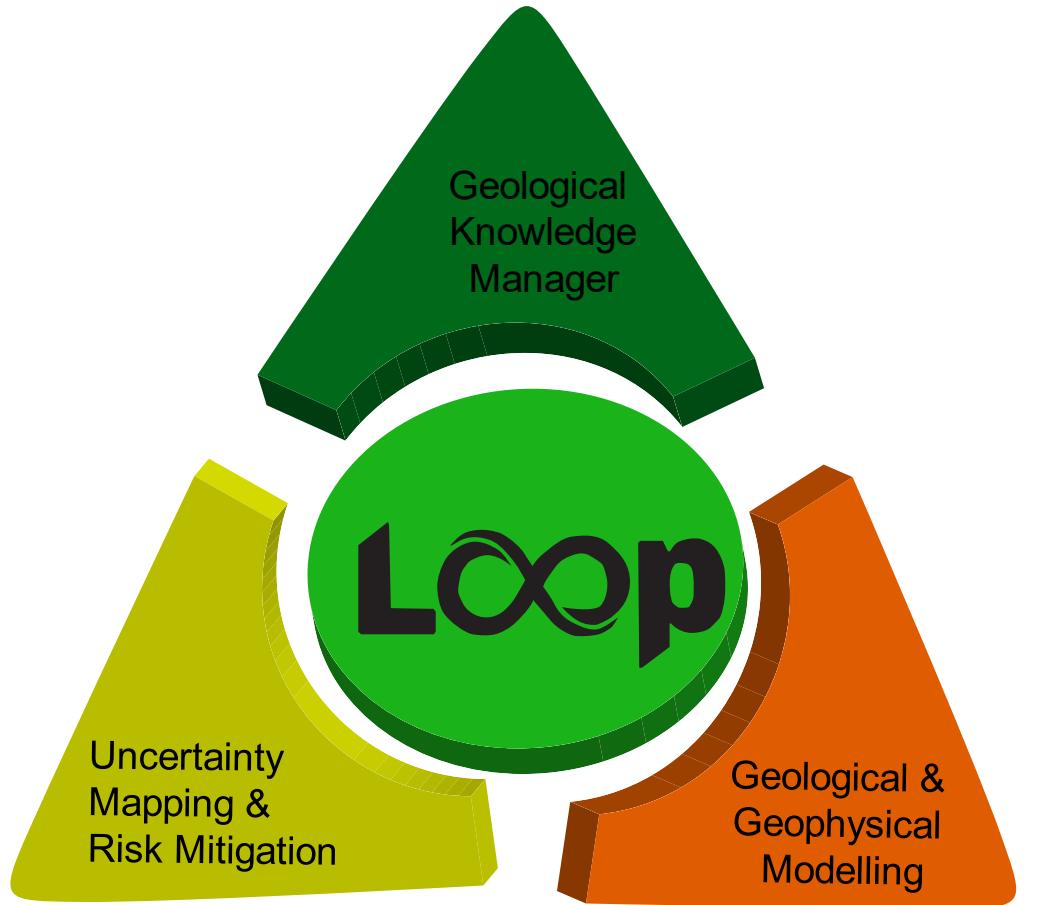


An integrated and interoperable platform enabling
3D stochastic geological modelling

