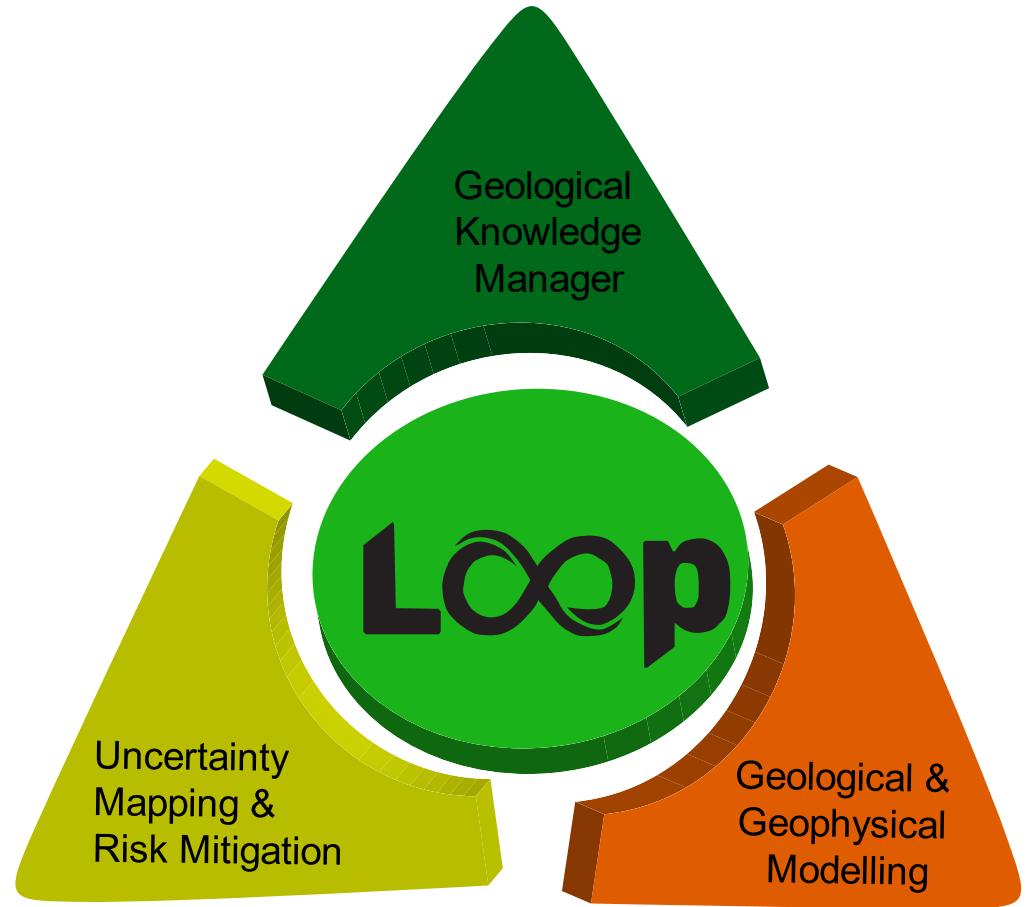


An integrated and interoperable platform enabling  
3D stochastic geological modelling

# Quarterly Report #10

## May 2021



MONASH University

THE UNIVERSITY OF  
WESTERN  
AUSTRALIA



RING  
UNIVERSITÉ  
DE LORRAINE

RWTH AACHEN  
UNIVERSITY

Australian Government  
Australian Research Council

AuScope

Australian Government  
Geoscience Australia

Government of Western Australia  
Department of Mines and Petroleum

SOUTH  
AUSTRALIA

NORTHERN  
TERRITORY  
GOVERNMENT



Regional  
NSW

brgm



MICROMINE

BHP

Providing geoscience data globally

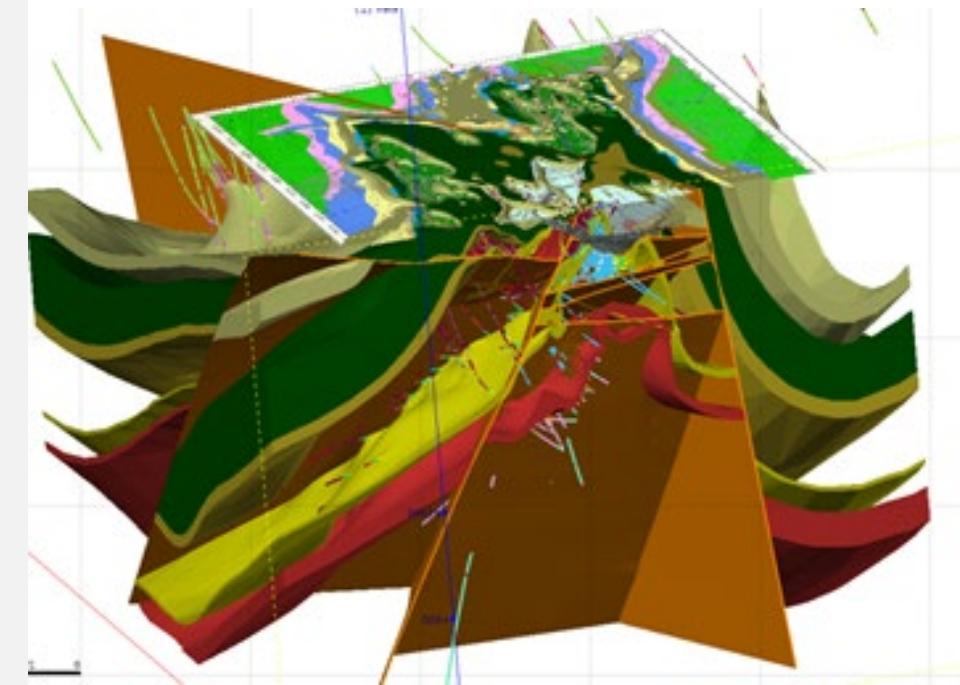
# Loop – Why a new platform?

- Current technology does not allow for modelling of poly-deformed terranes in a reproducible sense  
-> structural geology based modelling algorithm
- Need for uncertainty characterisation
- Need for better geophysical integration
- Maximisation of 3D geology uncertainty reduction

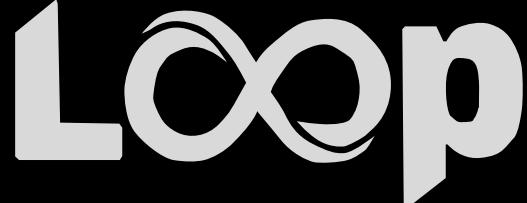
This can only happen through automatisation of the modeling workflow

- **Open-source is the future**

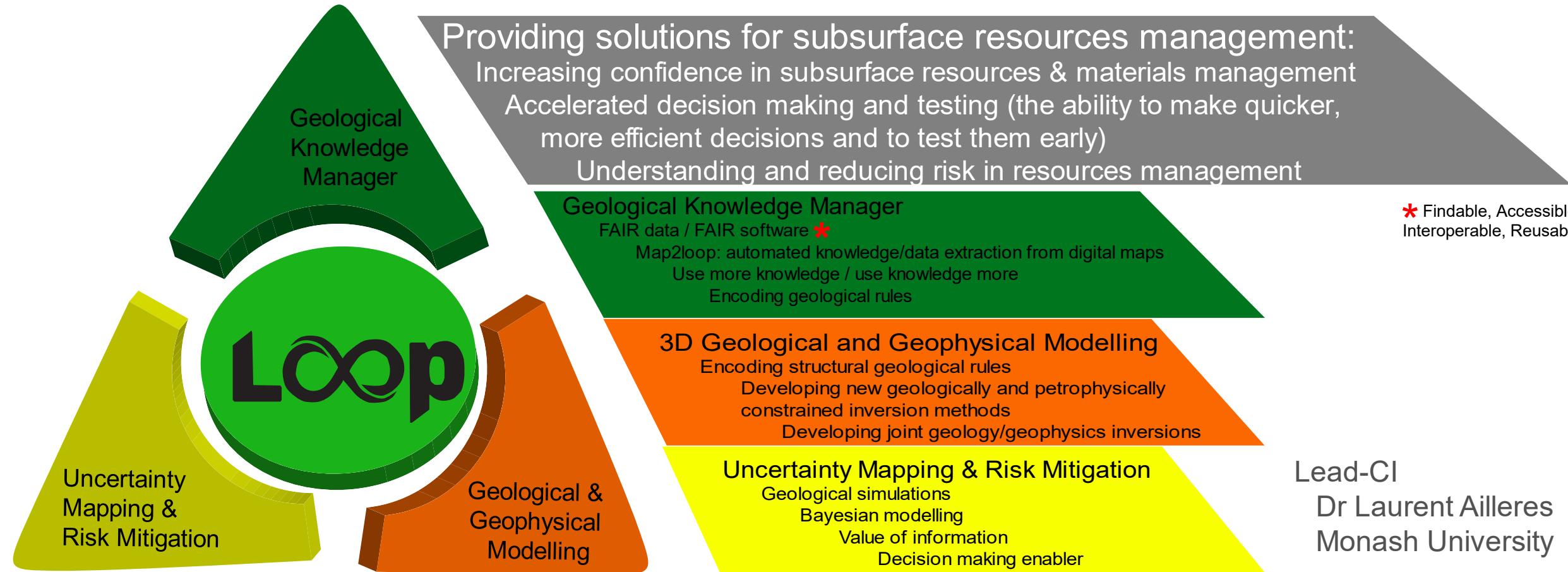
<https://github.com/Loop3D/LoopStructural>



A complex model like this would have had to be “hand-drawn”



# An integrated and interoperable platform enabling 3D stochastic geological modelling



MONASH University

THE UNIVERSITY OF  
WESTERN AUSTRALIA  
Centre for EXPLORATION TARGETING

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RWTH AACHEN  
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Australian Government  
Australian Research Council

AuScope

Australian Government  
Geoscience Australia

Government of Western Australia  
Department of Mines and Petroleum

Government of South Australia  
Department of State Development

SOUTH  
AUSTRALIA

British Geological Survey  
NATIONAL ENVIRONMENT RESEARCH COUNCIL

MinEx CRC

AngloAmerican

100 YEARS

brgm

CANADA  
GEOSCIENTIFIC SURVEY - COMMISSION GÉOLOGIQUE

MICROMINE

BHP

# Research Organisations



British  
Geological Survey  
Expert | Impartial | Innovative



Australian Government  
Geoscience Australia



# Funding Organisations (cash & in-kind)



ARC LP170100985



Geological Survey of  
Western Australia



# Partner Organisations



Welcome to New Partners in the ARC LP200301341 – “Loop - Enabling Interoperable, Integrated & Probabilistic 3D Geological Modelling” application.  
Let's hope we get funded!!



New Partners

Loop

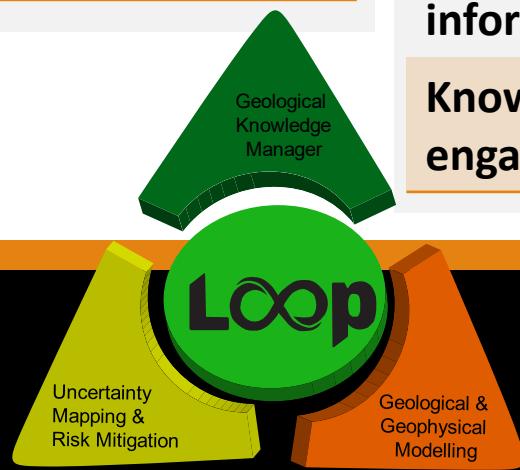
# Governance

## One Steering Committee:

Chair	<b>Carina Kemp (Aarnet)</b>
Monash – Lead CI	<b>Laurent Ailleres</b>
UWA / MinEx CRC	<b>Mark Jessell</b>
AuScope	<b>Tim Rawling</b>
Geoscience Australia	<b>Steve Hill</b>
GSWA / State and Territory Surveys of Australia	<b>Klaus Gessner</b>
BRGM / OneGeology	<b>Matthew Harrison</b>

## Research and Development team:

<b>Lead Chief Investigator</b>	<b>Laurent Ailleres (Monash)</b>
<b>Senior Software Architect</b>	<b>Roy Thomson (Monash)</b>
<b>Geological Knowledge Manager</b>	<b>Boyan Brodaric (Geol. Survey Canada)</b>
<b>map2loop (pre-processing)</b>	<b>Mark Jessell (UWA)</b>
<b>LoopStructural</b>	<b>Lachlan Grose (Monash)</b>
<b>Geophysical integration and modelling</b>	<b>Jeremie Giraud (UWA)</b>
<b>Uncertainty &amp; value of information</b>	<b>Guillaume Pirot &amp; Mark Lindsay (UWA)</b>
<b>Knowledge transfer &amp; community engagement</b>	<b>Robin Armit (Monash)</b>



# Loop

# Highlights THIS Quarter

## Staff movement:

- We are sad to see **Jeremie Giraud** and **Mark Lindsay** leave from UWA to fortunately go to more stable position. I, on behalf of the entire research and sponsors team, would like to thank them both for their work in Loop, their contribution to scientific discussions, the development of innovative methods for geophysical modelling and uncertainty characterisation and their invaluable contribution to students's supervision.
- **Mark** is gone to CSIRO where he is the “Science Leader – Minerals 4D” bridging the gap between geology / exploration and data analytics. Mark remains on an adjunct position at UWA as well and promises to remain involved as much as he can.
- **Jeremie** is joining the Universite of Lorraine, in the RING group, where he has taken up a prestigious “EU Marie Curie” post-doctoral fellowship. Jeremie will remain involved as well in Loop



# Highlights THIS Quarter

## Staff movement:

- We are also sad to see **Marion Parquer** finish her post-doctoral work at the Geological Survey of Canada. Similarly, I, on behalf of the entire team, would like to thank her for her innovative development of the 3D geological consistency checker and her scientific contribution in general.
- **Marion** has taken up a position at Universite de Lorraine as well and promises to remain involved as much as she can. We look forward to further collaboration with her!!
- In better news, **Vitaliy Ogarko** will join UWA to work on the MinEx opportunity funding OP6. Vitaliy Ogarko, one of the original authors of TOMOFAST and of map2model (the topology engine in map2loop) will commence at UWA 1st July 2021. Please join me in welcoming (back) Vitaliy to the team.

# Highlights THIS Quarter

- The **Geoscience Ontology** has been released (B. Brodaric and S. Richard)! Have a look on the Loop3d.org website under publications / data are also available under “downloads”
- The **GeoSwarm** has been released (E. de Kemp) – loop3D.org under downloads. Eric has a paper in discussion in GMD also available from loop3d.org under publications.
- Two **Auscope Opportunity funding** grants were submitted in June
- A surge in **papers** in discussion or now published in the **Special Issue of Geosci. Model Dev.**
- PhD candidate **Fernanda Alvarado models the Voisey's Bay intrusion!!** See p.70 of this report
- The **Loop application** is making awesome progress – see p.29 and the download section of Loop3d.org
- Guillaume Pirot generalises the concept of ensemble generation to Loop and proposes a **mitigation method for the underestimation** of uncertainty using pilot-sticks (see the next slide)



# Funding and Resources

# Funding and Resources – Current Applications

ARC LP200301341 Enabling Interoperable, Integrated & Probabilistic 3D Geological Modelling – imminent announcement

Auscope Opportunity Funding: 2 x applications – outcome known in Jul-Aug 2021

- *3D uncertainty quantification cloud compute facility* – to support cloud computing of Loop stochastic uncertainty quantification.
- *A Bayesian approach to building a continental-scale fault network of Australia* – to develop a Bayesian framework for the analysis of faults geometry, offset and kinematics from maps.



# Current Funding



## Project 6- Automated 3D geological modelling

\$1.2M Project 6 – CRC + \$540K awarded March 2021

Project 6 Leaders **Mark Jessell & Mark Lindsay**

1: week for uncertainty-characterised model suites



## Loop Consortium

\$3M OneGeology/ARC Linkage Consortium

Project Leader **Laurent Ailleres**

Make a better world for 3D modellers



## Data Analytics in Resources and the Environment ARC

ARC Industrial Transformational Training Centre

\$10M Multi-institutional Graduate School in applied Data Analytics (15 PhD & 3 Postdocs)

Centre Director: Prof **Sally Cripps**, Co-Director of Centre of Translational Data Science Sydney University

Lead Minerals Exemplar: Dr **Mark Lindsay**, ARC DECRA Fellow



DECRA

## Value of Information

\$1M ARC DECRA

Project Leader **Mark Lindsay**

What (geophysical) data should I collect?



# Funding Leverage

- ARC LP + MinEx CRC P6 + DECRA  $\approx$  \$5.6M research expenditure
- Sponsors investment leverage of between 10:1 to 170:1

# Loop in Numbers

- 7 in-kind CI
- 9 in-kind PI
- 4 NEW research positions
- 3 NEW software design/development positions
- 7 non initially named PI's at partner organisations
- 10 NEW PhD candidates
- 4 Universities, 4 National Geological Survey Organisations
- 5 countries, 3 continents
- *Problem: the senior research team is **heavily lacking diversity***

# The most important resource: People! CI/PI on the initial ARC LP grant

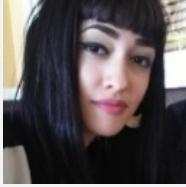
- Monash Uni: Laurent Ailleres, Robin Armit, Peter Betts, Sandy Cruden, Tiangang Cui, Jerome Droniou
- UWA: Mark Jessell, Mark Lindsay (now a DECRA Fellow)
- RING – Nancy, FRA: Guillaume Caumon
- RWTH Aachen, GER: Florian Wellmann
- GS of Canada: Eric de Kemp
- BGS - UK: Matthew Harrison (**now with BRGM**) & Holger Kessler
- GA Carina Kemp (now at Aarnet // chair of the steering committee)
- Auscope: Tim Rawling
- GSNSW/GSWA Giovanni Spampinato & Klaus Gessner

# People – leverage of collaborative research in open source

- Monash Uni:
  - Lachlan Grose – post-doc LoopStructural (ARC LP)
  - Roy Thomson - software architect (ARC LP)
  - Yohan de Rose – software engineer (ARC LP)
- UWA:
  - Jeremie Giraud – G-Loop “LoopGeophysics” (ARC LP +/- Minex CRC)
  - Guillaume Pirot – value of information (MinEx CRC)
  - Khavita Madaiah – software engineer (MinEx CRC)
- RING – Nancy, FRA:
  - Francois Bonneau – meshing and algorithmic (in-kind)
- RWTH Aachen, GER:
  - Miguel de la Varga (PhD RWTH Aachen)
- GS Canada
  - Boyan Brodaric / Steve Richard – ontology of geology // knowledge manager (In-kind)
  - Michael Hillier – (staff and new PhD @ RWTH Aachen ) Interpolant constrained by anisotropy
  - Marion Parquer - post-doc // 3D models consistency checker (new position @ GSC)
- BGS:
  - Rachel Heaven, Edd Lewis, Russell Lawley, Katherine Royse (CDO BGS)



# The most important resource: People! (PhD)

- Multi-scale 3D modelling Yalgoo–Singleton greenstone belt (Ranee Joshi, 21/1/2019) (MinEx CRC scholarship)
- Integrated 3D modelling of the Paterson Orogen (Polyanna Moro, 25/2/2019) (MinEx CRC scholarship)
- Data fusion methodologies for geology-geophysics inversion (Mahtab Rashidi Fard, 1/9/2019) (MinEx CRC scholarship)
- Factors Contributing to Metal Endowment in the Wabigoon Subprovince (Becky Montsion, Cotutelle with Uni Laurentian & GSC) (Canadian scholarship)
- Integrated 3D modelling in a drilling/Electrical methods (Nuwan Suriyaachchi)(1/10/2019) (MinEx CRC scholarship)

# The most important resource: People! (PhD)

- The value of structural data (Rabii Chaarani, Mar 2019) (APA)
- Modelling intrusion from field observations (Fernanda Alavarado, Aug 2019) (APA)
- Integrated geophysical and geological 3D modelling: Marina Jeronimo-Zarate (starting in March 2021) (APA)



# Detail Progress Report

# WP #0 – Infrastructure // Software Development

Is work on track against plan? update all deliverables

Work completed

On track

Delayed

Problem

Will not happen

New

- 1. Recruit one post-doctoral fellow for structural modelling: completed / Dr Lachlan Grose
- 2. Organise and run the kick off meeting – completed and run in Nov 2018
- 3. Set up high level infrastructure: GitHub repository / Slack workspace running, website, central GitHub repository with each work package as a sub-module
- 4. Recruiting one senior software engineer with knowledge of software architecture: Roy Thomson
- 5. Recruiting a software developer: Yohan de Rose
- 6. Data structure / API's design by Sept 2019 (was June 2019) : completed – refined and completed python and C++ implementation of data structures for WP 2 and 3 and continuing work on WP1,4,5 components and Fortran versions (ongoing)

# WP #0 – Infrastructure // Software Development

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 7. Report on redefinition of the work packages / report of meeting / Distributed via email, google drive and slack
- 8. Software architecture: First-pass UI design complete and data passing from online sources, re-projected, sampled, used in forward inverse structural modelling and displayed, incorporating new version of map2loop
- 9. Collate deliverables / milestones of all WP's by start of Feb 2019 (done) and ongoing with updates
- 10. Engage with Auscope to assess their level of support: ongoing // involved in the current strategic planning meetings and proposals.
- 11. Manage Quarterly reports (ongoing quarterly)
- 12. Design and implement mechanism to calculate and display permutations of possible geological event histories with feedback that shows which events contribute to the greatest uncertainty

# WP #0 – Infrastructure // Software Development

Is work on track against plan? update all deliverables

Work completed

On track

Delayed

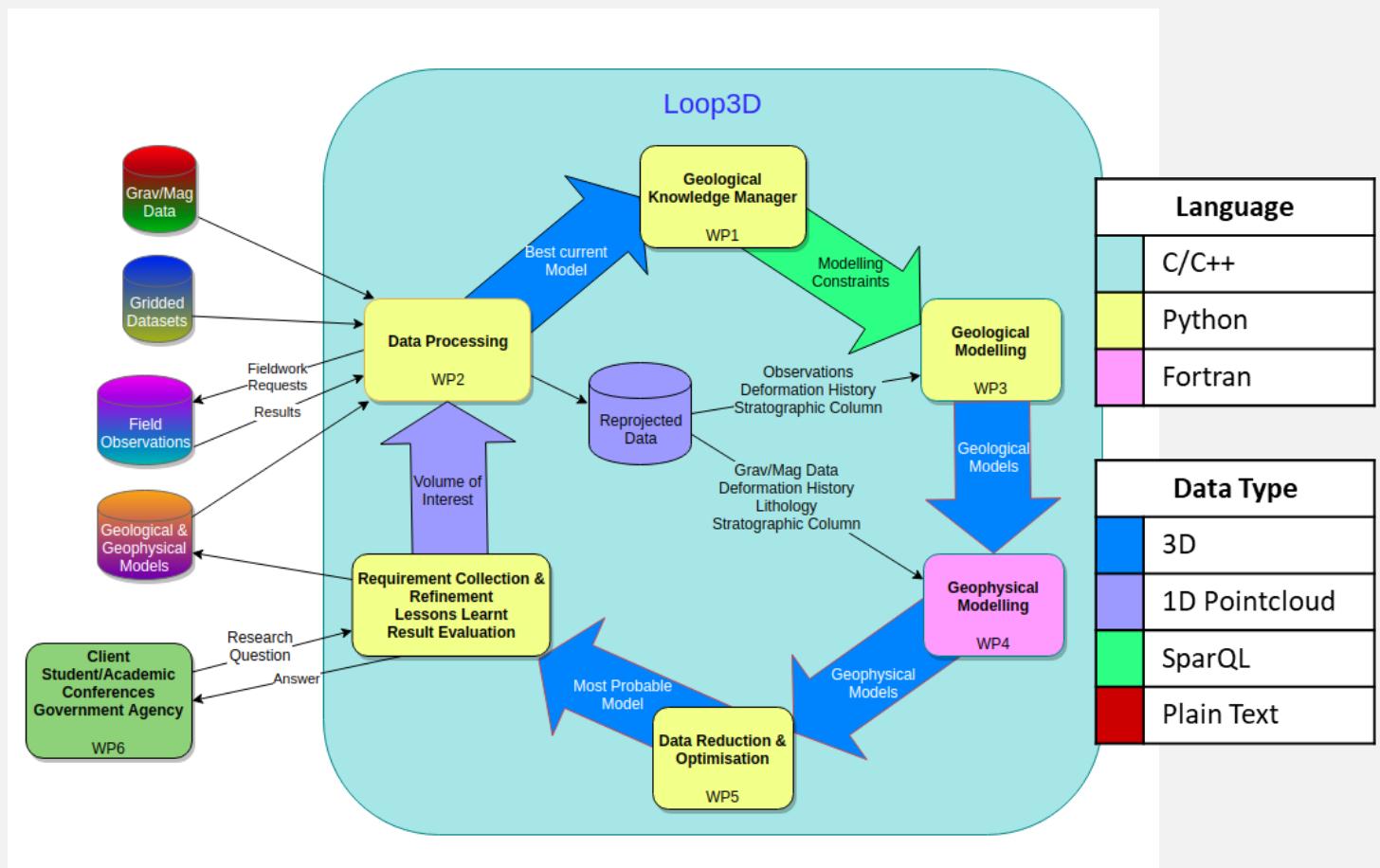
Problem

Will not happen

New

- 13. Adding optional data review procedure into the Loop GUI to fix errors in downloaded and re-projected data (such as mis-classified observations)
- 14. Software architecture: (ongoing) Incorporation of additional WP software modules and also online data sources (GADDS2, OneGeology)
- 15. Implementation of parallel processing of python modules within GUI including optimisation
- 16. Full access to configuration options of Data Collection and Geological Modelling steps within GUI
- 17. Demonstration and first release of GUI software in mid March 2021
- 18. Rework graph of stratigraphic column ordering and permutations, adding extracted event relationships
- 19. Addition of custom data import/export functionality

# WP #0 – Infrastructure // Software Development



## Loop Workflow

Data Types are to be encoded in a single netCDF project file (with .loop3d extension)

