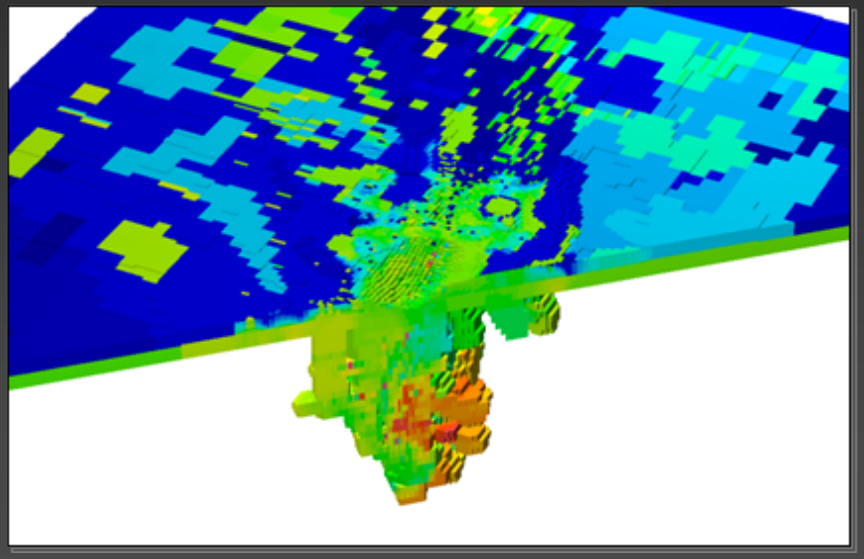
Automated 3D physical property model builder for sparse constraints



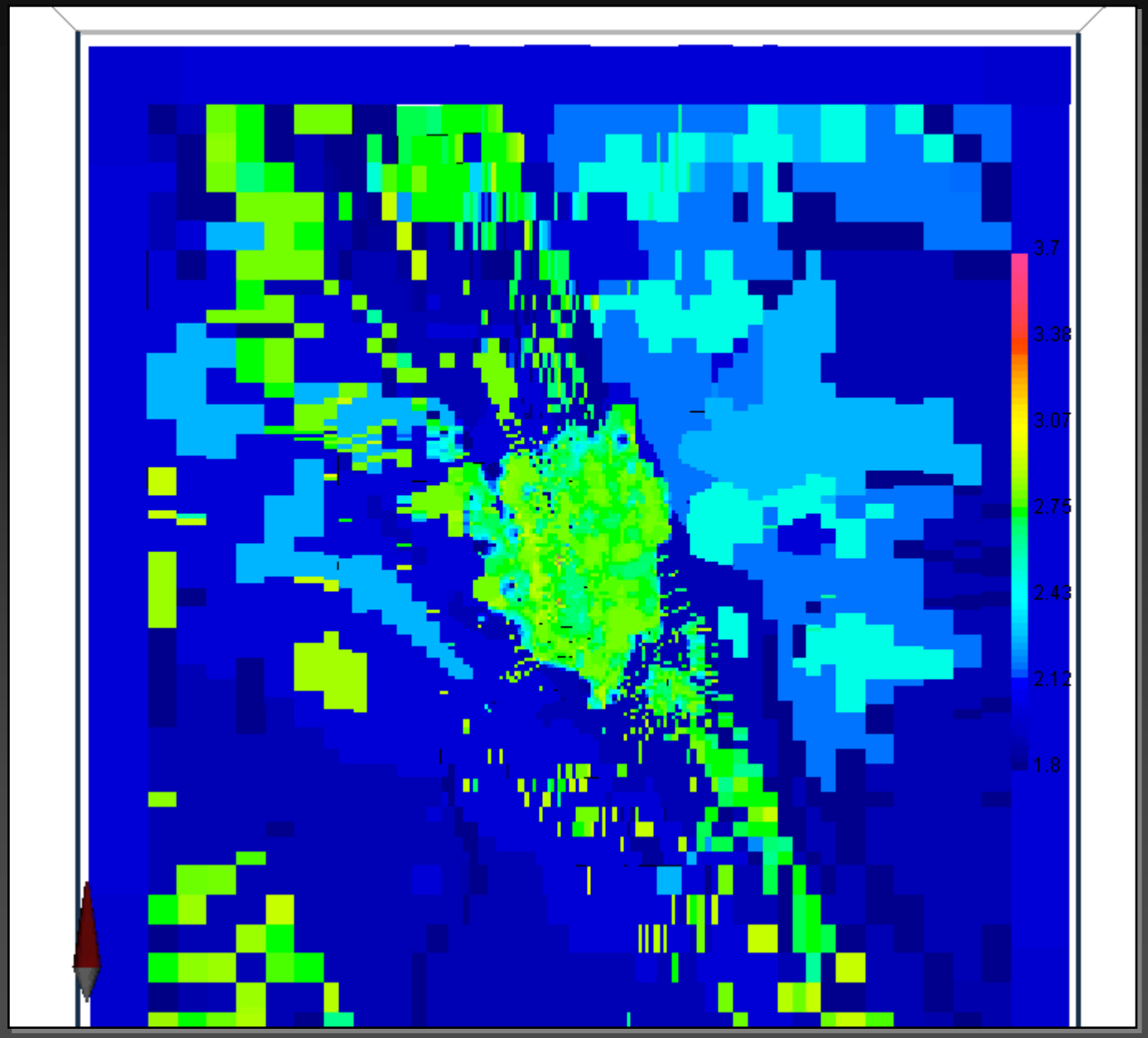
Nick Williams

Report to sponsors

November 2007

Sponsors and supporters:

Australian Government
Geoscience Australia
pmd*CRC
bhpbilliton
MDRU
Mineral Deposit Research Unit
UBC
GIF



Model of expected densities at Perseverance Ni deposit, WA:
30 % of model's 921,000 cells are populated ***based purely on data***.
Mesh volume: 8.3 km × 8.8 km × 4 km

Motivation for a new way to build models

- **Building full 3D geological models requires:**
  - **Too much knowledge**
    - Is it really possible to assign geology (let alone properties!) to every cell in a full 3D model of the subsurface?
  - **Too much interpretation**
    - No two model builders will create the same model
    - Interpretations are not repeatable from model to model
    - Difficult to distinguish fact from fiction
  - **Too much effort to update with new data**
    - Even GeoModeller requires some tender loving care to update a model (changing hypothesis points, etc.)
  - **Too much specialist software**
    - Gocad, Mira, GeoModeller, FracSIS/FracSDS,…

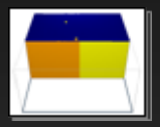
3D physical property models from sparse data

- ~~**Too much knowledge**~~
  - Only assign values to those cells that have data
    - If a 3D model is available it can still be used, but is treated with low reliability
- ~~**Too much interpretation**~~
  - Data driven
  - Optional automatic data-based extrapolation
- ~~**Too much effort to update with new data**~~
  - Can easily run the code with new data and the same settings and get a new updated model in minutes
- ~~**Too much software**~~
  - Only need MATLAB… It reads the raw data directly
    - Maybe a stand-alone application in the future?
    - Maybe part of GIFTools?

Models for inversions

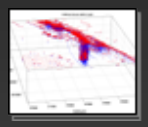
- **Gravity and magnetic inversions use up to 4 models at once**
  - **Reference properties:**
    - The best estimate of the physical property in each cell
  - **Smallness weights (w_s):**
    - Relative estimate of confidence in the assigned reference property
    - Higher smallness forces the inversion to match the reference property more closely
  - **Lower property bounds:**
    - The minimum allowed property
  - **Upper property bounds:**
    - The maximum allowed property
- **All 4 models are related**
  - Should be made at the same time from the same data using the same methods

Data inputs



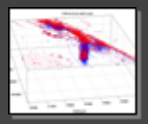
3D model of **domains**

Property **measurements** on **surface samples**

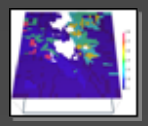


Property **measurements** along **drill holes**

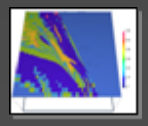
3D model of **geology**



Drill hole geology logs



Outcrop geology maps



Basement geology maps

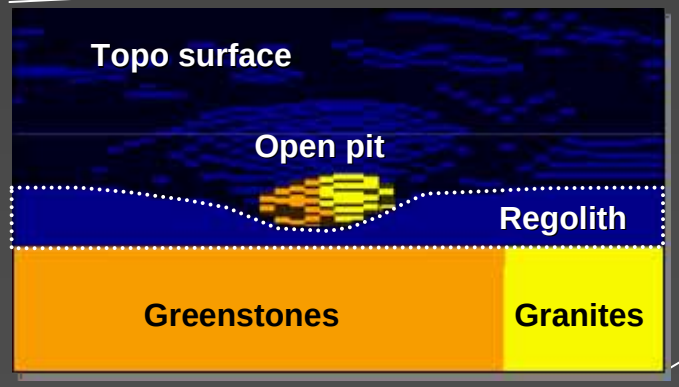
Physical property estimates
derived from all available sources

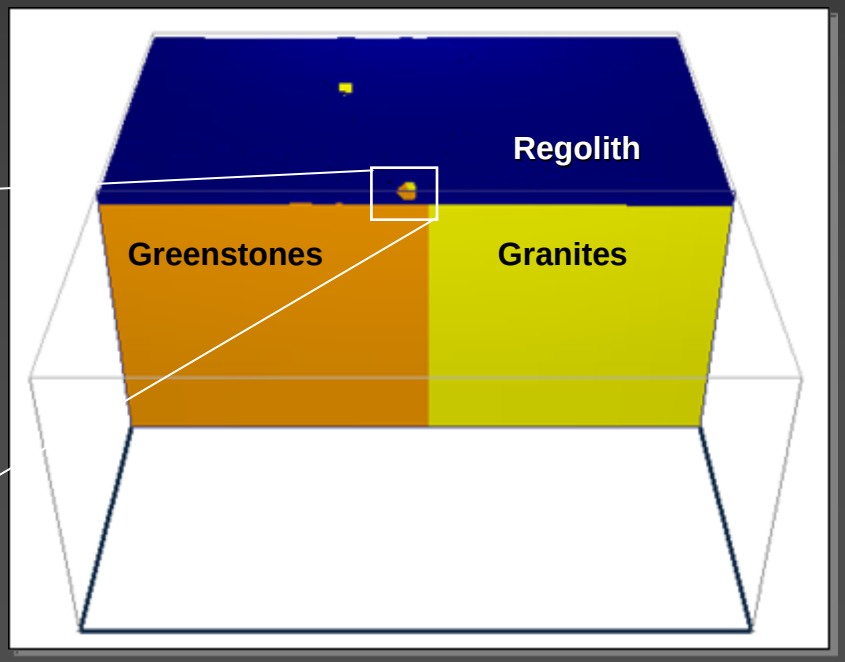
Data inputs: 3D domain models

- **Any 3D model of geological <u>domains</u> built in any way, formatted as a UBC–GIF model file**
  - Domains have poorly-defined boundaries and may span many rock types with varied properties
    - e.g., “cover”, “basin”, “greenstones”
- **Reads a UBC–GIF model file and a domain definition text file**

ZONE_ID	LOWER_BOUND	REF_PROPERTY	UPPER_BOUND	WS	COMMENTS
1	2.3	2.8	4.5	2	Greenstone
2	2.3	2.7	2.9	2	Granite

- **Option to automatically add a cover/weathering zone at surface**

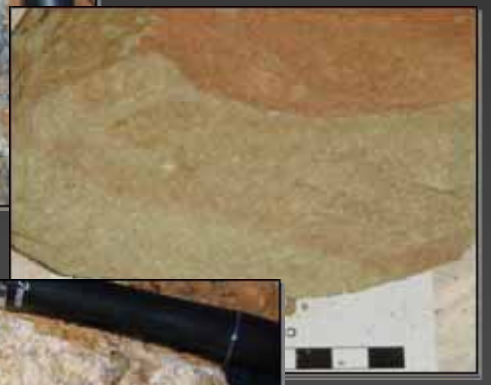




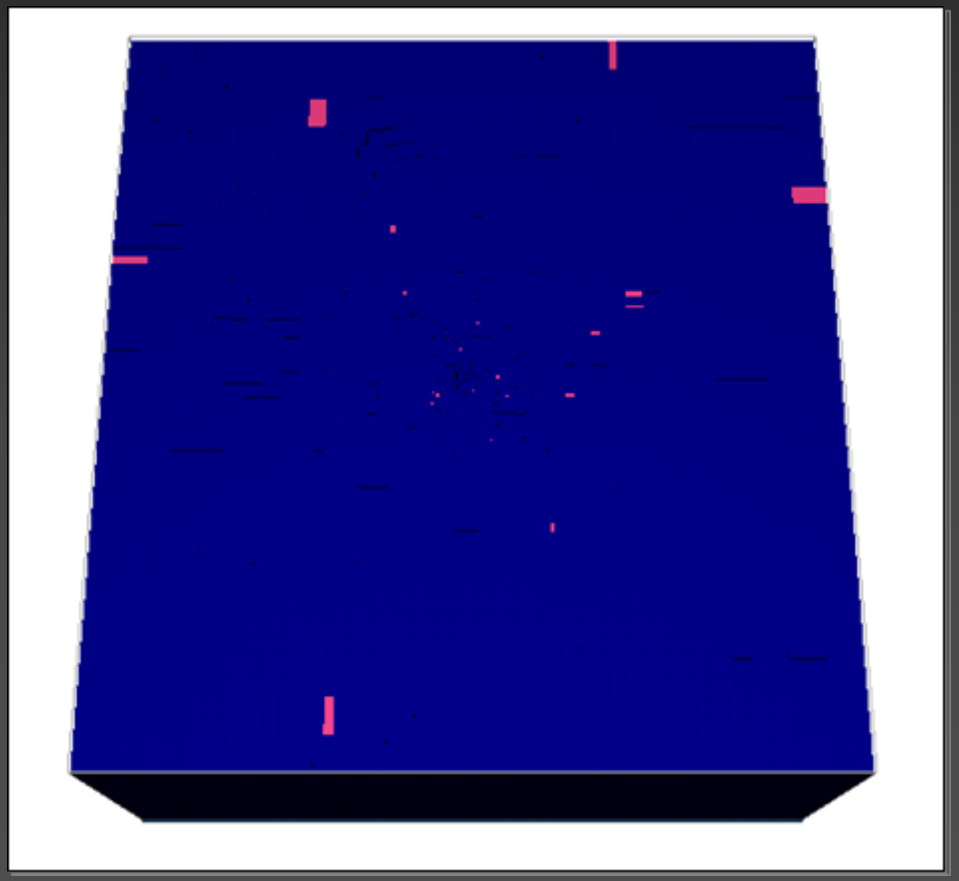
Data inputs: Surface sample properties

- **Read from ASCII text column file**

LABID	EASTING	NORTHING	ELEV	MEAN_DB_DEN(G/CM3)
S0101	266542	6903872	526	2.93
S0201	264150	6903050	512	1.75
S0301	262531	6902387	512	2.35
S0401	259427	6901178	531	1.99
S0601	255703	6897438	516	2.93



(Just stuff to fill this space!)



