Unified geophysical and geological 3-D Earth models

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Acknowledgments

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Goal

⋆ A single 3-D Earth model for both geology and geophysics.

Outline

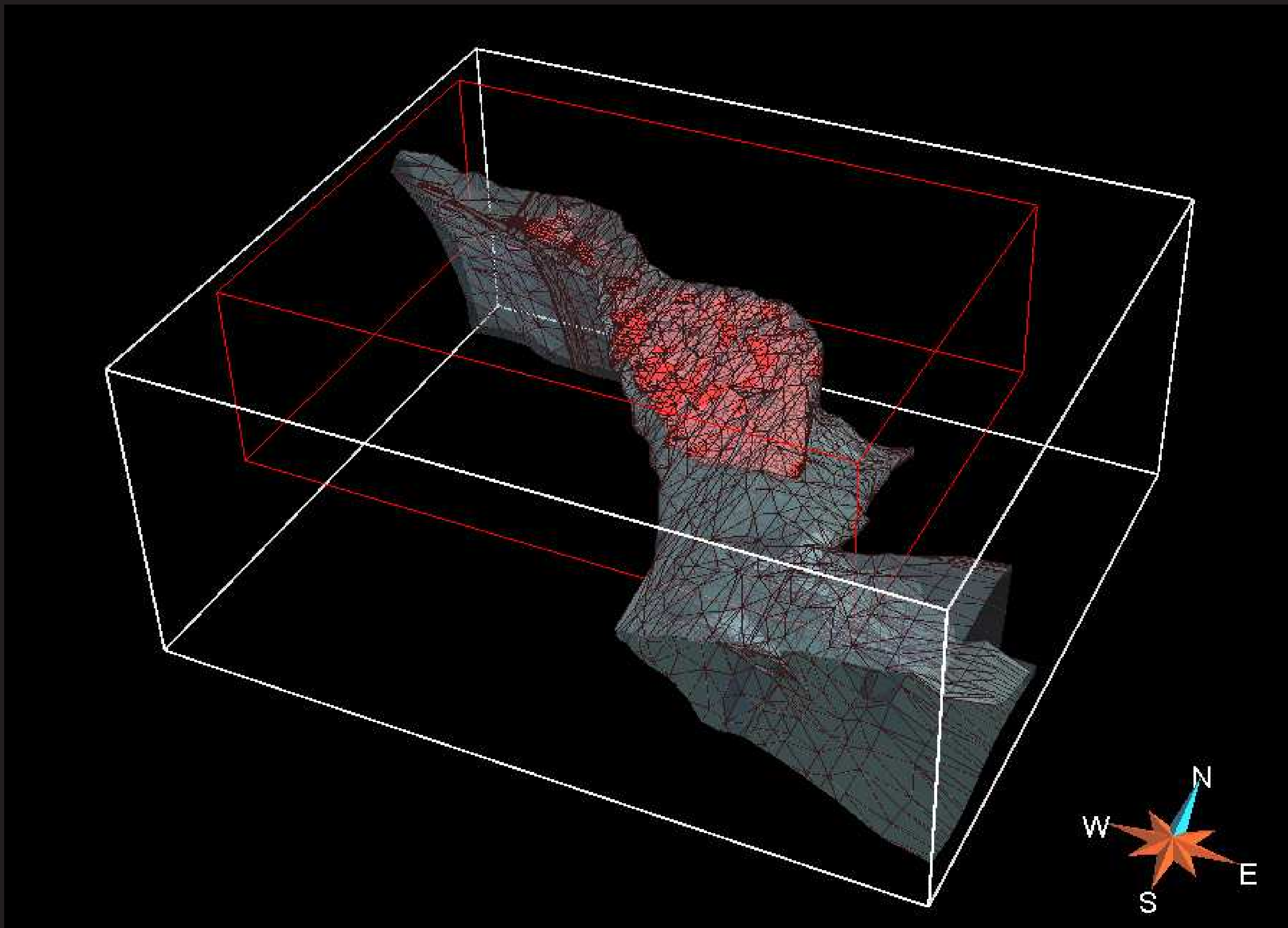
⋆ Geological models

⋆ Geophysical models and numerical modelling

⋆ Rectilinear grids vs. unstructured grids

⋆ Working with unstructured grids

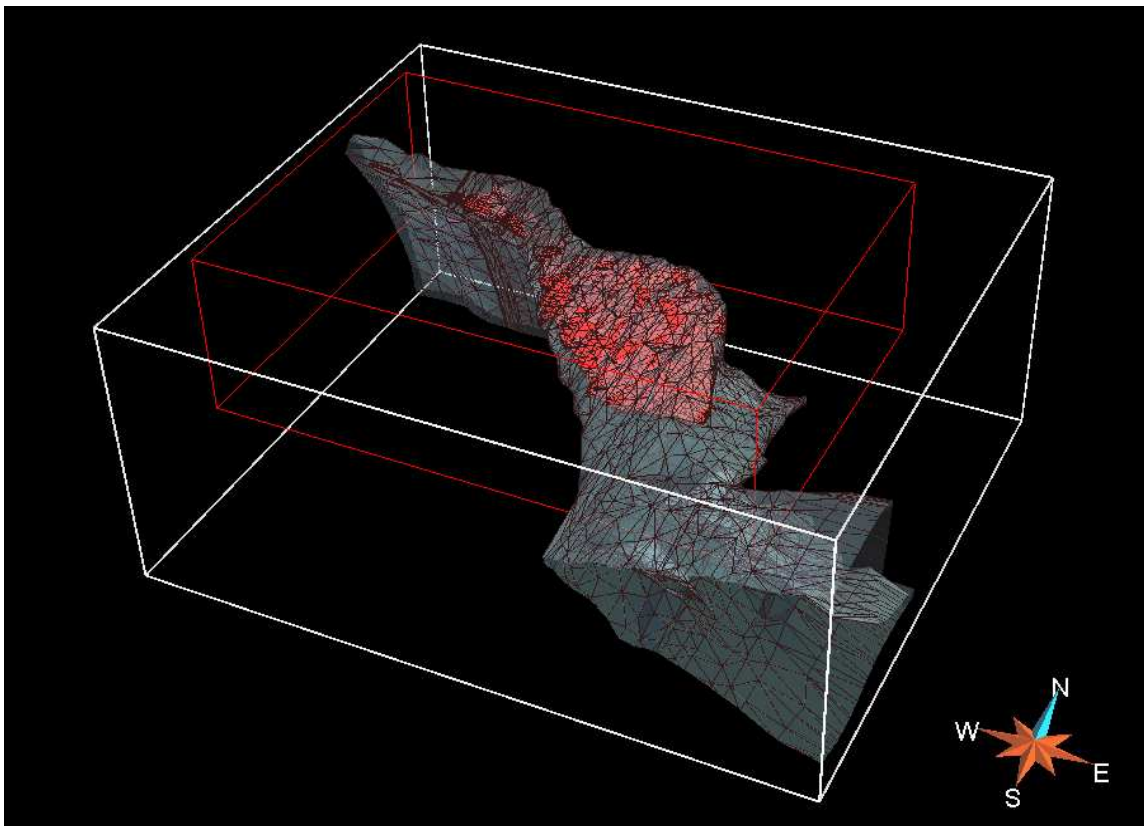
Geological models: tessellated surfaces



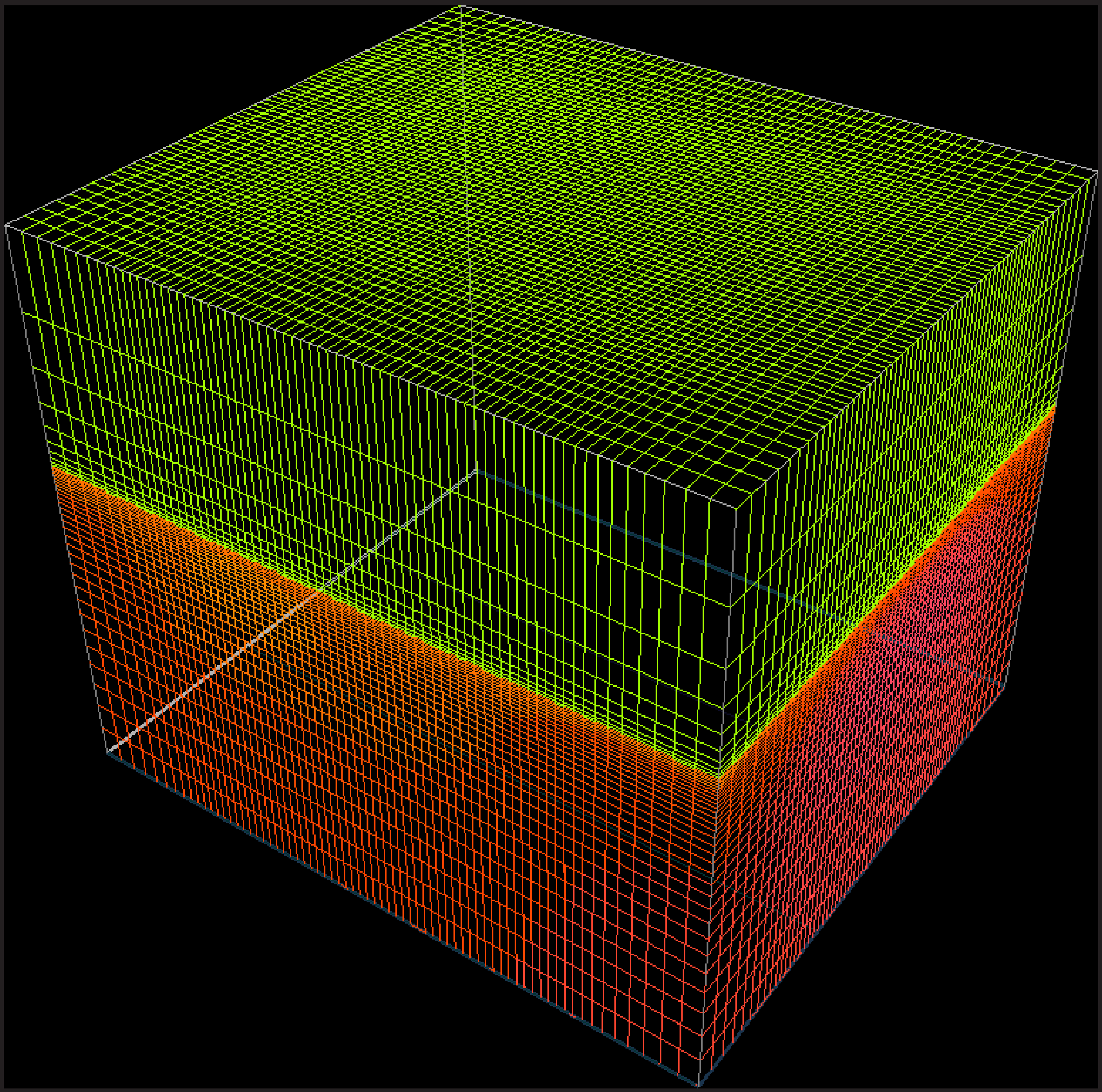
Voisey's Bay Ovoid ore-body and troctolite.