Quarterly Report #9

Feb2021



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

CANADA
GEOSURVEY - COMMISSION GÉOLOGIQUE

MinEx CRC

AngloAmerican

100
YEARS

MICROMINE

BHP

Providing geoscience data globally

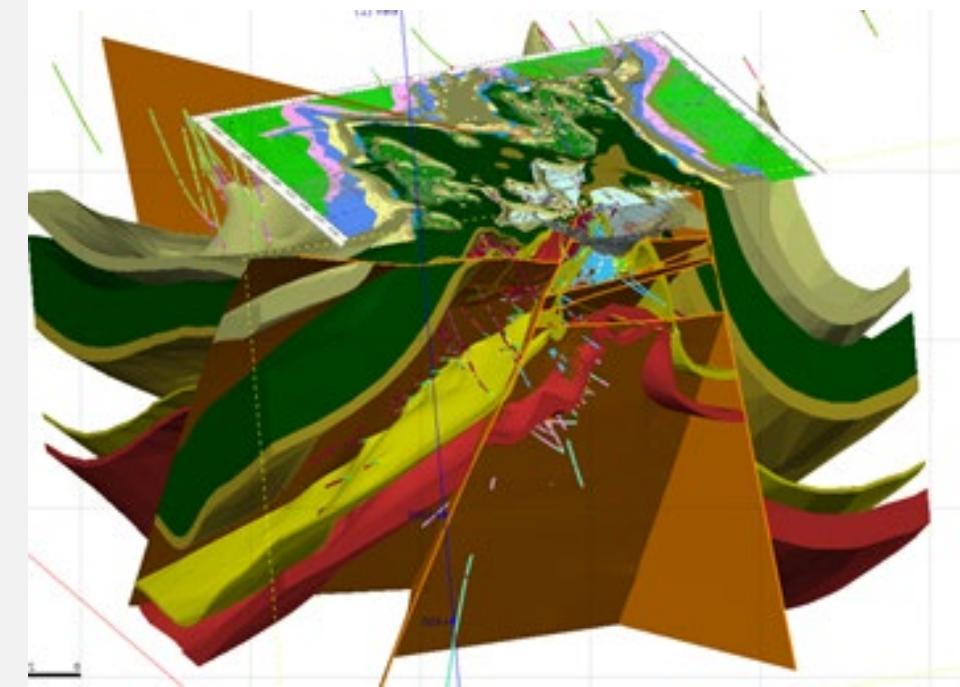
Loop – Why a new platform?

- 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

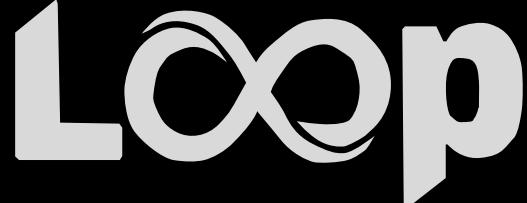
This can only happen through automatisation of the modeling workflow

- **Open-source is the future**

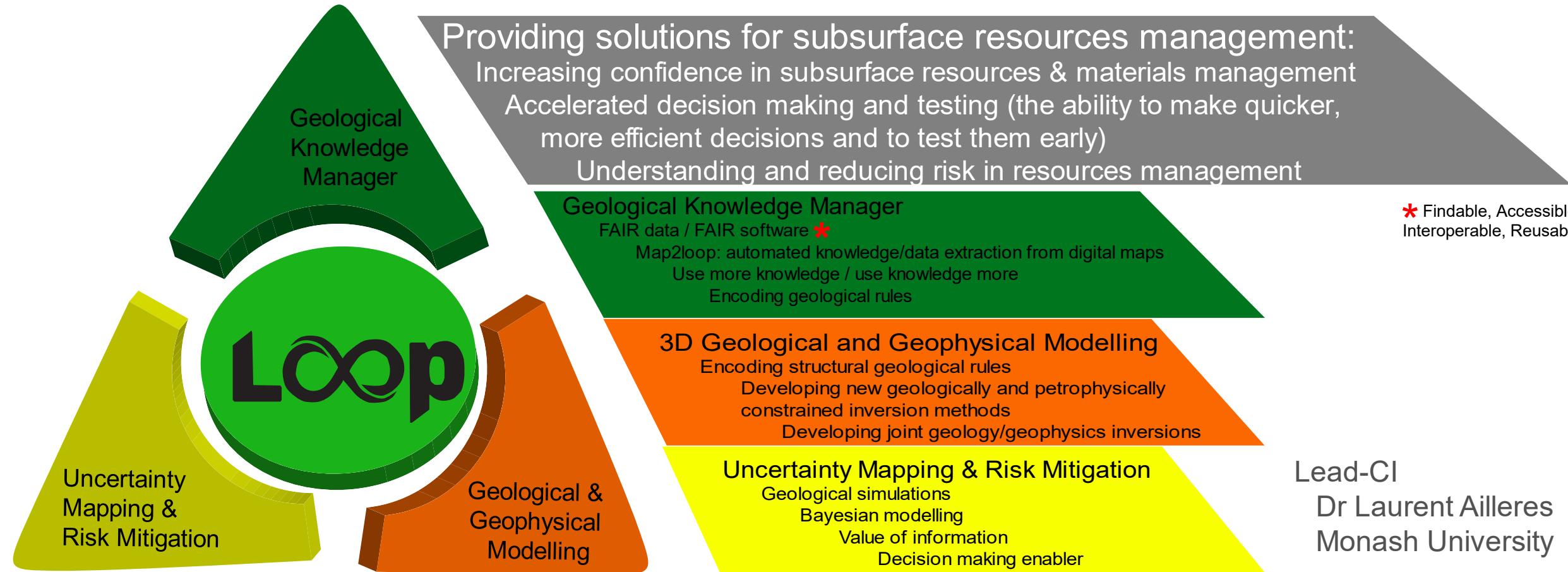
<https://github.com/Loop3D/LoopStructural>



