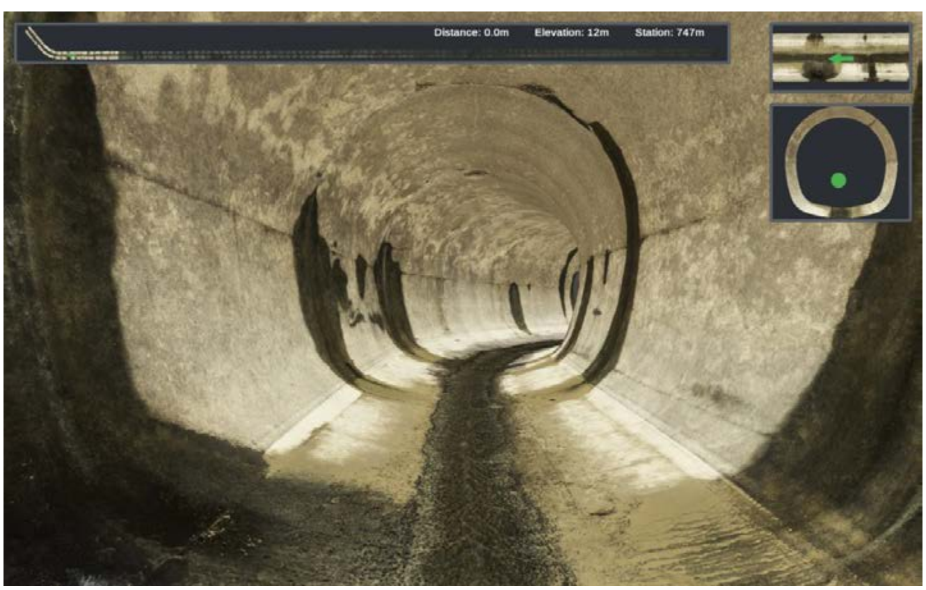

Figure 1: Custom interface with photogrammetric model of the concrete lined section of Grand Falls intake tunnel.

Very fine cracks are documented in the photogrammetric model, whereas only large cracks and holes are documented in the traditional inspection (Figure 2). Specialized experts can also complete detailed assessments of the tunnel in an office environment. The photogrammetric inspection system facilitates assessment and prediction of the excavation liner condition given the aforementioned improvements.

The photogrammetric inspection system has also been applied in the #5 turbine discharge ring and draft tube bay walls at the Mactaquac Generating Station in New Brunswick. Concrete expansion due to alkali aggregate reactions at this site presents a particular need for improved inspection tools. This investigation resulted in modifications to data collection procedures due to different site access and excavation geometries. 3D point clouds were produced with millimeter to sub-millimeter resolutions, which are improvements to the current surveying practice.

In addition to assessing and predicting condition and planning rehabilitation, the models can be used for other activities such as familiarizing new personnel with the underground environment and planning new construction of related engineering works. The improvements of the photogrammetric inspection over traditional inspections enable better informed decisions, a record of the basis of decisions, and therefore instill confidence in their implementation. More informed decisions could lead to several benefits, including reduced lifecycle spending, reduced risk of failure, increased asset performance, and extended service life.

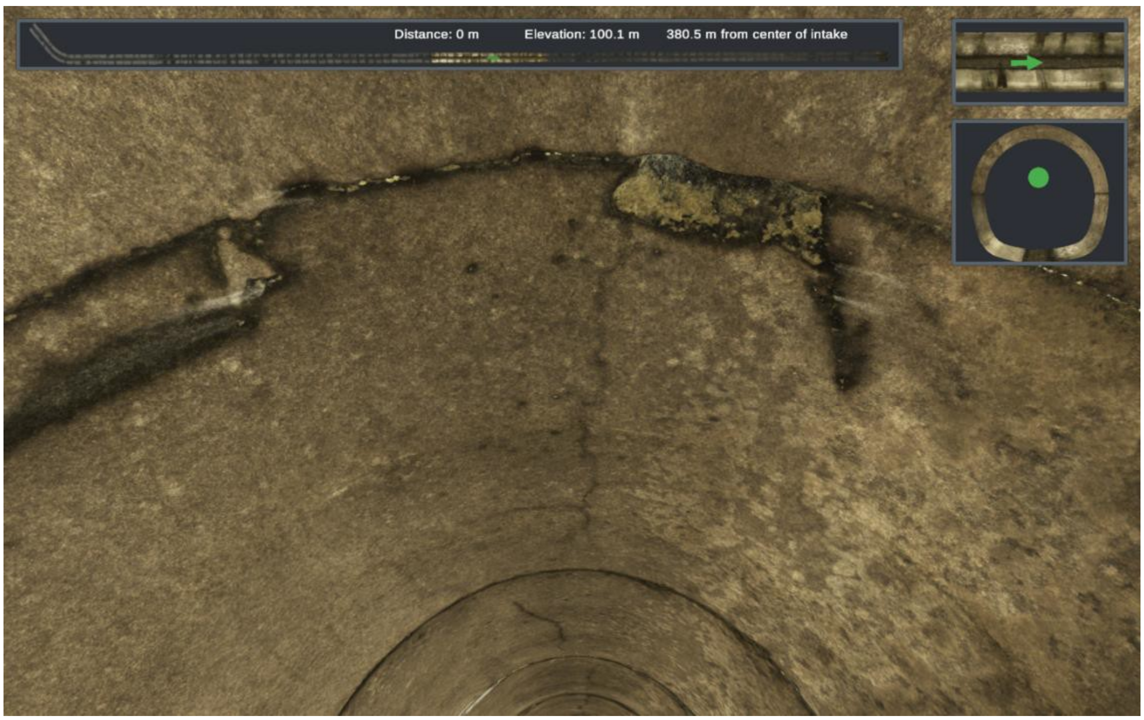

Figure 2: Example of the level of deterioration documented in the Grand Falls intake tunnel photogrammetry model.

Acknowledgements: Thanks to New Brunswick Power and NSERC for funding the research, the University of New Brunswick technicians for the fabrication assistance, and Scott MacDonald for proposing the initial research idea.

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BRADLEY, C., WAUGH, L., & HANSCOM, G. 2018. Photogrammetric Modelling of The Grand Falls Hydroelectric Generating Station. *Canadian Society for Civil Engineering 2018*. June 13-16, 2018, Fredericton, New Brunswick.

An open-source method for georeferenced SfM 3D models of outcrops

Laurent Froideval[1,2,3*], Kevin Pedoja[1,2,3*], Franck Garestier[1,2,3], Pierre Moulon[4], Xavier Pellerin Le Bas[1,2,3] & Laurent Benoit[1,2,3]

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Key words: *Structure from motion, photogrammetry, 3D survey, rocky coast, OpenMVG, LiDAR*

This study presents an open source method to generate georeferenced 3D point clouds of outcrops. Although studies using UAVs to model outcrops proved to be efficient, they are somewhat costly and can face increasing restrictive legal constraints. In addition, widespread commercial software like Agisoft Photoscan can produce accurate models but act like black boxes and don't give access to advanced customization. Moreover their license cost can restrain some research. Lastly, use of DGPS for georeferencing require expensive receivers and do not take into account error propagation. This work describes what an open source approach can bring to outcrop modeling from data acquisition to 3D point cloud generation and DGPS-free georeferencing. As a case study, we used a rocky outcrop of Saint-Honorine-des-Pertes in Normandy. We acquired 278 pictures on foot over an 800-meter baseline to produce the main 'frame' model and 168 pictures for the second more detailed 'patch' model. Details are given on the models generation, their accuracy assessment and their georeferencing, using freely available external reference data. Results show that this open-source method can produce dense 3D models with centimetric accuracy, sub-centimetric resolution and metric georeferencing. Very few resources were used at almost no cost. As this method is fast, simple and easily reproducible, it makes 3D outcrop modeling available to a wider audience.