Geological models: tessellated surfaces

- ⋆ Surfaces consist of connected triangles.
- ⋆ Can capture arbitrarily complicated subsurface contacts.

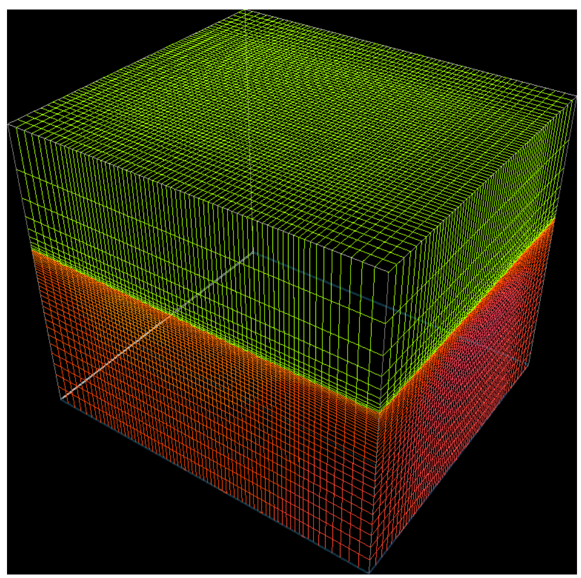


Geophysical models: rectilinear grids

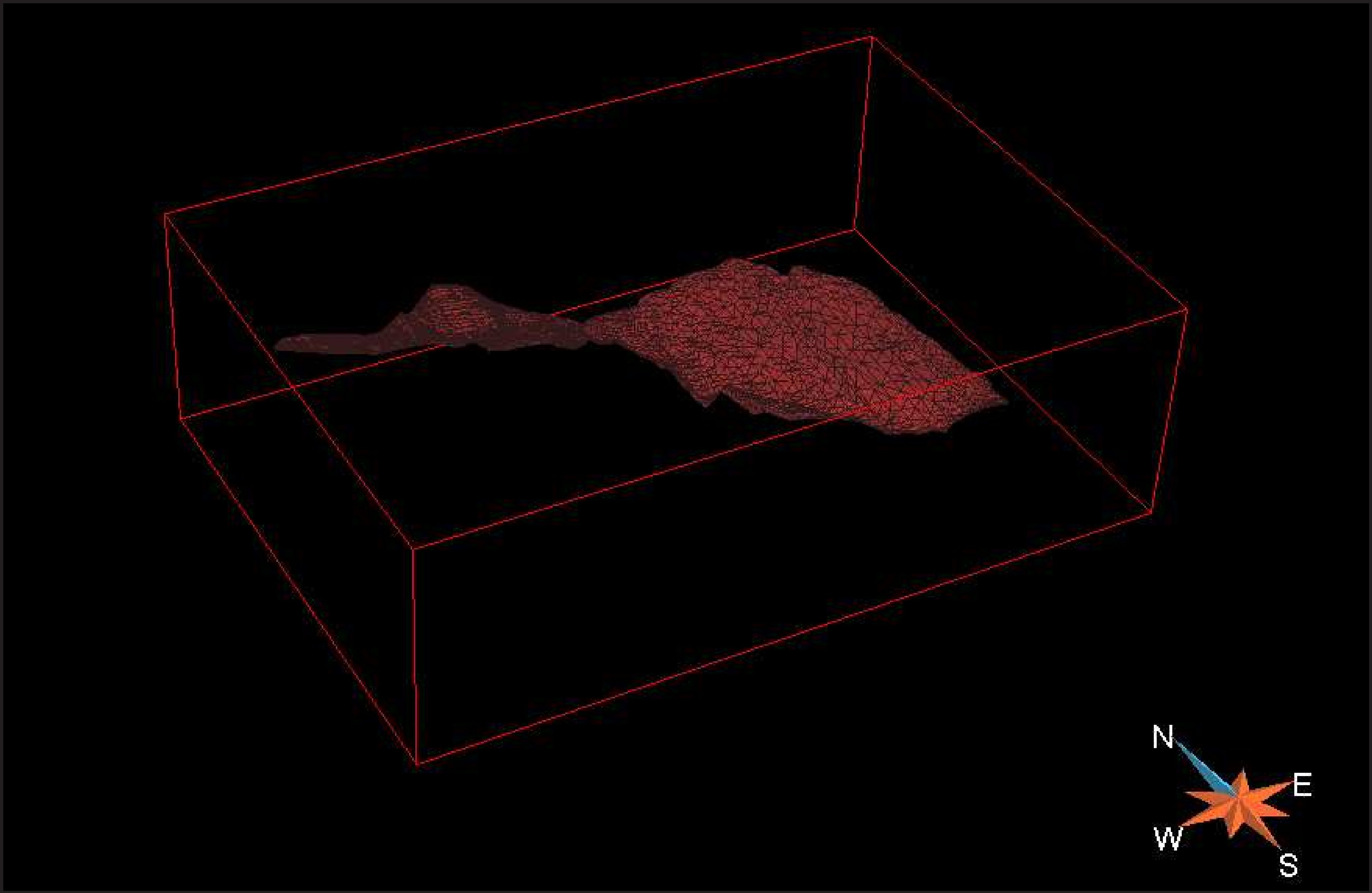


Geophysical models: rectilinear grids

- ⋆ Regular mesh of brick-like cells, physical properties uniform within each cell but different between cells . . .
  - → Pixellated representation of the subsurface.
- ⋆ Mathematics for computing data response are easier.
- ⋆ In principle, arbitrary spatial variations can be represented if a sufficiently fine discretization is used.

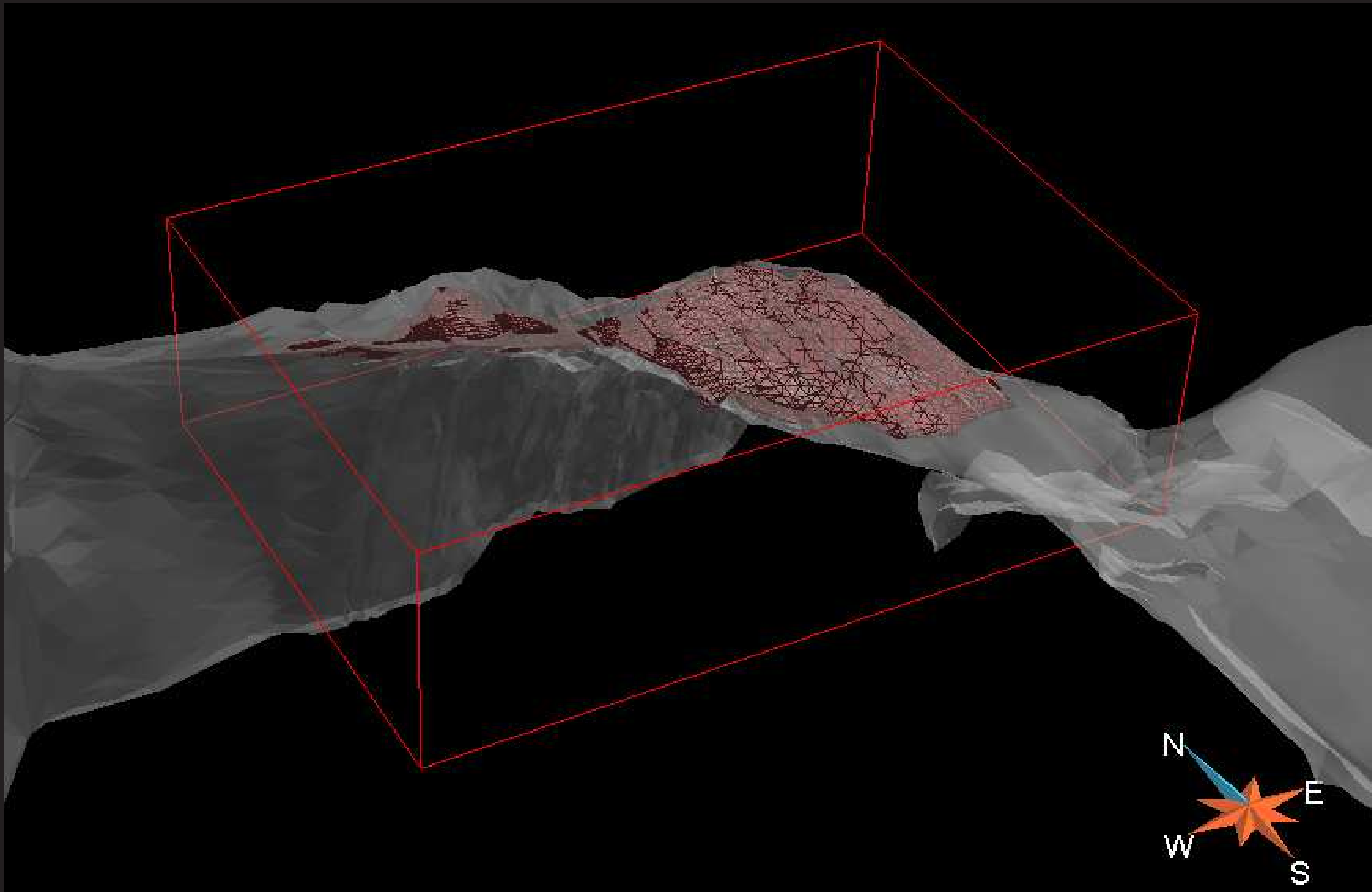


From surfaces to a rectilinear grid



(Mike Ash, M.Sc. thesis)

