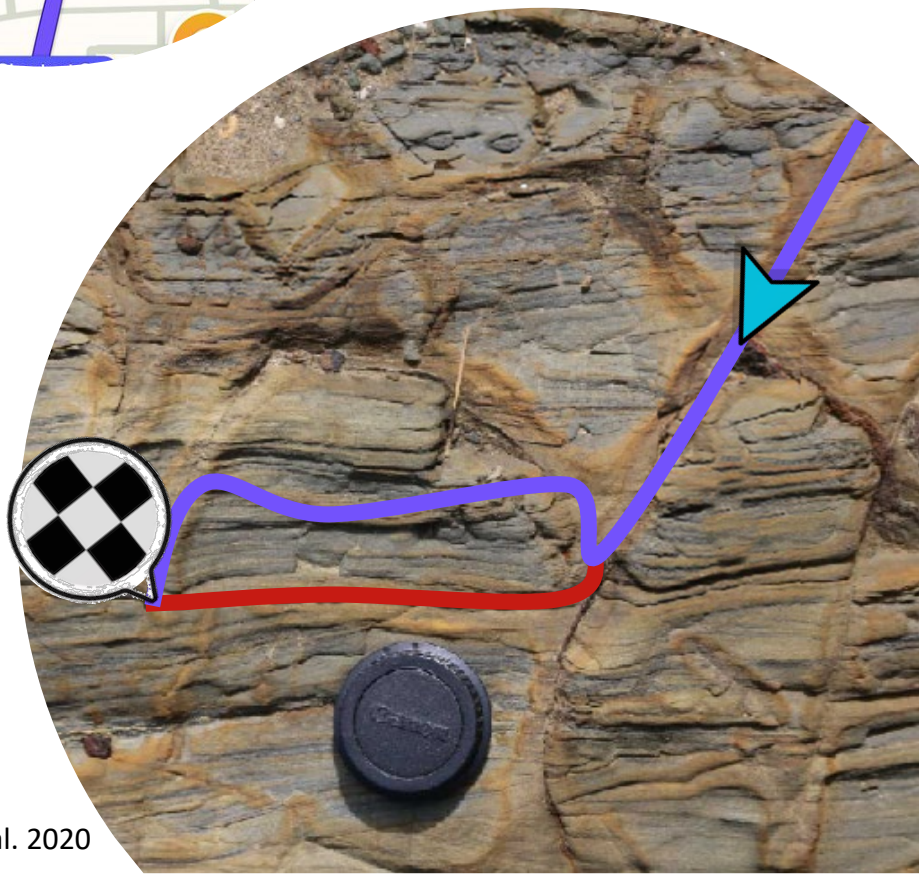
A very short history of Geological Modelling

+

Waze for rocks, navigating through the crust

Mark Jessell [UWA], Guillaume Pirot [UWA],
Laurent Ailleres [Monash], Lachlan Grose [Monash],
Mark Lindsay [CSIRO], Ranee Joshi [UWA]



Dimmen et al. 2020

LP210301239: Three-dimensional Bayesian Modelling of Geological and Geophysical data 2023-2026

ARC + Partner contributions $1.5M

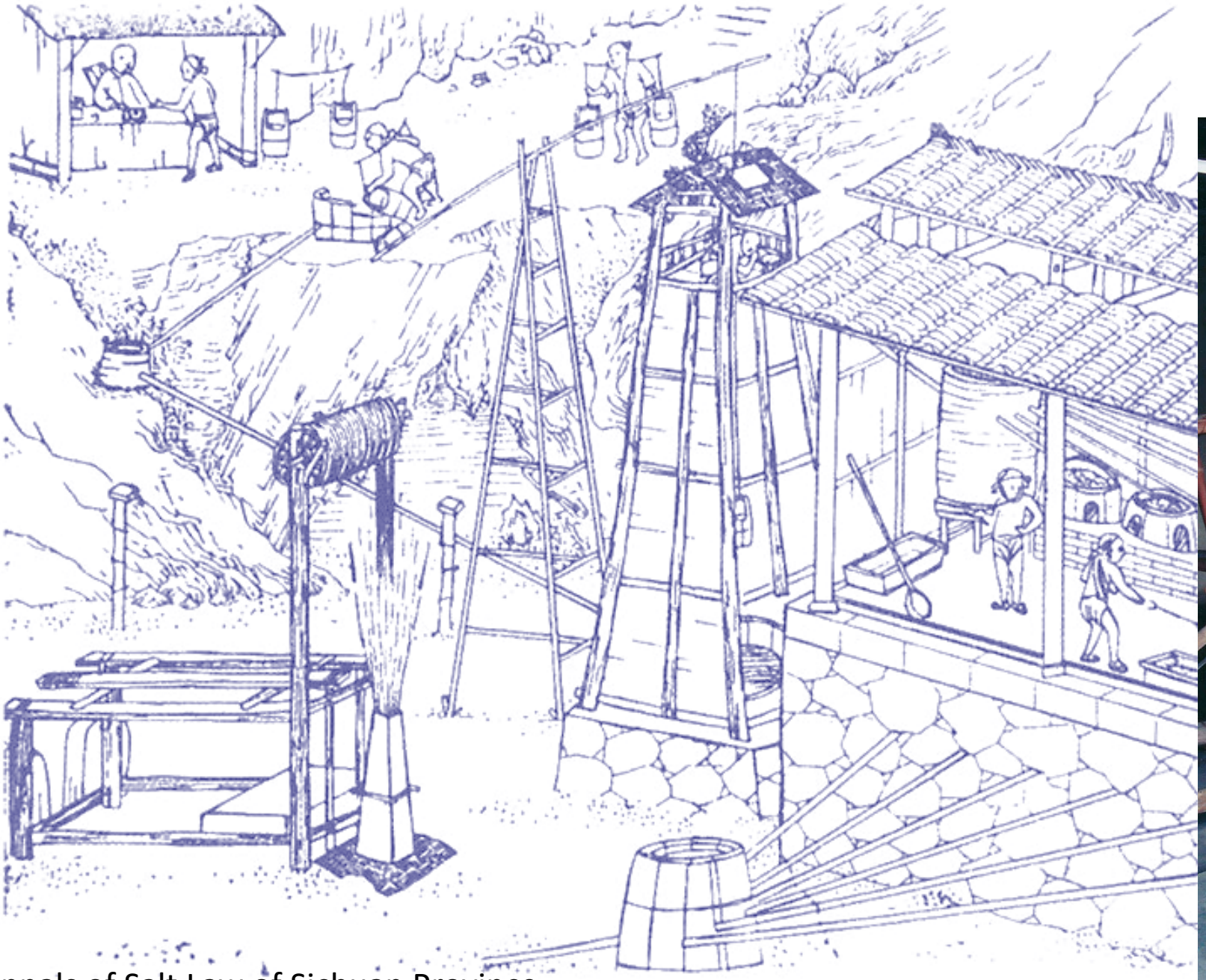
Lead Institution Monash Uni

- Monash University
- The University of Western Australia
- Geoscience Australia
- Research for Integrative Numerical Geology, Georessources, Université de Lorraine
- University of Orléans
- British Geological Survey
- Commonwealth Scientific and Industrial Research Organisation
- Auscope Ltd
- Geological Survey of Western Australia
- Northern Territory Geological Survey
- Department for Energy and Mining
- Department of State Growth
- Geological Survey of Queensland
- Department of Jobs, Precincts and Regions
- RWTH Aachen University of Technology, Germany
- Geological Survey of Canada
- Department of Regional NSW
- United States Geological Survey
- Alpine Environment Research Centre

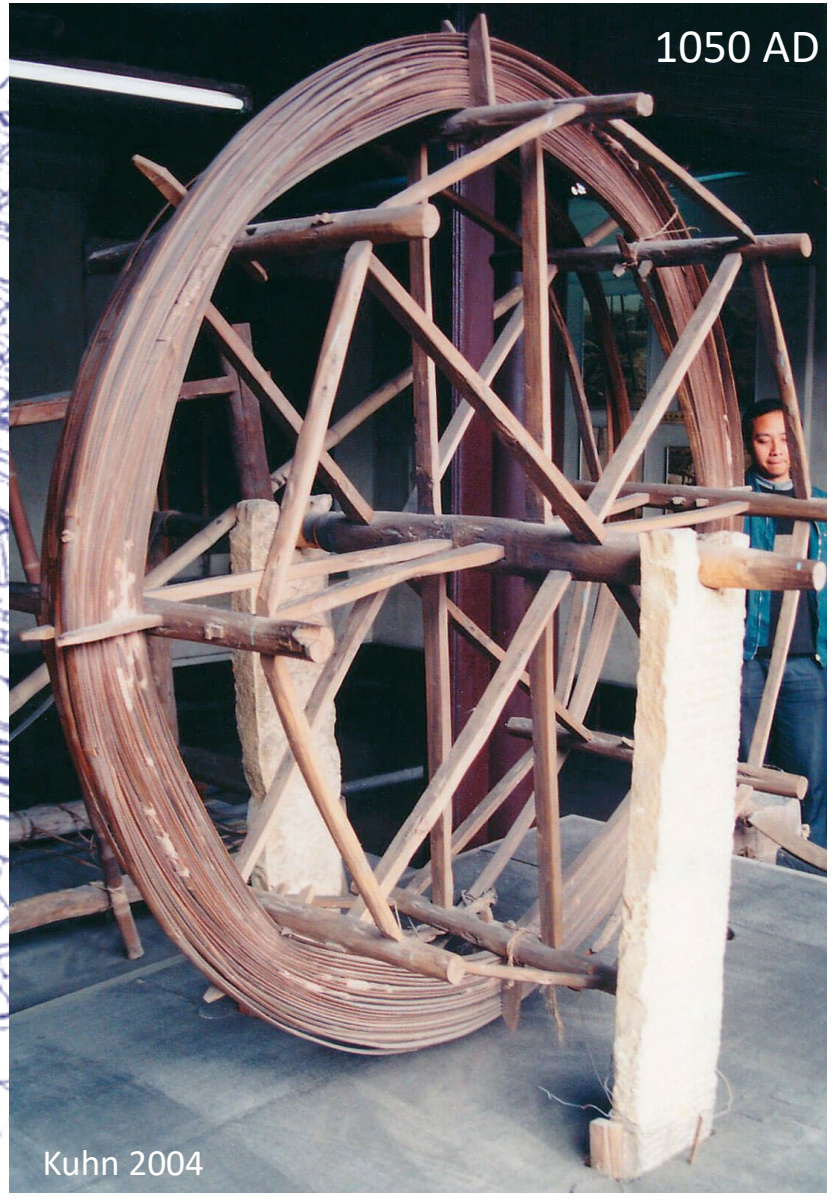
Map of sandstone quarry, gold mine and settlement at Bir Umm Fawakhir, 1160 BC

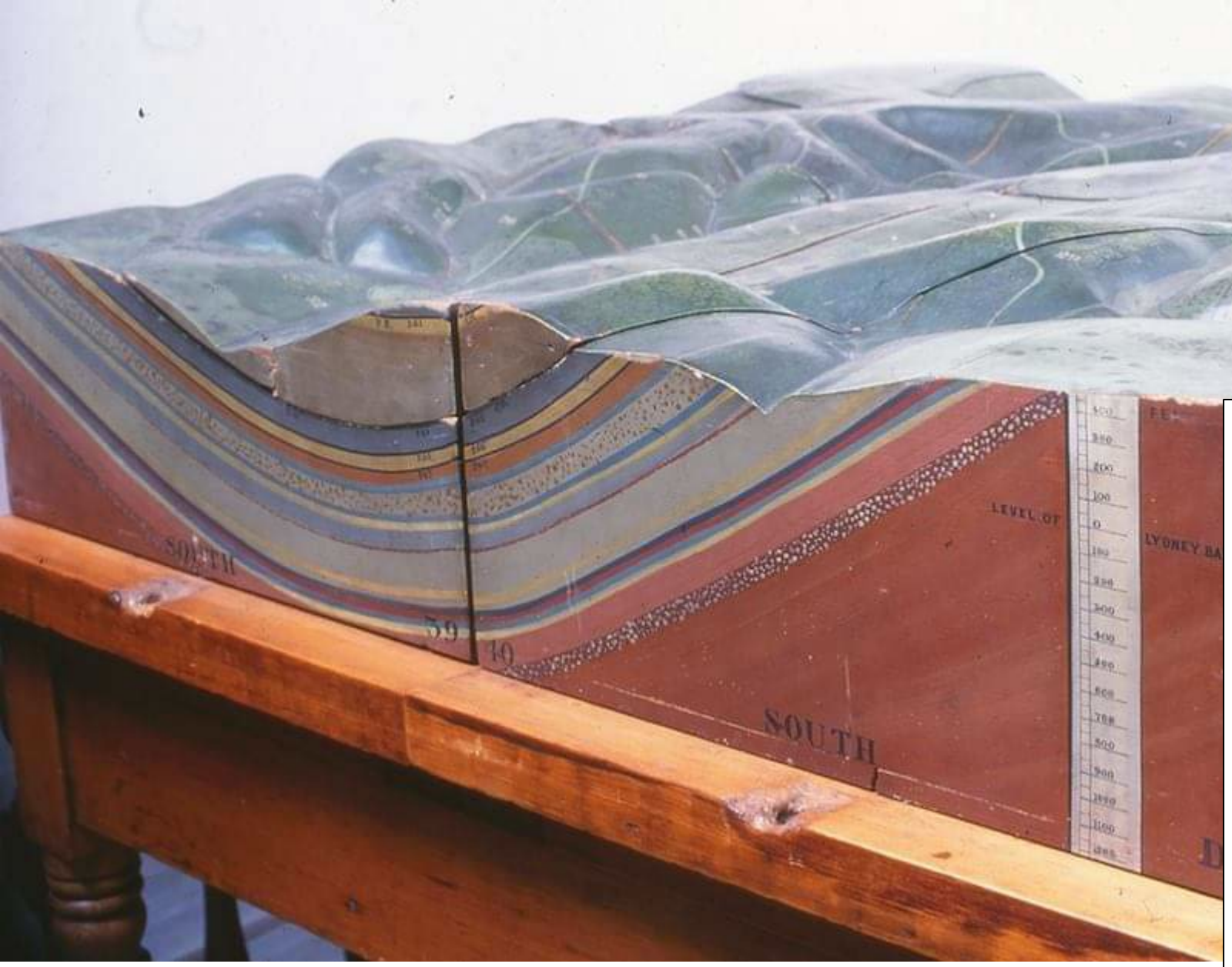
Scribe-of-the-Tomb Amennakhte, son of Ipuy, 1160 BC

Bamboo Drill Rigs
140m holes ~300 AD



The Annals of Salt Law of Sichuan Province





Model of the Forest of Dean coal measures, 1837

DESCRIPTION

OF A

SERIES OF ELEMENTARY

GEOLOGICAL MODELS

ILLUSTRATING

THE NATURE OF STRATIFICATION;
VALLEYS OF DENUDATION;
THE EFFECTS PRODUCED BY FAULTS OR DISLOCATIONS;
INTERSECTION OF MINERAL VEINS, ETC.