Data inputs: Drill hole properties

- **Reads standard drill hole definition text files:**

Collars:

HOLEID	EASTING	NORTHING	ELEVATION	LENGTH
ADJC415	250615.980	6995239.030	532	249
ADJC423	250311.700	6996727.340	529	189
ADJC440	248648.910	6997992.320	526	260
ADJC442	249638.930	6995832.680	530	200

Surveys:

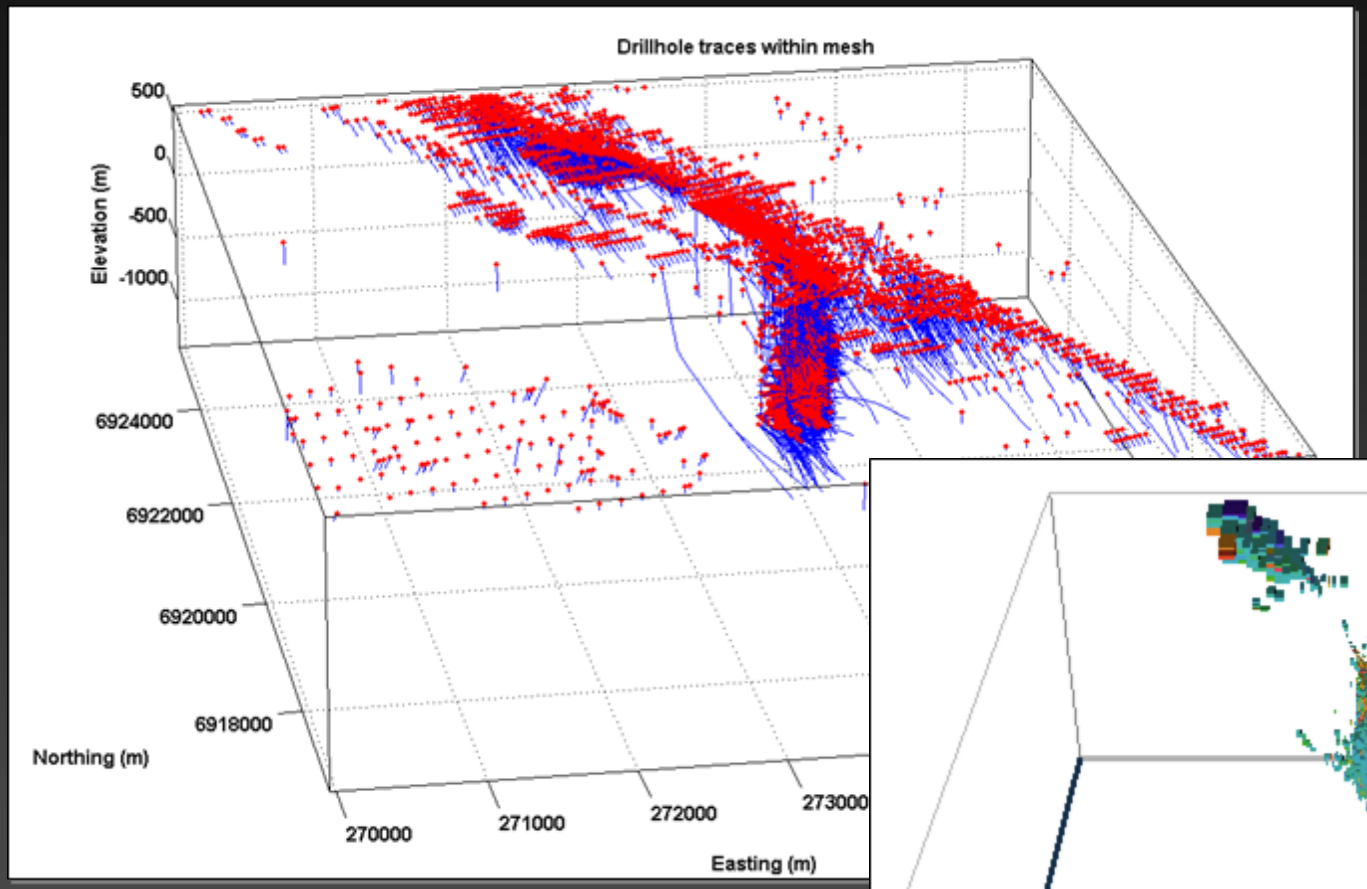
HOLEID	SURVEYDEPTH	AZIMUTH	INCLINATION
ADJC415	0.0	69.35	-60.0
ADJC415	249.0	79.35	-55.0
ADJC423	0.0	69.35	-60.0
ADJC423	189.0	77.35	-58.0
ADJC440	0.0	249.35	-60.0
ADJC440	130.0	250.35	-63.0
ADJC440	170.0	251.35	-61.5
ADJC440	210.0	252.35	-61.0

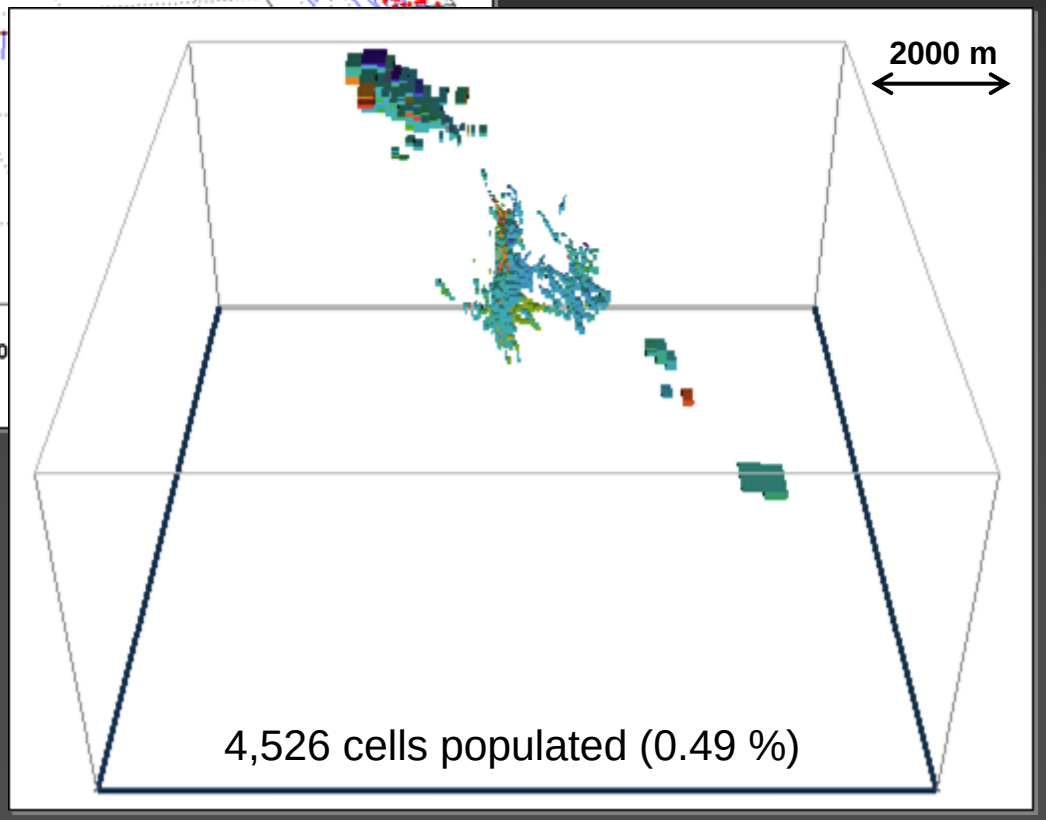
Properties:

HOLEID	FROM	TO	SG_gcc
ART1	0.70	2.70	3.40
ART1	2.70	4.20	4.32
CCD1	357.50	359.70	2.81
CCD1	359.70	361.75	2.77
CCD1	361.75	362.55	4.41
CCD1	362.55	363.15	3.02
CCD1	363.15	364.00	3.29
CCD1	364.00	365.00	2.96
CCD1	365.00	365.60	3.34
CCD1	365.60	367.00	3.00

- **Calculates 3D drill hole traces using minimum curvature**
- **Samples the drill hole traces at user-specified intervals**
- **Query property data to extract any measured properties at those points**

Data inputs: Drill hole properties

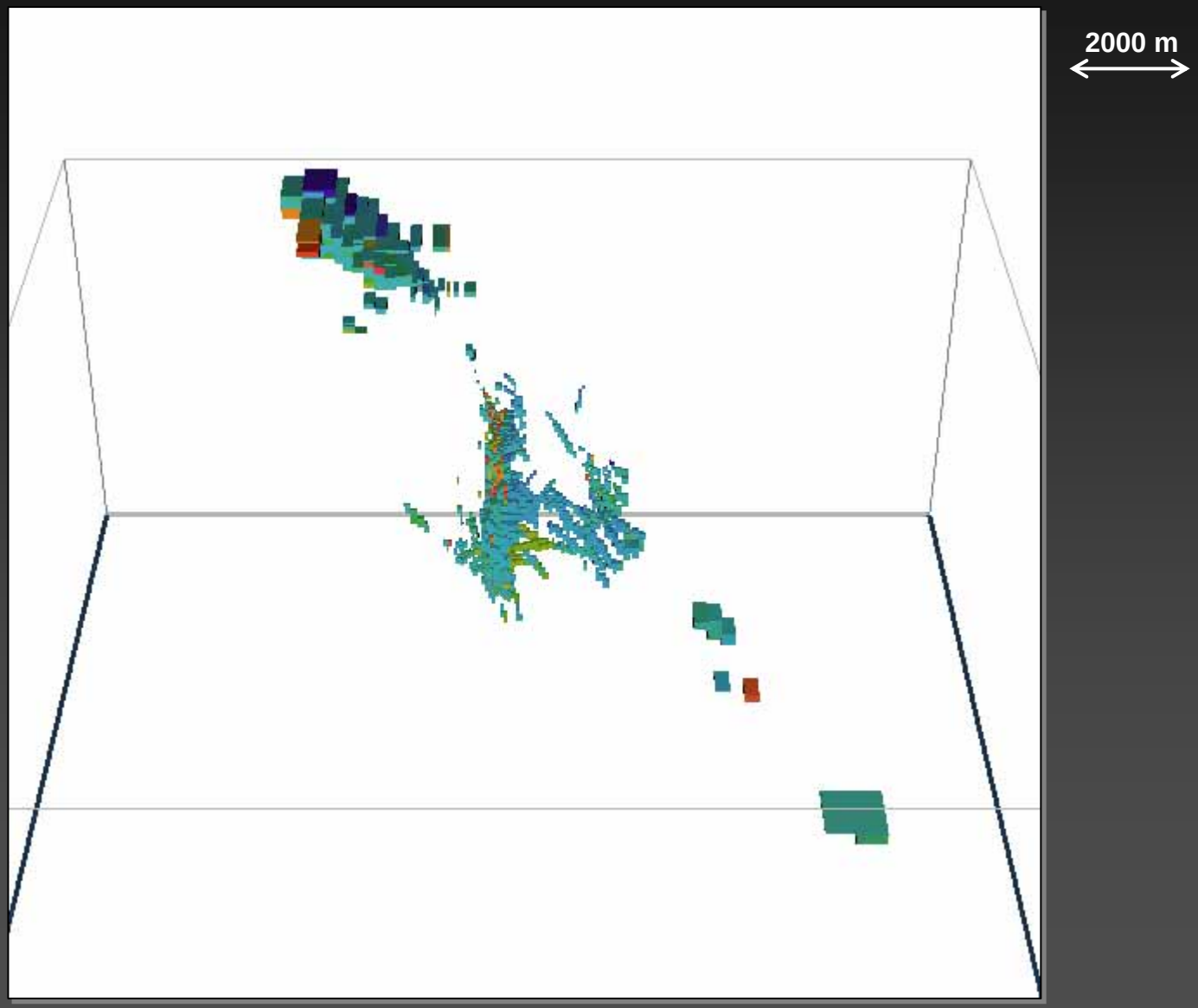




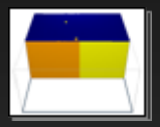
Density measurements

- Input 116,344 measurement intervals on 34,293 holes
- Recovered 648,810 points with meas. properties on 5459 holes

