Space Resources Round Table - 2024
Session 3: Resource Prospecting and Exploration

Commercial Exploration, Extraction, and Reporting of Lunar Resources (LORS-101)

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ispace Europe
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ispace

Agenda

1. ispace's Vision
2. ispace's M2 - Space Resources Contract
3. Market Demand Driving Resources Exploration
4. Resource Modelling for Hydrogen
5. Exploration planning
6. Reserves?
7. LORS Reporting Example and Next Steps

ispace's Vision

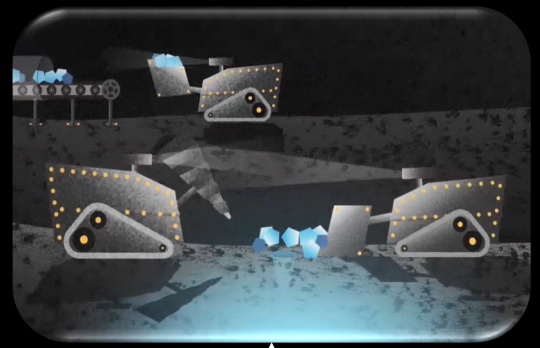
Expand our Planet Expand our Future

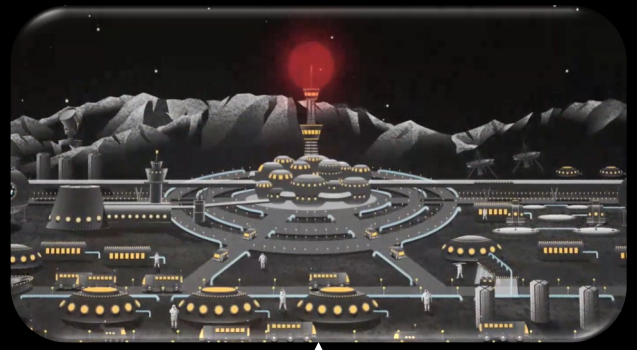
10 Year Milestone
Pioneer of Water Ice Resources
(~2030)

→

Sustainable Cislunar Economy | ISRU Based

(~2040)





ISRU

3 Pillar Strategy to Achieve Vision

Exploration (Rovers)
- Data Acquisition Serv.
  - Rovers
  - Orbiters
  - Instruments, etc.

Partnerships
- Tech & Commercial
- Consortiums

Transportation (Landers)

M1 – Setting the path

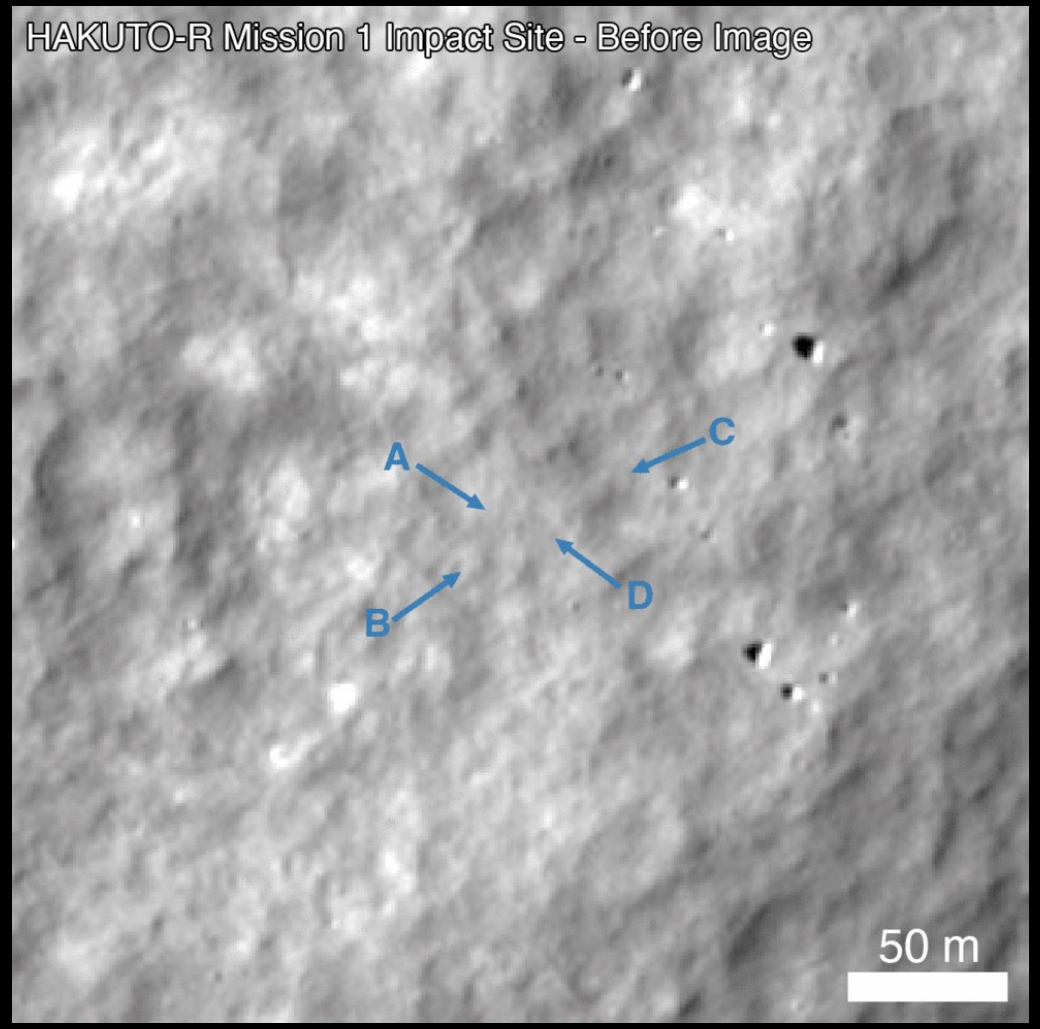
M1 Mission – Starting Lunar Commercial Transportation

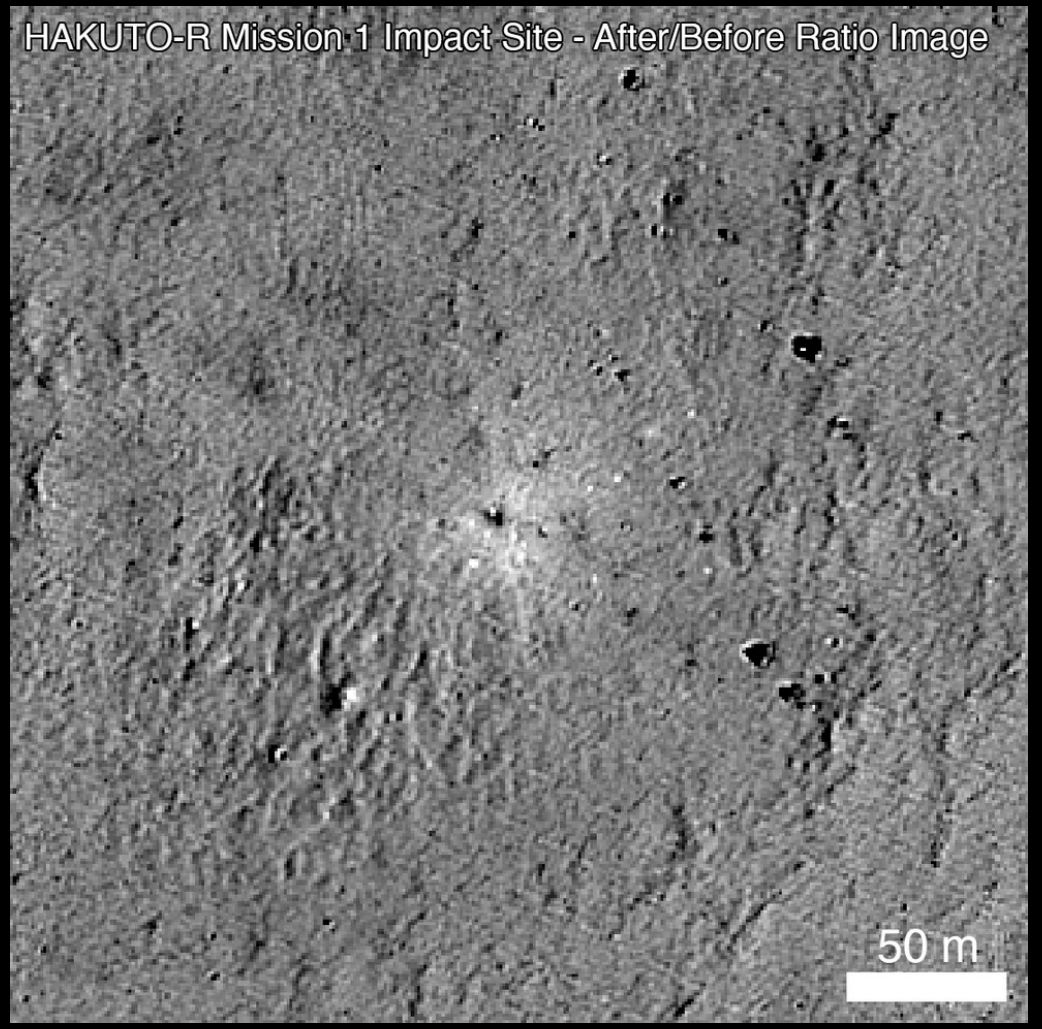
Attempted Landing: Tuesday 25th of April 2023

HAKUTO-R

ispace

NASA's LRO Views Impact Site of HAKUTO-R Mission 1 Moon Lander 2023





(NASA, 2023)

ispace

Many Milestones Achieved:

One of the First Commercial Companies to Reach the Moon.

M2 Mission

Kick starting Commercial Resource Extraction/Exploration

RESILIENCE

Lander: Series 1

M2 Update

1. Resilience and payloads are under integration (on schedule).
2. Launching Q4 2024 – Falcon9
3. Navigating ~4 months in Space
4. Landing Q2 2025

M2 Objectives

1. Prove ispace's **Landing capabilities**
2. Deploy/operate ispace's Micro rover, one of the first **commercial Rovers** on the Lunar surface.
3. Execute one of the first **Space resources contracts** in History (NASA regolith contracts).
4. Prove **resource exploration capabilities** (sample collection).
5. Deploy other commercial payloads as **Takasago's Electrolysis experiment**.


M2 Mission
Q2-2025
ispace
HAKUTO-R

M2 Commercial Partner (Mining Industry)

First Long-Term Partnership with Mining Equipment Company

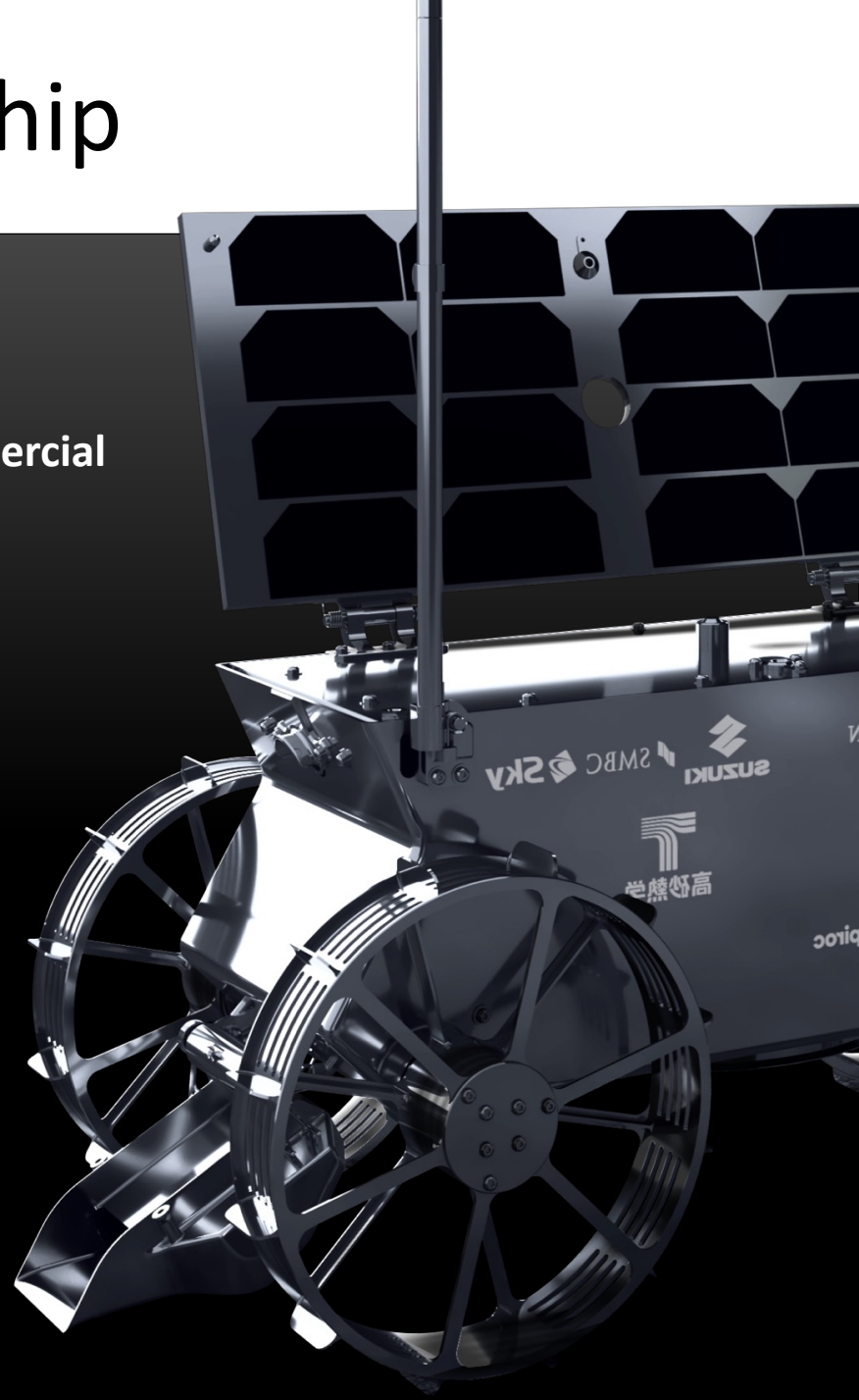
ispace and Epiroc | Strategic Partnership

1. Long Term Collaboration Agreement (LTCA)

Collaboration on **Lunar activities / missions**. To **develop technology** and **commercial solutions** in the field **of space resources (Exploration, Extraction, etc.)**.