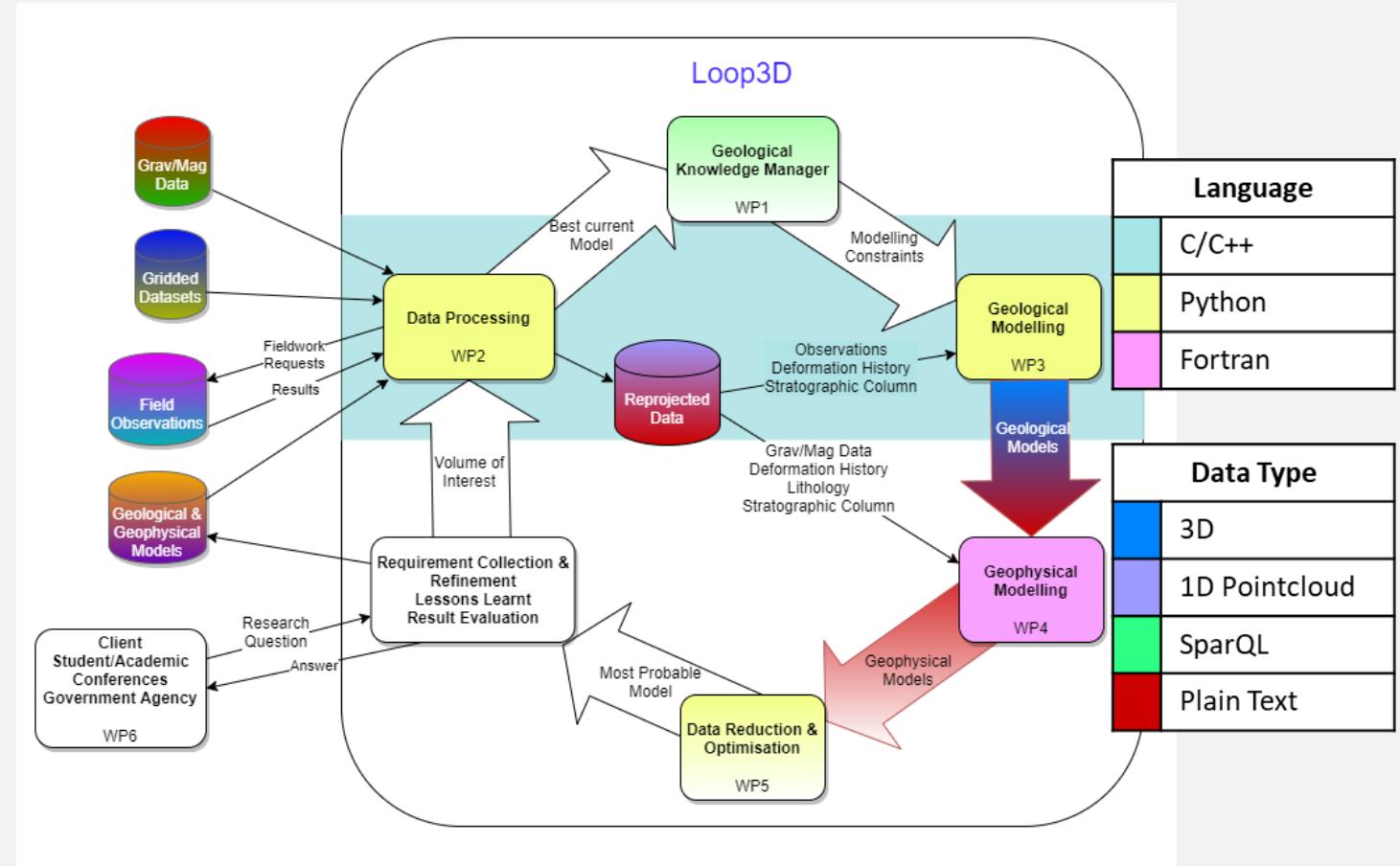
**Loop**

# WP #0 – Infrastructure // Software Development

## Implemented Workflow

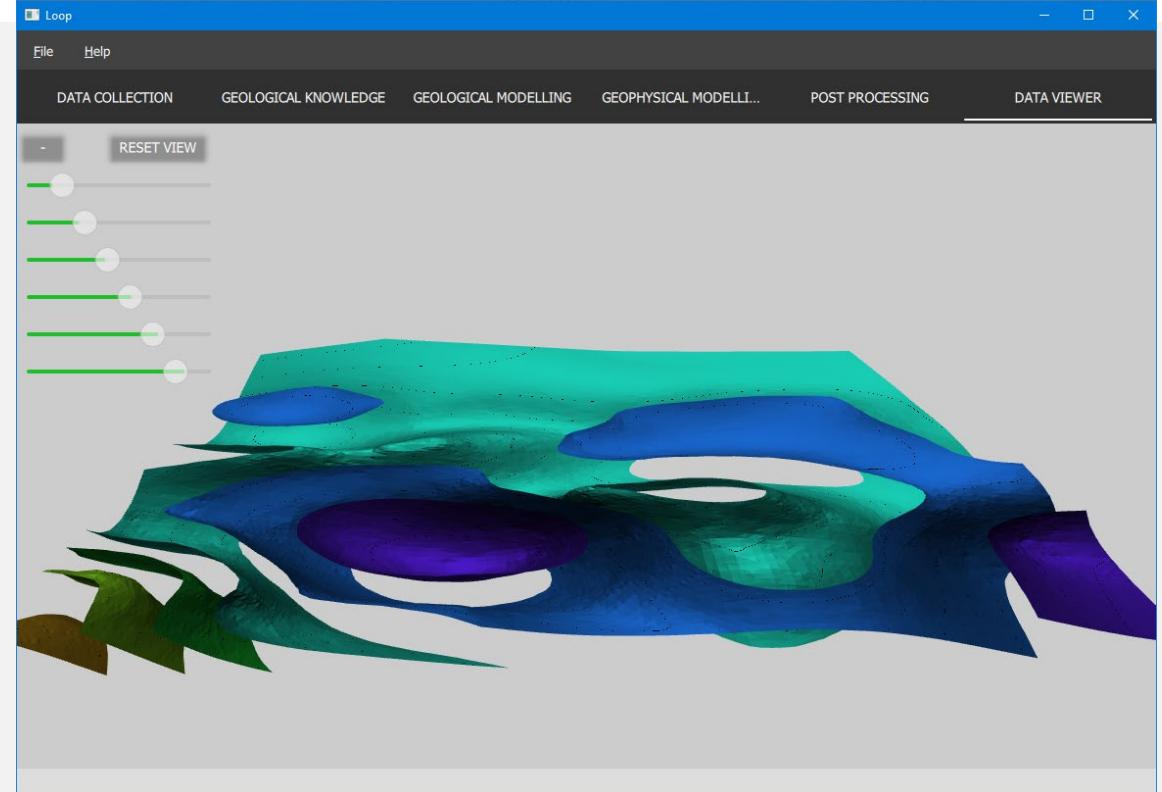
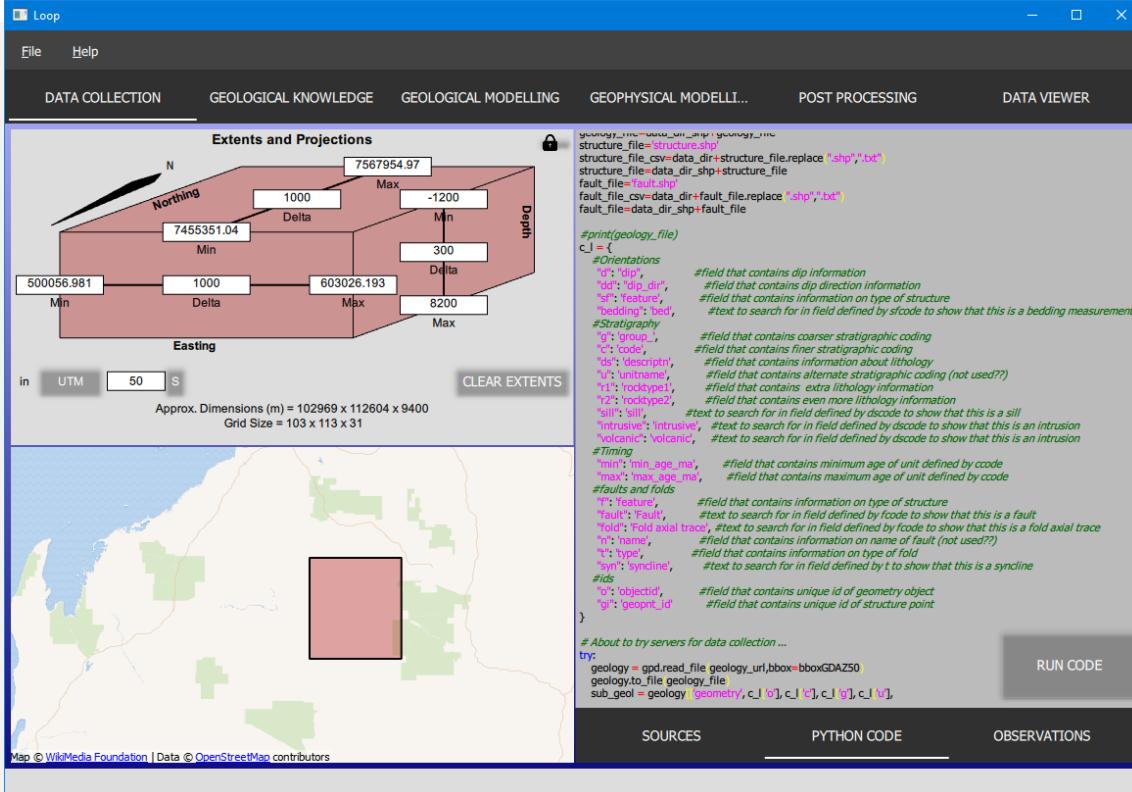
Python version of NetCDF data structures completed

Further progress towards inclusion of WP1 & WP5



**Loop**

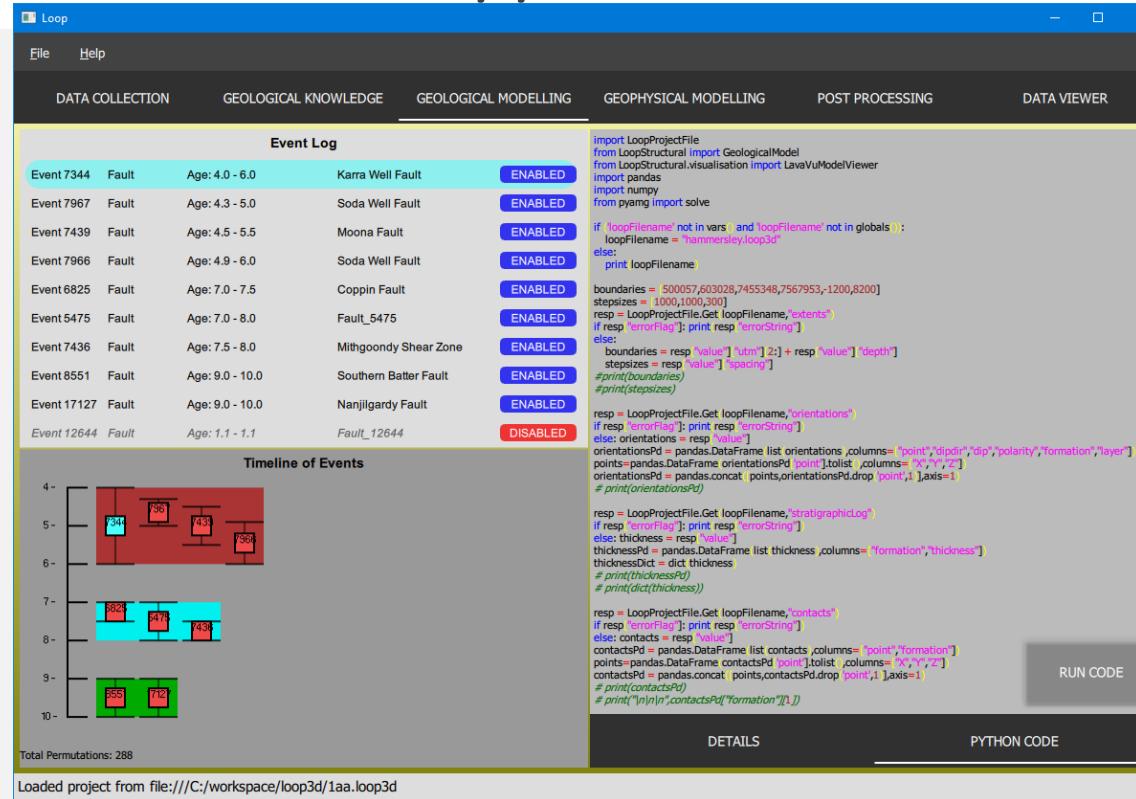
# WP #0 – Infrastructure // Software Development



Left – GUI in construction showing the workflow to modelling. First step: setting the model volume of interest and running WP2 map2loop to extract data for modelling (WP #1 & 2).  
Right: iso-slices through a first pass LoopStructural model of the Hammersley Group.

Loop

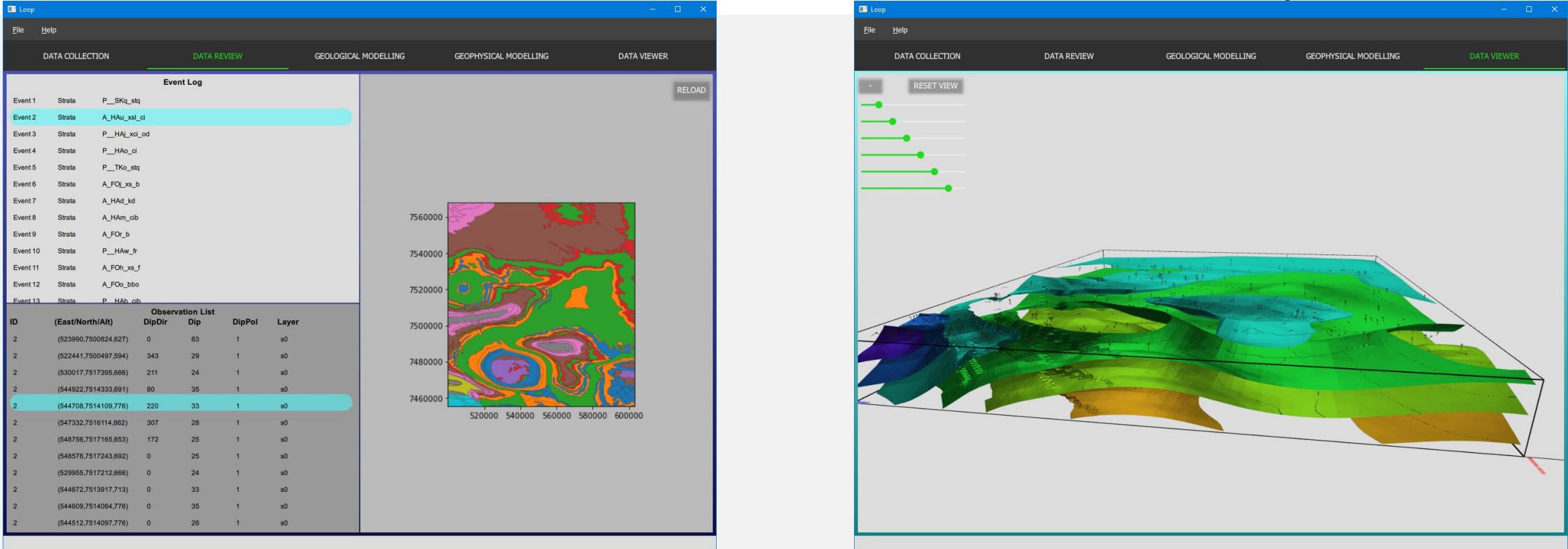
# WP #0 – Infrastructure // Software Development



GUI Image showing calculation of total permutations of an event log including basic colouring interface based on the complexity of sub-sections of the event log

Loop

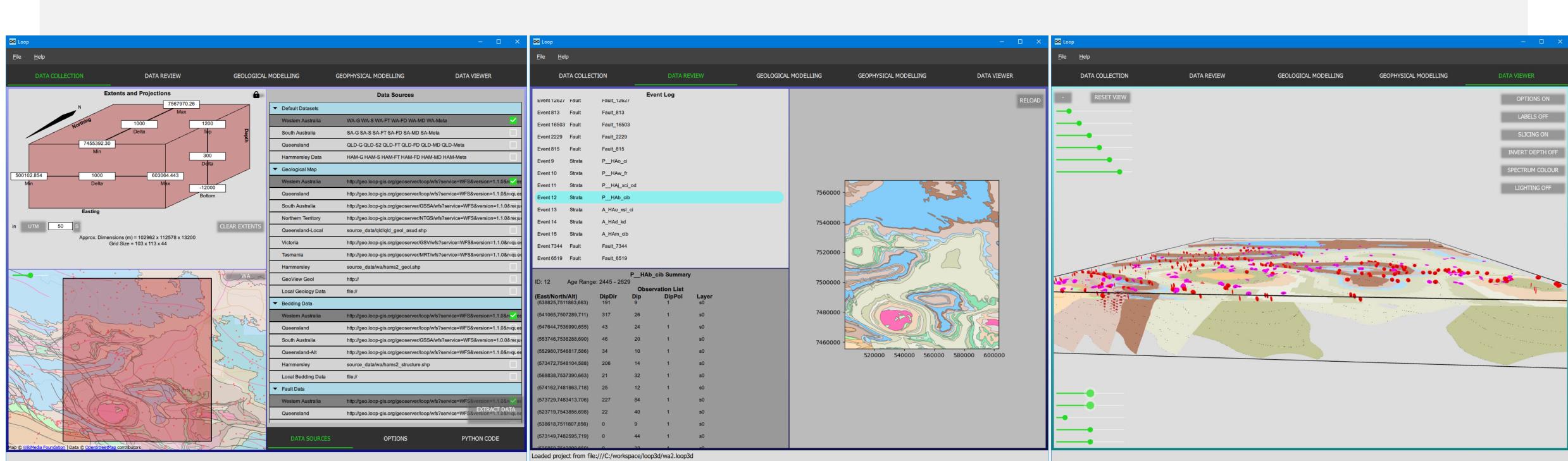
# WP #0 – Infrastructure // Software Development



GUI Image showing first pass of data review/update UI as well as an updated 3D viewer of the same region with observation arrows

Loop

# WP #0 – Infrastructure // Software Development



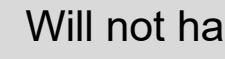
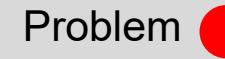
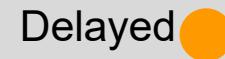
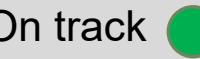
GUI Image showing sequence of data from collection -> review -> 3D model with slicing volumetric data

**Loop**

# WP #1 – Geoscience Knowledge Manager

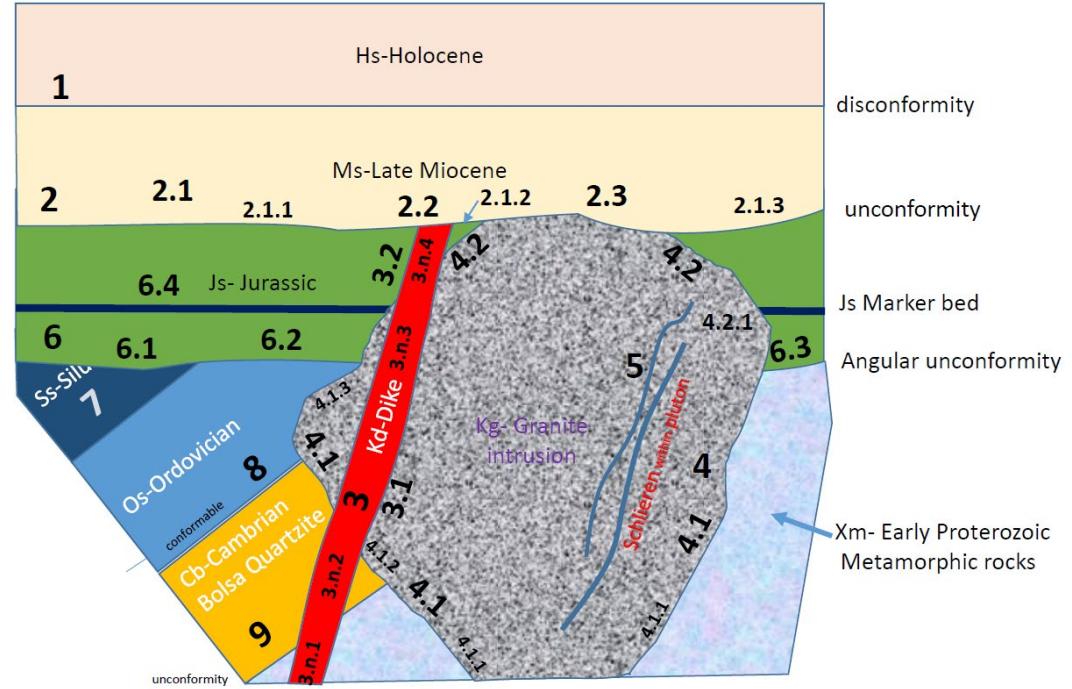
Is work on track against plan? update all deliverables

Work completed



- |  |  |
|--|--|
| <input type="radio"/> 1. <b>Task:</b> Establish working group membership and procedures.   | <b>Deliverable:</b> working group membership.  |
| <input type="radio"/> 2. <b>Task:</b> recruit one knowledge representation geoscientist.   | <b>Deliverable:</b> staffing contract.         |
| <input type="radio"/> 3. <b>Task:</b> develop draft <i>geoscience knowledge manager</i> (GKM) architecture.  | <b>Deliverable:</b> draft GKM implementation.  |
| <input type="radio"/> 4. <b>Task:</b> develop draft <i>geoscience knowledge ontology</i> (GSO).  | <b>Deliverable:</b> draft GSO encoding & notes |
|  5. <b>Task:</b> develop <i>knowledge capture methods</i> , populate GSO and GKM.   | <b>Deliverable:</b> knowledge (test) in GKM.   |
|  6. <b>Task:</b> evaluate GKM access and explore <i>usage scenarios</i> (with WPs). | <b>Deliverable:</b> GKM query patterns.        |

# WP #1 – Geoscience Knowledge Manager



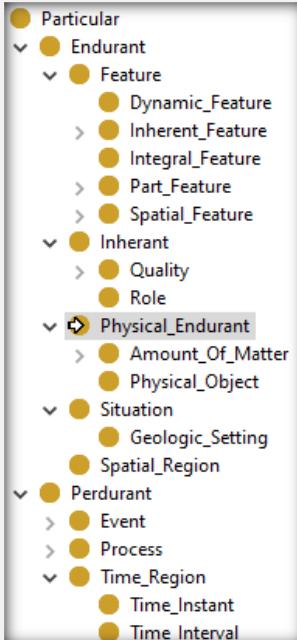
```
ejs:JsFormation
  rdf:type geo:Formation;
  rdfs:label 'Js Formation';
  rdfs:comment 'upper part is massive limestone';
  geo:hasTemporalProperty [
    rdf:type geo:Chronostratigraphic_Age;
    geo:hasYoungerAge
      tim:Lower_Jurassic_Epoch;
    geo:hasOlderAge
      tim:Lower_Jurassic_Epoch
  ];
  common:hasPart ejs:JsFormation-lower;
  common:hasPart ejs:baseJs-6;
  common:hasPart ejs:JsFormation-upper;
  common:hasPart ejs:topJs-2;
  common:hasPart con:KdInJsDikeContact-3.2.4;
```

**Task 4:** progress on GSO development – refinements made post-LOOP workshop Mar 2020; v1 document draft.

**Task 5:** progress on GSO content – developed **petrophysical** examples, with more planned.

**Task 6:** evaluate GKM access and explore *usage scenarios* – **petrophysical** testing scenario in progress.

# WP #1 – Geoscience Knowledge Manager



GSO top-level

```
bcs:AquaCreekcomplex-dioritic_rock
  gsoc:hasQuality [
    a gsoq:Density ;
    gsoc:determinedBy [
      a gsoc:Mean_Value_Calculation ;
      gsoc:hasConstituent ppbc:weightairoverweightwater ;
      rdfs:comment "average value and standard deviation from 4 observations" ;
      rdfs:comment "dct:source -- British Columbia Geological Survey, 2008, I"
    ] ;
    gsoc:hasDataValue 2.88 ;
    gsoc:hasUOM [
      a gsuom:gramspercubiccm ;
    ] ;
    gsoc:hasUncertainty 0.11 ;
    rdfs:label "average Density for dioritic_rock in the Aqua Creek complex"
  ] ;
```

GSO example petrophysical property encoding

Loop3D GeoScience Ontology	
Version 1, Draft 2020-08-31 11:37 AM	
Stephen M. Richard, US Geoscience Information Network	<a href="mailto:smrTucson@gmail.com">smrTucson@gmail.com</a>
Boyan Brodaric, Geological Survey of Canada	<a href="mailto:boyan.brodaric@canada.ca">boyan.brodaric@canada.ca</a>
Table of Contents	
Introduction.....	1
GitHub Repository.....	2
Terminology.....	2
GSO Common.....	3
GSO Geology and Geology Modules.....	6
Namespaces.....	14
CGI Vocabularies.....	15
Quality Pattern.....	16
URI Pattern.....	16
Examples .....	17
Test Instances.....	23
References.....	23
Appendix 1. SPARQL Queries.....	25

GSO documentation v1

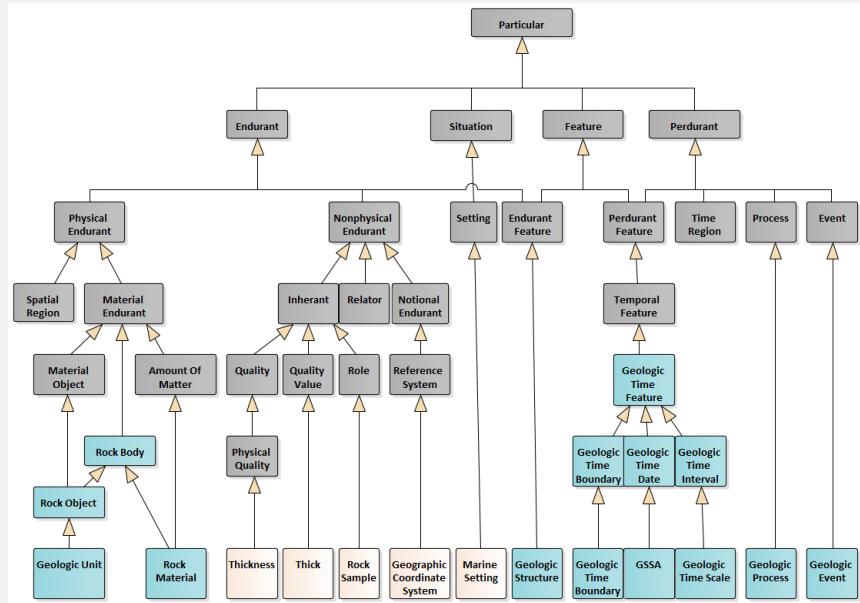
**Task 4:** progress on GSO development – refinements made post-LOOP workshop Mar 2020; v1 document draft.

**Task 5:** progress on GSO content – developed **petrophysical** examples, with more planned.

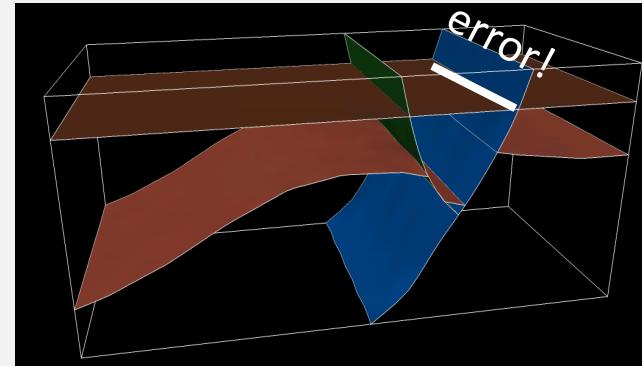
**Task 6:** evaluate GKM access and explore *usage scenarios* – **petrophysical** testing scenario in progress.



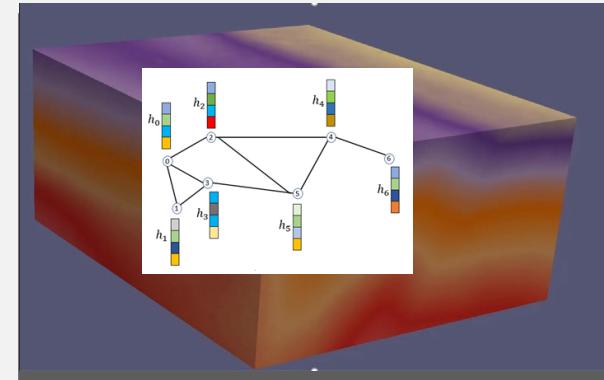
# WP #1 – Geoscience Knowledge Manager



GSO top-level



3D Model Consistency Checker



3D GNN Modeller

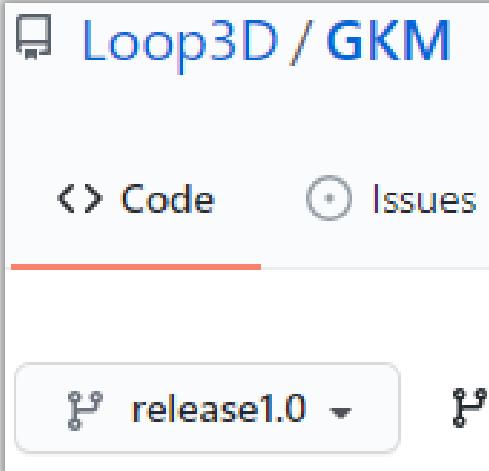
**Task 4:** progress on GSO development – major refinements completed; reference document completed.

**Task 5:** progress on GSO content – refined test examples.

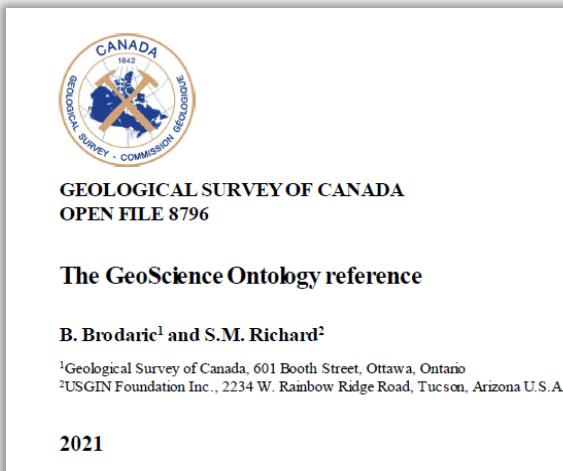
**Task 6:** evaluate GKM access and explore *usage scenarios* – **consistency checker** and **GNN modeller** prototyped.

# WP #1 – Geoscience Knowledge Manager

## Public release of the GeoScience Ontology (GSO)



public GitHub



published reference

A screenshot of a Zenodo page for 'GeoScience Ontology: Release 1.0.2'. The page features a blue header with the Zenodo logo, a search bar, and 'Upload' and 'Comm' buttons. The main content area shows the date 'May 11, 2021', the title 'GeoScience Ontology: Release 1.0.2', and the authors 'Boyan Brodaric; Stephen Richard'. Below this is a detailed description of the ontology, mentioning its layers and serialization. The page also lists several files available for download.

published ontology files

**Task 4:** progress on GSO development – public release of GSO: (1) Github, (2) reference doc, (3) ontology files.

**Task 5:** progress on GSO content – further refined test examples.

**Task 6:** evaluate GKM access and explore *usage scenarios* – published **GNN modeler** paper, refined algorithm.

# WP #2 – Data Pre-Processing & input

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New 

- 1. Recruit one post-doctoral fellow for uncertainty: Guillaume Pirot hired, start date 1/9/2019
- 2. Recruit one Scientific programmer: Kavitha Madaiah hired, started 17/6/2019
- 3. Recruit one post-doctoral fellow geophysics (WP4) : Jeremie Giraud hired, started 1/4/2019
- 4. 2 new PhD scholarships candidates found (Babak Ghane (still having visa issues), Nuwan Suriyaachchi)
-  5. Acquire company data for testing purposes: provisional confirmation from BHP
-  6. Define 1-3 year software capabilities

# WP #2 – HR News and new project

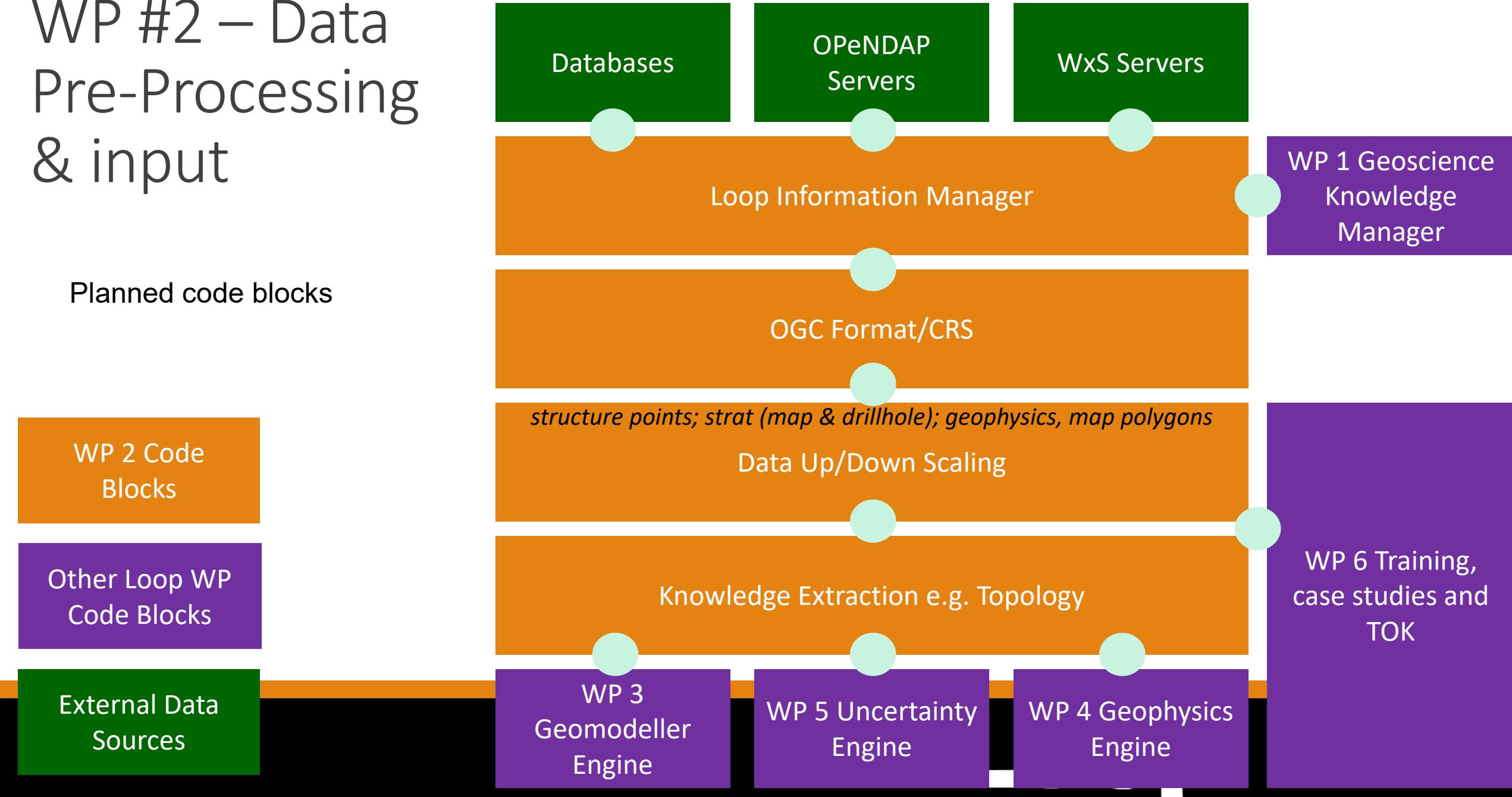
HR News from WP2: MinEx Opportunity Fund OP6 hires **Vitaliy Ogarko**

The project *RECOVERY OF LITHOLOGICAL AND STRATIGRAPHIC DATA FROM DRILLHOLE DATABASES* has been funded to support a programmer at DataCode in India and a 3-year postdoc at UWA. Legacy and new drillhole data are a key constraints for geological understanding and subsequent 3D prediction. Company databases held by Australian Geological Survey Organisations (GSOs) contain complexly coded lithological information, but limited stratigraphic data. This project will develop Open Source algorithms automating the extraction of lithological and stratigraphic data.