From surfaces to a rectilinear grid



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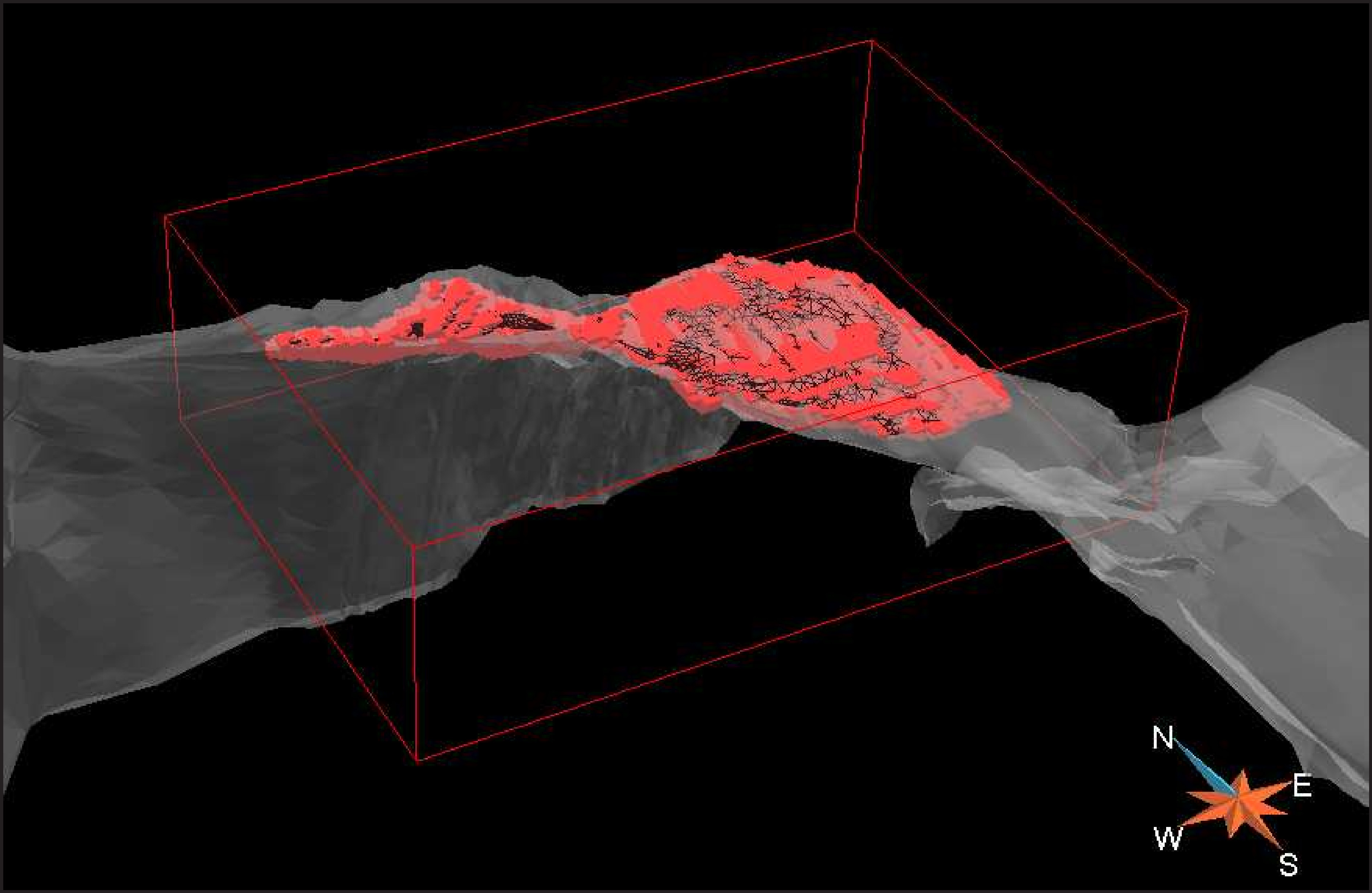

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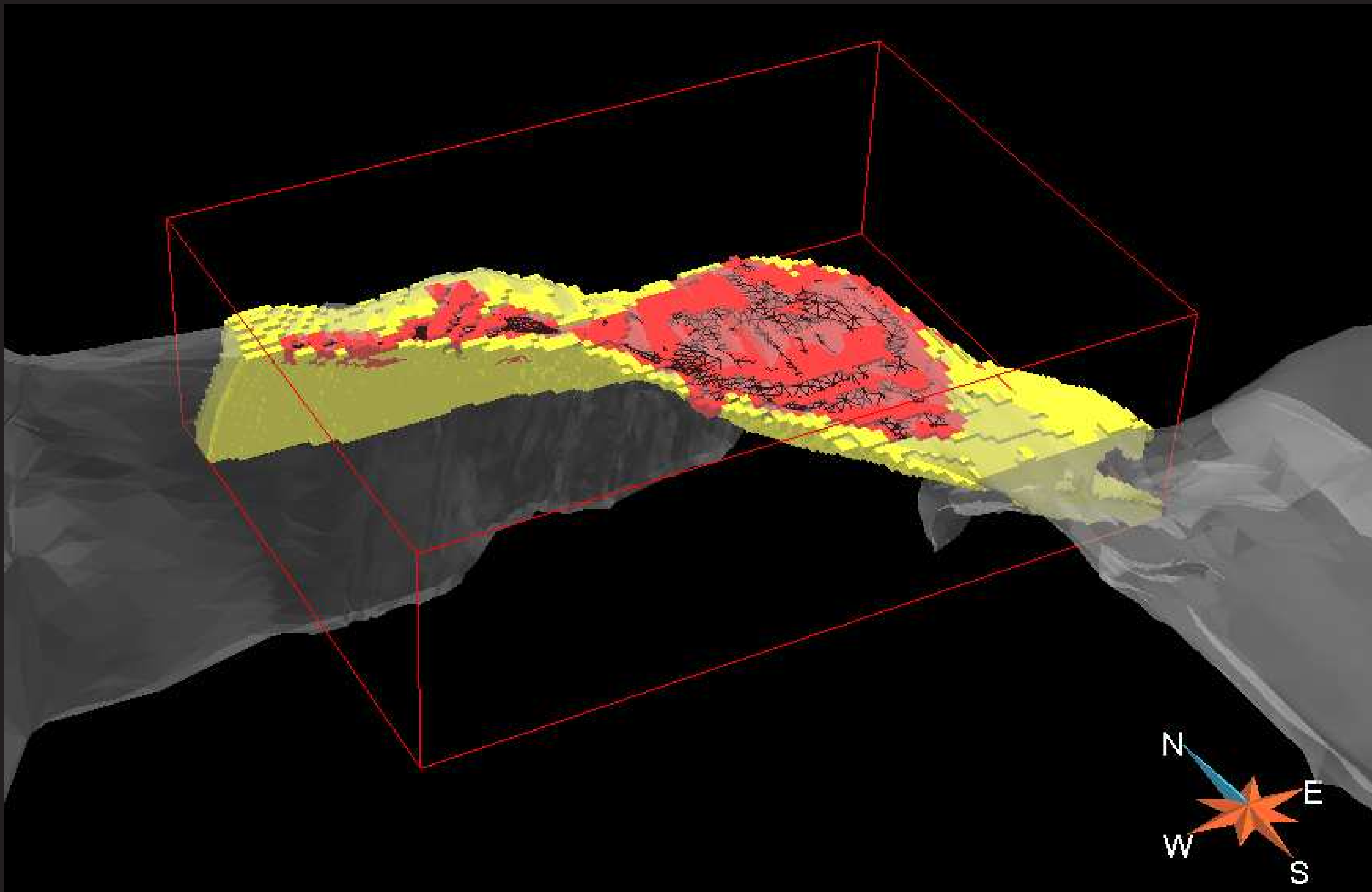
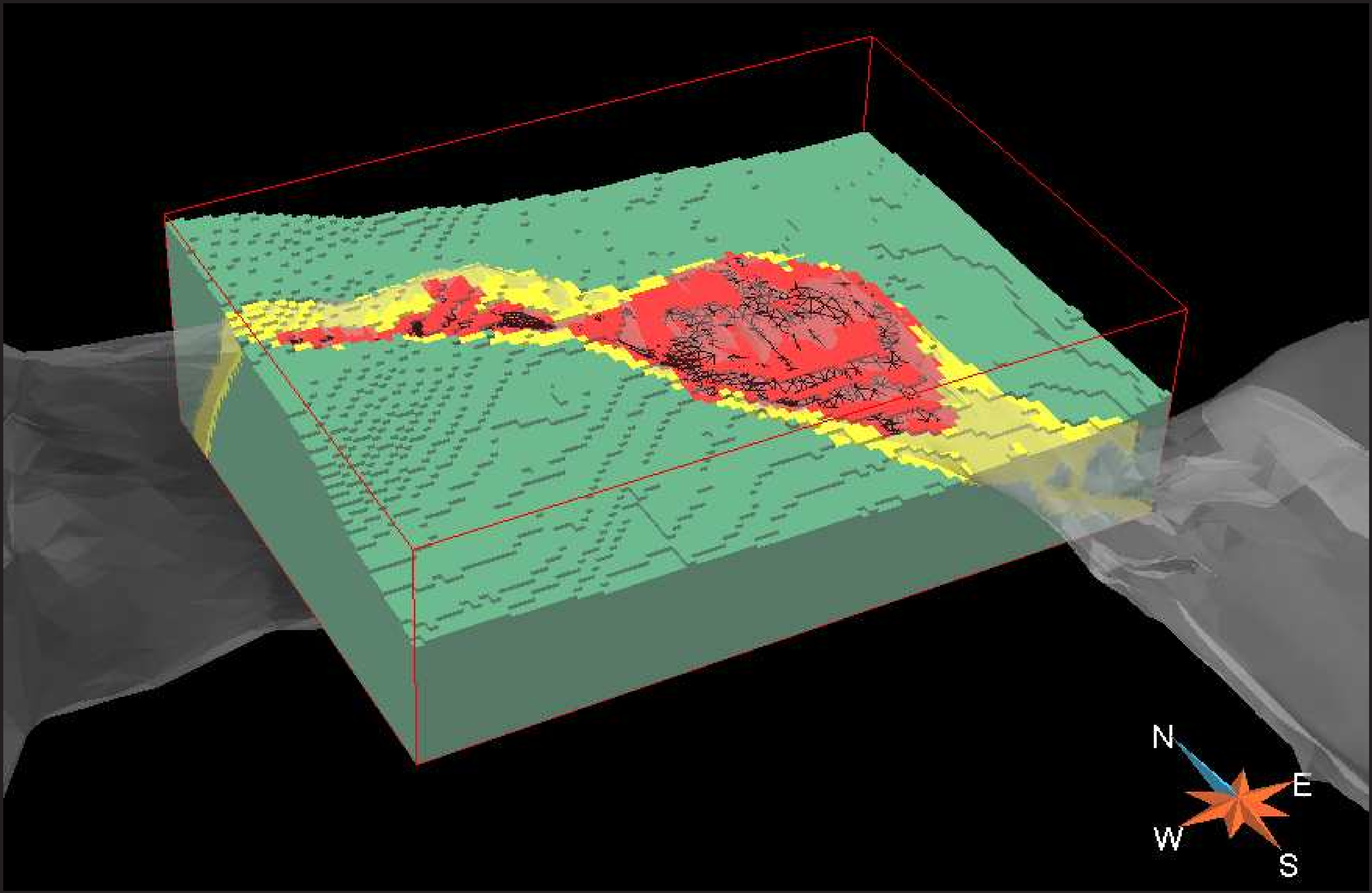