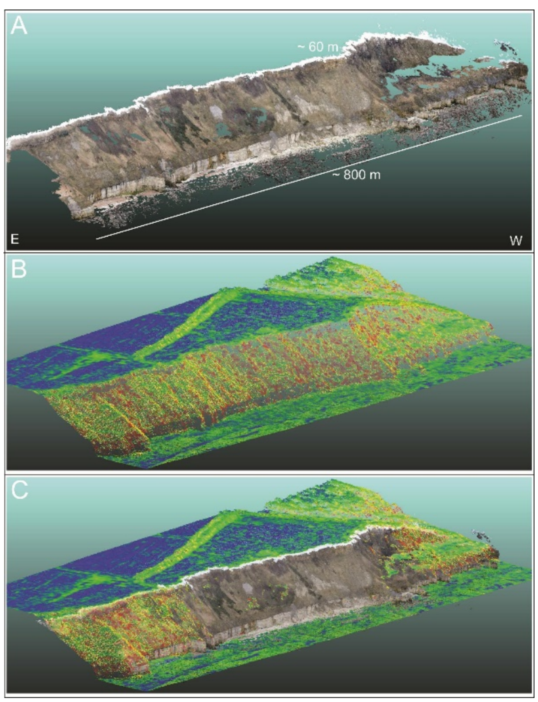

Figure 1: Georeferencing. (A) SfM model at Saint-Honorine-des-Pertes; (B) LiDAR data of the studied area; (C) georeferencing of the 'frame' model through LiDAR.

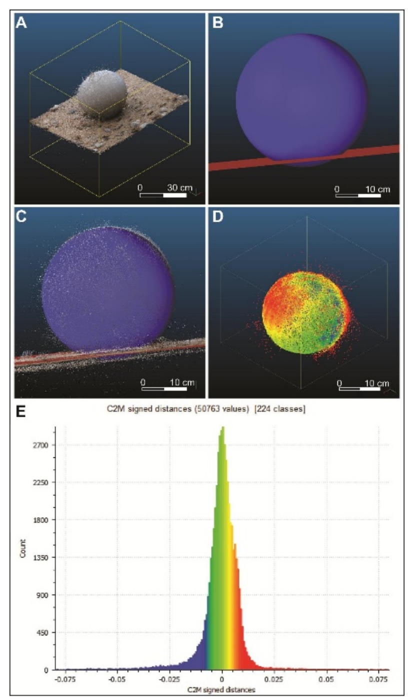

Figure 2: Accuracy assessment. (A) SfM model; (B) interpolation; (C) interpolation and model; (D) differences; (E) histogram of the differences.

Session 7

Chair: Thomas Dewez
BRGM – French Geological Survey, France

Friday 10:30 am – 12:00 pm, 24th August

Discontinuity Trace Identification and Rockmass Assessment from TLS Data

Ioannis Vazaios[1*], Nicholas Vlachopoulos[2] & Dimitrios Bolkas[3],
[1] *Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, Canada;13iv@queensu.ca*
[2] *Department of Civil Engineering, Royal Military College of Canada, Kingston, Ontario, Canada*
[3] *Department of Surveying Engineering, Penn State Wilkes-Barre, Pennsylvania, USA*

Key words: *Terrestrial laser scanning (TLS), discontinuity identification, rockmass assessment, edge detection*

Rockmass assessment is an integral part of the geotechnical and geological engineering design. Remote sensing techniques have turned into a practical and indispensable tool of the rockmass assessment process in the last decade. During the evaluation of a rockmass, specific information including discontinuity orientation, number of fractures, trace size and other geometrical features are measured either manually in the field or within 3D surface models generated from terrestrial laser scanning (TLS) or photogrammetry data. More specifically, TLS scans of exposed rockmasses can be processed either manually, with the discontinuity geometrical features identified and mapped by the user, or automatically, with the identification and mapping of discontinuity surfaces and traces conducted by automated algorithms. Following that, the mapped features can be extracted and used to evaluate the rockmass joint geometry conditions and perform a quantitative assessment of the examined geomaterial.

Within this concept and regarding discontinuity data acquisition, discontinuity traces have been mapped within 3D surface models for two different rockmass cases by applying both manual and automated techniques. In Fig. 1a, TLS scans from an unsupported tunnel located in Brockville, Ontario, Canada were used to examine the efficiency of automatic discontinuity trace detection by employing edge detection algorithms (BOLKAS *et al*, 2017). The obtained traces were compared to manually acquired ones showing the potential of some edge detection algorithms not only to identify discontinuity traces but also being trained for a specific section of the tunnel and then used to detect traces in another part (Fig. 2a). Furthermore, data obtained from laser scanning conducted at St. Mary's Quarry located in Bowmanville, Ontario, Canada was used to manually identify and record discontinuity traces (Fig. 1b). Extracted traces were processed further in order to determine a number of quantitative indices for the rockmass assessment. More specifically, the spacing between the extracted discontinuities was measured in order to determine its distribution for that specific site (Fig. 2b). Furthermore, the intact pieces of rock between the discontinuities were evaluated in order to obtain the Rock Quality Index (RQD) and provide a quantitative measure for the rockmass conditions (Fig. 2b). The aforementioned show the high potential of TLS scanning in providing quantitative and not only qualitatively measures for assessing the rockmass conditions in different projects and for different rockmasses.

Acknowledgements: The authors would like to thank the Nuclear Waste Management Organization of Canada (NWMO), the Ministry of National Defense, and the RMC Green Team for providing the founding and the resources for this work.

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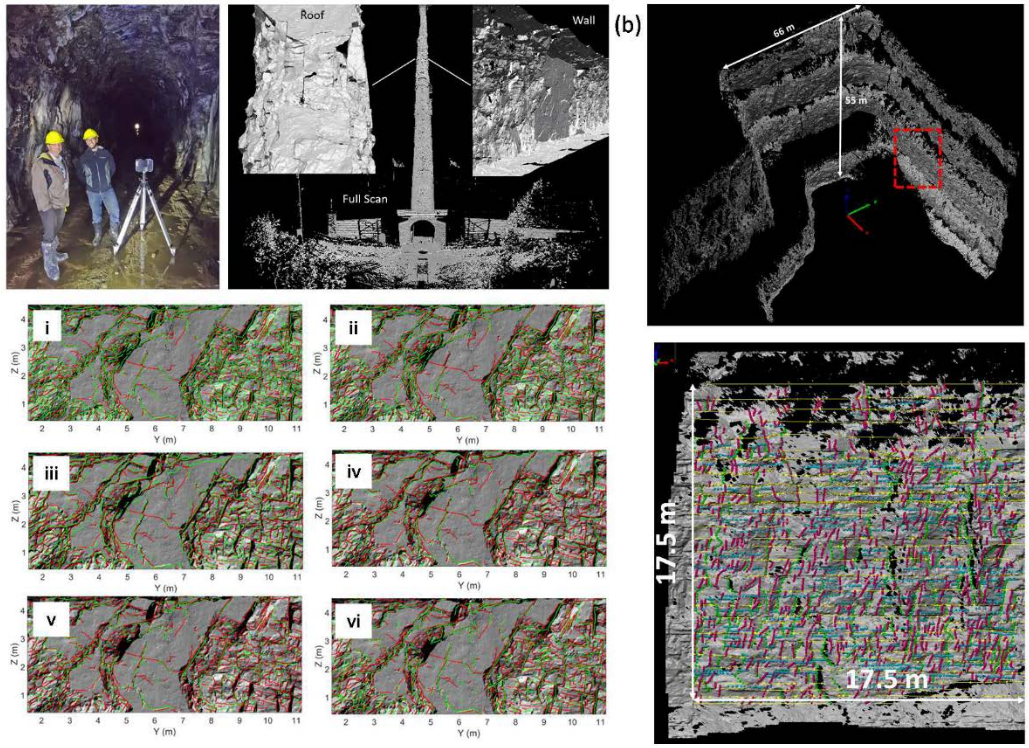