Data inputs: Drill hole properties

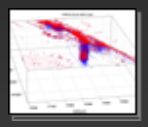


Data inputs



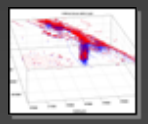
3D model of **domains**

Property **measurements** on **surface samples**

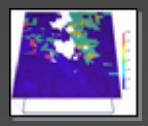


Property **measurements** along **drill holes**

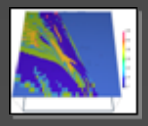
3D model of **geology**



Drill hole geology logs



Outcrop geology maps



Basement geology maps

Physical property estimates
derived from all available sources

Data inputs: Physical properties

- **Combine all available properties for all available geology labels**
  - Manually-specified properties *(these take precedence)*
  - Surface sample measurements
  - Drilling measurements
- **Calculate various statistics for each geology label**
  - Reference properties:
    - Mean
    - Median
    - Geometric mean ($\log_{10}$)
  - Bounds property pairs (only calculated if there are enough measurements):
    - Minimum, maximum
    - Mean ± 1, 2, or 3 σ
    - Geometric mean ± 1, 2, or 3 σ
    - Percentile ranges: 5-95 %, 10-90 %, 20-80 %

Property calculation process

Surface samples:

GEOLOGYCODE	DENSITY (G/CM3)
Aod	2.93
Afv	1.75
Afv	2.35
Abm/Czl	1.99
Abb	2.93
Abb	2.94

Drilling logs:

HOLE-ID	DEPTHFROM	DEPTHTO	GEOLOGYCODE
LSD297	0	4.00	--
LSD297	10	12.00	--
LSD297	100	105.30	MA
LSD297	105	105.80	U-A
LSD297	110	112.10	U-A
LSD297	112	115.40	UMA
LSD297	115	116.20	U-A

Combine all estimates into a single property database

Extract all properties for each geology label

But maps use different geology labels?!

Manually-specified properties:

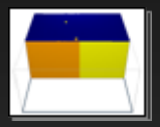
CODE	LOWER BOUND	REF	UPPER BOUND	COMMENTS
Aog	2.25	2.94	3.2	% Metagabbro: Added from Aoga/Aod
Cza	1.4	1.9	2.3	% Clay, silt and sand; pebbly in p
Czb	1.4	1.9	2.3	% Clay and dune sand, adjacent to p
Czc	1.4	1.9	2.5	% Sandy colluvium with limonitic p
Czc/Agf	1.4	1.9	2.5	% Sandy colluvium with limonitic p
Czf	1.4	2	2.5	% Pebbly colluvium and alluvium der
Czf/Ab	1.4	2	2.5	% Pebbly colluvium and alluvium der

Translation table (matches map names to geology labels using wildcards):

MAP_UNIT_NAME	CORRESPONDING_DRILLING_CODES
Andesitic-Dacitic Porphyritic Volcanic and Volcaniclastics	FP%
Basalt	MB, MA, MR, $MA, $MB, $MR, AA%, AB%, AR%,
Basalt - Plagioclase Phyric	MB, MA, MR, $MA, $MB, $MR, AA%, AB%, AR%,
Black Shale	SH, SB, $SH, $SB
Conglomerate and Interbedded Sandstone	SG, Asc, Asjc
Dolerite	MD, MA, MR, $MD, $MA, $MR, Aod
Drilling indicated olivine orthocumulate to mesocumulate	UO%, UM%, $UO%, $UM%
Felsic Volcaniclastic Sandstone - Siltstone	Afv, SS%, SA%, $SS, $SA

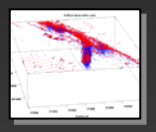
Calculate statistics on all data to create property estimates

Data inputs



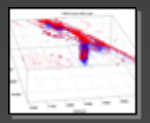
3D model of **domains**

Property **measurements** on **surface samples**

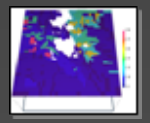


Property **measurements** along **drill holes**

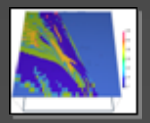
3D model of **geology**



Drill hole geology logs



Outcrop geology maps



Basement geology maps

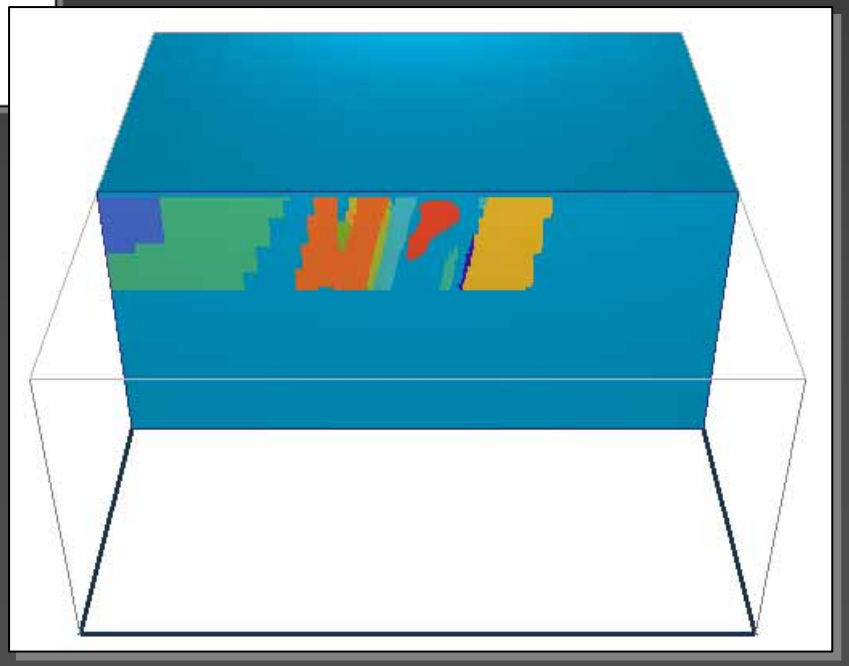
Physical property estimates
derived from all available sources

Data inputs: 3D geology models

- **Any 3D model of geological <u>units</u> built in any way, formatted as a UBC–GIF model file**
  - Geological units have well-defined boundaries and specific physical properties
    - e.g., metabasalt, TTG granite, Kathleen Valley gabbro
- **Reads a UBC–GIF model file and a geology definition text file**

ID	GEOLOGY_CODE	SMALLNESS (WS)
46	Mafic Intrusive	3
47	Mafic Intrusive Rocks	3
48	Felsic Extrusive	3
49	UMML	3
50	Dolerite	3
51	UAW	3

- **Query calculated properties database to extract property estimates for each geology label**



Data inputs: Drill hole geology logs

- **Reads standard drill hole definition text files:**

Collars:

HOLEID	EASTING	NORTHING	ELEVATION	LENGTH
ADJC415	250615.980	6995239.030	532	249
ADJC423	250311.700	6996727.340	529	189
ADJC440	248648.910	6997992.320	526	260
ADJC442	249638.930	6995832.680	530	200

Surveys:

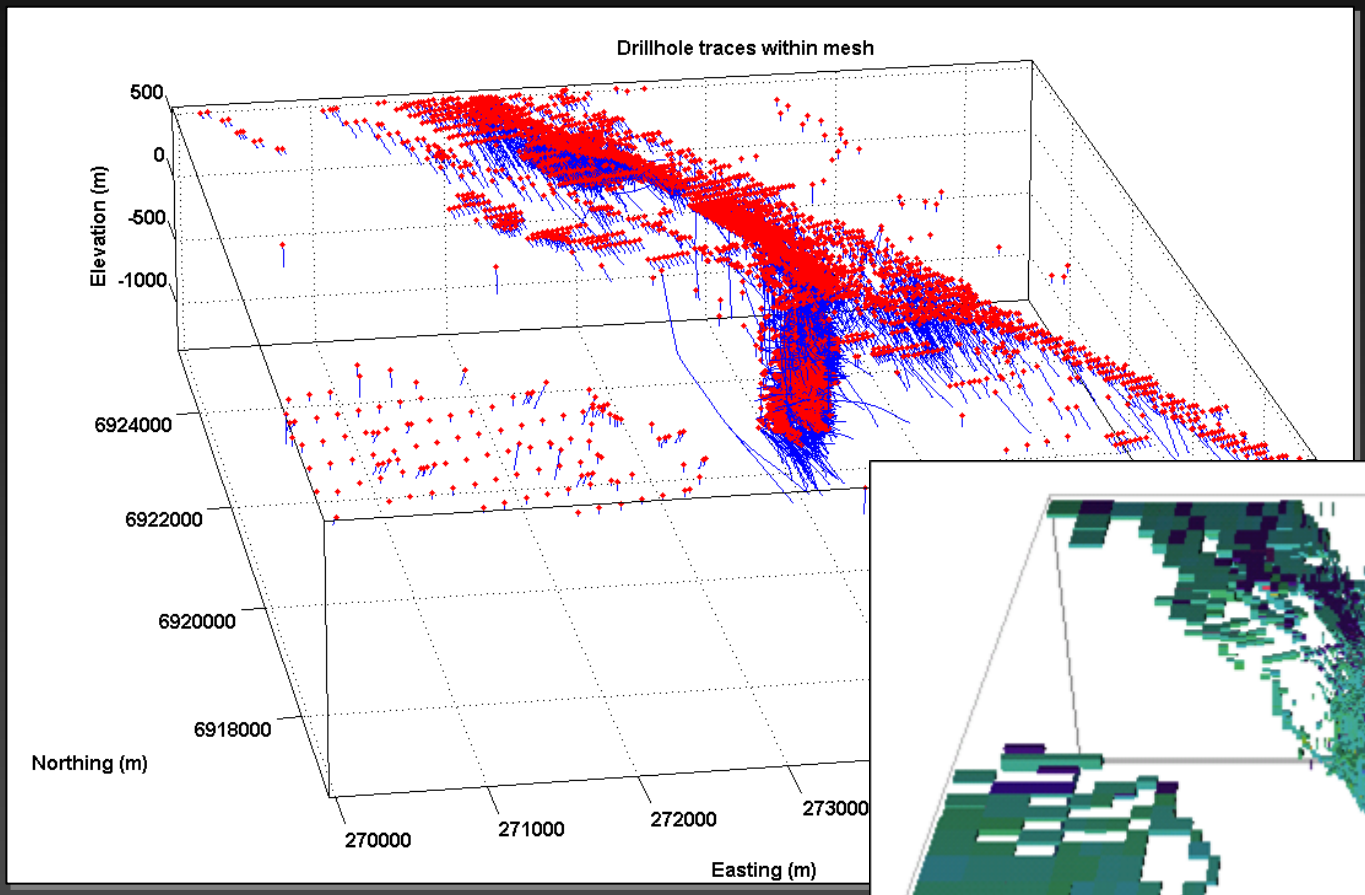
HOLEID	SURVEYDEPTH	AZIMUTH	INCLINATION
ADJC415	0.0	69.35	-60.0
ADJC415	249.0	79.35	-55.0
ADJC423	0.0	69.35	-60.0
ADJC423	189.0	77.35	-58.0
ADJC440	0.0	249.35	-60.0
ADJC440	130.0	250.35	
ADJC440	170.0	251.35	
ADJC440	210.0	252.35	