(Mike Ash, M.Sc. thesis)

From surfaces to a rectilinear grid



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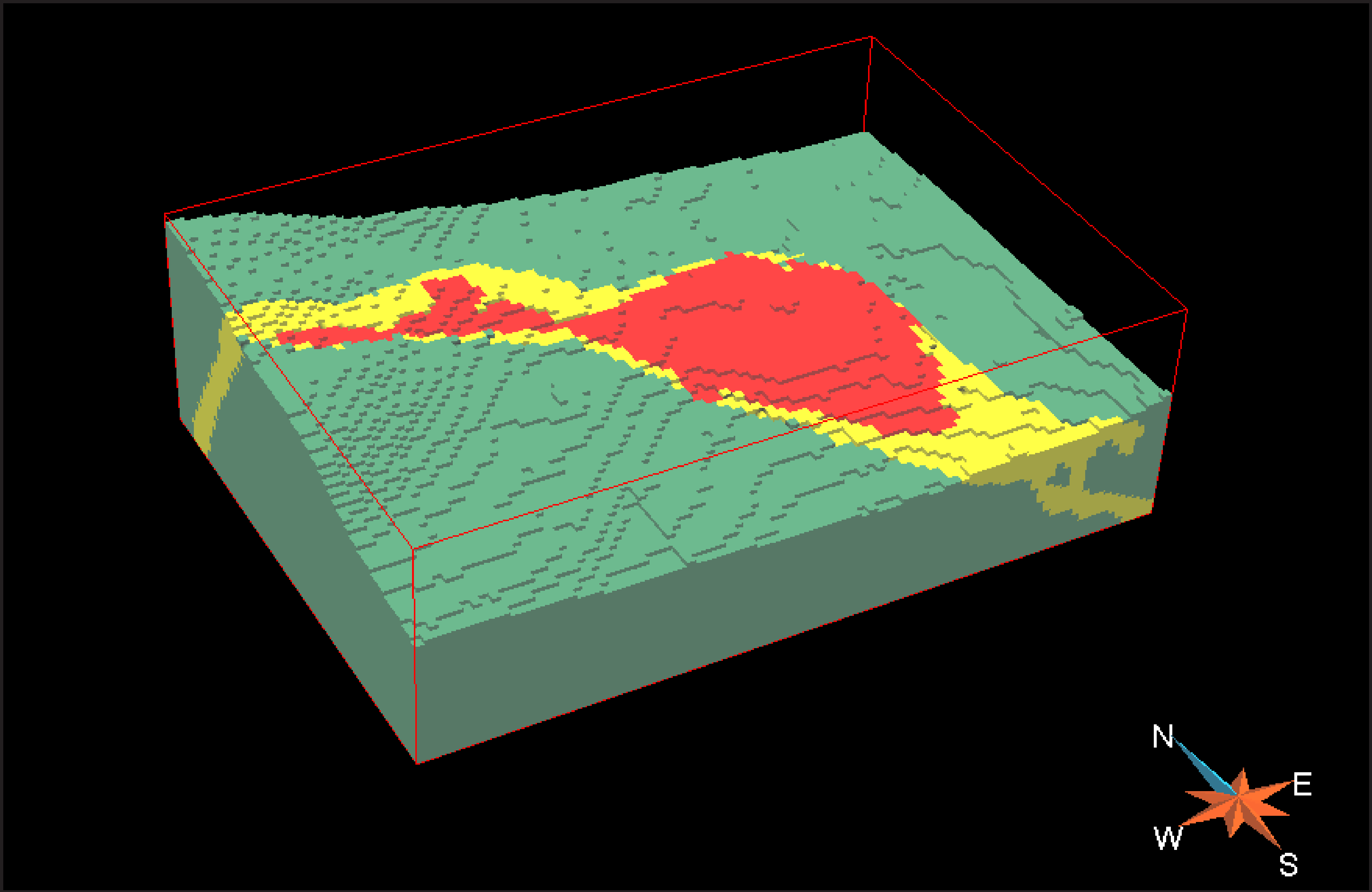
From surfaces to a rectilinear grid



(Mike Ash, M.Sc. thesis)

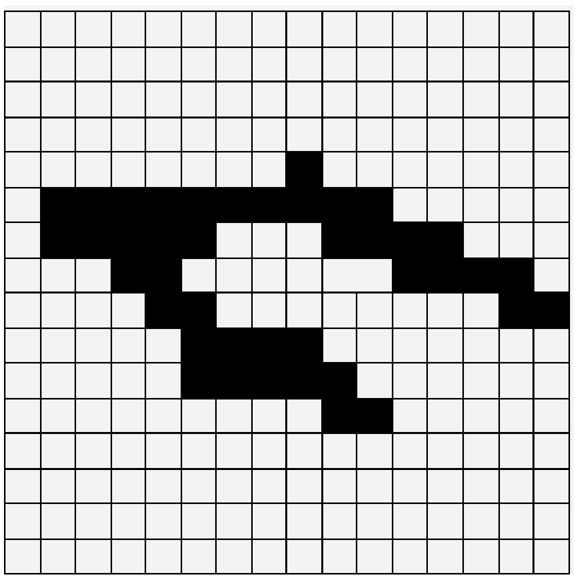
From surfaces to a rectilinear grid

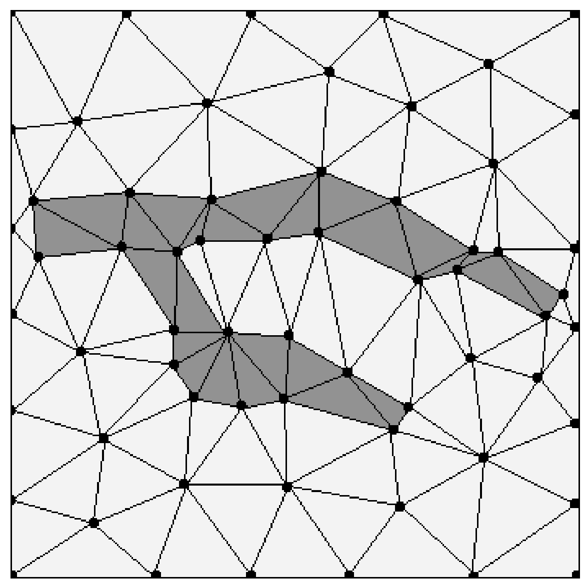
- ⋆ Previous example: $87 \times 61 \times 54 = 286{,}578$ cells …
  $\rightarrow$ a reasonably fine discretization.

- ⋆ But “staircasing” of contacts still evident.