With Notes

ON THE CONSTRUCTION OF LARGE GEOLOGICAL MODELS.

By T. SOPWITH, M.A., F.R.S., F.G.S.,

John Tipper, 1976

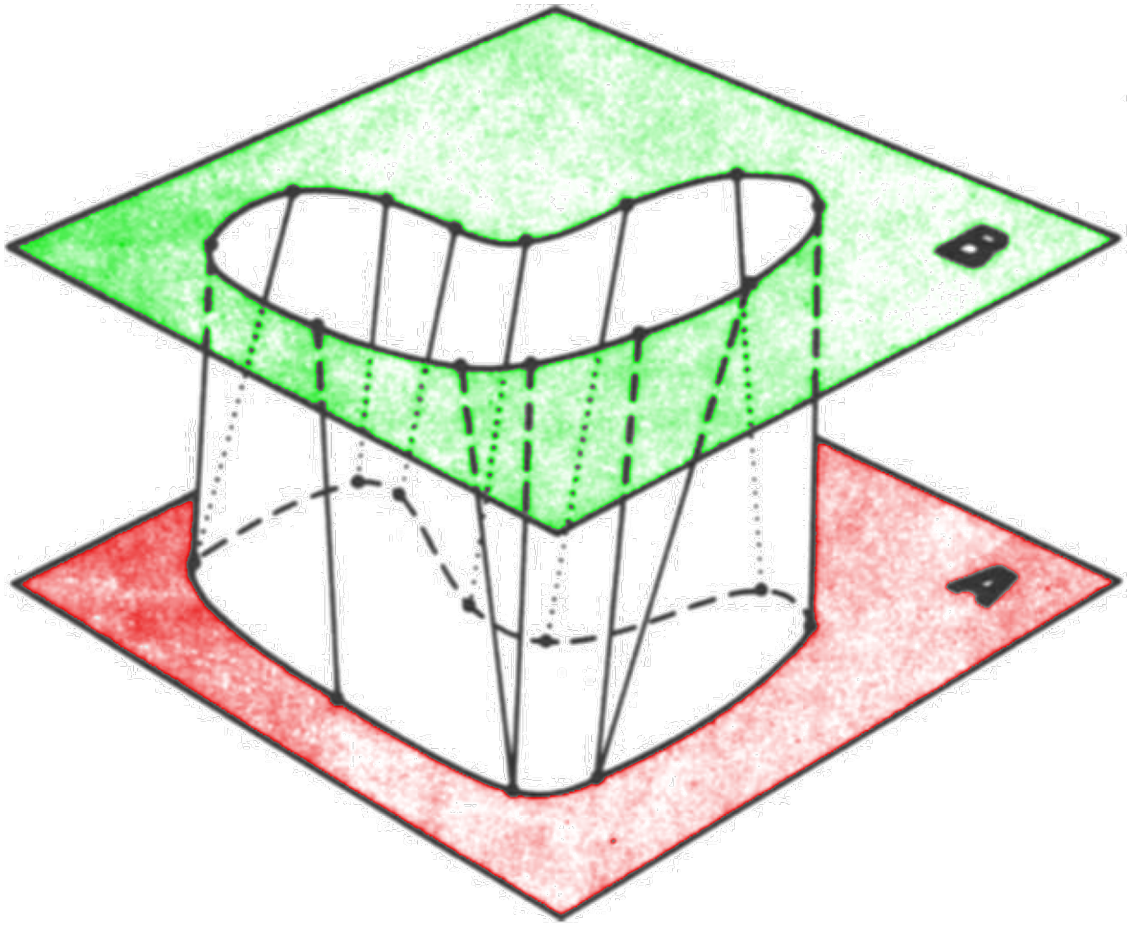
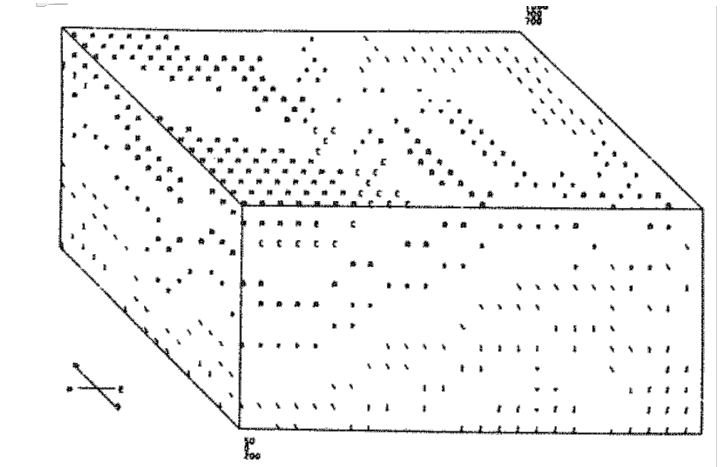


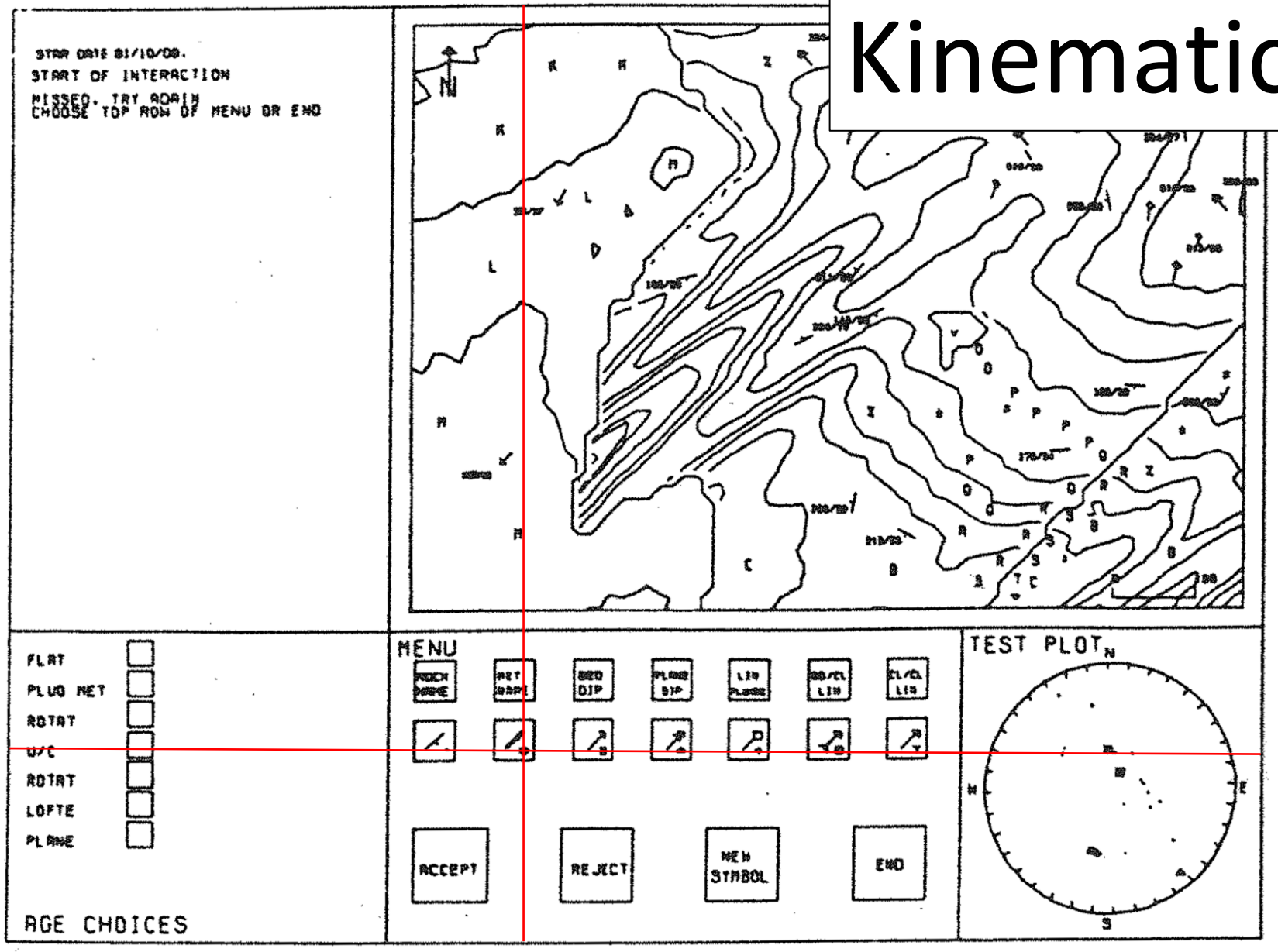
FIG. 3.—Result of point-to-point matching between sections A and B, showing the network of quadrilateral and triangular patches.

CAD

John C. Tipper. 1976. The Study of Geological Objects in Three Dimensions by the Computerized Reconstruction of Serial Sections. The Journal of Geology, Vol. 84, No. 4, 476-484

Kinematic



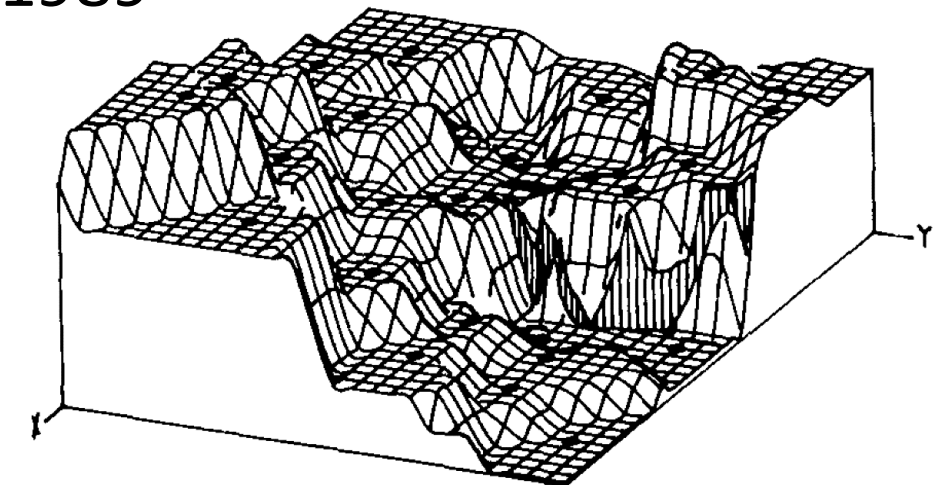


Mark Jessell, 1981

Jessell, M.W. 1981. An interactive Map Creation Package, Unpublished MSc thesis, Unversity of London

Interpolation

Jean-Laurent Mallet, 1989



Jean-Laurent Mallet 1989 , Discrete smooth interpolation. ACM Transactions on Graphics, 8, 121-144