Detailed Agreements

- **DA-1 | HAKUTO-R Corporate Partner**
- **DA-2 | Supply Agreement for “Regolith Collection System” or “Scoop”**



Epiroc

ispace

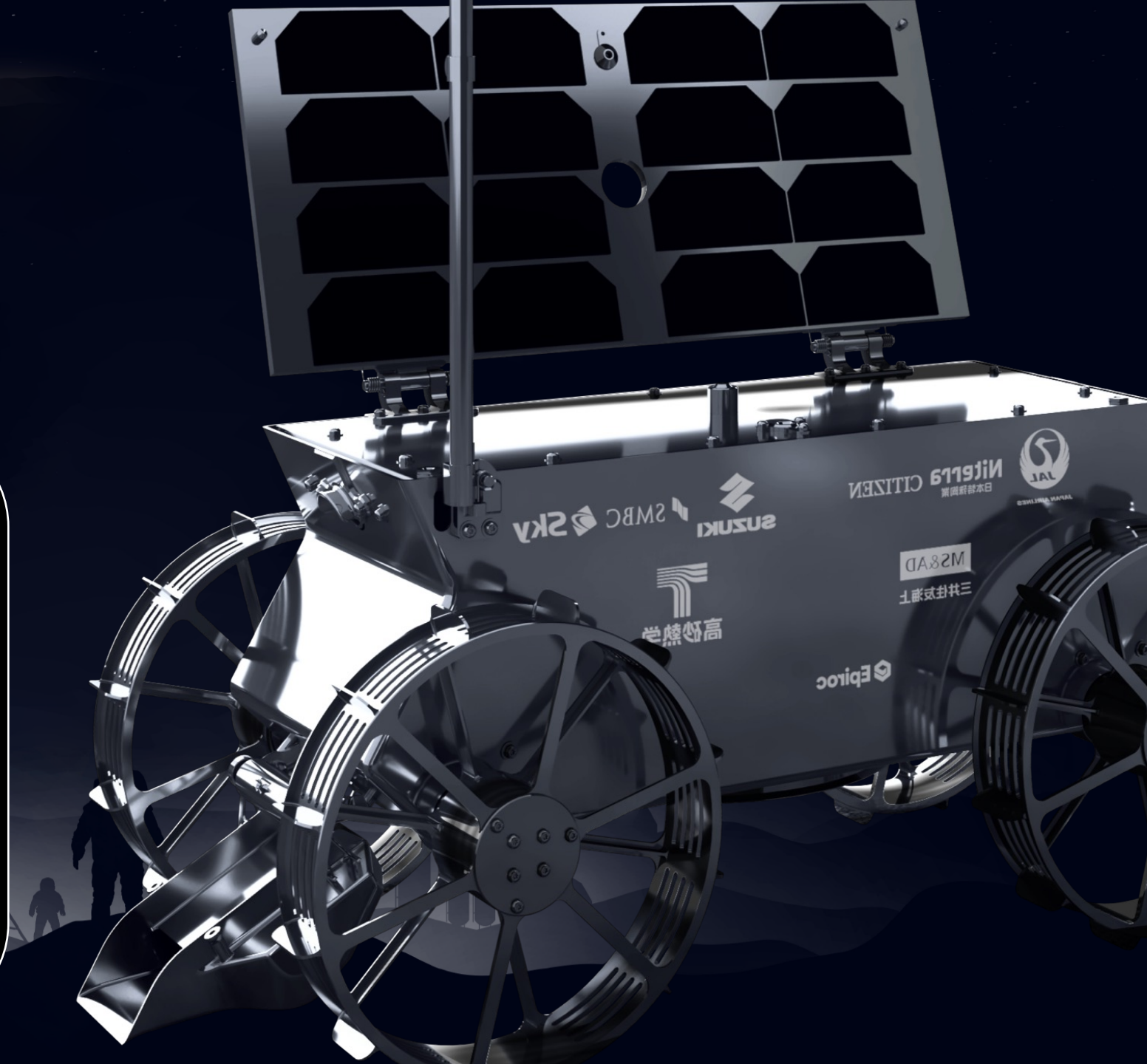
One of the leading Mining Equipment manufacturers in the world

Extraction Sampling Rover

Regolith Transaction Contract (50g)

- Legal Demonstration
- Commercial Demonstration
- Technology Demonstration

ispace Epiroc



ispace Epiroc

Market Demand will Drive Resources Exploration

Propellant and Construction

ispace | Market Demand| Markets Identification

Lunar Markets

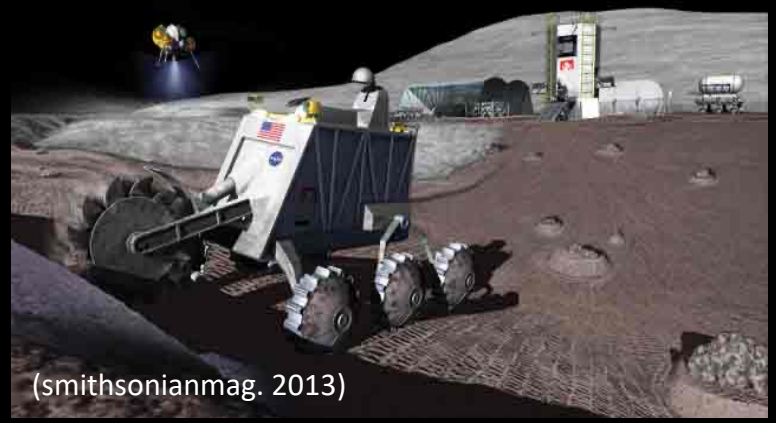
Lunar Construction and Infrastructure


(newcivilengineer.com, 2022)

Needs

- **Identification of regolith (Exploration)**
- **Extraction of Regolith.**
- **Transportation of Regolith.**
- **Selling of Specific Regolith.**

Propellant


(smithsonianmag. 2013)

Needs

- **Identification of H,O Resources (Exploration)**
- **Extraction of Resources**
- **Transportation of Material**
- **Propellant Sales.**

D

Scenario 3, Assumptions S3

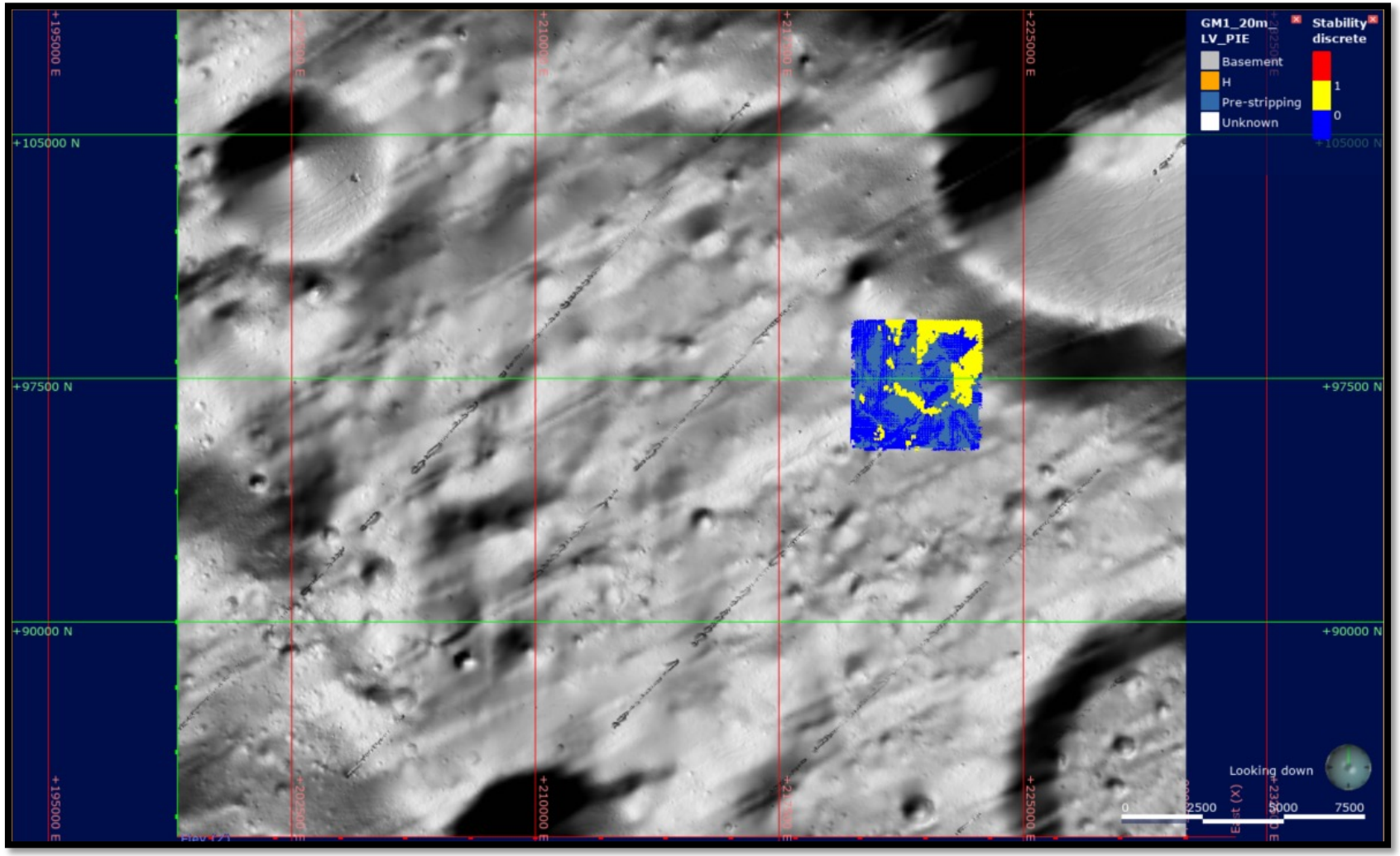
Demand – 26,000 tonnes of Propellant (H,O)

Supply - 10,382,602 tonnes (Resource Deposit Size)

Resource Modelling for Hydrogen

Supply Estimation and Exploration Planning

Resource Block Model – Hydrogen (Permafrost)



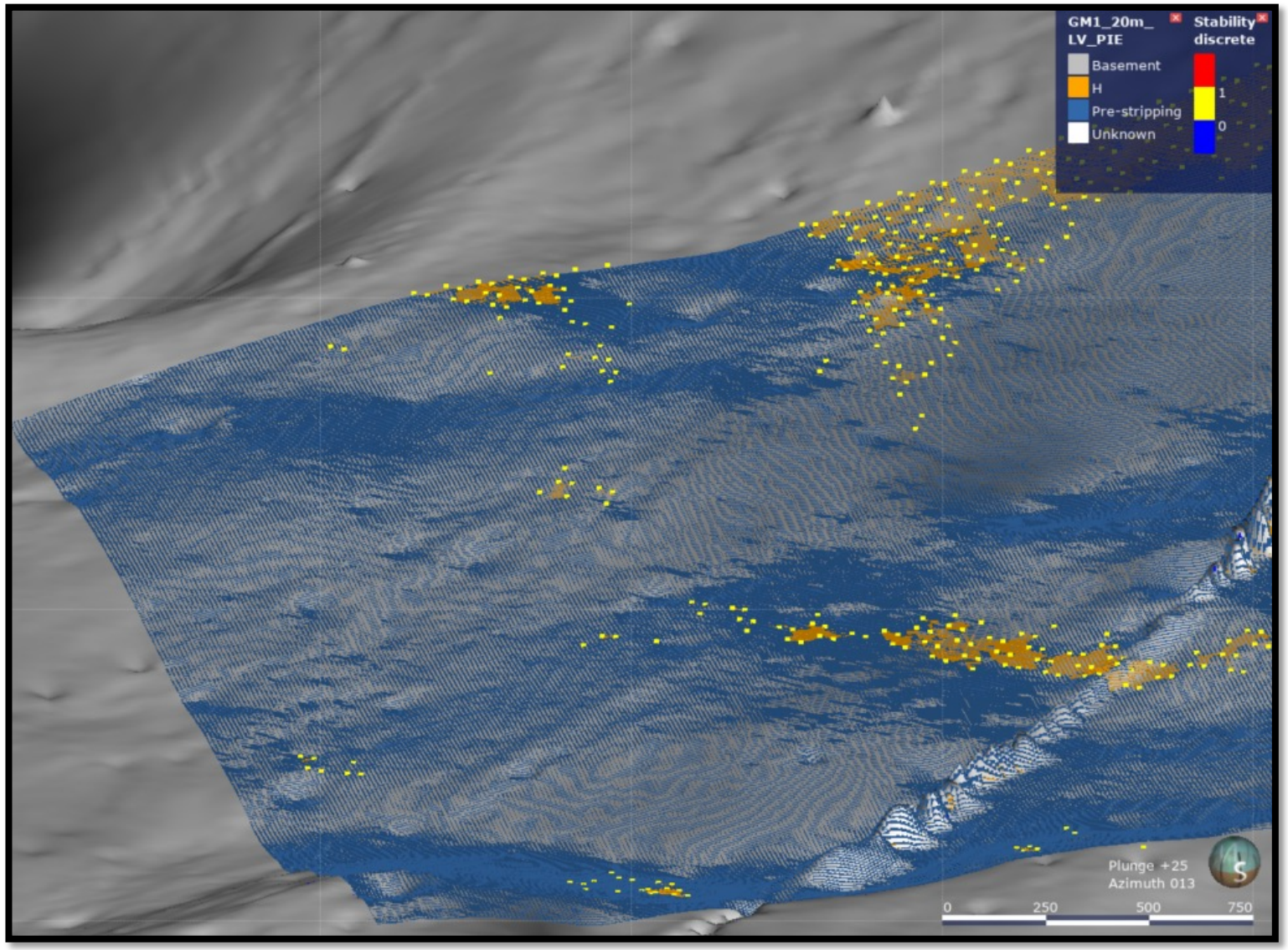
Input Data:

- High resolution DEM – LRO
  - DEM 80s_20m
- Paige Thermal Model
  - Shapefile Thermal Model
  - Hydrogen Anomalies
- USGS Geological Model

Coordinates: lat -82.04 long 66.36

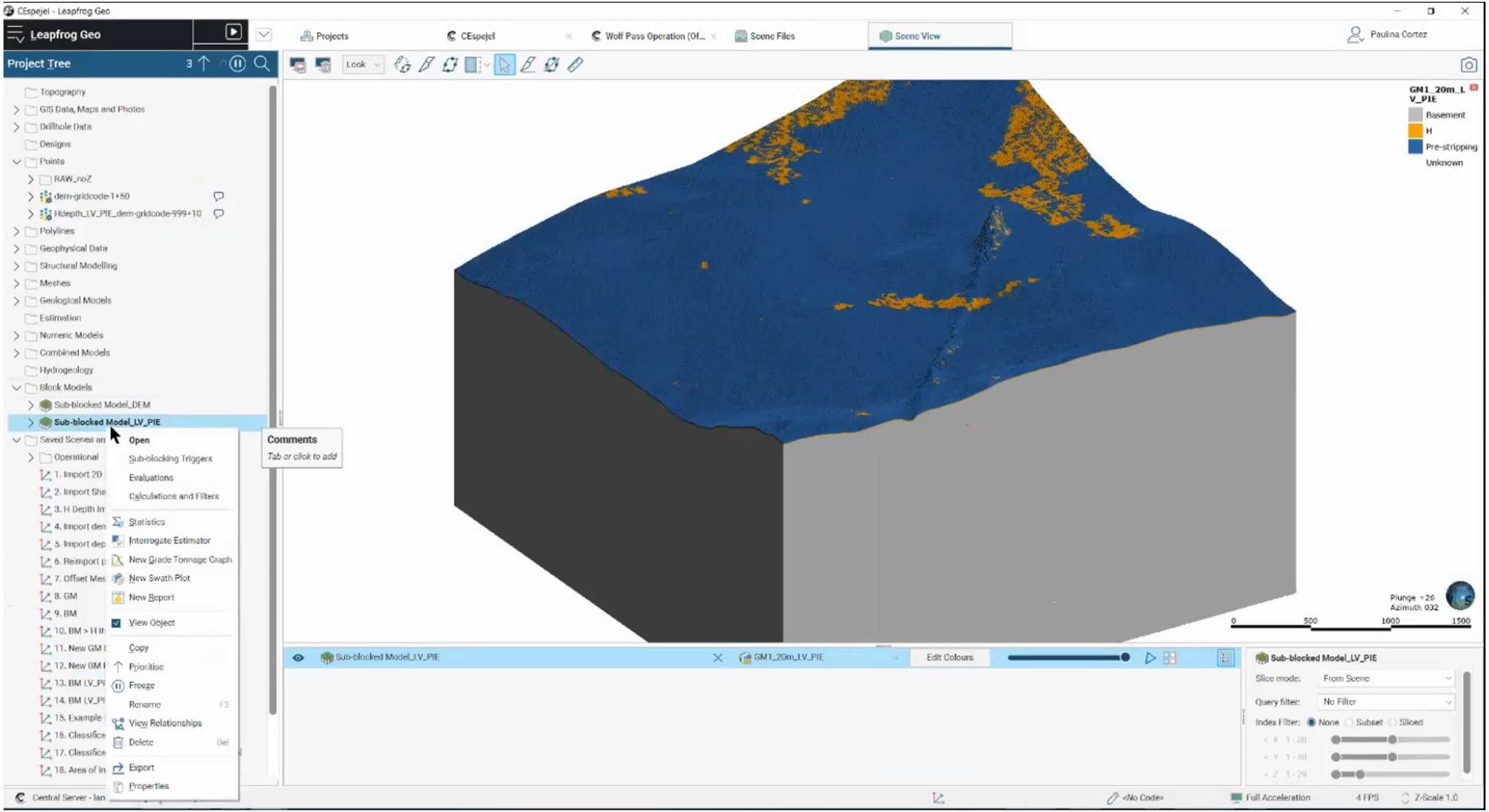
Coordinate System: Moon2000

Resource Block Model – Hydrogen (Permafrost)



