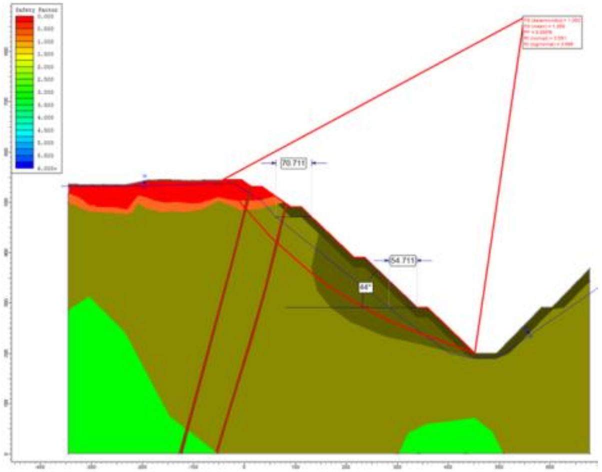
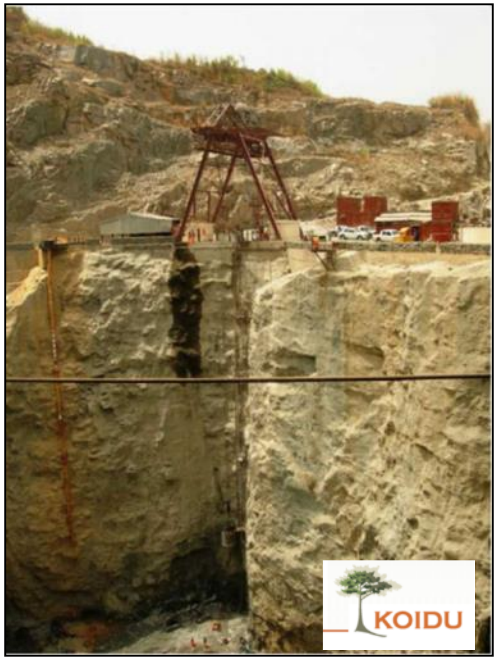
Careers in Mining and Mineral Resources:
Open Pit Rock Mechanics

Matthew Clark, BSc Eng. (GE), P.Eng.

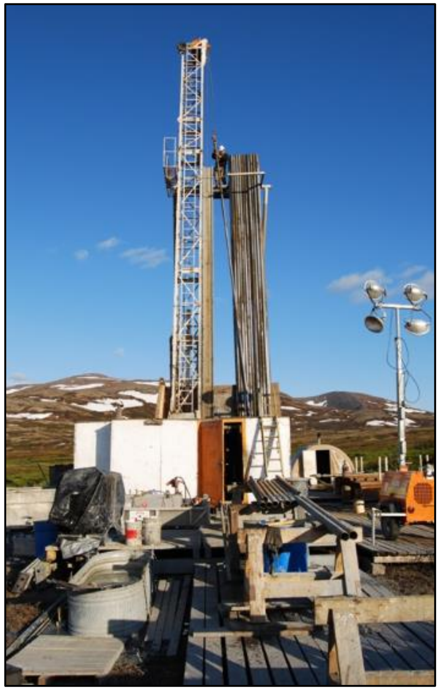
http://www.suidlanders.co.za





Overview

- What is rock mechanics?
- My path to rock mechanics
- Full time employer – SRK
- Where I've worked around the world
- Rock mechanics overview and common software
- How does a rock mechanics engineer design a slope?
- Who should go into rock mechanics?



Problem Statement

How do we go from this…

http://www.tunneltalk.com

…to a stable developed mine without having any…

…Pit Slope Failures!?

http://www.flickr.com/photos/riotinto-kennecottutahcopper/8643310015/in/photostream

We do need a bit more science and engineering than that used by these people,

however, they probably do have well tested empirical design concepts and methods.

High School – Liverpool, NS

- Excelled in sciences, but especially math
- Seemed like a math degree made the most sense
  - Math teacher convinced me otherwise
- Grandfather was a electrical engineer and I decided to follow that route (I didn't even know what an engineer really was)

University of New Brunswick, Fredericton

- Decided between UNB, Dal, and SFX
  - Even though I received the most support from Dal, I followed a number of my friends to UNB
- Started in Computer engineering

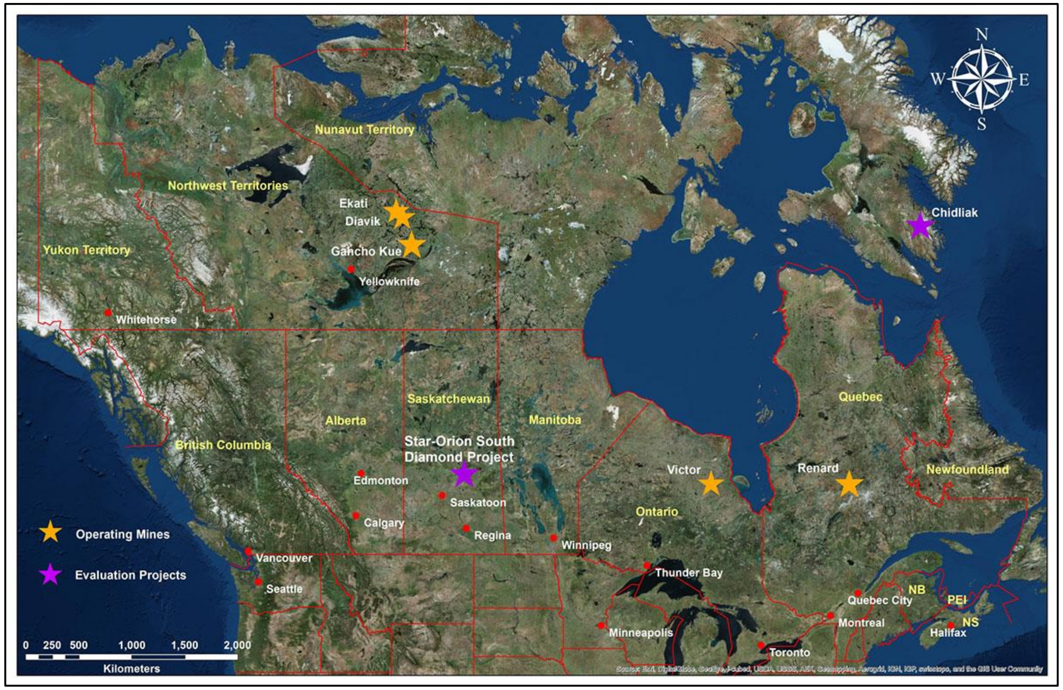
Transitions to Geology/Mining

- During first year, realized that I didn't want to be in computer engineering
- My neighbour in residence (she was a student academic advisor) was in geology. Talking with her made me consider moving to Geological Engineering
- Graduated in 2005 with a degree in Geological Engineering with the Geotechnical Option

Move to Vancouver

- Started with SRK on a contract basis (which is common in that company)
- Found (by googling) two companies in Vancouver and emailed them looking for work.
- Had two job interviews that day on the phone

- The job was located in Saskatchewan on a 28 day on, 7 days off rotation
- The site was Star-Orion Diamond project.
- Owned by Shore Gold and recently acquired by Rio Tinto



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

SRK Company profile

SRK is established
New offices: Vancouver, Cape Town, Durban

New offices: Denver, Harare, Reno, Cardiff

New offices: Port Elizabeth, Pietermaritzburg, Santiago, Perth, Brisbane, Elko, Fort Collins, Tucson, Sydney, Pretoria, Yellowknife

New offices: Toronto, East London, Ankara, Rustenburg, Newcastle, Beijing, Belo Horizonte, Saskatoon, Sudbury, Dar-es-Salaam, Kolkata, Moscow, Kimberley, Melbourne, Anchorage, Buenos Aires, Nanchang, Jakarta, Skellefteå

New offices: Queretaro, Almaty, Ulaanbaatar, Lubumbashi, Accra, Mendoza, Lima, St. Petersburg, Copenhagen, Hong Kong, Cameroon

With 40 years of experience behind us, we are looking to the future – working on new and better ways to serve our clients

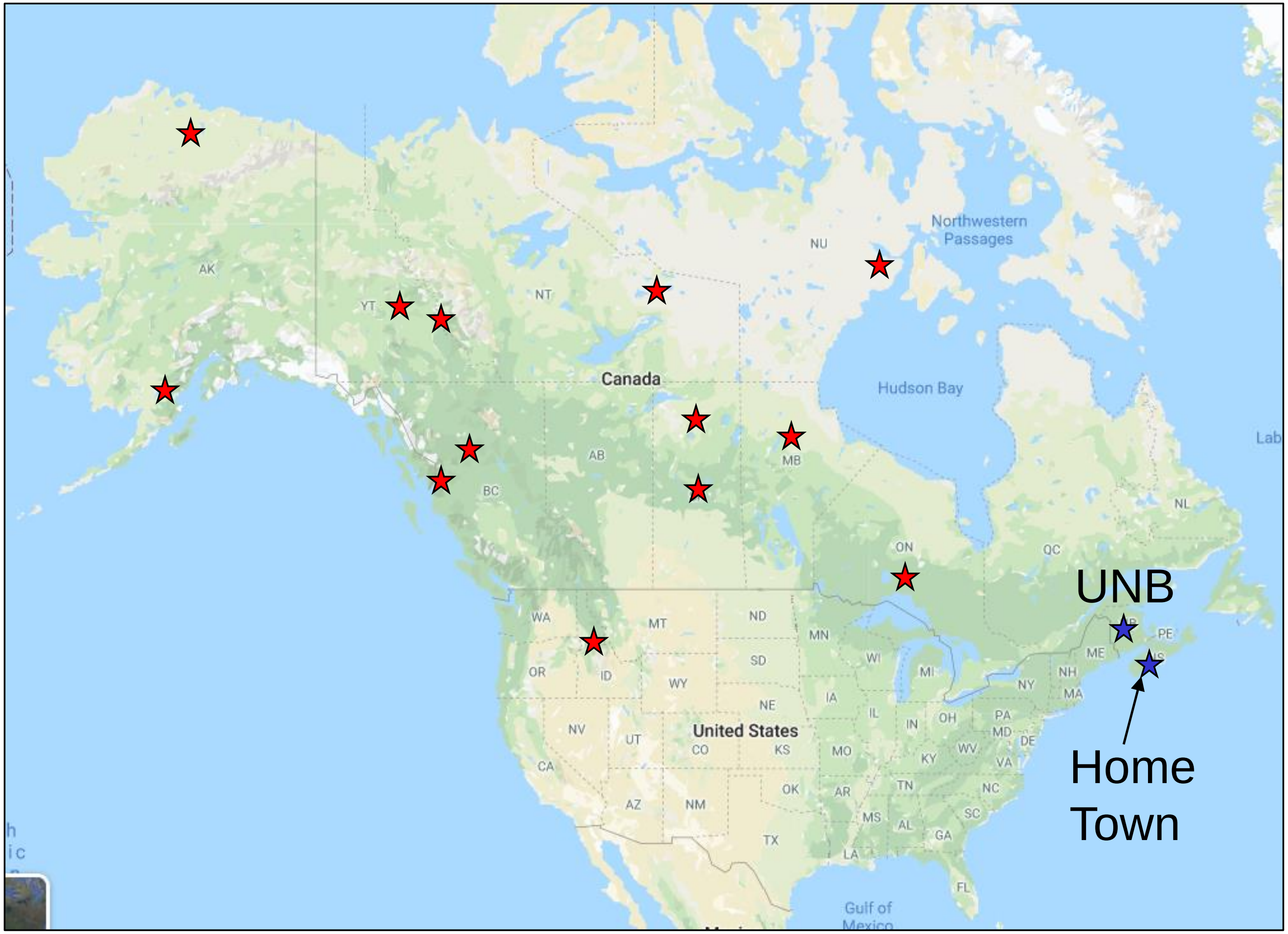
Founders:
Hendrik Kirsten, Andy Robertson, and Oskar Steffen