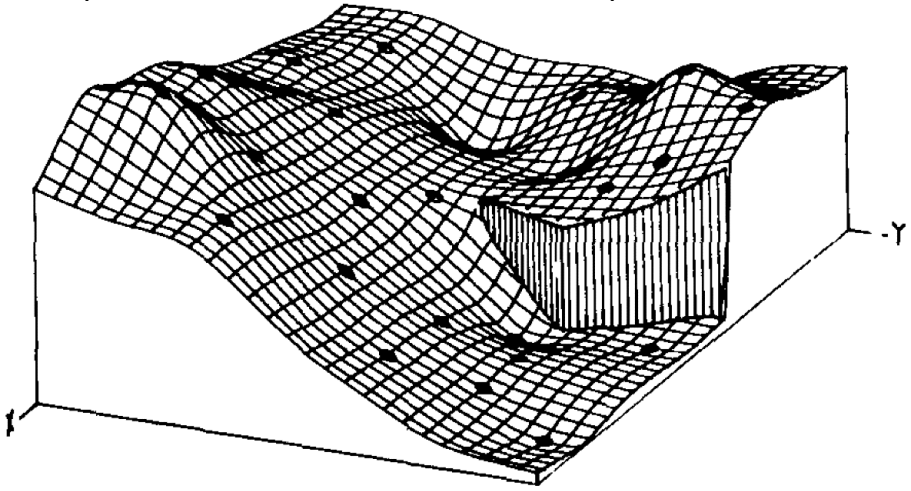


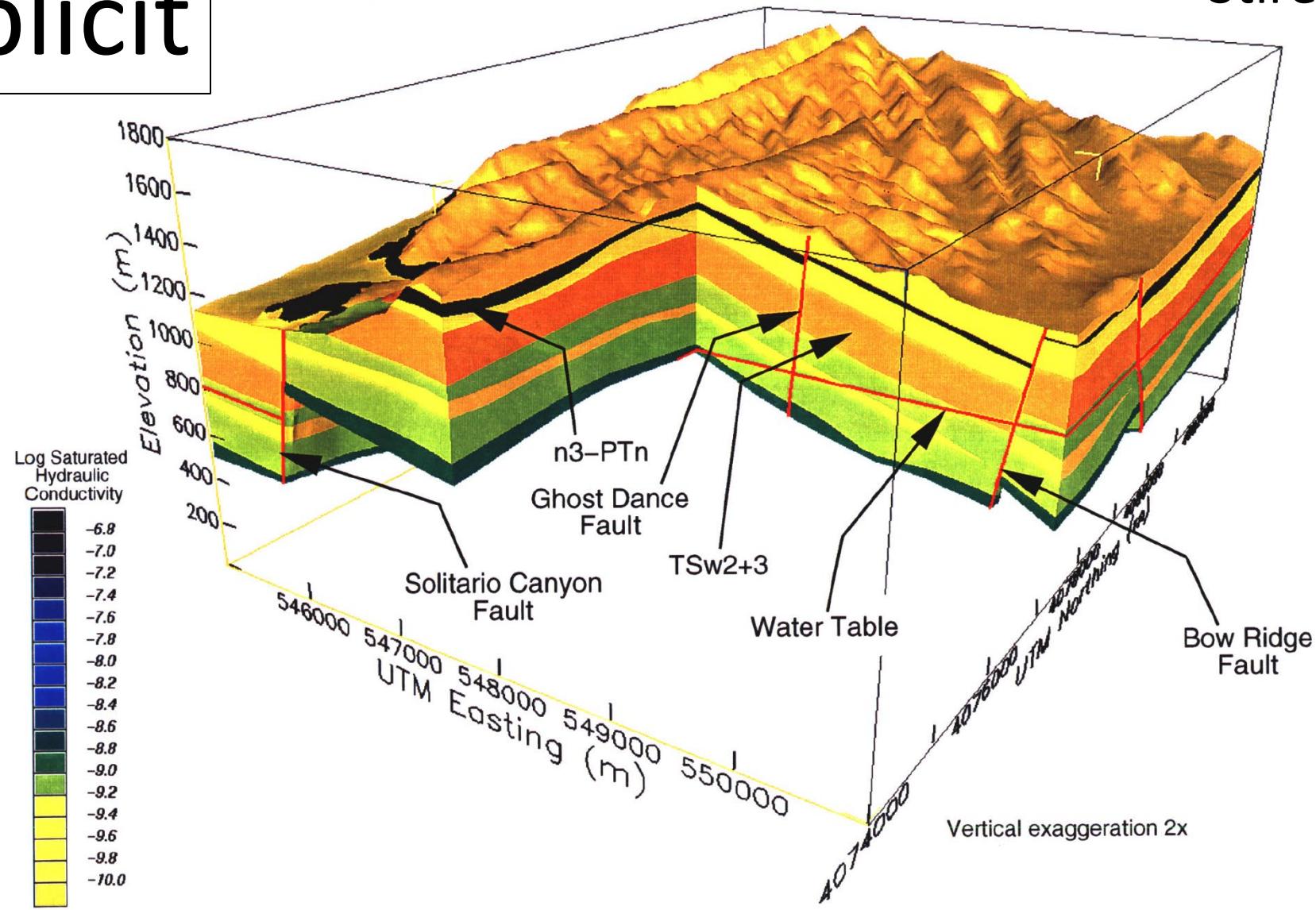
Fig. 8. The rough initial solution φ^0 and corresponding interpolation obtained with $\gamma = 0.2$ after 10 iterations (to be compared with Figure 9).

Fractal Graphics, 1999

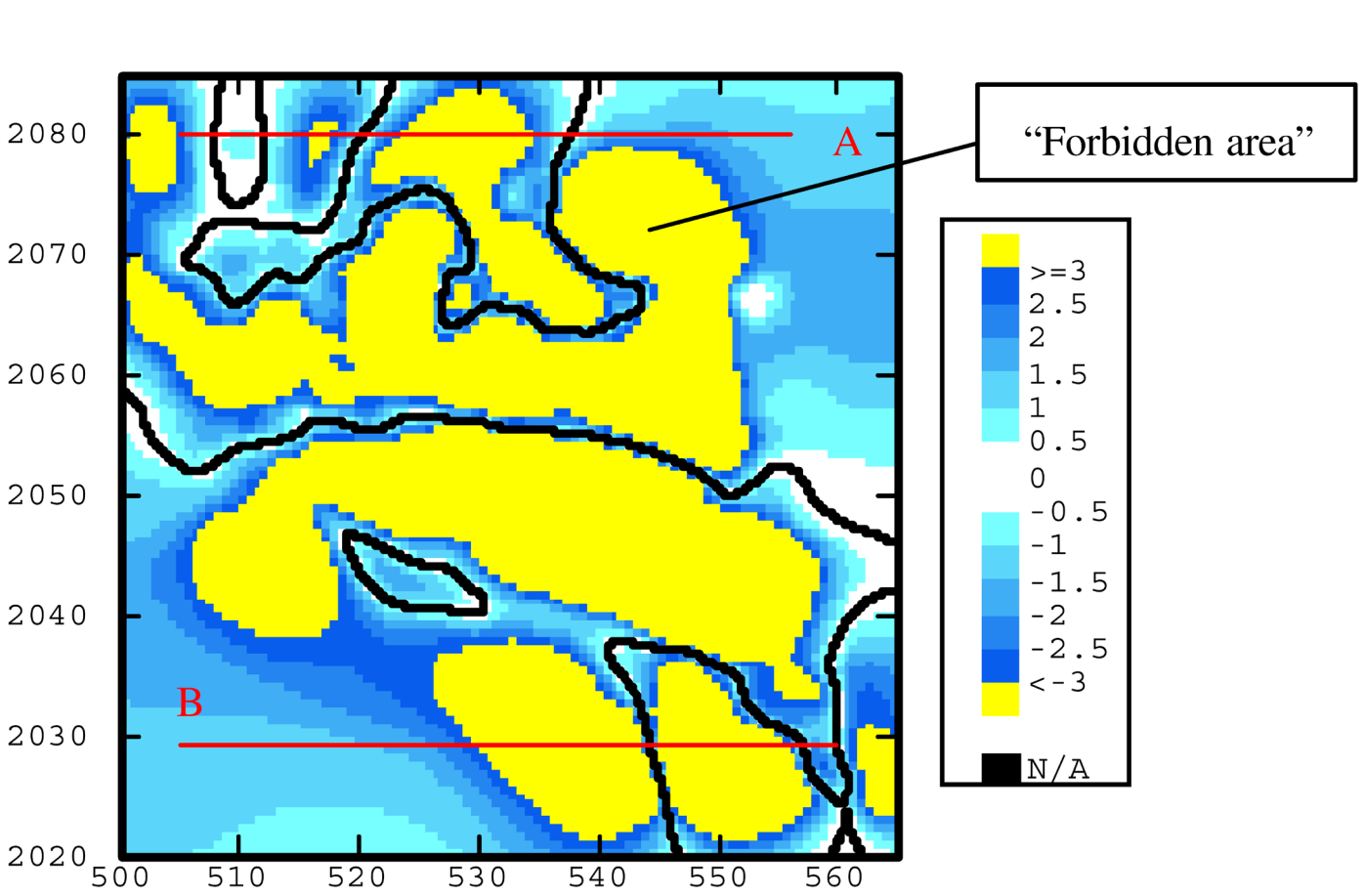
Fractal Graphics (Cowan Sheet)

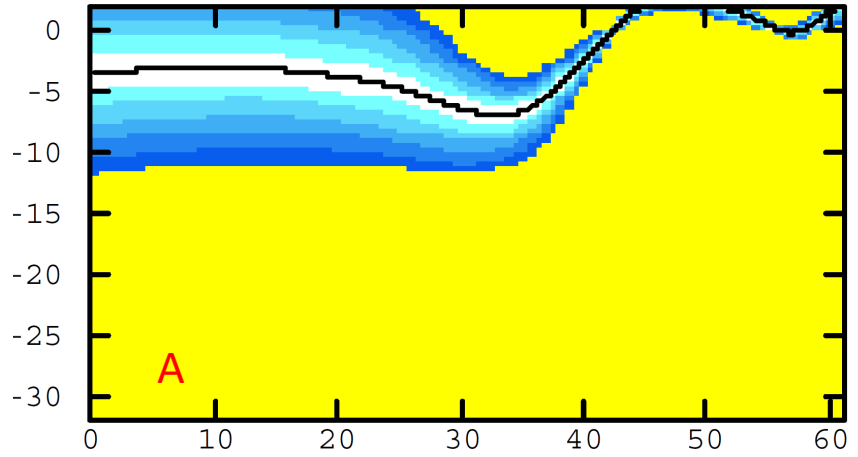
Implicit

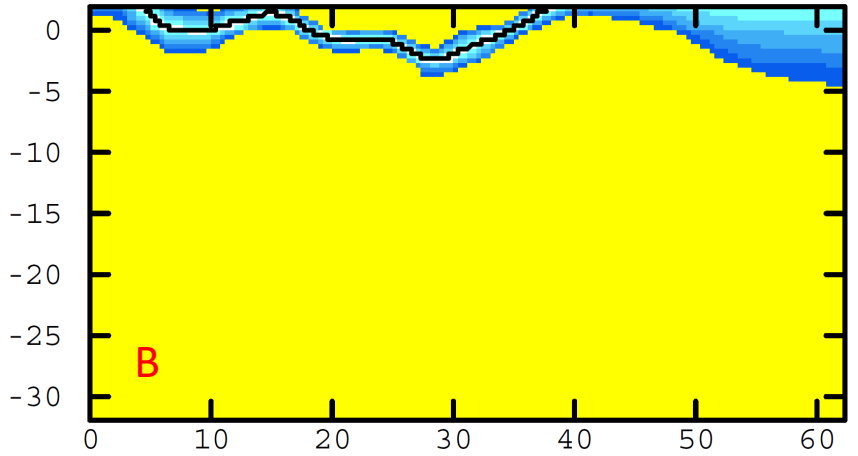
Stirewalt and Henderson, 1995



G. Stirewalt and B. Henderson, 1995, A Three-dimensional Geological Framework Model for Yucca Mountain, Nevada, with Hydrologic Application: Report to Accompany 1995 Model Transfer to the Nuclear Regulatory Commission