Surface and **Subsurface** Resource Distribution

- Potential Hydrogen (Permafrost)
- Page Model V.S Interpolation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Geophysical Data
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Meshes
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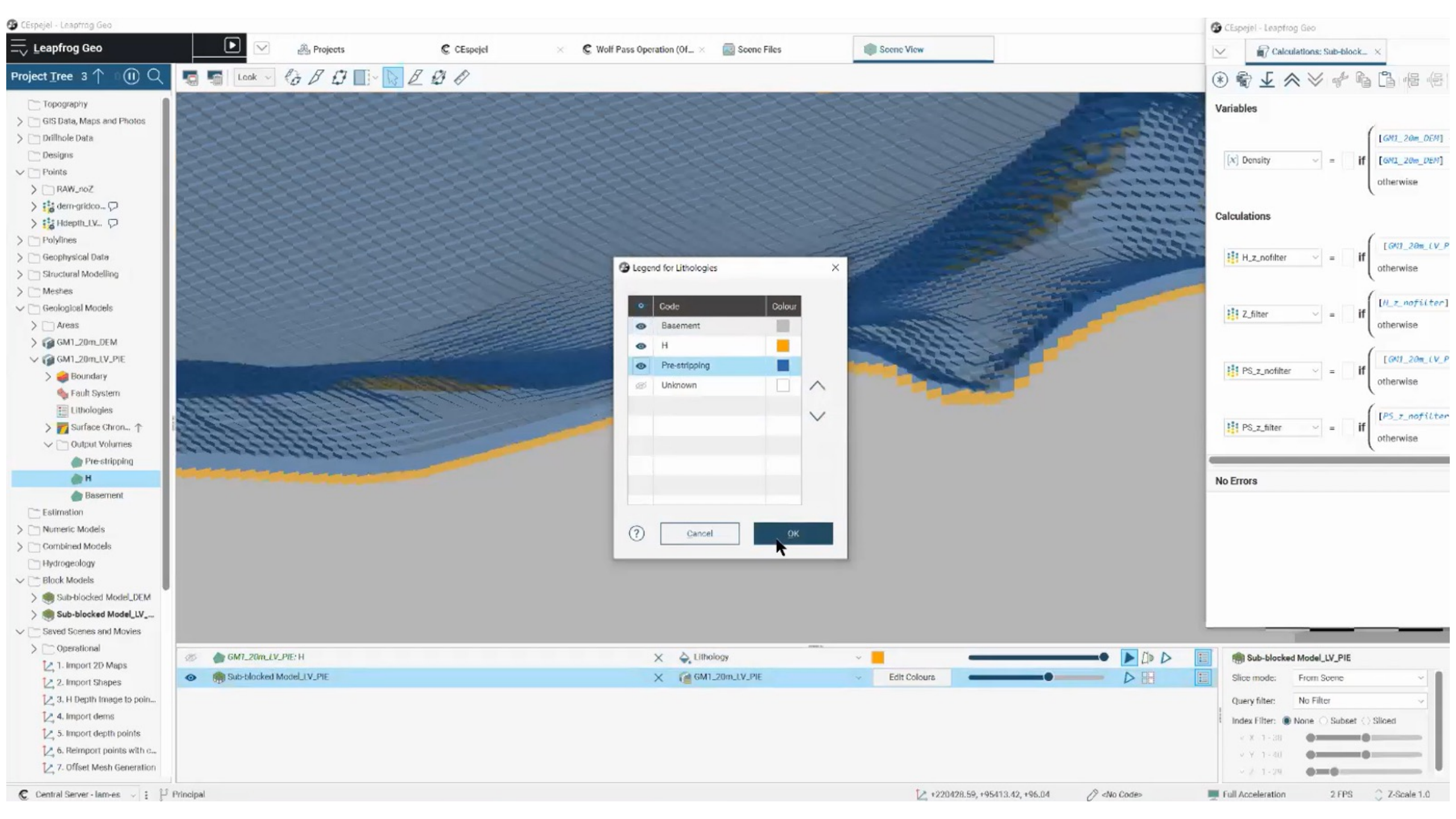
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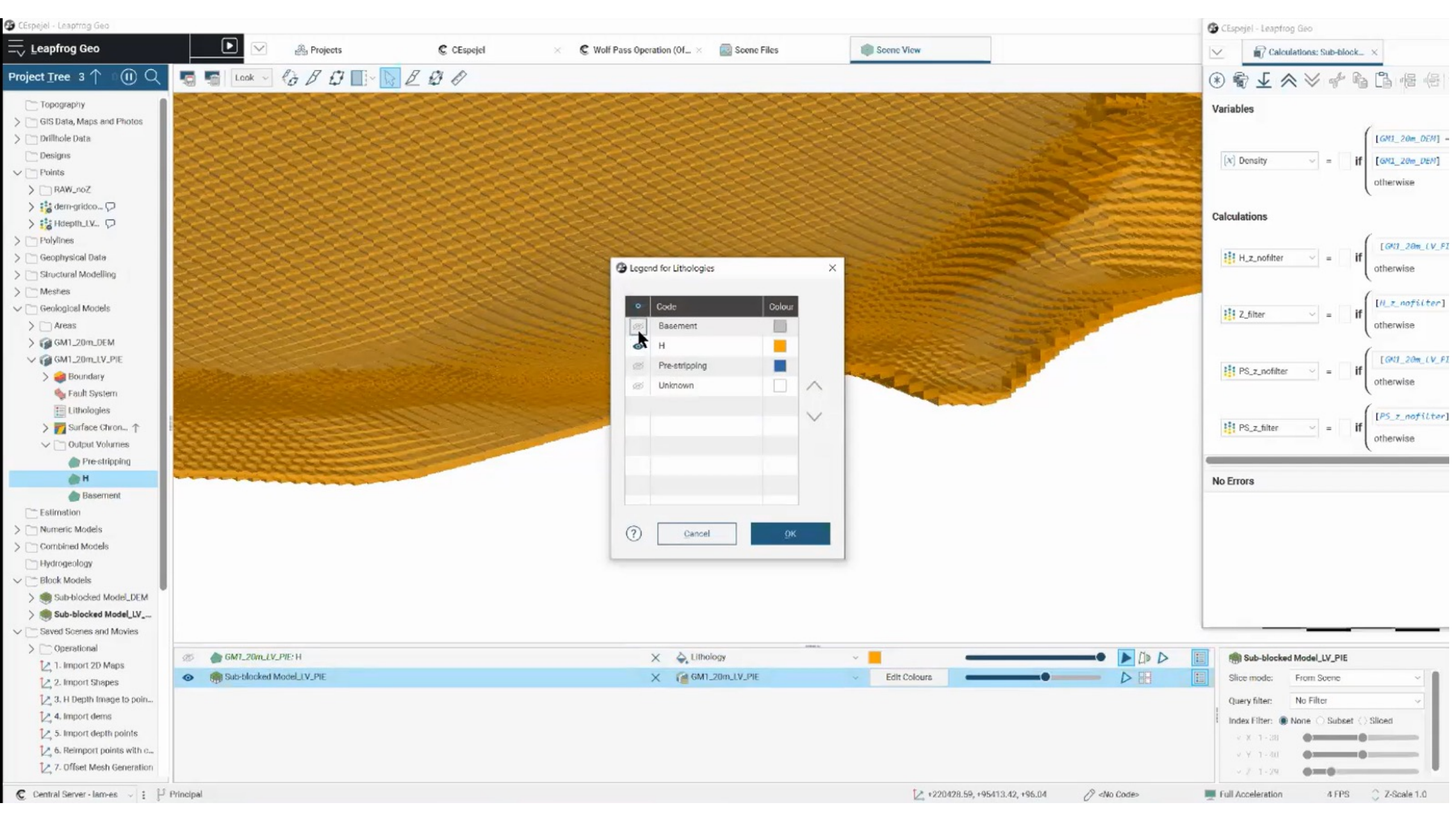
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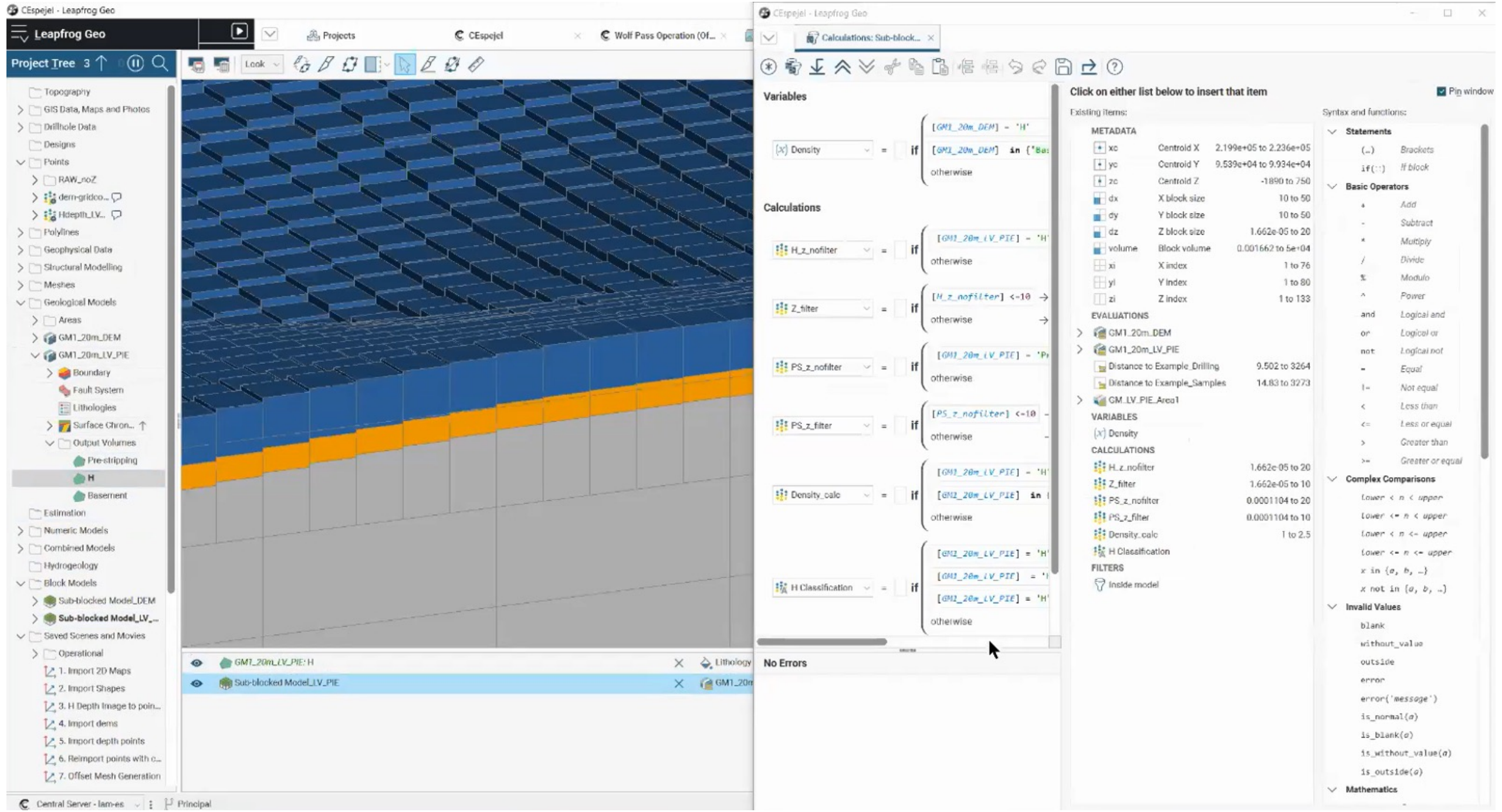
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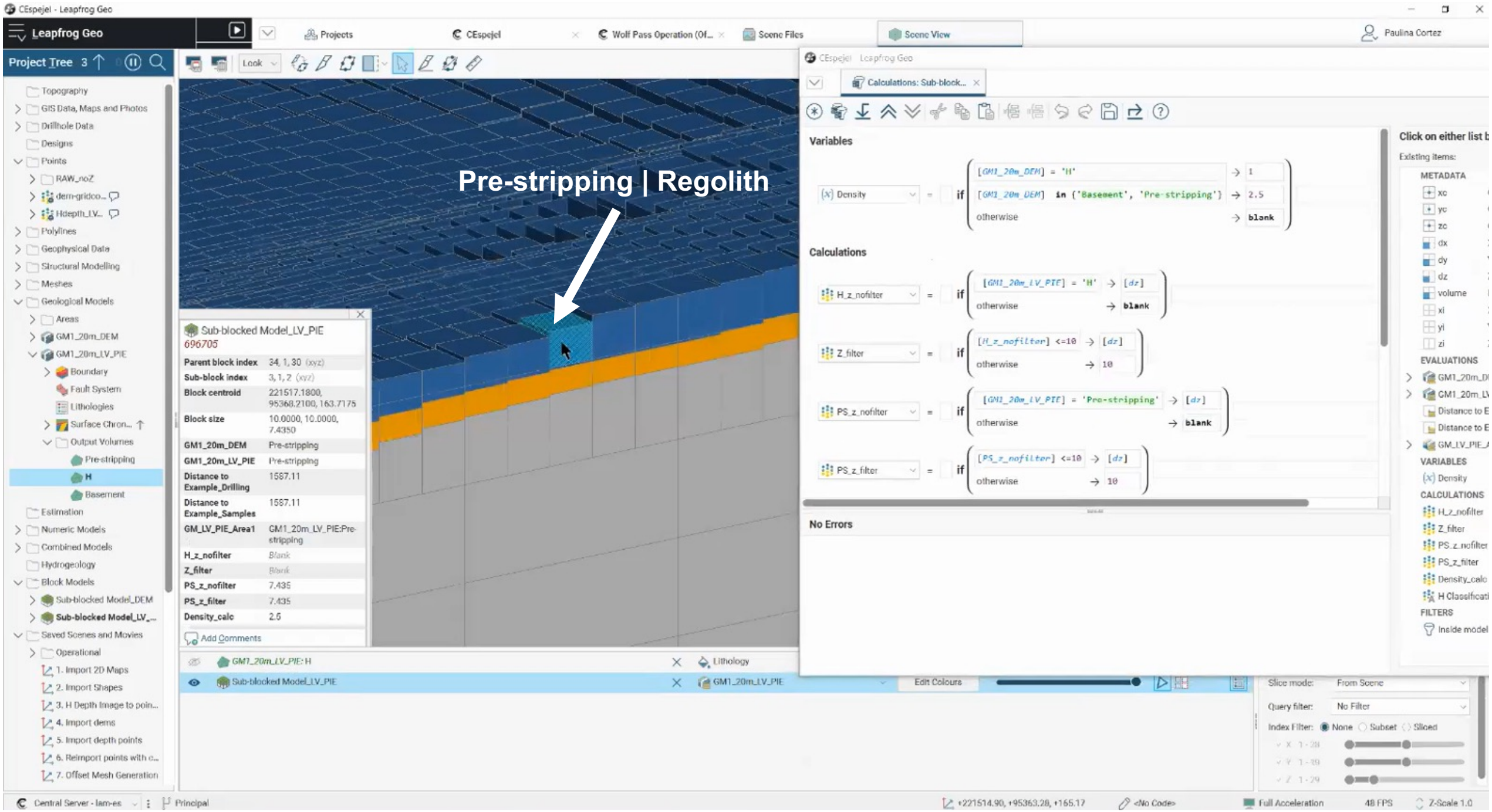
otherwise
Calculations
H_z_nofilter
[GM1_20m_LV_PIE] = 'H'
Z_filter
[H_z_nofilter] <=10
PS_z_nofilter
[GM1_20m_LV_PIE] = 'P
PS_z_filter
[PS_z_nofilter] <=10
Density_calc
[GM1_20m_LV_PIE] = 'H'
[GM1_20m_LV_PIE] in
H Classification
[GM1_20m_LV_PIE] = 'H'
No Errors
Click on either list below to insert that item
Pin window
Existing items:
METADATA
xc Centroid X 2.199e+05 to 2.236e+05
yc Centroid Y 9.539e+04 to 9.934e+04
zc Centroid Z -1890 to 750
dx X block size 10 to 50
dy Y block size 10 to 50
dz Z block size 1.662e-05 to 20
volume Block volume 0.001662 to 5e+04
xi X index 1 to 76
yi Y index 1 to 80
zi Z index 1 to 133
EVALUATIONS
GM1_20m_DEM
GM1_20m_LV_PIE
Distance to Example_Drilling 9.502 to 3264
Distance to Example_Samples 14.83 to 3273
GM_LV_PIE_Area1
VARIABLES
Density
CALCULATIONS
H_z_nofilter 1.662e-05 to 20
Z_filter 1.662e-05 to 10
PS_z_nofilter 0.0001104 to 20
PS_z_filter 0.0001104 to 10
Density_calc 1 to 2.5
H Classification
FILTERS
Inside model
Syntax and functions:
Statements
(...) Brackets
if(::) If block
Basic Operators
+ Add
- Subtract
* Multiply
/ Divide
% Modulo
^ Power
and Logical and
or Logical or
not Logical not
= Equal
!= Not equal
< Less than
<= Less or equal
> Greater than
>= Greater or equal
Complex Comparisons
lower < n < upper
lower <= n < upper
lower < n <= upper
lower <= n <= upper
x in {a, b, ...}
x not in {a, b, ...}
Invalid Values
blank
without_value
outside
error
error('message')
is_normal(a)
is_blank(a)
is_without_value(a)
is_outside(a)
Mathematics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2. Import Shapes
3. H Depth Image to poin...
4. Import dems
5. Import depth points
6. Reimport points with c...
7. Offset Mesh Generation
Pre-stripping | Regolith
Sub-blocked Model_LV_PIE
696705
Parent block index 34, 1, 30 (xyz)
Sub-block index 3, 1, 2 (xyz)
Block centroid 221517.1800, 95368.2100, 163.7175
Block size 10.0000, 10.0000, 7.4350
GM1_20m_DEM Pre-stripping
GM1_20m_LV_PIE Pre-stripping
Distance to Example_Drilling 1587.11
Distance to Example_Samples 1587.11
GM_LV_PIE_Area1 GM1_20m_LV_PIE:Pre-stripping
H_z_nofilter Blank
Z_filter Blank
PS_z_nofilter 7.435
PS_z_filter 7.435
Density_calc 2.6
Add Comments
GM1_20m_LV_PIE: H
Lithology
Sub-blocked Model_LV_PIE
GM1_20m_LV_PIE
Edit Colours
CEspejel Leapfrog Geo
Calculations: Sub-block...
Variables
Density = if [GM1_20m_DEM] = 'H' → 1
[GM1_20m_DEM] in ('Basement', 'Pre-stripping') → 2.5
otherwise → blank
Calculations
H_z_nofilter = if [GM1_20m_LV_PIE] = 'H' → [dz]
otherwise → blank
Z_filter = if [H_z_nofilter] <=10 → [dz]
otherwise → 10
PS_z_nofilter = if [GM1_20m_LV_PIE] = 'Pre-stripping' → [dz]
otherwise → blank
PS_z_filter = if [PS_z_nofilter] <=10 → [dz]
otherwise → 10
No Errors
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Existing items:
METADATA
xc
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EVALUATIONS
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VARIABLES
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Z_filter
PS_z_nofilter
PS_z_filter
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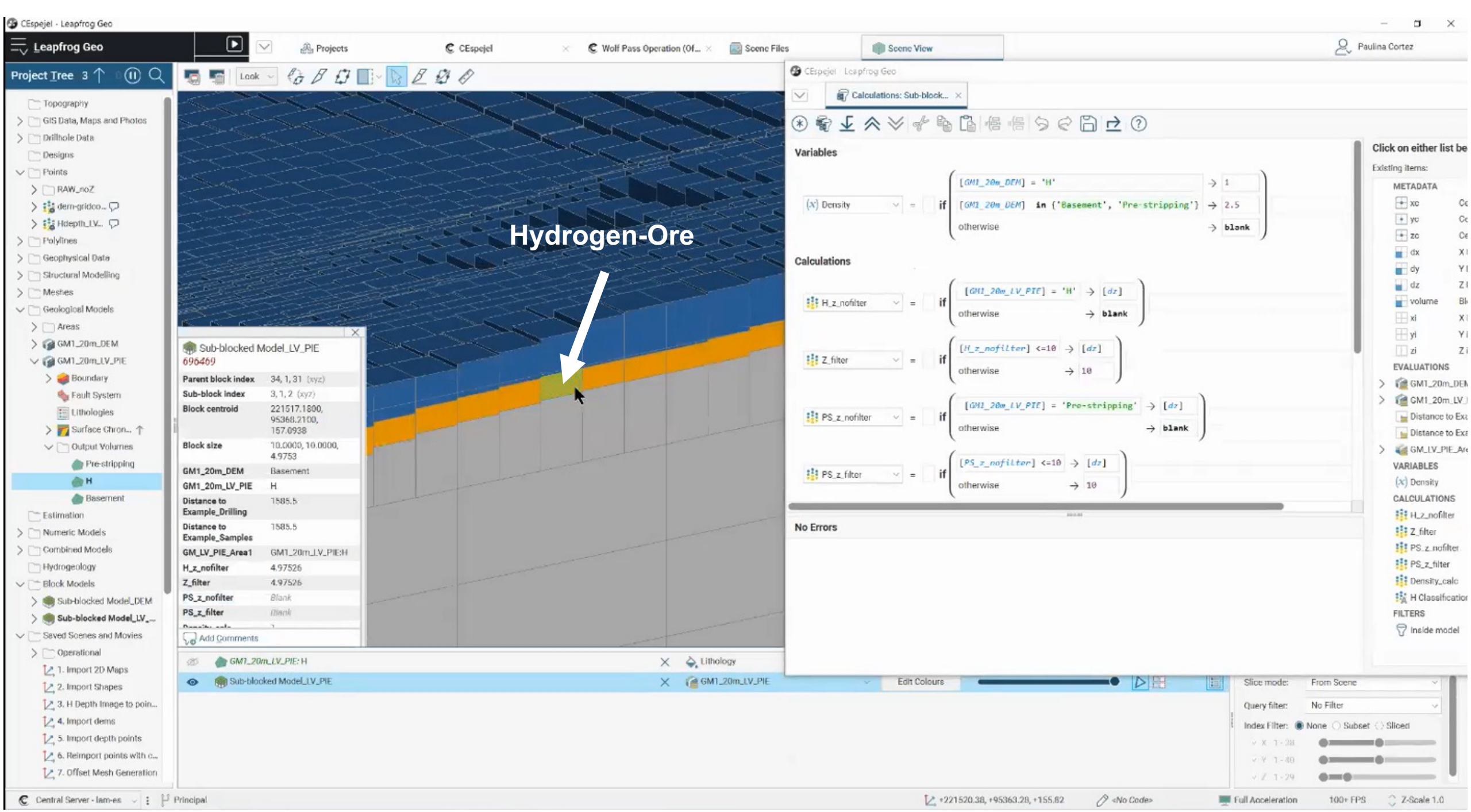
FILTERS
Inside model
Slice mode: From Scene
Query filter: No Filter
Index Filter: None Subset Sliced
Central Server - lam-es
Principal
+221514.90, +95363.28, +165.17
<No Code>
Full Acceleration
48 FPS
Z-Scale 1.0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1. Import 2D Maps
2. Import Shapes
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5. Import depth points
6. Reimport points with c...
7. Offset Mesh Generation
Look
Sub-blocked Model_LV_PIE
696469
Parent block index 34, 1, 31 (xyz)
Sub-block index 3, 1, 2 (xyz)
Block centroid 221517.1800, 95368.2100, 157.0938
Block size 10.0000, 10.0000, 4.9753
GM1_20m_DEM Basement
GM1_20m_LV_PIE H
Distance to Example_Drilling 1585.5
Distance to Example_Samples 1585.5
GM_LV_PIE_Area1 GM1_20m_LV_PIE:H
H_z_nofilter 4.97526
Z_filter 4.97526
PS_z_nofilter Blank
PS_z_filter Blank
Add Comments
GM1_20m_LV_PIE: H
Lithology
Sub-blocked Model_LV_PIE
GM1_20m_LV_PIE
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Paulina Cortez
Calculations: Sub-block...
Variables
Density = if [GM1_20m_DEM] = 'H' → 1
[GM1_20m_DEM] in ('Basement', 'Pre-stripping') → 2.5
otherwise → blank
Calculations
H_z_nofilter = if [GM1_20m_LV_PIE] = 'H' → [dz]
otherwise → blank
Z_filter = if [H_z_nofilter] <=10 → [dz]
otherwise → 10
PS_z_nofilter = if [GM1_20m_LV_PIE] = 'Pre-stripping' → [dz]
otherwise → blank
PS_z_filter = if [PS_z_nofilter] <=10 → [dz]
otherwise → 10
No Errors
Click on either list be
Existing items:
METADATA
xc
yc
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EVALUATIONS
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FILTERS
Inside model
Slice mode: From Scene
Query filter: No Filter
Index Filter: None Subset Sliced
Central Server - lam-es
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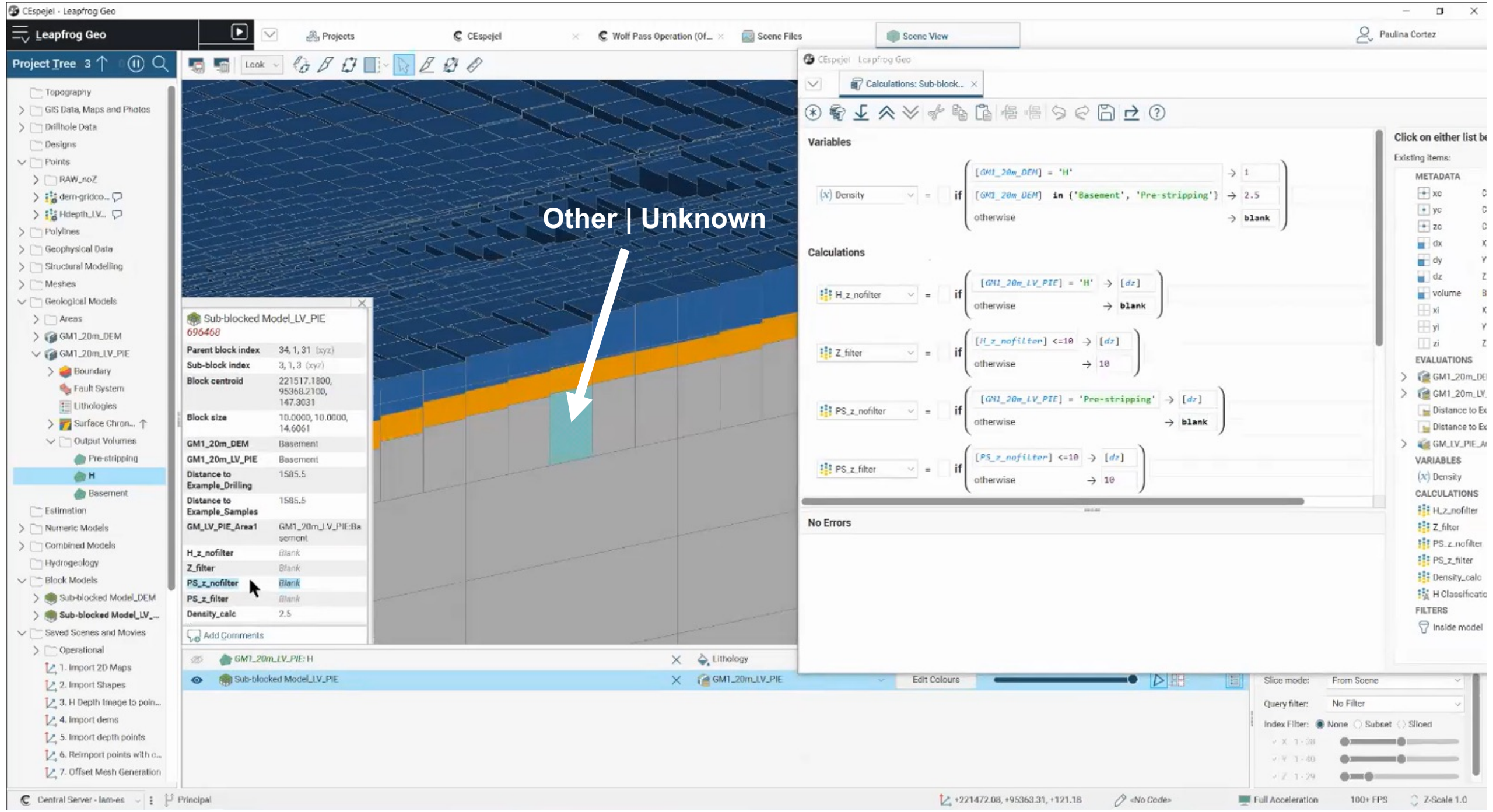
+221520.38, +95363.28, +155.82
<No Code>
Full Acceleration
100+ FPS
Z-Scale 1.0