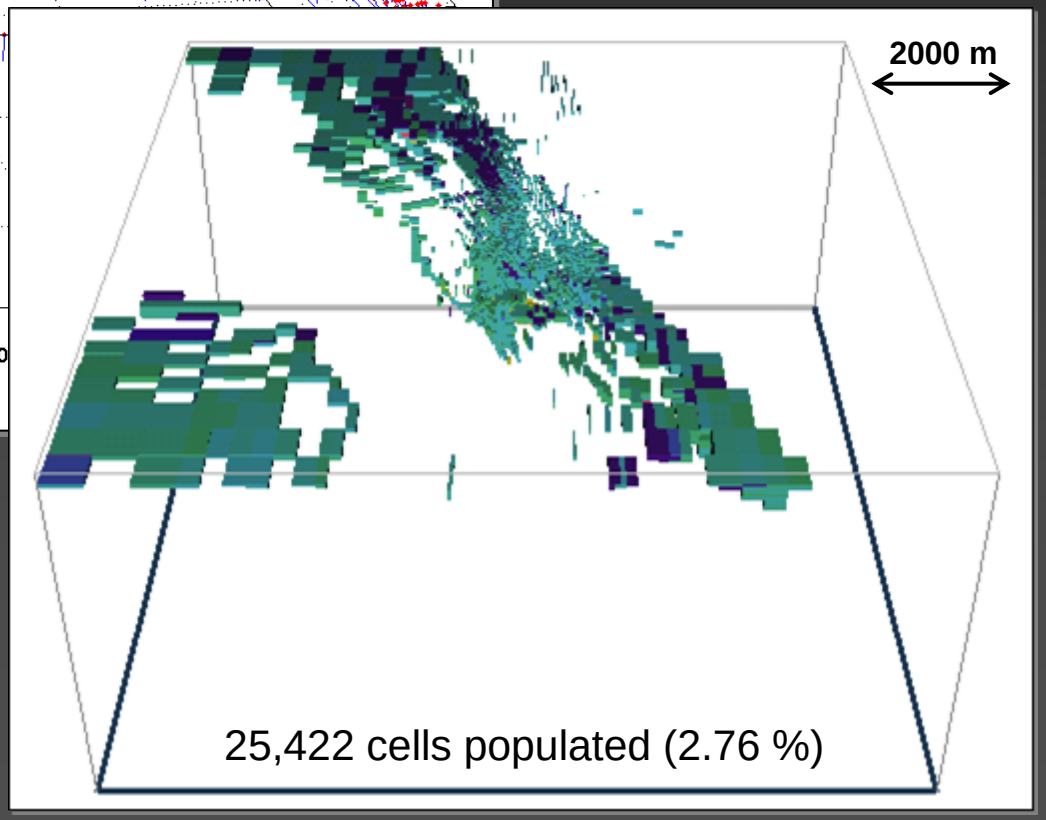
Drilling logs:

HOLE-ID	DEPTHFROM	DEPTHTO	GEOLOGYCODE
LSD297	0	4.00	--
LSD297	10	12.00	--
LSD297	100	105.30	MA
LSD297	105	105.80	U-A
LSD297	110	112.10	U-A
LSD297	112	115.40	UMA
LSD297	115	116.20	U-A

- **Finds coordinates on drill hole traces for each interval**
- **Query calculated properties database to extract any property estimates for geology labels at those points**

Data inputs: Drill hole geology logs

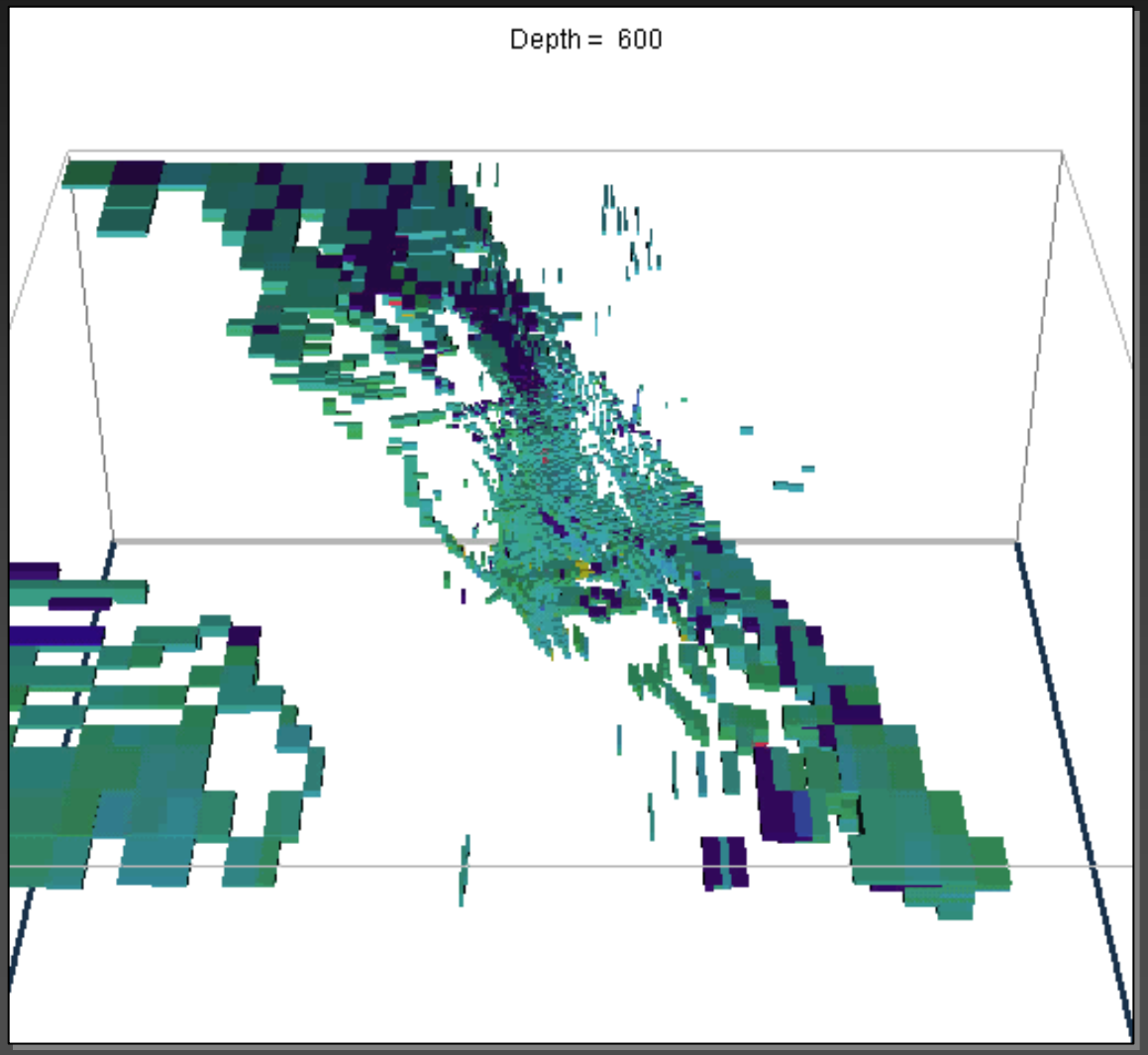




Geology observations

- Input 292,550 geology intervals on 34,293 holes
- Recovered 3,512,884 points with est. properties on 5459 holes

Data inputs: Drill holes geology logs

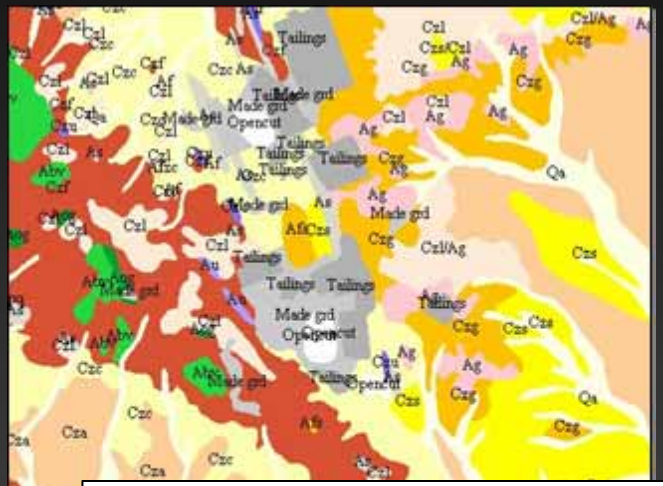


Data inputs: Maps

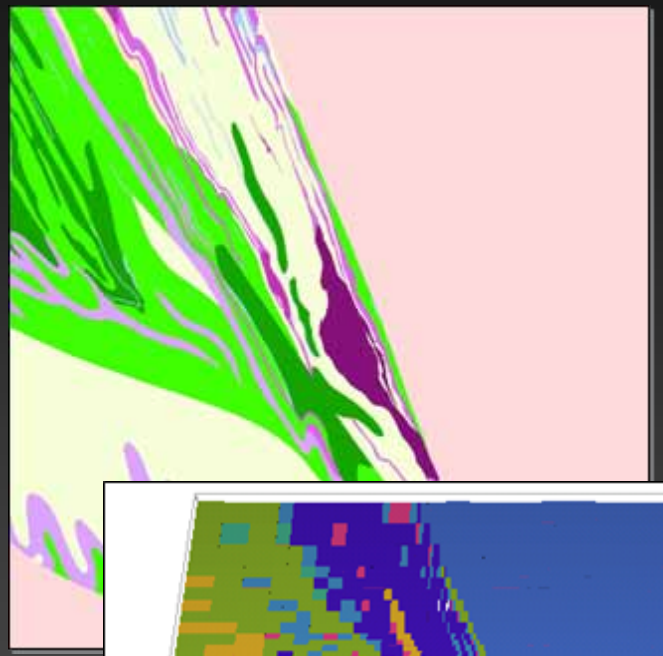
- **Read ESRI ArcView/ArcInfo/ArcGIS shapefiles (polygon format)**
  - Stitches any number of shapefiles together if different maps are required in different areas of the mesh
  - Does some basic coordinate transformations if required
    - UTM ↔ WGS84 (≈GDA94) latitudes & longitudes
- **Interpolate geology labels onto mesh at either:**
  - Topography surface, or some distance below it
  - Basement surface, or some distance below it
  - Allows use of either outcrop maps or basement geology maps
- **Query calculated properties database to extract any property estimates for geology labels at those points**
  - Outputs a list of geology labels that have no property estimates
  - Cells with no map information are assigned default values

Data inputs: Maps

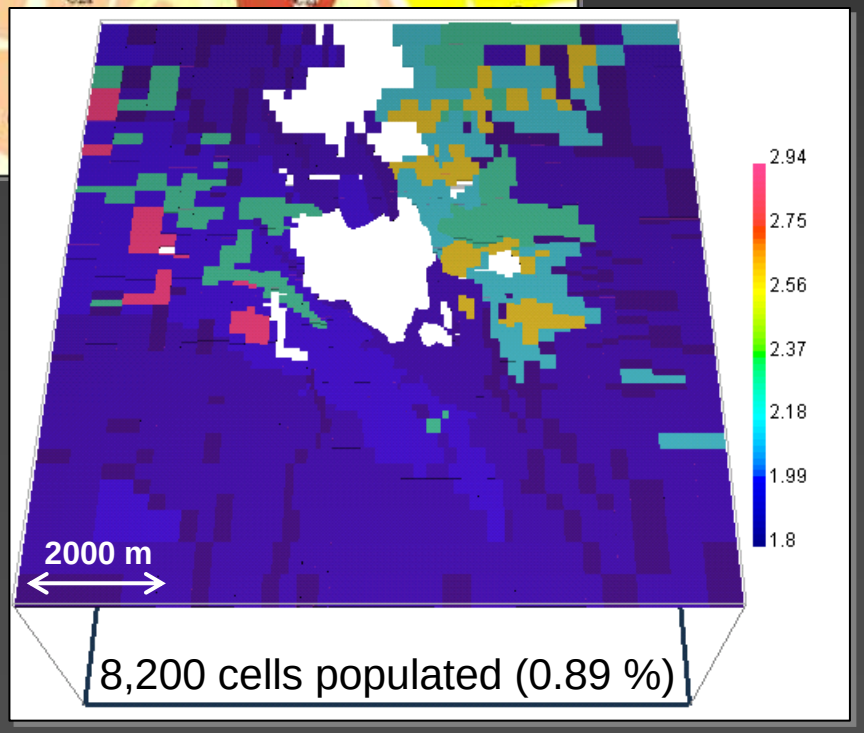
1:100k outcrop geology map (GSWA)



Basement geology map

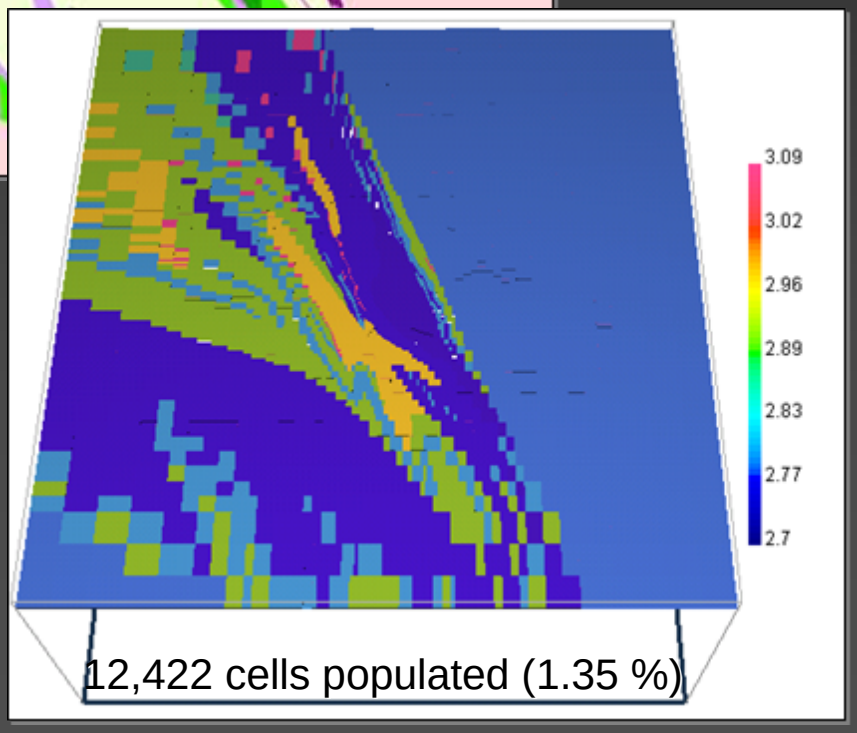


At surface



8,200 cells populated (0.89 %)