Figure 1 (a) TLS scanning conducted at the Brockville Tunnel (Top left), 3D surface model of the entire tunnel (Top right) (VAZAIOS et al., 2017), and manual (red lines) and automatic (green lines) identification of discontinuity traces (Bottom centre) (BOLKAS et al., 2017. (b) TLS scanning at the St. Mary's Quarry, Bowmanville, Ontario, Canada with highlighted the area of discontinuity mapping (red dashed square) (Top), and manual discontinuity trace mapping (Bottom).

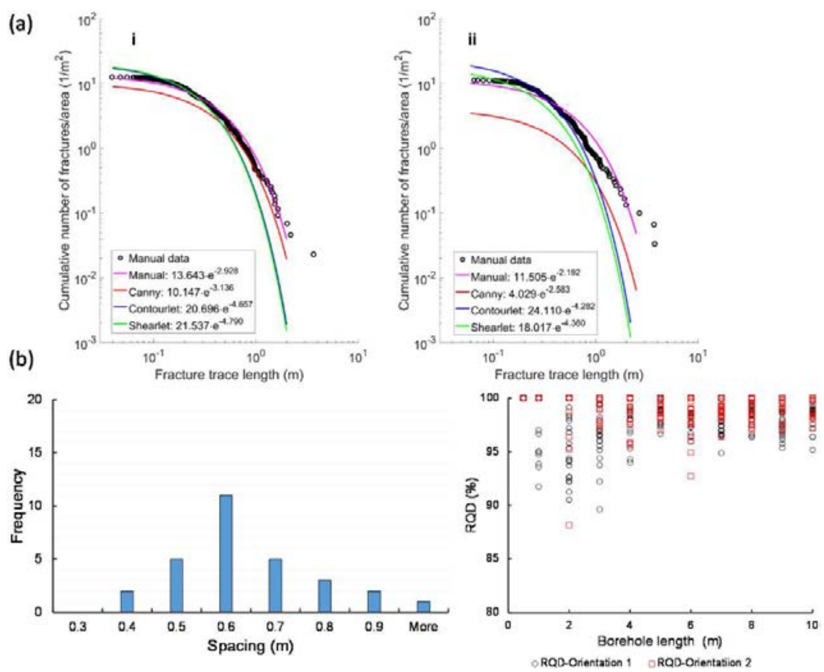

Figure 2 (a) Comparison of trace length distributions from manually and automatically extracted traces (i) calibrated parameters for the tight wall of the tunnel, and (ii) trained parameters used on the left wall (BOLKAS et al., 2017). (b) Evaluation of discontinuity spacing and RQD for the rockmass at the St. Mary's Quarry based on the extracted traces.

3D Models of Fracture Corridors : analysis of their internal connectivity and density variability

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Key words: *photogrammetry, automated detection, connectivity, fracture density, fracture corridors*

Outcrop analogues are the only available data for characterizing the spatial organization of fractures (CASINI *et al.*, 2016). For several decades, the LIDAR and photogrammetry techniques allow geoscientists to obtain 3D representations of targeted outcrops. The photogrammetry, especially, provides accurate, textured and dense 3D Digital Outcrop Models (DOM, BELLIAN *et al.*, 2005).

Such a dataset was acquired in La Fare Les Oliviers (SE France), where two fracture corridors crop out. Fracture corridors are particular geological structures within which the fracture density is particularly high. Recently, it has been shown (CHATELÉE *et al.*, 2015) that the internal architecture of fracture corridors is more complex than expected. Indeed, the fracture density may vary within the fracture corridors and other geological structures (breccia, etc.) may be also included. Fracture corridors lead to major challenges in carbonate reservoirs (ANTONELLINI *et al.*, 1994; GAUTHIER *et al.*, 2000; HANSFORD *et al.*, 2009). The study of the flow behavior in such cases is difficult to undertaken. It mainly depends on fracture network topology and density.

In this study, the acquired DOM is used as a support for interpreting and modelling fracture networks to study the fracture connectivity and density within the fracture corridors. The workflow is summarized in Fig. 1 and explained below.

From field study, several fracture families are generally identified. A fracture family i is characterized by its mean normal $\boldsymbol{N_{fi}}$. Let be $\boldsymbol{N_j}$ the normal vector of a local point j of the topographic point-cloud. If the point j belongs to a topographic surface parallel to the i^{th} family, then: $\boldsymbol{N_{fi}}.\ \boldsymbol{N_j} = \pm 1$ or $S_f = abs(\boldsymbol{N_{fi}}.\ \boldsymbol{N_j}) = 1$. Considering a threshold $t \in [0,1]$, these points belong to i when $S_f \geq t$, as presented in (VISEUR *et al.*, 2016). t corresponds to a tolerance angle between the average fracture normal $\boldsymbol{N_{fi}}$ and its effective variability on the field. However, this means that this variability is isotropic, but more variability may exist on azimuth compared to dip angles, for instance. Equations are then proposed to integrate observed anisotropic angle variabilities (Fig. 1).

Since the points are filtered using these equations, it is necessary to cluster them into groups of points that belong potentially to the same fracture plane (point-clouds have no topology). A clustering algorithm is proposed by combining Canopy (MCCALLUM *et al.*, 2000) and k-mean (LLOYD, 1957) approaches to obtain extended patches representing the fracture planes by sets of points. A distance based on planarity, proximity and density criteria is defined for clustering. The point clusters serve as conditioning points for building surface network using Gocad-Skua. Manual validations and interpretations complete this procedure to assert reliable fracture networks. Automatic results may be also compared to manual interpretations.

This workflow was used to build a 3D models of the 2 fracture corridors from the outcrop of La Fare les Oliviers. Then, several connectivity parameters of fracture networks are computed using Gocad research plugins as well as 1D and 3D fracture densities using approach proposed in (VISEUR *et al.*, 2015). The results are analysed and discussed.