Other | Unknown
Leapfrog Geo
Project Tree 3
Sub-blocked Model_LV_PIE
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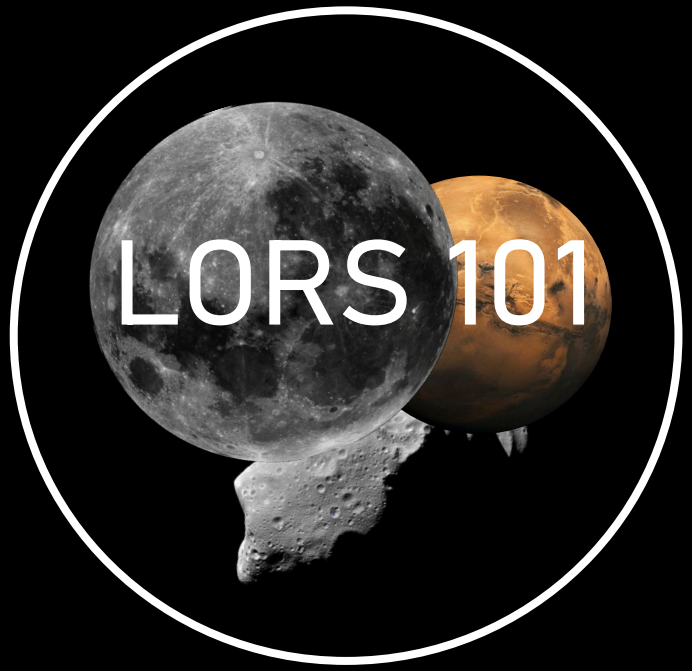
Block size 10.0000, 10.0000, 14.6061
GM1_20m_DEM Basement
GM1_20m_LV_PIE Basement
Distance to Example_Drilling 1585.5
Distance to Example_Samples 1585.5
GM_LV_PIE_Area1 GM1_20m_LV_PIE:Basement
H_z_nofilter Blank
Z_filter Blank
PS_z_nofilter Blank
PS_z_filter Blank
Density_calc 2.5
Variables
Calculations
No Errors

Demand: 10,382,602 tonnes (Deposit Size)

Supply

tonnes (metric)

Resources or Reserves??



Lunar Ore Reserves Standards

Three Classification Systems: **GR-CS1 (Geological), GTX-CS2 (Operational), GTE-CS3 (Commercial)**

LORS Tools: Glossary of Definitions, Guidelines for Reporting, Compliance Recommendations (ESG)

Luxembourg National Research Fund

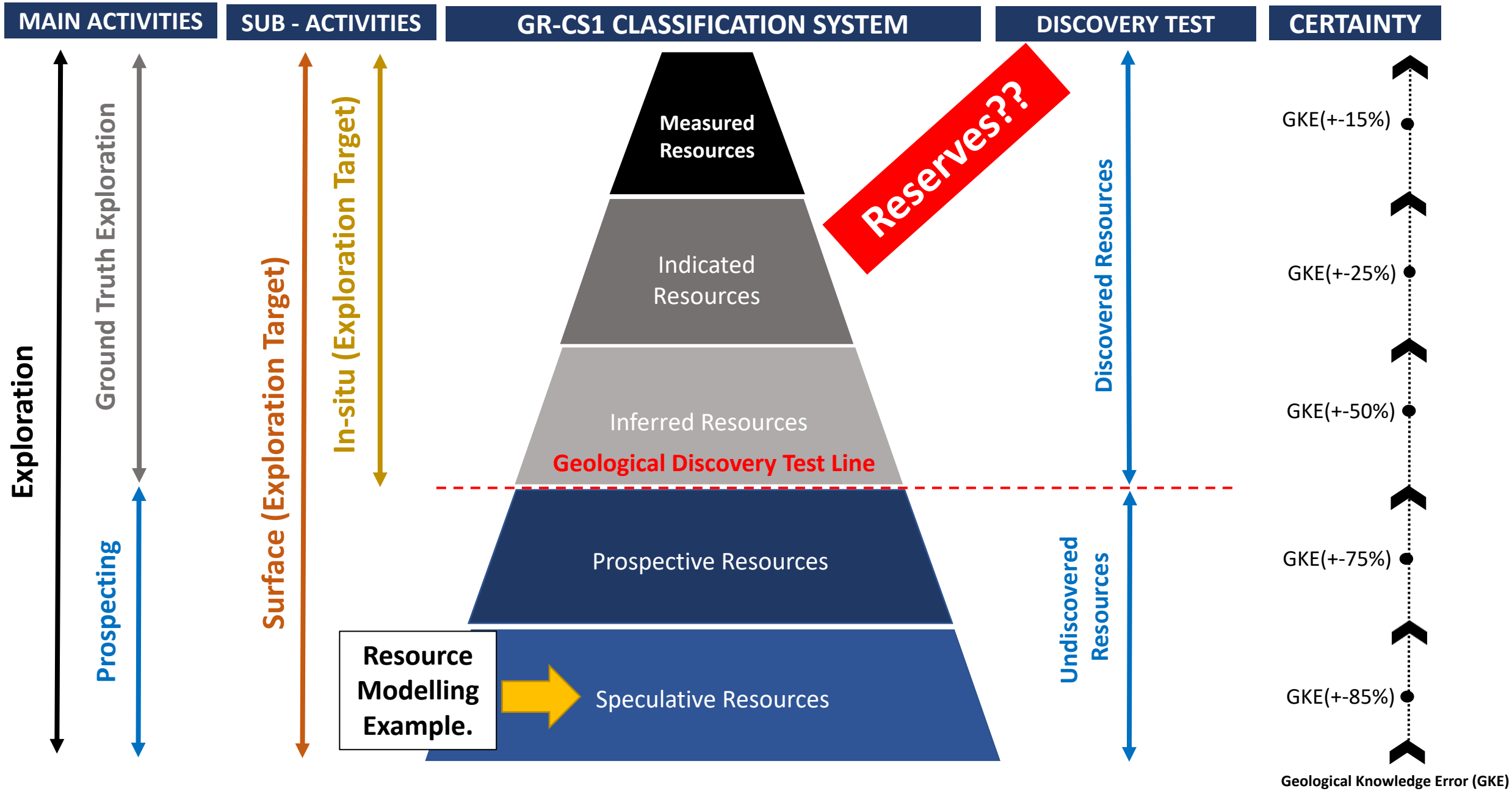
UNIVERSITÉ DU LUXEMBOURG

ispace

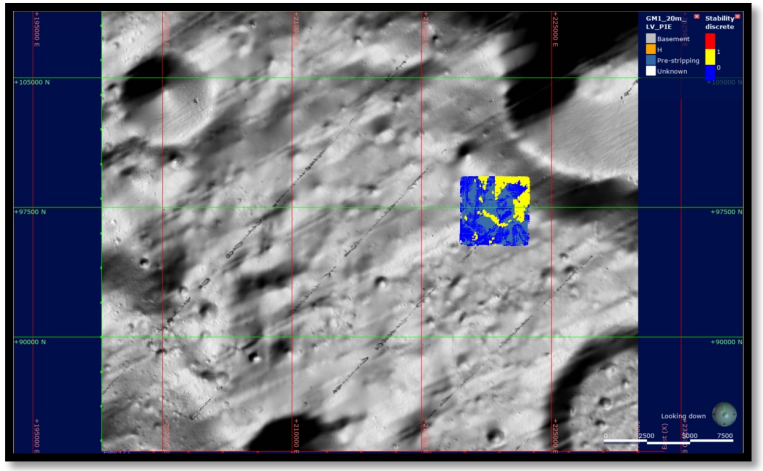
esa European Space Agency

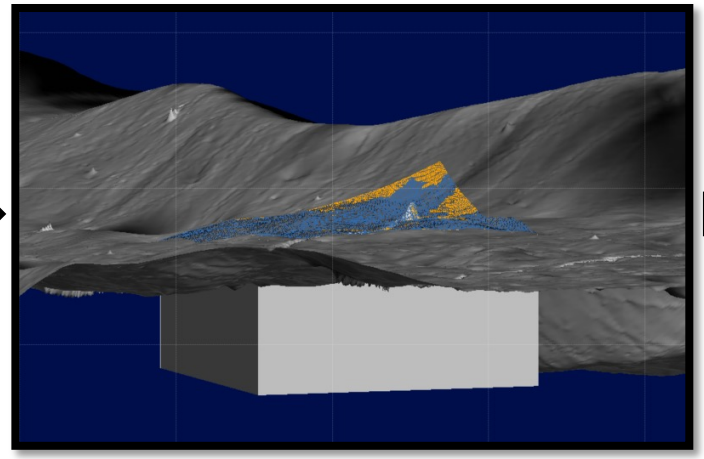
UNSW AUSTRALIA

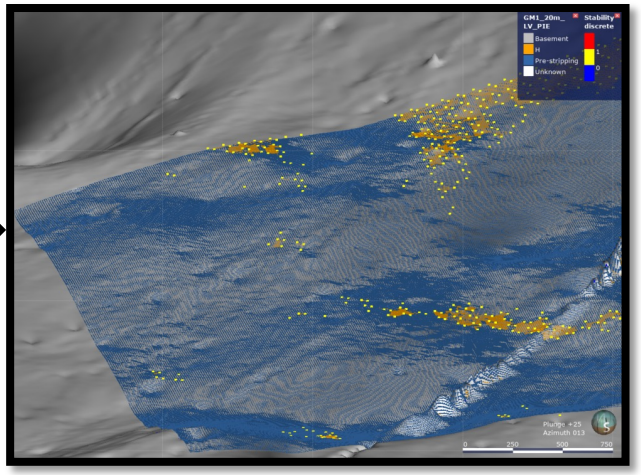
GR-CS1 - Geological Resources (Geological Survey Purposes)