Consultant of the Year, 2019

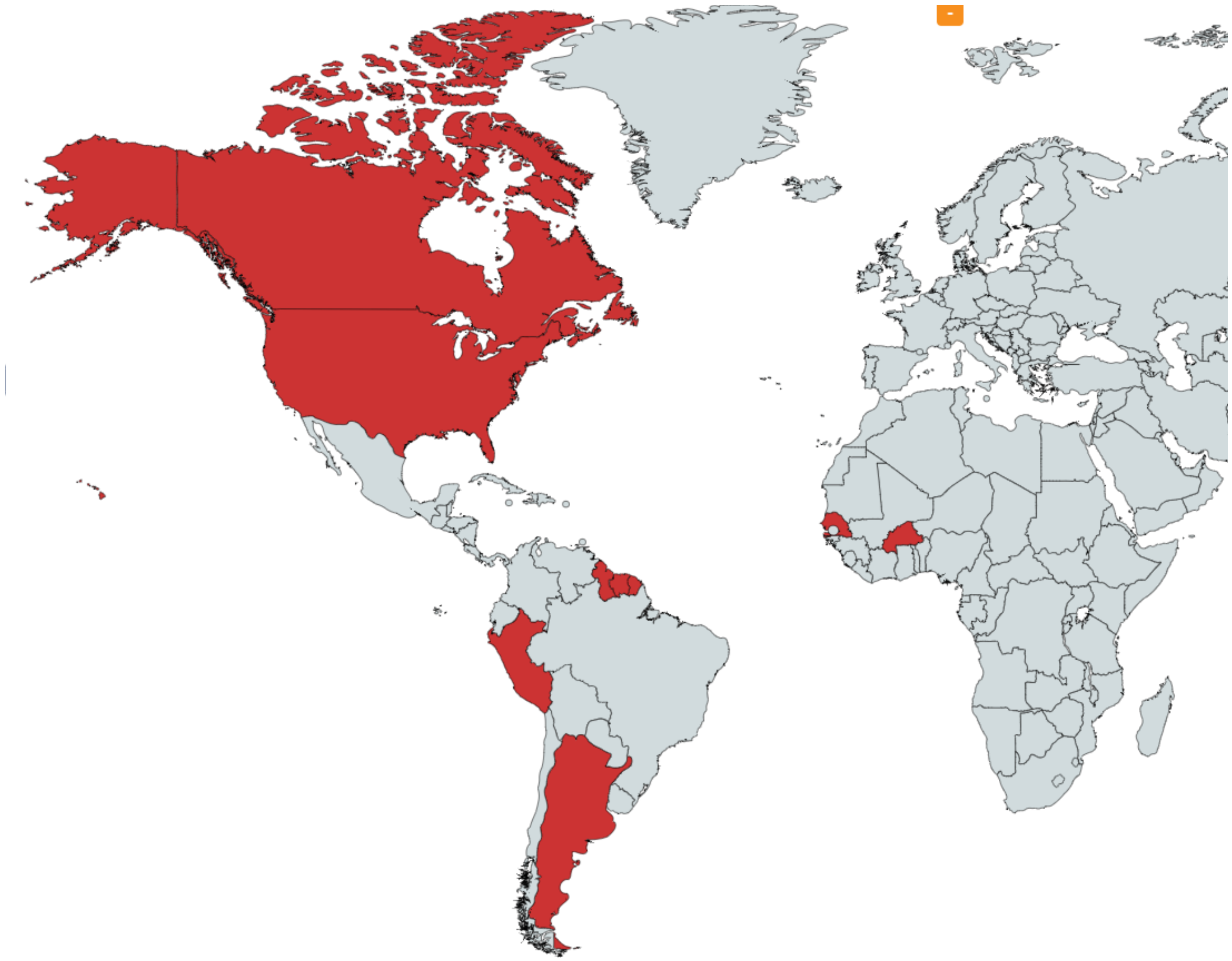
2019
BC's Top Employers

SRK Consulting

Where I’ve worked – North America



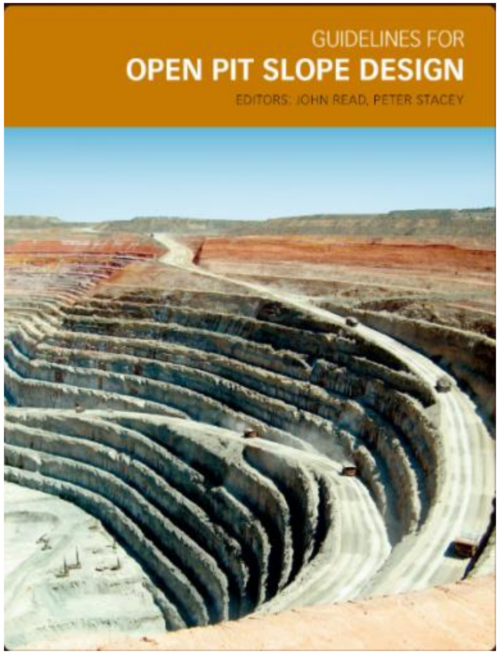
Where I’ve worked - World

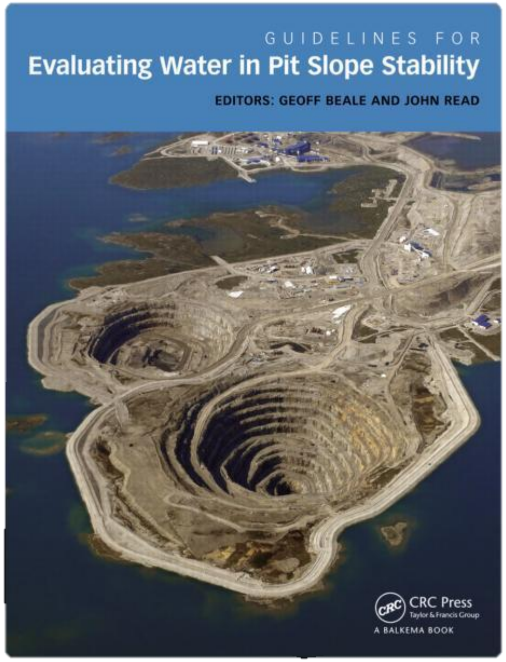


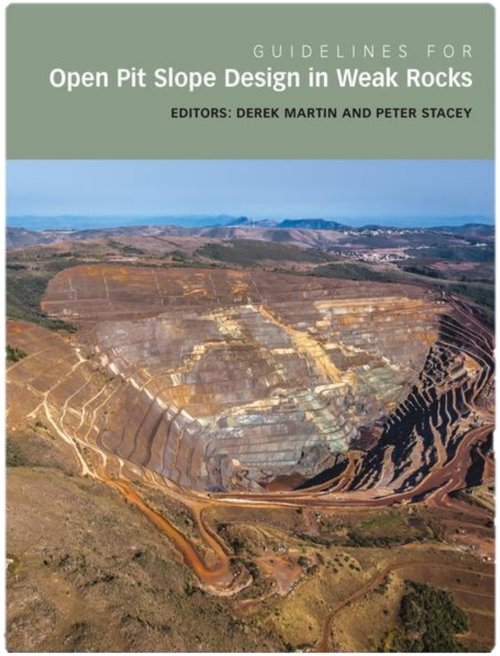
Geotechnical Rock Mechanics

- **Rock slope engineering**
- Underground rock engineering
- Mine backfill
- Blast design
- Soil and foundation engineering

Recommended Reading


GUIDELINES FOR
OPEN PIT SLOPE DESIGN
EDITORS: JOHN READ, PETER STACEY


GUIDELINES FOR
Evaluating Water in Pit Slope Stability
EDITORS: GEOFF BEALE AND JOHN READ
CRC Press
Taylor & Francis Group
A BALKEMA BOOK


GUIDELINES FOR
Open Pit Slope Design in Weak Rocks
EDITORS: DEREK MARTIN AND PETER STACEY


International Symposium on
Slope Stability
in Open Pit Mining and Civil Engineering 2013
ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | Curtin University | The University of Western Australia
Joint Venture
25-27 September 2013 | Sofitel Brisbane Central Hotel, Queensland, Australia

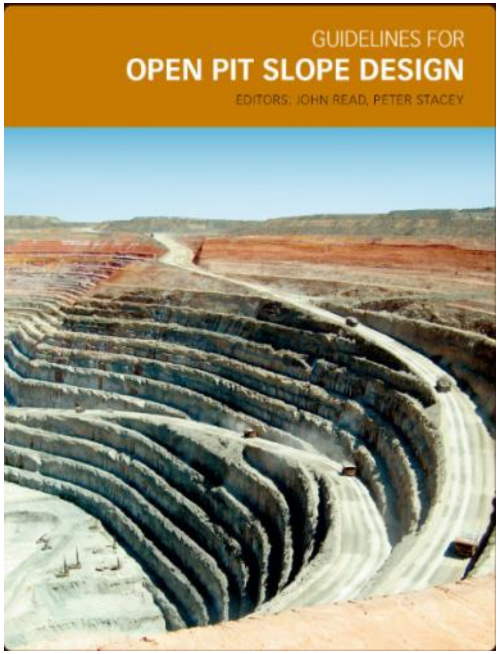
These three books are the background to what a rock mechanics engineer does

What Affects Pit Slope designs?

Team Effort

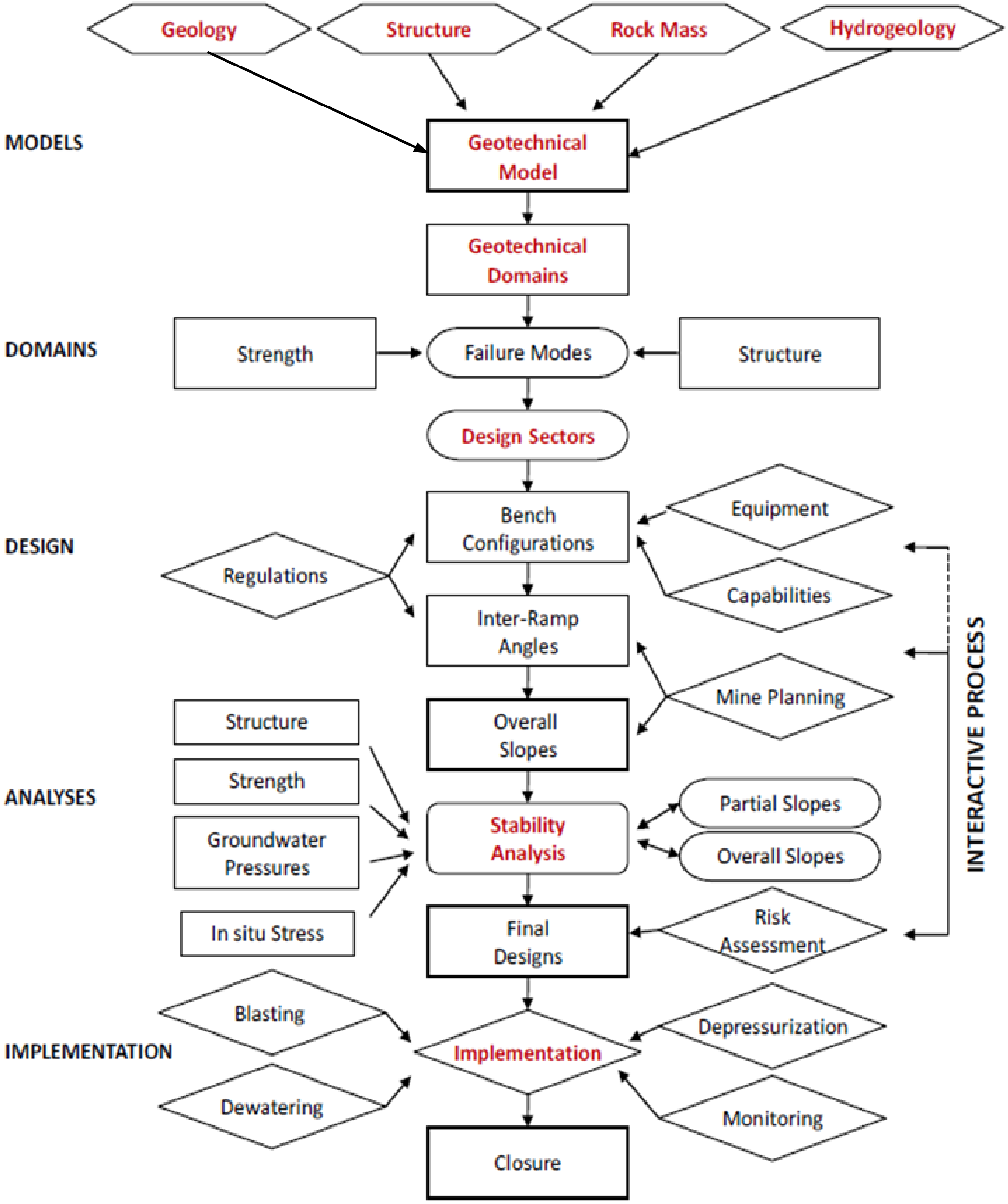
• **Geology:** Lithology, alteration, weathering	Geology Degree
• **Structure:** Fault/discontinuities, condition and orientation	Geology Degree
• **Rock Mass Conditions:** Intact Rock Strength (IRS), spacing of discontinuities, condition of discontinuities	Rock Mechanics Engineering
• **Hydrogeology:** Pore pressures	Hydrogeology
• **Slope Geometry:** Orientation and Confinement, stack and overall slope height, stress (Discussed in Part 2)	Mining Engineering

Slope Design Process



GUIDELINES FOR
OPEN PIT SLOPE DESIGN
EDITORS: JOHN READ, PETER STACEY

Guidelines for Open Pit Slope Design – 2009
Editors: John Read and Peter Stacey/John Read
Slope Stability 2013, Brisbane



Geology
Structure
Rock Mass
Hydrogeology

MODELS
Geotechnical Model
Geotechnical Domains

DOMAINS
Strength
Failure Modes
Structure
Design Sectors

DESIGN
Regulations
Bench Configurations
Equipment
Capabilities
Inter-Ramp Angles
Mine Planning
Overall Slopes

ANALYSES
Structure
Strength
Groundwater Pressures
In situ Stress
Stability Analysis
Partial Slopes
Overall Slopes
Risk Assessment
Final Designs

IMPLEMENTATION
Blasting
Dewatering
Implementation
Depressurization
Monitoring
Closure