Vitaliy Ogarko, one of the original authors of TOMOFAST and of map2model (the topology engine in map2loop) has been hired and will commence at UWA 1<sup>st</sup> July 2021.



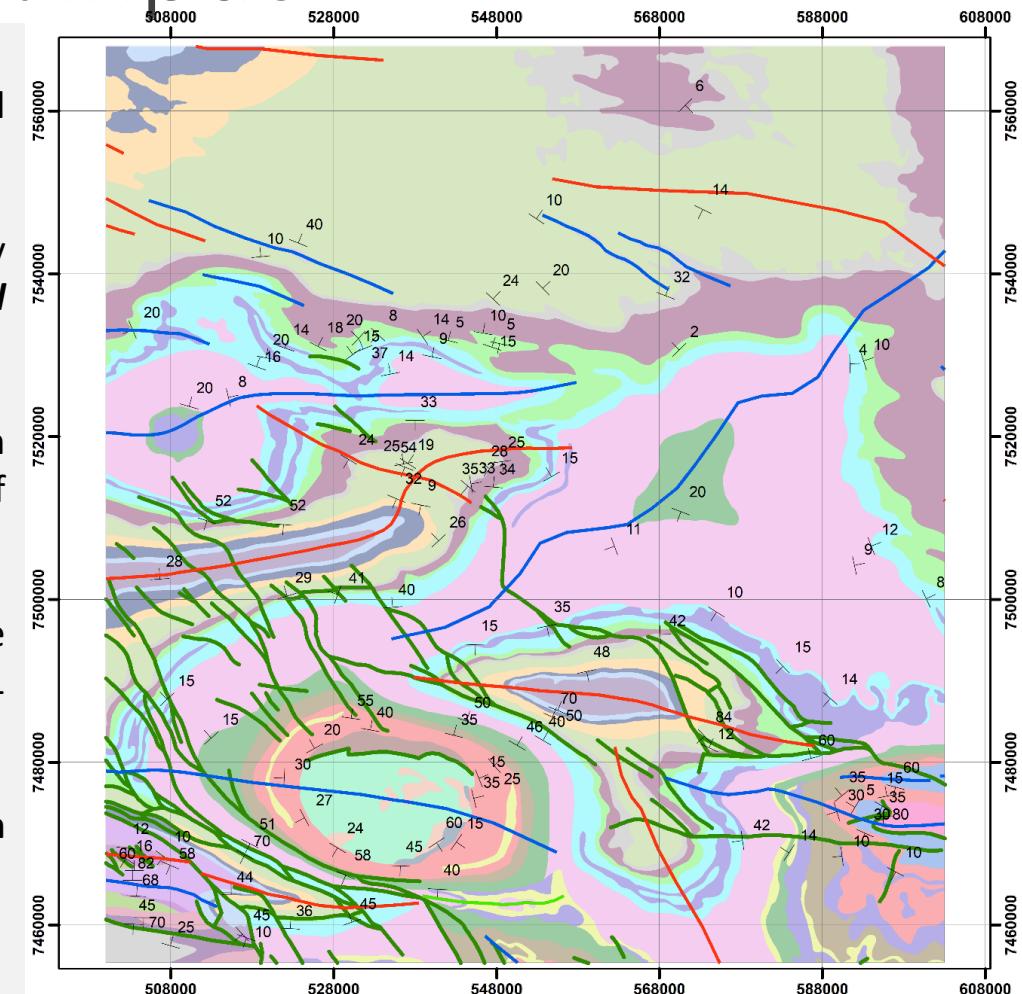
# WP #2 – Data Pre-Processing & input



# WP #2 – Data Pre-Processing & input

## Map2loop proof of concept

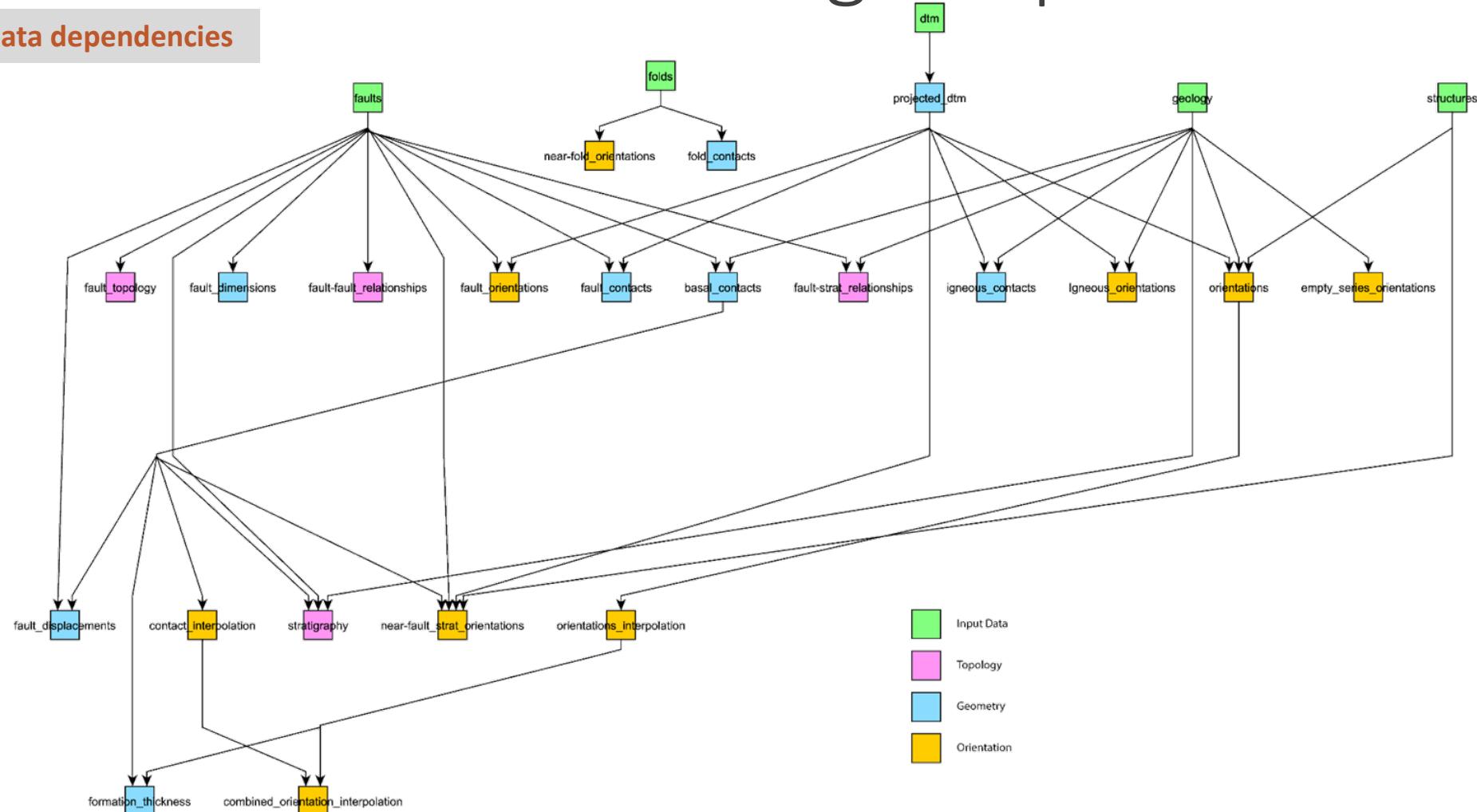
- One of the aims of WP2 is to automate as much as possible the input of data and transformation in appropriate inputs to Loop 3D modelling codes
- In this (first) example we have developed python & C++ codes to automatically derive the input data needed to produce ***gempy, geomodeller and LoopStructural (WP #3)*** models
- Specifically we started from a shapefile of the GSWA 500K geology map of Western Australia; the equivalent fault and fold axial trace layer; the WAROX database of structures and an online Geoscience Australia SRTM topography server
- By performing a topological analysis of the geology map we were able to provide the necessary inputs for a ***gempy, geomodeller and LoopStructural*** models for a 1 degree square of geology
- **No manual intervention was required to build the input layers and models shown in the next slides (apart from lots of coding)**
- Future developments will add sills



Loop

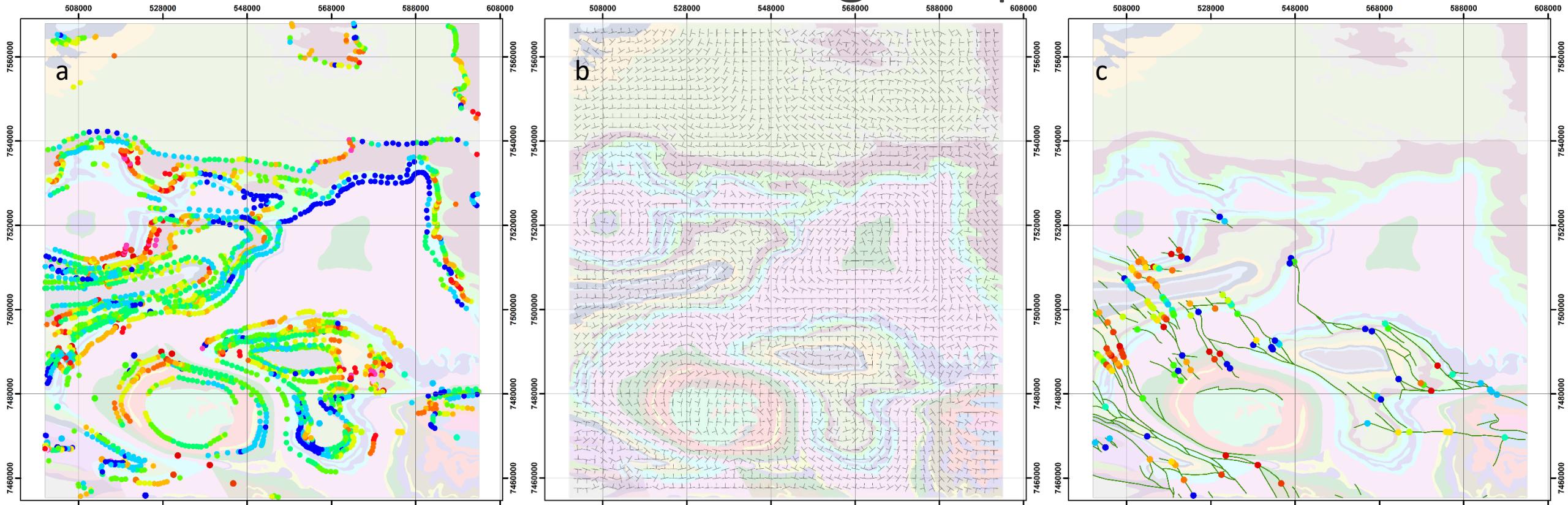
# WP #2 – Data Pre-Processing & input

Map2loop // Data dependencies



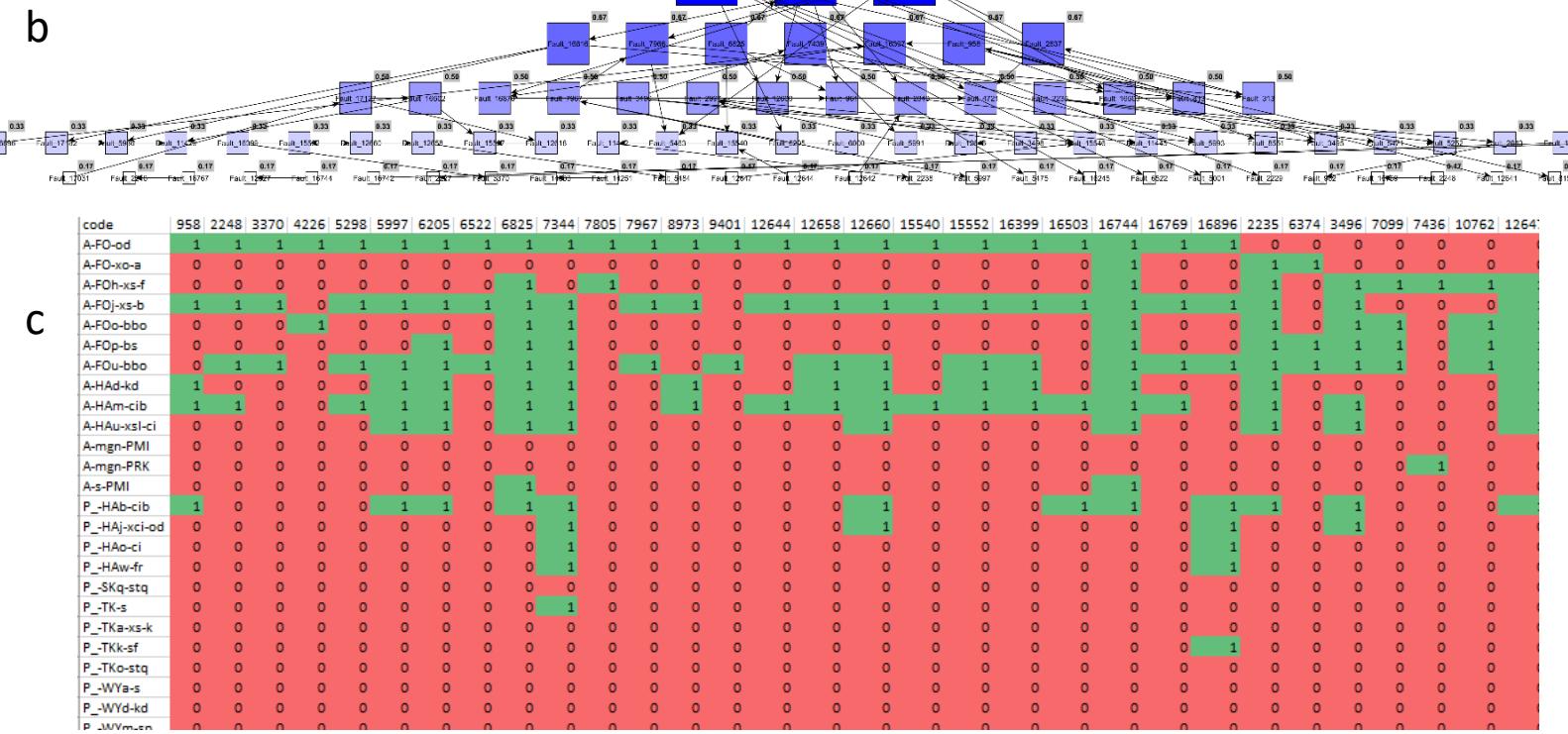
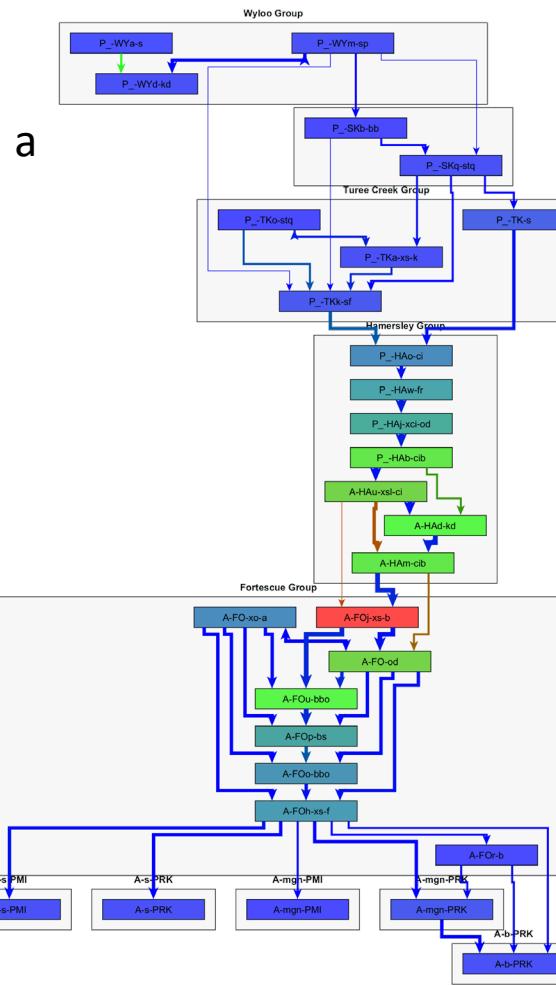
Loop

# WP #2 – Data Pre-Processing & input



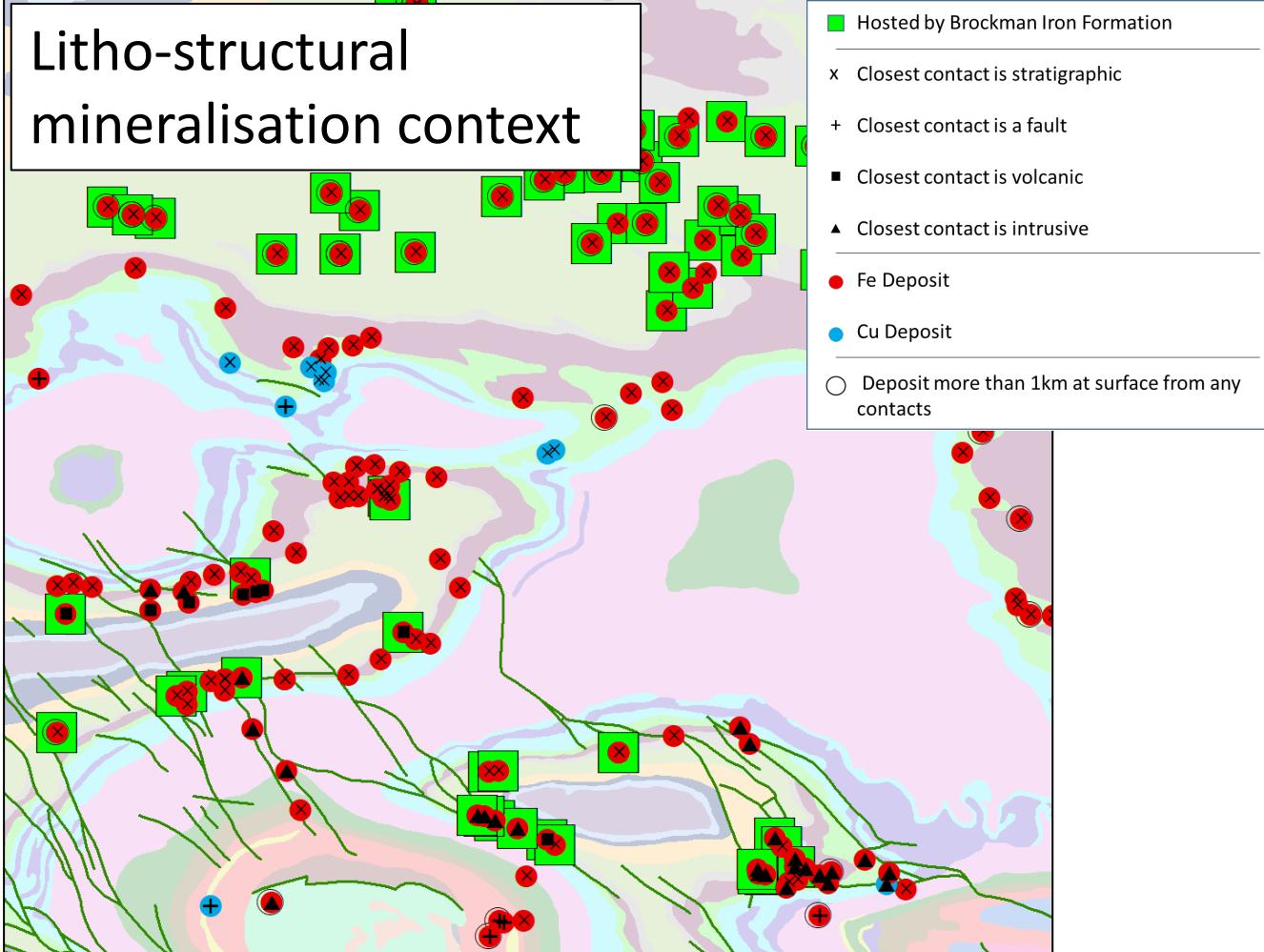
Map2loop // Secondary geological information automatically derived from maps. a) Normalised local formation thickness (hotter colours show thicker formations) b) Interpolated estimated bedding orientations for the Hamersley and Fortescue Groups c) Apparent fault throw (hotter colours show larger throw)

# WP #2 – Data Pre-Processing & input

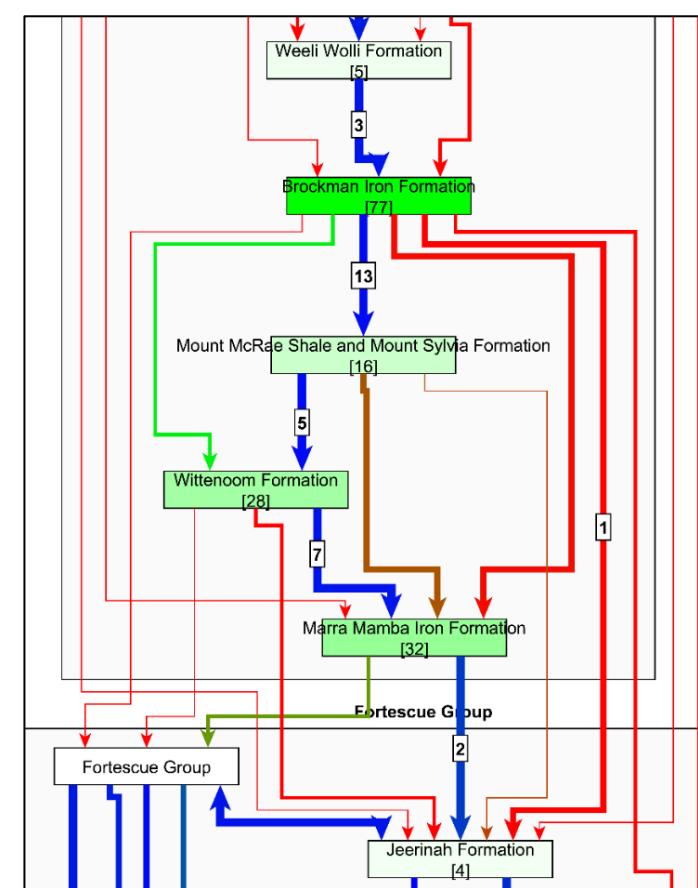


Topological information automatically derived from maps. a) Stratigraphic relationships between the different formations found in the region of interest. Each rectangle represents one formation, and the arrows point to younger formation. b) Fault relationships, each fault is one rectangle, and the larger and darker the rectangle, the more important the fault is based on a centrality index. c) The fault-formation relationship matrix. Green cells indicate that a specific fault (columns) intersects a given formation (rows), otherwise the cell is red.

# Litho-structural mineralisation context



Functionality added to *map2loop* to analyse the litho-structural context of mineral deposits, which will help in defining which elements to retain for modelling

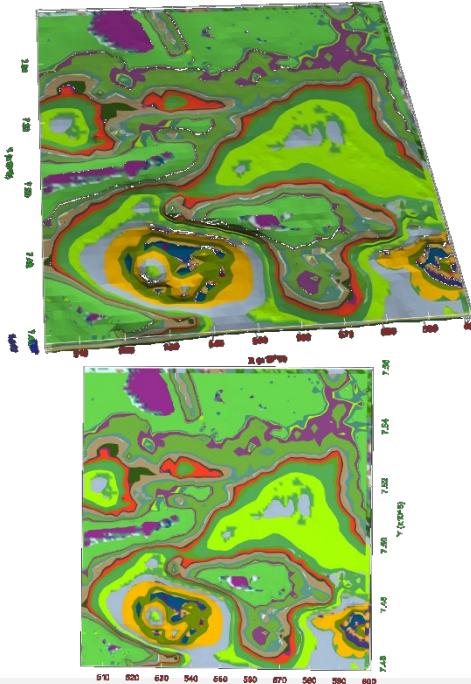


12	Deposits on/near contact	[7]	Deposits hosted by formation
Formation		Fault Contact →	Strat Contact →

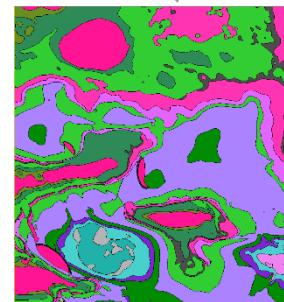
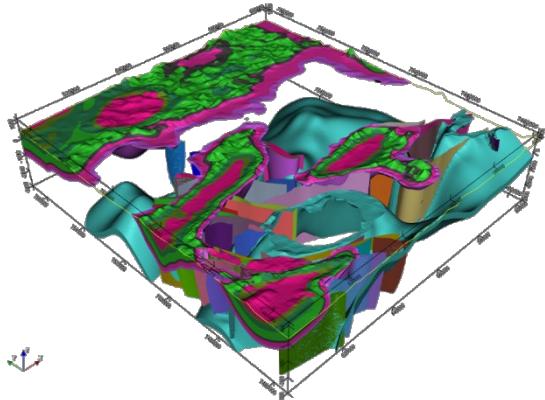
# Loop

# WP #2 – Data Pre-Processing & input

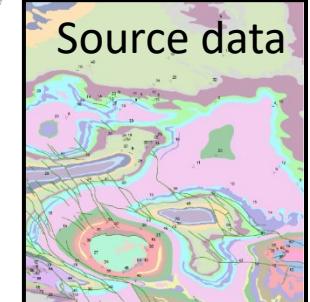
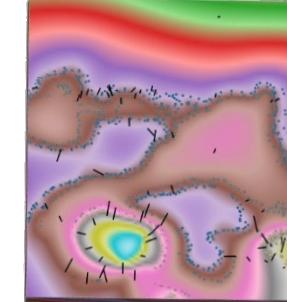
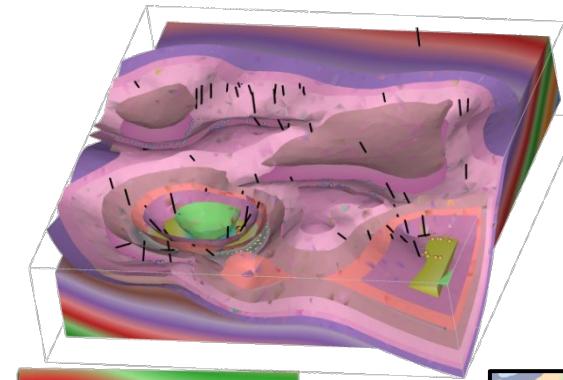
*gempy*



*Geomodeller*



*LoopStructural*



3D geological model produced using the input data created by map2loop. Top row: 3D model with some layers rendered transparent in the Geomodeller mode to highlight subsurface fault relationships. gempy and LoopStructural have no faults (yet). Lower row: top surface of the geology.