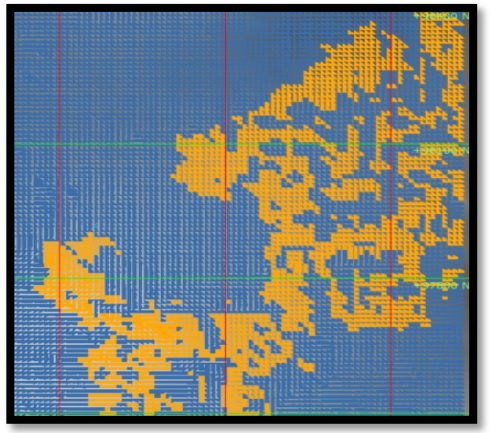


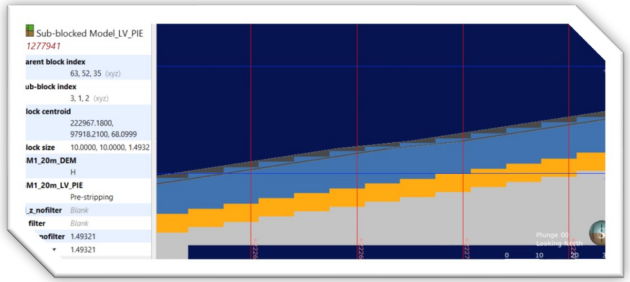
Resource Evaluation Example











LORS Reporting

Classification System Used
- GR-CS1 - Geological Resources

Activity Status
- Exploration
  - Prospecting (Remote Sensing)

Resources Classification
- Speculative Resources
  - Geological Knowledge Error(+- 75%)

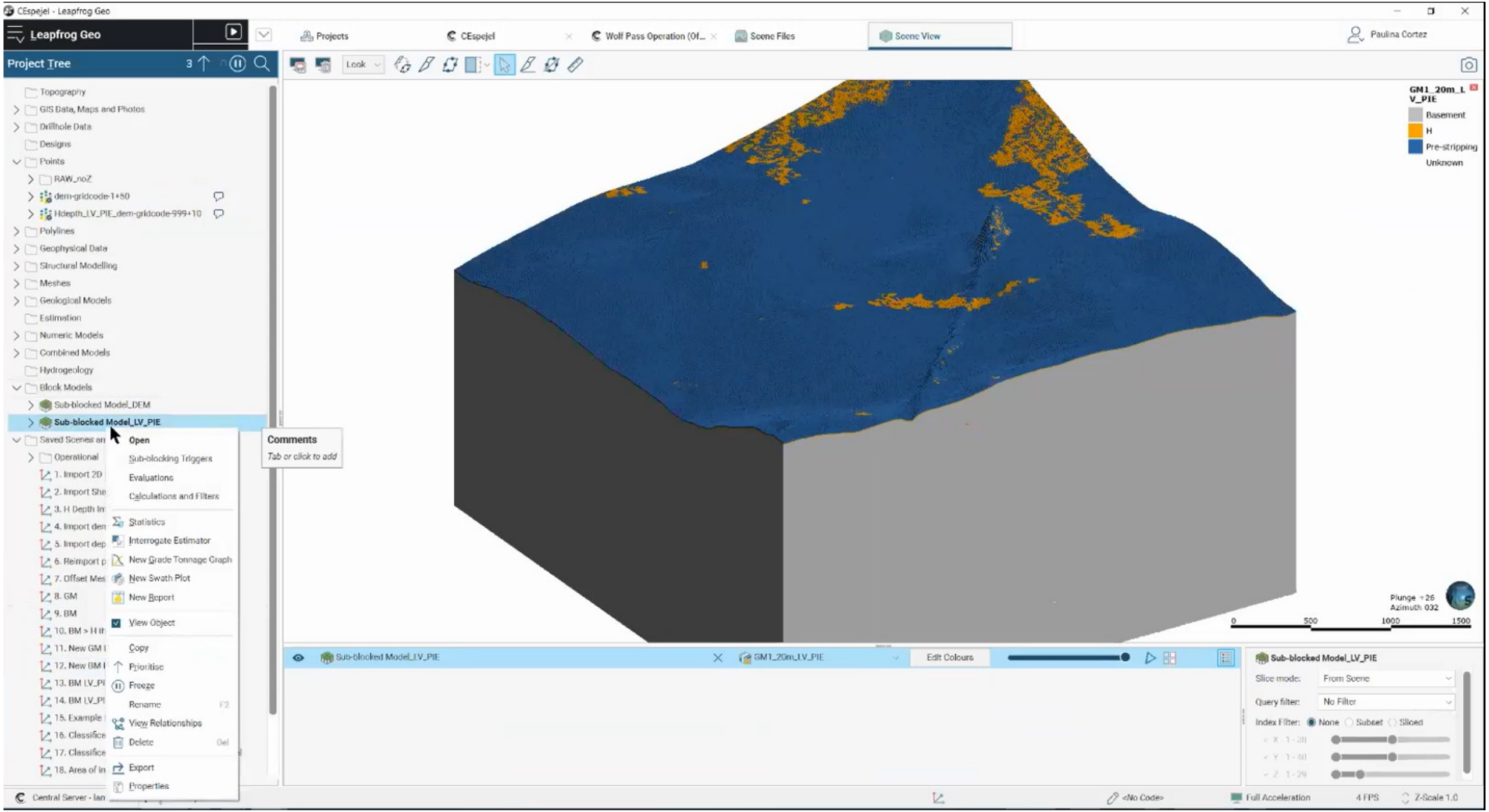
Geological Discovery Test Line
  - Undiscovered Resources. GKE > +-70%

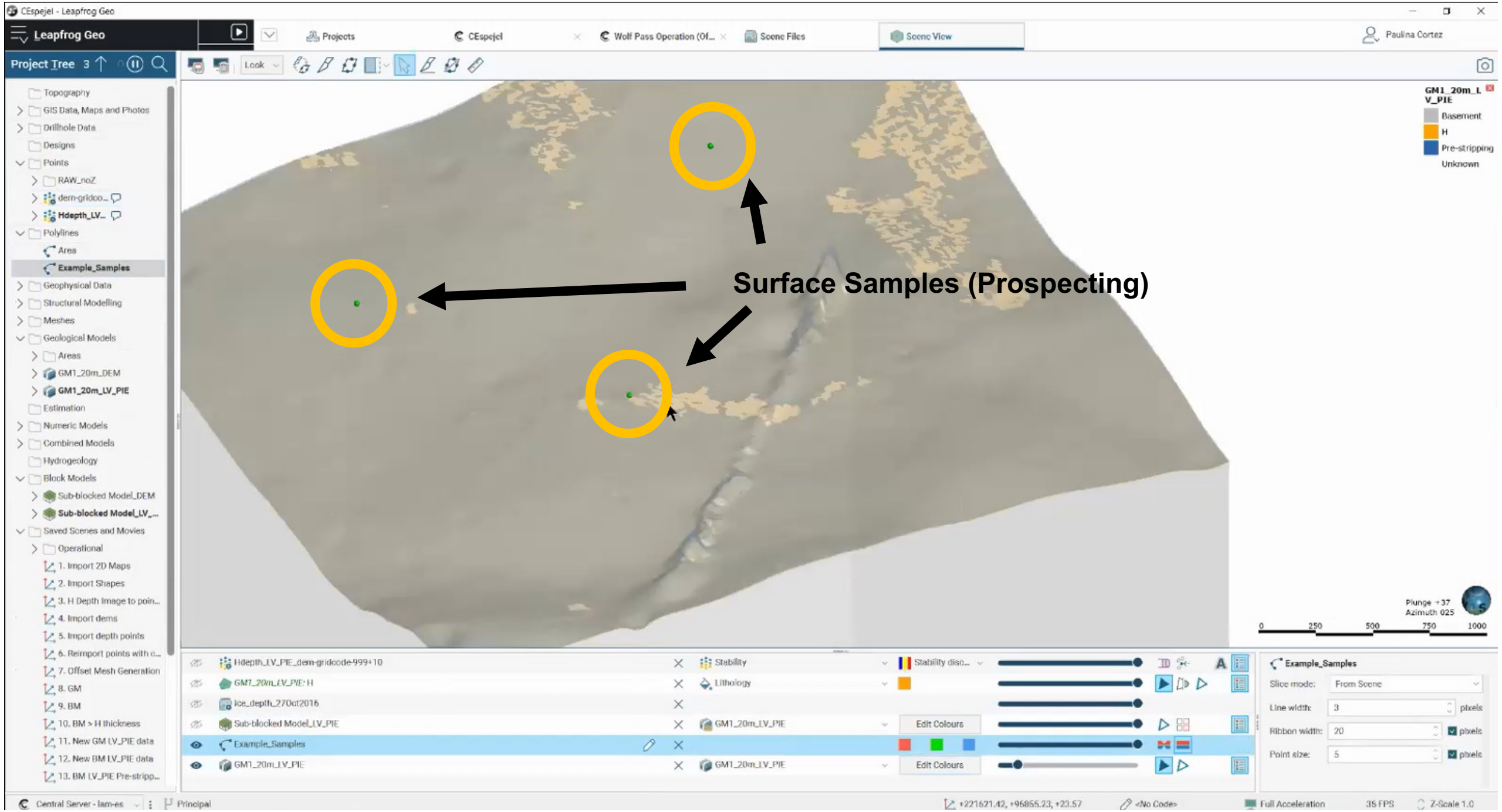
Next Step: Prospecting, and/or Ground Truth Exploration
  - Goal: Speculative Resources → Inferred Resources

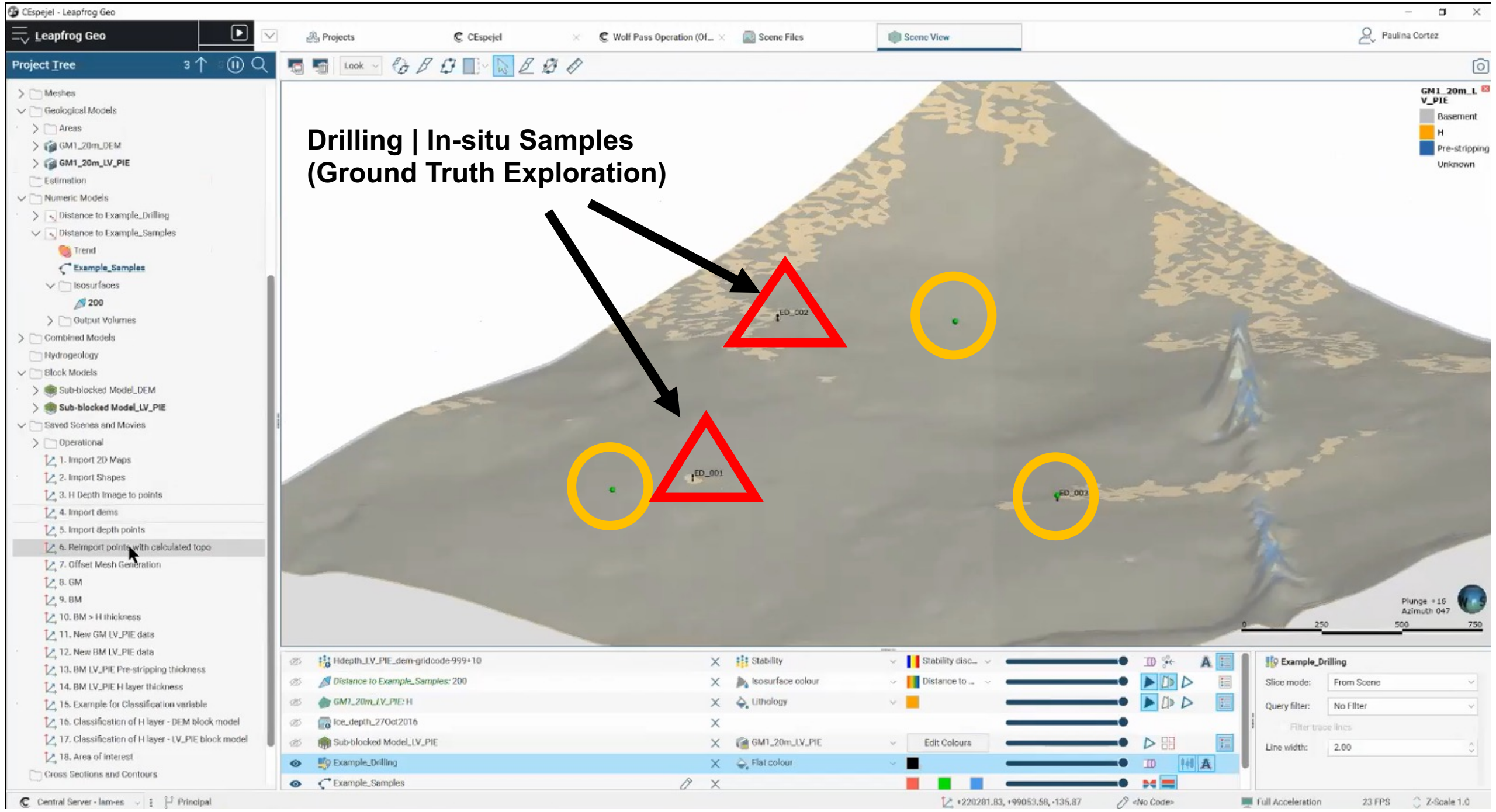
leapfrog
FAST, DYNAMIC GEOLOGICAL MODELLING