INTERACTIVE PROCESS

Most Common Software…

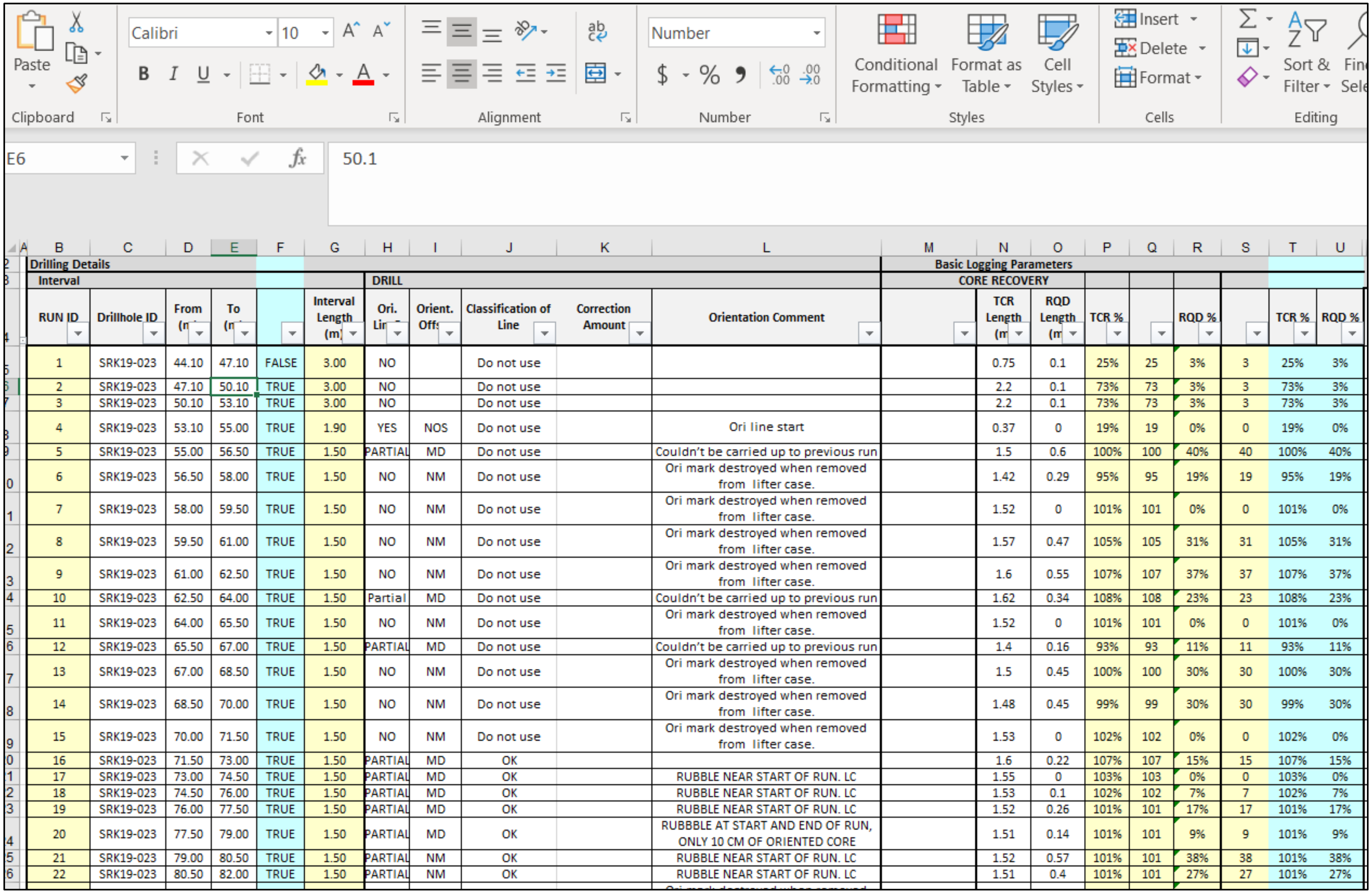
PowerPoint

Useful for organizing data and analysis into easy to digest format

Excel

Much of what we do involves processing lots of numeric data and Excel is the easiest format to use

Excel



E6

50.1

RUN ID	Drillhole ID	From (m	To (m		Interval Length (m)	Ori. Lir	Orient. Offs	Classification of Line	Correction Amount	Orientation Comment		TCR Length (m	RQD Length (m	TCR %		RQD %		TCR %	RQD %
Drilling Details											**Basic Logging Parameters**								
Interval						**DRILL**					**CORE RECOVERY**								
1	SRK19-023	44.10	47.10	FALSE	3.00	NO		Do not use				0.75	0.1	25%	25	3%	3	25%	3%
2	SRK19-023	47.10	50.10	TRUE	3.00	NO		Do not use				2.2	0.1	73%	73	3%	3	73%	3%
3	SRK19-023	50.10	53.10	TRUE	3.00	NO		Do not use				2.2	0.1	73%	73	3%	3	73%	3%
4	SRK19-023	53.10	55.00	TRUE	1.90	YES	NOS	Do not use		Ori line start		0.37	0	19%	19	0%	0	19%	0%
5	SRK19-023	55.00	56.50	TRUE	1.50	PARTIAL	MD	Do not use		Couldn't be carried up to previous run		1.5	0.6	100%	100	40%	40	100%	40%
6	SRK19-023	56.50	58.00	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.42	0.29	95%	95	19%	19	95%	19%
7	SRK19-023	58.00	59.50	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.52	0	101%	101	0%	0	101%	0%
8	SRK19-023	59.50	61.00	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.57	0.47	105%	105	31%	31	105%	31%
9	SRK19-023	61.00	62.50	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.6	0.55	107%	107	37%	37	107%	37%
10	SRK19-023	62.50	64.00	TRUE	1.50	Partial	MD	Do not use		Couldn't be carried up to previous run		1.62	0.34	108%	108	23%	23	108%	23%
11	SRK19-023	64.00	65.50	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.52	0	101%	101	0%	0	101%	0%
12	SRK19-023	65.50	67.00	TRUE	1.50	PARTIAL	MD	Do not use		Couldn't be carried up to previous run		1.4	0.16	93%	93	11%	11	93%	11%
13	SRK19-023	67.00	68.50	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.5	0.45	100%	100	30%	30	100%	30%
14	SRK19-023	68.50	70.00	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.48	0.45	99%	99	30%	30	99%	30%
15	SRK19-023	70.00	71.50	TRUE	1.50	NO	NM	Do not use		Ori mark destroyed when removed from lifter case.		1.53	0	102%	102	0%	0	102%	0%
16	SRK19-023	71.50	73.00	TRUE	1.50	PARTIAL	MD	OK				1.6	0.22	107%	107	15%	15	107%	15%
17	SRK19-023	73.00	74.50	TRUE	1.50	PARTIAL	MD	OK		RUBBLE NEAR START OF RUN. LC		1.55	0	103%	103	0%	0	103%	0%
18	SRK19-023	74.50	76.00	TRUE	1.50	PARTIAL	MD	OK		RUBBLE NEAR START OF RUN. LC		1.53	0.1	102%	102	7%	7	102%	7%
19	SRK19-023	76.00	77.50	TRUE	1.50	PARTIAL	MD	OK		RUBBLE NEAR START OF RUN. LC		1.52	0.26	101%	101	17%	17	101%	17%
20	SRK19-023	77.50	79.00	TRUE	1.50	PARTIAL	MD	OK		RUBBBLE AT START AND END OF RUN, ONLY 10 CM OF ORIENTED CORE		1.51	0.14	101%	101	9%	9	101%	9%
21	SRK19-023	79.00	80.50	TRUE	1.50	PARTIAL	NM	OK		RUBBLE NEAR START OF RUN. LC		1.52	0.57	101%	101	38%	38	101%	38%
22	SRK19-023	80.50	82.00	TRUE	1.50	PARTIAL	NM	OK		RUBBLE NEAR START OF RUN. LC		1.51	0.4	101%	101	27%	27	101%	27%

Large data processing

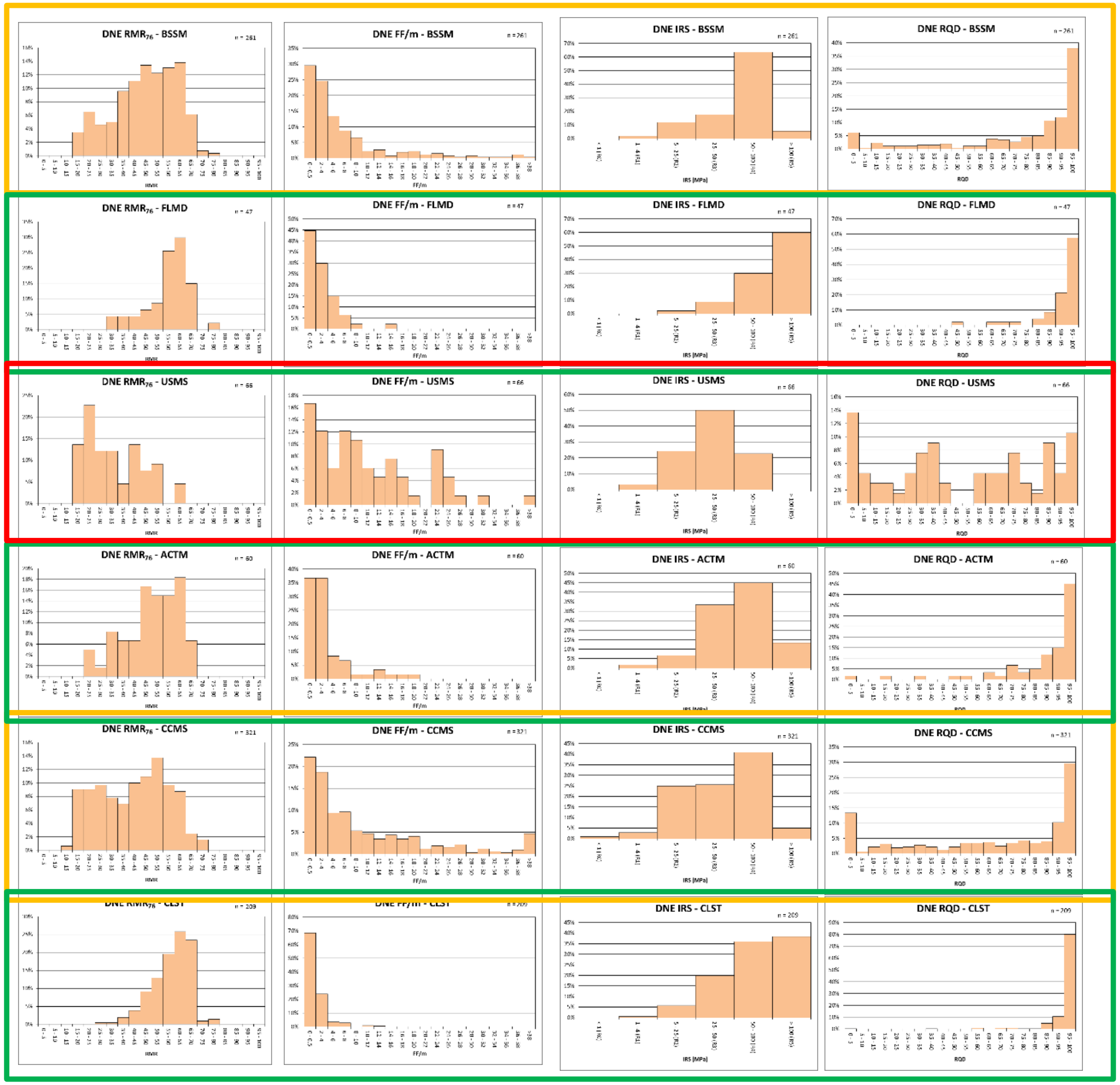
Excel

Deposit	Graphite	Length	Count	RMR_{76}		IRS (MPa)		RQD%		FF/m		JC_{76}		Greyscale	
				Average	StDev	Average	StDev	Average	StDev	Average	StDev	Average	StDev	Average	StDev
DNE	0	16.5	6	63	8	106	50	97	4	1.67	1.24	6	1	4.8	1.7
	1	500.7	255	56	11	91	35	89	19	3.79	4.20	6	4	6.6	1.3
	2	562.7	322	44	14	68	35	69	34	7.80	8.04	4	4	7.1	0.9
	3	291.5	190	36	15	47	34	54	36	14.41	12.51	3	3	7.3	0.7

Graphite	Litho	Length	Drilled Run Count	RMR_{76}		IRS (MPa)		RQD%		FF/m		JC_{76} (based on '89 conditions)		Greyscale	
				Average	StDev	Average	StDev	Average	StDev	Average	StDev	Average	StDev	Average	StDev
1	FLMD	80	39	61	8	128	35	96	4	3	2	7	3	4.7	1.0
	BSSM	238	126	55	12	85	27	89	21	4	5	6	4	7.1	0.9
	ACTM	32	15	61	7	129	33	94	7	2	2	7	3	5.7	0.6
	CCMS	123	61	53	9	75	21	85	19	5	5	7	4	7.2	0.5
	Total	**501**	**255**	**56**	**11**	**91**	**35**	**89**	**19**	**4**	**4**	**6**	**4**	**6.6**	**1.3**
2	BSSM	172	103	44	13	62	19	71	32	8	8	3	3	7.3	0.6
	USMS	53	40	33	13	48	25	45	36	12	9	3	4	7.9	0.4
	ACTM	83	39	49	12	66	35	84	22	5	5	4	3	6.6	1.0
	CCMS	231	127	47	15	78	44	68	36	8	9	5	4	7.1	0.7
	Total	**563**	**322**	**44**	**14**	**68**	**35**	**69**	**34**	**8**	**8**	**4**	**4**	**7.1**	**0.9**
3	BSSM	38	31	34	13	43	24	51	34	14	12	2	3	7.6	0.5
	USMS	28	21	36	13	32	19	56	32	10	9	3	3	7.7	0.6
	CCMS	210	128	36	16	49	37	52	37	16	13	3	3	7.2	0.6
	Total	**292**	**190**	**36**	**15**	**47**	**34**	**54**	**36**	**14**	**13**	**3**	**3**	**7.3**	**0.7**