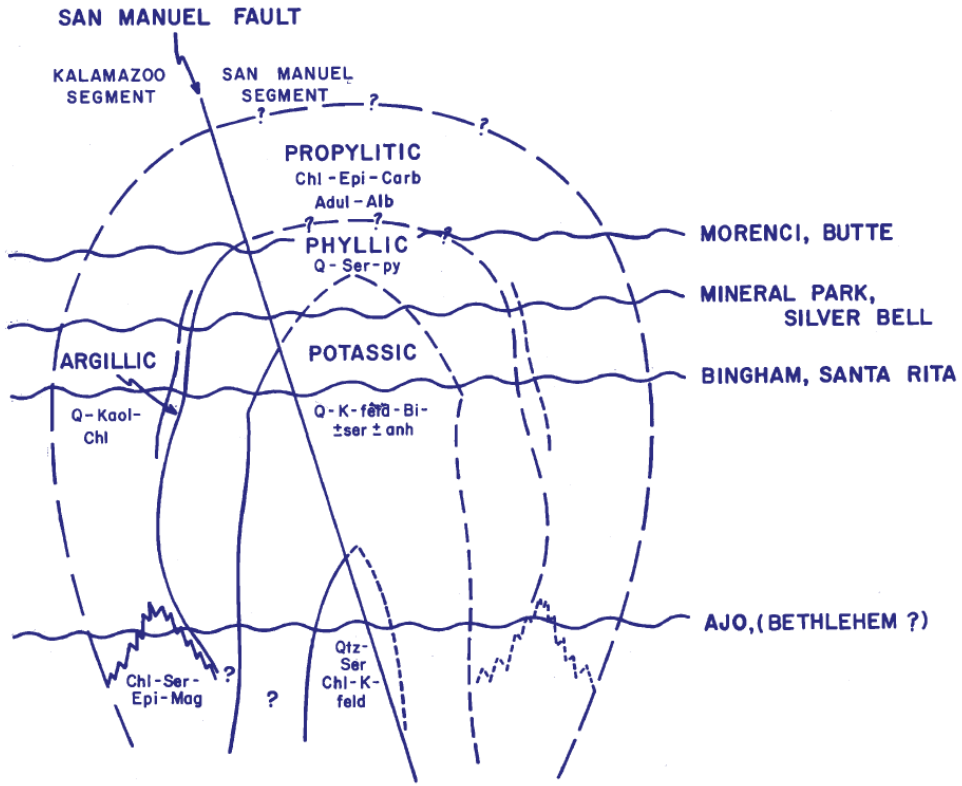




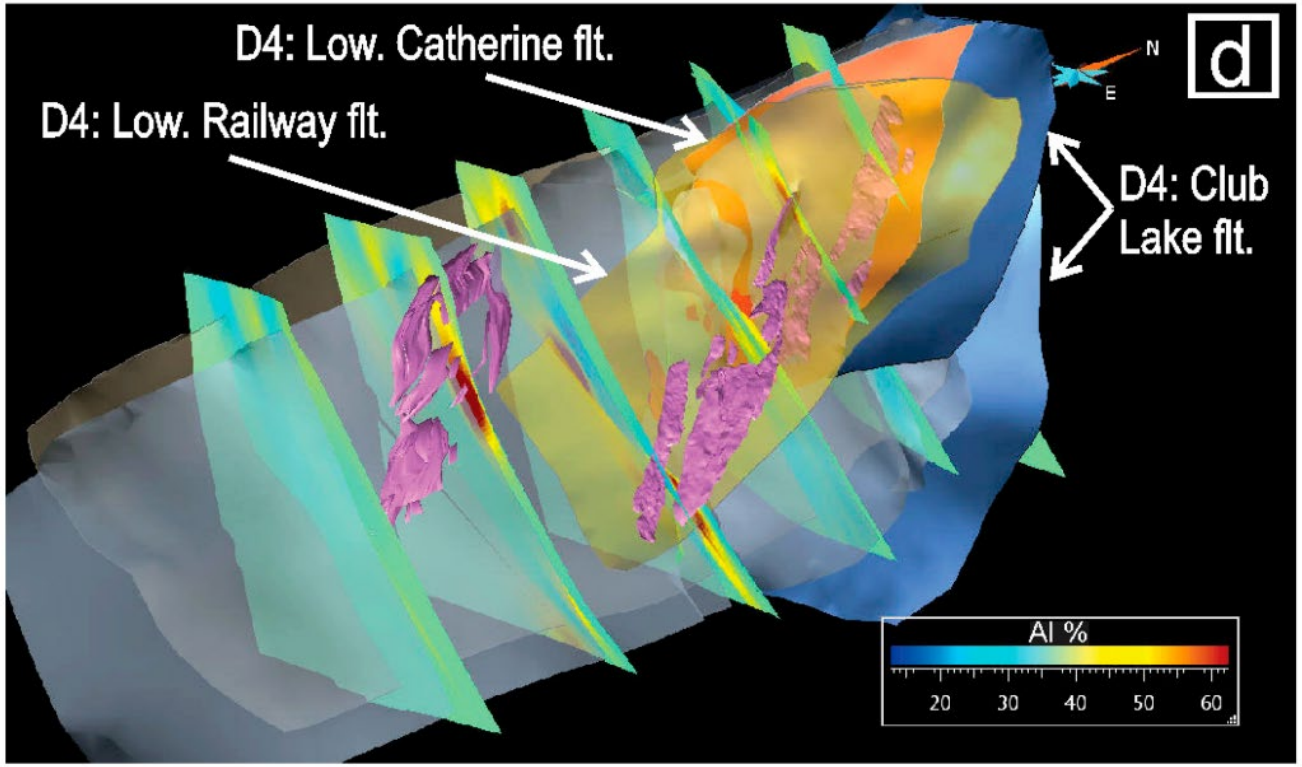
Uncertainty Quantification

C. Aug 2004 Modélisation géologique 3D et caractérisation des incertitudes par la méthode du champ de Potentiel.

Alteration Halo models

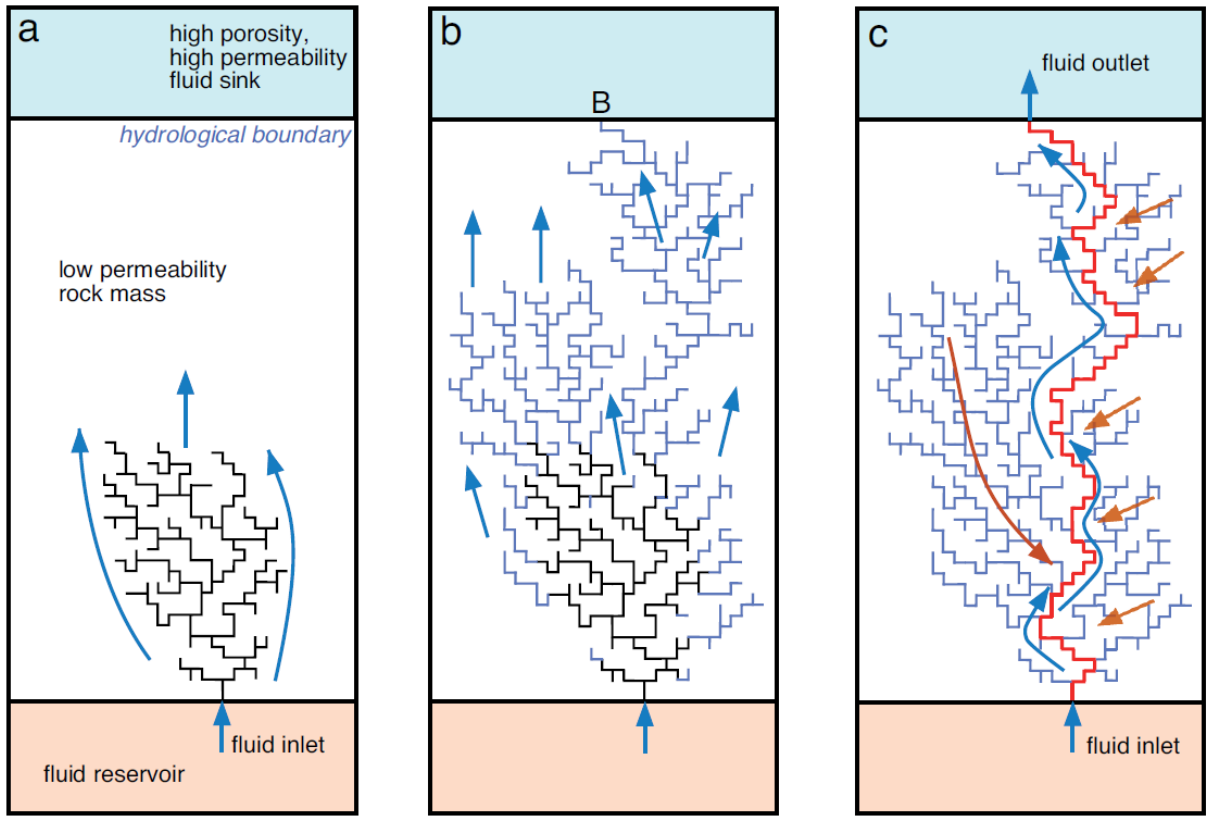


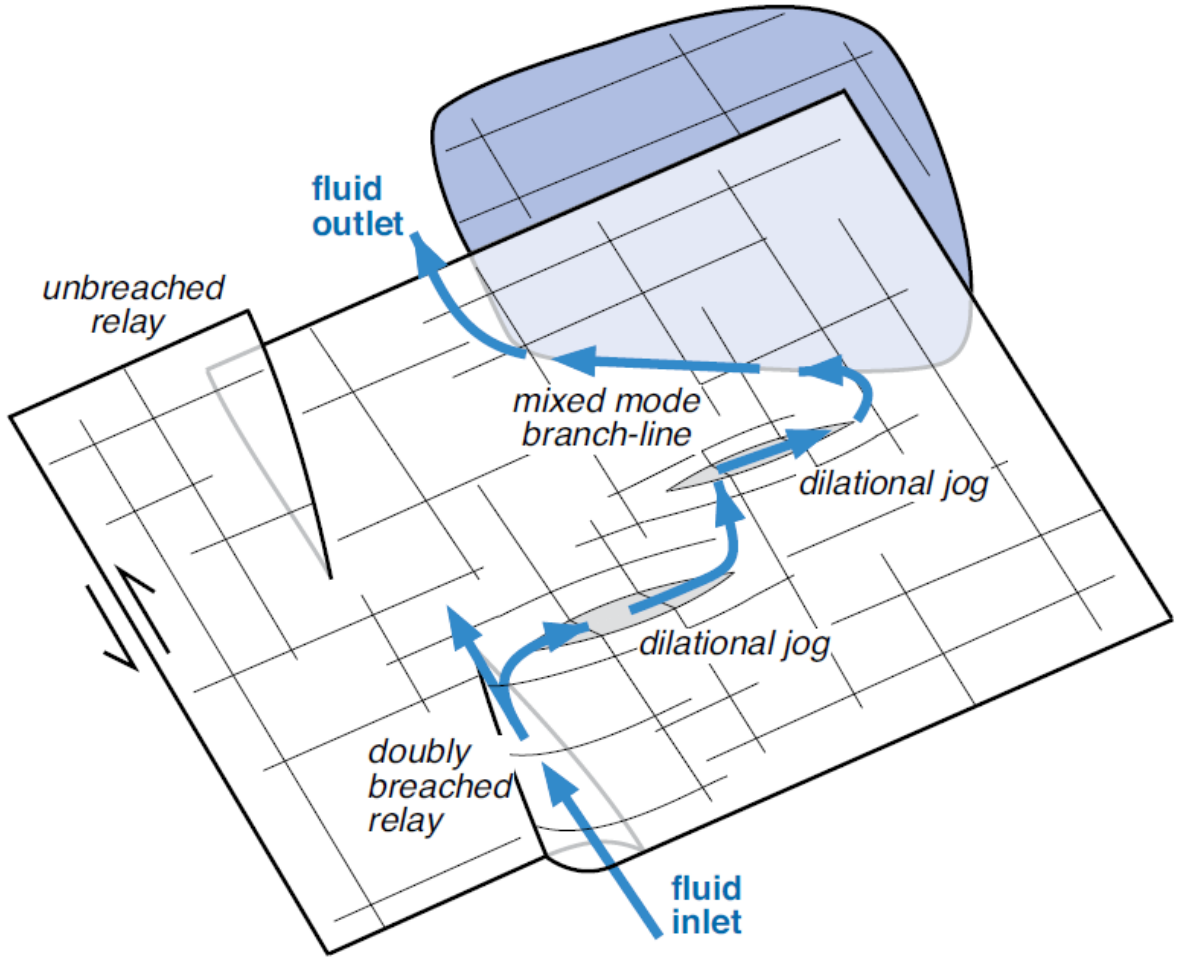
Lowell & Guilbert, 1970



Integrated 3D Geological Modeling to Gain Insight in the Effects of Hydrothermal Alteration on Post-Ore Deformation Style and Strain Localization in the Flin Flon Volcanogenic Massive Sulfide Ore System
Schetselaar et al., 2018

Waze for rocks, navigating through the crust



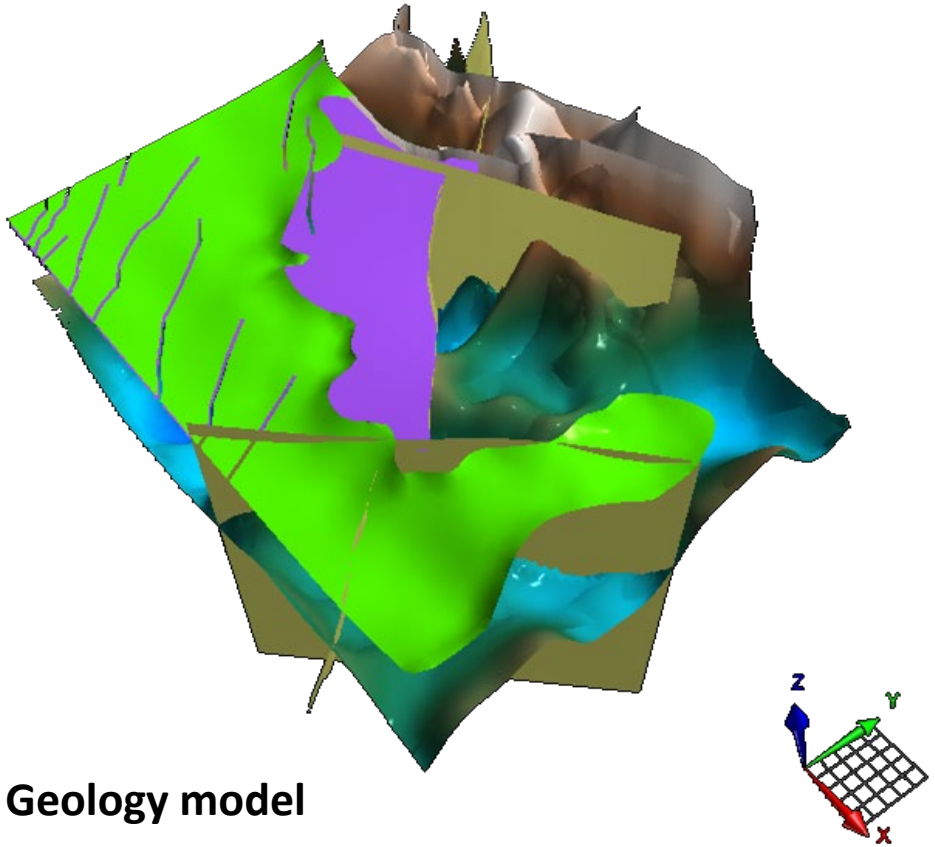


The Dynamics of Permeability Enhancement and Fluid Flow in Overpressured, Fracture-Controlled Hydrothermal Systems
Stephen F. Cox, Rev in Econ Geol 2020

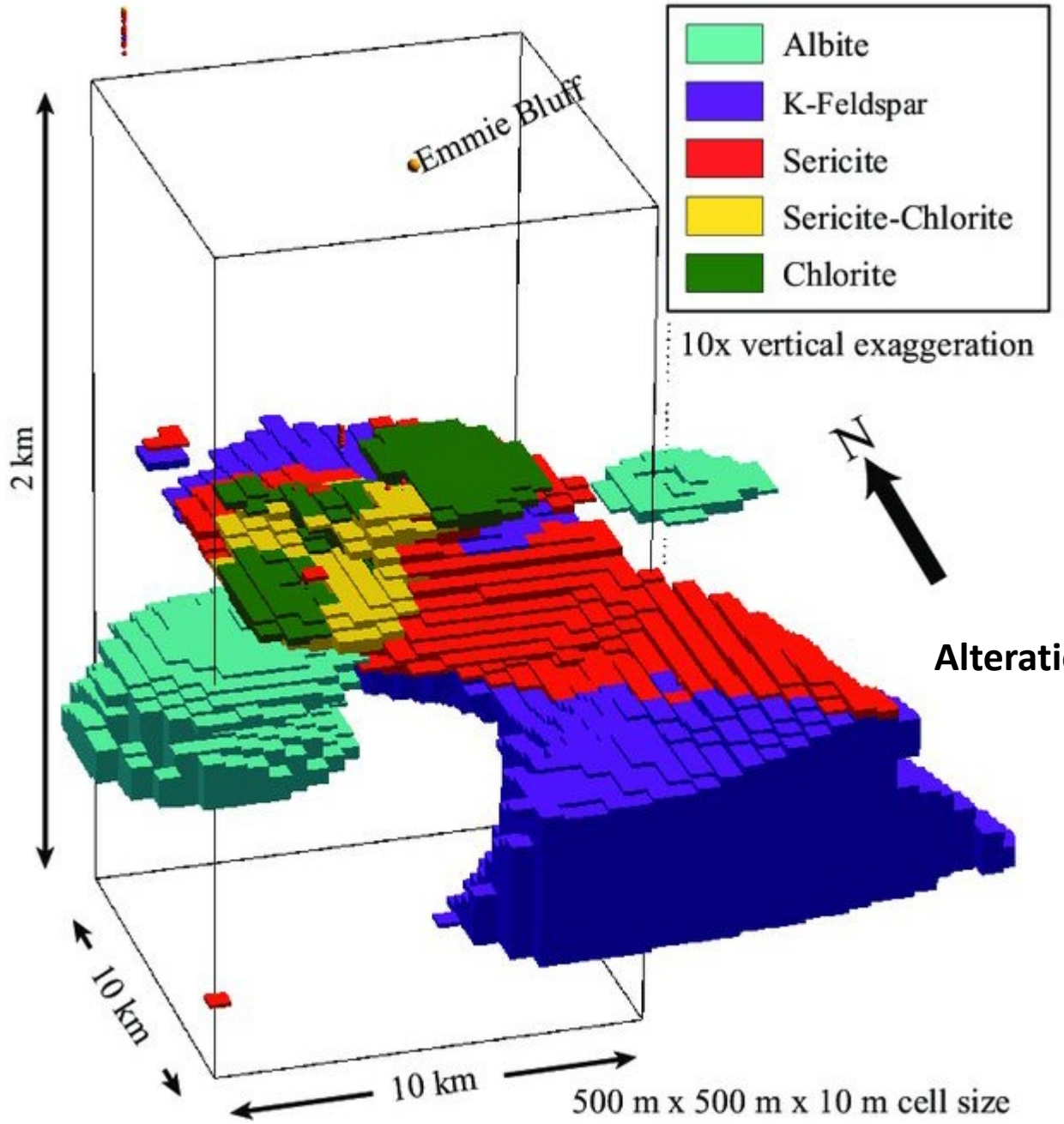
An exploration strategy for IOCG mineral systems under deep cover