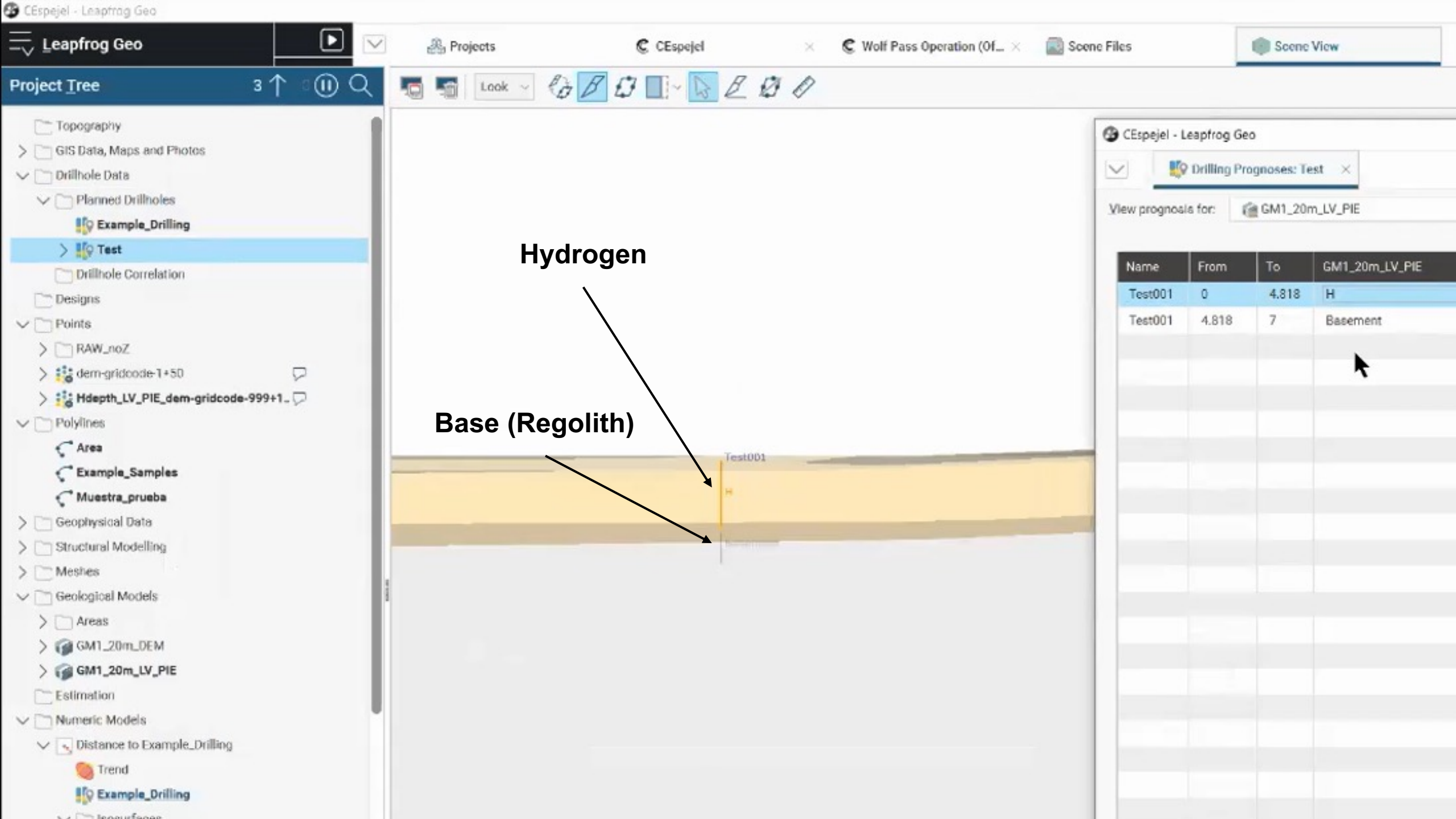
Exploration Planning

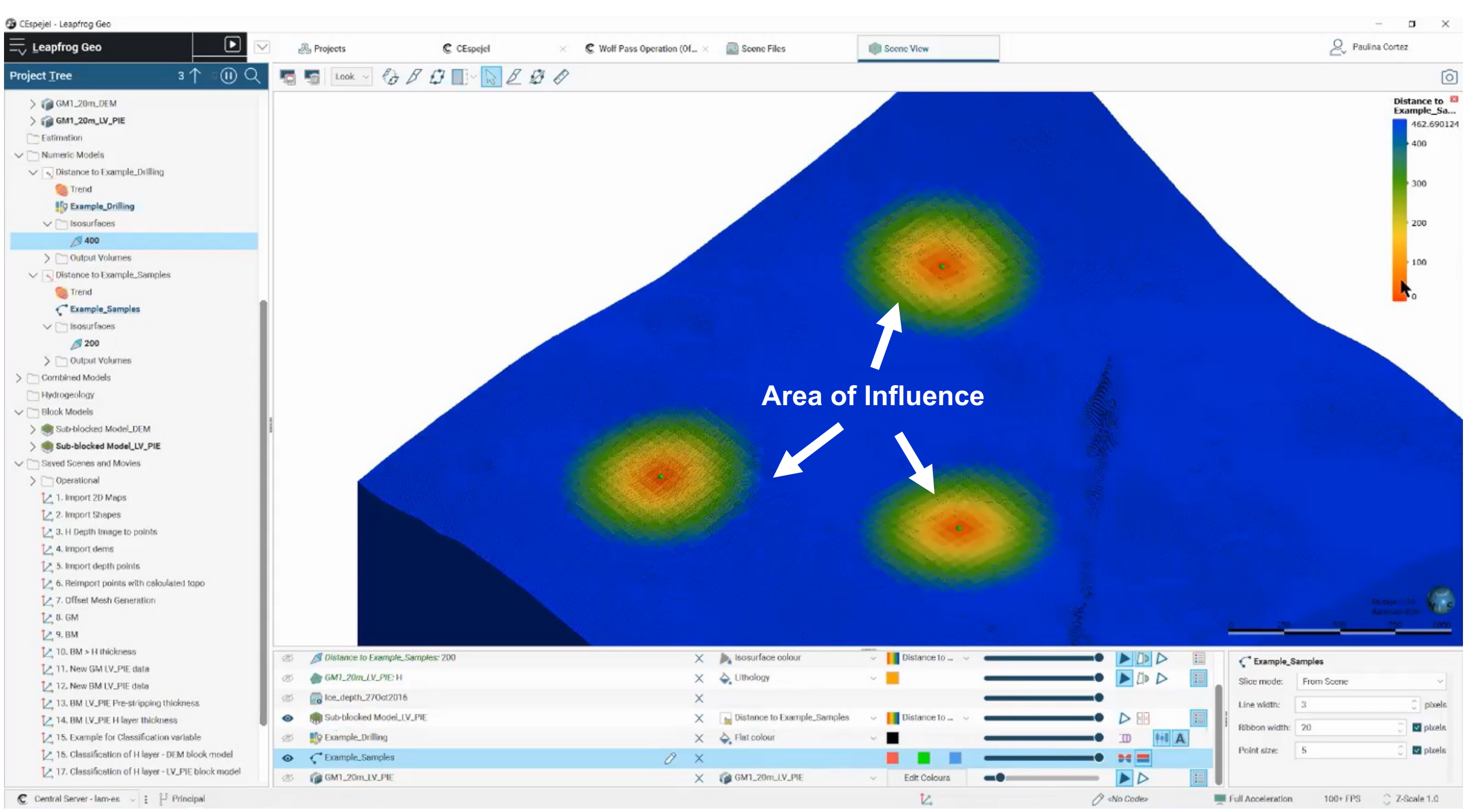
Resources Block Model | Lunar South Pole

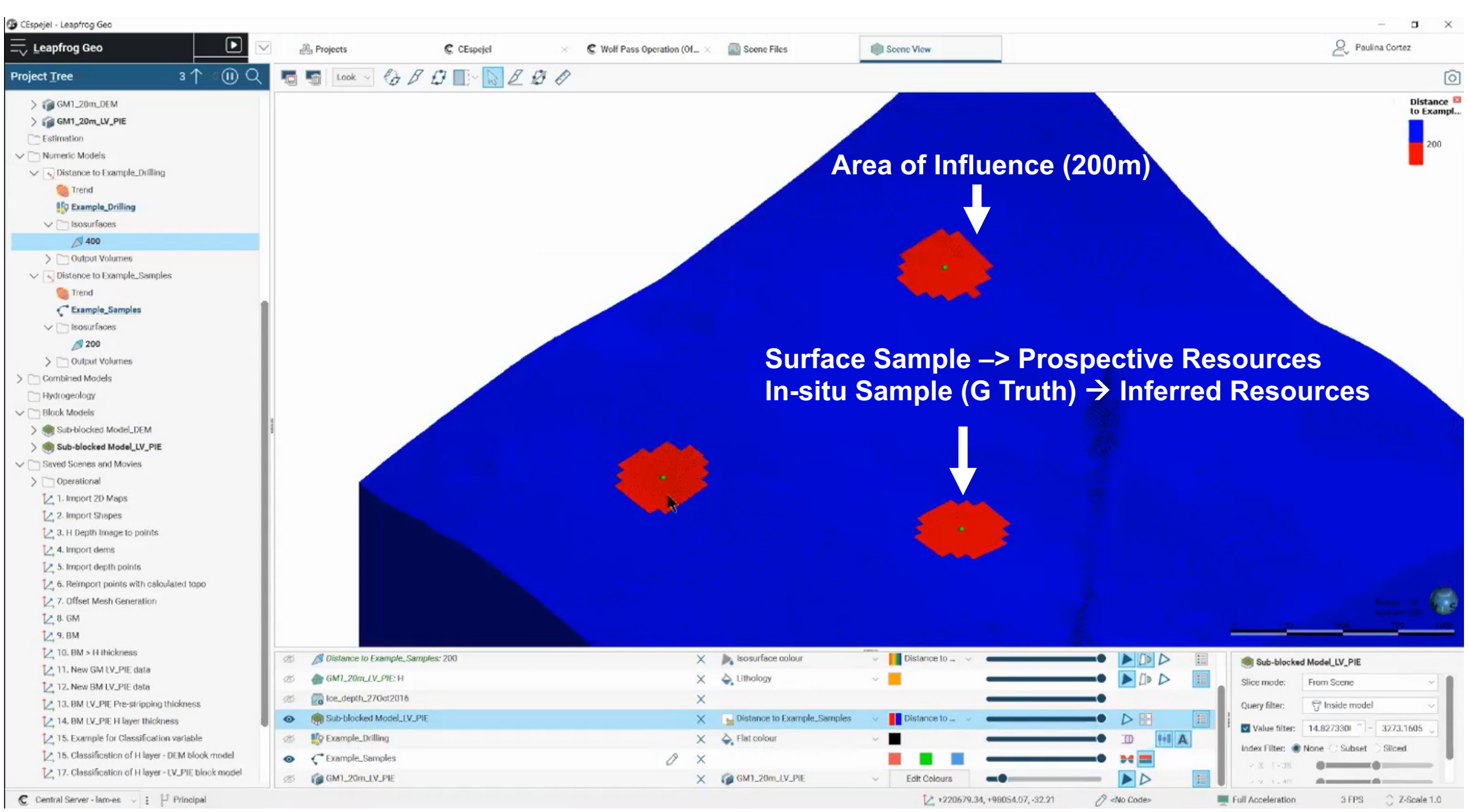

CEspejel - Leapfrog Geo
Leapfrog Geo
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Paulina Cortez
Project Tree
Look
Topography
GIS Data, Maps and Photos
Drillhole Data
Designs
Points
RAW_noZ
dem-gridcode-1+50
Hdepth_LV_PIE_dem-gridcode-999+10
Polylines
Geophysical Data
Structural Modelling
Meshes
Geological Models
Estimation
Numeric Models
Combined Models
Hydrogeology
Block Models
Sub-blocked Model_DEM
Sub-blocked Model_LV_PIE
Saved Scenes an
Operational
1. Import 2D
2. Import She
3. H Depth In
4. Import den
5. Import dep
6. Reimport p
7. Offset Mes
8. GM
9. BM
10. BM > H th
11. New GM I
12. New BM I
13. BM LV_PI
14. BM LV_PI
15. Example
16. Classifica
17. Classifica
18. Area of in
Open
Sub-blocking Triggers
Evaluations
Calculations and Filters
Statistics
Interrogate Estimator
New Grade Tonnage Graph
New Swath Plot
New Report
View Object
Copy
Prioritise
Freeze
Rename F2
View Relationships
Delete Del
Export
Properties
Comments
Tab or click to add
GM1_20m_LV_PIE
Basement
H
Pre-stripping
Unknown
Plunge +26
Azimuth 032
0
500
1000
1500
Sub-blocked Model_LV_PIE
GM1_20m_LV_PIE
Edit Colours
Sub-blocked Model_LV_PIE
Slice mode:
From Scene
Query filter:
No Filter
Index Filter:
None
Subset
Sliced
Central Server - Ian
<No Code>
Full Acceleration
4 FPS
Z-Scale 1.0