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



RWTH AACHEN
UNIVERSITY



AuScope



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



100 YEARS



CANADA
GEOSURVEY
COMMISSION GÉOLOGIQUE DU CANADA



BHP

Providing geoscience data globally

Research Organisations



British
Geological Survey
Expert | Impartial | Innovative



Australian Government
Geoscience Australia



Funding Organisations (cash & in-kind)



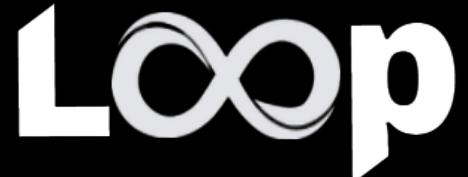
ARC LP170100985



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

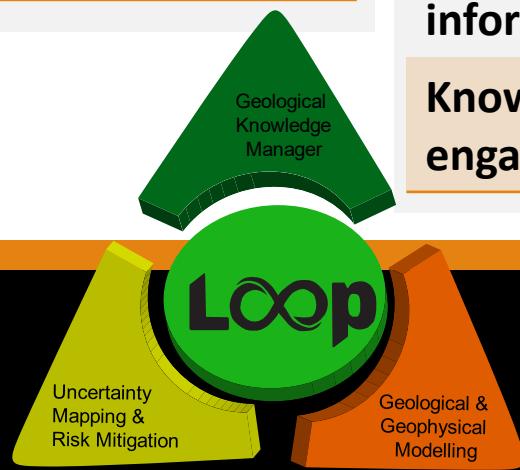
Governance

One Steering Committee:

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

Research and Development team:

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



Loop

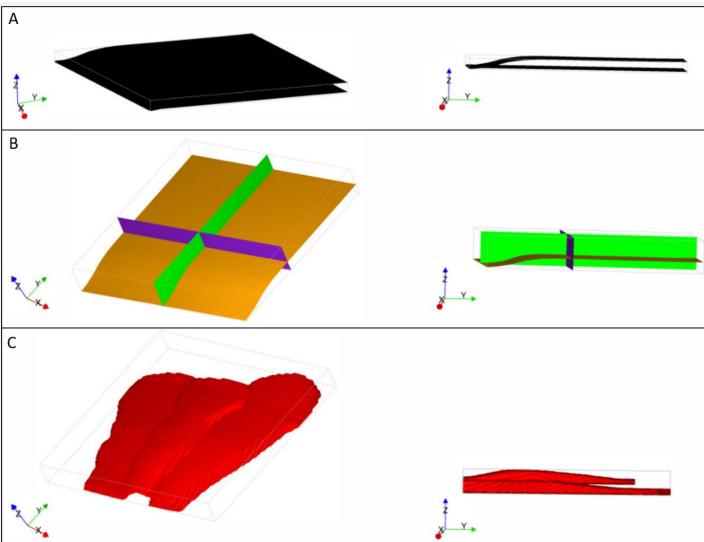
Highlights this Quarter

- ARC LP200301341 – “Enabling Interoperable, Integrated & Probabilistic 3D Geological Modelling”:
 - submitted in Dec 2020.
 - Three very positive assessments received in March 2021 and a rejoinder submitted.
 - The new grant includes all current partners (**Monash, UWA, GA, GSWA, NTGS, GSSA, GSNSW, GSC, BGS, RWTH Aachen, RING – Universite de Lorraine and Auscope**) and welcomes new partners including ALL Federal, State and Territory Australian geological survey organisations (**+GSQ, MRT and GSV**), the **USGS, AARNet, Universite d'Orleans - France, CSIRO & Uni Sydney**. The **BRGM** is an unofficial partner.
- March 15/16: a series of 3 Loopinars offered on European time with 180+ registered participants. Video recordings available on loop3d.org->presentations
- The MinEx CRC has **awarded** Project 6 (Automated 3D Geological Modelling) **an additional AU\$540K** to fund a three-year extension project: Recovery of Lithological and Stratigraphic Data from Drillhole Databases. This will fund a Postdoc at UWA and a Programmer at DataCode, India, to develop open source algorithms automating the extraction of lithological and stratigraphic data from new and legacy drill hole data. This project is a partnership of the Loop Consortium.

Congratulations to: Mark Jessell and S. Karunakar Rao (DataCode, India), Dr Mark Lindsay, UWA; Ms Kavitha Madaiah, UWA; Dr June Hill , CSIRO; Dr Rian Dutch, GSSA; Dr Simon van der Wielen (GA); Dr Klaus Gessner & Sarah Sargent, GSWA; Dr Giovanni Spampinato, GSNSW and Dr Tim Rawling, AuScope