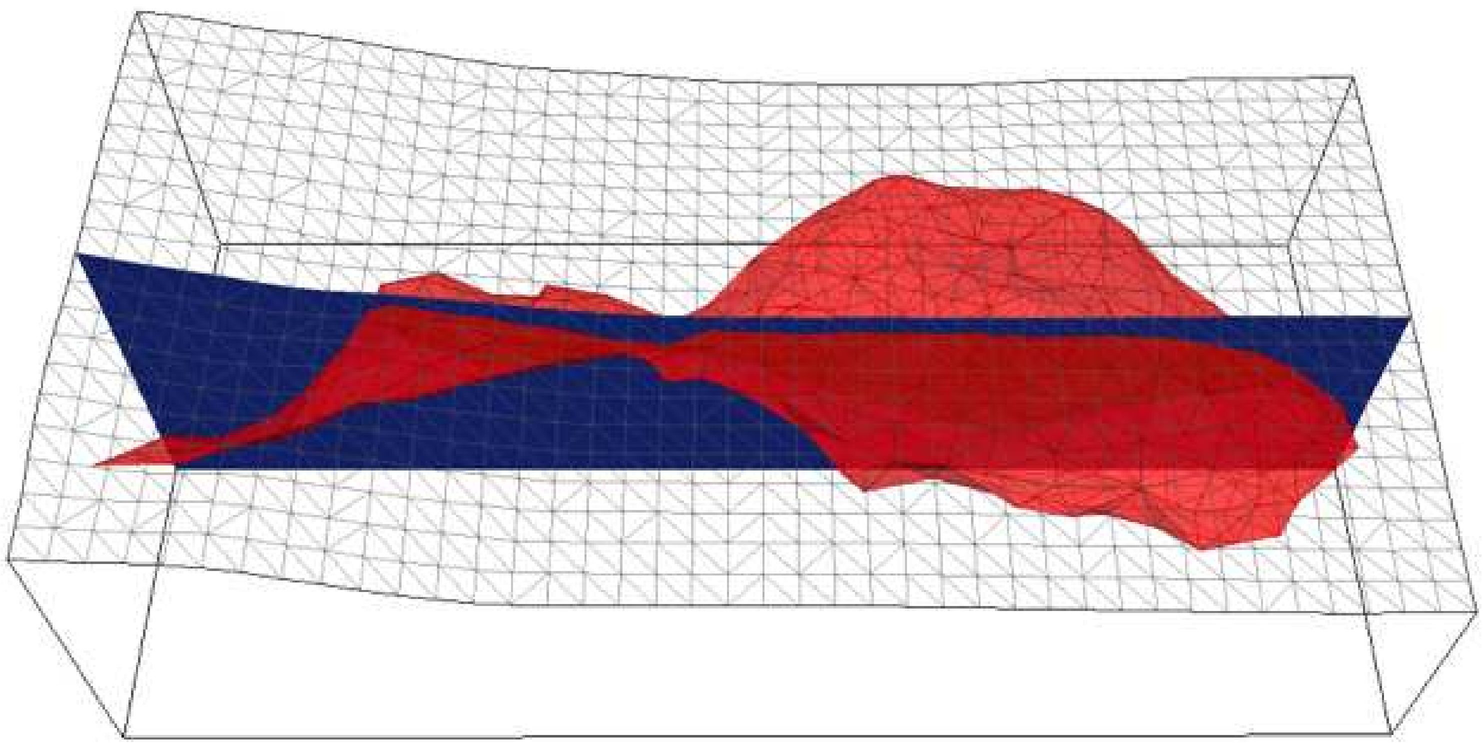
- ⋆ Finer is possible, but computation times and memory requirements quickly become inconvenient / infeasible.

So …

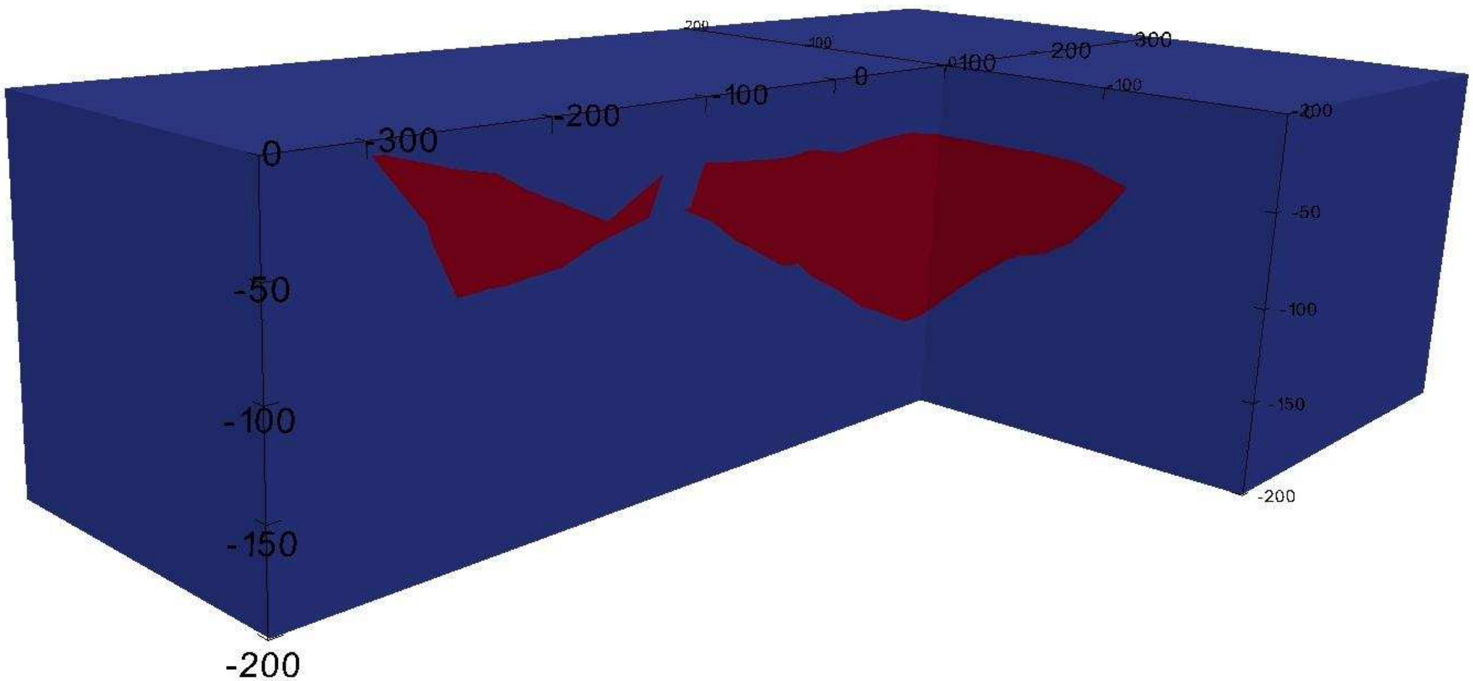




Geophysical models: unstructured tetrahedral grids



Geophysical models: unstructured tetrahedral grids



(Cassandra Tycholiz, M.Sc. student)

Geophysical models: unstructured tetrahedral grids

- Discretize the volume between surfaces while maintaining exactly the tessellated surfaces.

- Geological and geophysical models can share the same grid …
  - → can be the same model,
  - → no translation or transformation from one kind of model to the other.

- Unstructured discretizations can capture fine-scale structure without greatly increasing memory requirements.

Geophysical models: unstructured tetrahedral grids

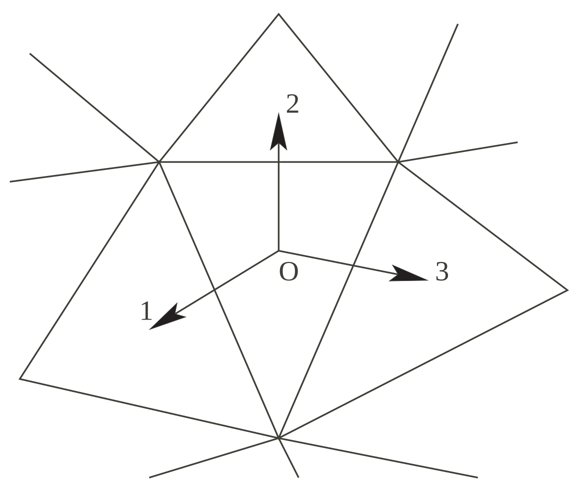
- ⋆ But we need to perform the mathematics on the unstructured tetrahedral grids,

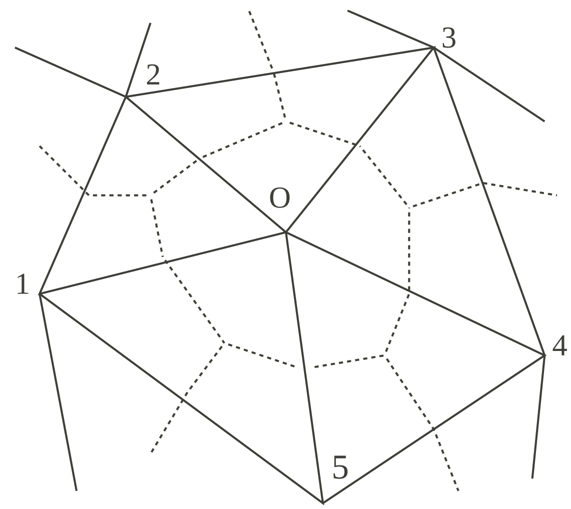
- ⋆ And build and manipulate Earth models discretized using an unstructured tetrahedral grid.

Computing synthetic geophysical data: gravity

⋆ Closed-form expression for a tetrahedron (Okabe, 1979).

⋆ Finite-volume solution of Poisson's equation ...





(Hormoz Jahandari, Ph.D. student.)