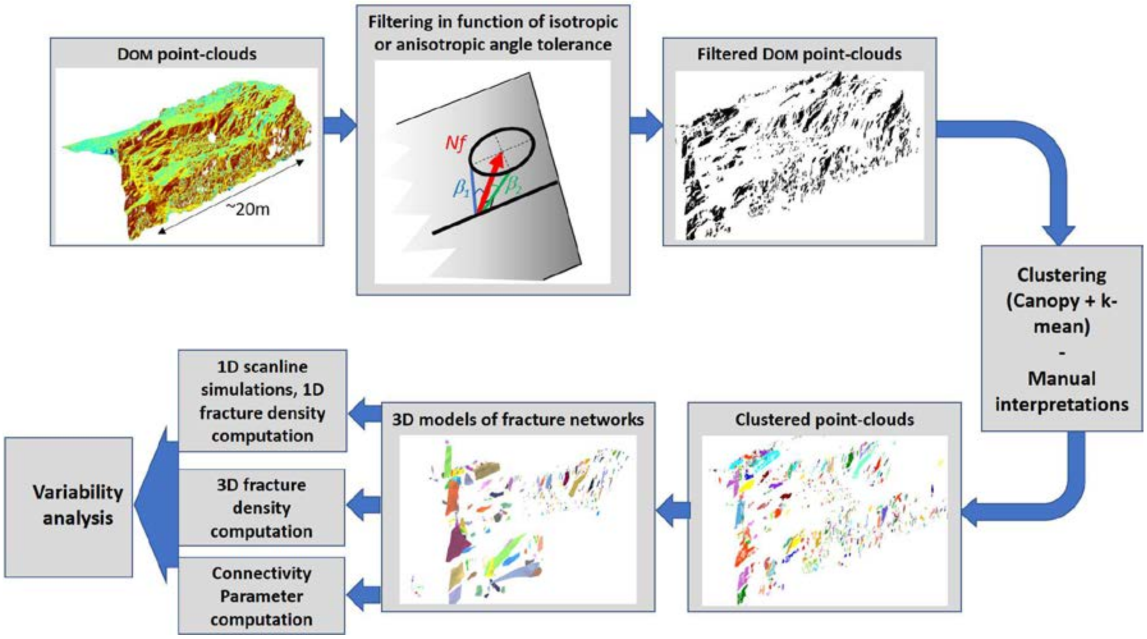

Figure 1: Workflow for: 1) extracting fracture point groups; 2) modelling fracture surfaces; 3) studying the internal variability of the fracture connectivity and density within fracture corridors in La Fare Les Oliviers, (SE France). β_1 and β_2 represent tolerance angles around, respectively, the dip azimuth and the dip angles of the main fracture family. Nf is the average normal of the fracture family.

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Acknowledgements: The authors would like to thank ParadigmGeo and ASGA for providing Gocad- Skua and the associated commercial and research-plugins. They also would like to thank Total SA for sponsoring this work.

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Physical Modelling of Retrogressive, Sensitive Clay Landslides

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Key words: *Retrogressive Landslides, Sensitive Clay, Soil-Cement Mixtures, Physical Modelling, Centrifuge Modelling.*

A major component of understanding sensitive clay landslides is being able to diagnose how far back a potential failure event may extend, referred to as the maximum retrogression distance, to define the limits of the hazard. While there have been developments on the numerical modelling front in recent years, much of the available physical information is from case studies of complex natural failures, with little observational data regarding the stages of failure or exact process. Empirical methods for estimating the retrogression distance, such as the Taylor's stability number relationship proposed by Mitchell & Markell in 1974, while useful, may be subject to criticism with the inclusion of additional, more recent data showing widespread scatter (DEMERS et al., 2014). In addition, the role of varying geometric constraints, such as the base slope angle, is difficult to quantify from case studies. This work presents the results of several centrifuge tests conducted at C-CORE in St. John's, Newfoundland, aimed at investigating the retrogressive failure process of an artificially sensitive clay material across various strength and geometric conditions. The discussion accompanying the results of this testing targets a relationship between the observed retrogression distance and initial Taylor's Stability Number, as well as the limit equilibrium analyses of the failure stages with simplistic GeoSLOPE software analyses.

An artificially sensitive, repeatable material was created from a mixture of Speswhite Kaolin clay and Portland Type III cement, which has a seven-day curing time. Undrained shear strength testing was performed with the Swedish fall cone and the miniature lab vane apparatuses. The selected material was able to reach shear strengths of 30 kPa within two days, while exhibiting a miniature lab vane sensitivity of greater than 10 (ATSM D4648/D4648M - 16). Rather than attempting to simulate an initial pore-pressure or erosion-induced local failure at the toe, a retaining door was used to contain a soil block during centrifuge spin-up, after which the door was released. The focus of this testing was on the successive, undrained failures that could potentially occur after the initial door-drop failure. The sample was flanked on either side by glass walls, allowing for high frame rate recording of the failure sequence under plane strain conditions. Particle image velocimetry analyses allowed for the determination of failure displacement vectors, retrogression distances, and coordinate tagging of the various failure stages. An increasing relationship between Taylor's stability number and retrogression distance was evident, as was a significant increase in retrogression distance with even a 5 degree increase in the base slope angle. Limit equilibrium analyses were found to be in visual agreement with the observed failure geometry, with consideration of soil regions that may have been mobilized at the corresponding residual shear strength.

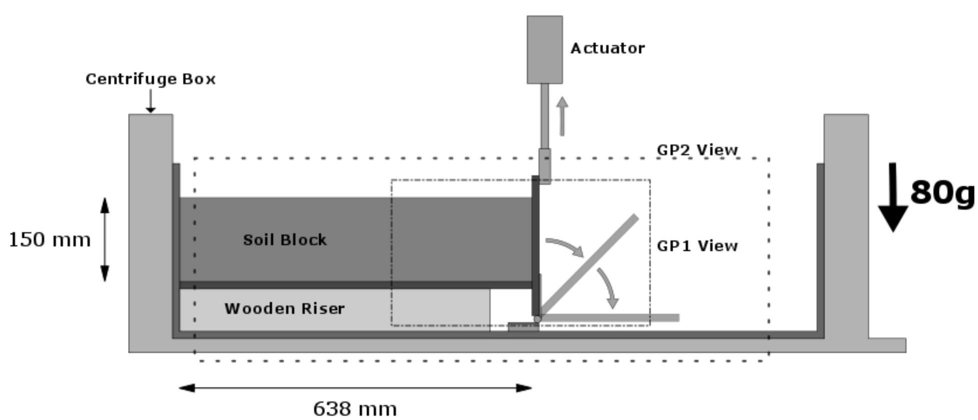

Figure 1: The experimental setup in the centrifuge box at C-CORE. A soil block is cured, textured, and carefully placed in the box. The retaining door is held shut by an actuator rod during spin-up to 80g, after which it is opened to observe the behaviour of the suddenly unstable soil mass. The GP2 and GP1 boxes designate the extent of the two camera views.