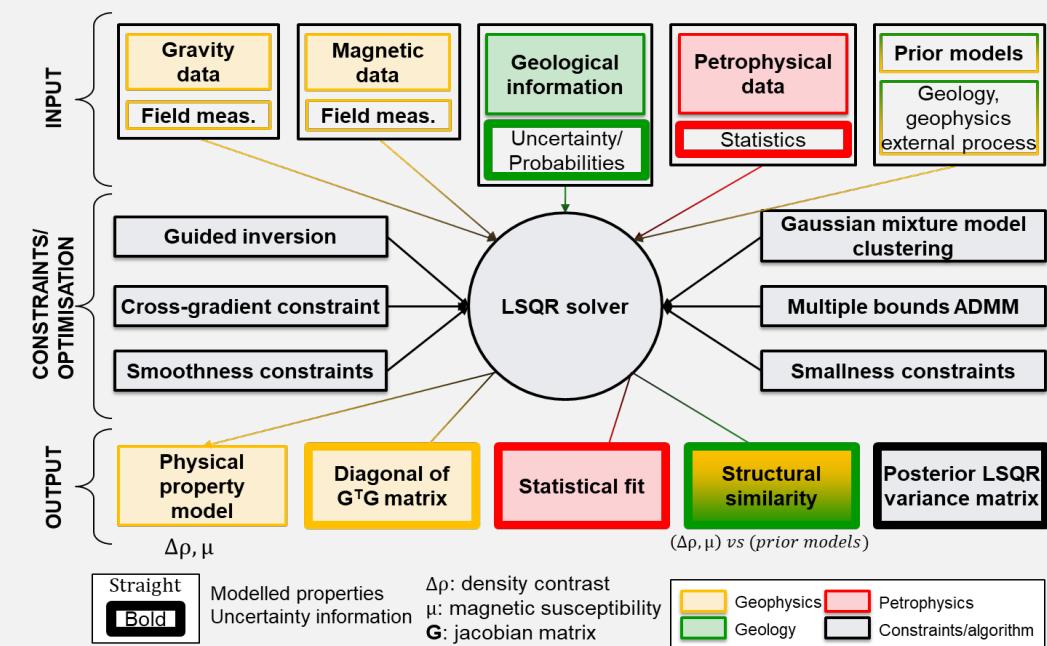


Highlights this Quarter



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

Tomofast-x functionalities summary



Funding and Resources

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

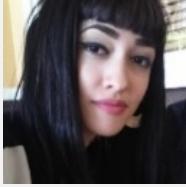
- Monash Uni: Laurent Ailleres, Robin Armit, Peter Betts, Sandy Cruden, Tiangang Cui, Jerome Droniou
- UWA: Mark Jessell, Mark Lindsay (now a DECRA Fellow)
- RING – Nancy, FRA: Guillaume Caumon
- RWTH Aachen, GER: Florian Wellmann
- GS of Canada: Eric de Kemp
- BGS - UK: Matthew Harrison (**now with 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

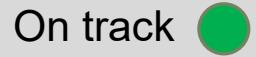
WP #0 – Infrastructure // Software Development