100m below pre-mining surface



12,422 cells populated (1.35 %)

Assigning properties to cells with data

- **Any cell that contains data will be assigned values from the most reliable data type(s) in that cell**

1. Surface samples
2. Drilling measurements
3. Drilling geology logs

Statistics calculated on all available observations. Choice of mean, median, etc…

4. Outcrop maps
5. Basement maps
6. 3D geology model
7. 3D domain model

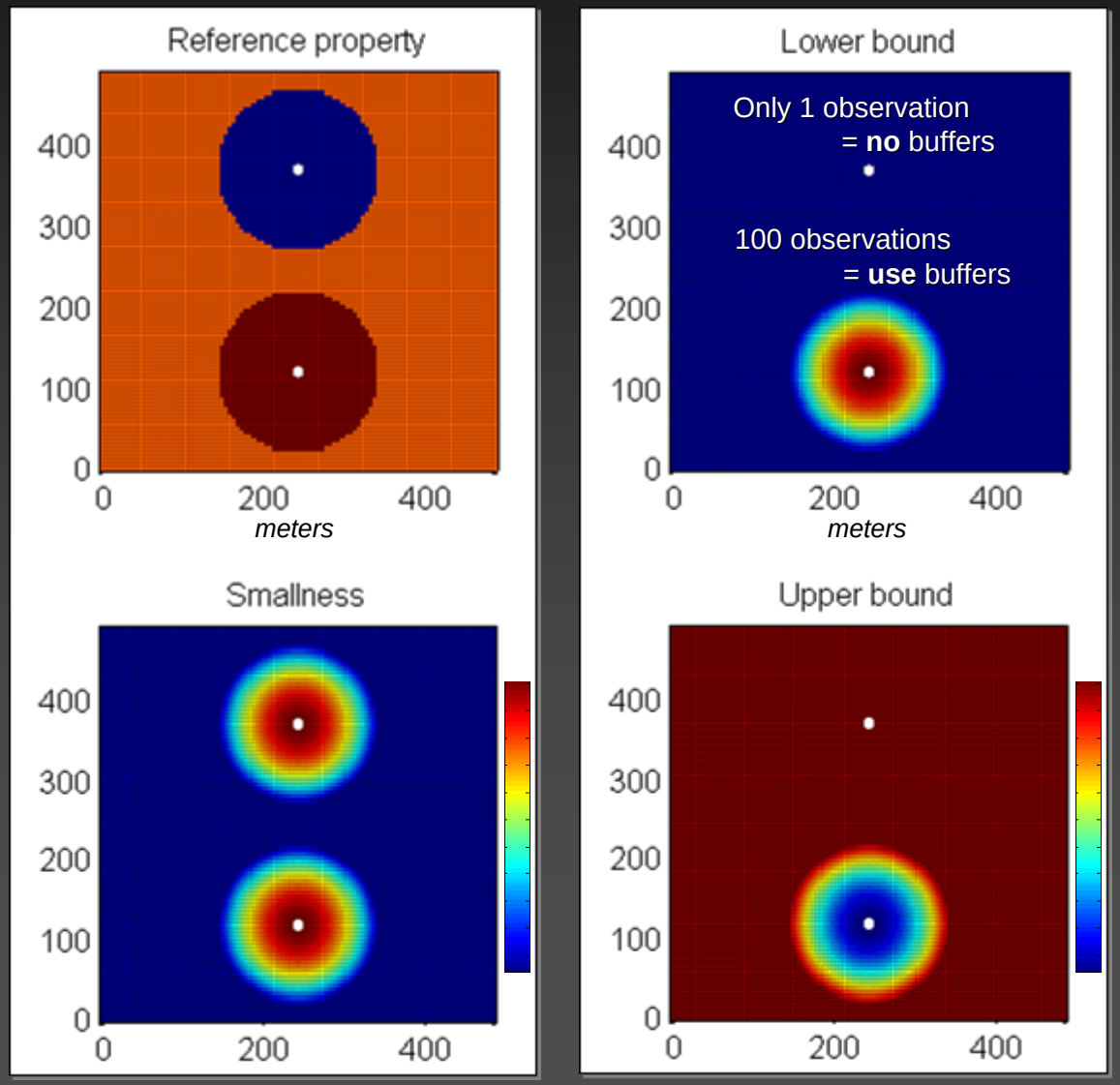
The 3D models only provide the default property values

Buffer cells

- **Optional buffers extrapolate properties away from observation points**
  - Buffers provide data-based estimates of the properties near data-bearing cells
  - Can use different buffer distances for different data types
  - Properties will extend to the buffer edge or the nearest data cell
- **Key difference between 3D geology and domain models**
  - For geology models:
    - Properties are only extrapolated within geological units
    - Buffers are truncated by any geological boundaries in the model (*which are assumed to be well-defined*)
  - For domain models:
    - Properties will be extrapolated across domain boundaries (*which are assumed to poorly-defined*)

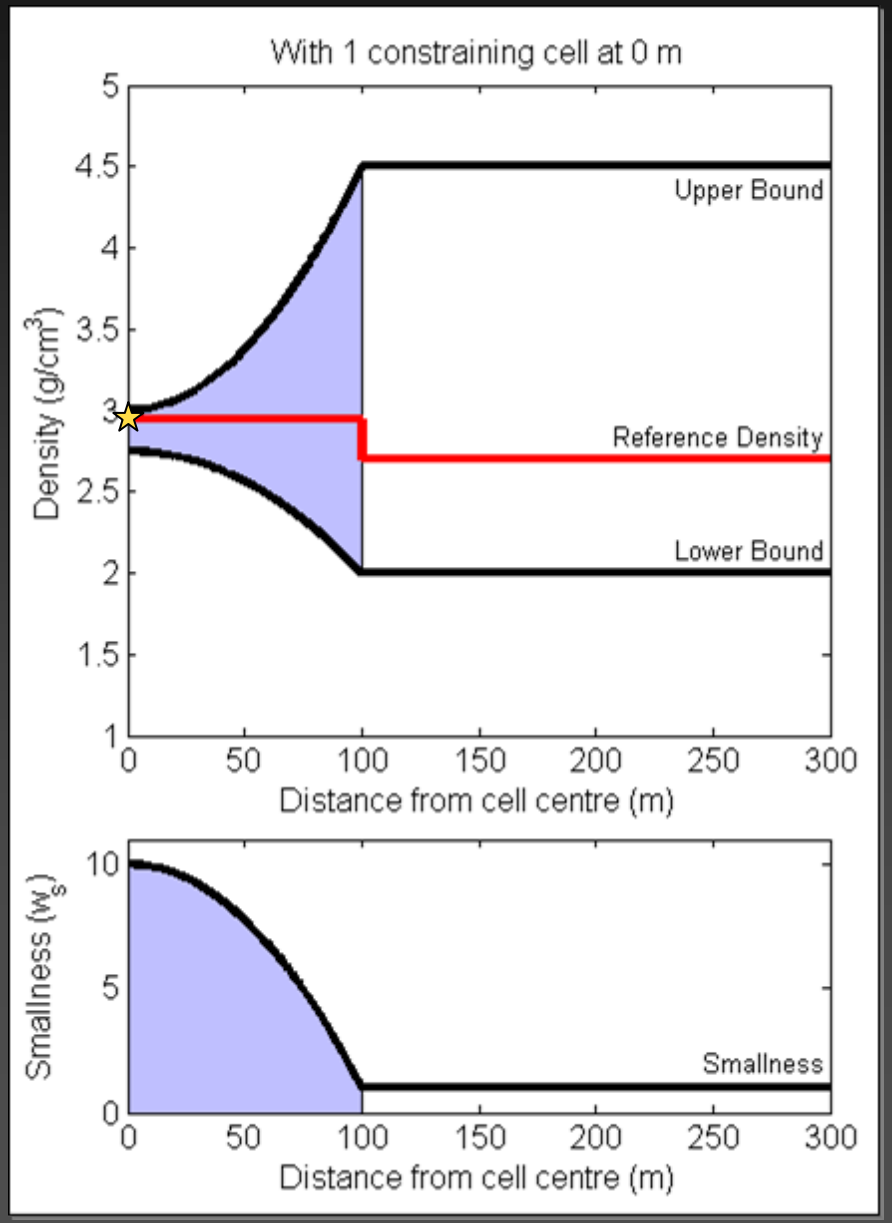
Buffer cells

- **Buffers are spherical around data cells**
  - Ellipsoids would be better to reproduce geological trends
- **Reference properties and smallness:**
  - Buffers applied throughout
- **Property bounds:**
  - Buffers only applied if the cell is sufficiently sampled

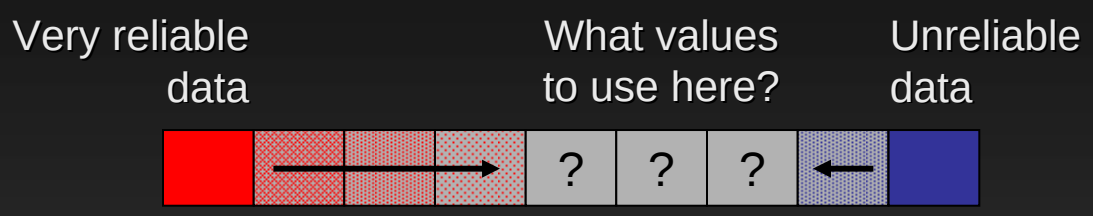


If only 1 data cell within the buffer zone:

- **Reference property**
  - Data value applied equally to all cells in buffer
- **Smallness, and lower & upper bounds**
  - Taper to background values with square of distance-from-data



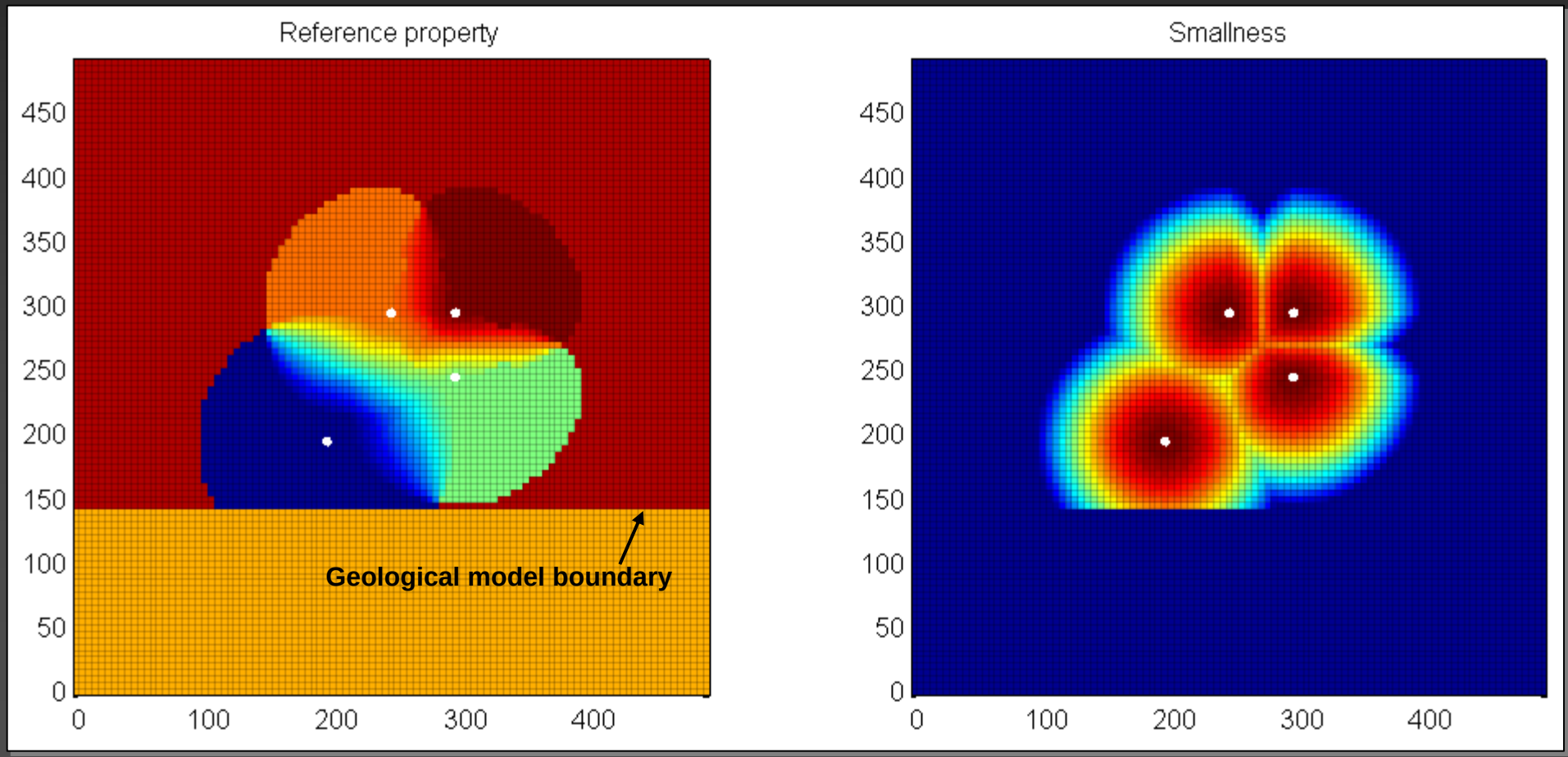
If multiple data cells within the buffer zone:



- **Reference properties: 3 methods**
  1. **Weighted average based on distance from data cells and smallness (reliability) of data types**
     - All data should contribute, but trust some types more than others
  2. Median from the highest smallness (most reliable) data cells
     - Only take the “best” estimates
  3. Median from the nearest data cells
     - Only take the nearest estimates
- **Smallness (w_s)**
  1. **Maximum distance-weighted smallness in each buffer cell**
     - The more data we get, the higher our confidence
     - The closer we get to the data, the higher our confidence

Multiple data cells: Reference properties

- Smallness is maximum of inverse-distance weighted values from data cells
- Reference property is weighted by the inverse-distance smallness weights

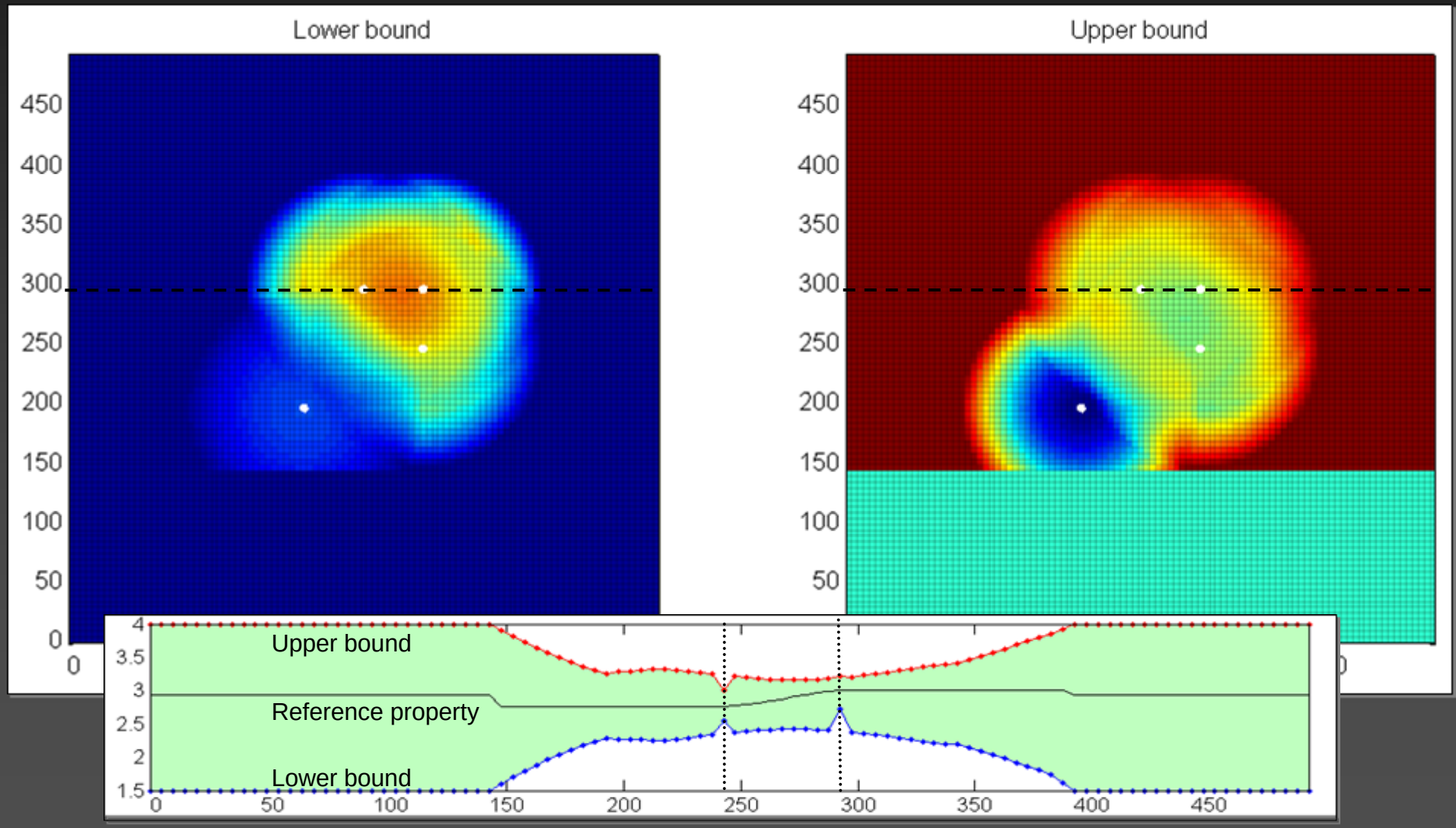


Multiple data cells: Property bounds

- **Bounds: Choice of 4 methods**
  - 1 based on *values* only
    1. Most extreme bounds from nearest data
  - 2 based on *distance* from data cell
    2. Median of distance-weighted bounds from nearest data
    3. Most extreme distance-weighted bounds from nearest data
  - 2 based on *distance-weighted smallness*
    4. **Weighted average of smallness- and distance-weighted bounds from all data**
    5. Most extreme distance-weighted bounds from the nearest, most reliable data

Multiple data cells: Property bounds

- **Bounds are weighted by the inverse-distance smallness weights. Median**

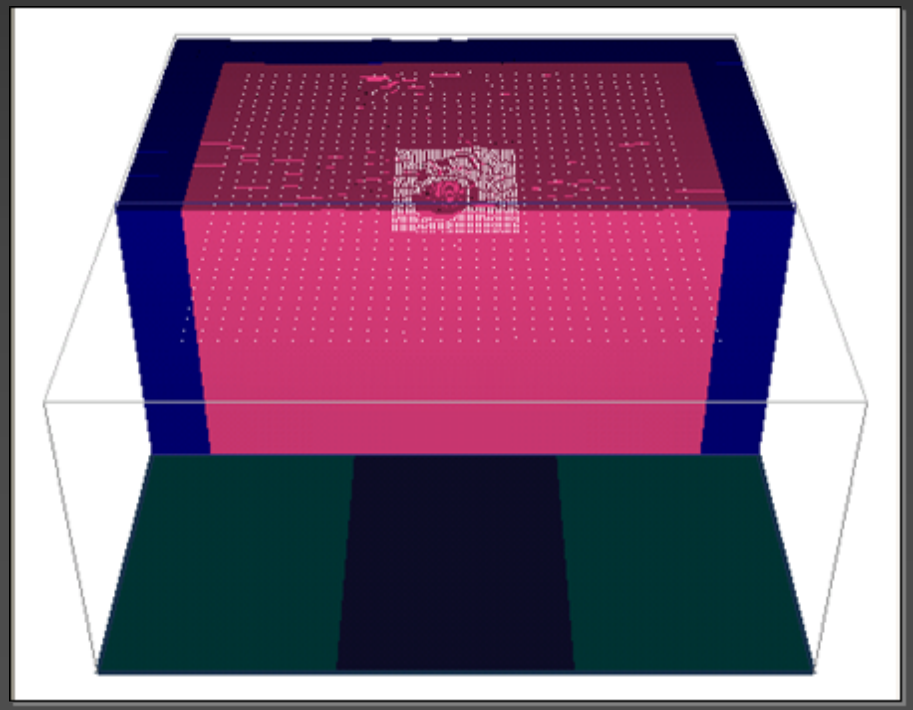


Why no kriging of properties?

- **Kriging estimates the mean and variance at a location based on the spatial distribution of samples around that location and their values**
  - Our general case is a very special kriging case
    - Poorly sampled, very irregularly spaced observations from disparate data (geology v. measurements) across different geological units and domains in 3D
  - Kriging smoothes out heterogeneities, but heterogeneities in physical properties are important because they produce the gravity and magnetic responses
- **Inversion models have a different goal**
  - Require estimate of the mean and the confidence interval containing the mean for each cell based on the contents of that cell
- **Some geostatistical techniques may still be useful**

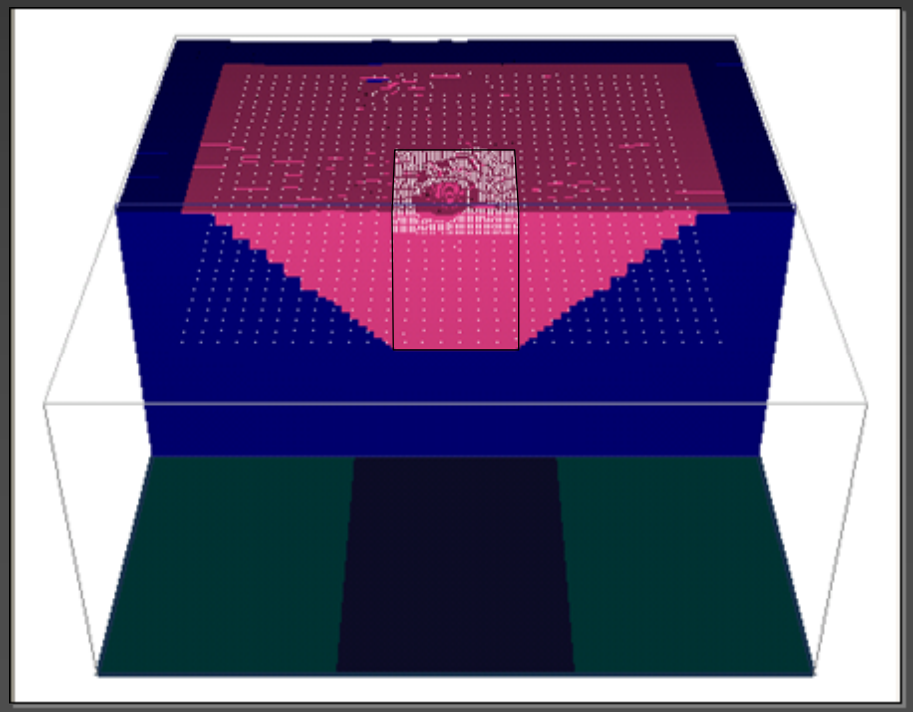
Cropping constraints: To data area

- **Only expect to match constraints where geophysical data is available, so crop the model to those cells that lie below the geophysical data**
  - User supplies a mesh for the volume below the data area
  - Can be used to crop the constraints to any sub-mesh volume.



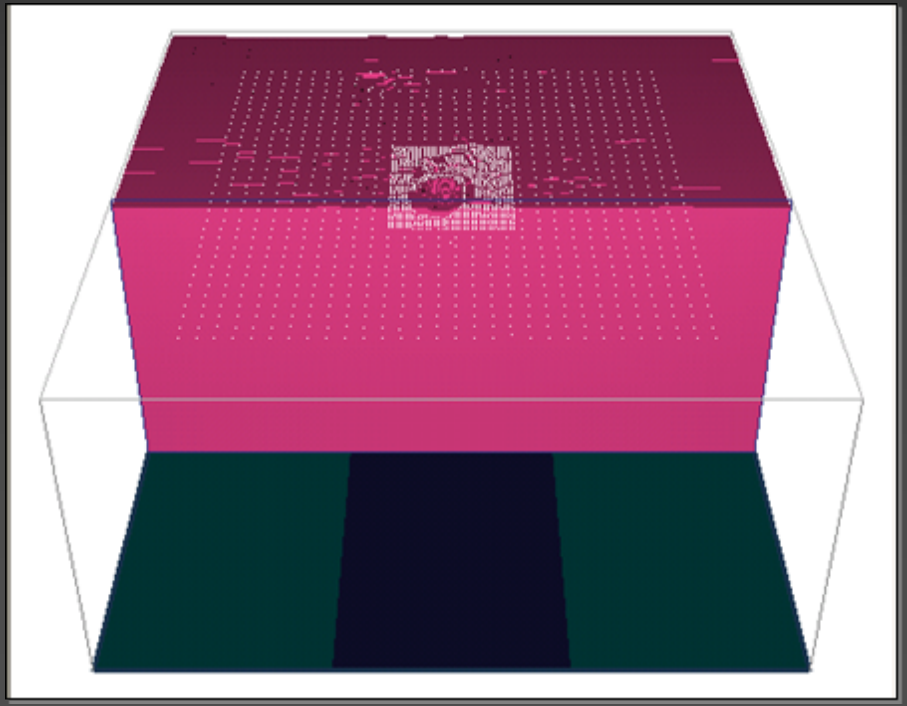
Cropping constraints: To bowl region (best)

- **Also crops the model to those cells that lie below the geophysical data**
- **But, narrows the zone of constraints with increasing depth due to the larger wavelengths required at greater depths**
  - User supplies a mesh for the volume below the data area and a mesh for the “trusted” core region.