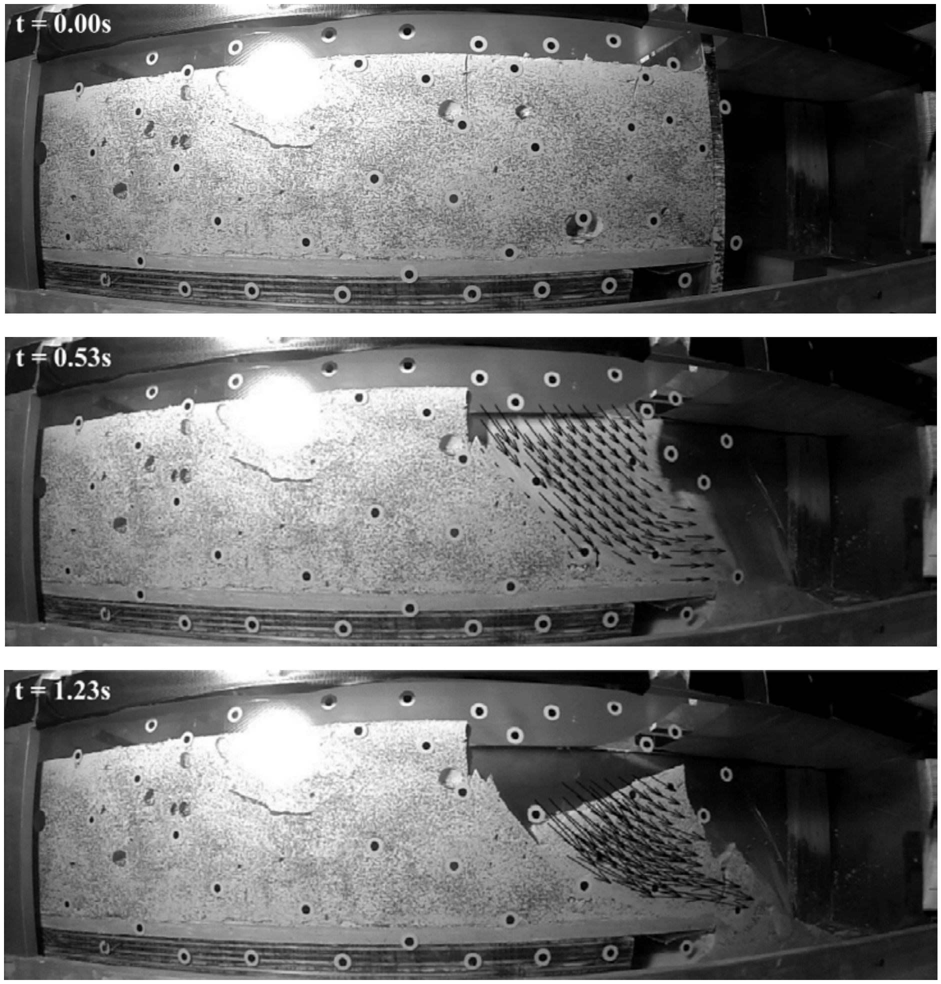

Figure 2. The initial condition, secondary failure, and final resting condition of a flat base test. Upper left corner time values correspond to the time since the retaining door was released, while the black vector overlay shows the image analysis tracking extended from the prior picture.

Acknowledgements: The assistance provided by Gerry Piercey, John Barrett, Ryan Phillips, Karl K., and Madison Bailey at C-CORE in St. John's, Newfoundland during the planning, construction, and testing phases of this project is greatly appreciated.

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Slope Monitoring using TLS at the Site C Project – Effectively Presenting Results

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Key words: *Terrestrial lidar scanning, slope monitoring, landslide, web-based GIS, change detection*

The Site C Clean Energy Project involves the construction of a hydroelectric dam on the Peace River, south of Fort St. John in British Columbia. Construction of the dam began in 2015 and is ongoing. The Peace River Valley contains an abundance of landslides which have a variety of morphologies and movement types, from slow, deep-seated slides in horizontally bedded marine shale and rapid flow slides to slow moving slides in Quaternary sediments (SEVERIN, 2004). BGC has been working with BC Hydro since 2010 to assist in reservoir shoreline and slope monitoring surrounding the project site.

Remote sensing techniques have been used to monitor ground changes due to slope movements and shoreline erosion within the study area throughout various stages of the project. Prior to construction, regional-scale airborne LiDAR scanning (ALS) change detection was used to identify areas of recent slope movement and erosion within the reservoir area (MITCHELL *et al*., 2017). This analysis was supplemented by change detection analysis for specific sites of interest using Structure from Motion (SfM) techniques to generate 3D models from oblique helicopter photographs (OHP) to compare to existing ALS data. The results of these studies were used to prioritize additional monitoring work, including the use of terrestrial LiDAR scanning (TLS).

Since October 2016, BGC has used TLS and change detection analysis to monitor select slopes within the dam construction area, and reservoir slopes upstream. The purpose of this work includes monitoring slope response to excavation and construction, assessment of rock fall and landslide activity along construction access roads, and monitoring natural slopes that may be affected by landslides and erosion following future reservoir filling. The results have been used to identify rock falls, surficial erosion, shallow rotational failures, shoreline retrogression, and tension crack formation (Figure 1).

Several challenges have been encountered throughout this work, including collecting data within an active construction site, and performing change detection on slopes where construction is ongoing. This can lead to slope movements being obscured by construction changes.

Effectively communicating the change detection results from this project has presented both a challenge and an opportunity. TLS provides high-resolution, 3D slope models, but the large data files and specialized software required to view the raw data can prevent effective presentation of the results. BGC has worked to develop a web-based GIS platform that can be used to display the change detection results in a variety of formats including coloured map overlays, 2D images, and embedded 3D slope models coloured with identified ground changes (Figure 2). The results can also be viewed and compared to the regional ALS change detection results, aerial- and satellite-based imagery, high-resolution panoramic site photographs, and instrumentation data such as slope inclinometers. The system also is designed to allow for effective data management over the expected 10-year monitoring program, with the ability to be updated with new data as it becomes available. This system allows for the communication of the results to a wide audience without the need for specialized software, providing an improved understanding of the results within the project team.

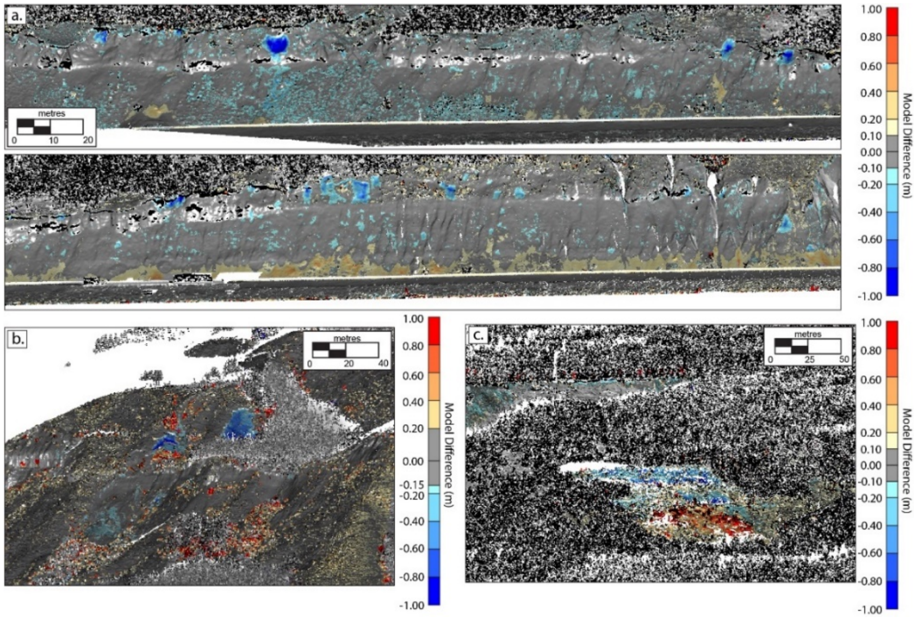

Figure 1. Example TLS change detection results showing a) rock falls along construction access road, b) slope failures and surface erosion on natural slopes c) shallow rotational failure on vegetated slope.