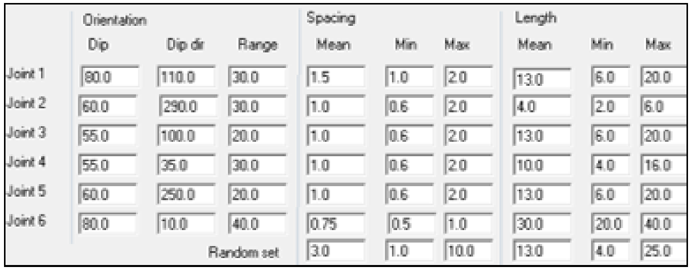
Statistical analysis on various aspects of collected data

Excel

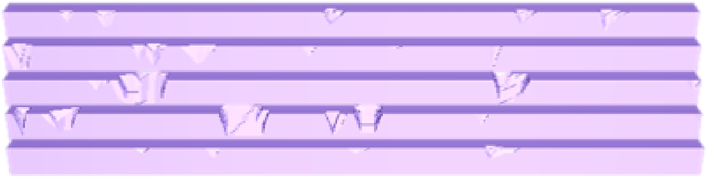


Plotting data to compare across project areas

PowerPoint

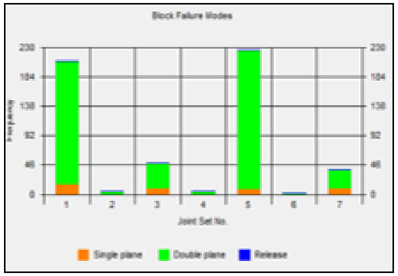


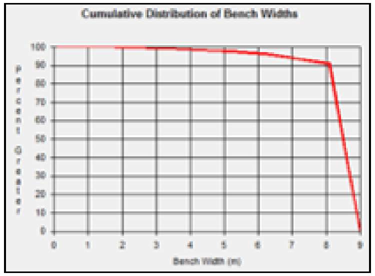
	Orientation			Spacing			Length		
	Dip	Dip dir	Range	Mean	Min	Max	Mean	Min	Max
Joint 1	80.0	110.0	30.0	1.5	1.0	2.0	13.0	6.0	20.0
Joint 2	60.0	290.0	30.0	1.0	0.6	2.0	4.0	2.0	6.0
Joint 3	55.0	100.0	20.0	1.0	0.6	2.0	13.0	6.0	20.0
Joint 4	55.0	35.0	30.0	1.0	0.6	2.0	10.0	4.0	16.0
Joint 5	60.0	250.0	20.0	1.0	0.6	2.0	13.0	6.0	20.0
Joint 6	80.0	10.0	40.0	0.75	0.5	1.0	30.0	20.0	40.0
			Random set	3.0	1.0	10.0	13.0	4.0	25.0

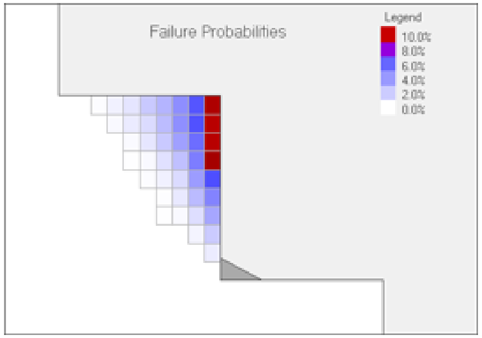


RESULTS	
Average Failure Volume (m²/m)	1.0
Average Factor of Safety of Blocks/Wedges	5.61
Average Effective Bench Width (m)	8.8
Failure Free Bench Length (%)	91.0
Average NonZero Failure Volume (m²/m)	7.2
Average Required Bench Width (m)	2.2

DATA	
Domain	EPC_180
Bench face dip (deg)	90.0
Bench face dip dir(deg)	180.0
Bench face height (m)	10.0
Design bench width (m)	9.0







Comments:
Sblock does not show a primary toppling style failure those these results will need to be looked at in more detail in Phase2.

Indicated IRA = 48° (without toppling)

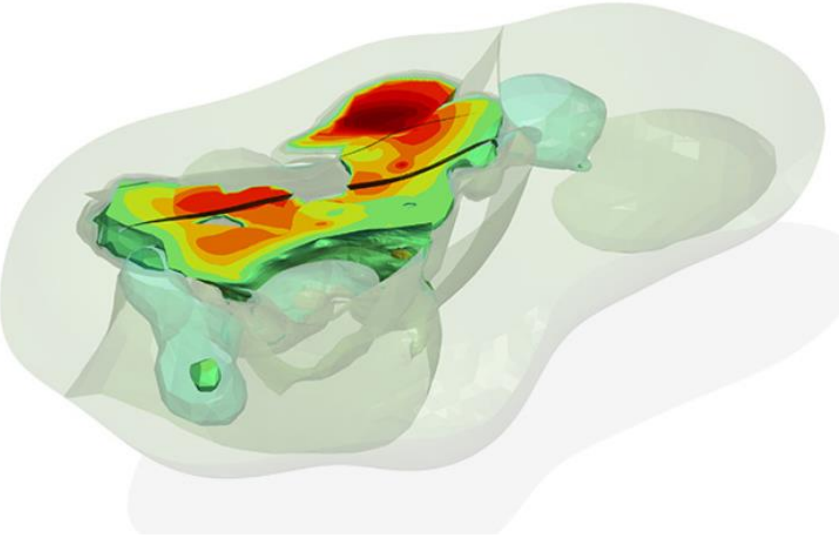
Probability of Failure	10%	**Average Req. Bench Width (m)**	2.2
Factor of Safety	5.61	**Average Effective Bench Width (m)**	8.8
Percent retained by catch benches	95%	**80% Cumulative Bench width (m)**	8.3

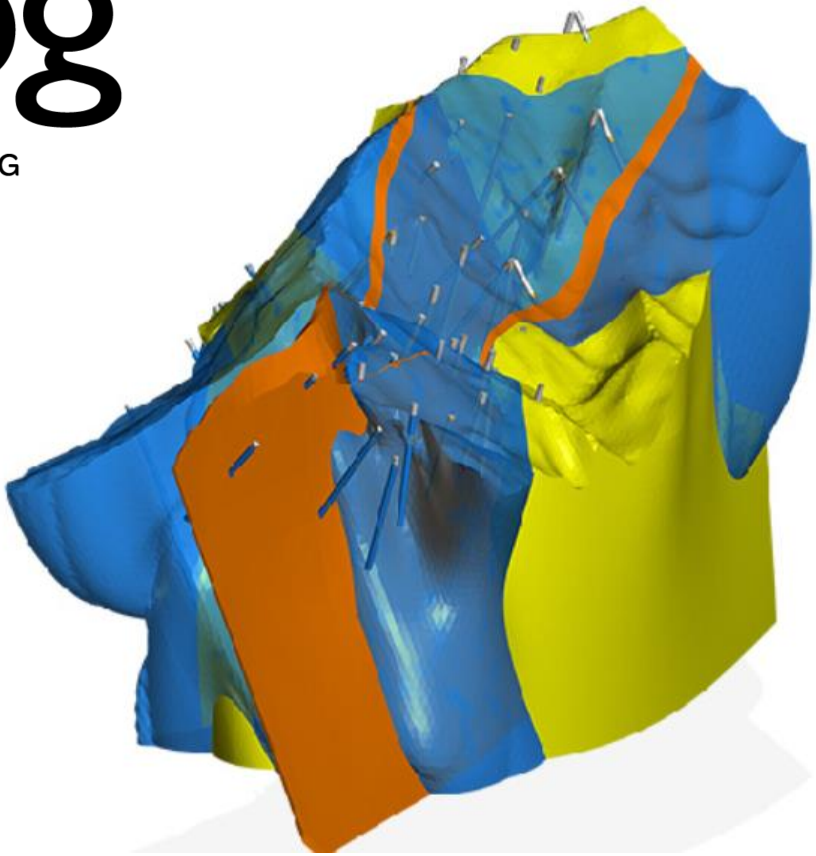
Organizing various outputs to allow reviewer to quickly look at the results

Other Software - LeapFrog

leapfrog®

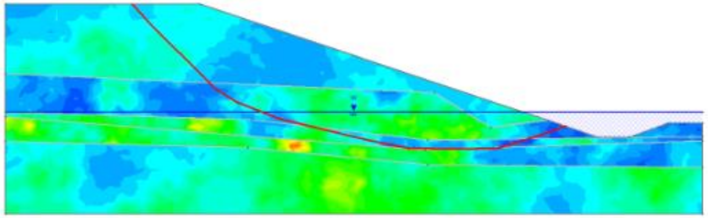
FAST, DYNAMIC GEOLOGICAL MODELLING





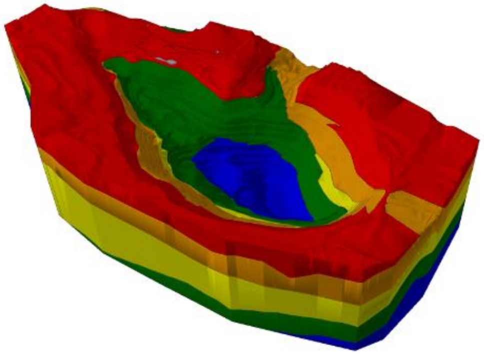
Other Software - RocScience

Slide2



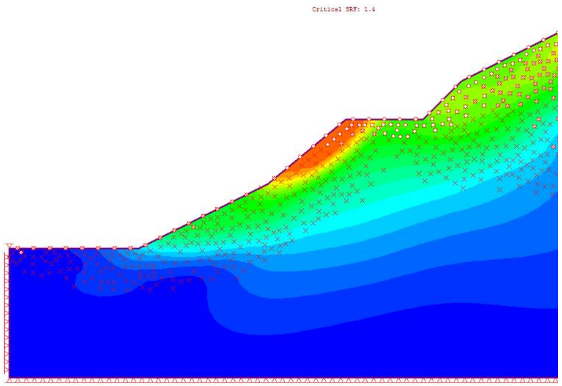
- Modeling slopes using a simplified method of slices

Slide3



- Three Dimensional version of Slide2

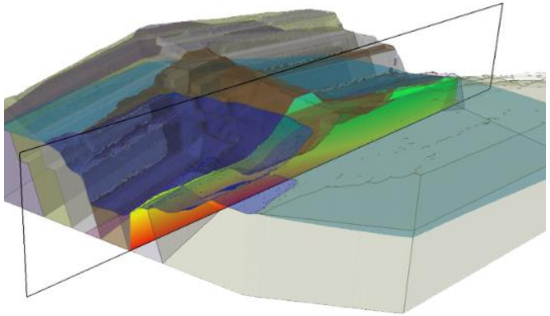
RS2



- Similar to Slide2, but the model is split into triangle instead of larger slices

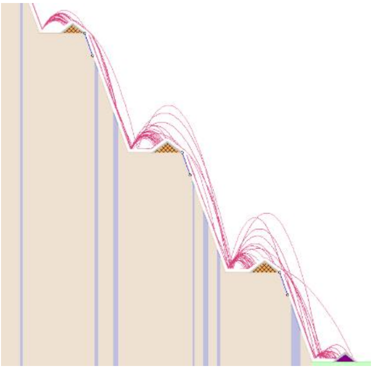
Other Software - RocScience

RS3



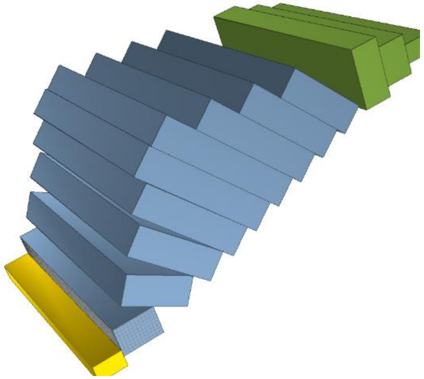
- Three dimensional version of RS2

RocFall



- Analyses of where small-scale failures will land

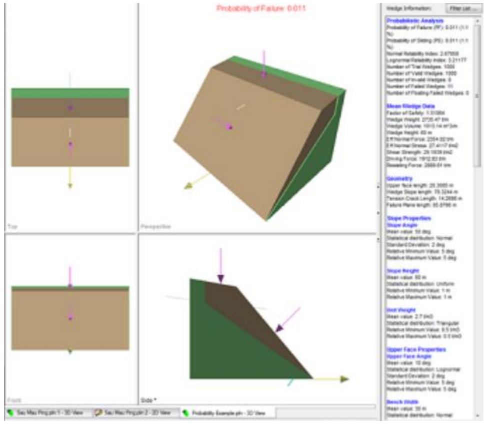
RocTopple



- High angle perpendicular discontinuities can fall over like a stack of books

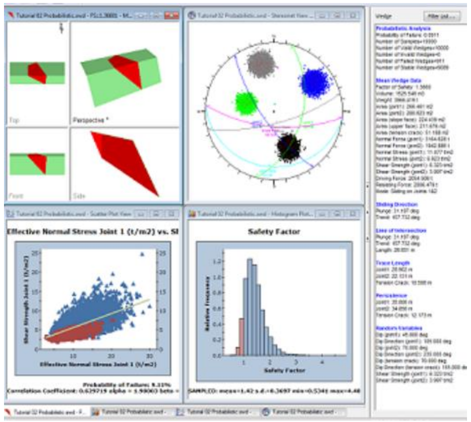
Other Software - RocScience

RocPlane



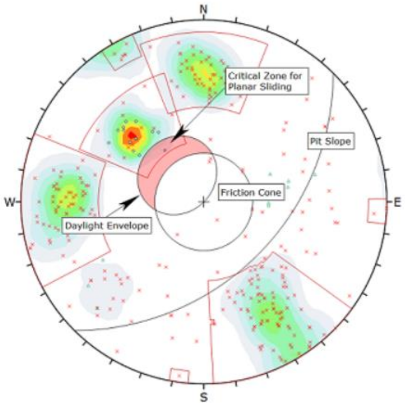
- Analysis of a single discontinuity that runs sub parallel to a slope