Computing synthetic geophysical data: EM

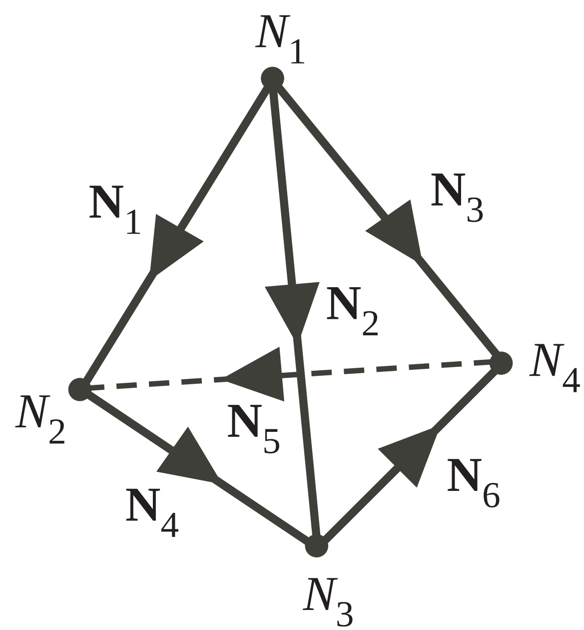
⋆ Decomposition into inductive and galvanic parts …

$$\mathbf{E} = -i\omega\mathbf{A} - \nabla\phi.$$

⋆ Finite-element solution using edge and nodal elements …

$$\mathbf{A}(\mathbf{r}) = \sum_{j=1}^{N_{edges}} A_j\,\mathbf{N}_j(\mathbf{r}),$$

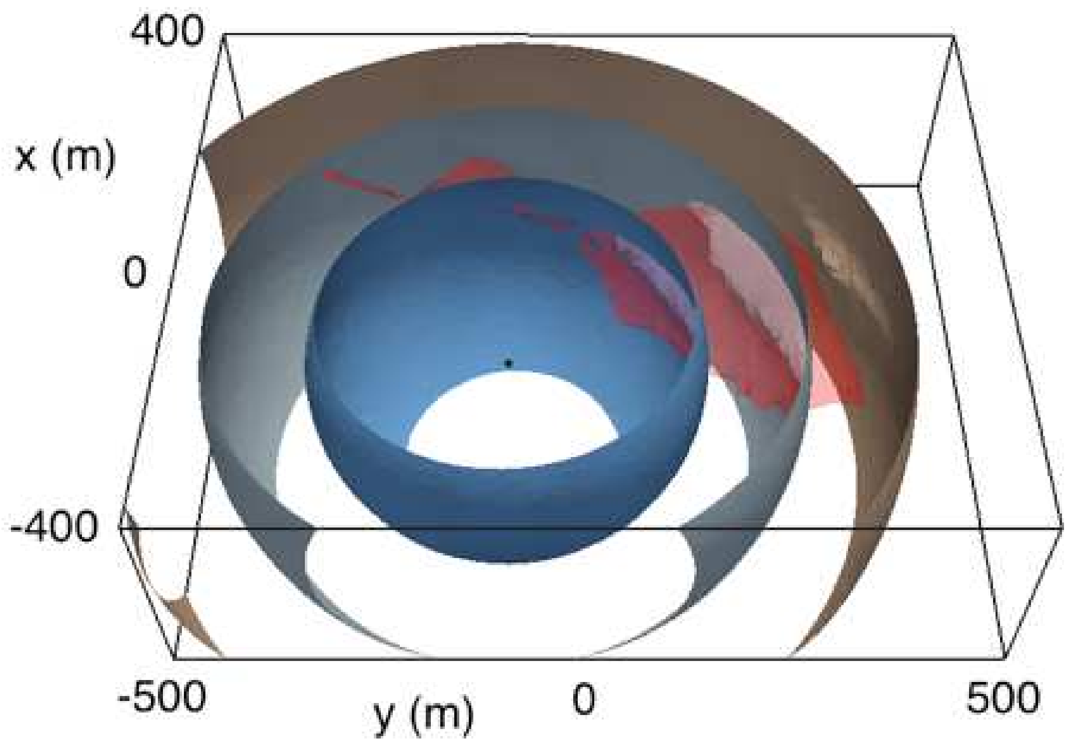
$$\phi(\mathbf{r}) = \sum_{k=1}^{N_{nodes}} \phi_k\,N_k(\mathbf{r}).$$



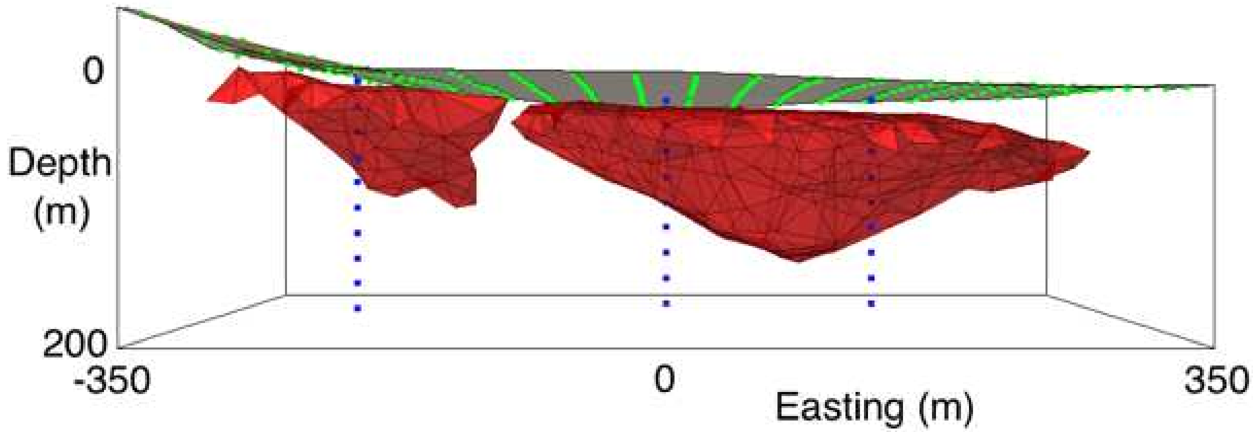
(Seyedmasoud Ansari, Ph.D. student.)

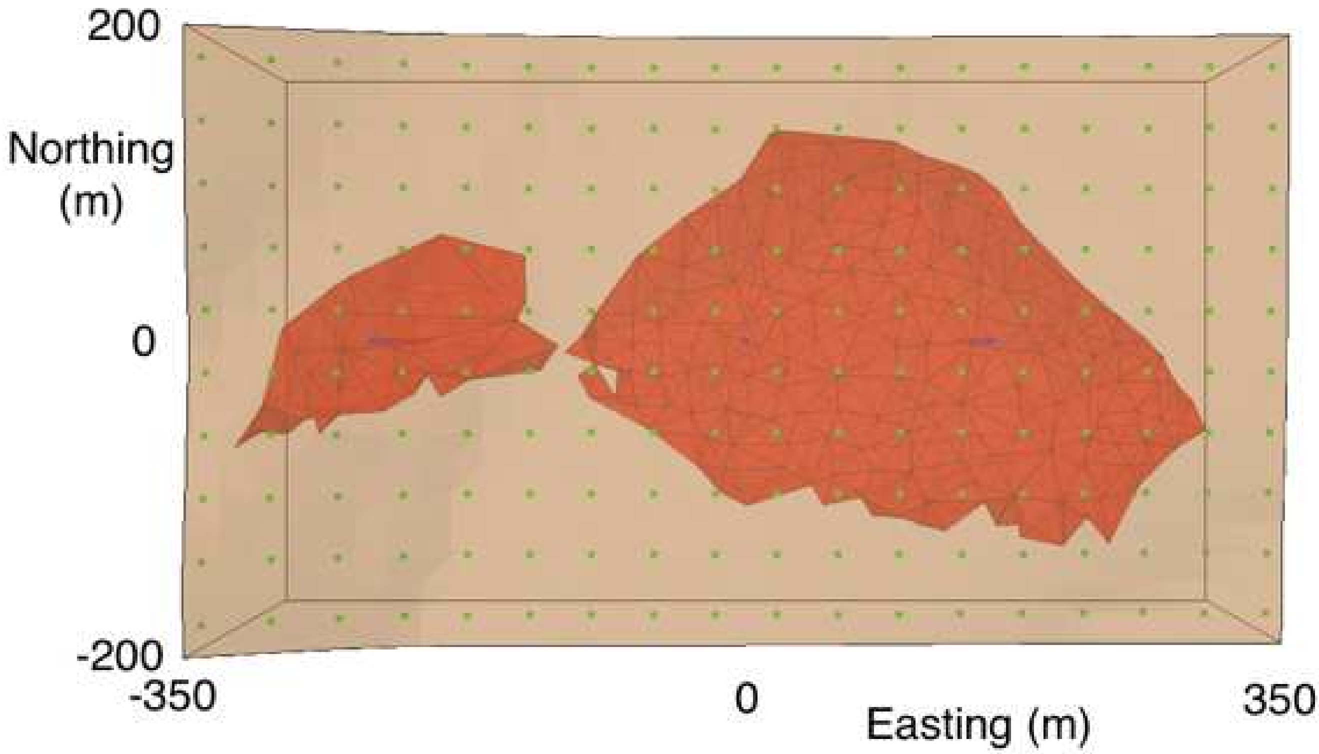
Computing synthetic geophysical data: seismic traveltimes

⋆ Fast marching method . . .