CEspejel - Leapfrog Geo
Leapfrog Geo
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Paulina Cortez
Project Tree 3
Look
Topography
GIS Data, Maps and Photos
Drillhole Data
Designs
Points
RAW_noZ
dem-gridoo...
Hdepth_LV...
Polylines
Area
Example_Samples
Geophysical Data
Structural Modelling
Meshes
Geological Models
Areas
GM1_20m_DEM
GM1_20m_LV_PIE
Estimation
Numeric Models
Combined Models
Hydrogeology
Block Models
Sub-blocked Model_DEM
Sub-blocked Model_LV_...
Saved Scenes and Movies
Operational
1. Import 2D Maps
2. Import Shapes
3. H Depth Image to poin...
4. Import dems
5. Import depth points
6. Reimport points with c...
7. Offset Mesh Generation
8. GM
9. BM
10. BM > H thickness
11. New GM LV_PIE data
12. New BM LV_PIE data
13. BM LV_PIE Pre-stripp...
Surface Samples (Prospecting)
GM1_20m_LV_PIE
Basement
H
Pre-stripping
Unknown
Plunge +37
Azimuth 025
0
250
500
750
1000
Hdepth_LV_PIE_dem-gridcode-999+10
Stability
Stability disc...
GM1_20m_LV_PIE: H
Lithology
Ice_depth_27Oct2016
Sub-blocked Model_LV_PIE
GM1_20m_LV_PIE
Edit Colours
Example_Samples
GM1_20m_LV_PIE
GM1_20m_LV_PIE
Edit Colours
Example_Samples
Slice mode:
From Scene
Line width:
3
pixels
Ribbon width:
20
pixels
Point size:
5
pixels
Central Server - lam-es
Principal
+221621.42, +96855.23, +23.57
<No Code>
Full Acceleration
35 FPS
Z-Scale 1.0


Drilling | In-situ Samples
(Ground Truth Exploration)
Leapfrog Geo
Project Tree
Meshes
Geological Models
Areas
GM1_20m_DEM
GM1_20m_LV_PIE
Estimation
Numeric Models
Distance to Example_Drilling
Distance to Example_Samples
Trend
Example_Samples
Isosurfaces
200
Output Volumes
Combined Models
Hydrogeology
Block Models
Sub-blocked Model_DEM
Sub-blocked Model_LV_PIE
Saved Scenes and Movies
Operational
1. Import 2D Maps
2. Import Shapes
3. H Depth Image to points
4. Import dems
5. Import depth points
6. Reimport points with calculated topo
7. Offset Mesh Generation
8. GM
9. BM
10. BM > H thickness
11. New GM LV_PIE data
12. New BM LV_PIE data
13. BM LV_PIE Pre-stripping thickness
14. BM LV_PIE H layer thickness
15. Example for Classification variable
16. Classification of H layer - DEM block model
17. Classification of H layer - LV_PIE block model
18. Area of interest
Cross Sections and Contours
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Paulina Cortez
Look
ED_002
ED_001
ED_003
GM1_20m_LV_PIE
Basement
H
Pre-stripping
Unknown
Plunge +16
Azimuth 047
0
250
500
750
Hdepth_LV_PIE_dem-gridcode-999+10
Stability
Distance to Example_Samples: 200
Isosurface colour
GM1_20m_LV_PIE: H
Lithology
Ice_depth_27Oct2016
Sub-blocked Model_LV_PIE
GM1_20m_LV_PIE
Edit Colours
Example_Drilling
Flat colour
Example_Samples
Example_Drilling
Slice mode:
From Scene
Query filter:
No Filter
Filter trace lines
Line width:
2.00
Central Server - lam-es
Principal
+220281.83, +99053.58, -135.87
<No Code>
Full Acceleration
23 FPS
Z-Scale 1.0


CEspejel - Leapfrog Geo
Leapfrog Geo
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Project Tree
3
Look
Topography
GIS Data, Maps and Photos
Drillhole Data
Planned Drillholes
Example_Drilling
Test
Drillhole Correlation
Designs
Points
RAW_noZ
dem-gridcode-1+50
Hdepth_LV_PIE_dem-gridcode-999+1...
Polylines
Area
Example_Samples
Muestra_prueba
Geophysical Data
Structural Modelling
Meshes
Geological Models
Areas
GM1_20m_DEM
GM1_20m_LV_PIE
Estimation
Numeric Models
Distance to Example_Drilling
Trend
Example_Drilling
Hydrogen
Base (Regolith)
Test001
H
CEspejel - Leapfrog Geo
Drilling Prognoses: Test
View prognosis for:
GM1_20m_LV_PIE
Name
From
To
GM1_20m_LV_PIE
Test001
0
4.818
H
Test001
4.818
7
Basement


CEspejel - Leapfrog Geo
Leapfrog Geo
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Paulina Cortez
Project Tree
GM1_20m_DEM
GM1_20m_LV_PIE
Estimation
Numeric Models
Distance to Example_Drilling
Trend
Example_Drilling
Isosurfaces
400
Output Volumes
Distance to Example_Samples
Trend
Example_Samples
Isosurfaces
200
Output Volumes
Combined Models
Hydrogeology
Block Models
Sub-blocked Model_DEM
Sub-blocked Model_LV_PIE
Saved Scenes and Movies
Operational
1. Import 2D Maps
2. Import Shapes
3. H Depth Image to points
4. Import dems
5. Import depth points
6. Reimport points with caloulated topo
7. Offset Mesh Generation
8. GM
9. BM
10. BM > H thickness
11. New GM LV_PIE data
12. New BM LV_PIE data
13. BM LV_PIE Pre-stripping thickness
14. BM LV_PIE H layer thickness
15. Example for Classification variable
16. Classification of H layer - DEM block model
17. Classification of H layer - LV_PIE block model
Distance to Example_Sa...
462.690124
400
300
200
100
0
Area of Influence
Distance to Example_Samples: 200
Isosurface colour
GM1_20m_LV_PIE: H
Lithology
Ice_depth_27Oct2016
Sub-blocked Model_LV_PIE
Distance to Example_Samples
Example_Drilling
Flat colour
Example_Samples
GM1_20m_LV_PIE
Edit Colours
Example_Samples
Slice mode:
From Scene
Line width:
3
pixels
Ribbon width:
20
pixels
Point size:
5
pixels
Central Server - lam-es
Principal
<No Code>
Full Acceleration
100+ FPS
Z-Scale 1.0


CEspejel - Leapfrog Geo
Leapfrog Geo
Projects
CEspejel
Wolf Pass Operation (Of...
Scene Files
Scene View
Paulina Cortez
Project Tree
Look
Distance to Exampl...
200
Area of Influence (200m)
Surface Sample –> Prospective Resources
In-situ Sample (G Truth) → Inferred Resources
GM1_20m_DEM
GM1_20m_LV_PIE
Estimation
Numeric Models
Distance to Example_Drilling
Trend
Example_Drilling
Isosurfaces
400
Output Volumes
Distance to Example_Samples
Trend
Example_Samples
Isosurfaces
200
Output Volumes
Combined Models
Hydrogeology
Block Models
Sub-blocked Model_DEM
Sub-blocked Model_LV_PIE
Saved Scenes and Movies
Operational
1. Import 2D Maps
2. Import Shapes
3. H Depth Image to points
4. Import dems
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6. Reimport points with caloulated topo
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12. New BM LV_PIE data
13. BM LV_PIE Pre-stripping thickness
14. BM LV_PIE H layer thickness
15. Example for Classification variable
16. Classification of H layer - DEM block model
17. Classification of H layer - LV_PIE block model
Distance to Example_Samples: 200
Isosurface colour
Distance to ...
GM1_20m_LV_PIE: H
Lithology
Ice_depth_27Oct2016
Sub-blocked Model_LV_PIE
Distance to Example_Samples
Example_Drilling
Flat colour
Example_Samples
GM1_20m_LV_PIE
Edit Colours
Sub-blocked Model_LV_PIE
Slice mode:
From Scene
Query filter:
Inside model
Value filter:
14.827330
3273.1605
Index Filter:
None
Subset
Sliced
Central Server - lam-es
Principal
+220679.34, +98054.07, -32.21
<No Code>
Full Acceleration
3 FPS
Z-Scale 1.0

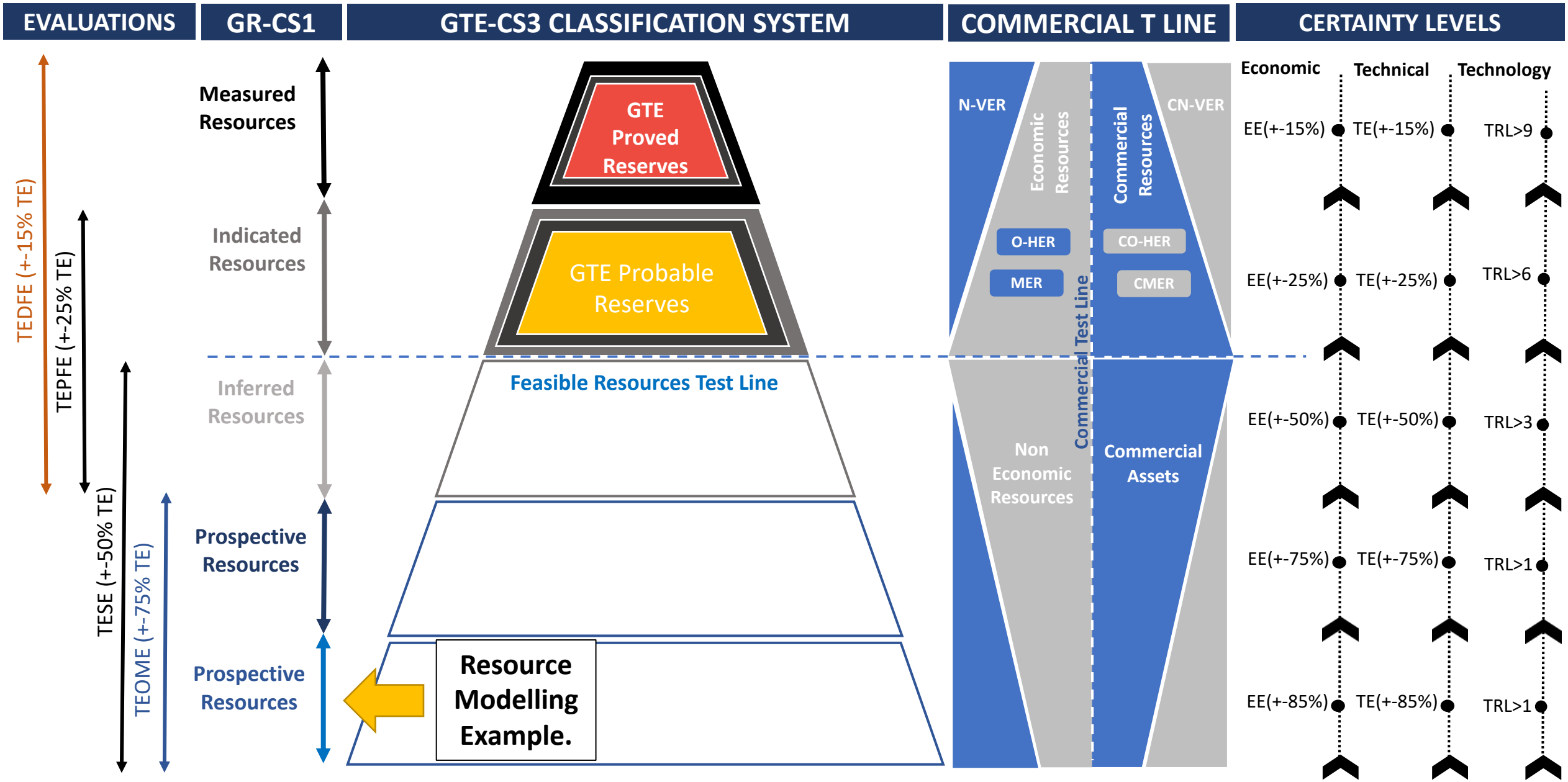
(Technically)

How do we get to Reserves?

With the combination of high certainty on:

1. Geology (Resource Exploration)
2. Technology Development
3. Technical Feasibility Studies
4. Economic Assessments

GTE-CS3 – Extractable Economic Reserves (Commercial Purposes)



(Practically)

How do we get to Reserves?

Through **collaboration between Government, Commercial and Research entities:**

- Resource Exploration (e.g., The International Lunar Resource Prospecting Campaign)
- Technology Development (e.g., extraction, processing, etc.)
- Feasibility Studies between exploration and technology companies.
- Economic Assessments (e.g., update Market Demand Assessments, OPEX – CAPEX from technology companies, etc.)
- Officialization of Space Resources Standards (e.g., LORS)

LORS Next Steps

- Independent
- Inclusive
- Collaborative
- Living Document

ILNAS

esric
powered by LSA, ESA & LIST

JORC

ispace

ISO International Organization for Standardization

LORS 101

LORS **Latest version** available at “Handbook of Space Resources” (Viorel Badescu et all, 2023, Springer)

Space Resources Round Table - 2024
Session 3: Resource Prospecting and Exploration

Commercial Exploration, Extraction, and Reporting of Lunar Resources (LORS-101)

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ispace Europe
c-espejel@ispace-inc.com

ispace