SWedge



- Analyses of how two discontinuities can create a wedge

Dips

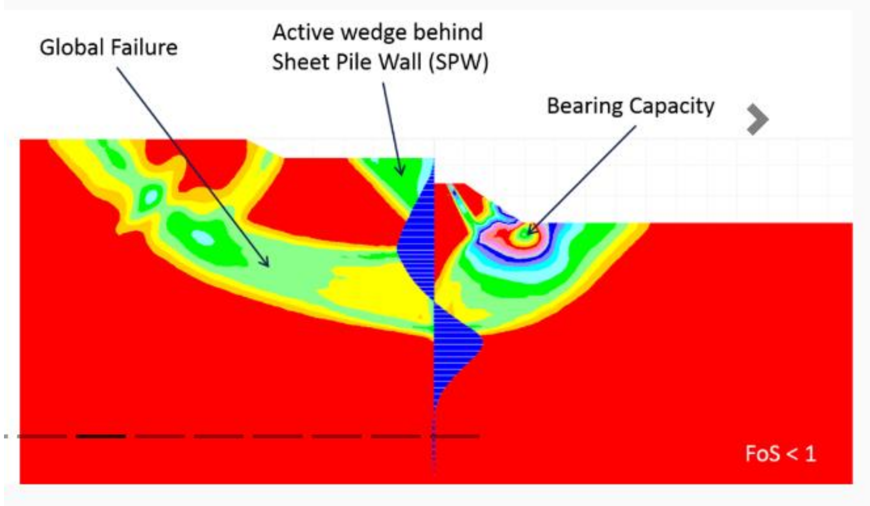


- Analysis of discontinuities over a large data set

Other Software - Itasca

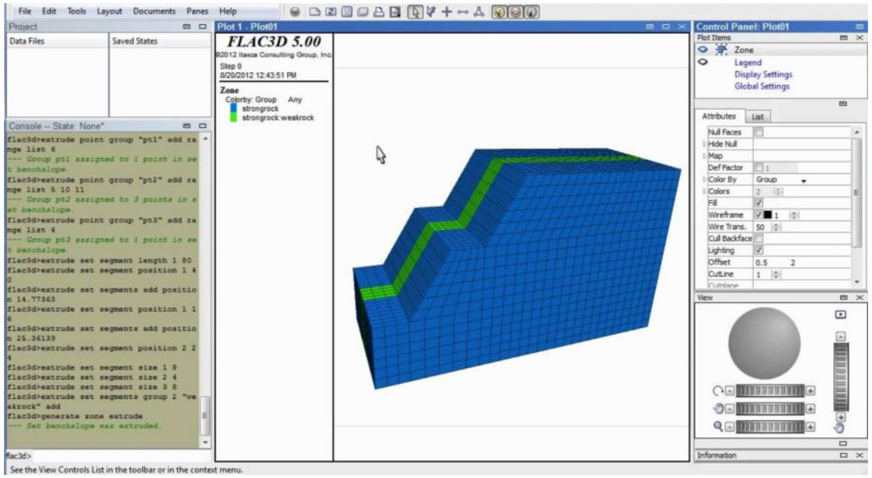
FLAC® VERSION 8.1

Explicit Continuum Modeling of Non-linear Material Behavior in 2D



FLAC3D™ VERSION 7.0

Explicit Continuum Modeling of Non-linear Material Behavior in 3D



FLAC3D 5.00

©2012 Itasca Consulting Group, Inc.

Step 0

8/20/2012 12:43:51 PM

Zone

Colorby: Group Any

🟦 strongrock

🟩 strongrock:weakrock

Console -- State: None*

```
flac3d>extrude point group "pt1" add ra
nge list 6
--- Group pt1 assigned to 1 point in se
t benchslope.
flac3d>extrude point group "pt2" add ra
nge list 5 10 11
--- Group pt2 assigned to 3 points in s
et benchslope.
flac3d>extrude point group "pt3" add ra
nge list 4
--- Group pt3 assigned to 1 point in se
t benchslope.
flac3d>extrude set segment length 1 80
flac3d>extrude set segment position 1 4
0
flac3d>extrude set segments add positio
n 14.77363
flac3d>extrude set segment position 1 1
6
flac3d>extrude set segments add positio
n 25.36139
flac3d>extrude set segment position 2 2
4
flac3d>extrude set segment size 1 8
flac3d>extrude set segment size 2 4
flac3d>extrude set segment size 3 8
flac3d>extrude set segments group 2 "we
akrock" add
flac3d>generate zone extrude
--- Set benchslope was extruded.
```

flac3d>

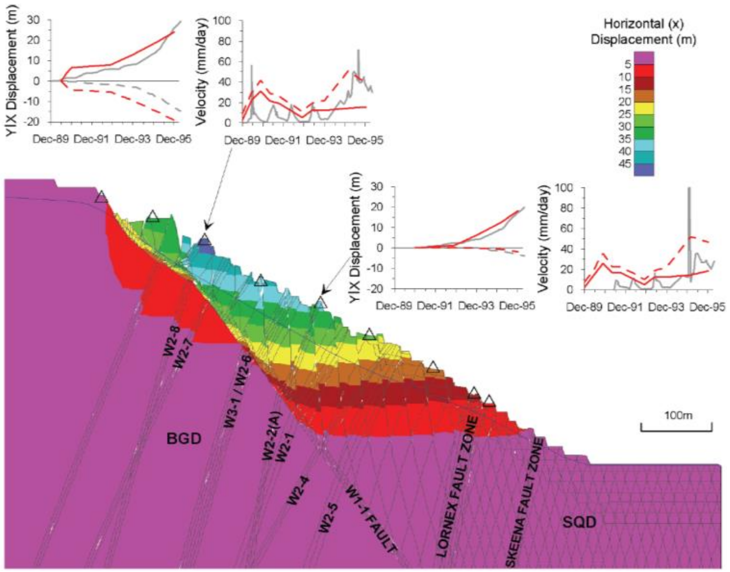
See the View Controls List in the toolbar or in the context menu.

Null Faces	☐
Hide Null	
Map	
Def Factor	☐ 1
Color By	Group
Colors	2
Fill	☑
Wireframe	☑ ■ 1
Wire Trans.	50
Cull Backface	☐
Lighting	☑
Offset	0.5 2
CutLine	1

Other Software - Itasca

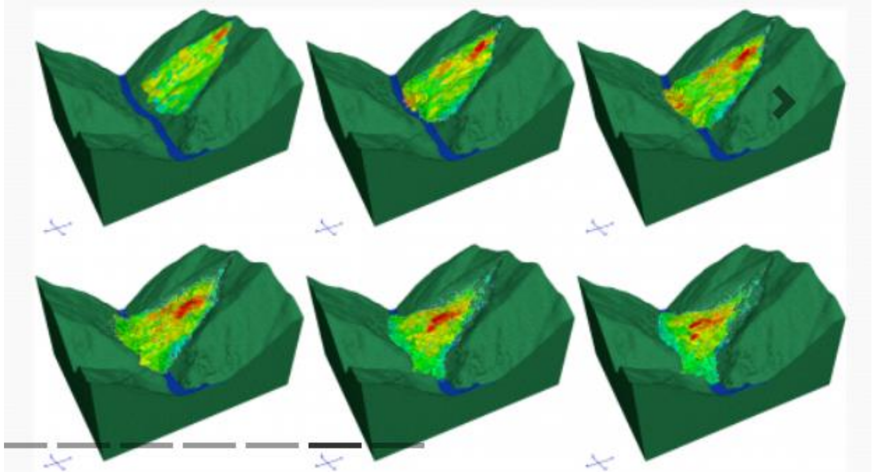
UDEC™ VERSION 7.0

Distinct-Element Modeling of Jointed and Blocky Material in 2D



3DEC™ VERSION 5.2

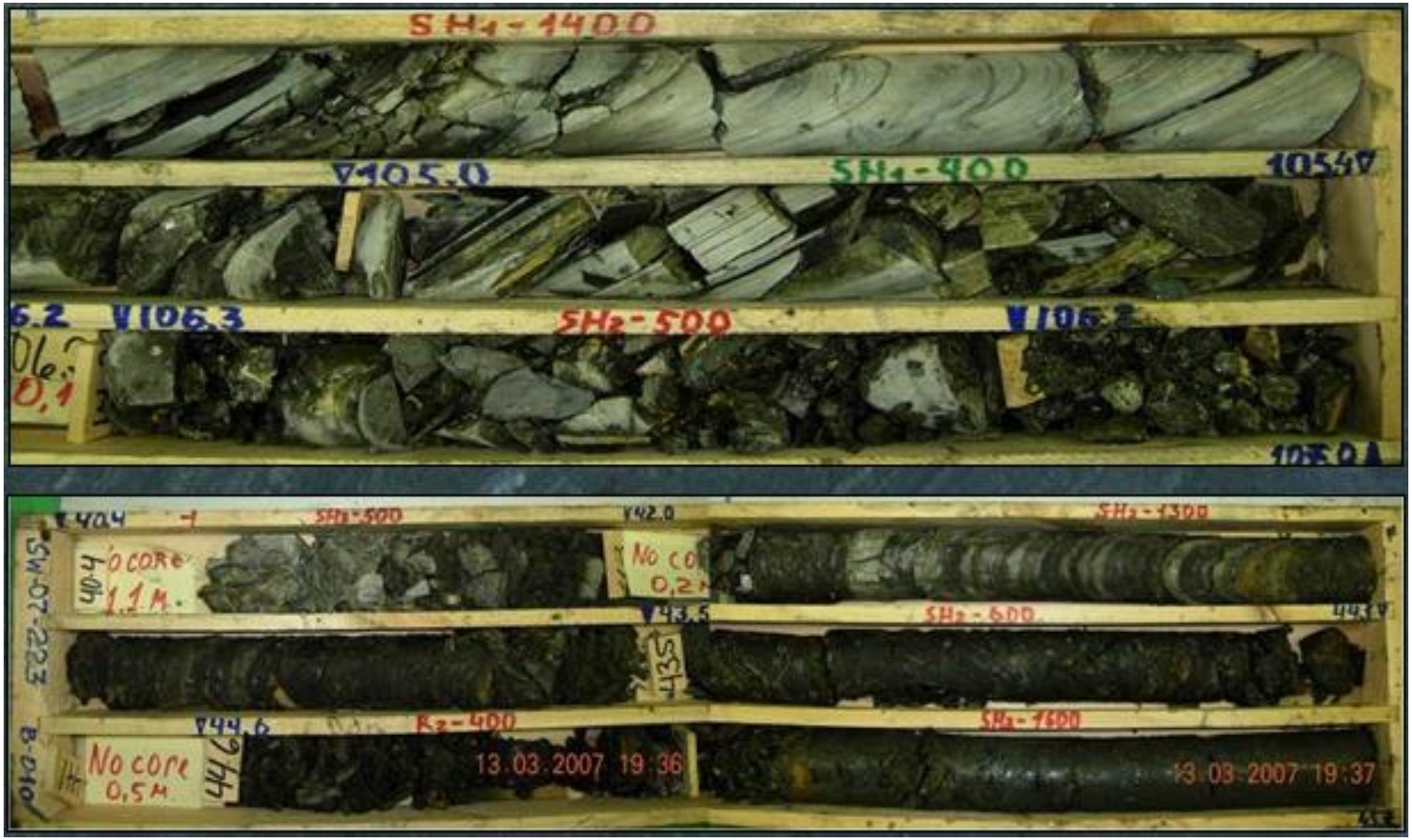
Distinct-Element Modeling of Jointed and Blocky Material in 3D