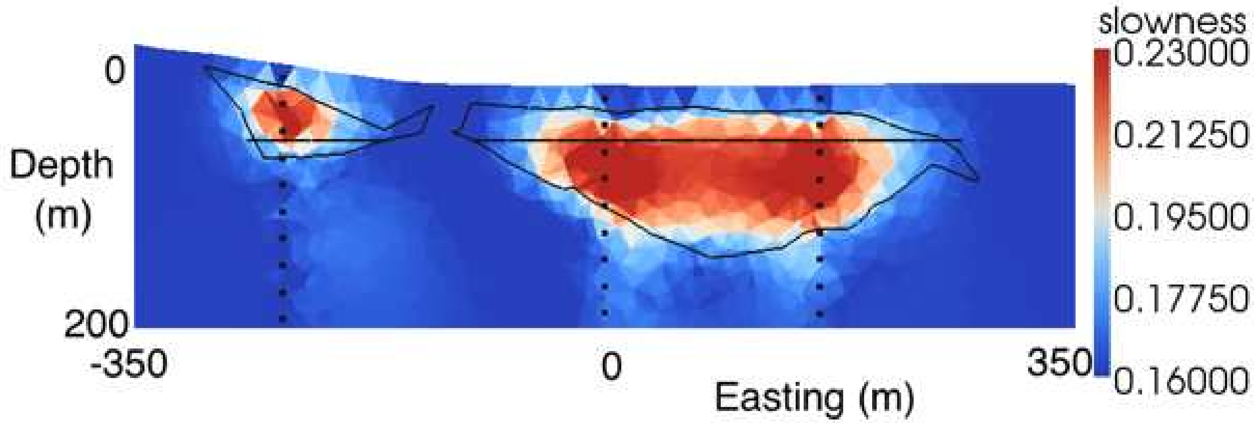


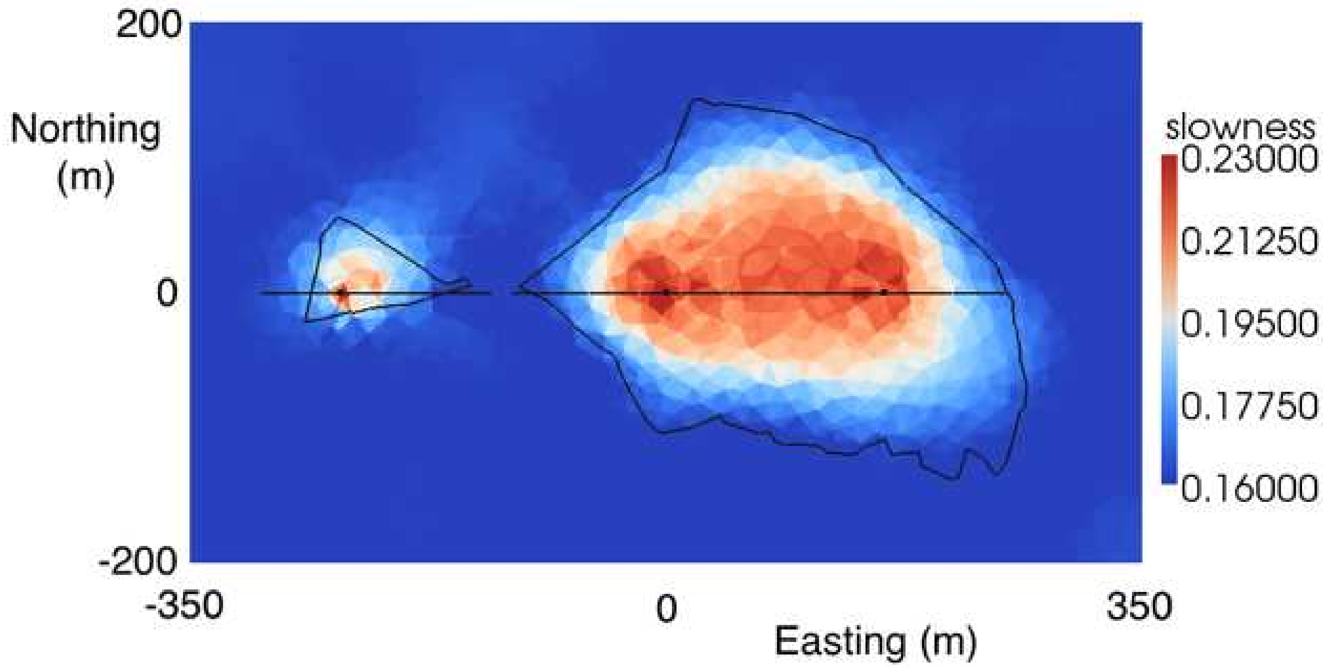
Geophysical inversion: seismic traveltimes