MESA Journal 71 Issue 4 – 2013

Simon van der Wielen, A. Fabris, S. Halley, J. Keeling, A. Mauger, G. Gordon, T. Keeping, D. Giles and S. Hill



Geology model



Alteration model

Possible scenarios

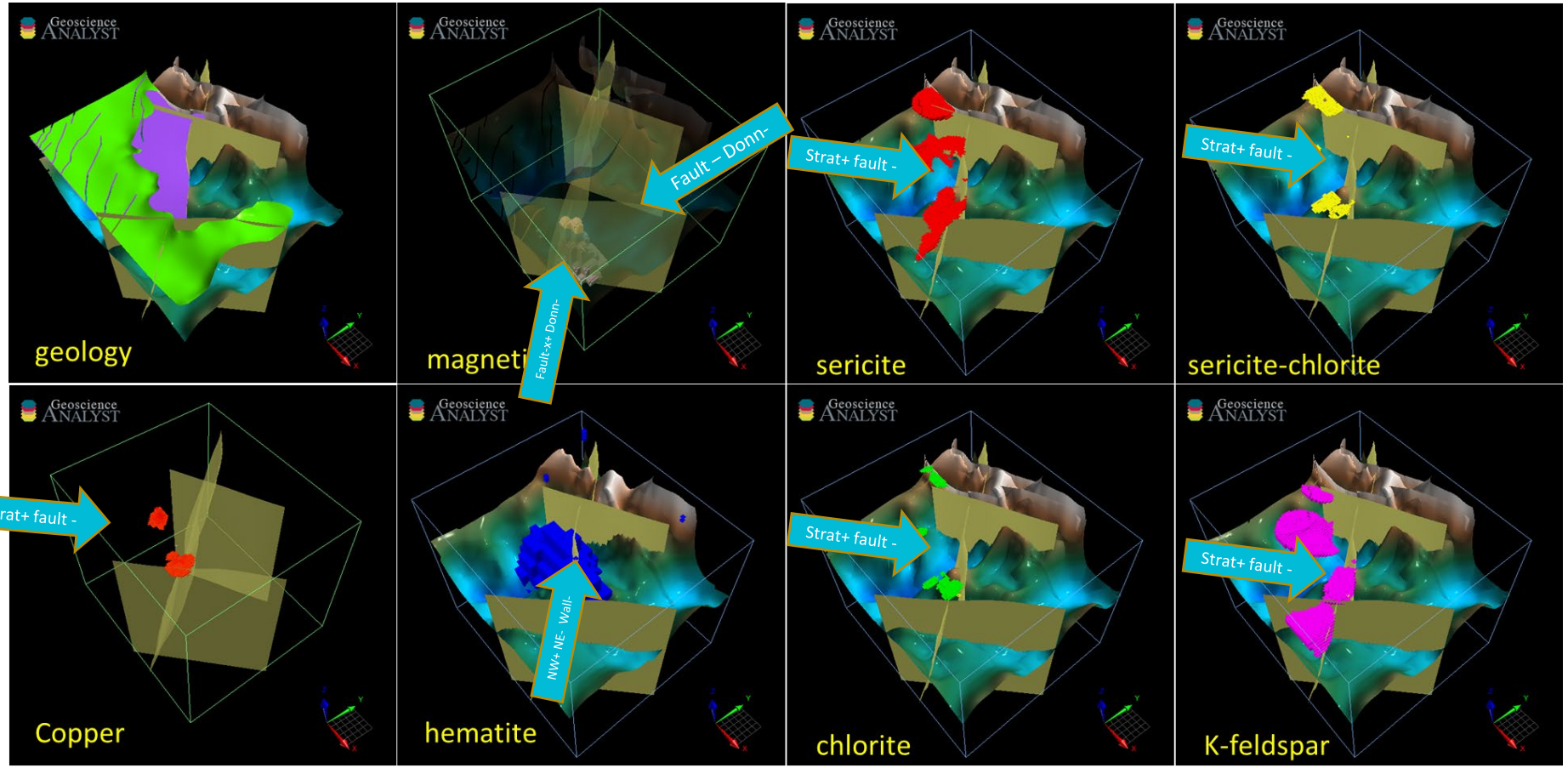
Dykes ca. 820 Ma Gairdner dykes vs 600 Ma mineralisation? Do dykes act as barriers to flow?

Sericite, chlorite, K-feldspar Source from SW, all faults as barriers within Nowhere and Wallaroo-Gawler Range

Magnetite Fault intersections OR limited by both if flow from NE as pathways stops at Donnington

Hematite NW Faults as pathways, limited by NE Faults, stops below Gawler Range

Copper At fault intersections and EJ Nowhere and Wallaroo-Gawler Range (within sericite, chlorite, K-feldspar zones)



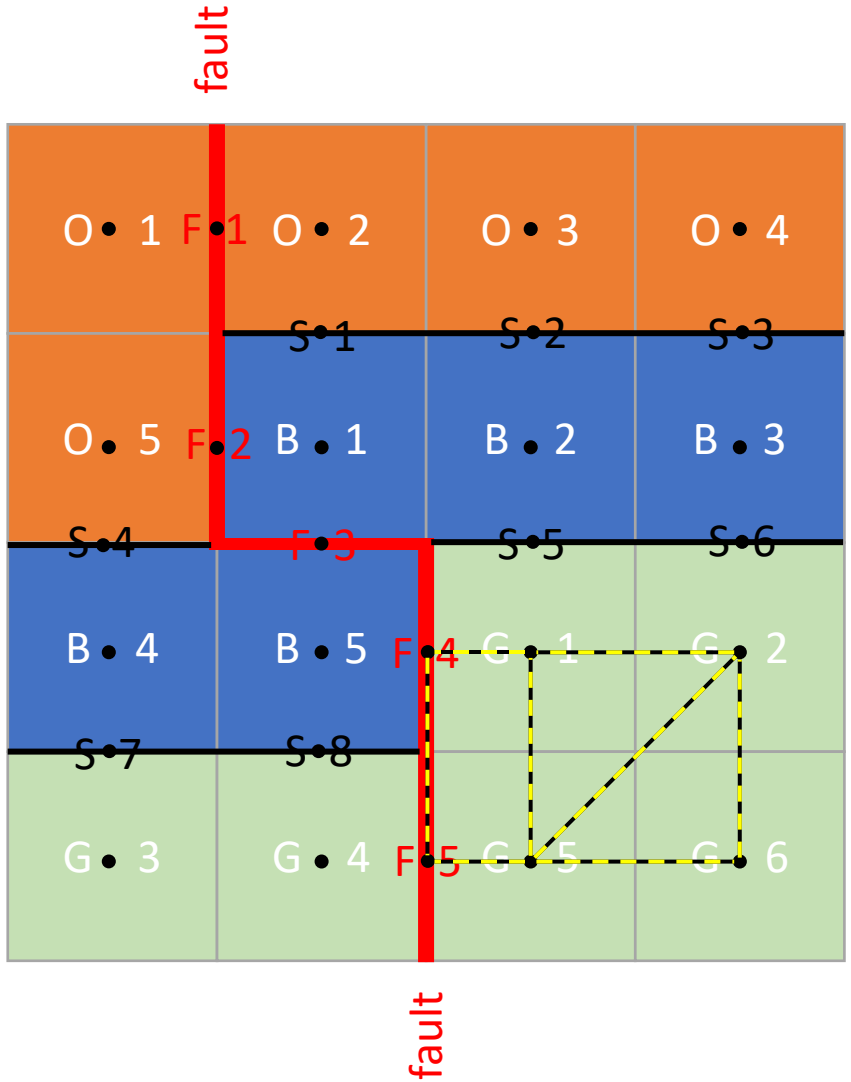
History

1. DEM
2. Neoproterozoic
3. Gairdner Dyke Swarm
4. Pandurra
5. NE Faults
6. NW Fault
7. Gawler Range
8. Wallaroo Group
9. Donnington

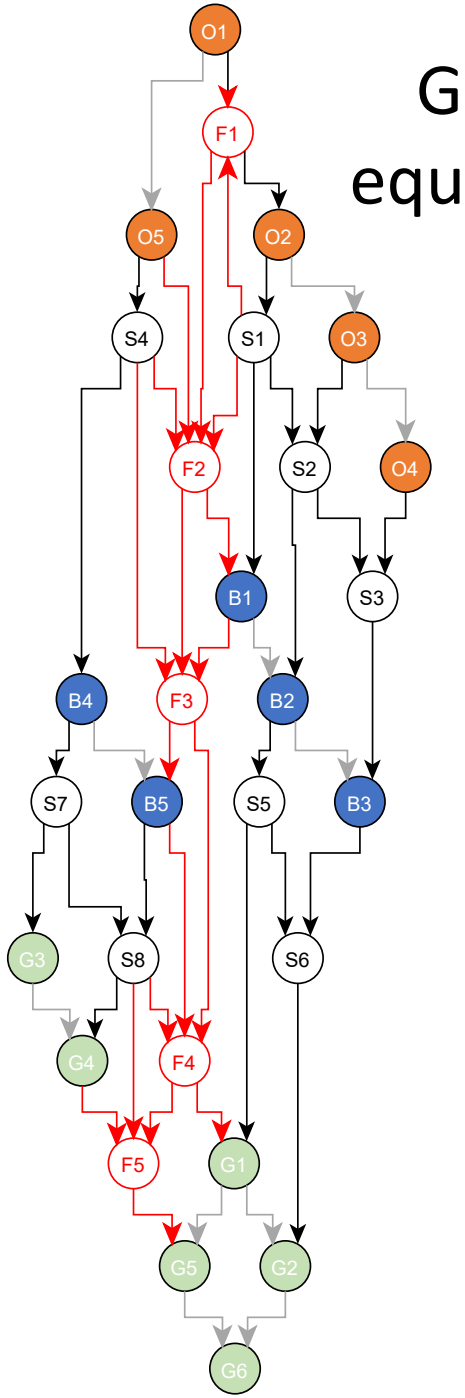
Method

- van der Wielen 2013 Gocad surfaces converted to inputs to Loop
- 5 km of extra geology calculated above current land surface
- 3D voxel model converted to directed graph
- Resulting graph used to explore scenarios of fluid source and geological pathways

Small slice through voxel model



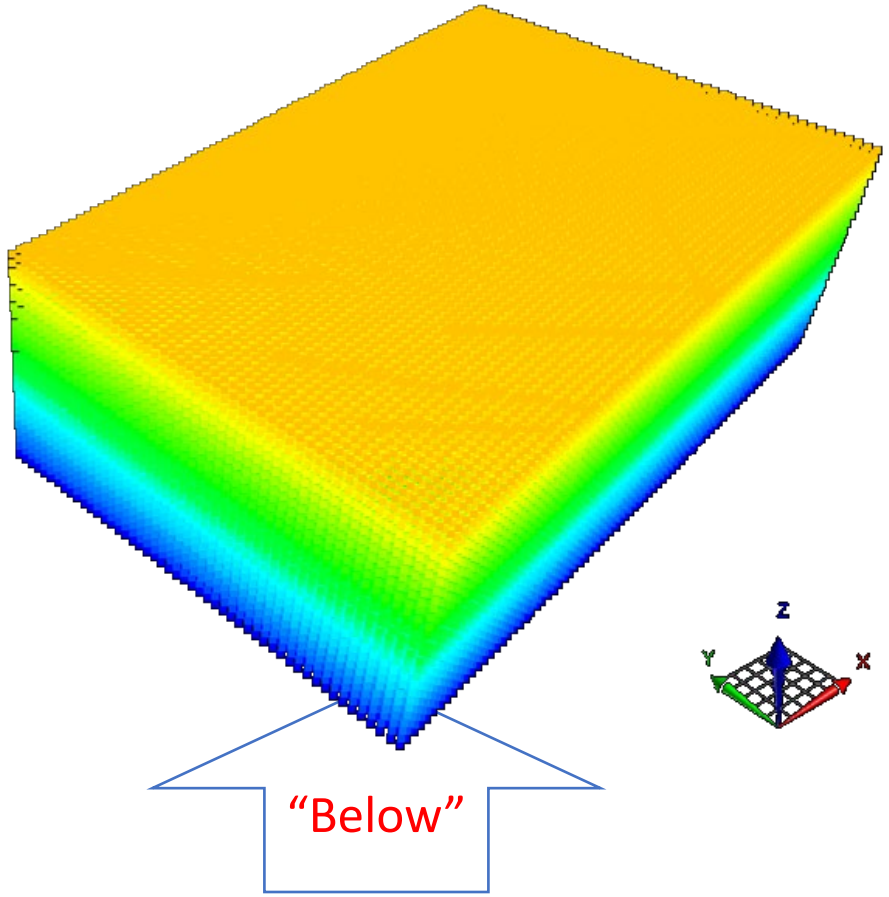
Graph equivalent

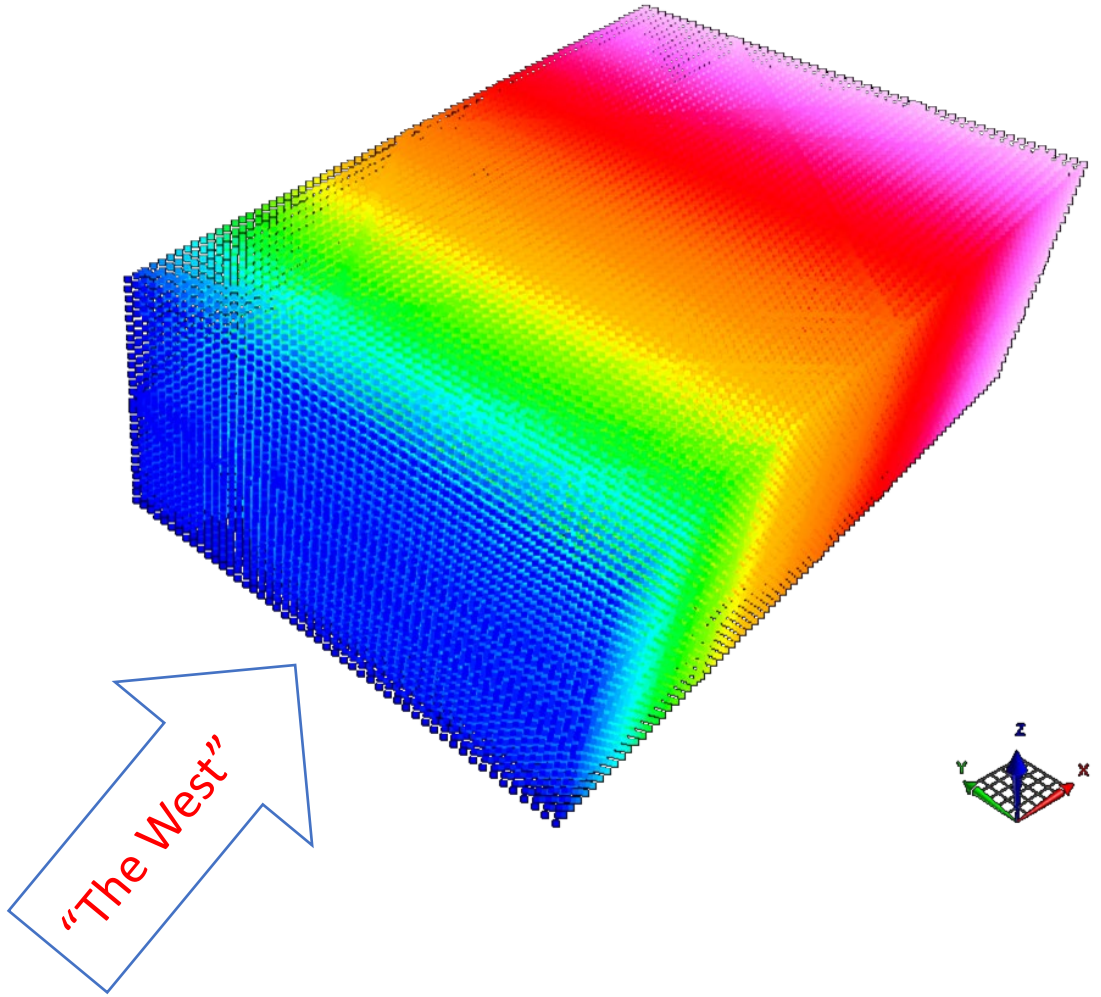


What is the fastest route home?