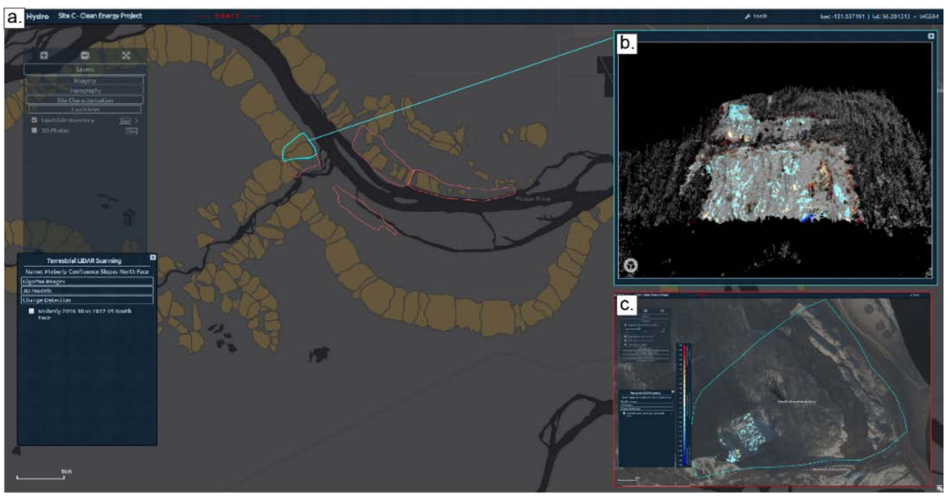

Figure 2. Example of web-based GIS interface a) showing mapped landslides and outline of slopes where TLS has been collected, b) embedded 3D model with change detection results and c) change detection results overlain on satellite imagery.

Acknowledgements: The authors would like to acknowledge our colleagues Leo Guzman and Siobhan Whadcoat for their contributions to this work. We also acknowledge Davide Donati and Emre Onsel from Simon Fraser University in Burnaby for their assistance with field data collection.

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Session 8

Chair: Rob Harrap
Queen's University, Canada

Friday 1:30 pm – 2:45 pm, 24th August

Gravitational unstabilities: an automatic pipeline for the analysis of time series of high frequency terrestrial optical images.

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Key words: *time-lapse, landslide, photogrammetry*

In the case of gravitational unstabilities, digital passive sensors such as Single Lens Reflex (SLR) cameras, are increasingly being used for ground-based used geohazards monitoring. Compared to terrestrial laser scanner (TLS) or radar imaging (GB-InSAR) systems, cameras are low-priced while also ensuring high sensor resolution (>15 megapixel). Qualitative information can be extracted from images such as the identification of changes in the surface morphology, or the weather conditions. Using stereo- views for its part provides quantitative 3D information as Digital Surface Models or changes of the surface states.

Two studied areas are disassociating: slope stability problems and changes in the morphology of rockfaces. On one hand most researches are focused on the development of image correlation techniques to determine the average spatial shift between a pair of images. This technique has proven its performance for characterizing the displacement fields of ice-glaciers and slow-moving landslides at sub-pixel accuracy ($1/10^{th}$ pixels) and generates a pseudo-continuous map of deformation. On the other hand, studies are mainly focused on the quantification of erosion rates or the detection of rockfall scarps and accumulated debris.

The objective of this work it's to develop, test and implement an automated image processing pipeline for the analysis of long time series which process the amount of data.

For that, cameras such as CANON 100D or PENTAX K200D are set up in the field. The focal lens depends on the distance between camera and the area and the landslide dimension. Images are taken frequently according to the maximum of the displacement magnitude . Images are then embedding in the processing pipeline which is based on the open-source photogrammetric library MicMac. The pipeline associates different modules such as:

(1) Pre-treatement module : In a long time series, some images can't be analyzed because of weather conditions (presence of snow, rain, mist or shadow). For that we propose to select them following their radiometric properties.

(2) Coregistration module :In most cases, images have also to be corrected for the camera movement induced by temperature, wind or soil movement. Different techniques based on characteristics points are mainly used like the Harris detection method (Gance *et al.*, 2014) or the SIFT method (Lowe, 2004). Here, we implement the module by a statistic correlation method named COREGIS (Stumpf *et al.*, 2018). Mainly used for the satellite images coregistration, this technique is adapted for terrestrial images.

(3) Change detection module : Change detection is determined by sub-pixel correlation technique implemented in MicMac. Results are then converted in meters integrating DSM such as LiDAR acquisition or photogrammetry.

Results are compared to validation data therafter (DSM, measures from automatic theodolite, extensometers...).The pipeline will be presented and its performance evaluate on several cases : the Sanières rockslide (Alpes-de-Haute-Provence, Ubaye, France), the Chambon landslide (Isère, Oisans, France), the Montgombert landslide (Savoie, Arly, France), the Pas de l'Ours landslide (Hautes-Alpes, Queyras, France) and the Rampe des Commères unstable rock slope (Isères, Romanche, France).

Acknowledgements: These works are part of a CIFRE / ANRT agreement between IPGS/CNRS UMR7516 and the SAGE society.

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Infrared Thermal Imaging for Rock Slope Investigation – Potential and Issues

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Key words: *Thermal infrared, Lidar, rockfall*

Daily temperature fluctuations of a rock surface can reach an amplitude of 50 °C. Recent studies have shown the effect of these fluctuations on rock deformation and progressive weakening in granite (COLLINS & STOCK, 2016). Other researches using high spatial and temporal LiDAR monitoring have demonstrated the importance of temperature on rockfall activity in sedimentary rocks (WILLIAMS, 2017). An obvious continuation of these contributions is to use thermal images. Modern thermal infrared (TIR) cameras, based on an uncooled microbolometer sensor within the LWIR band (8-12 micron), have now enough spatial and temperature resolution to be operational in field conditions. But the temperatures on a TIR image can be very different from the real temperatures of the rock surface!

Temperatures shown on a TIR image are controlled predominantly by two types of factors: the rock properties (temperature and emissivity) and the radiative environment (thermal radiations from sky, sun, ground and other objects nearby). The radiations from the environment are emitted along specific directions and then reflected on the rock surface. For instance, a blue sky emits vertically downward a radiation corresponding to a -60°C temperature. This radiation will be reflected by the rock surface, depending on the surface emissivity and orientation, and it will be mixed with the radiation coming from the "real" temperature of the rock. The consequence is that a rock at constant temperature will show completely different temperatures on a TIR image depending on the orientation of its surface (Fig.1).