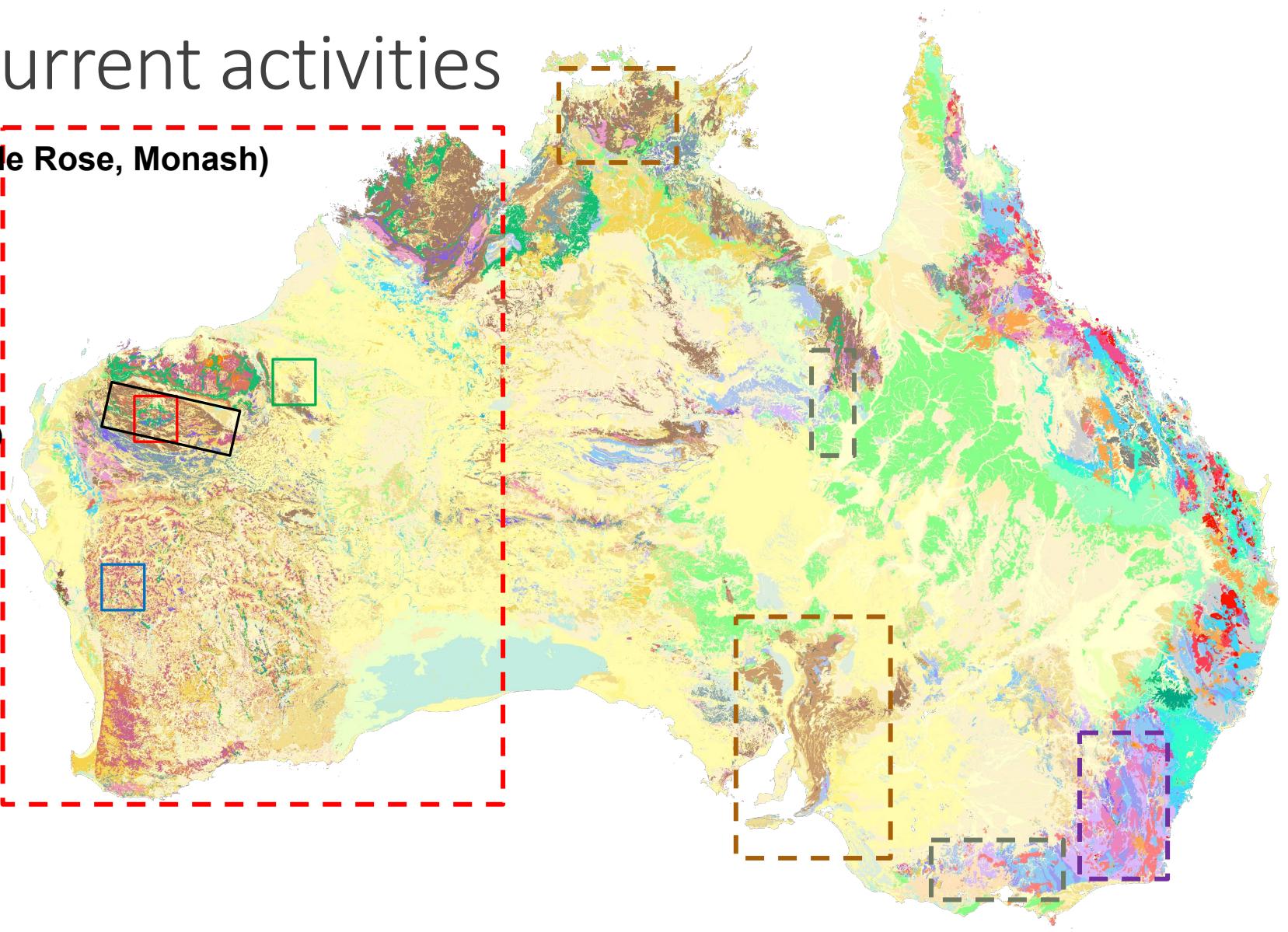
# WP #2 – Map2loop-current activities

## a) Refactoring of map2loop code: (Yohan de Rose, Monash)

- a) Ease of installation
- b) Conform code to Loop standards

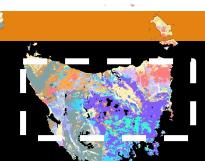
## b) Testing of map2loop code

- a) Mark Jessell Proof of concepts
- b) Nishka Piechocka (MRIWA 577 Hamersley project)
- c) Fabiele Dalmaso Spode
- d) (MRIWA 521/554 Paterson/Basins projects)
- e) Ranee Joshi Yalgoo Singleton GSB
- f) Mt Isa Inlier Rock Valenta/Karen Connors (UQ,AA)
- g) NSW Lachlan Orogen examples
- h) PCO NTGS
- i) Flinders Ranges – GSSA
- j) Victoria – GSV
- k) Tasmania MRT data

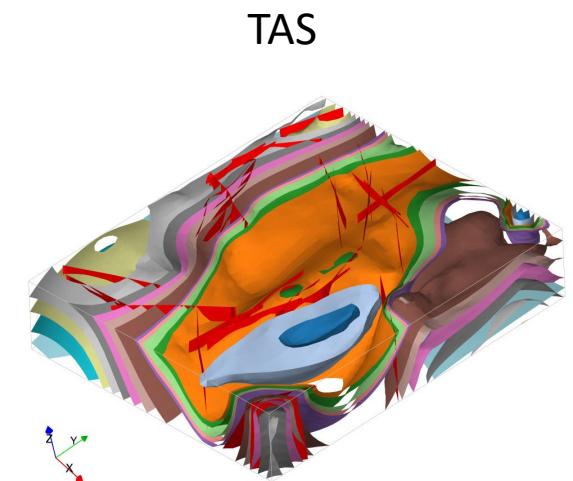
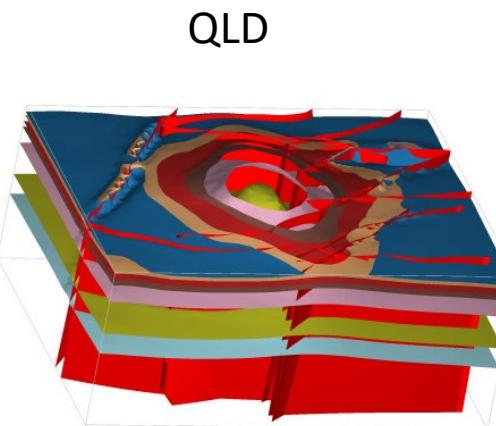
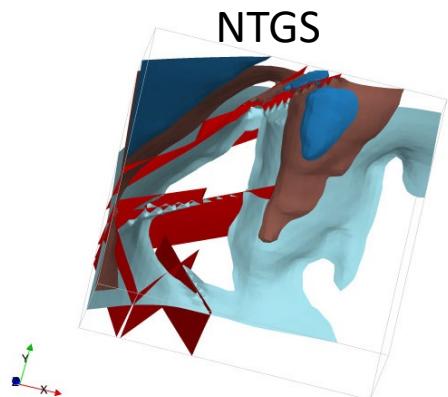
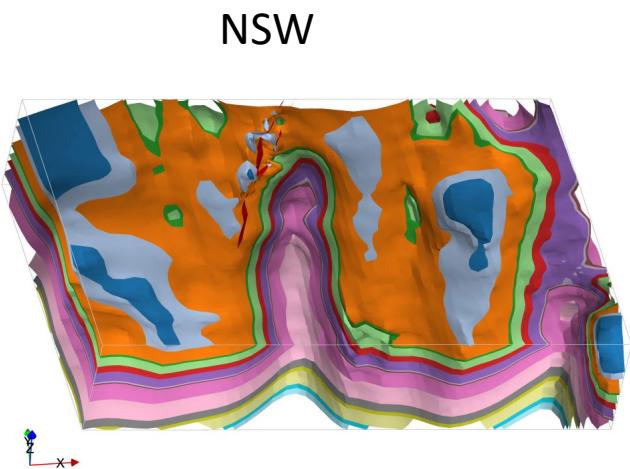
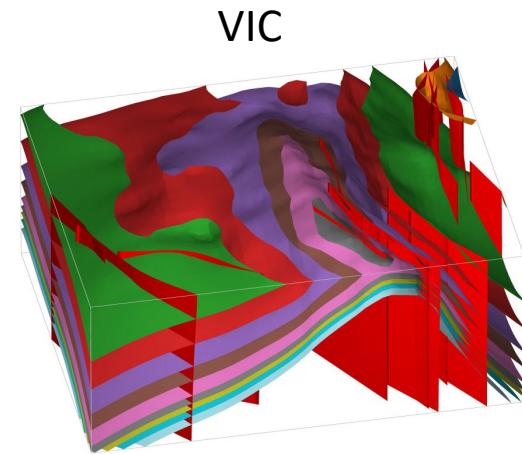
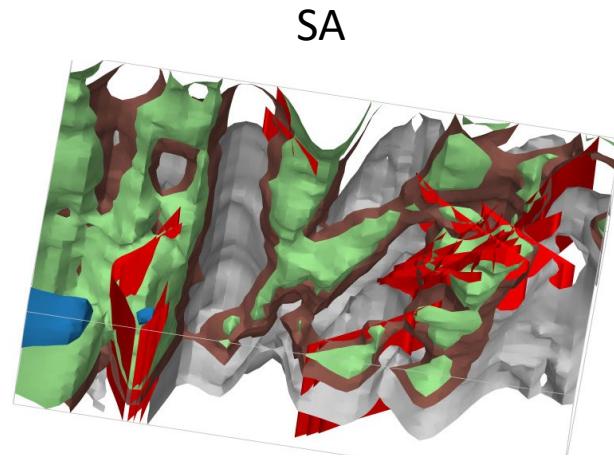
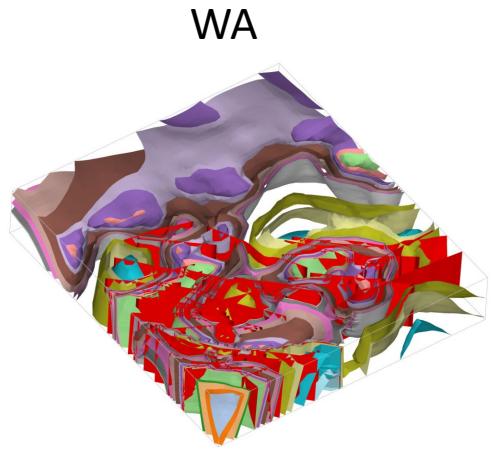


## c) Seeking additional funding for drillhole analysis from Auscope & MinEx CRC Opportunity funds

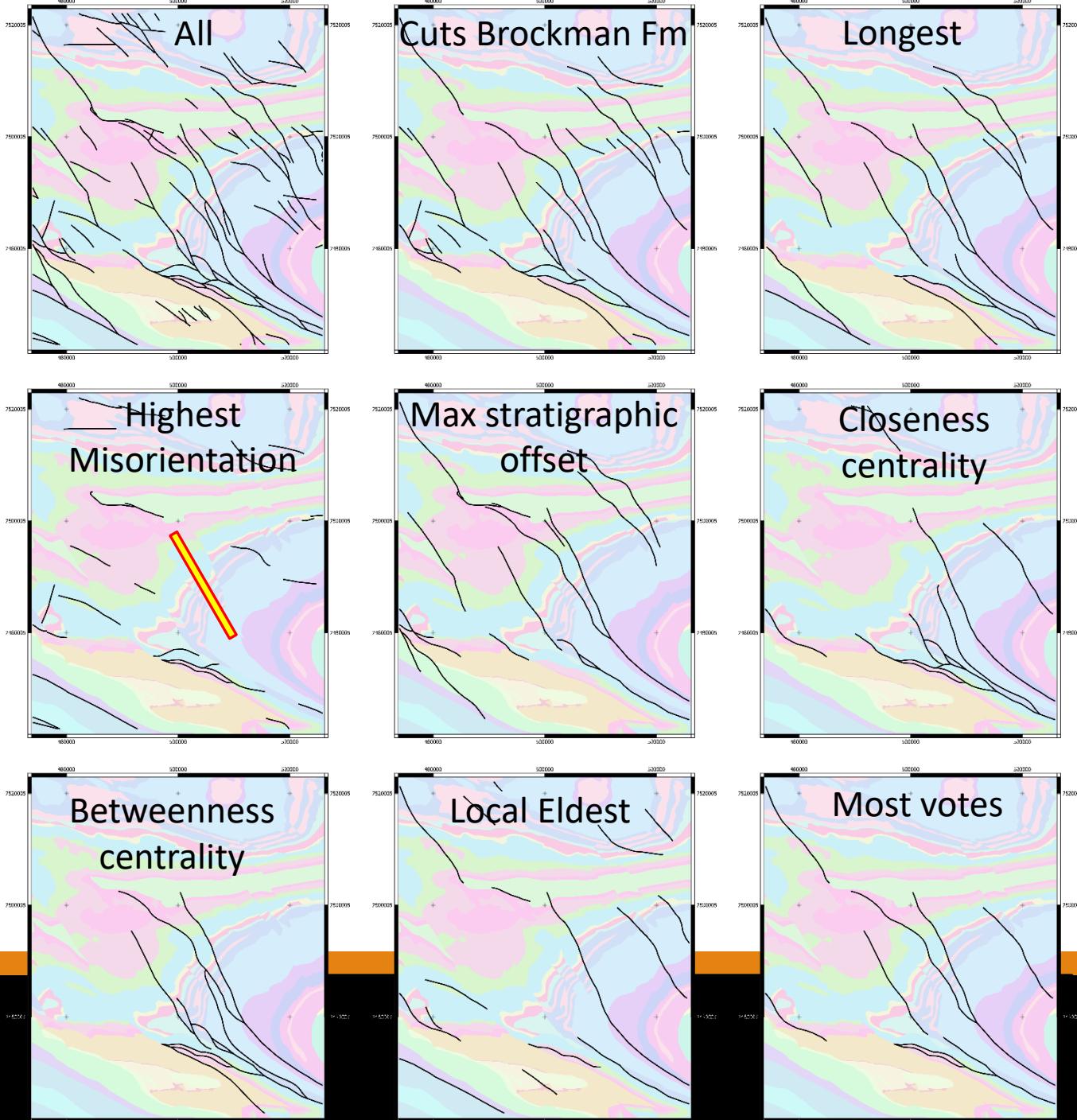
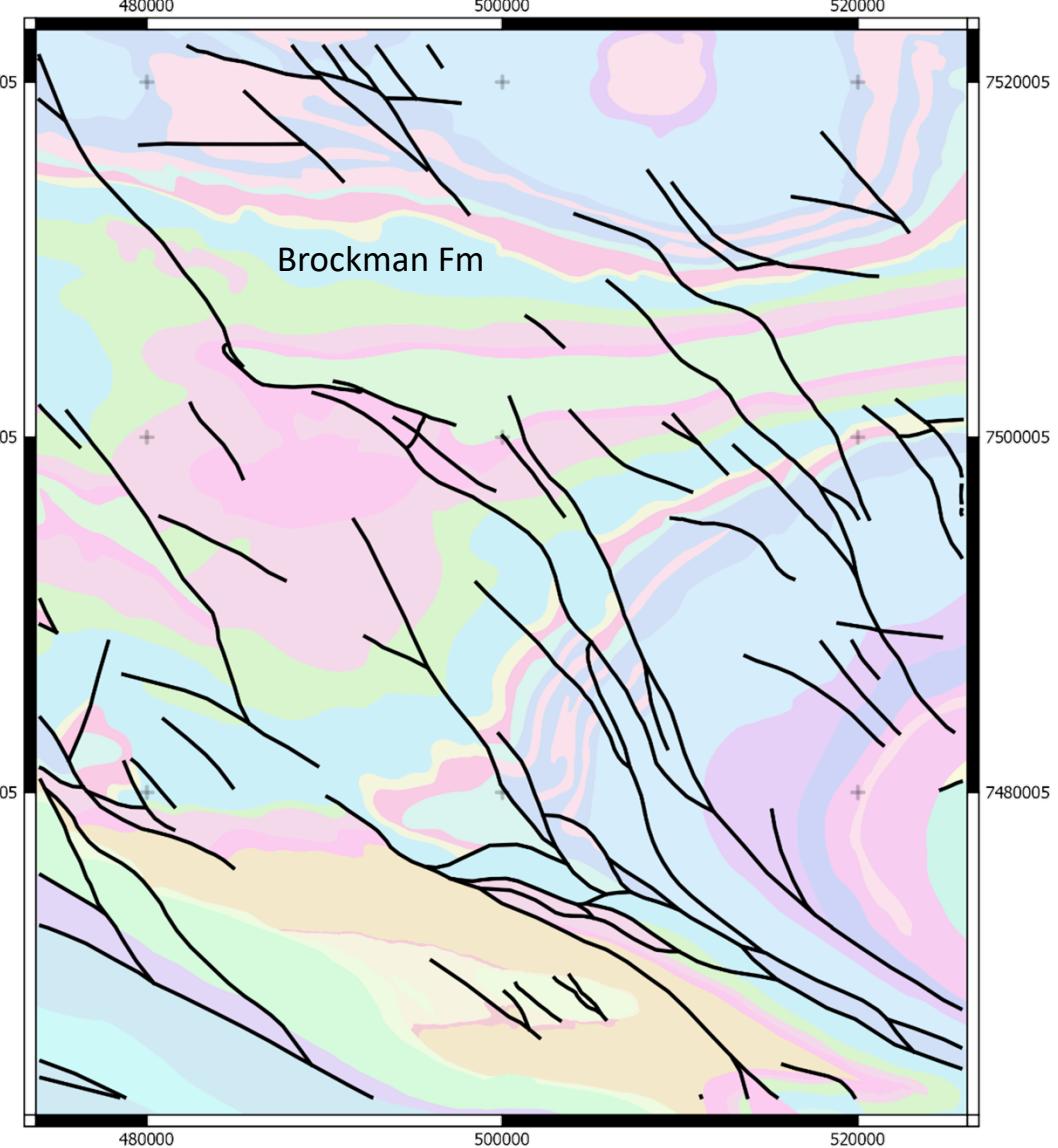
**Loop**



# WP #2 – Proof of concept models



Loop



Which Faults to Model?

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 1. Python library: FME has been renamed to LoopStructural
- 2. Developing/testing algorithms for representing fault networks (ongoing)
- 3. Planning a soft release of LoopStructural for beta testers identified at the SGTSG workshop early 2020 (delayed because of licensing issues with TetGen (AGPLV3). Dependency removed & now just testing)
- 4. Planning benchmark paper (GC) – draft for RING meeting
- 5. Mike Hillier (GSC) working porting tensor interpolation to python
- 6. Implemented folding code in FME

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New 

-  7. Loop Structural mailing list created with 25 people currently (<https://tinyurl.com/w4vp6os>)
-  8. Implemented high level API for LoopStructural – folding, faulting, unconformities, using different interpolation schemes
-  9. Preparing publication for fault method and another for integration of faults and folds in implicit modeling
-  10. Conceptual development of intrusion framework
-  11. Removed reliance on tetgen and implemented structured tetrahedron mesh
-  12. New API working for polydeformed folds, overprinting faults and unconformities

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 13. Testing impact of sample location on models produced by LoopStructural by subsampling a dataset on Noddy models for different sampling patterns 1) transect mapping 2) form line mapping.
- 14. Implementation of the Object-distance Simulation Method (Henrion et al. 2010) for intrusions modelling.
- 15. Identification of typical shapes for different types of intrusions. This is a work in progress and its outcome will be used to asses the limitations of different scalar fields.
- 16. Continuously testing link to map2loop
- 17. Started to discuss link with geophysical codes
- 18. Implemented probabilistic fold modelling using EMCEE sampler

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New

- 19. Implemented probabilistic faults displacement modelling
- 20. Discussing link with WP4/5
- 21. Ability to create model from parameter dictionary that can be saved as a .yml or .json file
- 22. Fault displacement map can be plotted
- 23. LoopStructural v1.0.4 released
- 24. Testing of Object-distance Simulation Method (ODSIM, Henrion et al. 2010) applied to intrusions modelling.

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New

- 25. Map colours are used for colouring map2loop generated LoopStructural models
- 26. Draft LoopStructural paper prepared and sent to coauthors
- 27. Ongoing testing of the value of structural information
- 28. Direct integration of map2loop with new model creation function
- 29. LoopStructural paper reviews received corrections due march 2021
- 30. LoopSturctural 1.0.8 released
- 31. LoopStructural refactored so model elements are only evaluated when required

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New

- 32. Quadratic interpolation using triangular mesh – paper in prep, figure showing comparison to linear
- 33. Probability branch of LoopStructural created including Theano wrapper for gradient evaluation
- 34. Testing inversion of fault geometry
- 35. Conda, pip and docker builds + loopstructural works on google colab
- 36. Intrusion frame testing ongoing
- 37. Value of structural information using probabilistic definition of folds
- 38. Loopstructural documentation updated

# WP #3 – LoopStructural

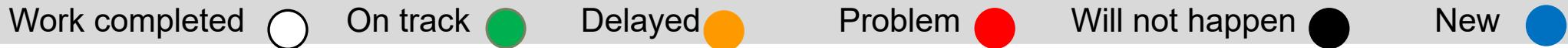
Is work on track against plan? update all deliverables

Work completed On track Delayed Problem Will not happen New

- 39. Automated documentation building and deployment for LoopStructural
- 40. Released version 1.1 of LoopStructural ([changes here](#))Quadratic interpolation using triangular mesh – paper in prep, figure showing comparison to linear
- 41. LoopStructural paper accepted and will be published in GMD special issue soon
- 42. Fault paper submitted to GMD in discussion currently
- 43. Inversion of fault geometry using pymc3 showing promising results (attached figure) and will be presented at RING meeting
- 44. Tested uncertainty of models due to thickness variations

# WP #3 – LoopStructural

Is work on track against plan? update all deliverables



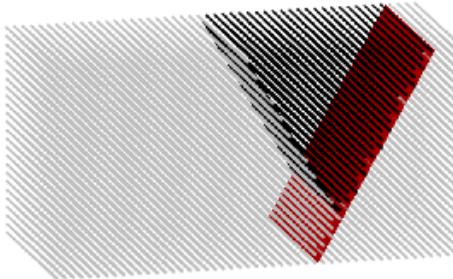
- 45. Intrusion modelling uses sequential gaussian simulation to build body of intrusion
- 46. Testing intrusion model on Voiseys bay case study
- 47. LoopStructural paper accepted and will be published in GMD special issue soon
- 48. Fault paper submitted to GMD in discussion currently
- 49. Inversion of fault geometry using pymc3 showing promising results (attached figure) and will be presented at RING meeting
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# WP #3 – LoopStructural

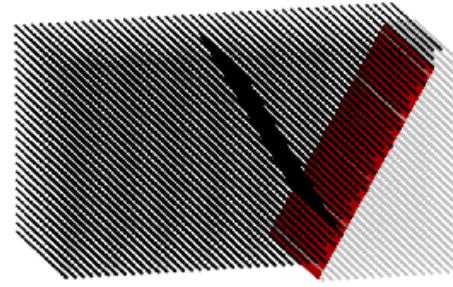
A. Fault network



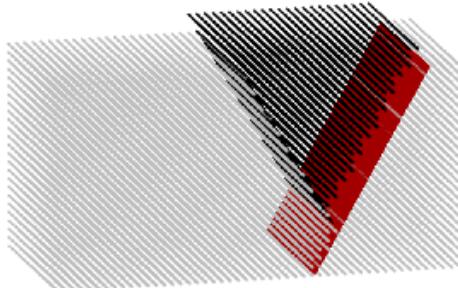
B. Model support before restoration



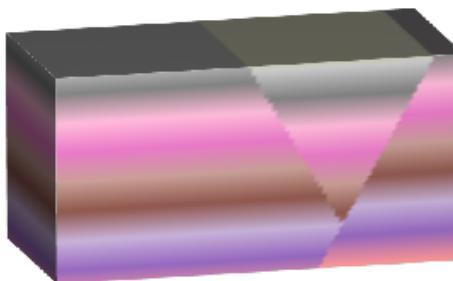
C. Model support restored by main fault



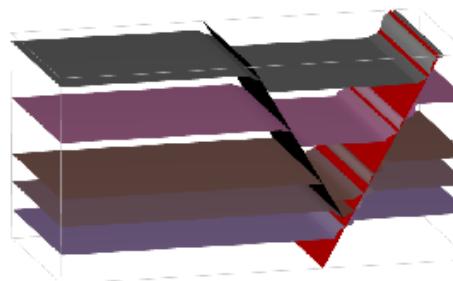
D. Model support restored by antithetic fault



E. Interpolated stratigraphy scalar field



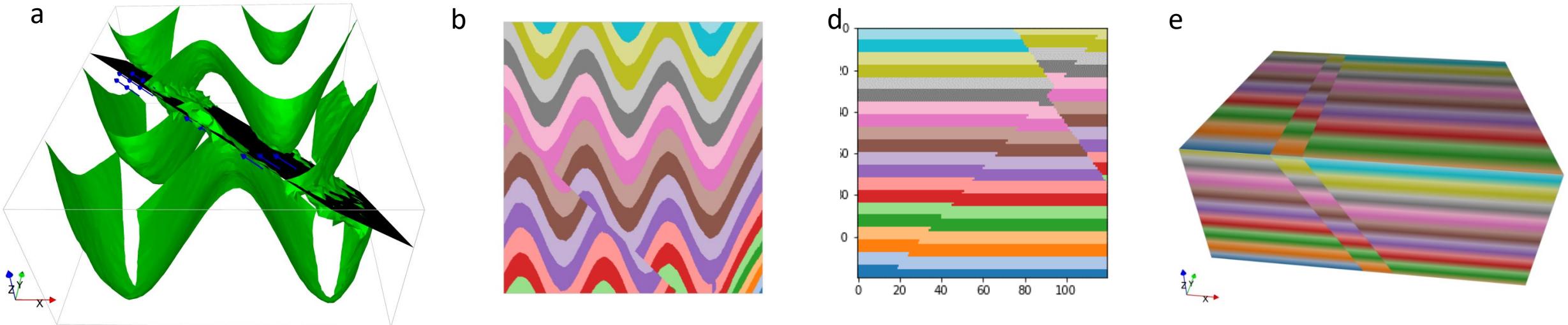
F. Isosurfaces extracted from scalar field



Implicit fault network for a graben with antithetic faulting.

Loop

# WP #3 – LoopStructural



LoopStructural – examples: a) faulted folds; b) map view of model a); c) Duplex; d) two antithetic sequential faults; e) two parallel faults with oblique offsets. Faults are modelled as ellipses with an ellipsoidal damage zone with varying offset profiles. Faults as folding events are time aware and are modelled from younger to older faults.

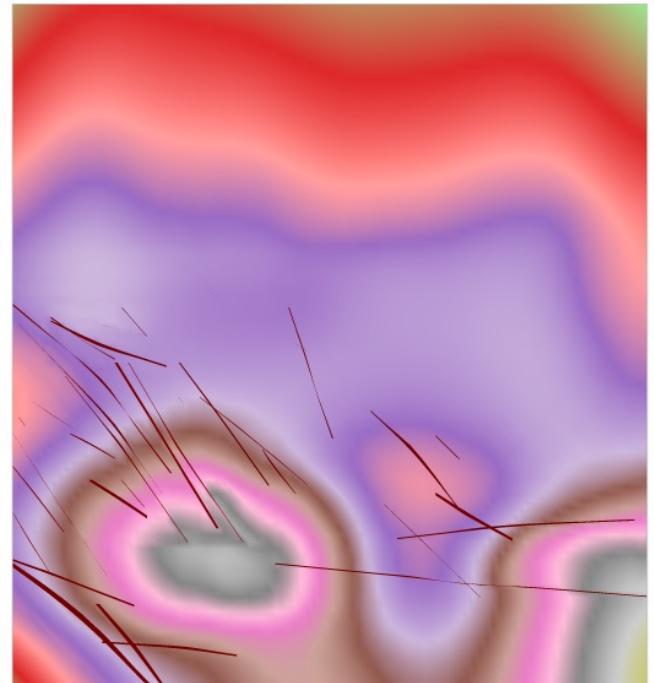
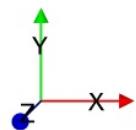
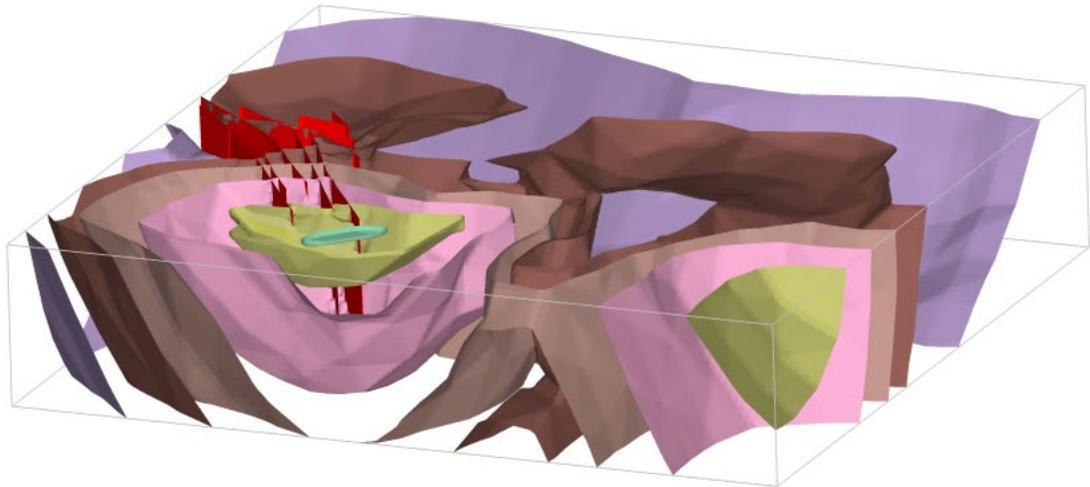
# WP #3 – LoopStructural

```
: model = GeologicalModel(bb[0,:],bb[1,:])
model.set_model_data(df2)
fold_frame = model.create_and_add_fold_frame('s1',
                                             nelements=1e4,
                                             regularisation=[1.,1.,.1],
                                             interpolatortype='PLI',
                                             gxxgy=0.,
                                             solver='lu')
s0 = model.create_and_folded_foliation('s0',
                                         fold_frame=fold_frame['feature'],
                                         nelements=1e5,
                                         limb_wl=0.4,
                                         av_fold_axis='True',
                                         solver='lu')
```

executed in 1m 13.3s, finished 13:18:59 2019-12-12

Example of new streamlined api for modelling a folded foliation

# WP #3 – LoopStructural



Loop structural modelling using map2loop output  
and including faults

Loop

# WP #3 – LoopStructural

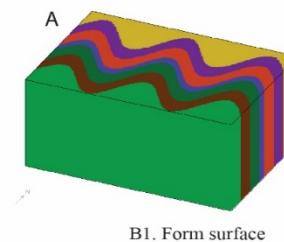
## Sampling structural data

Form-surface sampling vs Across structure sampling.

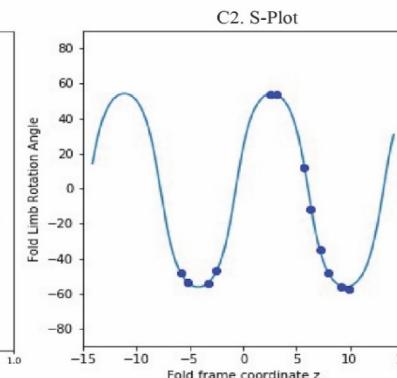
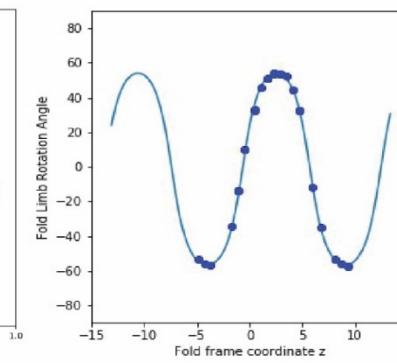
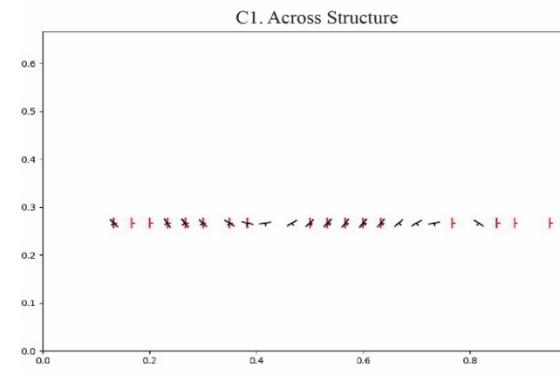
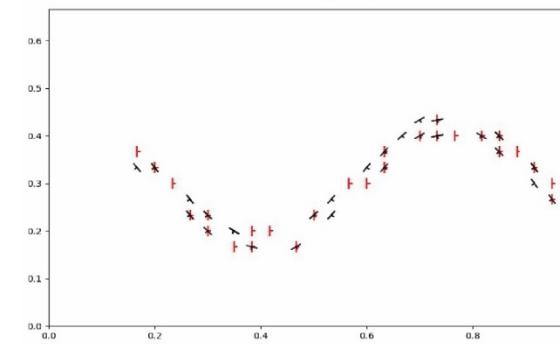
The reference model generated using Noddy (A) is an upright cylindrical fold with a fold axis plunging vertically.