Fluid Source Scenarios

What is the presumed source of the fluid?

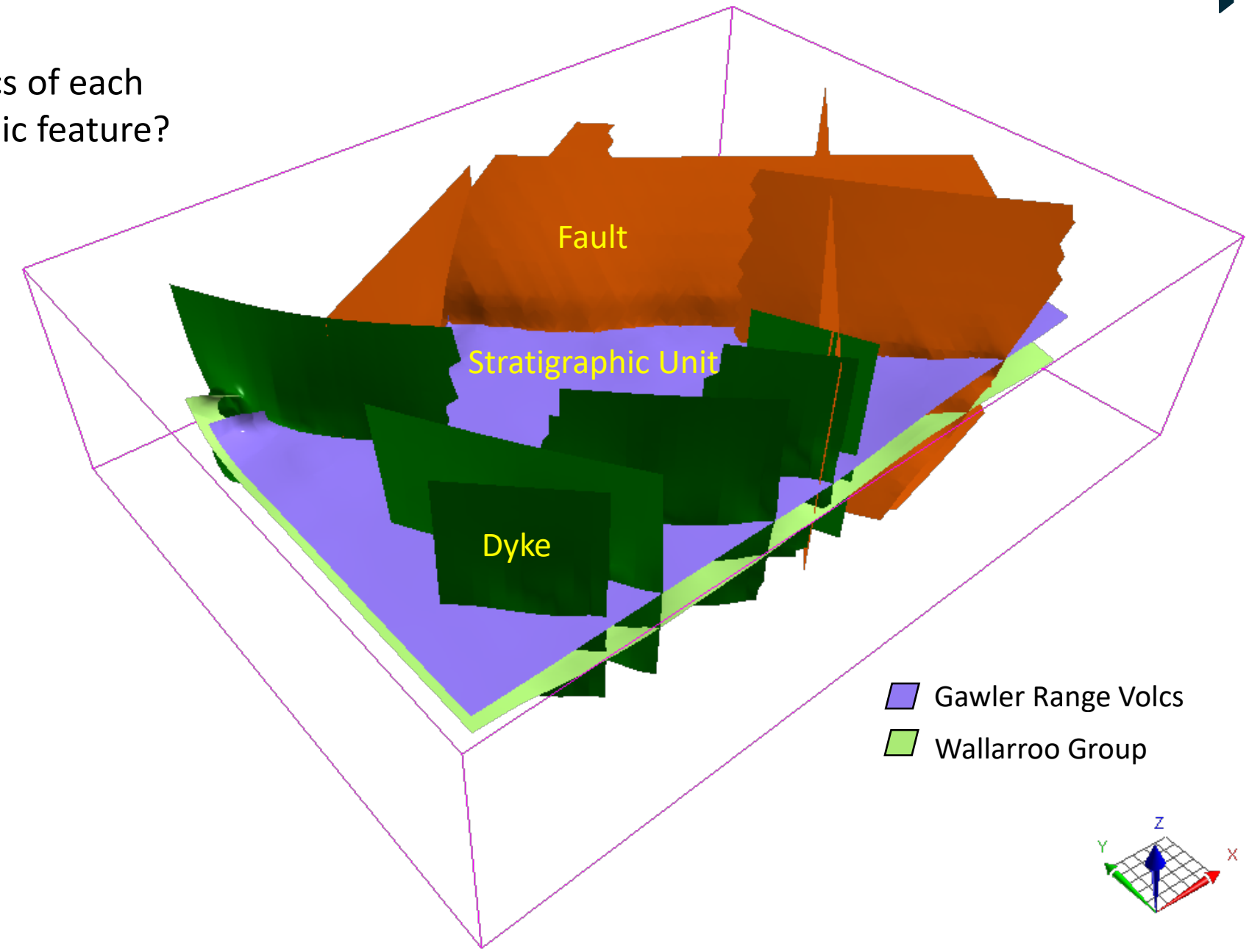




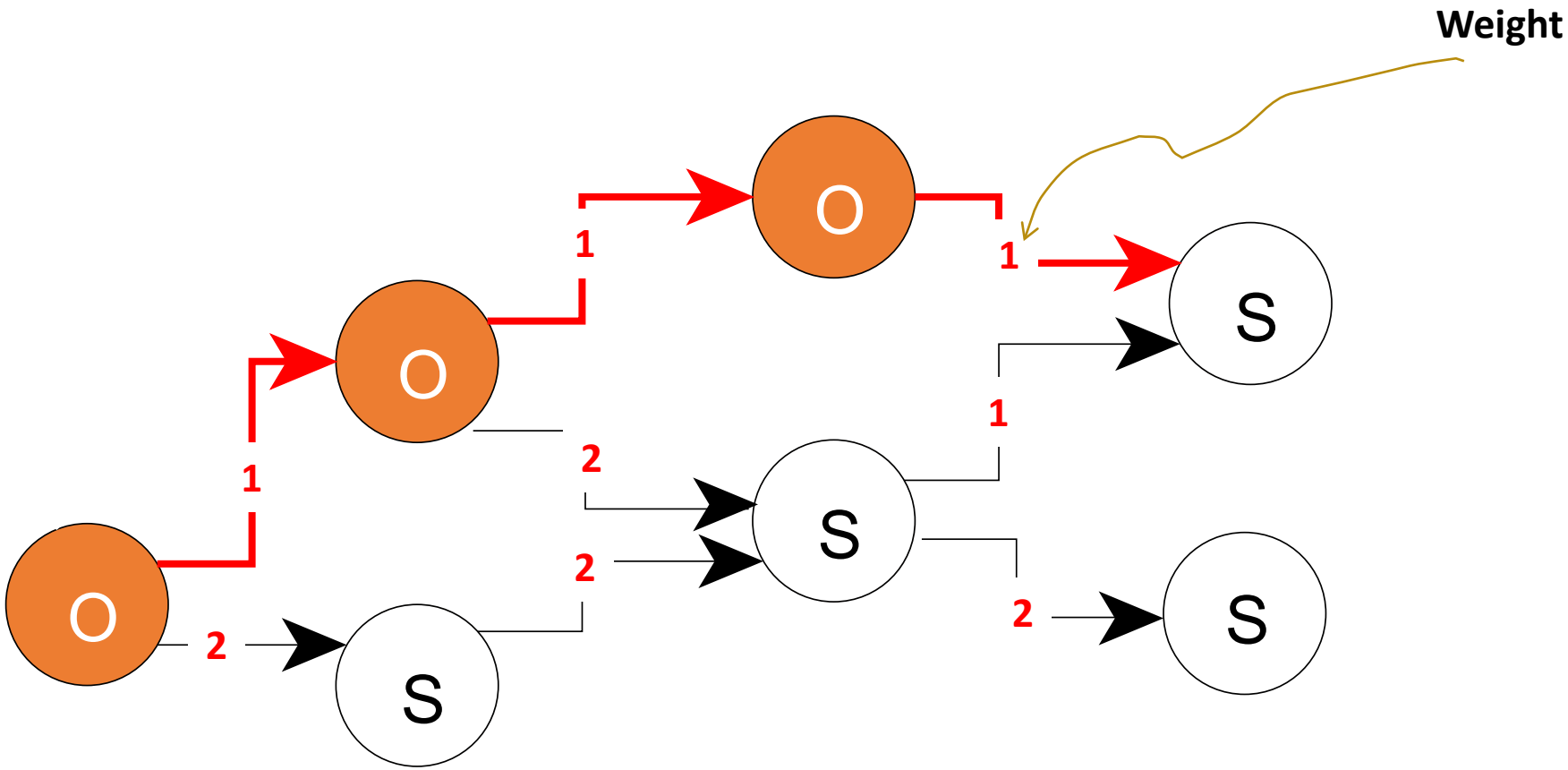
Fluid Pathway Scenarios

What are the flow characteristics of each geological structural/stratigraphic feature?

- Faults
- Stratigraphic unit
- Fault intersections
- Dykes (always slow)