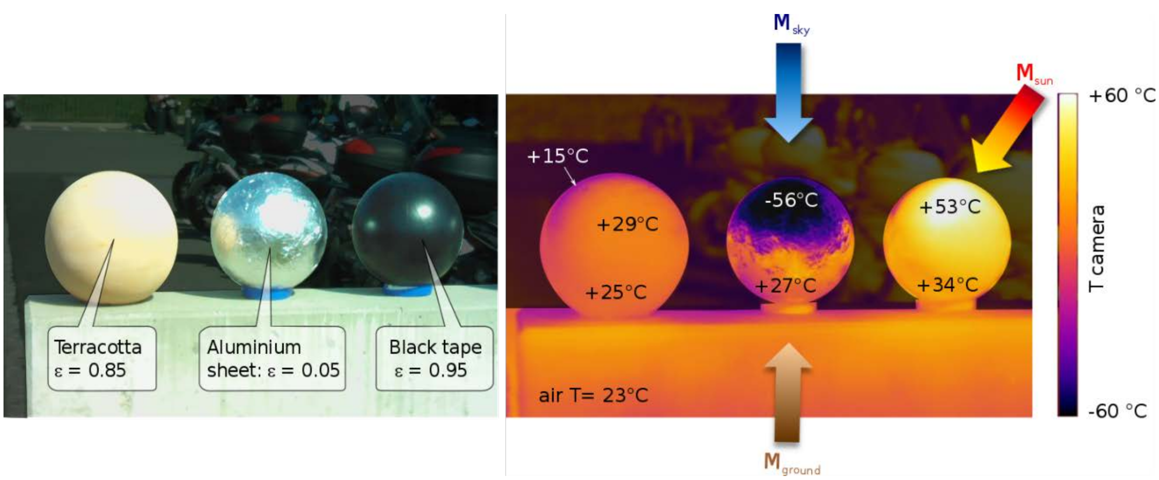

Figure 1: Left: Spheres of different emissivities are used to estimate the radiative environment temperature for a full range of orientations. Terracotta is used as proxy for rock, an aluminium sheet as diffuse reflector and black tape as approaching a black body. Right: The "blue sky" influence is of particular importance (T≈ -60°C). Apparent temperature on the upper part on the terracotta sphere, facing the sky, is significantly cooler than the "real rock" temperature (up to 10°C less).

One way to avoid the problem of the rock surface orientation relatively to the radiative environment is to work with relative temperatures on a rock slope made of a single rock (i.e. constant emissivity) and with a unique orientation (close to planar). That has been done for the big wall of El Capitan (Yosemite National Park, California) to detect the rock bridges behind vertical granitic flakes and unsuspected cracks elsewhere in the wall (GUÉRIN et al. 2016).

The other way is to correct the TIR image temperatures in function of the surface orientation (dip angle and dip orientation). This is done by coupling TIR images with terrestrial laser scanning (TLS) data in order to get in each pixel of the TIR image the geometric parameters required to correct the apparent temperature (dip angle and direction, range, local incidence angle). Once these geometric parameters determined, models of corrections have to be tested to correct the apparent temperatures of TIR image (with lambertian or non-lambertian reflexions). Preliminary tests are done along this line.

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LiDAR applications to underground rock blasting optimization

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Key words: *Lidar, three-dimensional mapping, rock fragmentation by blasting, underground mining.*

The field of three-dimensional mapping has made great strides towards democratization with modern compact tools and intuitive interfaces. LiDAR and photogrammetry have generated momentum towards various applications for geotechnical and civil engineering. As is often the case with new technologies, the mining industry has been slow to implement modern survey methods now available for surface and underground mapping. Some niche applications have sparked interests towards research and development and greater utilization of the available technologies such as for rock piles fragmentation analysis (e.g. CAMPBELL, 2017), and automated geotechnical characterization (e.g. VAZAIOS et al., 2017). FEKETE et al (2010) provided a concise review of LiDAR applications for underground geotechnical engineering. Unfortunately, the utilization of LiDAR and photogrammetry in the mining industry is still arguably limited to high end consulting applications.

The following presents three applications of LiDAR technology towards rock blasting optimization at Morton Salt underground mines. The applications showcase the in-house use of LiDAR technology for systematic characterization and testing of drilling and blasting configurations. The reviewed applications focused on mining and comminution productivity through muckpile shape optimization, reduction of explosives consumption through blast patterns optimization, and assessment of blasted surface quality from roughness analysis.

The present review of LiDAR applications for rock blasting optimization emphasizes the tools used and implemented procedures for consistent and systematic replication of the work. Special considerations are provided for visual referencing and data structure for consistent information sharing. Figure 1 shows muck pile point clouds for blasted rock salt in a room and pillar mine. The figure showcases two different blasts results on the right to illustrate the changes in muckpile profile from the tested blasting configuration. Figure 2 illustrates crater blasts conducted as part of a rock blasting characterization campaign. The figure showcases a three-dimensional point cloud of the resulting crater with color scale for the absolute distance from the original surface.

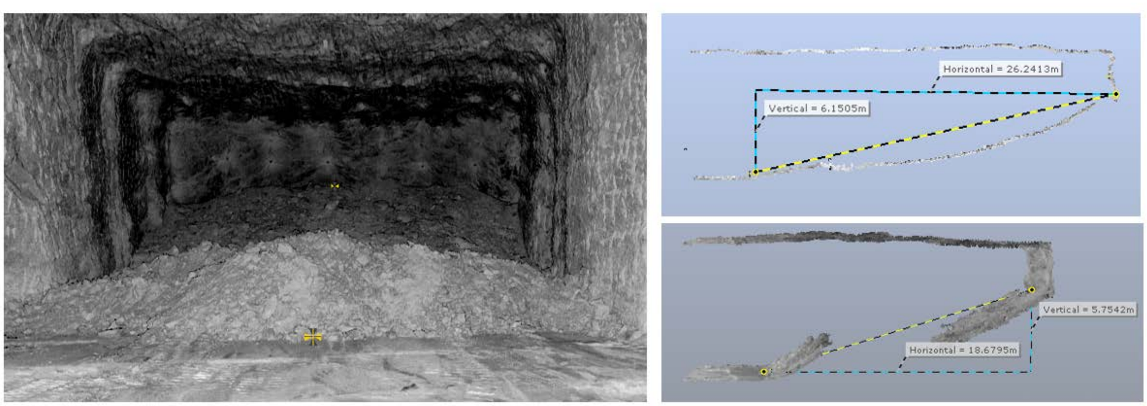

Figure 3: Muckpile profiles and cross-sections for material handling optimization.

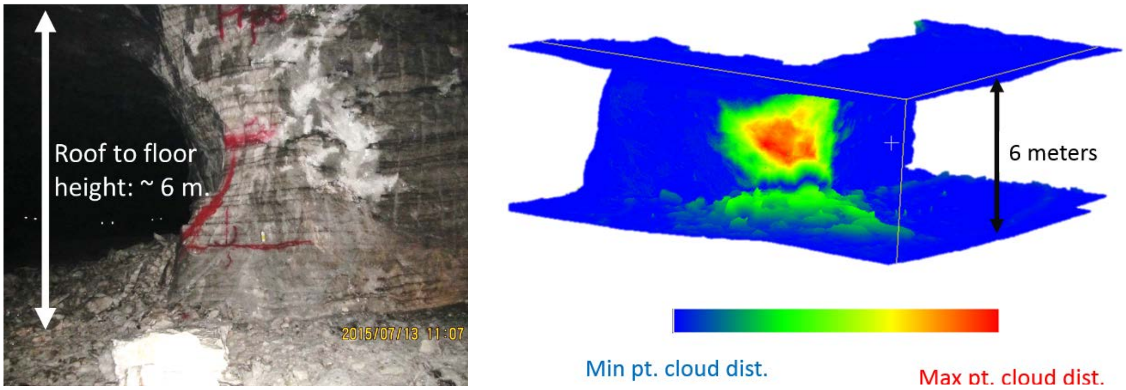

Figure 4: Picture (left) and three-dimensional point cloud (right) of a crater blast shot as part of the characterization campaign for rock blasting optimization purposes. The point cloud color scale is for the absolute distance from the original blasted surface.