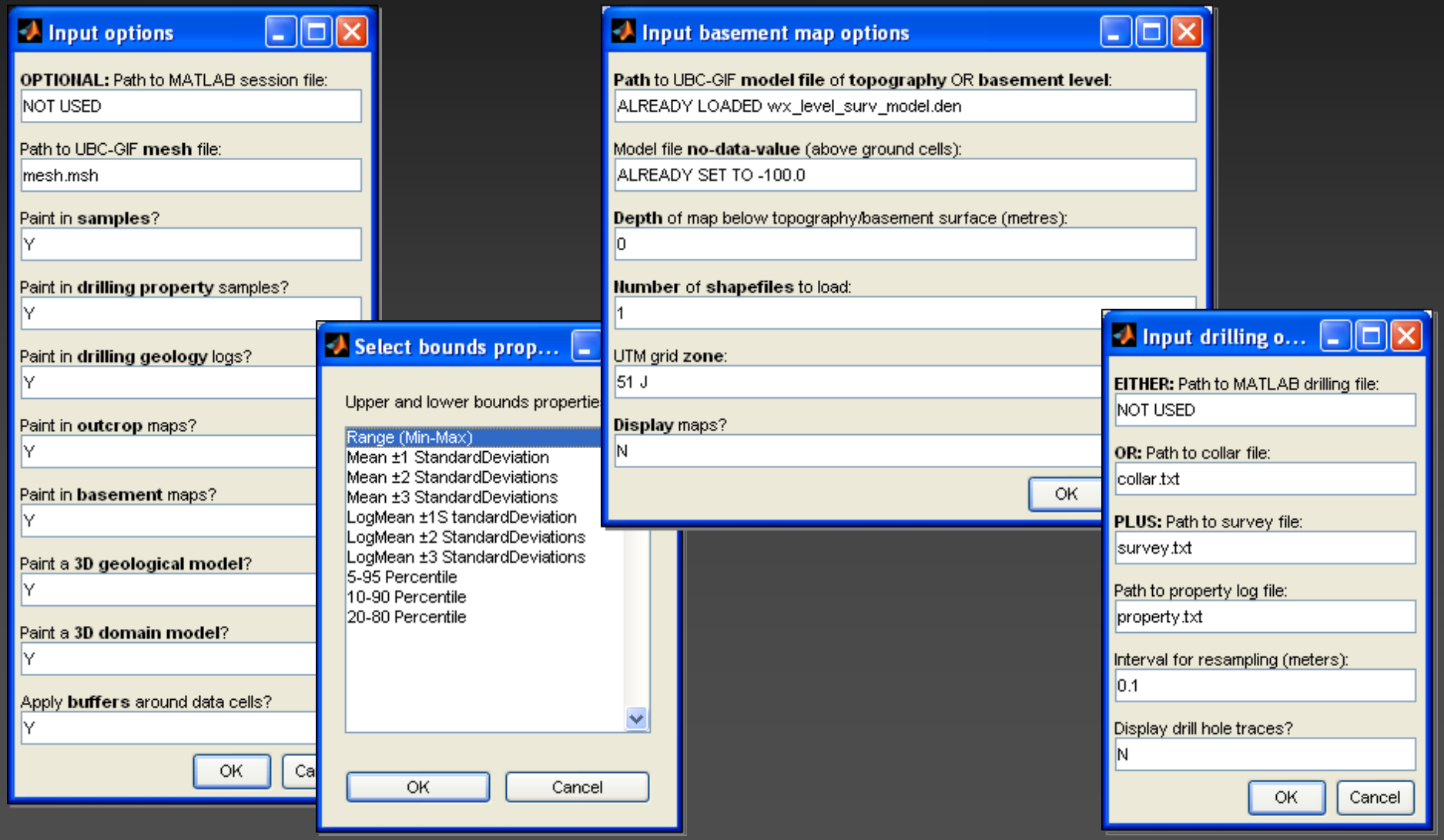
Cropping constraints: None

- **Take all the constraints within the mesh**
  - Not advised.
  - Might find use as a quick-and-dirty approach since other two methods require extra meshes to be defined.



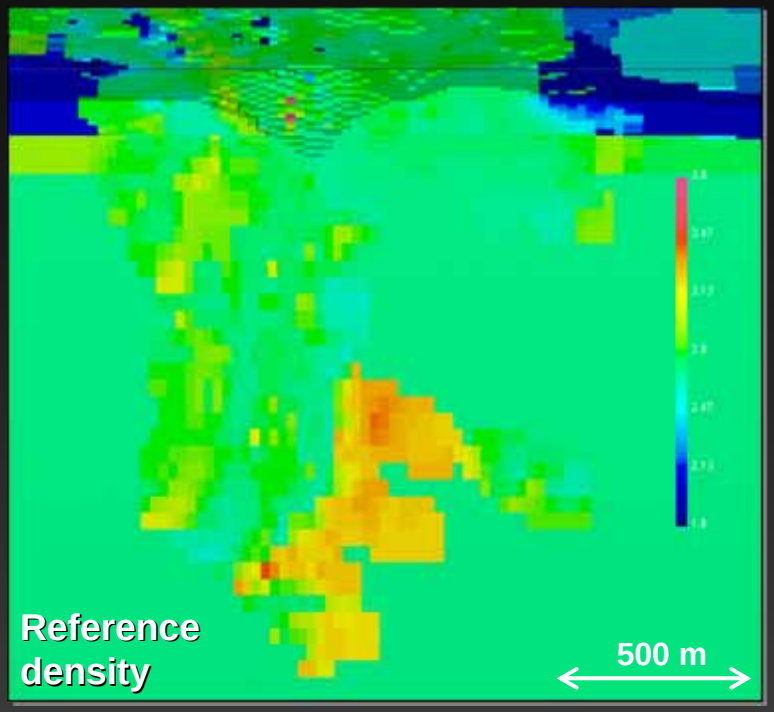
Interface: Basic GUI

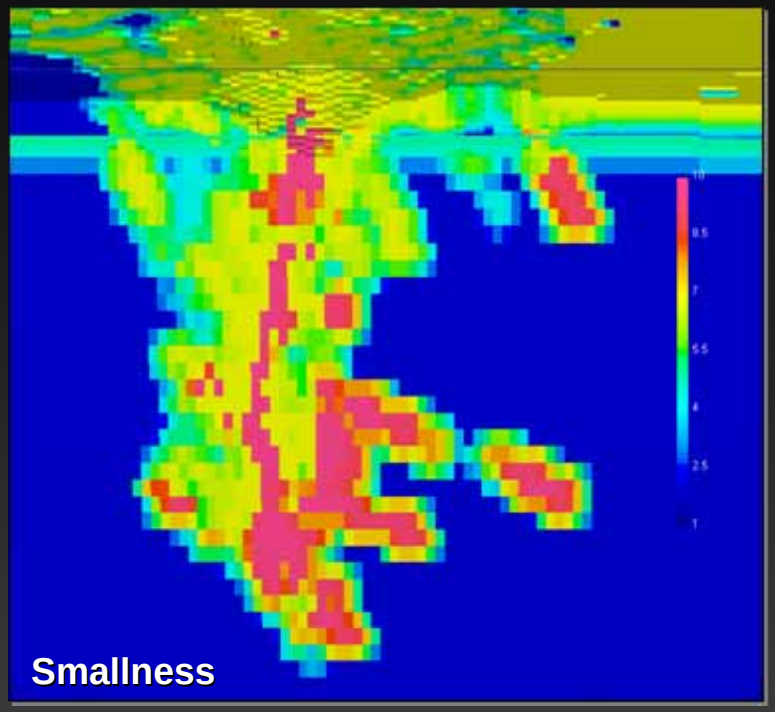
- **Series of MATLAB standard dialog boxes for text input of choices, parameters, filenames**

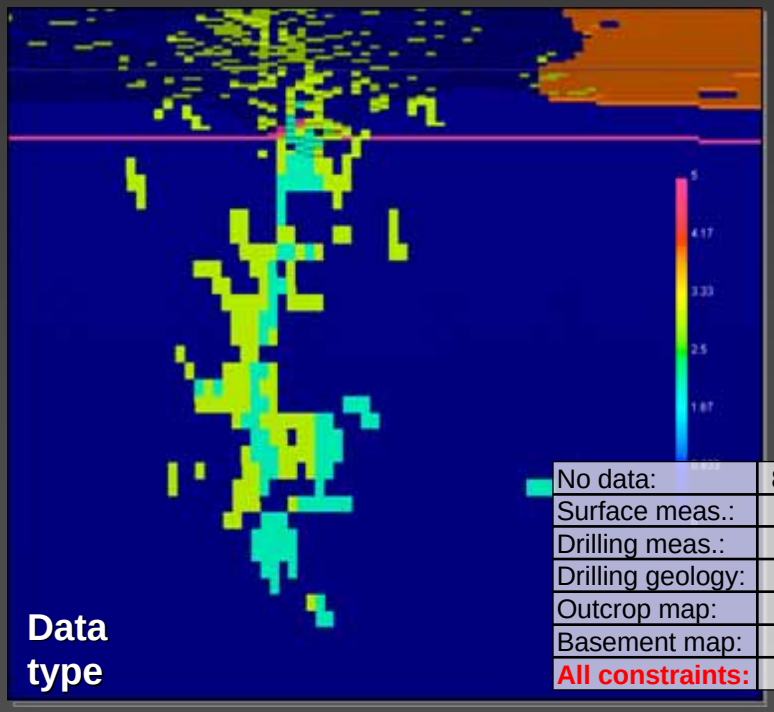


Interface: Options

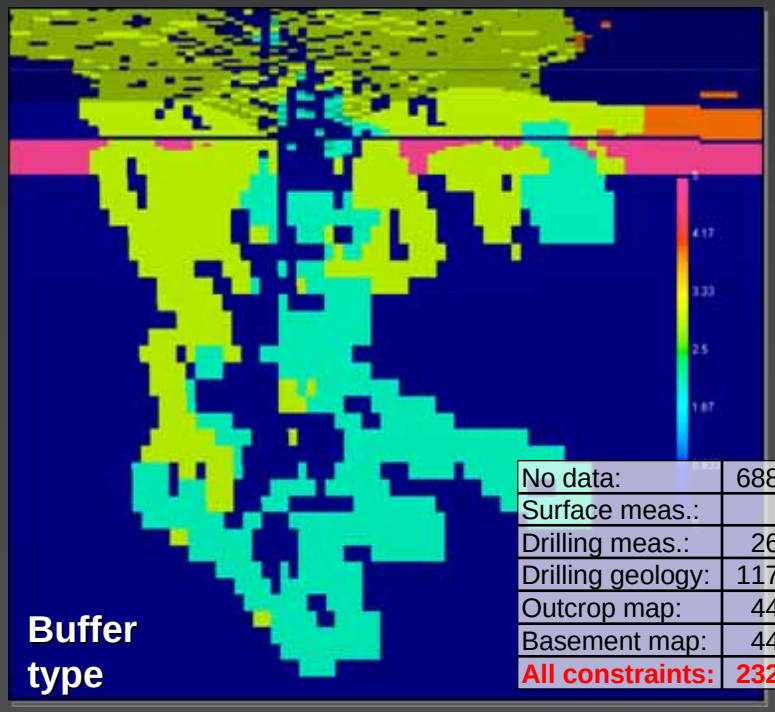
- **All options are stored in a series of MATLAB files**
  - Any existing option files are automatically used as defaults for the next run
  - Options can be reloaded to recreate or update a model
- **Some displays and statistics for the input data**
- **Choose density or susceptibility**
- **Create reference model with smallness weights, or bounds model, or both**
  - With or without user-defined buffers distance
- **Time required?**
  - Less than 45 minutes including all data types, and creating reference, smallness, and bounds models with buffers