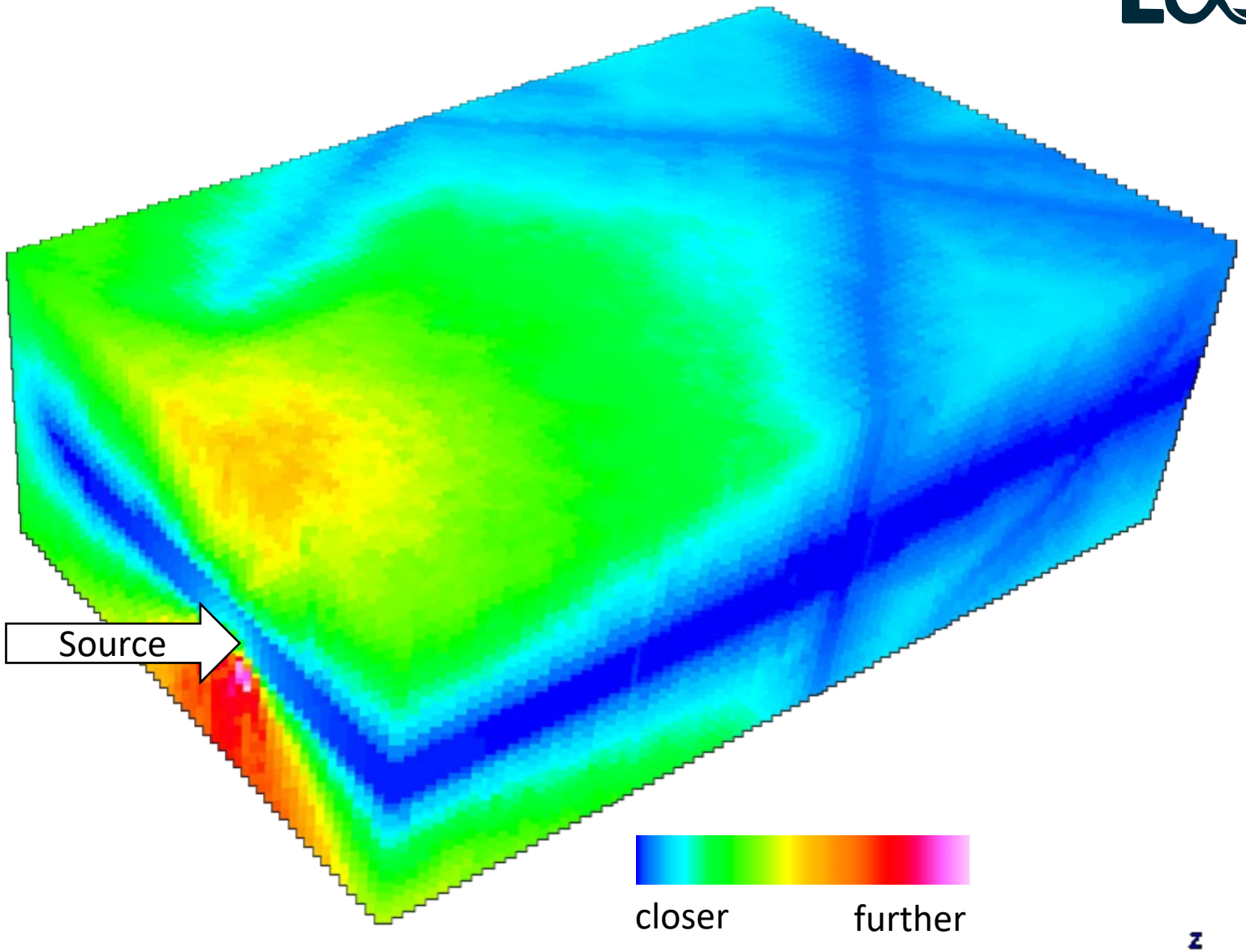


Distance, pathways, scenery…



Geological Distance

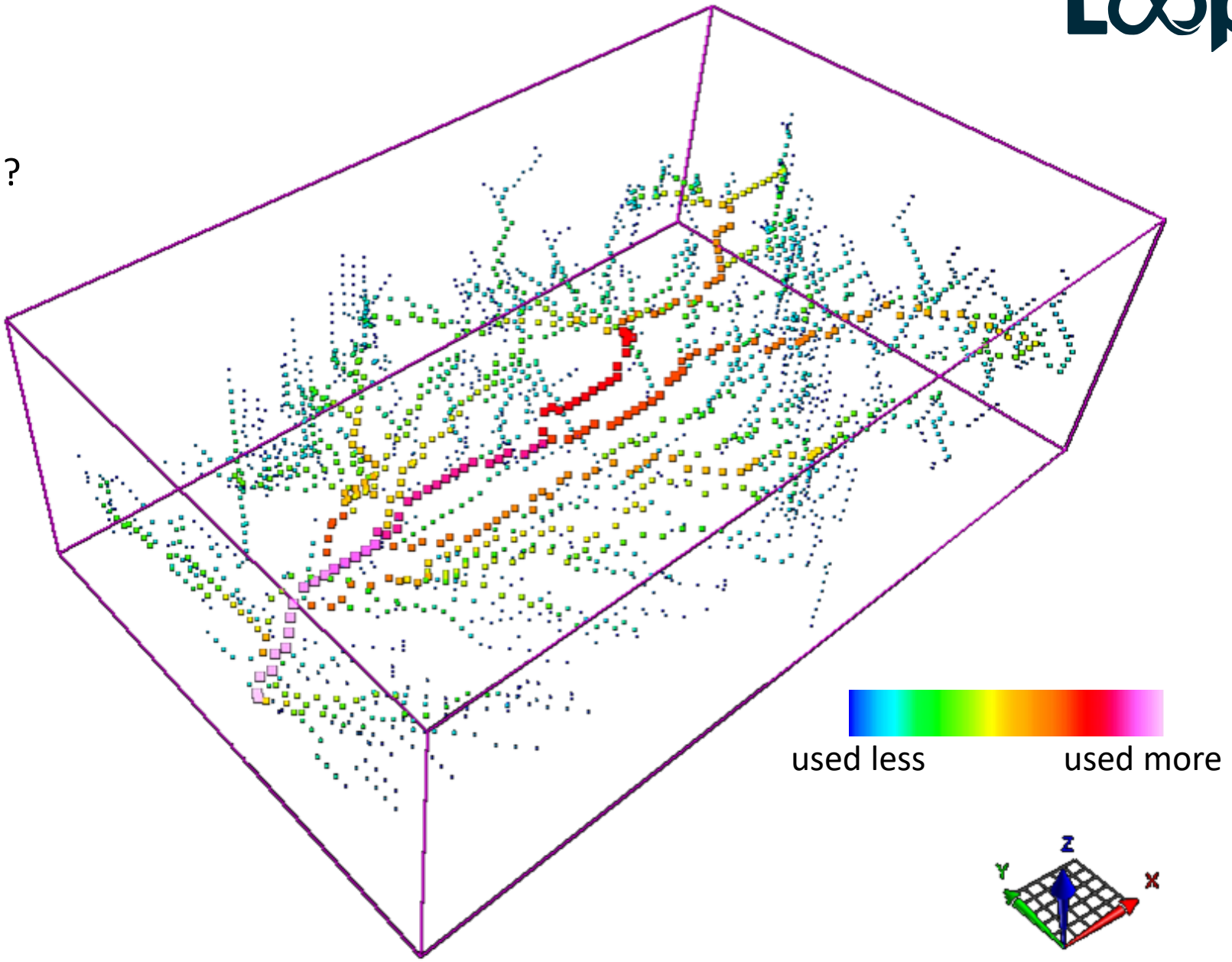
- How far is each point from the source?
- Can be normalised to its straight-line distance.



Which areas will see more fluid?

Preferred Pathways

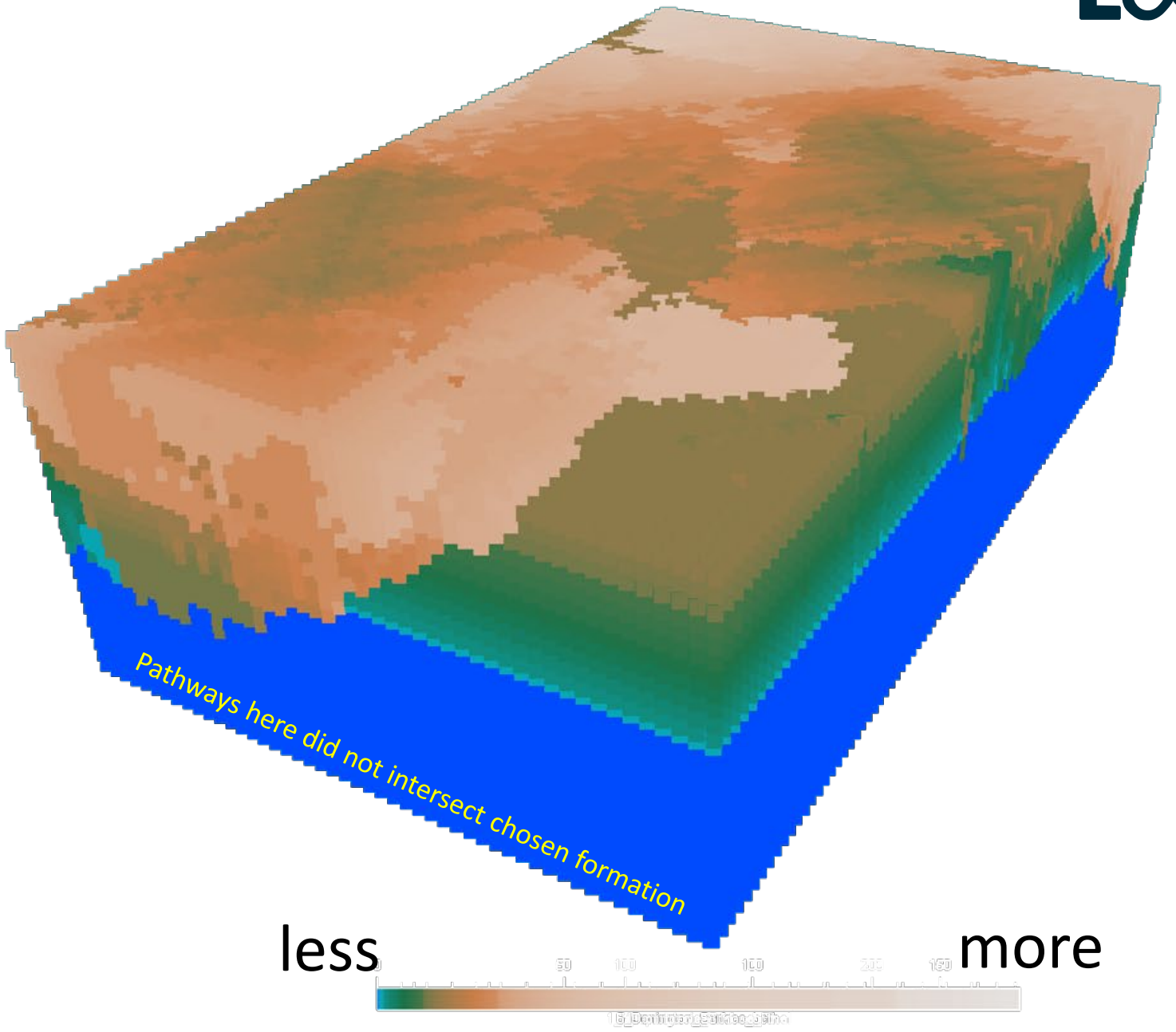
- Which pathways were most used?



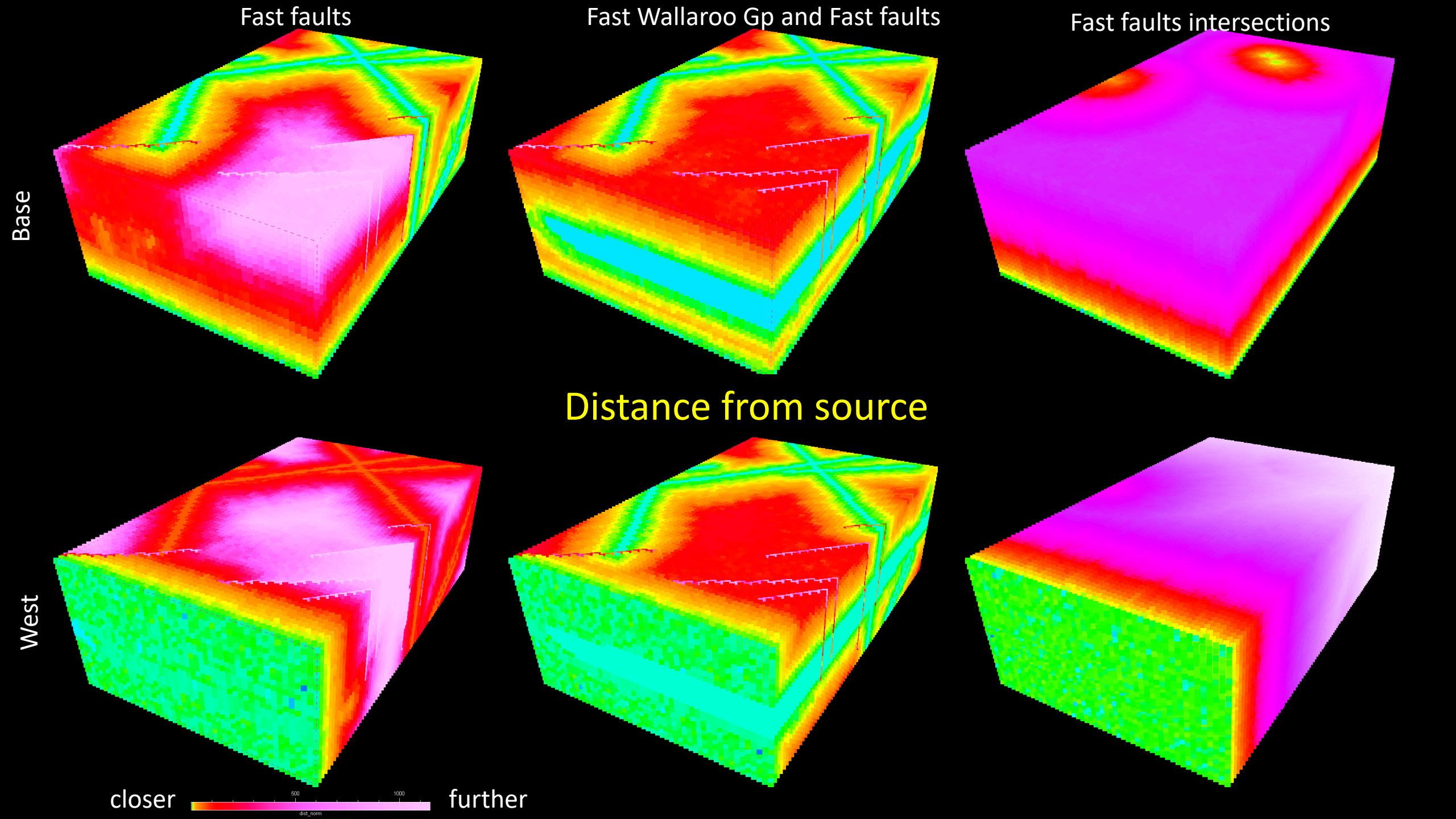
Identifies pathways

Scenery=
Wall-rock interaction

- How much of each wall rock stratigraphy was interacted with each pathway?
- Relative to four different units in the model
- Each patterns reflects potential chemical variations in fluids



Record of wall-rock interaction


Fast faults
Fast Wallaroo Gp and Fast faults
Fast faults intersections
Base
Distance from source
West
closer
further
500
1000
dist_norm