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

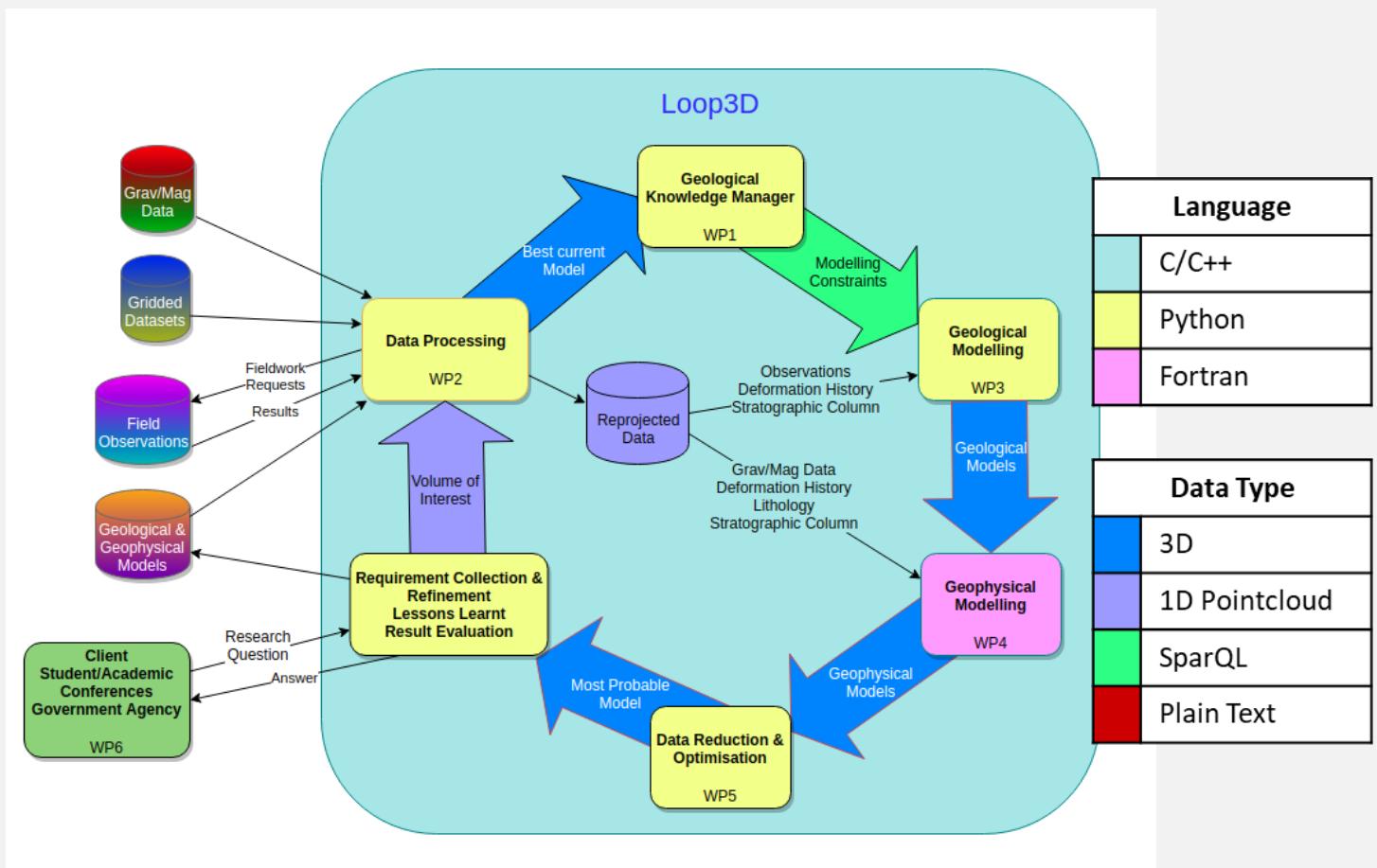
Problem

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)
- 13. Implementation of parallel processing of python modules within GUI including optimisation
- 14. Full access to configuration options of Data Collection and Geological Modelling steps within GUI
- 15. Demonstration and first release of GUI software in mid March 2021