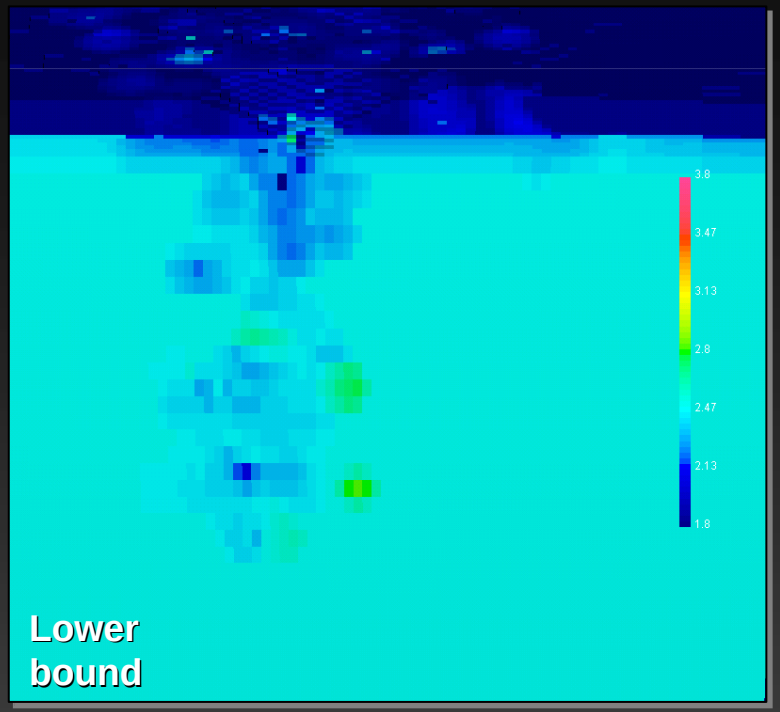


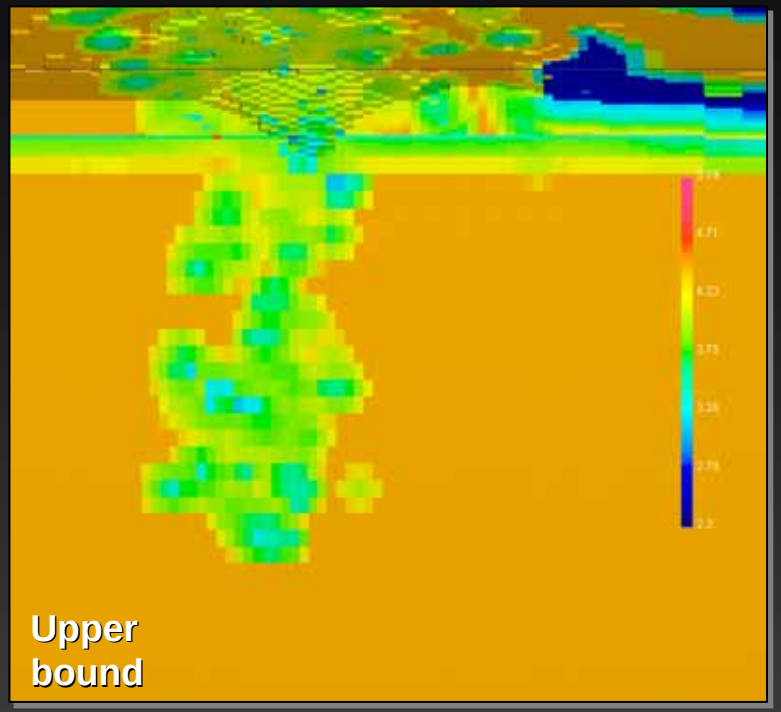


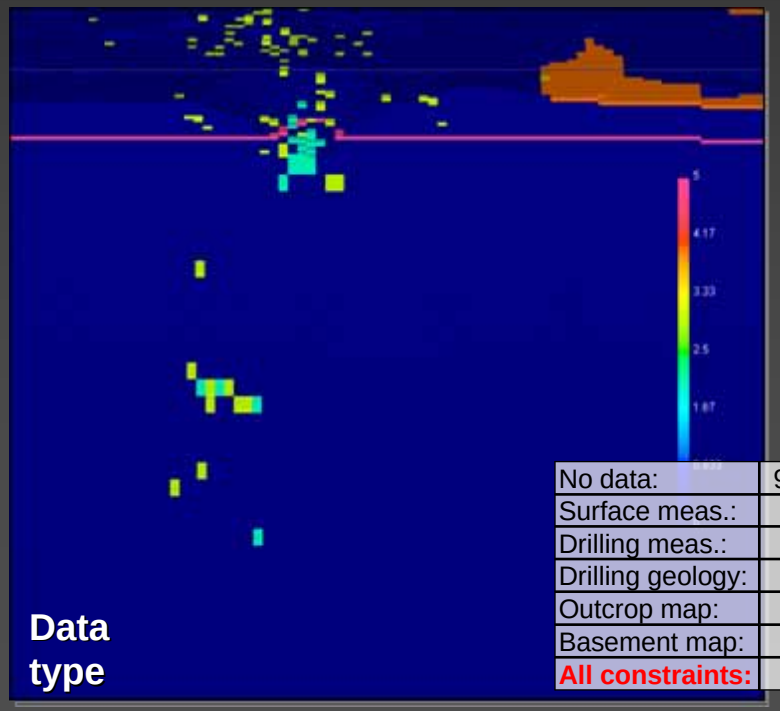
No data:	881,476	95.7%
Surface meas.:	0	0.0%
Drilling meas.:	4,302	0.5%
Drilling geology:	18,178	2.0%
Outcrop map:	6,355	0.7%
Basement map:	10,545	1.1%
All constraints:	**39,380**	**4.3%**



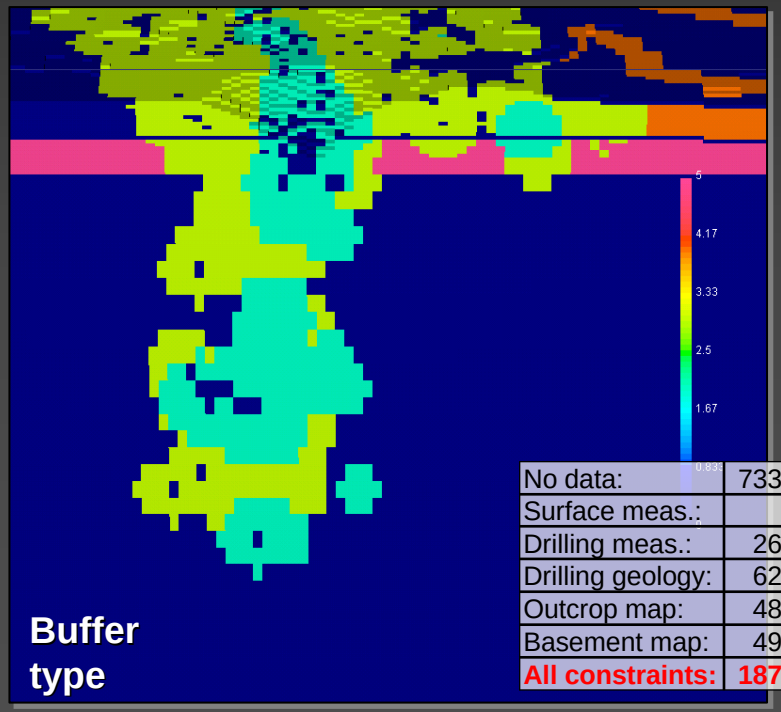
No data:	688,085	74.7%
Surface meas.:	0	0.0%
Drilling meas.:	26,276	2.9%
Drilling geology:	117,344	12.7%
Outcrop map:	44,636	4.8%
Basement map:	44,515	4.8%
All constraints:	**232,771**	**25.3%**





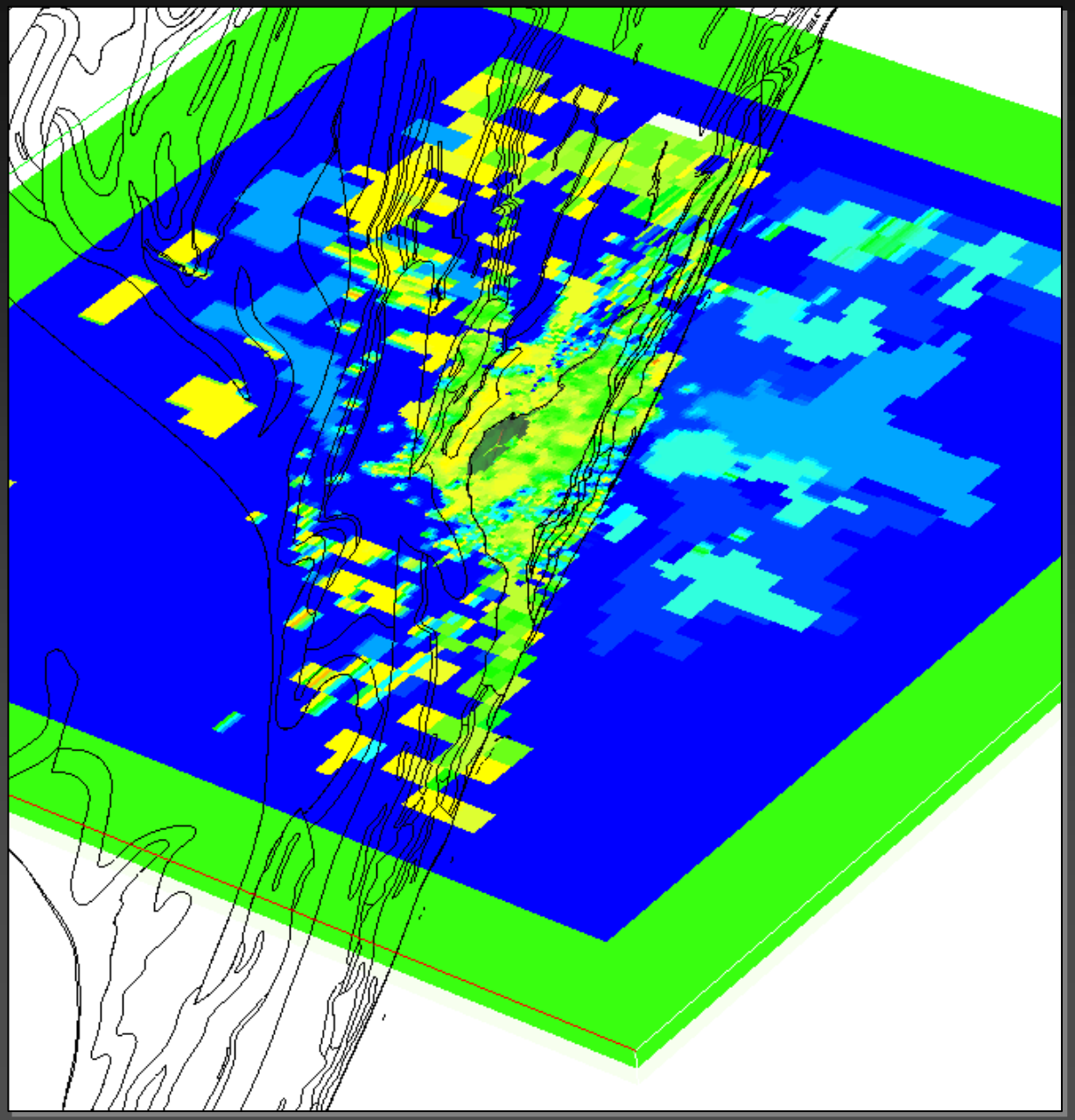


No data:	901,043	97.8%
Surface meas.:	0	0.0%
Drilling meas.:	832	0.1%
Drilling geology:	2,636	0.3%
Outcrop map:	5,374	0.6%
Basement map:	10,971	1.2%
All constraints:	**19,813**	**2.2%**



No data:	733,371	79.6%
Surface meas.:	0	0.0%
Drilling meas.:	26,683	2.9%
Drilling geology:	62,755	6.8%
Outcrop map:	48,237	5.2%
Basement map:	49,810	5.4%
All constraints:	**187,485**	**20.4%**

Comparison with existing wireframe models



The wireframes were ***NOT*** used when creating the model

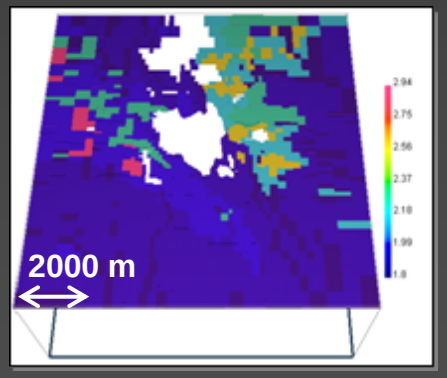
What do you need?

1. Download an outcrop geology map shapefile

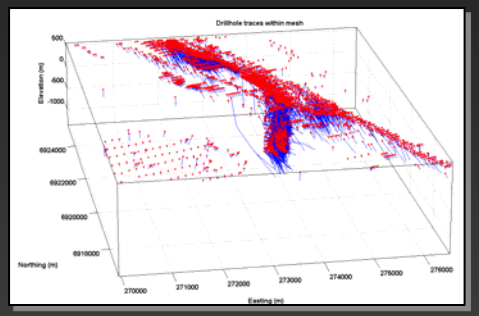
Or extract properties from your state/national physical property database?

2. Define some properties (use a textbook!)

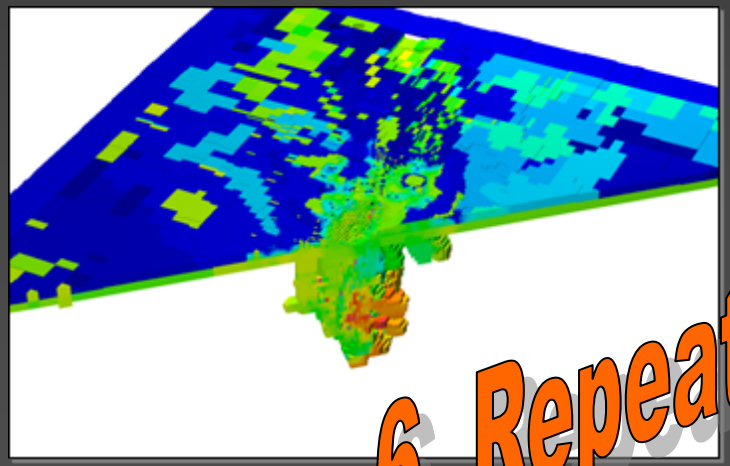
3. Run model builder (with buffers)



4. Start making measurements (surface samples & drilling)) and logging core!



5. Run model builder



6. Repeat

- **Provides constraints for the critical surface layers.**
- **Populates ~11 % of the model at Perseverance.**
- **Constrained inversion for $0 down!**

Future plans

- **Define buffers with ellipsoids rather than spheres**
- **Other data types**
  - Cross sections
    - What input format? Shapefiles? Raster images?
- **Triangulated surfaces**
  - Use surfaces to prevent buffers from spreading across known contacts
  - Build smoothness constraints from surfaces
- **Smoothness constraints**
  - From structural measurements
  - Buffer smoothness over a larger distance than properties
- **A real GUI?**
- **Suggestions??**