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From underground laser scans to 3D urban geological and geotechnical models

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The near sub-surface geology, say down to 20-30-m-depth, of many cities has been massively exploited for extracting building stones and various other industrial or agricultural materials (gypsum, lime, etc…). The long-term instability of these cavities poses a significant collapse hazard conditioned by their geometry (void location, dimensions and shape) and by their surrounding rock mechanics properties. In this presentation, we show how handheld laser scanning surveys efficiently document geometric variables and can interact with 3D geological modelling of the surrounding rocks. The construction of near-surface urban geological models can then be turned into 3D geotechnical models by attributing geotechnical parameters to rock horizons and ultimately become a key subsurface knowledge component of BIM (Building Information Model).

Acquiring surface and subsurface geometry is no longer a challenge thanks to handheld laser scanners. Survey loop traverses can be pieced together to link surface and subsurface geometry with accuracies better than 1 m (an accuracy level compatible with urban risk management maps at 1/5.000) (DEWEZ *et al.*, 2017). However, the hundreds of-millions of 3D points describing the cavity surface cannot be integrated as such into geomodeling software. Too many points with not high enough information. We suggest two different scenarios to perform their integration: (i) as independent validation of geomodeling hypotheses, or (ii) as geomodel constraints.

In the first integration scenario, point cloud information is passed to the geomodeling software at a minimal level. A decimated triangular meshed model can be used to intersect the geomodel. Triangulation is performed at the point cloud processing software level (e.g. GeoSLAM desktop or Cloud Compare) and intersection is handled at the geomodelling software level with a generic query concept (here GeoModeller software with a generic query API – LOISELET *et al.*,2016). In this instance, cavity mesh triangular faces are refined based on the geological model queries (relying on the *marching triangles* algorithm) and provide geotechnical attributes based on the geological formations given by the geomodel. This scenario offers a visual display of geological properties (Fig. 1) for checking that modelled layers and structures match those observed in underground outcrops.

In the second scenario, which is more integrated, higher level information is passed to the geomodelling tool. Planar surfaces of marker horizons are segmented from the point cloud either manually using Compass (THIELE *et al.*, 2017) or semi-automatically with FACETS (DEWEZ *et al.*, 2016) and passed as structural data objects to constrain the geomodel (Fig. 2).

This data integration is demonstrated on a ca. 1 ha underground building stone quarry of the eastern suburbs of Orléans, Central France. The cavity was scanned at ca. 1pt/1cm with a Zeb-Revo (90 Mpts underground and 35 Mpts above ground). A geomodel of the subsurface area (Calcaire de Beauce, Tertiary) was created with the GeoModeller software as a tabular sub-horizontal multilayer environment. The geomodel infers rock distribution over a domain of *ca.* 200 x 200 m with geological and geotechnical information (e.g. limit pressure for dimensioning building foundations).

Both approaches leverage a generic API query tool informing which domain surrounds a point and whether a geological contact cross-cuts a triangular face.

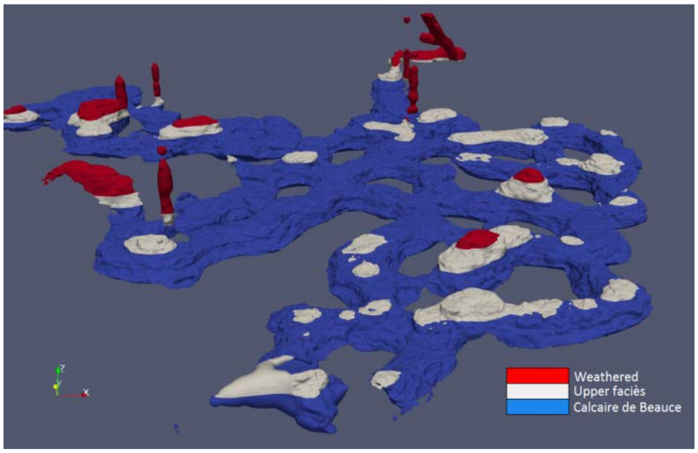

Figure 1: Intersecting the geological model (GeoModeller) with the cavity wall 3D mesh. Modelled layers interpolate limit pressure values (p_l) spatially. Weathered : p_l* 0.5 – 1 MPa; Upper facies: p_l* 1.5-2.5 MPa; Calcaire de Beauce : p_l* 4.0 MPa*

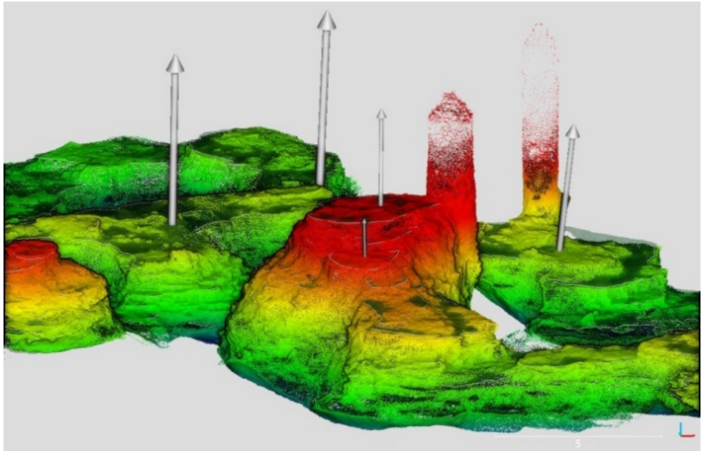

Figure 2: Capturing bedding orientations from the dense point cloud with the Compass plugin shipping with Cloud Compare.

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How virtual can become real: The advantages of a good reference geological model and its related reliability

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In the last two decades engineering geology has certainly strongly benefited of the technological improvements, including remote sensing, SAR, LiDAR and several other advanced tools. Today we can acquire and process mega data packages with reasonably low budgets by using total stations and drones.

We are able to survey rock falls, automatically measuring foliations, joint sets, dip and dip directions, generating potentially useful structural analyses. Most of these information are then incorporated in efficient models within GIS and BIM environments.

Also directs Investigations can provide thousands of potentially interesting data by the mean of drilling data loggers, BHTV and all kind of physical and chemical sensors. Sophisticated equipment can generate much more laboratory test data then only twenty years ago.

Somewhere, today a geologist, if supported by a consistent budget, disposes of almost all the tools to generate a reliable GBR. If so, why so many infrastructure projects worldwide are staked by severe technical problems due to "unforeseen geological conditions"? Is it only due to a lack of investigations? Or by the facts that several projects are still located in remote areas?

Or, could be, by the fact that "…if you do not know what you should be looking for in a site investigation, you are not likely to find much of value" (Glossop, 1968)?

It's our belief that in most of the cases the absence of consistent Reference Geological Model (RGM) generates these "unforeseen conditions".

In fact the reference geological model is a conceptual reconstruction of the three-dimensional geometric framework and of the temporal and spatial succession of the geological events that characterize a certain portion of the crust.

Without this framework in several circumstances can become almost impossible to correctly interpret the results of the investigation. We are also deeply convinced that the "old style" field survey still represent the best approach to enhance the potentiality of the virtual geology.

The presentation will focus on some meaningful project examples were several advanced investigations without a reliable MGR generated serious disruptions.