B-C1,2,3 are respectively the input dataset, the S-Plot of the resulting model and the S-Variogram.

The models resulting from both samples reproduce a wavelength close to the wavelength of the reference model and the model resulting from the form surface sample is slightly more asymmetrical than the across-structure sample.

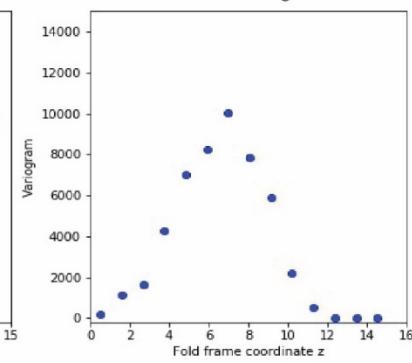


Wavelength : 20 000 m  
Amplitude : 7 000 m  
Fold axis : Vertical

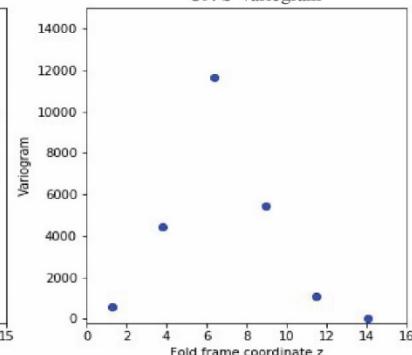


Form surface sampling  
versus  
Across structure sampling

B3. S-Variogram



C3. S-Variogram



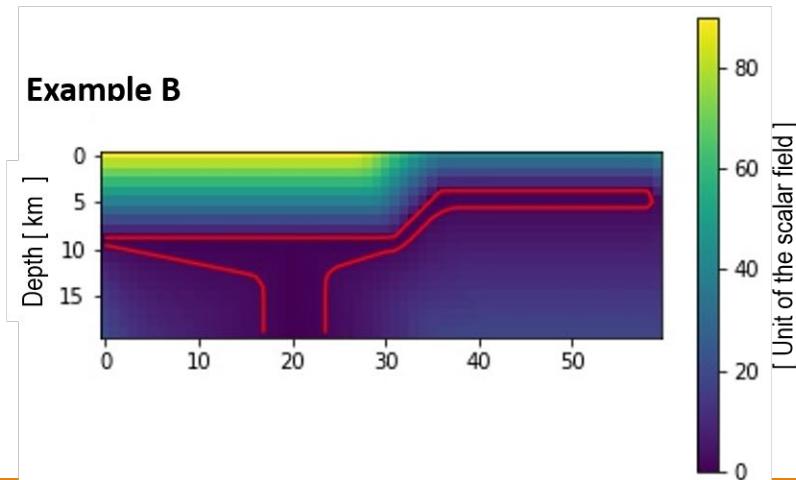
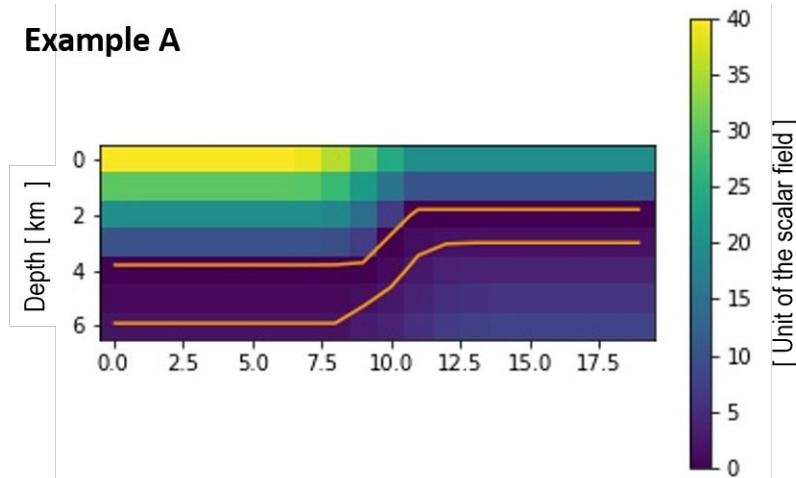
# WP #3 – LoopStructural

## Modelling intrusions

Using the Object-distance Simulation Method (Henrion et al. 2010)

Example A: Sill-dyke-sill transition. Orange contour shows scalar field  $\phi(p) = 2$ .

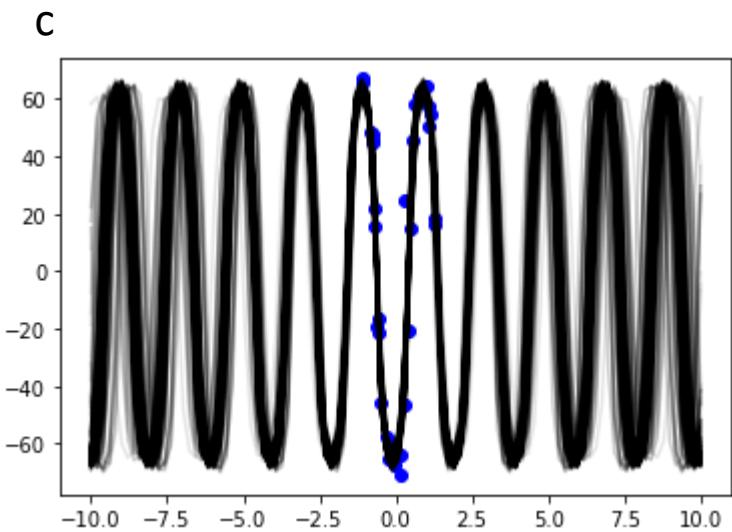
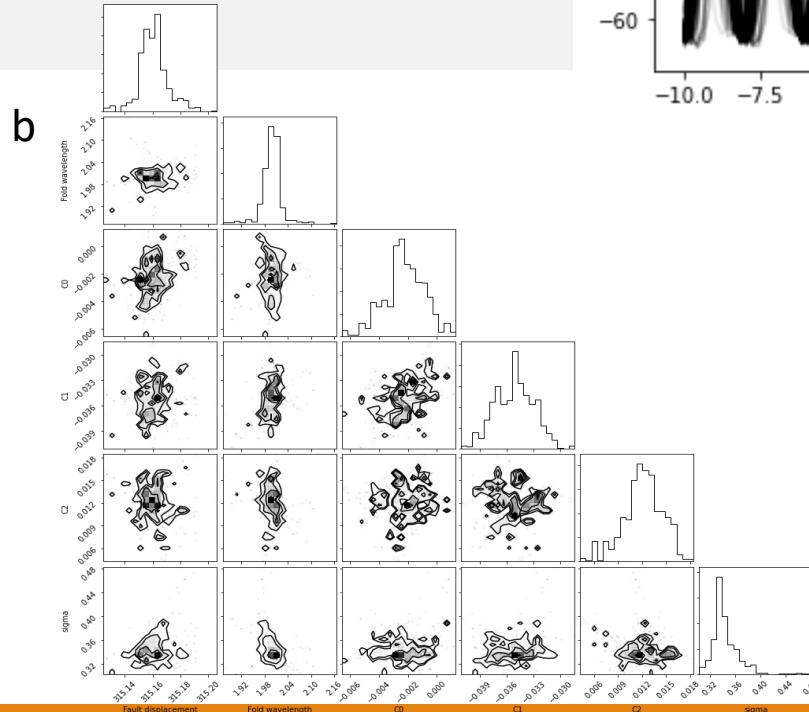
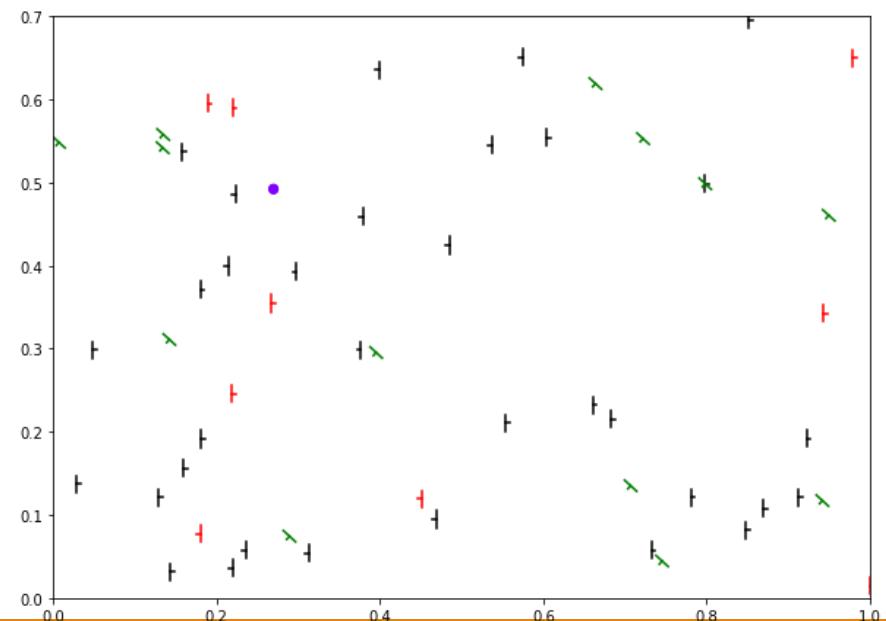
Example B. Feeder-sill-dyke-sill transition. Red contour shows scalar field  $\phi(p) = 2$



# WP #3 – LoopStructural

## Bayesian modelling – proof of concept

- a) Faulted fold series map where probabilistic folding and faulting was used to recover the fault displacement and fold geometry.
- b) Posterior probabilities for displacement and fourier series coefficients
- c) S-Plot showing 1000 realisations of the fold profile sampled from the posterior distribution.

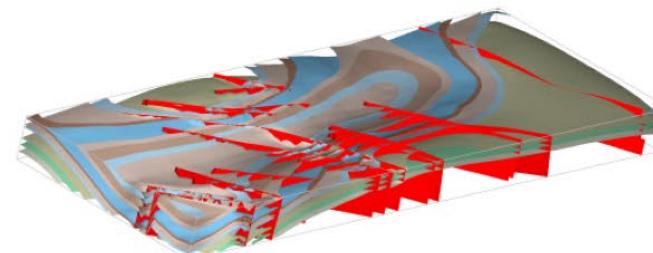
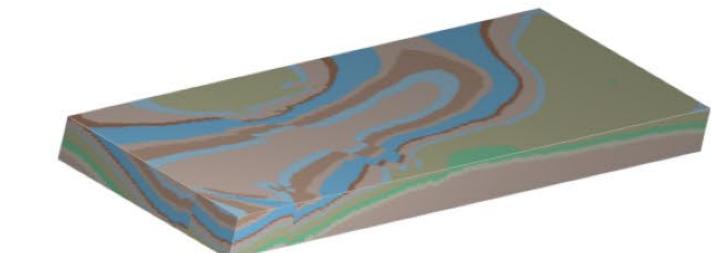


Loop

# WP #3 – LoopStructural

## Geological map colours for 3D model

Model for turner syncline using map2loop with surface and geology colours being automatically extracted from 100k mapsheets



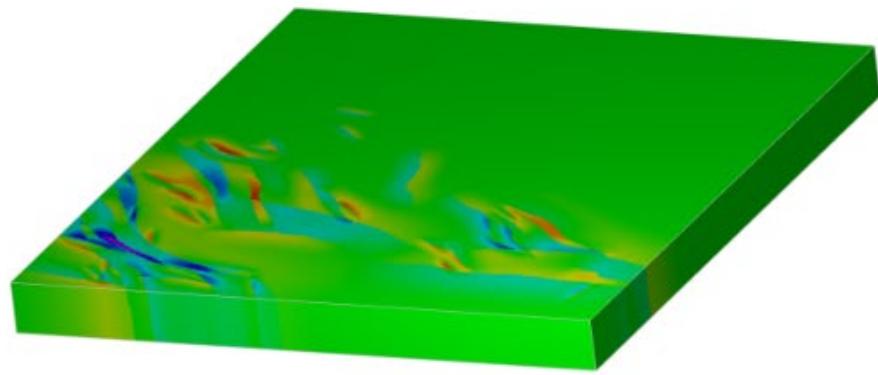
**Loop**

# WP #3 – LoopStructural

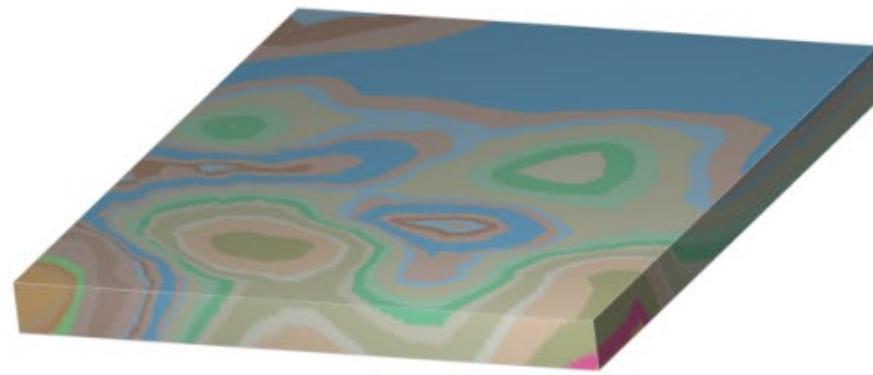
## Fault displacement map

Model for Hamersley area showing fault displacement magnitude. This new visualisation option shows the cumulative fault displacement for the geological model. It can be used in the 3D viewer or in the 2D mapview

Fault displacement



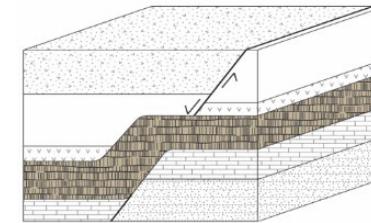
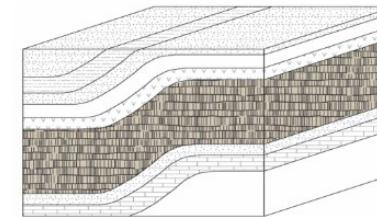
Geological model



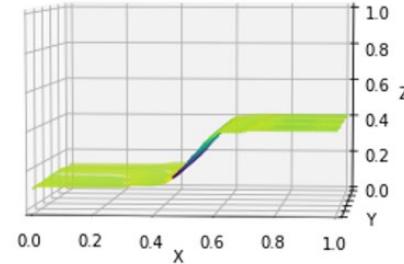
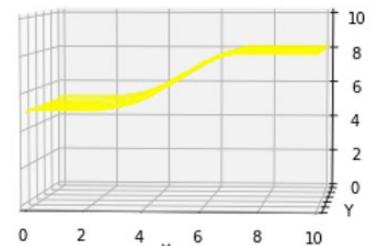
# WP #3 – LoopStructural

*ODSIM applied to intrusions. (A) Schematic representation of two synthetic cases. To the left, a sheet Intrusion emplaced in a folded and conformable sedimentary sequence. To the right, a sheet Intrusion emplaced in a faulted and conformable sedimentary sequence. (B) Intrusion network. (C) Coarse-scale geometry of the intrusions, showing the intrusion network (yellow surface), the intrusion body (blue volume) and the data points (red dots).*

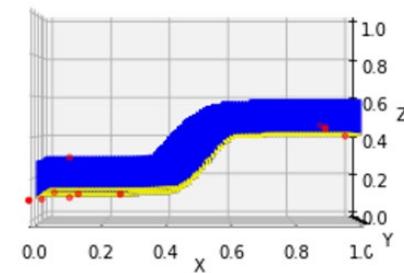
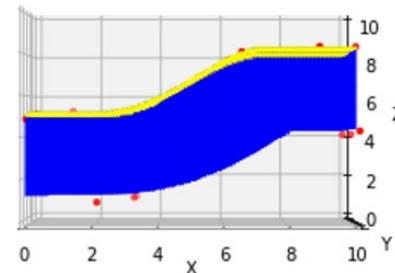
(A) Schematic representation of synthetic cases



(B) Outcome of Step 1

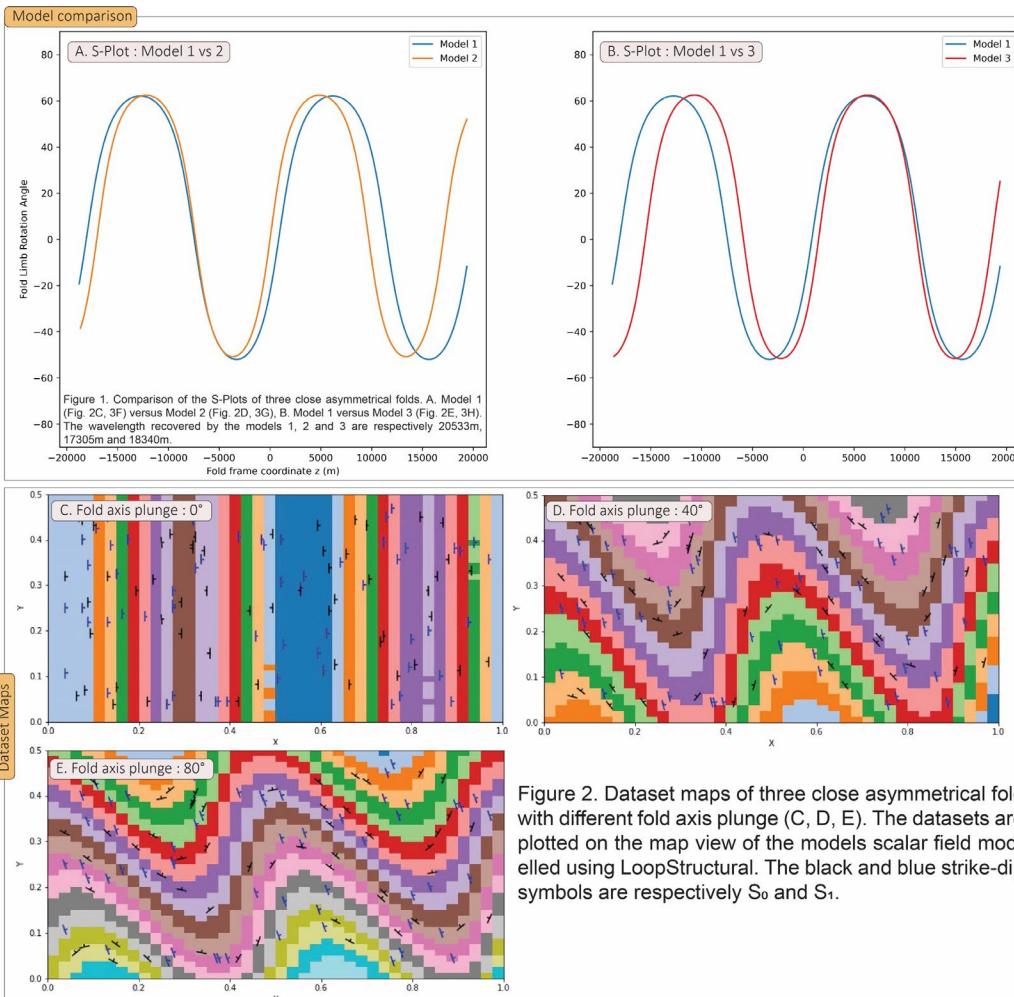


(C) Outcome of Step 2

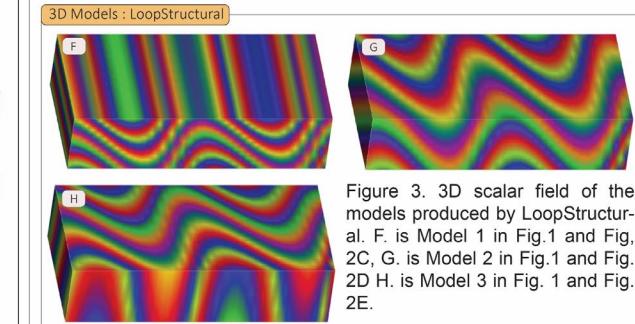


# WP #3 – LoopStructural

*Figure showing LoopStructural sensitivity to data sampling for folded structures.*



Wavelength Recovery : Cylindrical folds

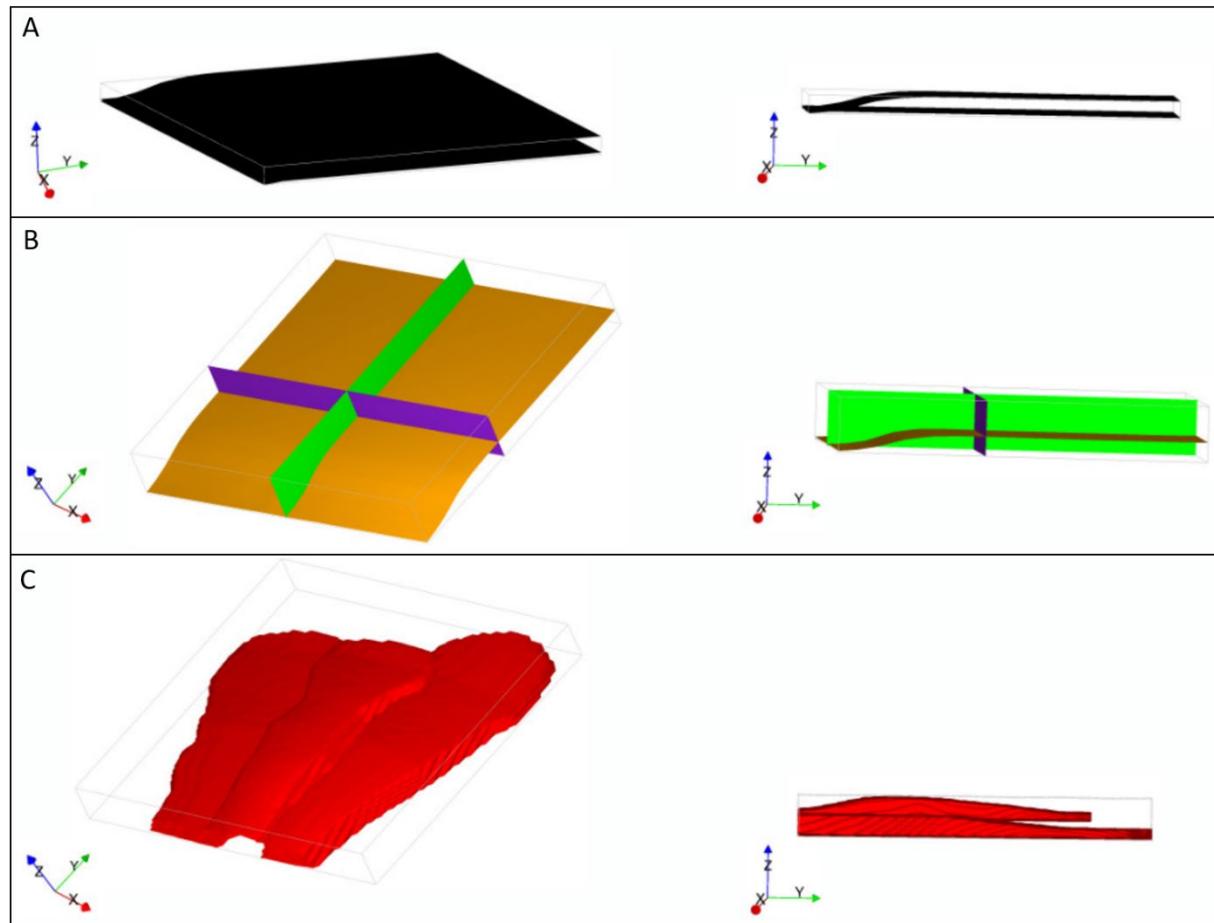


Preliminary conclusions

- The models (e.g. Model 1, Fig. 1, 2C, 3F) that recovered the best the reference wavelength had their inflection points sampled. This, underline the importance of inflection points in sampling folds to constrain any fold wavelength/geometry.
- The asymmetric folds require the sampling of the inflection points that capture the whole wavelength whereas symmetric folds require only inflection points that capture the half wavelength. This difference can be explained by the fact that in asymmetric folds, the fold limb rotation angle at the inflection points in the long limbs will be different of those in short limbs. In symmetric folds, the fold limb rotation angle at the inflection points are equal or very close.
- Sampling at the location of the maximum curvature in the hinges are important to constrain the hinges and hence the fold wavelength. However, not well constrained limbs introduced more variability in the fold geometry than not constrained hinges.
- The comparison between the three models ( $M_{1,2,3}$ , Fig. 1) showed that the cause behind the difference between the models in terms of wavelength recovery, is matter of the structural location of each measurement than just the distance between measurements.

# WP #3 – LoopStructural

Synthetic example representing the main features of a sill complex and sill segmentation. The middle intrusion exploits a pre-existing structure and propagates through a higher stratigraphic level. Closer to the source, the intrusions coalesce and develop broken bridges structures. At distal locations, the intrusions remain unconnected, developing bridges between them. (A) Intrusion network surface; (B) Structural frame of middle intrusion; (C) Isosurface 0 representing the outer surface of the intrusion.

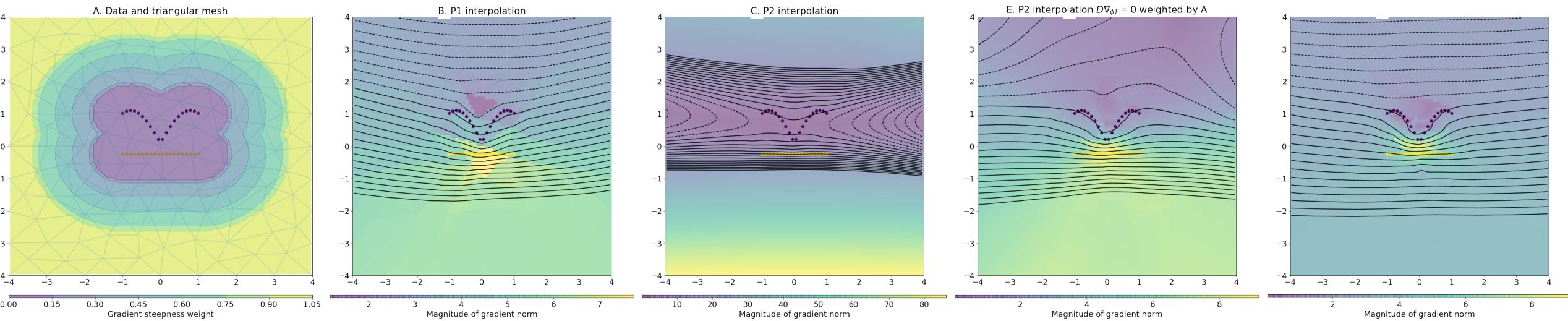


# WP #3 – LoopStructural

Fault intersection matrix calculated from 3D fault surfaces. This can be compared with the map pattern to identify intersections below the map

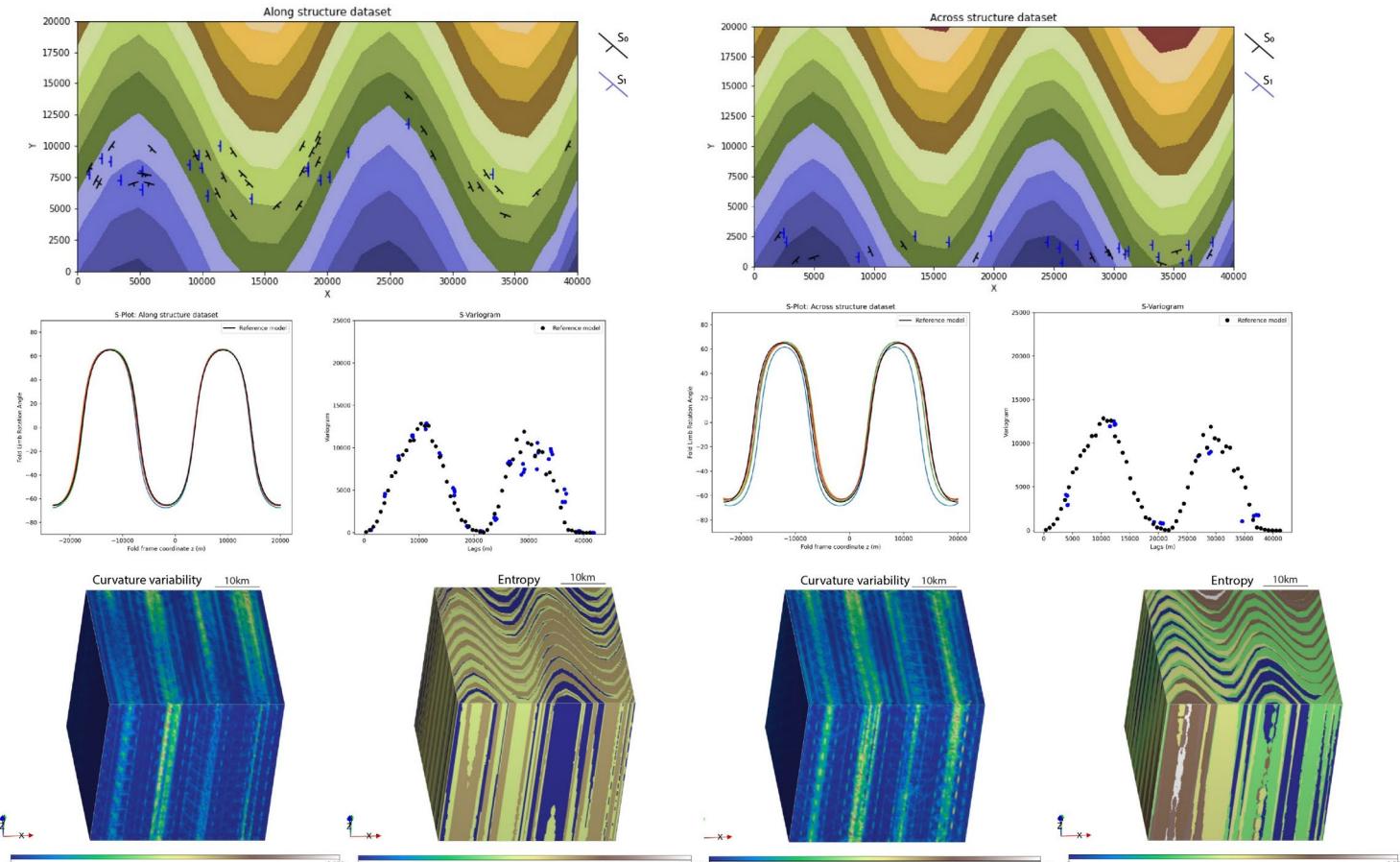
	Fault_2248	Fault_2843	Fault_3496	Fault_3498	Fault_12647	Fault_12658	Fault_12660	Fault_14378	Fault_15552	Fault_16769	Fault_2997
Fault_2248	0	0	0	0	0	0	0	0	0	1	0
Fault_2843	0	1	0	0	0	0	0	0	0	0	0
Fault_3496	0	0	1	0	0	0	0	0	0	0	0
Fault_3498	0	0	0	0	0	0	1	0	0	0	1
Fault_12647	0	0	0	0	1	0	0	0	0	0	0
Fault_12658	0	0	0	0	0	1	0	0	0	0	0
Fault_12660	0	0	0	0	0	0	1	0	1	0	0
Fault_14378	0	0	0	0	0	0	0	1	0	0	0
Fault_15552	0	0	0	0	0	0	1	0	1	0	0
Fault_16769	1	0	0	0	0	0	0	0	0	1	0
Fault_2997	0	0	0	1	0	0	0	0	0	0	1

# WP #3 – LoopStructural



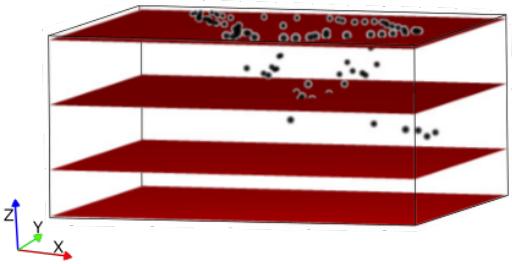
2D interpolation comparison: A) reference data and spatial weighting function B) Linear interpolation. C) quadratic interpolation D) quadratic interpolation using gradient steepness weight and E) quadratic interpolation using weight function from A) for gradient steepness.