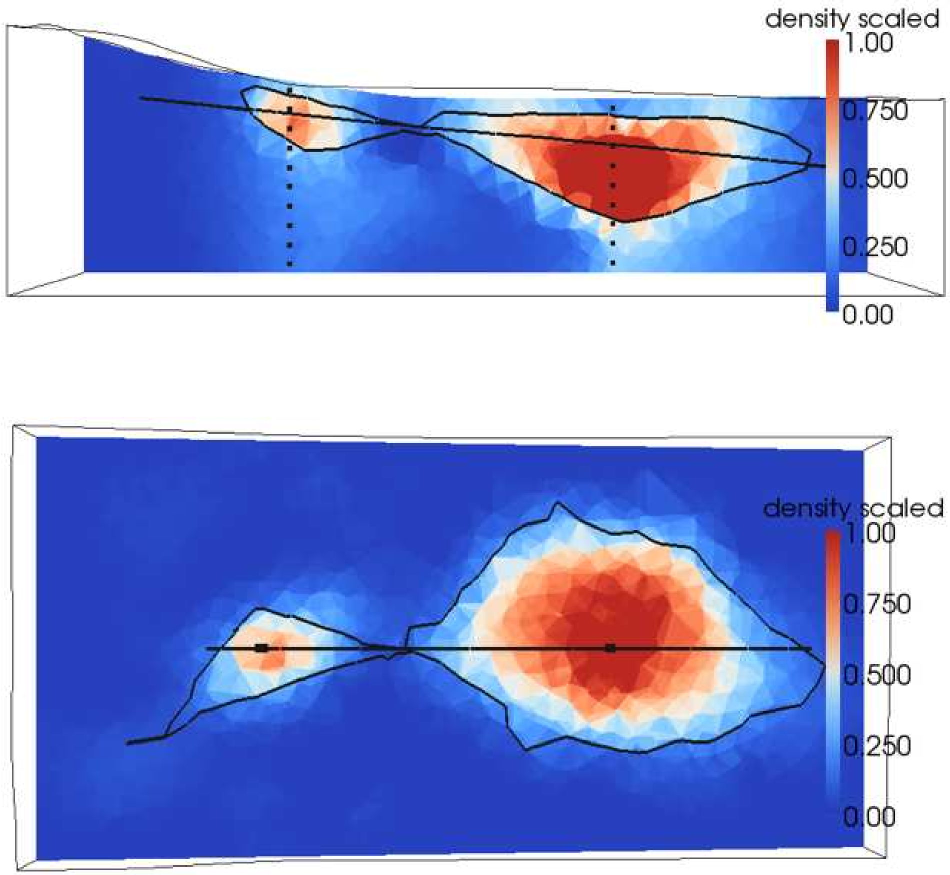


Geophysical inversion: seismic traveltimes

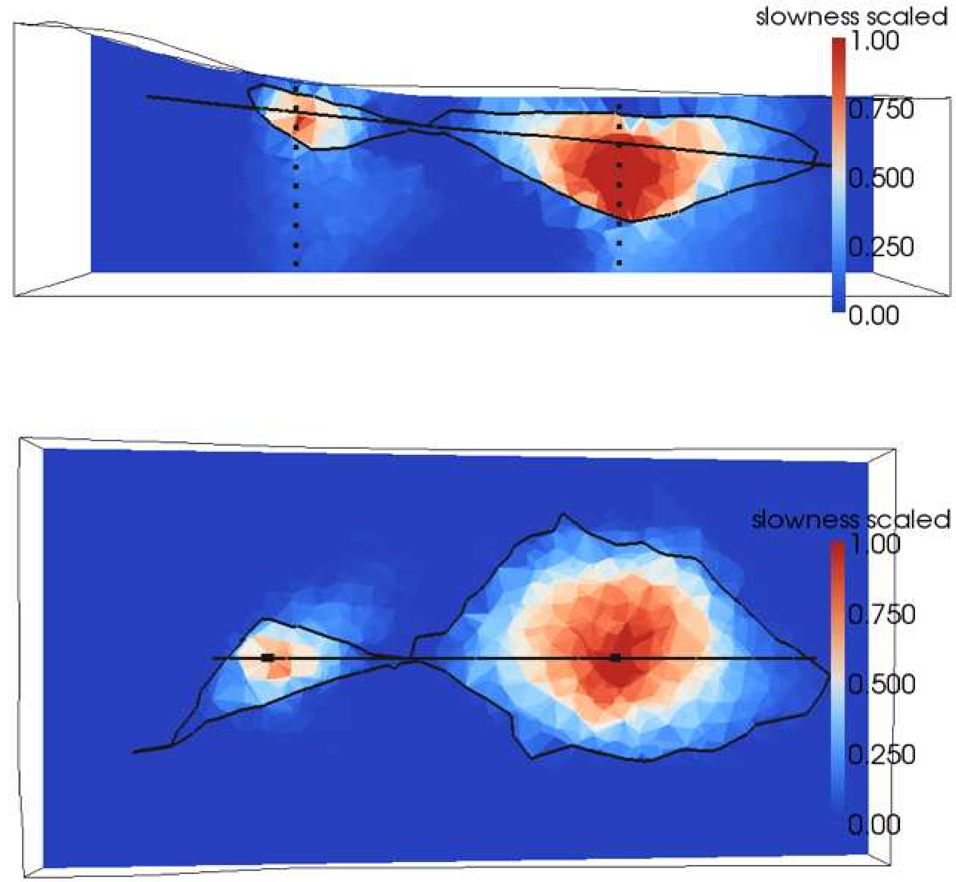




Geophysical inversion: joint seismic traveltime and gravity



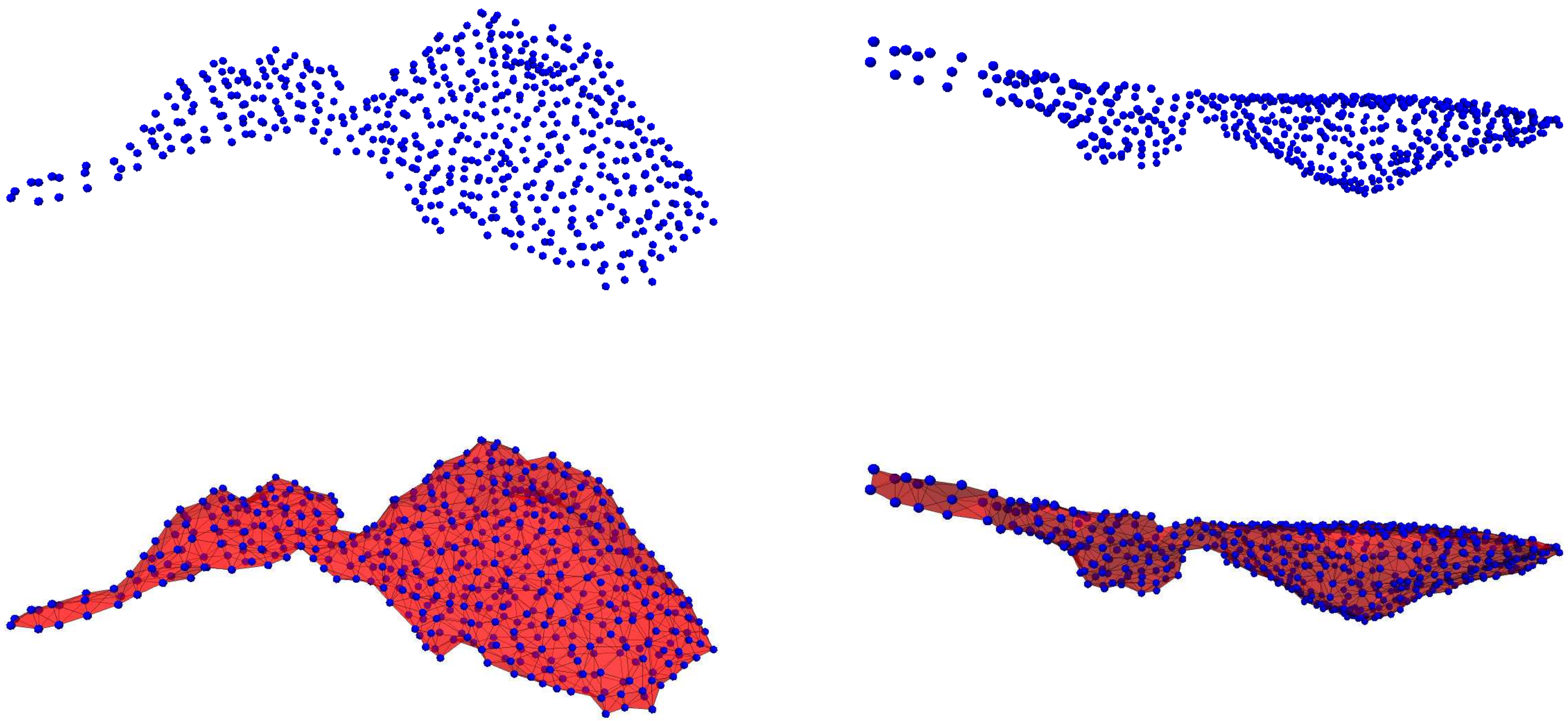
density



slowness

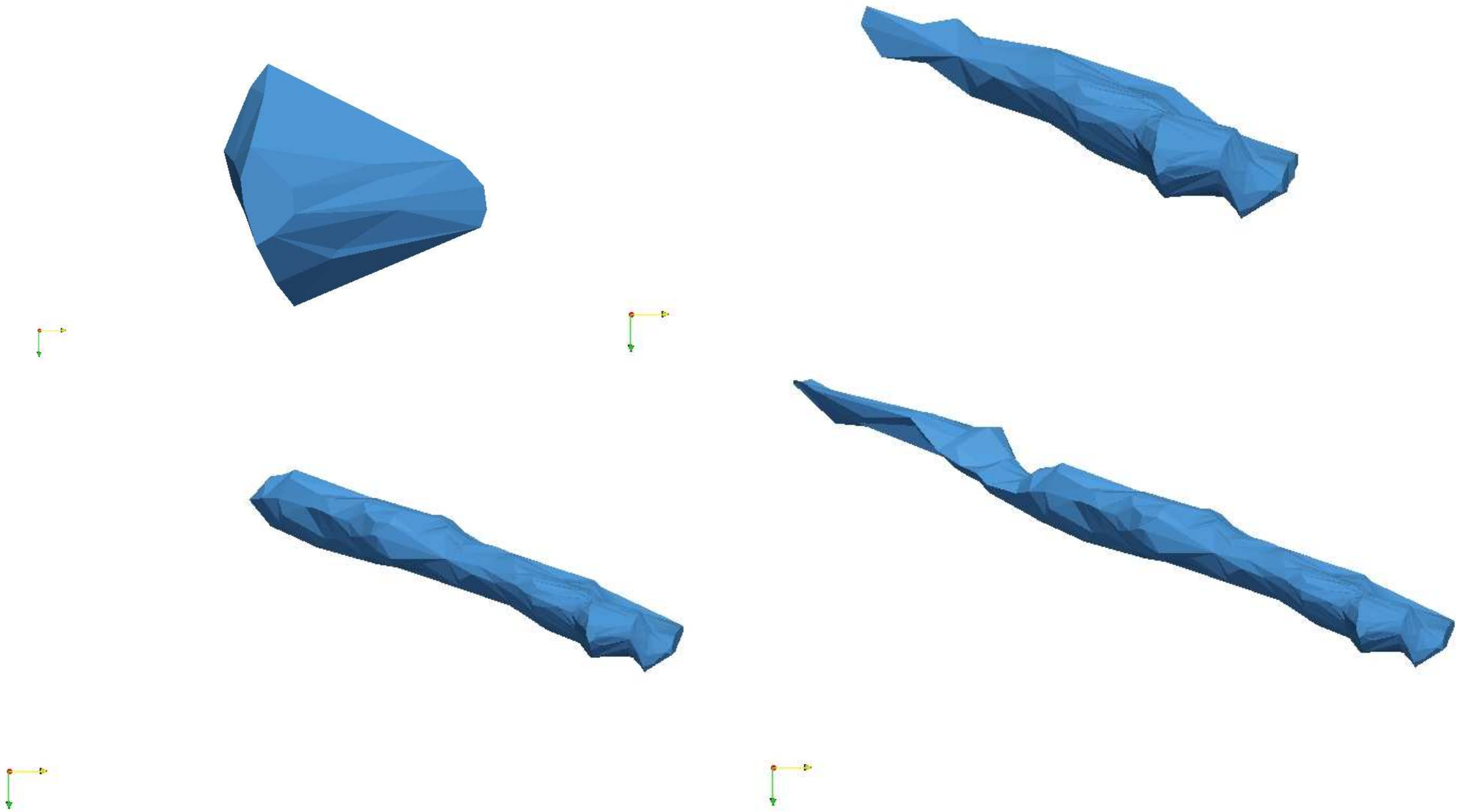
Manipulating unstructured tetrahedral Earth models

⋆ Automated surface reconstruction from point clouds.



Manipulating unstructured tetrahedral Earth models

- ⋆ By hand, making use of 3-D graphics and visualization software.



(Angela Carter-McAuslan, M.Sc. student)

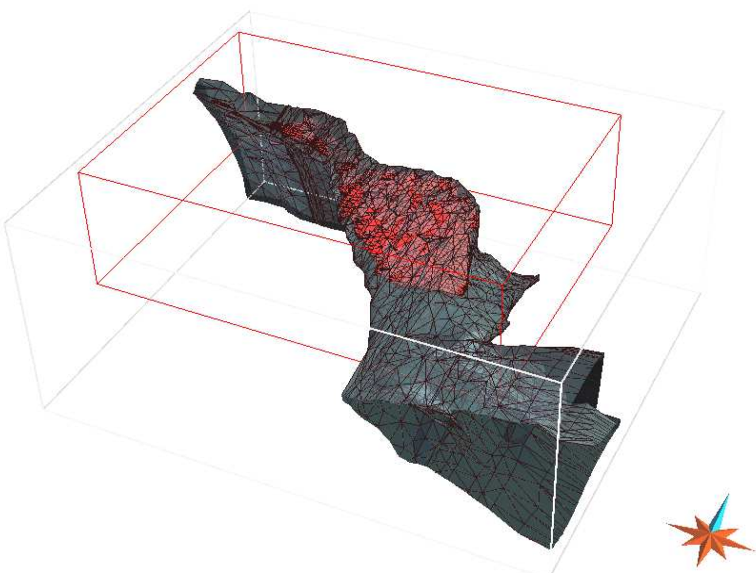
Conclusions

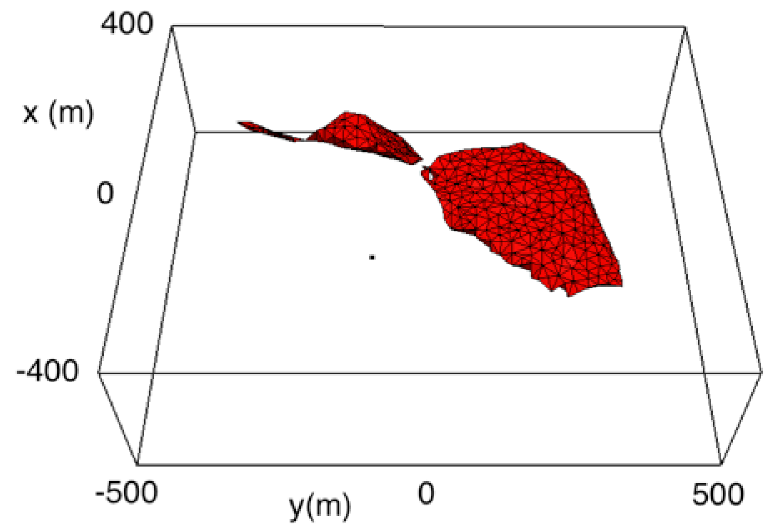
⋆ Unstructured tetrahedral grids ...

→ can honour geological surfaces,

→ can represent fine-scale structure, and yet

→ are efficient discretizations of the modelling domain.





⋆ **A single 3-D Earth model for both geology and geophysics.**