Fast faults

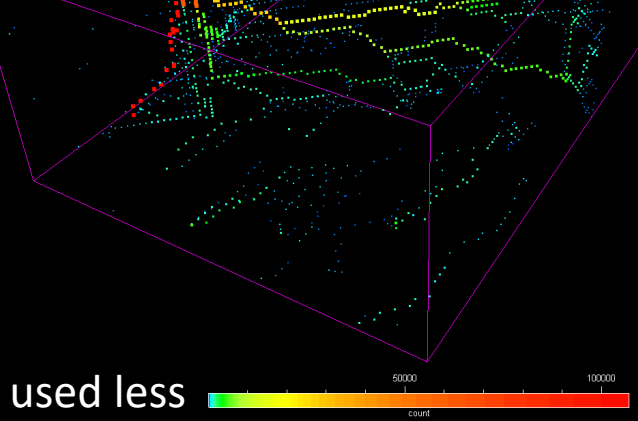
Fast Wallaroo Gp and Fast faults

Fast faults intersections

Base

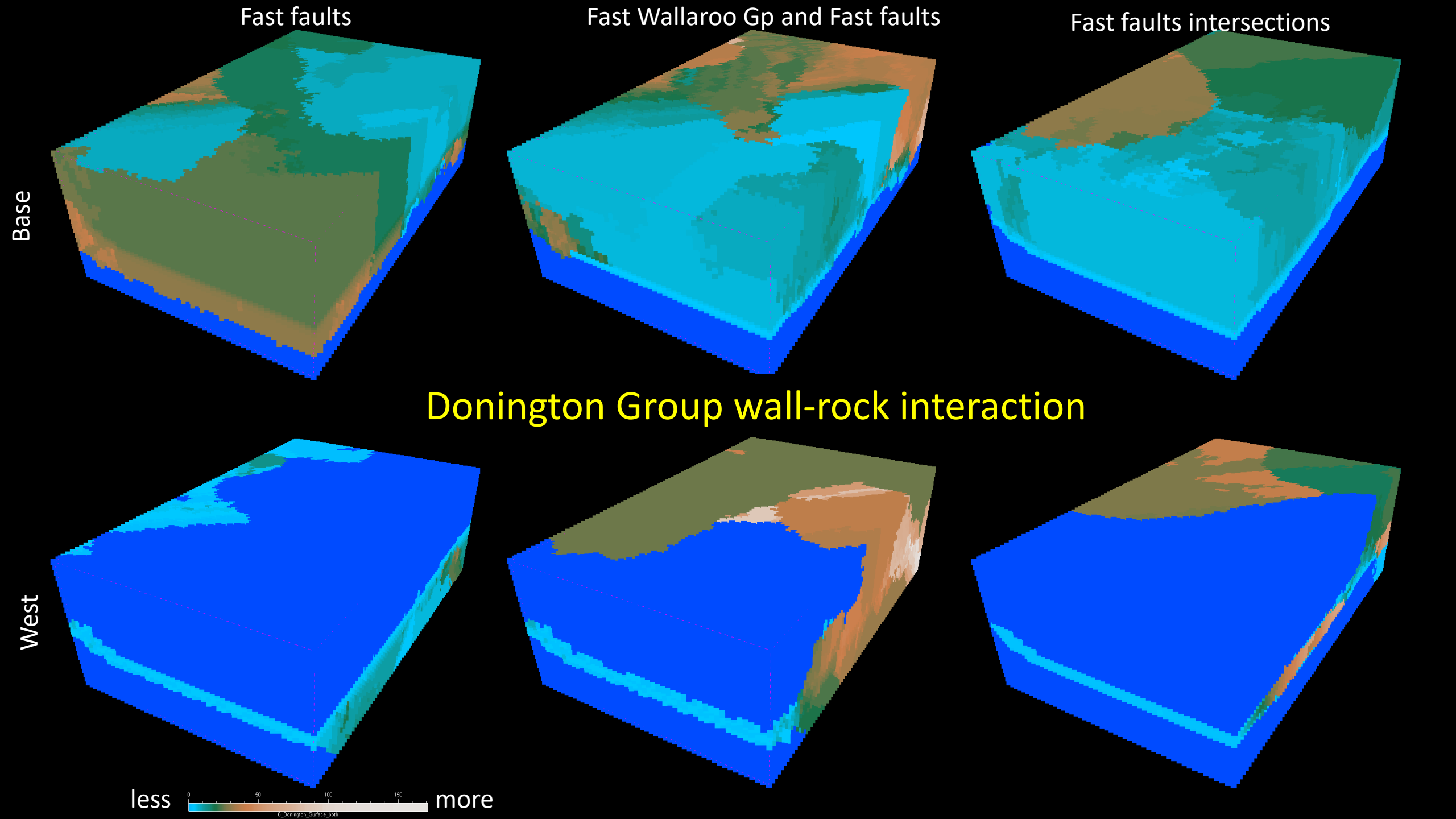
Preferred Pathways

West

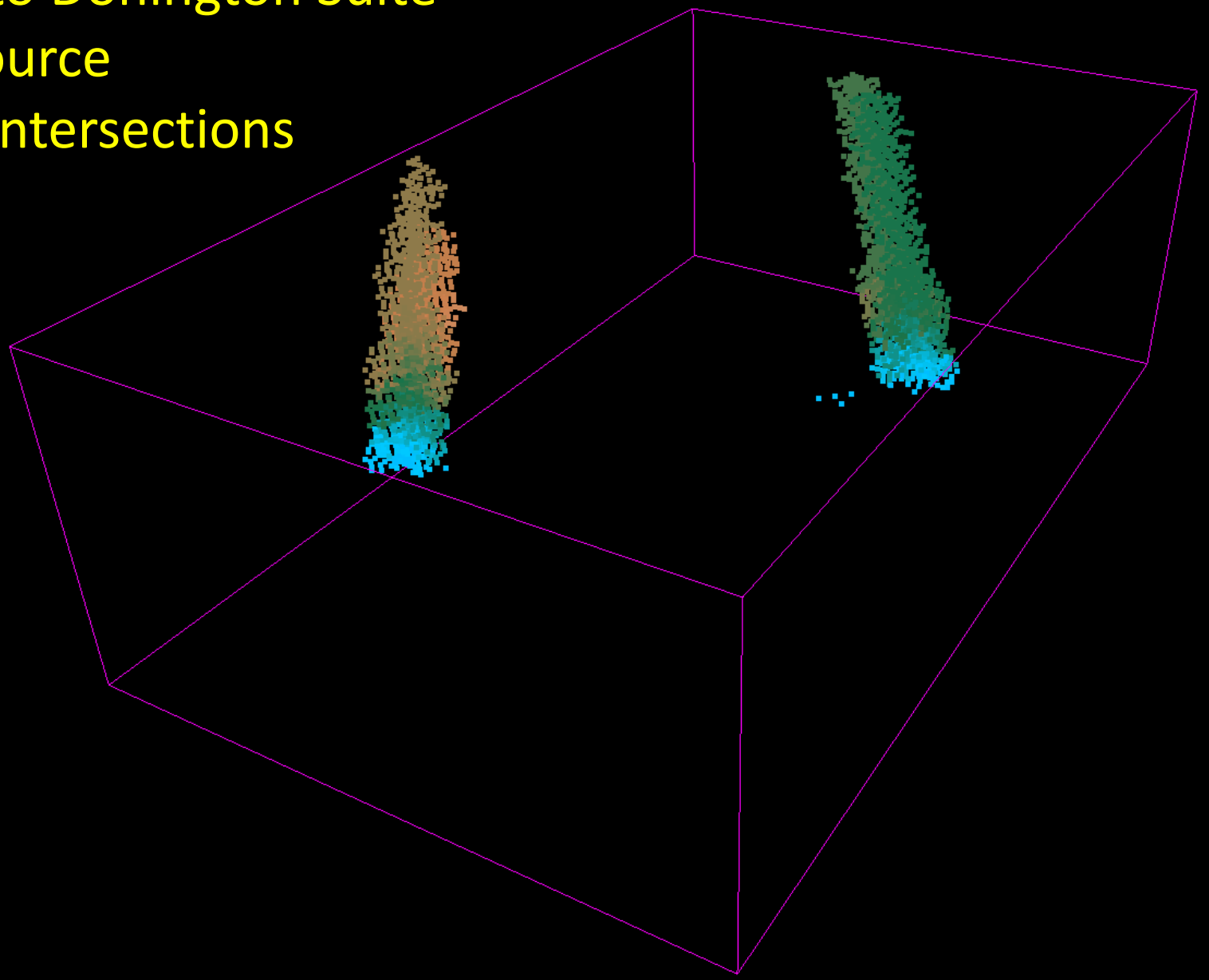


used less

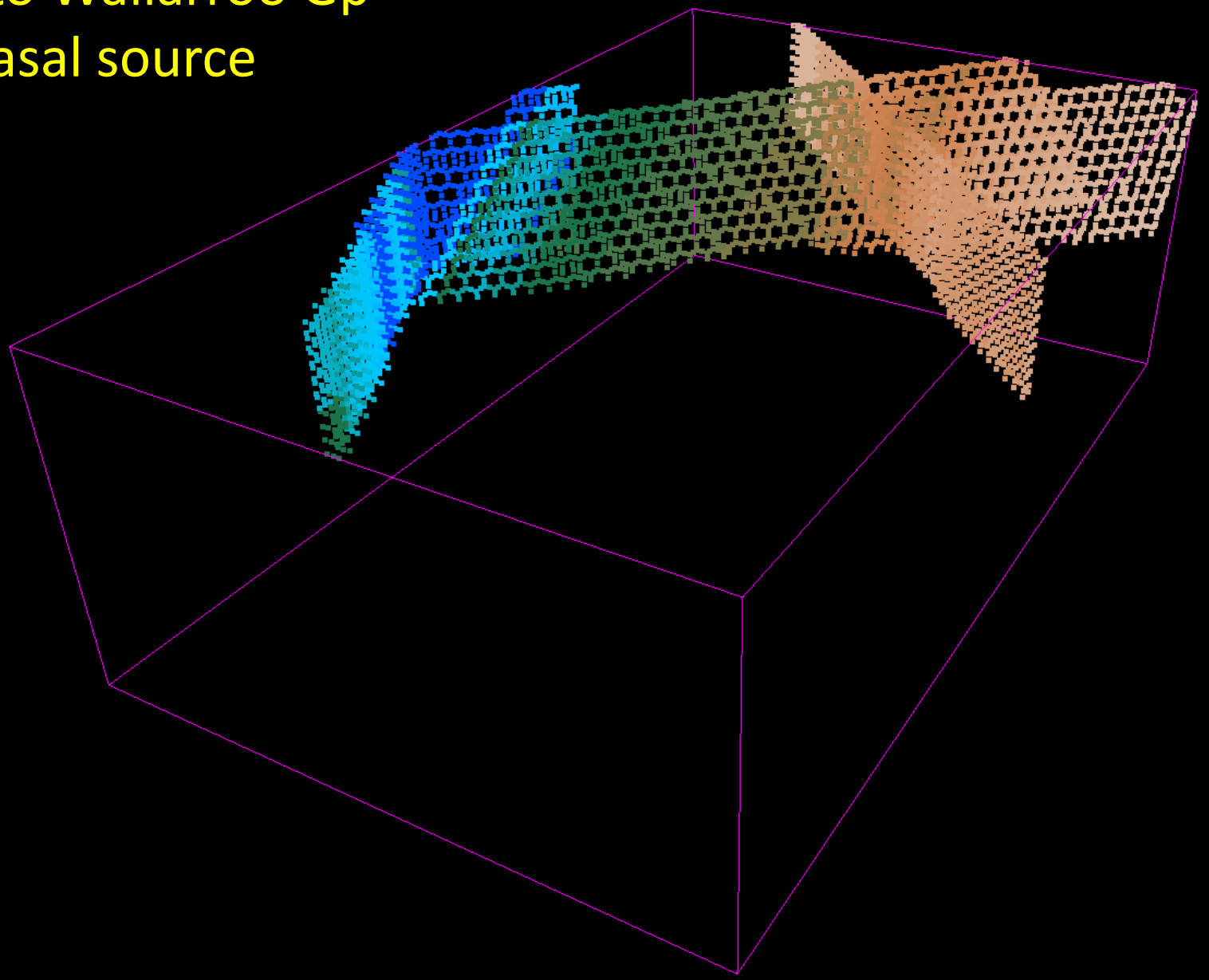
used more

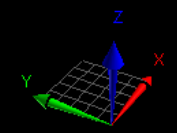

Fast faults
Fast Wallaroo Gp and Fast faults
Fast faults intersections
Base
Donington Group wall-rock interaction
West
less
0
50
100
150
more
6_Donington_Surface_both

Exposure to Donington Suite
close to source
Fast fault intersections



Exposure to Wallarroo Gp
Close to basal source
Fast faults





Caveats

- Only a model!
- Only a proxy!
- Base model, source and weighting uncertainty still needs to be explored

Future Improvements

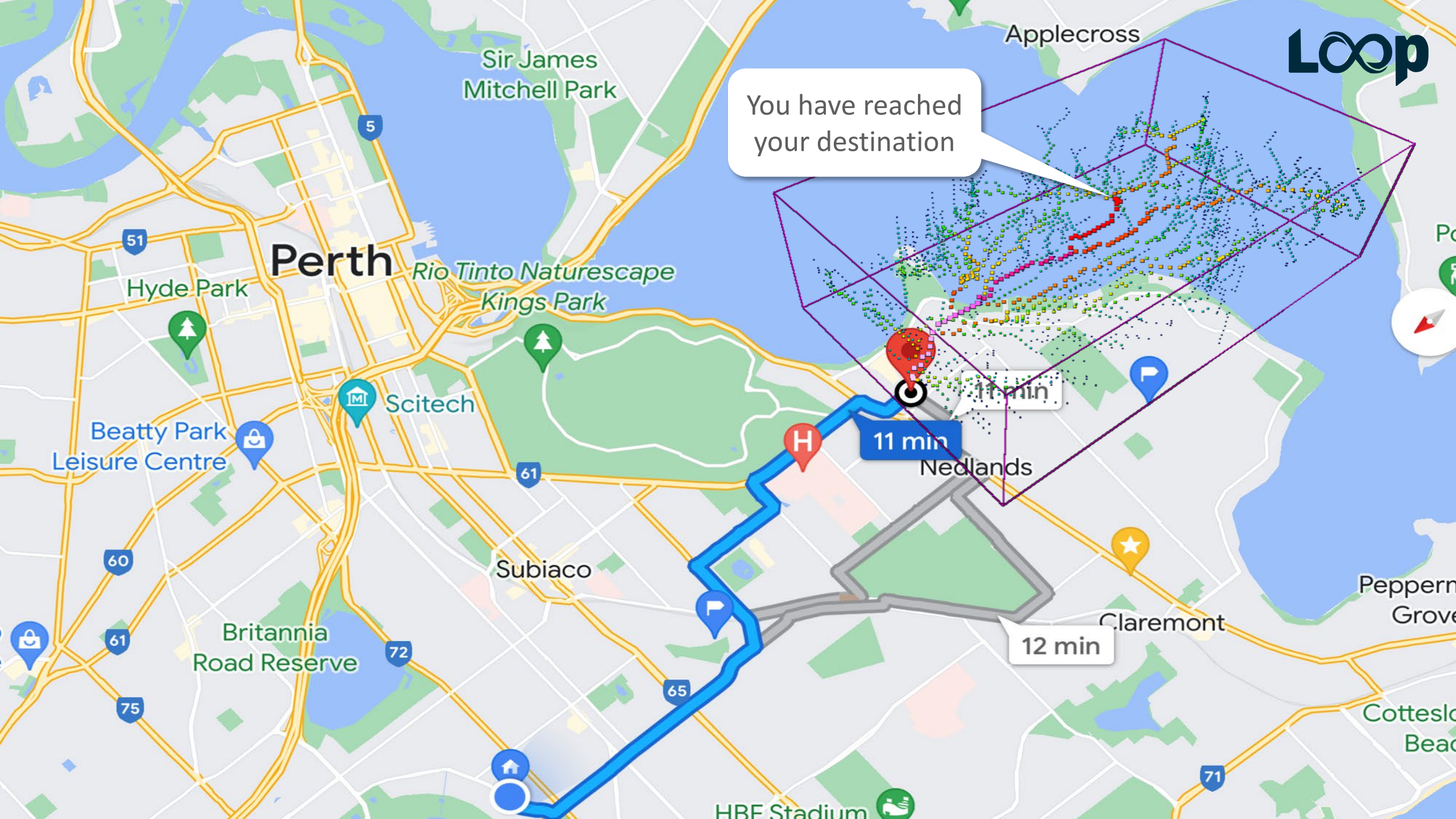
- Include stress-related orientation effect
  e.g. NW-oriented faults preferred
- Definition of fluid/depth/structural traps
  e.g. Structural/stratigraphic definitions
- Impose regional flow fields to control fluid pathways
  e.g. Fluids can only ascend or descend
- Spatial overlapping of multiple fluid generations

Summary

- In some parts of the world we have sufficient constraints to move beyond simple geometric descriptions of 3D geology to **regional models integrating petrophysics, mineralogy & chemistry**

- By converting our 3D models to graphs we have an efficient method for scenario-testing **fluid flow sources, pathways** and **wall-rock interaction** in the crust that will allow us to better understand alteration systems

- Based on a sample of ONE area:
  - quantities of fluid are controlled by permeability networks
  - “chemistry” of fluid controlled by source location


You have reached your destination
Loop
Applecross
Sir James Mitchell Park
Perth
Hyde Park
Rio Tinto Naturescape
Kings Park
Scitech
Beatty Park Leisure Centre
Nedlands
11 min
11 min
Subiaco
Britannia Road Reserve
Claremont
12 min
HBF Stadium
5
51
61
60
61
72
75
65
71