# WP #3 – LoopStructural

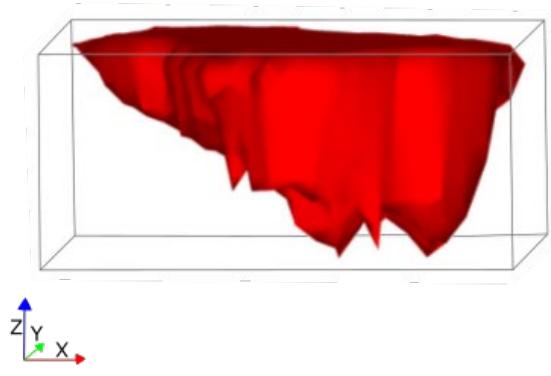
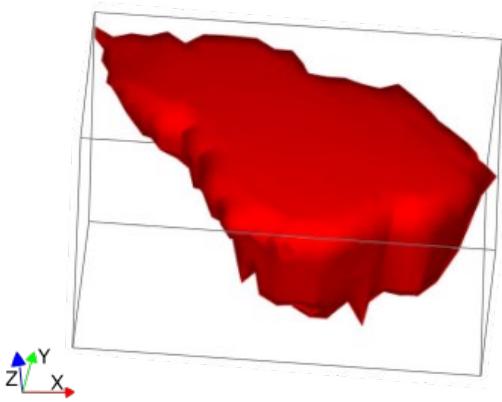
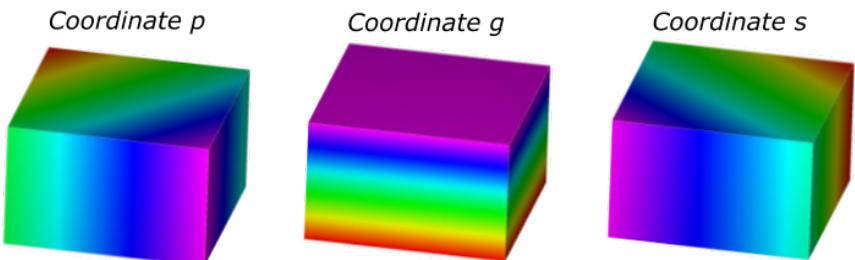
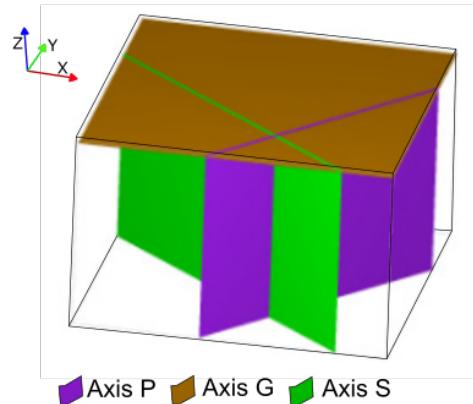
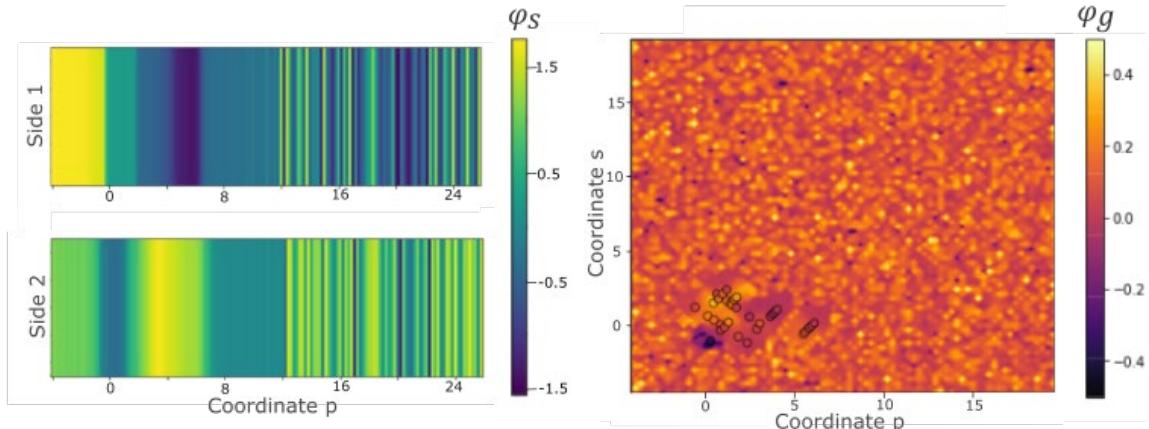


**3D Comparison between form surface and across structure sampling using a cylindrical upright fold example** (three perturbed datasets are used for each example). The fold curvature variability shows that the hinges display high variability between the models. These results show that the way of mapping and sampling structural data produce datasets that lead to different model geometries. When modelling complex fold geometries the variability is expected to be very high.

# WP #3 – LoopStructural



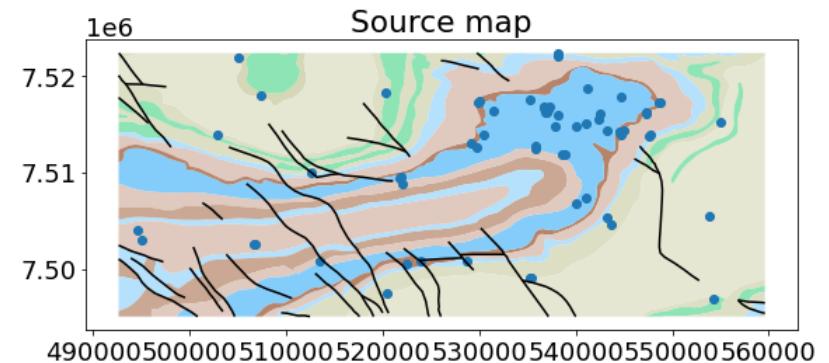
- Intrusion contact picks on surface mapping and drill holes
- Isosurfaces representing the stratigraphy of the area



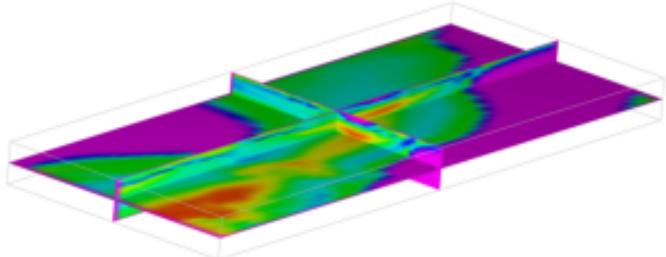
Structural frame of Voisey's Bay intrusion. Top left: intrusion contact points and horizontal stratigraphy. Bottom left: Structural frame axes and coordinates. Top right Realization of residual values  $\varphi_s$  (left) and  $\varphi_g$  (right). Bottom: resulting intrusion body

# WP #3 – LoopStructural

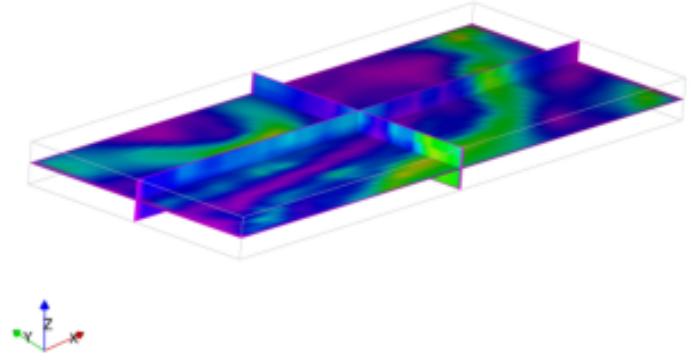
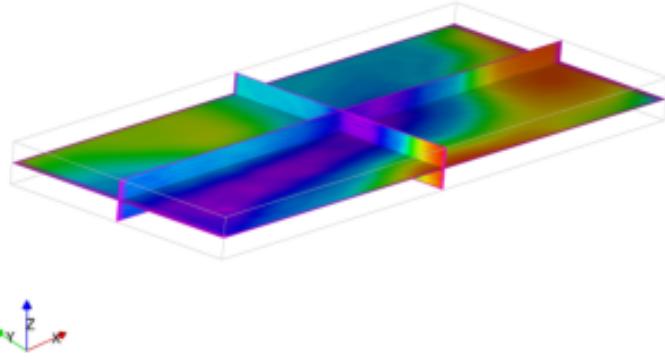
Source map processed by map2loop for LoopStructural. The thickness of each stratigraphic unit is estimated locally by map2loop and a global value (median) is usually used as input into the 3D model. Here we sample the thickness values from a probability density function where the mean and standard deviation are defined by the map2loop calculated values.



A. Stratigraphic Entropy



B. Continuous Entropy



The results show that thickness estimates can contribute to the resulting model geometries. Stratigraphic entropy is concentrated near the faults and continuous entropy (the variability in the scalar field is concentrated in the cream unit which has the highest apparent thickness variability in the map). Angle variability highlights the variation in the geometry resulting from the thickness estimates.

# WP #4 – Integrated Geophysical Inversion

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen  New 

-  1. GLoop/Tomofast-related or potentially related journal papers: accepted in Geophysical Journal International and Geophysics.
-  2. Redaction of paper towards public release of Tomofast-x inversion platform: delayed but will happen.
-  3. Redefining file formats for I/O to abide by recognized standards, writing of codes for communication between Tomofast-x and other modules.
-  4. Documentation of Tomofast and 2D simplified version: Nuwan working on editing it and do website.
-  5. Model Intercomparison Project – discussed in Busselton; model to be chosen/designed in discussion.

# WP #4 – Integrated Geophysical Inversion

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen  New 

-  6. Implicit functions (level-set) to define geometries in geophysical inversion: case study performed, paper came back for revisions; working on revised manuscript.
-  7. Sub-consortium to support student(s) to extend Tomofast application to IP/Res: suitable student not found.
-  8. Potential new collaboration(s): discussions with Memorial Uni. of Newfoundland.
-  9. Damien Ciolczyk 's internship (6 month, double degree ENSG-EOST): delayed beginning but otherwise on track. Working on geology-geophysics integration and probabilistic MT + deterministic gravi cooperative modelling.
-  10. Joint project with CSIRO on probabilistic MT/potential fields integration. Phase 1: Progress on synthetic case and starting field application. Use of LoopStructural planned in phase 2.
-  11. Marie Curie Fellowship awarded to Jeremie Giraud to develop Geology-Geophysics joint modelling in/with Loop.

# WP #4 – Integrated Geophysical Inversion

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen  New 

- 12. Case study using data from Yamarna region using 3D geometrical inversion of gravity data constrained by sparse 2D seismic modelling.
- 13. Developed methodology for integration of 1D MT + passive seismic for depth to basement modelling.
- 14. Started case study in collaboration with GTK (Finnish geological survey) for shallow seismically-constrained geometrical gravity inversion in vicinity of ore body.
- 15. Preprint of GMD discussion paper showcasing Tomofast-x: publicly available.
- 16. Preprint of level-set (geometrical inversion) paper: accepted paper publicly available.
- 17. Preprint of Solid Earth discussion paper for item 12: publicly available.

# WP #4 – Integrated Geophysical Inversion

Is work on track against plan? update all deliverables

Work completed  On track  Delayed  Problem  Will not happen  New

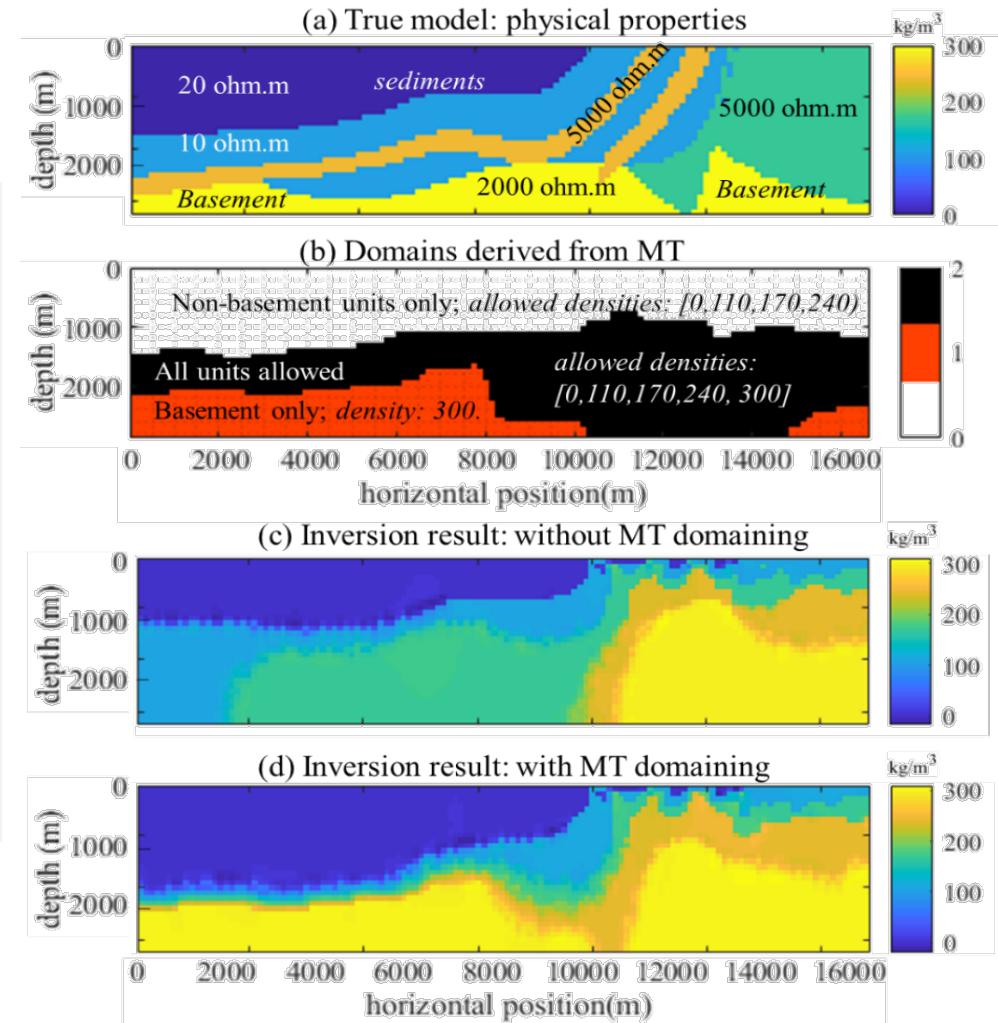
- 18. Paper for item 13, proof-of-concept and case study of 1D MT + mag. data: nearly ready for submission.

# WP #4 – Integrated Geophysical Inversion

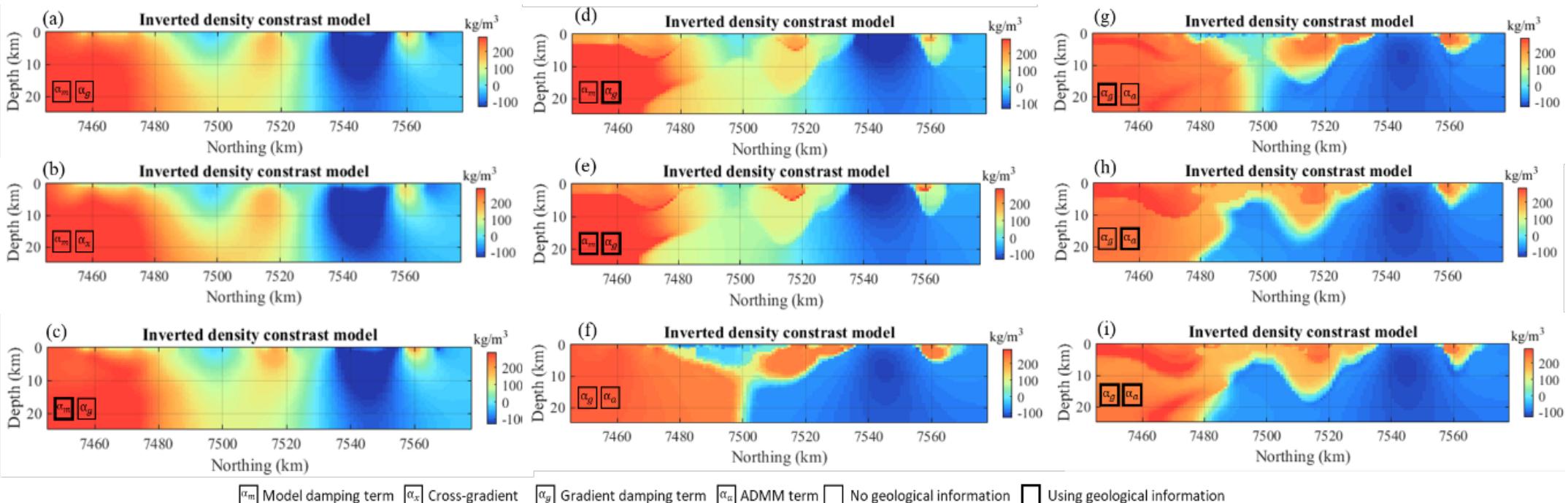
Feasibility study of proposed workflow for the integration of gravity and magnetotellurics data.

Domains are derived from MT probabilities of rock units. Each domain allows a range of densities to be used by gravity inversion accordingly with rock types allowed.

From Giraud et al. 2020 [submitted]. Utilisation of stochastic MT inversion results to constrain gravity inversion, extended abstract submitted to EAGE's **Unpublished material; not for public sharing.**



# WP #4 – Integrated Geophysical Inversion

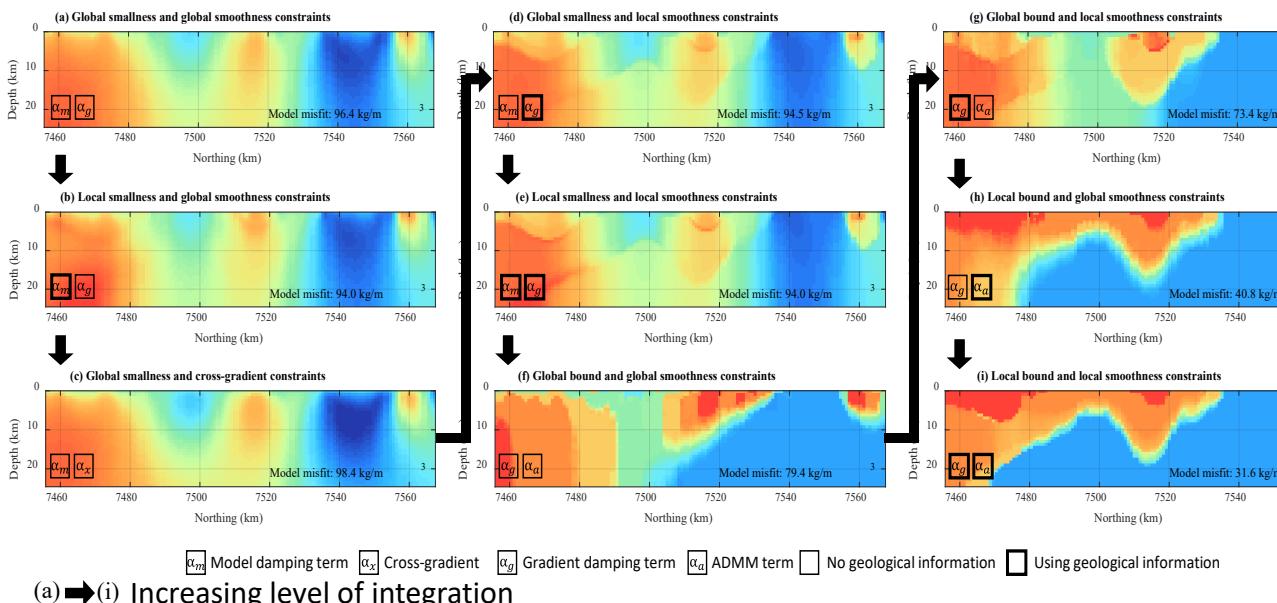


Comparison of inversion results for density contrast models recovered using different kinds of constraints from petrophysics and/or geology and/or structural prior information.

From Giraud et al. 2020 [in prep, submission expected in Q4 2020]. **Unpublished material; not for public sharing.**

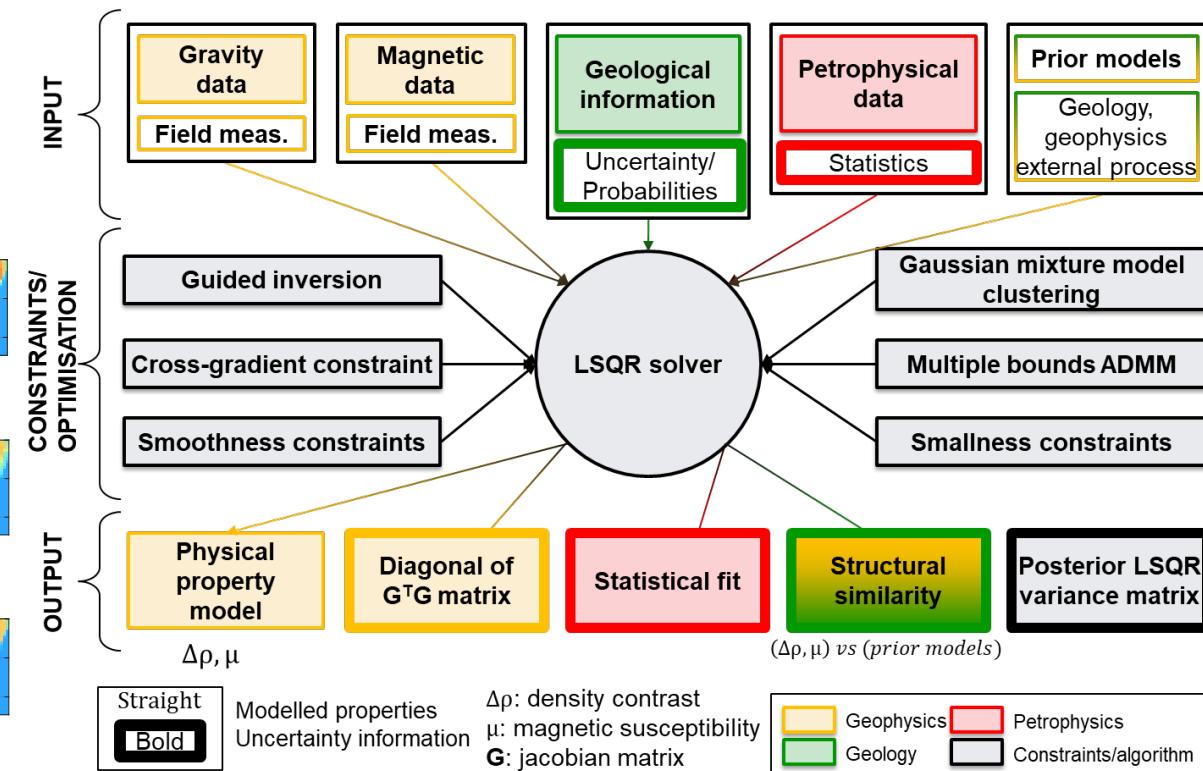
# WP #4 – Integrated Geophysical Inversion

Finalisation of Tomofast-x inversion platform and preparation of released complete. Code and examples online in referenced repository; paper submitted.



Sensitivity study to data integration in inversion

From Giraud et al. 2021 [submitted in Q1 2021].



Tomofast-x functionalities summary

Loop

# WP #4 – Integrated Geophysical Inversion

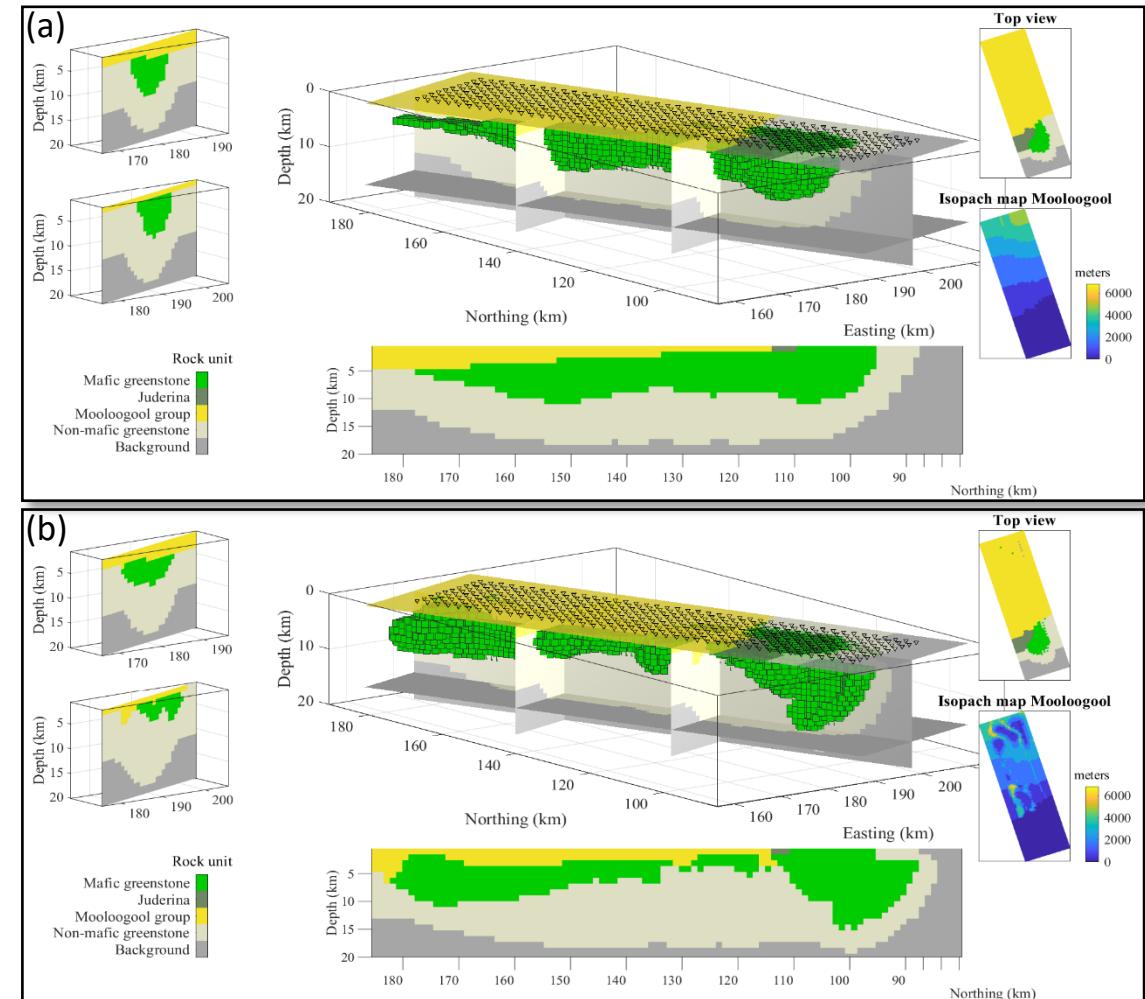
Results of gravity data inversion using level-set formulation of geometries to adjust geological bodies' shapes. Application to greenstone belt from Yerrida basin (WA)

(a) Starting model derived from probabilistic geological modelling alone

(b) Inversion results: geological model deformed and adjusted by level-set inversion of Bouguer anomaly

From Giraud et al., 2021 [pending], Generalisation of level-set inversion to an arbitrary number of geological units using a regularized least-squares approach, submitted for publication in Geophysics.