Field Work – Site Conditions

Field Work - Rock Mass Conditions

These can vary substantially from *very weak* to…



Field Work - Rock Mass Conditions

… massive These can vary substantially from *very weak* to…

Field Work – Lots of Variability


Altered


Blocky and Altered


Blocky

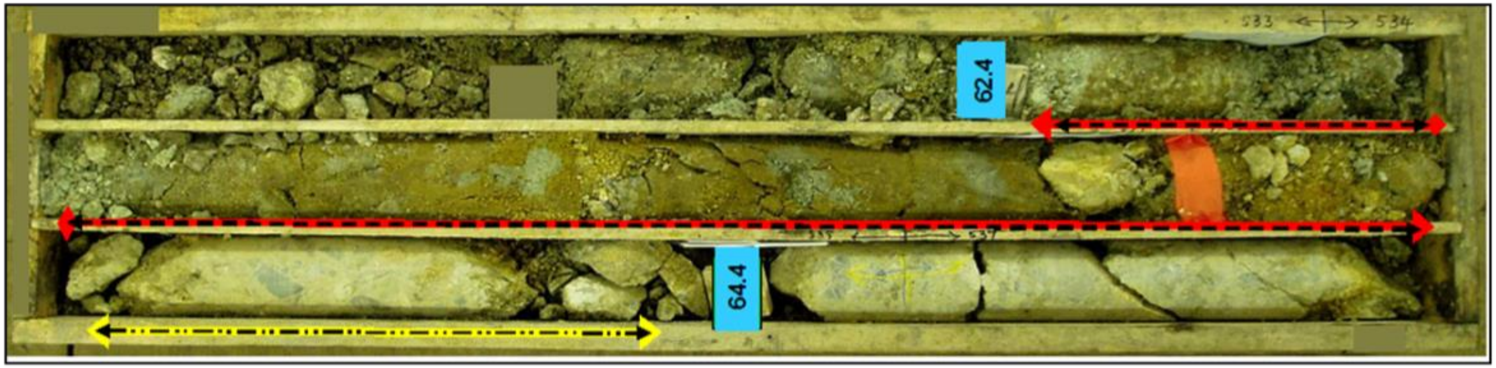

More Massive

Slope Design – Two Paths

Rock Mass VS Kinematics

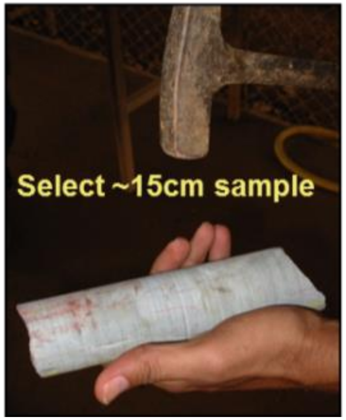
Independently find a design for each part of the wall and select the lowest angle

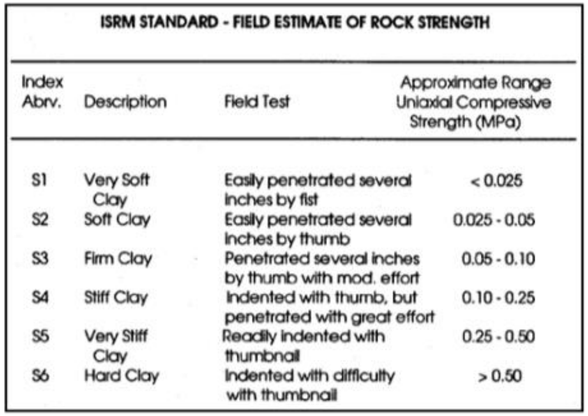
Rock Mass: Intact Rock Strength – Empirical



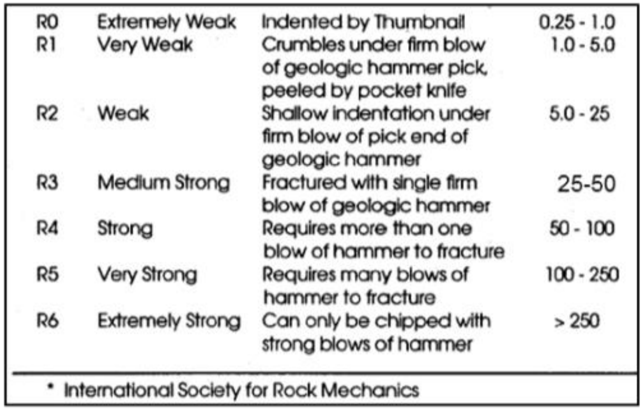
IRS		
Strong	Weak	% Weak
R3	S3	80

- Start with the rock pick test, and then continue further tests to see whether the intact rock is weaker.
- The weak rock is classified in the R0 – R1 range if more rock like material, or the S1 – S6 range if more soil like material


Select ~15cm sample

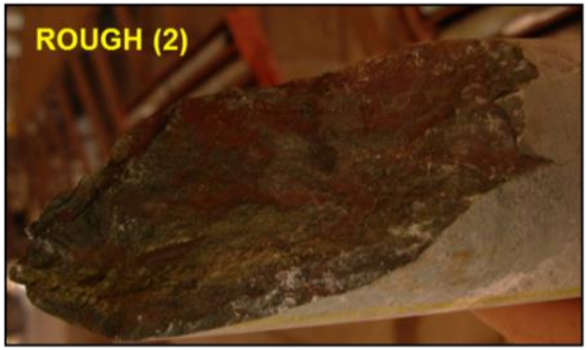

ISRM STANDARD - FIELD ESTIMATE OF ROCK STRENGTH

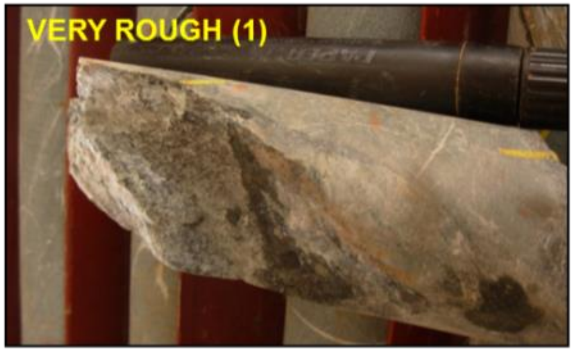
Index Abrv.	Description	Field Test	Approximate Range Uniaxial Compressive Strength (MPa)
S1	Very Soft Clay	Easily penetrated several inches by fist	< 0.025
S2	Soft Clay	Easily penetrated several inches by thumb	0.025 - 0.05
S3	Firm Clay	Penetrated several inches by thumb with mod. effort	0.05 - 0.10
S4	Stiff Clay	Indented with thumb, but penetrated with great effort	0.10 - 0.25
S5	Very Stiff Clay	Readily indented with thumbnail	0.25 - 0.50
S6	Hard Clay	Indented with difficulty with thumbnail	> 0.50

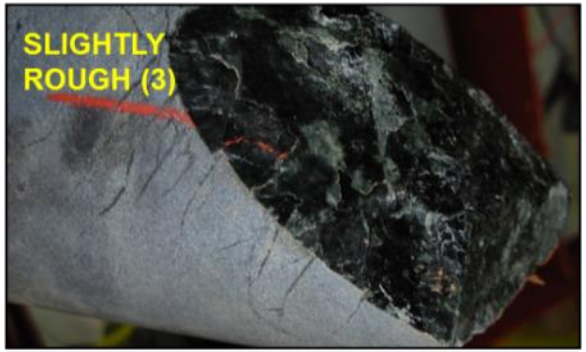

R0	Extremely Weak	Indented by Thumbnail	0.25 - 1.0
R1	Very Weak	Crumbles under firm blow of geologic hammer pick, peeled by pocket knife	1.0 - 5.0
R2	Weak	Shallow indentation under firm blow of pick end of geologic hammer	5.0 - 25
R3	Medium Strong	Fractured with single firm blow of geologic hammer	25-50
R4	Strong	Requires more than one blow of hammer to fracture	50 - 100
R5	Very Strong	Requires many blows of hammer to fracture	100 - 250
R6	Extremely Strong	Can only be chipped with strong blows of hammer	> 250

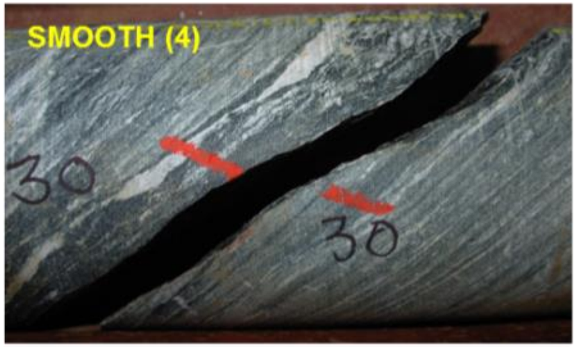
* International Society for Rock Mechanics