**Unpublished material: not for public sharing.**



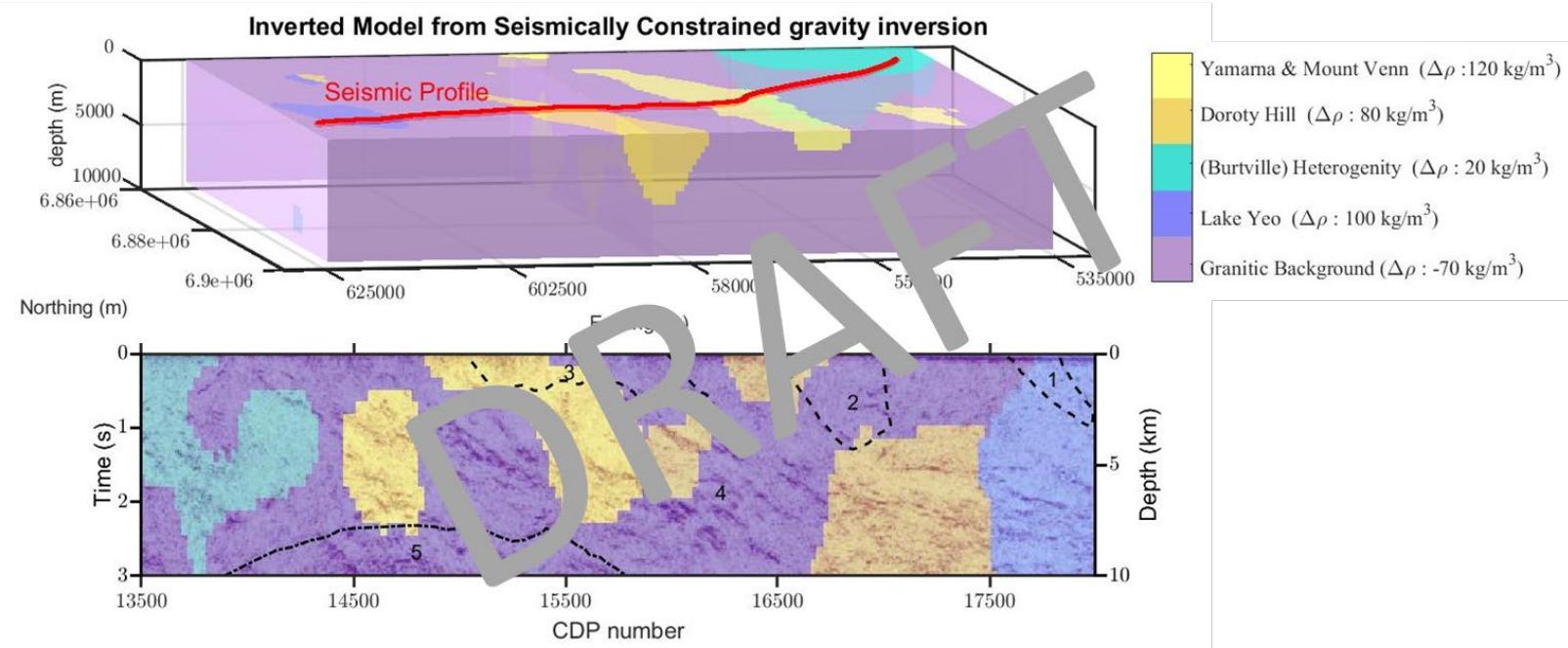
# WP #4 – Integrated Geophysical Inversion

Field application example of 3D geometrical gravity inversion using a generalized level-set formulation constrained by sparse 2D seismic modelling in the Yamarna area.

From Rashidifard et al. 2021 [in prep].

A 2D crooked seismic line is used to constrain 3D level-set gravity inversion to adjust the geometry of geological units. Topological rules are applied during inversion.

**Unpublished material: for internal use only.**



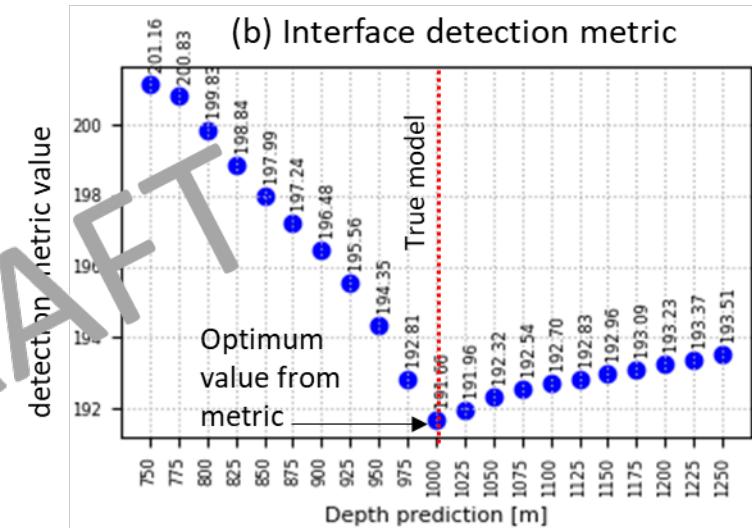
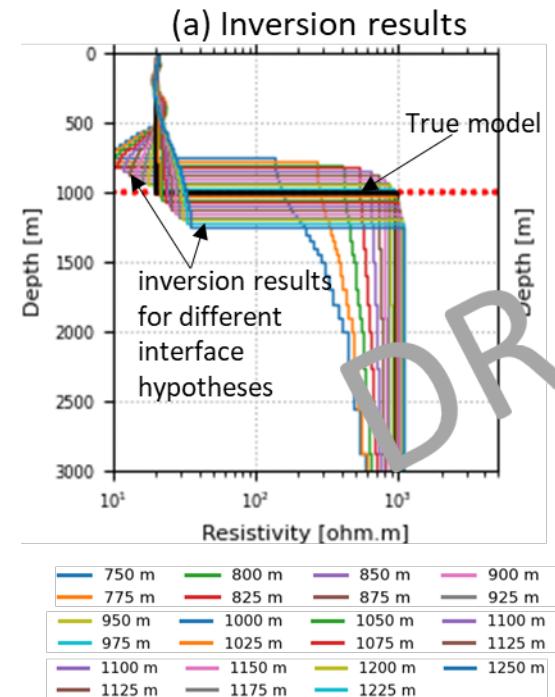
# WP #4 – Integrated Geophysical Inversion

Numerical investigation for constraining MT inversion using passive seismic to reduce the depth-to-basement uncertainty.

From Suriyaarachchi et al. [in prep].

Depths for the basement interfaces are sampled from the range compatible with passive seismic modelling and tested against MT data inversion. The metric introduced here is calculated from MT inversion results. Tests reveal that it is minimum at the true interface depth and is suitable for depth-to-basement modelling and uncertainty reduction.

**Unpublished material: for internal use only.**

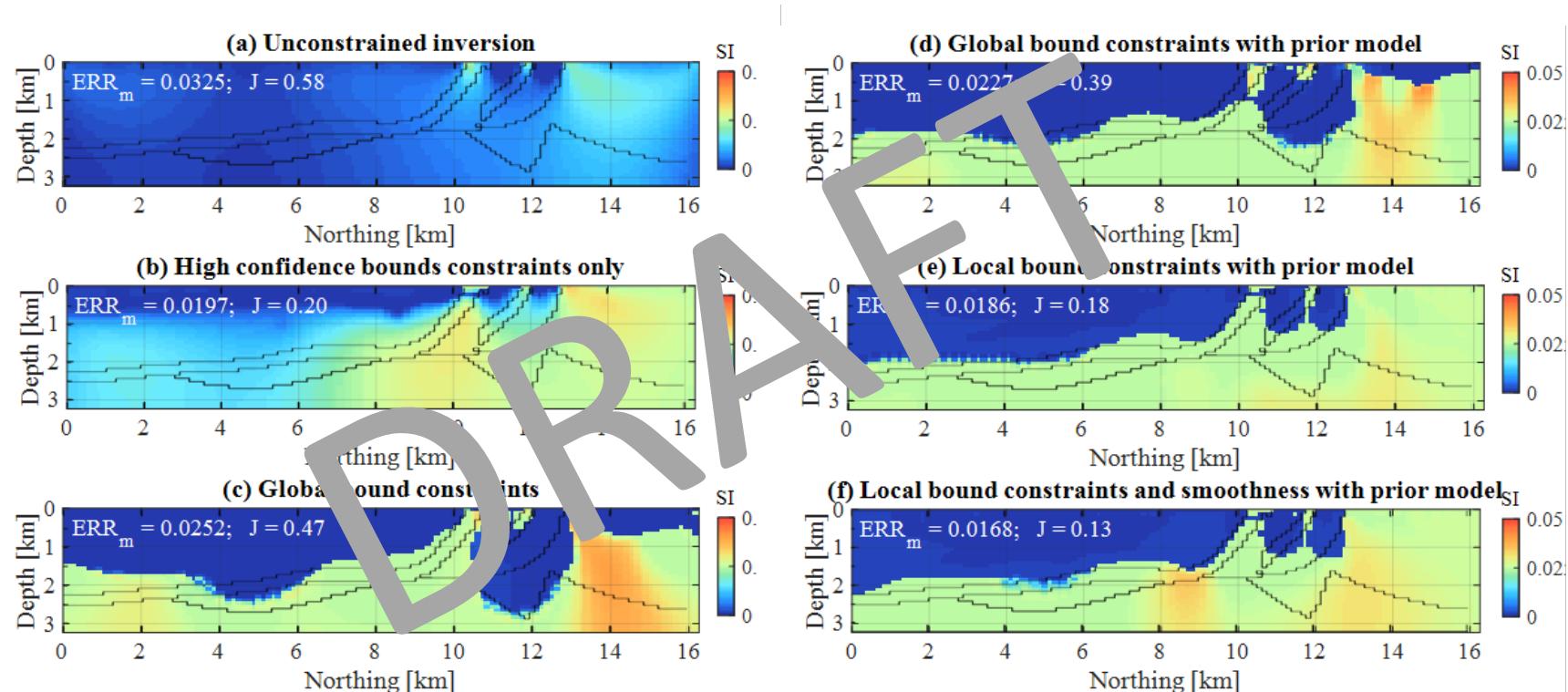


# WP #4 – Integrated Geophysical Inversion

## Utilisation of probabilistic MT to constrain magnetic inversion.

The grey lines materialise the interfaces between geological units in the true model.  $\text{ERR}_m$  refers to the RMS model misfit between inverted and true model. The progression from (a) through (e) increasingly uses MT information to categorize basement vs non-basement units. From Giraud et al. 2021 [in prep].

**Unpublished material: for internal use only.**



# WP #5 – Model Analysis & Uncertainty Reduction

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen 

New 

-  1. Uncertainty characterization - Guillaume Pirot started September 2<sup>nd</sup> 2019
-  2. PhD student – Babak Ghane has been offered a place at UWA and has accepted. Awaiting visa approvals
-  3. Ontology development of geophysical methods and mineral systems detection (assoc. with WP1)
-  4. Measuring information loss/change from data upscaling/processing
-  5. Design WP5 analytical framework – aspects related to Vol considered (next slides)
-  6. Paper preparation: Utility of gravity data with geochemistry to understand basin development (Paper published – Solid Earth)
-  7. Paper preparation: Extracting geological knowledge from petrophysics using machine learning on drillcore

# WP #5 – Model Analysis & Uncertainty Reduction

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen 

New 

-  8. Paper preparation: Objective assessment of structural geophysical interpretation & impact on 3D uncertainty
-  9. 3D modelling survey to improve our understanding of modellers needs and uses
-  10. Letter/paper preparation - 3D modelling and uncertainty quantification: needs and practices in the mining industry
-  11. Assessing input data quality and uncertainty (from exploratory analysis to data richness, assoc. with WP1 & WP2)
-  12. Identifying plausible geological scenarios from the Yalgoo-Singleton dataset, based on the probability estimation of spatio-temporal geological events
-  13. Towards a parametric representation of geological concepts (assoc. with WP2)
-  14. Reducing prior uncertainty with data integration (additional geological or geophysical data, assoc. with WP1, 2&4)

# WP #5 – Model Analysis & Uncertainty Reduction

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

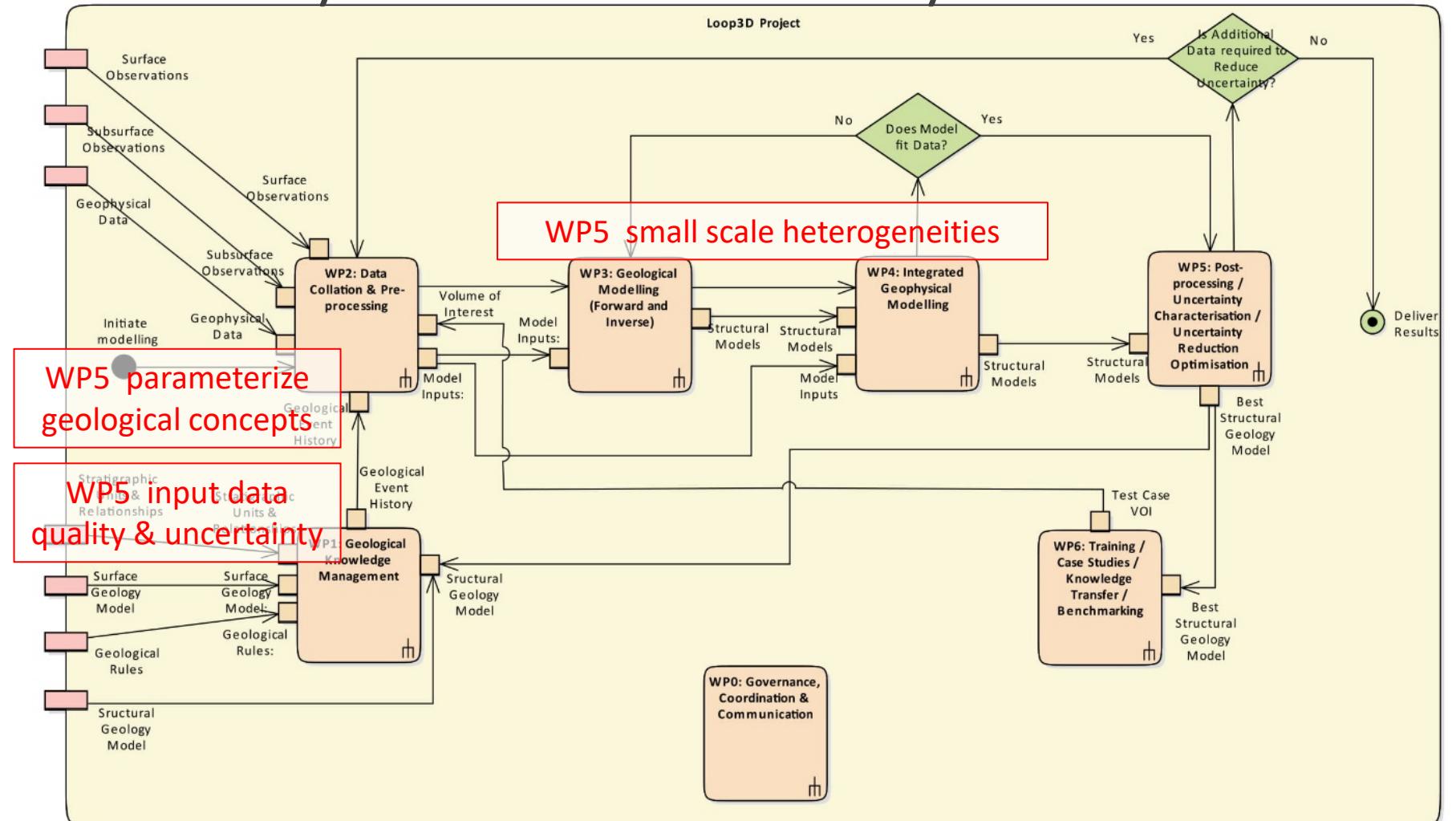
Will not happen 

New 

-  15. Assessing the effects of hierarchical versus joint inversion on prediction confidence (precision) and bias (accuracy)
-  16. Assessing the effects of sampling based versus deterministic driven inversion on prediction confidence (precision) and bias (accuracy)
-  17. Importance of small scale heterogeneities: up to what scale does it matters ? (multiple-point statistics, assoc. with WP1, WP2, WP3 & WP4)

# WP #5 – Model Analysis & Uncertainty Reduction

WP5 uncertainty reduction with additional geological or geophysical data



Loop

# WP #5 – Model Analysis & Uncertainty Reduction

## Sources of uncertainty

- Errors
- Lack of data
- Unknown

## Uncertainty types

- Conceptual (often ignored)
- Parametric and algorithmic (MCMC, CURE-like approaches)
- Stochastic (ensemble modelling)

## Objectives

- How does (geological concept) uncertainty affects decision making?
  - Characterize the sensitivity of decision threshold to geological concepts (& other input data, parameters or error)
  - How to define a wide prior of plausible geological scenarios?
  - Improve assessment of input data quality and uncertainty
- Reducing uncertainty (conceptual, parametric and algorithmic prior)
  - Data richness, Vol, where to drill next? what kind of additional geological or geophysical data?
  - Scenario selection via parameter space exploration
  - Bayesian optimization techniques
  - Null-space exploration
- How do methodological choice influence prediction uncertainty?
  - Hierarchical versus joint inversion
  - Deterministic driven versus sampling based approaches
- How and when do small scale heterogeneities matter for mining applications?

# WP #5 – Model Analysis & Uncertainty Reduction

*Model engine*

Co-kriging (Geomodeller)

Loop Structural

RBF (Leapfrog)

*Kriging parameters (global or per formation) Faults not included*

Range

Nugget (interfaces, orientations)

Drift degree (0,1,2)

Anisotropy

## Bayesian Optimisation

*Characterising parametric uncertainty from CURE-like process*

Cardinality – Global/Local

Entropy - Global/Local

Spatial entropy - Global/Local

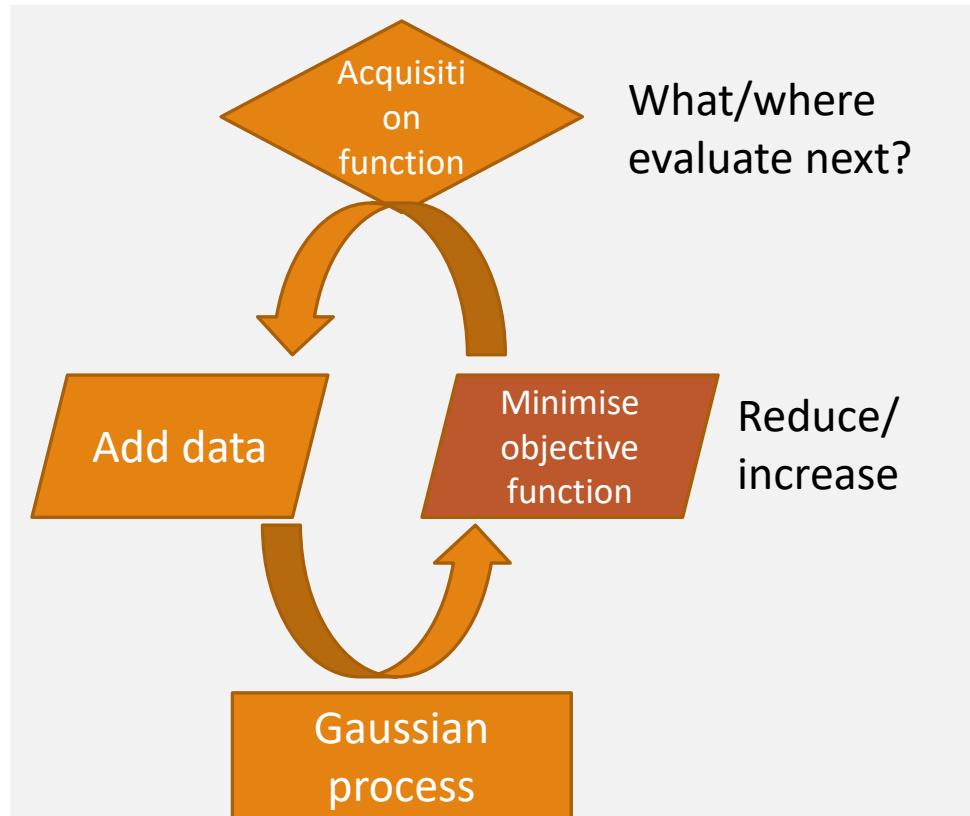
OLS - Global/Local

P1 - Global/Local

Frequency/Probability - Global/Local

Geometric - Geodiversity (Volumes, Surface areas, Depths, neighbourhood relationships) Local

Topology - Multiscale



**Loop**

## Ontology (WP1)

- ? Are we using the right
- Data for this
  - Commodity/ Mineral System in this
  - Region/ Geological domain

Optimising data collection

Remote Sensing  
Geophysics  
Mapping  
Drilling  
Geochem

Considering 'Coupling'  
e.g. grav and mag  
 $R^2$  of the two datasets (simple)

Cost of collection while considering

Logistics < $\sigma$   
Markets > $\sigma$

OVX – Crude = proxy for logistics  
GVZ – Au  
VXSLV – Ag  
VXGDX – Gold Miners  
VXXLE – Energy  
Longitudinal Indices  
3/6/9/12mth volatility  
XGD (ASX allords Au index)

Value of Information

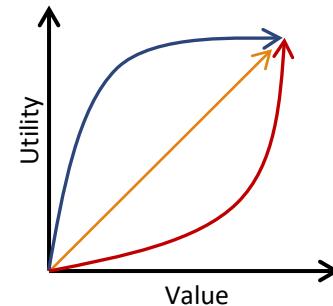
## Decision analysis

- Is the decision process:  
Hierarchical?  
Flexible?  
What sequence is optimal?

Certain Equivalent  
(the amount of payoff that an agent would have to receive to be indifferent between that payoff and a given gamble)

This depends on

- Risk personalities
- Averse
  - Neutral
  - Seeking



How do we best communicate this to the decision maker?

There is a tendency for the decision maker to ignore accurate data and information  
Can we address this? How to address this?

Loop

# WP #5 – a Hamersley derived synthetic case

Objective: establish a proof of concept to reduce uncertainty based on the value of information

- Where to drill next? How deep?
- Where to collect more geophysical data
- How fast can geological uncertainty be reduced and stabilized?
- Sensitivity to budget and drilling strategy

Other advantages and challenges of the iterative ensemble modelling approach:

- Mitigate uncertainty underestimation resulting from black-box implicit modelling with fictive pilot drill-holes
- Minimize an iteratively integrated Uncertainty using non-linear multi-objective sampling design
- Ensemble of realizations and reference will be available for further LOOP testing

Agenda

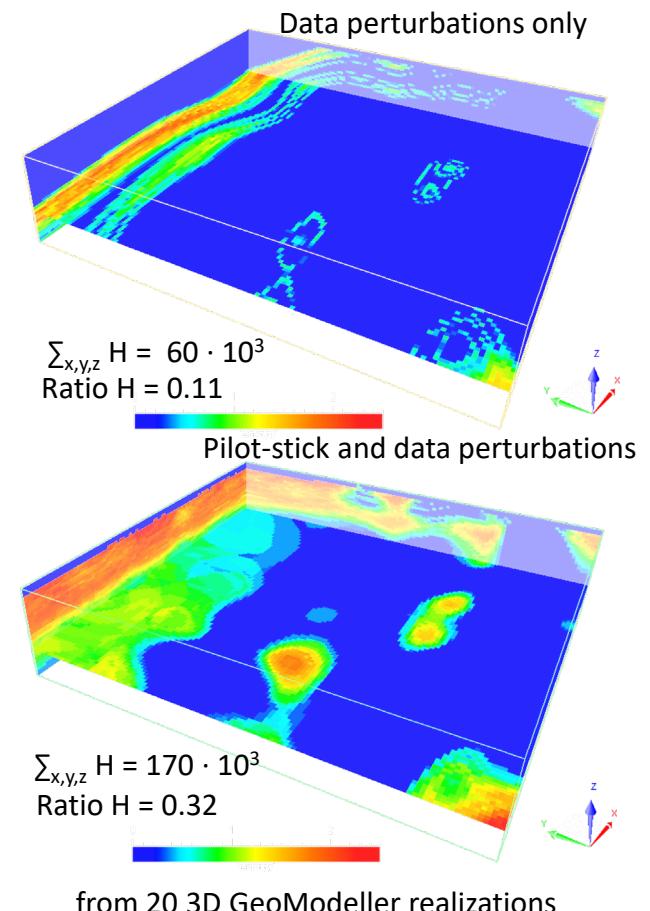
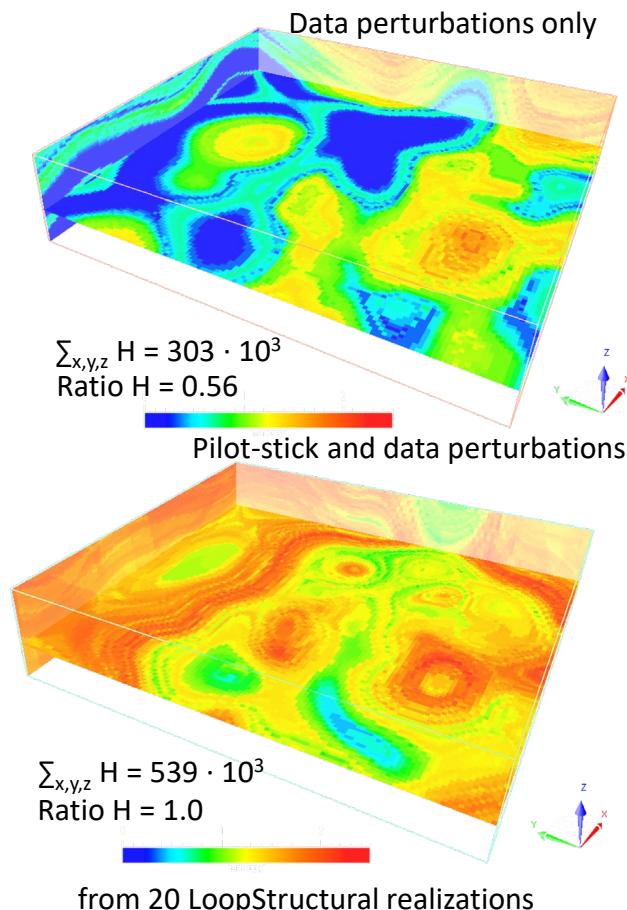
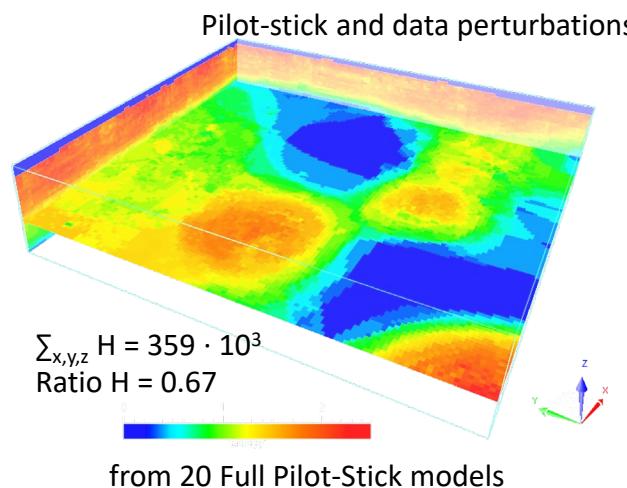
- Define a synthetic reference and prior information (Done)
- Implement pilot drillhole perturbations (Done, improvement in progress)
- Select (Done) and implement the optimization algorithm (Done)



# WP #5

1. ensemble generator integrated in the workflow
2. mitigating uncertainty underestimation with Pilot-Stick Perturbations (illustration below)

Entropy H as uncertainty indicator



# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen  New 

- 1. Training / Self Tutorial: ‘LoopStructural’ python library for structural modelling is available to sponsors (email Lachlan Grose to get access to the GitHub – public release mid 2020). This includes Jupyter notebooks guiding users through interactive structural modelling workflows. More beta testers required!
- 2. Loop Workshops:
  - AEGC 2019 conference 2nd-6th September, Perth, WA // Loop/MinexCRC workshop Fri 6th Sep // Workshop on Uncertainty in 3D modelling and Inversion; organised by CET MJ/ML/JG – WP5
  - SGTSG 2019 conference 18th-23th November, Port Lincoln, South Australia // LoopStructural Jupyter notebooks An opt in mailing list was setup at the completion of the workshop with ~30 researchers currently signed up to date // organized by Monash Uni LA/LG/RA // SGTSG LoopStructural workshop successfully completed with 45 participants from academia, geological survey and universities.
- 3. Visited NTGS to demonstrate LoopStructural and discuss Loop overall including future funding opportunities including in-house case studies and applications.



# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 4. Recruited 3 PhD students to Monash University:
  - Rabii Chaarani to work on the Broken Hill case study looking at the value of structural information in poly-deformed terranes.
  - Fernanda Alvarado: Modelling intrusions: field observations, encoding rules.
  - Marina Jeronimo-Zarate: Integrated geophysical and geological 3D modelling (starting March 2021 – Delayed due to COVID-19).
- 5. Proposed case study for the Amadeus Basin revised to the Birrindudu Basin in the Northern Territory. NTGS staff member and honours student to be found by early 2021.
- 6. Proposed visit to the Geological Survey of South Australia in Q2 2019 to discuss SA case study possibilities. Case study proposal - structural mapping (currently underway) in the Tarcoola goldfields. Face to Face meeting not possible due to COVID-19. 2 videomeetings proposed for June 2020.

# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen 

New 

-  7. Benchmarking case studies to be developed with ED and established by mid 2019.
-  8. Plan benchmark paper for comparing existing 3D modelling methods: GC leading this.
-  9. Develop case study to test fault geometries and apply to geophysical inversion schemes from WP4: Started discussion with JG.
-  10. Develop a week long course to align with sponsors meeting in mid 2020 for knowledge transfer and feedback to WP1-5.
-  11. Loop collaboration meeting – UWA/Monash – October 21st to 23rd 2019, Perth. All work programs discussed.
-  12. Mid Loop progress meeting – 10th to 14th March 2020. In Busselton. Technical sessions, demonstration and hands-on practicals. Map2Loop, LoopStructural, Gloop and uncertainty assessment workflows demonstrated during the meeting. 47 participants

# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed  On track  Delayed

Problem  Will not happen  New

- 13. Develop a program to visit all supporting surveys to develop training and case studies. Ideally a centralized meeting for sponsor surveys proposed but may require one-on-one meetings.
- 14. A series of video-meetings proposed to sponsors to include: (1) high-level project progress and forward planning including funding; (2) A half day technical workshop (Loopinar) for all interested personnel to outline the software developments to date. Plan to hold these by end of Sep 2020.
- 15. An advanced video workshop for identified modelling specialists at each survey. This workshop will be hands-on including demonstrations and examples in Jupyter notebook format of the different Loop packages and use of the GUI.
- 16. Repeat Mid-Loop meeting workshop required for NTGS in mid 2020 due to conference clash in March. 2 videomeetings to be proposed for mid to late 2020.
- 17. Loop @ GA workshop required mid to late 2020.

# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 18. Establish a series of training course and source funding opportunities with industry bodies (AusIMM, GSA, ASEG, SEG, IAMG).
- 19. Development of a 2 day workshop for AESC 8th-12th Feb 2021.
- 20. Proposed and convene a session on 3D Modelling at AESC Feb 2021
- 21. Loop focused session for AGU 2020 approved - ‘There’s more than one way to bake a cake; global examples of building interoperable multidimensional geological frameworks’.
- 22. Proposed videoconference with potential new sponsors (e.g. QLD, TAS, VIC, GNS geological surveys) to outline Loop project progress to date and identify future opportunities.

# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



New



- 23. Website – 2<sup>nd</sup> version went live 9<sup>th</sup> April. Update required to fix current format.
- 24. Establish a calendar of Loop relevant conferences and disseminate to all Loop working groups to increase awareness of the project and outcomes.
- 25. Loop generic introduction slides to promote the project. Slide deck to be shared with sponsors to clearly articulate the entire Loop project, leveraging and what sponsors will have access to.
- 26. Create a Loop related publication folder (dropbox) to share with sponsors.
- 27. Vision is to have Map2Loop->LoopStructural + potentially uncertainty assessment integrated workflow ready for the AESC 2021
- 28. Session proposal for SGA 2021 in Rototua, NZ submitted - Automated 3D Geological modelling - new methods and applications from automated data analysis to 3D geological models. Convenors: Robin Armit, Laurent Ailleres & Mark Jessell

# WP #6 – Training, Case Studies & Knowledge Transfer

Is work on track against plan? update all deliverables

Work completed



On track



Delayed



Problem



Will not happen



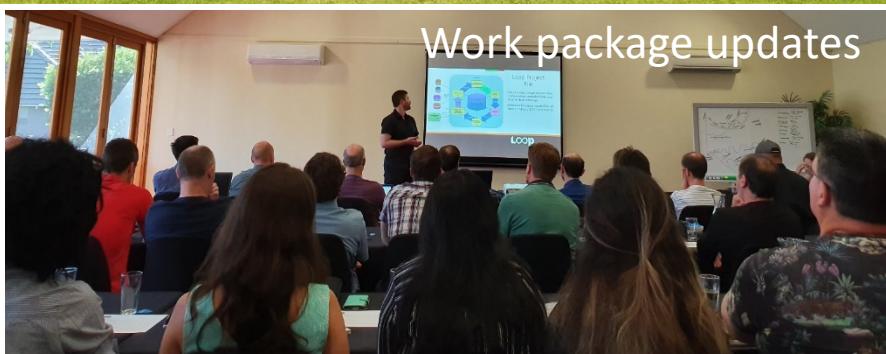
New



- 29. Map2loop and LoopResources presentation at Global ROAR 1010 session, November 2020
- 30. Loop European Workshop held in March 2021
- 31. Loop/MinEx CRC workshop held in March 2021
- 32. Tutorial on 3D modelling with Loop provided at Transform 2021, April 2021
- 33. EGU presentation ‘Current and future limits to automated 3D geological model construction’ April 2021
- 34. Loop presentation at GeoHug scheduled for September 2021

# Happy memories from the Mid-Loop meeting

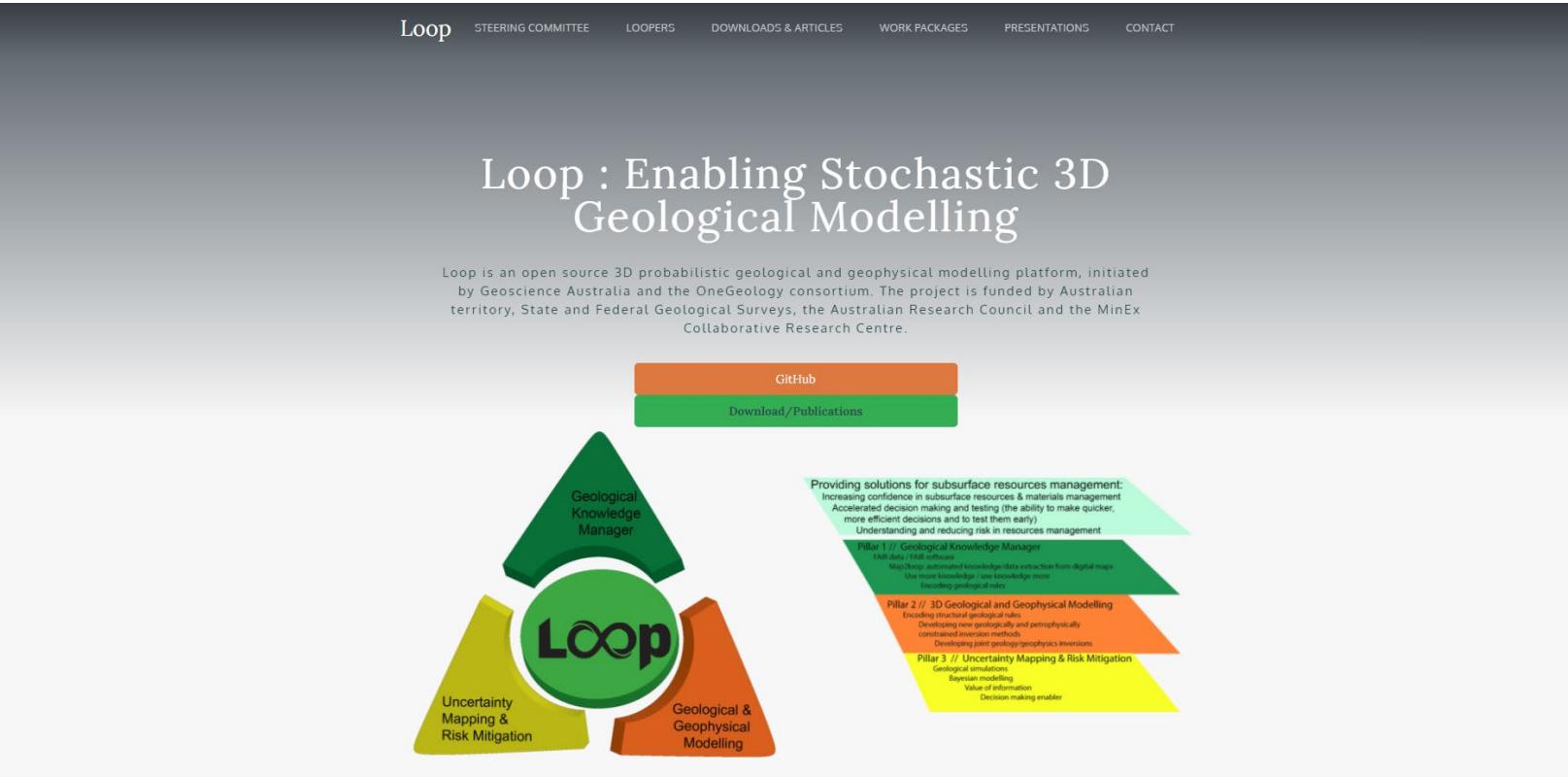
The Mid-Loop Meeting was held in early March 2020 in Busselton WA with 50 participants from across the globe. The meeting included 5 days of presentations and hand-ons workshops



Loop

# Happy memories from the virtual 2020/21 Loop sessions

The Loop team has presented at EGU, Roar, GA and provided a very well attended European Workshop in 2020/21. These are available on the Loop website – [loop3d.org](http://loop3d.org)



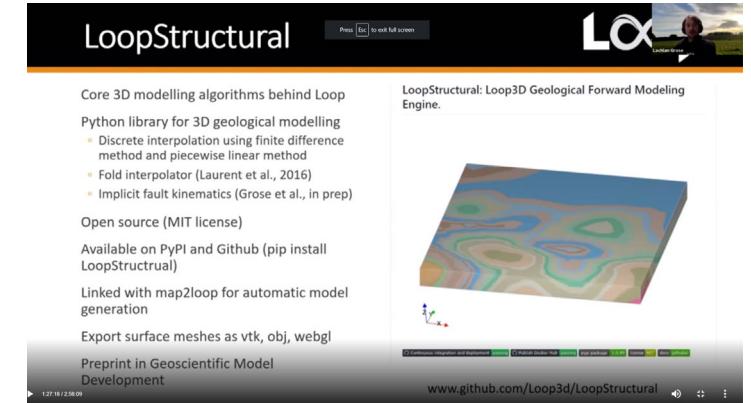
The screenshot shows the official Loop website. At the top, there's a navigation bar with links: Loop, STEERING COMMITTEE, LOOPERS, DOWNLOADS & ARTICLES, WORK PACKAGES, PRESENTATIONS, and CONTACT. Below the navigation, the title "Loop : Enabling Stochastic 3D Geological Modelling" is displayed in large, bold, white font. A detailed description follows, mentioning it's an open source 3D probabilistic geological and geophysical modelling platform initiated by Geoscience Australia and the OneGeology consortium, funded by Australian territory, State and Federal Geological Surveys, the Australian Research Council, and the MinEx Collaborative Research Centre. Two buttons are present: "GitHub" (orange) and "Download/Publications" (green). To the right, a diagram illustrates the three pillars of the Loop system: Geological Knowledge Manager (green), Geological & Geophysical Modelling (orange), and Uncertainty Mapping & Risk Mitigation (yellow). Each pillar is connected to a central green circle labeled "LOOP". A callout box provides more details about the Geological Knowledge Manager pillar.

Providing solutions for subsurface resources management:  
Increasing confidence in subsurface resources & materials management  
Accelerated decision making and testing (the ability to make quicker, more efficient decisions and to test them early)  
Understanding and reducing risk in resources management

Pillar 1 // Geological Knowledge Manager  
FAIR data / FAIR software  
Map3D: automated knowledge extraction from digital maps  
User interface technology / User interface design  
Encoding geological rules

Pillar 2 // 3D Geological and Geophysical Modelling  
Encoding structural geological rules  
Developing new geologically and petrophysically constrained inversion methods  
Developing new geophysical inversions

Pillar 3 // Uncertainty Mapping & Risk Mitigation  
Geological simulations  
Bayesian modelling  
Value of information  
Decision making enabler



The screenshot shows the LoopStructural page. It features a large "LoopStructural" logo at the top left. To the right is a video player showing a presentation slide titled "LoopStructural: Loop3D Geological Forward Modeling Engine." The slide contains text about the core 3D modelling algorithms, Python library, open source status, and linked map2loop. It also includes a 3D geological model visualization and a GitHub link: [www.github.com/Loop3d/LoopStructural](https://www.github.com/Loop3d/LoopStructural).



Loop

# Loop Papers and Conference presentations

## ▪Papers (new / paper status changed)

- Geoscientific Model Development – Special Issue: The Loop 3D stochastic geological modelling platform – development and applications (Laurent Ailleres coordinator)
  - de Kemp, E., 2021. Spatial Agents for Geological Surface Modelling. *Geosci. Model Dev. Discuss.*. <https://doi.org/10.5194/gmd-2021-66>
  - Giraud, J., Ogarko, V., Martin, R., Jessell, M., Lindsay, M., 2021. Structural, petrophysical and geological constraints in potential field inversion using the Tomofast-x v1.0 open-source code. *Geosci. Model Dev. Discuss.*, <https://doi.org/10.5194/gmd-2021-14>
  - Grose, L., Ailleres, L., Laurent, G., Jessell, M., 2021. LoopStructural 1.0 time aware geological modelling. *Geosci. Model Dev.*, **14**, 3915-3937. DOI: <https://doi.org/10.5194/gmd-14-3915-2021>
  - Grose, L., Ailleres, L., Laurent, G., Caumon, G., Jessell, M., Armit, R. 2021. Realistic modelling of faults in LoopStructural 1.0. *Geosci. Model Dev. Discuss.*, <https://doi.org/10.5194/gmd-2021-112>



# Loop Papers and Conference presentations

## ▪Papers (new / paper status changed)

▪Geoscientific Model Development – Special Issue: The Loop 3D stochastic geological modelling platform – development and applications (Laurent Ailleres coordinator)

- Jessell, M., Ogarko, V., Lindsay, M., Joshi, R., Piechocka, A., Grose, L., de la Varga, M., Ailleres, L., Pirot, G., 2021. Automated geological map deconstruction for 3D model construction. Geosci. Model Dev. Discuss., <https://doi.org/10.5194/gmd-2020-400>
- Joshi, R., Madaiah, K., Jessell, M., Lindsay, M., Pirot, G., 2021. dh2loop 1.0: an open-source python library for automated processing and classification of geological logs. Geosci. Model Dev. Discuss., <https://doi.org/10.5194/gmd-2020-391>



# Loop Papers and Conference presentations

## ▪Papers (new this quarter)

- Guo, J., Li, Y., Jessell, M., Giraud, J., Li, C., Wu, L., Li, F., Liu, S., 2021. 3D Geological Structure Inversion from Noddy-Generated Magnetic Data Using Deep Learning Methods. *Computers & Geosciences* (149), 2021, 10.1016/j.cageo.2021.104701.
- Hillier, M., Wellmann, F., Brodaric, B., de Kemp, E., Schetselaar, E., 2021. Three Dimensional Structural Geological Modelling using Graph Neural Networks. *Math. Geosci.*
- Ogarko, V., Giraud, J., Martin, R., Jessell, M., 2021. Disjoint intervals bound constraints using the alternating direction method of multipliers (ADMM) for geologically constrained inversions: application to gravity data. *Geophysics*, 86: G1-G11
- Giraud, J., Lindsay, M., Jessell, M., Ogarko, V., 2020. Towards plausible lithological classification from geophysical inversion: honouring geological principles in subsurface imaging, *Solid Earth*, 11, 419-436.
- Martin, R., Giraud, J., Ogarko, V., Beller, S., Gegout, P., Jessell, M., 2020. Three-dimensional gravity anomaly inversion in the Pyrenees using compressional seismic velocity model as structural similarity constraints. *Geophysical Journal International*, ggaa414

# Loop Papers and Conference presentations

## ▪Papers (new this quarter)

- Rashidifard, M., Giraud, J., Lindsay, M., Jessell, M., Ogarko, V. Constraining 3D geometric gravity inversion with 2D reflection seismic profile using a generalized level-set approach: application to Eastern Yilgarn craton. Solid Earth. 10.5194/se-2021-65

## ▪Submitted Papers

- Giraud, J., Lindsay, M., Jessell, M. Submitted. Generalisation of level-set inversion to an arbitrary number of geological units using a regularized least-squares approach. Submitted for publication in Geophysics.
- Lindsay, M., Occhipinti, S., Aitken, A., LaFlamme, C., Ramos, L., Submitted. Mapping undercover: integrated interpretation and 3D modelling of a Proterozoic basin. Solid Earth
- Pirot, G., Joshi, R., Giraud, J., Lindsay, M., Jessell, M. 3D geological modelling in the mining sector: challenges to improve prediction confidence. Geoscientific Model Development - Special Issue: The Loop 3D stochastic geological modelling platform – development and applications.
- Wang, N., Martin, R., Plazolles, B., Chevrot, S., Borisov, D., Ogarko, V., Giraud, J., Monteiller, V., Submitted. On the joint inversion of seismic waveforms and gravimetric anomalies. Geophysical Journal International



# Loop Papers and Conference presentations

## ■ EGU 2021 – Abstracts submission

- Hillier, M., Wellman, F., Brodaric, B., de Kemp, E., Schetselaar, E. Using Graph Neural Networks for 3-D Structural Geological Modelling. Proceedings: European Geophysical Union Annual Meeting 2021.

## ■ 2021 Presentations

- Brodaric, B. and Richard, S. (2021) Stratigraphic Knowledge and the GeoScience Ontology. MinEx Opportunity Fund Project 6 Workshop, 30 March 2021.
- Schetselaar, E. (2021) Lithostratigraphic encoding of drillhole data: a basic requirement for building 3D geological models. MinEx Opportunity Fund Project 6 Workshop, 30 March 2021.
- Brodaric, B. and Richard, S. (2021) The GeoScience Ontology. CGI-IUGS webinar, 23 June 2021.
- Brodaric, B., de Kemp, E., Hillier, M., Parquer, M., Russell, H. Enhanced Methods for National 3D Geological Modelling in Canada. US National Geological Mapping Forum, 28 Jan 2021.



# Loop Papers and Conference presentations

## ▪ Loopinars – Loop European Workshops March 2021 (presenter listed only)

- Ailleres, L. Loop – overall vision and progress
- Alvarado, F. Structural frames for modelling intrusions
- Brodaric, B. and Richard, S. The GeoScience Ontology.
- Chaarani, R. The value of structural data in folded domains
- Giraud, J. Level-set inversions method and application to the Yerrida greenstone beltGrose, L. LoopStructural – Structural frame for the geometrical modelling of polydeformed terranes
- Giraud, J. Use of prior information to constrain geophysical inversions in Tomofast
- Giraud, J. The future of inversions – Guided inversions and geology/geophysics inversions
- Heaven, R.E. Extracting Stratigraphic Knowledge from Text and Visualising in an Interactive Network Graph.
- Hillier, M. Using Graph Neural Networks for 3D Structural Geologic Modelling.
- Jessell, M. Map2loop – generating an augmented dataset from maps analysis for 3D structural modelling
- Joshi, R. dh2loop 1.0: an open-source python library for automated processing and classification of geological logs
- Lindsay, M. Reducing uncertainties: data quantity versus data precision
- Lindsay, M. Regional mineral exploration and calculation of the value-of-Information
- Montsion, R. Structural complexity from the interpretation of geophysical data



# Loop Papers and Conference presentations

## ■ Loopinars – Loop European Workshops March 2021 (presenter listed only)

- Parquer, M. Automated 3D Geological Consistency Checking.
- Pirot, G. Propagation of Pilot-Stick Perturbations through different geological modelling engines – how does it influence uncertainty assessment?
- Pirot, G. Reducing epistemic uncertainty related to sparse spatial data with Pilot-Stick Perturbations
- Rashidifard, M. Using sparse seismic and small-scale morphological constraints in level-set inversions
- Suriyaarachchi, N. Passive seismic derived geological constraints for MT inversions
- Thomson, R. The Loop GUI

# Loop Papers and Conference presentations

## ▪ AESC 2021 – Hobart Online

- Ailleres, L., Grose, L., Caumon, G., Jessell, M. LoopResources – Reducing the Mining Footprint
- Grose, L., Ailleres, L., Laurent, G., Jessel, M. LoopStructural 1.0 time aware geological modelling (Keynote)
- Jessell, M., Ogarko, V., Lindsay, M., Joshi, R., Piechocka, A., Grose, L., de la Varga, M., Fitzgerald, D., Aillères, L., Pirot, G. Reproducible 3D model construction using map2loop
- Lindsay, M., Pirot, G., Jessell, M., Giraud, J., Scalzo, R., Cripps, E., Aitken, A. Geophysical Data Optimisation for Modelling: Data collection in a value-of-information framework
- Lindsay, M., Richard, S., Brodaric, B., Giraud, J., de Kemp, E., Jessell, M. The “Loop” knowledge manager: property retrieval and geophysical modelling
- Moro, P., Giraud, J., Ogarko, V., Jessell, M. Lithospheric structure of the Kidson reflection seismic line 18GA-KB1 (Western Australia) from 2D multi-constrained gravity inversion
- Pirot, G., Lindsay, M., Grose, L., de La Varga, M., Jessell, M. Propagation of data and algorithmic uncertainty based on borehole calibration and perturbation – a sensitivity analysis



# Loop Papers and Conference presentations

## ▪ AESC 2021 – continued

- Pirot, G., Lindsay, M., Jessell, M. Optimization of sequential drilling locations to reduce geological uncertainty
- Rashidifard, M., Giraud, J., Lindsay, M., Jessell, M., Ogarko, V. Constrained Gravity Geometry Inversion with Reflection Seismic Section (Keynote)
- Rashidifard, M., Giraud, J., Ogarko, V., Lindsay, M., Jessell, M. How to computationally include regional interpretations into the seismic imaging process.
- Suriyaarachchi, N., Giraud, J., Seille, H., Jessell, M., Lindsay, M., Hennessy, L., Ogarko, V. A new approach to integrate passive seismic HVSR depth models in magnetotelluric (MT) 1D inversion to characterize the cover-basement interface
- Giraud, J. Lindsay, M., Jessell, M. Morphological gravity inversion to refine geological models

# Loop Papers and Conference presentations

## ■ AGU Fall Meeting 2020 – Online

- Ailleres, L., Jessell, M., deKemp, E., Caumon, G., Grose, L., Welmann, F., Armit, R., Brodaric, B., Loop: an Integrated and Interoperable Platform Enabling 3D Stochastic Geological and Geophysical 3D Modelling
- Alvarado, F., et. al., Modelling of Igneous Intrusions Based on Emplacement Mechanisms
- Brodaric, B. and Richard, S.M. The GeoScience Ontology.
- Chaarani, R., et al., The effect of structural data distributions on 3D fold geometries
- Giraud, J., Pirot, G., Jessell, M., Lindsay, M. Recovering lithology geometries via geophysical data inversion based on a generalized level set approach.
- Grose, L., et al., LoopStructural 1.0: Time aware geological modelling
- Lindsay, M., Occhipinti, S., LaFlamme, C., Aitken, A., Ramos, L.N.R.A. Mapping Undercover: Using Integrated Potential Field Interpretation, Inversion and 3D Modelling to Assess Basin Prospectiveity
- Parquer, M., de Kemp, E., Brodaric, B., Hillier, M. Automated 3D geological consistency checking: a geomodelling tool.



# Loop Papers and Conference presentations

- AGU Fall Meeting 2020 – continued

- Pirot, G., Lindsay, M., Grose, L., Jessell, M. A sensitivity analysis of geological uncertainty to data and algorithmic uncertainty
- Rashidifard, M. Giraud, J. Lindsay, M., Jessell, M., Ogarko., V. Constrained Gravity Geometry Inversion with Sparse Low-Uncertainty Data.

- Other presentations

- Suriyaarachchi, N., Giraud, J., Seille, H., Jessell, M., Lindsay, M., Hennessy, L., Ogarko, V., 2020. Integration of Magnetotellurics (MT) and Passive seismic data to characterize cover depth, MinEx CRC annual conference 2020.
- Rashidifard, M., Giraud, J., Ogarko, V., Jessell, M., Lindsay, M., 2020. Integrated Inversion/Modelling of Gravity Data and Reflection Seismic Data with Different Spatial Coverage, Invited speaker at ASEG Tech Night.
- Ailleres, L., Nov 2020 - Amira Global ROAR 1010 2020 - LoopResources - Reducing the Mining Footprint
- Jessell, M., Nov 2020 - Amira Global ROAR 1010 2020 - map2loop - Automated map deconstruction for 3D models
- Ailleres, L., Aug 2020. Loop – an integrated, interoperable platform enabling 3D stochastic geological modelling, Geoscience Australia Public Talk.



# Loop Papers and Conference presentations

## ▪ Other presentations ct'd

- Giraud, J., Lindsay, M., Jessell, M., Ogarko, V., 2020. Towards plausible lithological classification from geophysical inversion: honouring geological principles in subsurface imaging, SEG 2020 Annual meeting (workshop 10: Machine Learning/Artificial Intelligence in Mineral Exploration)

## ▪ Conference Extended papers 2019-2020

- Jessell, Mark Lindsay & Vitaliy Ogarko. 2020. Loop 3D geological modelling: speeding up the workflow. GSWA Open Day extended Abstract, Feb 2020.
- Giraud, J., Lindsay, M., Ogarko, V., and Jessell, M., Sensitivity of constrained geophysical inversion to geological input measurement uncertainty. Extended Abstract, EAGE Annual Meeting London 2019.

## ▪ EAGE “3rd Conference on Geophysics for Mineral Exploration and Mining” 2020 – Submitted

- Giraud, J., Seille, H., Visser, G., Ogarko, V., Lindsay, M., Jessell, M. Utilisation of stochastic MT inversion results to constrain gravity inversion, extended abstract.
- Rashidifard, M., Giraud, J., Ogarko, V., Jessell, M., Lindsay, M. Cooperative inversion of seismic and gravity using a weighted structure-based constraint, extended abstract



# Loop Papers and Conference presentations

## ■ EGU General Assembly 2020

- Caumon, G., Godefroy, G., Marchal, P., 2020. Fault network uncertainty assessment with a generative graph-based algorithm – Current status and perspectives.
- Collon, P., Rongier, G., Parquer, M., Clausolles, N., Caumon, G., 2020. Uncertainty assessment in subsurface modeling: considering geobody shape and connectivity in complex systems
- de la Varga, M., Wellmann, F., 2020. Probabilistic Machine Learning in Structural Geology
- Giraud, J., Seillé, H., Visser, G., Lindsay, M., Jessell, M., 2020, Utilisation of stochastic MT inversion results to constrain potential field inversion, <https://doi.org/10.5194/egusphere-egu2020-15067>
- Grose, L., Laurent, G., Ailleres, L., 2020. Using structural frames to integrate structural geology into implicit 3D modelling
- Rashidifard, M., Giraud, J., Ogarko, V., Lindsay, M., Jessell, M., 2020, Cooperative inversion of gravity and seismic data with different spatial coverage



# Loop Papers and Conference presentations

## ■ RING 2019

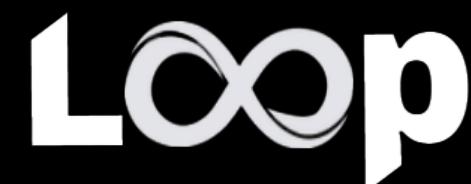
- Grose et al., Fault modeling kinematics

## ■ AEGC 2019

- Grose et al., Integrating fault kinematics into implicit 3D modeling of fault networks

## ■ SGTSG, 2019

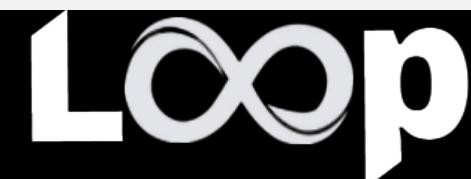
- Ailleres et al., overview of the Loop project
- Lindsay, M., Spratt, J., Aitken, A.R.A., Occhipinti, S., Dentith, M. (2019) A multiscale investigation of a gold mineral system in the eastern Yilgarn SGTSG2019
- Giraud, J., M. Lindsay, V. Ogarko, M. Jessell, Geology and geophysics-based lithological classification for structural interpretation in the Yerrida basin (Western Australia), SGTSG
- Giraud et al., Integration of geology and geophysical inversions
- Grose et al., Fault modelling using kinematics
- Joshi et al., Multiscale 3D geological modelling



# Loop Papers and Conference presentations

- **Other & Reports (new)**

- Brodaric, B. and Richard, S.M. (2021) The GeoScience Ontology Reference; Geological Survey of Canada, Open File 8796, 34 p. <https://doi.org/10.4095/328296>
- Brodaric, B., Richard, S., 2021. The GeoScience Knowledge Manager Release 1.0. <https://github.com/Loop3D/GKM>
- Brodaric, B. and Richard, S.M. (2021) The GeoScience Ontology Release 1.0.2; Zenodo, 11 May 2021. <https://doi.org/10.5281/zenodo.4750707>
- Lindsay, M.D., Jessell, M.W., Pirot, G., Giraud, J. 2020 Optimising the Collection of Geoscientific Data with Uncertainty Analysis, AOGS, Hongcheon, S. Korea
- Lindsay, M., Occhipinti, S., Aitken, A., LaFlamme, C., Ramos, L., 2020, Mapping Undercover: Using Integrated Potential Field Interpretation, Inversion and 3D Modelling to Assess Basin Prospective, 2020, AOGS, Hongcheon, S. Korea
- Lindsay, M.D., Jessell, M.W., Pirot, G., Giraud, J., 2020, Just add data: if only it were that simple Target2020, Perth, Western Australia
- Lindsay, M.D., Spratt, J., Aitken, A.R.A., Occhipinti S.A., Dentith, M., Shragge, J. 2020 An Integrated Multi-Scale Study of Crustal Structure and Prospective of the Eastern Yilgarn Craton and Adjacent Albany-Fraser Orogen, MRIWA Report 476, p.180
- Pirot, G., Joshi, R., Jessell, M., Lindsay, M., 2020. From geological data and historical scenarios to conceptual models, Subsurface 2020 conference



# Loop Visitors

## Visitors to CET

- Damien Ciolczyk, MSc Eng. Student doing internship remotely School and Observatory of Earth Sciences (Strasbourg, France), to perform joint geologically constraints geophysical modelling using Loop tools. Project Completed.
- Roland Martin (CNRS/Université Paul Sabatier, Toulouse, France) visited from 16 to 27th March. Focus on applying techniques developed in inversion platform Tomofast-x.
- Ashwani Prabhakar: 3 month internship to work on testing TOMOFASTx inversion codes (WP5) Complete, draft manual available.
- Clement Barriere: 2 month internship to work on TOMFASTx code. Jupyter notebook version of 2D tomofast near completion.
- Li Zhen Cheng: 6 month visiting scholar to work on integrated geology/geophysics inversion (WP5)
- Jiateng Guo: 12 month visiting scholar to work on building massive 3D database for 3D models and their geophysical response for Machine Learning
- Prototype map2model code allows fully automatic 3D model construction from geological maps (Mark Jessell & Vitaliy Ogarko), with internal UWA workshop held in Feb 2020 as preparation for Busselton workshop
- The UWA Loop group was part of a research collaboration that has been awarded a \$10M grant to build a graduate school in Data Analytics for Resources and Environments (DARE), the project will be led by Prof Sally Cripps and will have multiple hubs with the lead at Sydney University.
- Nishka Piechocka to work part-time at UWA in 2020 on building a 3D model of the Hamersley Basin using Loop technologies thanks to new MRIWA funding for a CSIRO-led project.



# Loop Github content

- Richard, S.M. (2020) Loop3D GeoScience Ontology, Loop3D Technical Report.  
<https://github.com/Loop3D/GKM/blob/master/Draft1.1Report.docx>.
- LoopStructural: The geometric and structural geology ruled modelling engine of Loop  
<https://github.com/Loop3D/LoopStructural>
- map2loop: Automated analysis of geological maps and data augmentation for input into LoopStructural  
<https://github.com/Loop3D/map2loop-2>
- dh2loop: Automated extraction of consistent lithologies code/names along drill holes <https://github.com/Loop3D/dh2loop>
- GeoSwarm: Spatial agents scalar and vector fields interpolator <https://github.com/Loop3D/GeoSwarm>
- Uncertainty indicator draft package (a collection of notebooks to illustrate the various indicators)  
<https://github.com/Loop3D/uncertaintyIndicators>