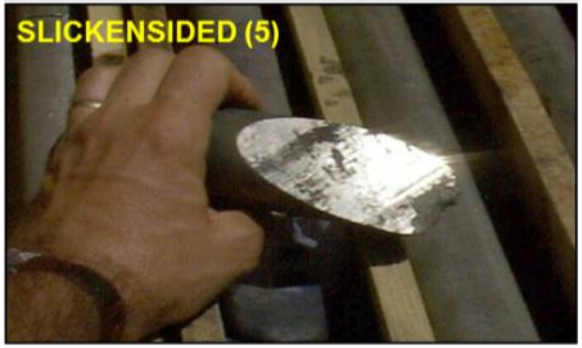
Rock Mass: Joint Roughness

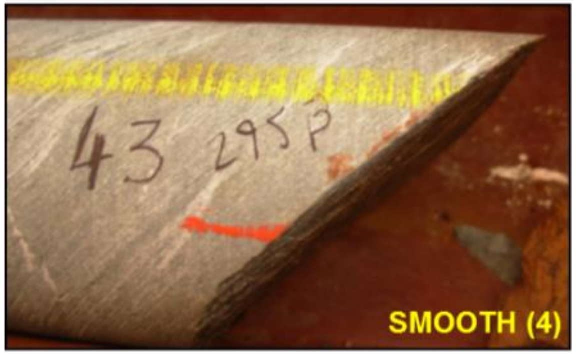


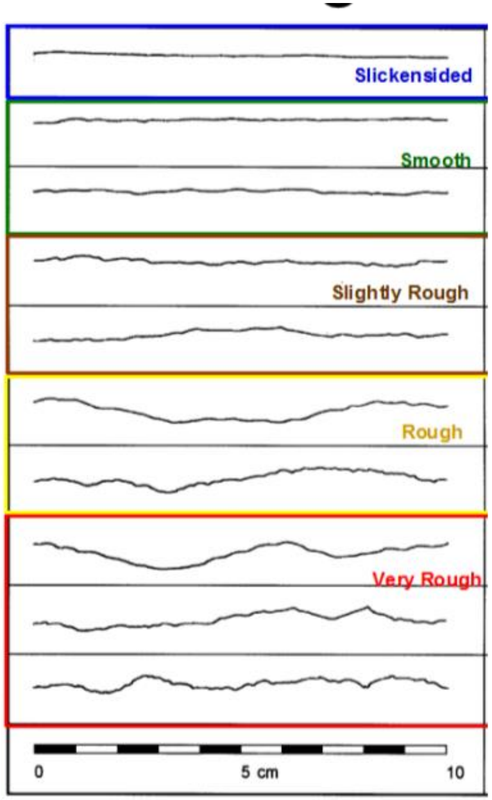






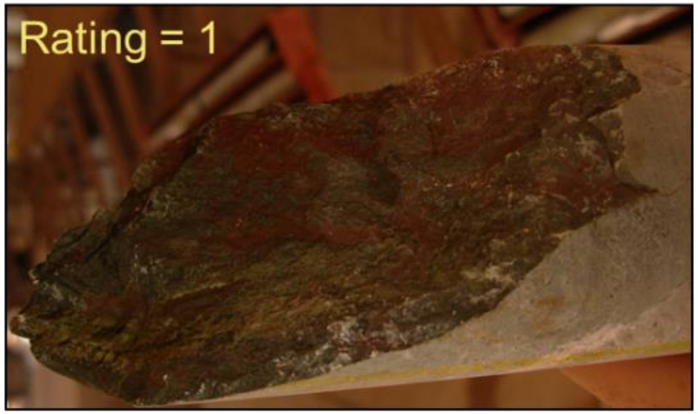






ROUGHNESS	
V. Rough	1
Rough	2
Slt Rough	3
Smooth	4
Slicken	5

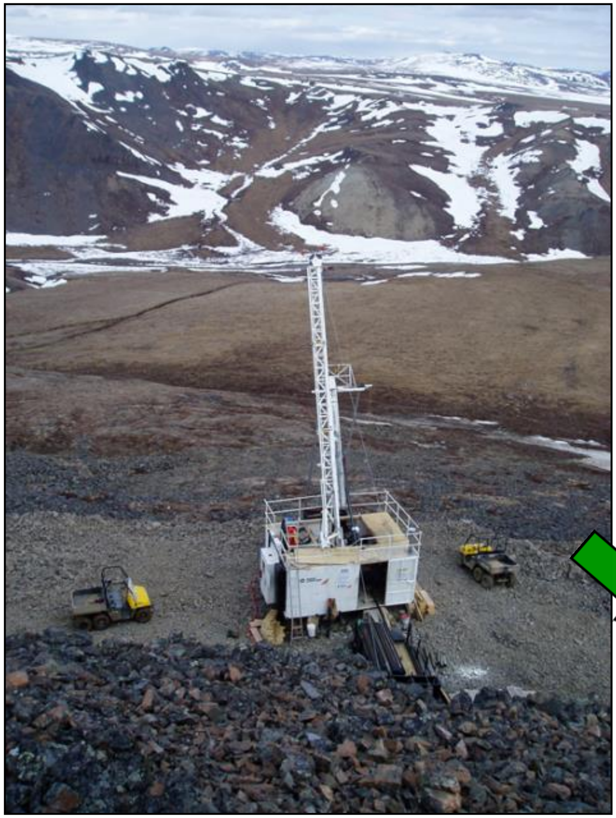
Rock Mass: Joint Fill Strength

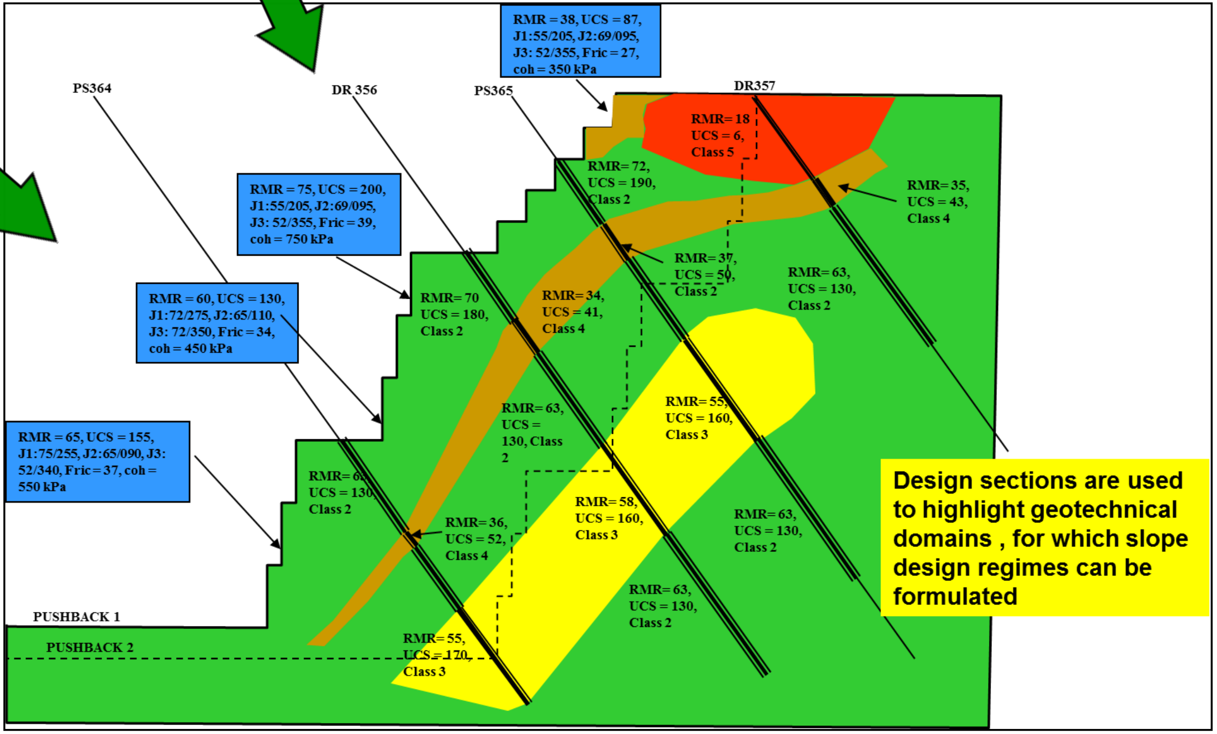


Fill Strength	
None	1
Hard <5 mm	2
Hard >5 mm	3
Soft <5 mm	4
Soft >5 mm	5

Note: Fill strength refers to the strength of fill in the fractures. A "soft" fill can be defined as material which can be scraped with minimal effort (e.g. chlorite, clay).

Rock Mass: From Drill Core To Slope Domains





RMR = 38, UCS = 87, J1:55/205, J2:69/095, J3: 52/355, Fric = 27, coh = 350 kPa

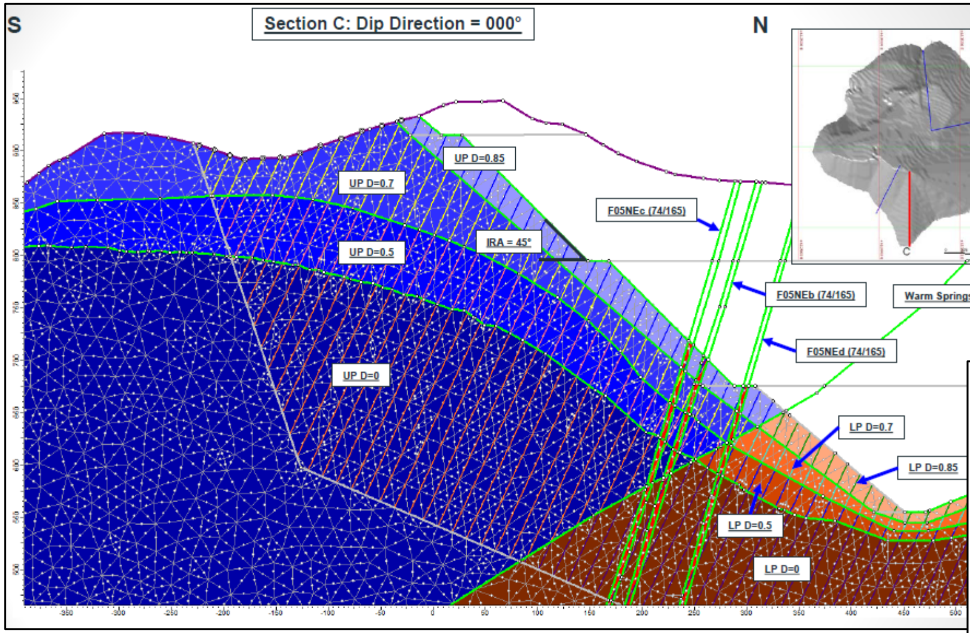
RMR = 75, UCS = 200, J1:55/205, J2:69/095, J3: 52/355, Fric = 39, coh = 750 kPa

RMR = 60, UCS = 130, J1:72/275, J2:65/110, J3: 72/350, Fric = 34, coh = 450 kPa

RMR = 65, UCS = 155, J1:75/255, J2:65/090, J3: 52/340, Fric = 37, coh = 550 kPa

Design sections are used to highlight geotechnical domains , for which slope design regimes can be formulated

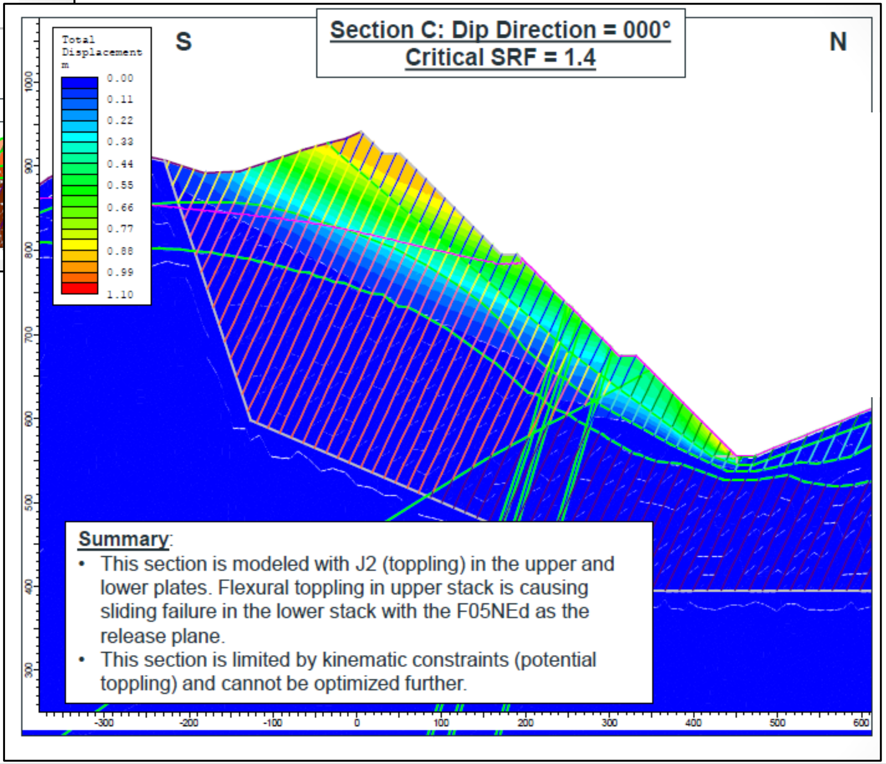
Rock Mass Modeling



RS2

Simply the rock units
Input the engineering properties
Build the slope geometry
Run the model

Objective: ensure the Factor of Safety is less than the acceptance (~1.3)

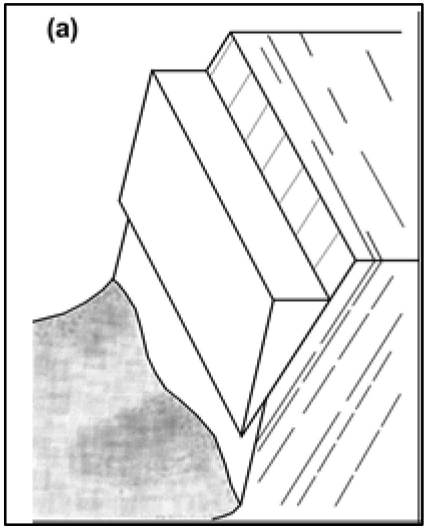


Summary:
- This section is modeled with J2 (toppling) in the upper and lower plates. Flexural toppling in upper stack is causing sliding failure in the lower stack with the F05NEd as the release plane.
- This section is limited by kinematic constraints (potential toppling) and cannot be optimized further.

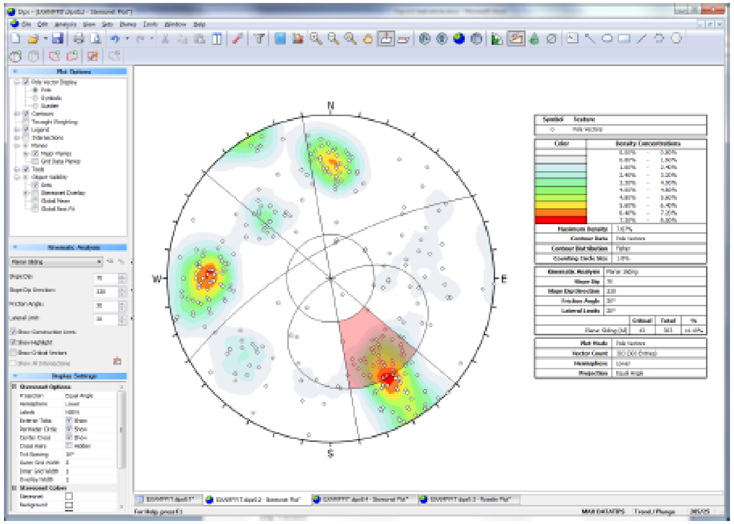
Rock Mass – Summary

General			Input Criteria and Slope Geometry				Results and Design			
Section ID	Objective	Section Location	Kinematic Constraints (Dip/Dip Direction)	Modelled IRA	Slope Height (m)	Slope Profile	SRF	Instability Mechanisms	Results Discussion	Design Considerations
A-A'	Confirm kinematic constraints on North Wall stability. Modelled Slope Azimuth: 175°	North wall (Domain 2L-E & 3)	Joints: J2: 65°/175° J3b: 85°/355° Faults: F02NE: 65°/310° F02NEd: 65°/315° F01NEd: 78°/317° F4Neb: 84°/330°	38° (top stack), and 45°	315	Convex (Bullnose)	1.5	Planar sliding on J2 + Flexural toppling on J3b	The interpreted failure mode is planar along J2 and potential toppling on J4b in the upper portion of the slope. There does not appear to be a noticeable change in results with the decrease in out of plane stress which may result in a need to examine this in more detail with 3-D analysis software package (i.e. FLAC3-D). Due to the location of this section and the current pit slope geometry, there will be a lack of confinement to the west due to the convex slope geometry (i.e. 'bullnose') which is represented in this section with a lower out of plane stress (0.5). J1 (S_1/S_0) has not been included in this section as it does not, geometrically speaking, represent a kinematic risk to the analyzed pit wall dip direction range. However, as this is a convex slope potentially impacted by more complex failure modes (potentially including J1).	This area should be confirmed with 3-D modelling if the slope geometry remains similar (i.e. convex slope)
B-B'	Confirm kinematic constraints on East Wall stability. Modelled Slope Azimuth: 255°	East wall (Domain 3)	Joints: J1 (S_1/S_0): 32°/266° J4a: 85°/255° Faults: F04NE: 80°/320° F01NE: 78°/315°	30°	295	Constant Azimuth (Linear)	1.3	Planar sliding on J1 (S_1/S_0)	The interpreted failure mode is planar sliding along the main foliation (J1 (S_1/S_0) at dip of 32°). **The slope remains stable when J1 is not undercut.**	It is unlikely that benches will be mined on this slope. The slope is likely to be stripped along J1 (S_1/S_0) fabric with geotechnical berms spaced every 60m. Ramps should not be constructed along this slope.
C-C'	Confirm kinematic constraints on South Wall stability. Modelled Slope Azimuth: 000°	South wall (Domain 4U & 4L)	Joints: J2: 65°/180° Faults: F05NEb: 74°/165° F05NEc: 74°/165° F05NEd: 74°/165°	45°	380	Concave	1.4	Toppling on J2	The lower stack of this modelled section falls within the 4L domain and the upper stacks are within the 4U domain. The pit slope was modeled at an IRA of 45°. The interpreted failure mode is toppling on J2. J1 was not included in this section and likely won't be an issue in the south due to it dipping into the slope so a 3-D analysis will not be necessary. This sector was not optimized over the kinematic recommended angle of 45°.	J6 was not included in this model as a basal plane for toppling. It will be important to insure that the set does not daylight in this section to allow for toppling otherwise a shallower angle will be required for the lower stack.
D-D'	Confirm design constraints with talc present in the final wall Model Slope Azimuth: 025°	South wall (Domain 4U & 4L)	Joints: J2: 65°/180° Faults: F05NEb: 74°/165° F05NEc: 74°/165° F05NEd: 74°/165°	Upper Plate: 45° Lower Plate: 40°	295	Constant Azimuth (Linear)	1.3	Toppling over J2 on top of the talc intersection	The lower stack of this modelled section falls within the 4L domain and the upper stacks are within the 4U domain. The pit slope was modeled at an IRA of 45° in the Upper Plate and 40° in the Lower Plate. The interpreted failure mode is toppling on J2 and along the talc intersection in the pit wall. J1 was not included in this section and likely won't be an issue in the south due to it dipping into the slope so a 3-D analysis will not be necessary.	Slopes that have partial sections of talc in the final wall can cause instability risk.

Kinematics – Plane Failure



Undercutting planes can lead to extensive instability

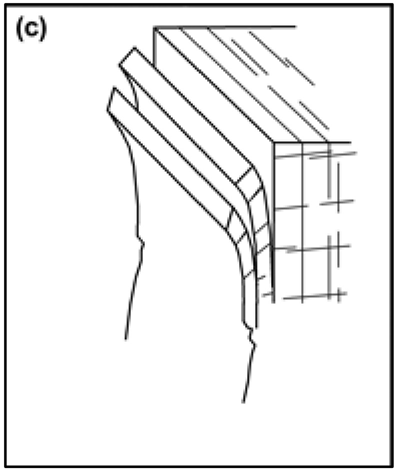


Kinematic overlay for planar sliding

http://www.rocscience.com/products/1/Dips

Kinematics – Toppling Failure

Figure 10.8: Bench scale block toppling on joints in granodiorite



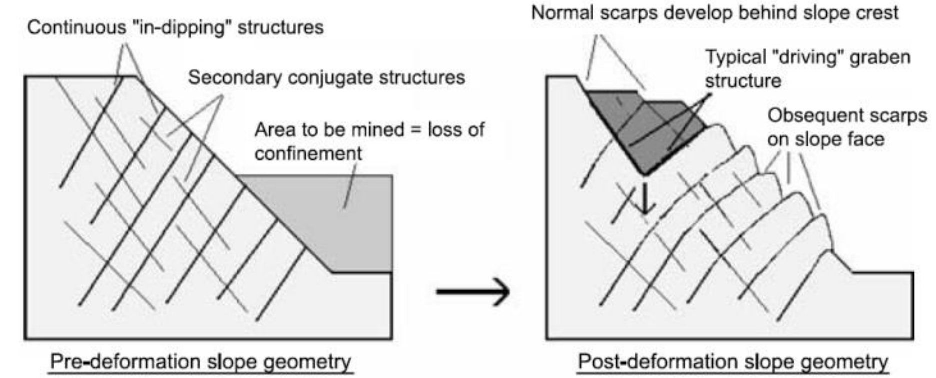
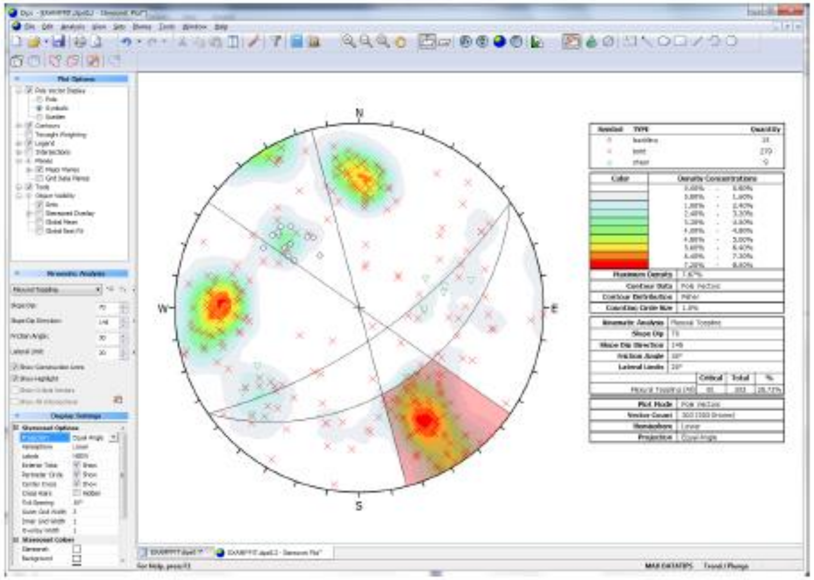


Fig. 3. The conceptual large scale toppling failure mechanism at HVC (from Tosney et al. [8]).

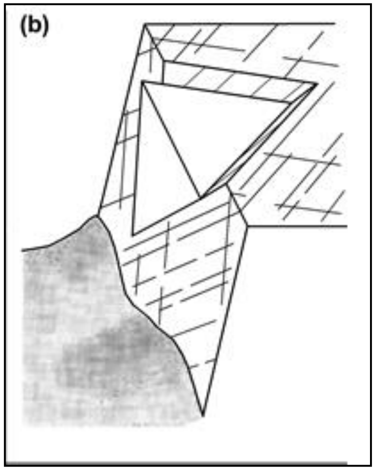
Tosney, J.R., Chance, A.V., Milne, D. and Amon, F.: A Modelling Approach for Large Scale Slope Instability at Highland Valley Copper. In: CIM Mining Millennium Conference Proceedings, Toronto, 2000.

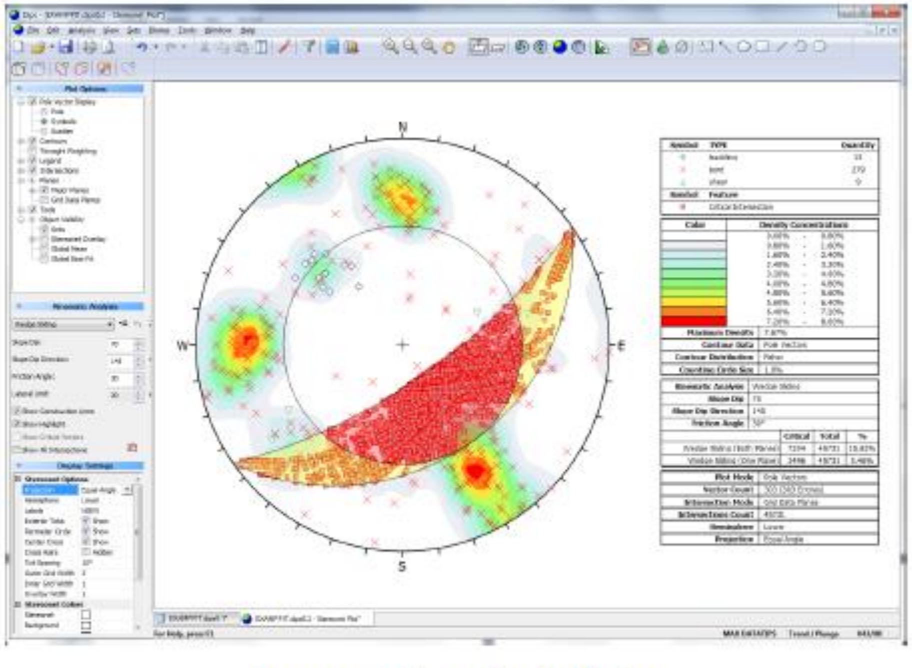


Kinematic Analysis of flexural toppling

http://www.rocscience.com/products/1/Dips

Kinematics – Wedge Failures





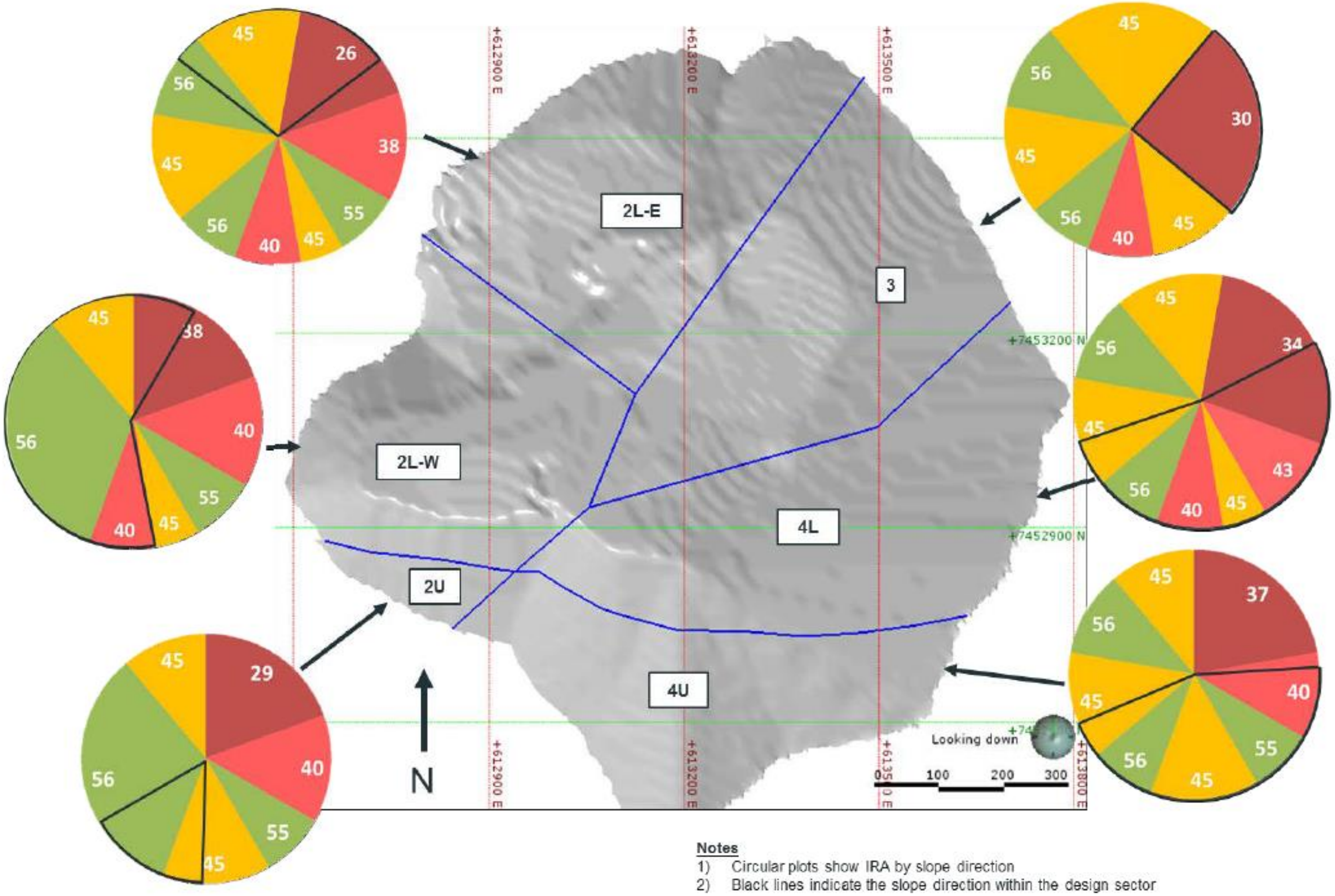
Kinematic Analysis of wedge sliding

http://www.rocscience.com/products/1/Dips

Kinematics – Summary

Domain	Slope Direction	Bench Risks	IRA Mitigated Risks			Design				Limitation
			Toppling	Planar	Wedge	IRA (°)	Effective BFA (°)	Bench Height (m)	Bench Width (m)	
2L-E	330 - 350	Low	J2 Mod	J3a Mod	Low	45	65	15	8.0	J2 Toppling
	350 - 020	Low	J2 High	J3a Mod	Low	40	65	15	11.0	J2 Toppling with J6 basal plane
	020 - 050	Low	Low	Low	Low	56	80	15	7.5	N/A
	050 - 100	Low	J4a Mod	Low	Low	45	65	15	8.0	J4a Toppling
	100 - 140	Low	Low	Low	Low	56	80	15	7.5	N/A
	140 - 190	Low	J3b Mod	Low	Low	45	65	15	12.5	J3b Toppling
	190 - 250	High	J4b Mod	J1 High	J1/NE Mod	26	27	60	8.0	J1 Planar
	250 - 300	Low	Low	Low	J1/NE High	38	80	15	16.5	J1/NE-Fault Wedge
	300 - 330	Low	Low	J3a Mod	Low	55	80	15	8.0	J3a Planar

Slope Design – Kinematic and Rock Mass



Notes
1) Circular plots show IRA by slope direction
2) Black lines indicate the slope direction within the design sector

Who should go into Rock Mechanics?

- Strong background in science and math
- An interest in simplifying complex environments
- People who like to travel around the world and be in helicopters
- People who enjoy being outside
- An interest in rocks

Questions?