WP #0 – Infrastructure // Software Development



Loop Workflow

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

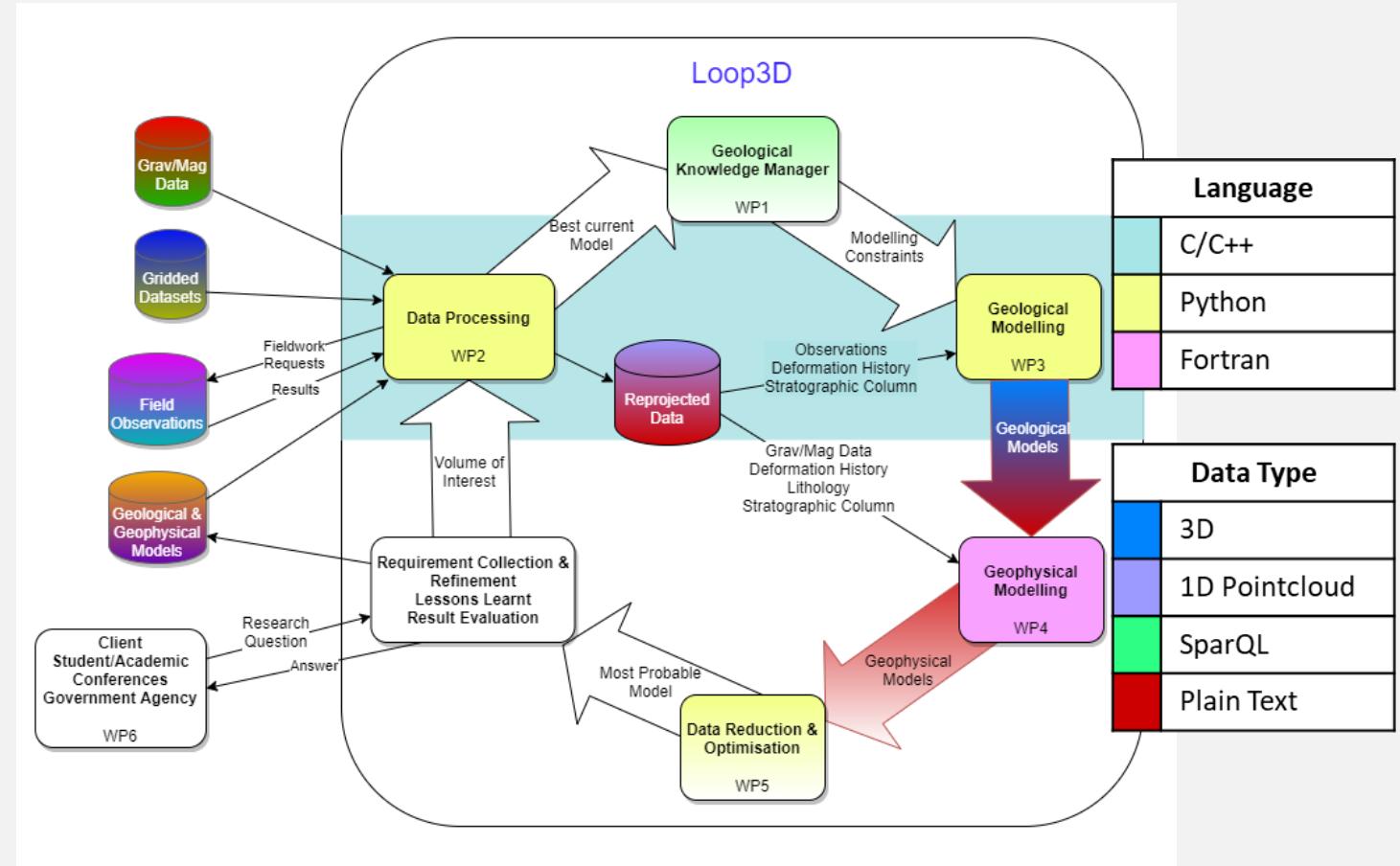
Loop

WP #0 – Infrastructure // Software Development

Implemented Workflow

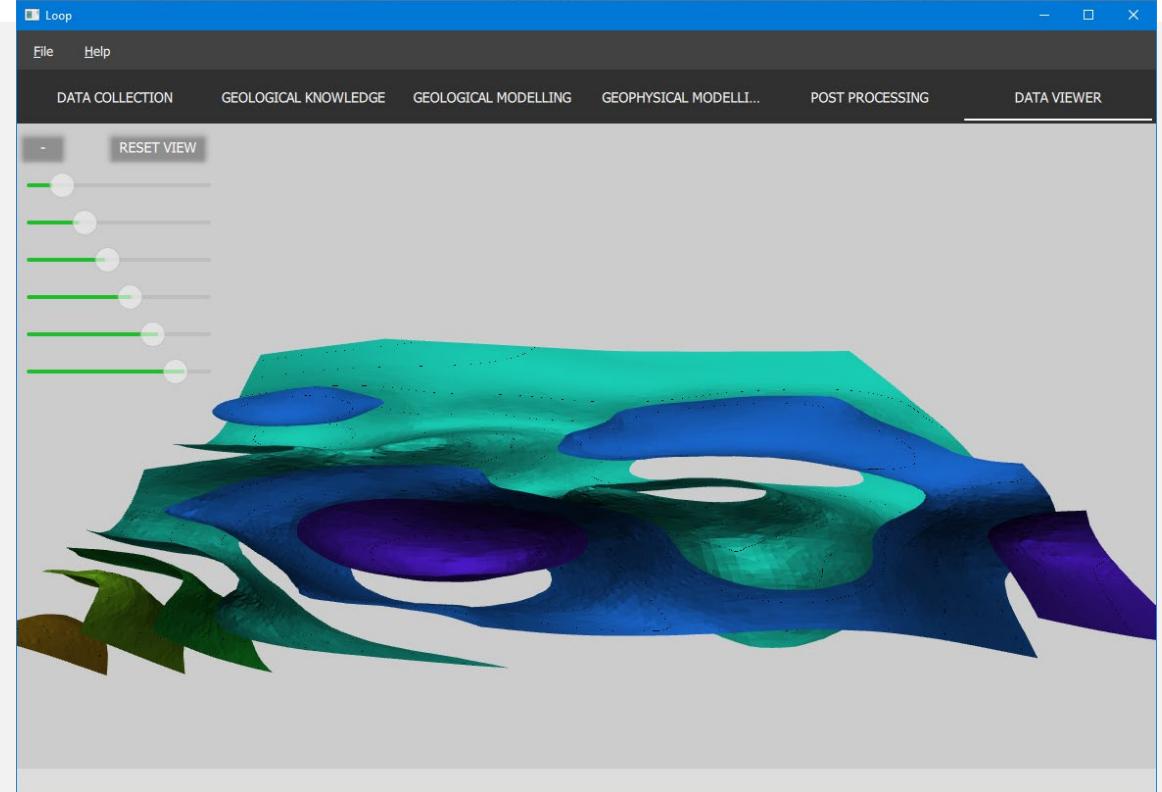
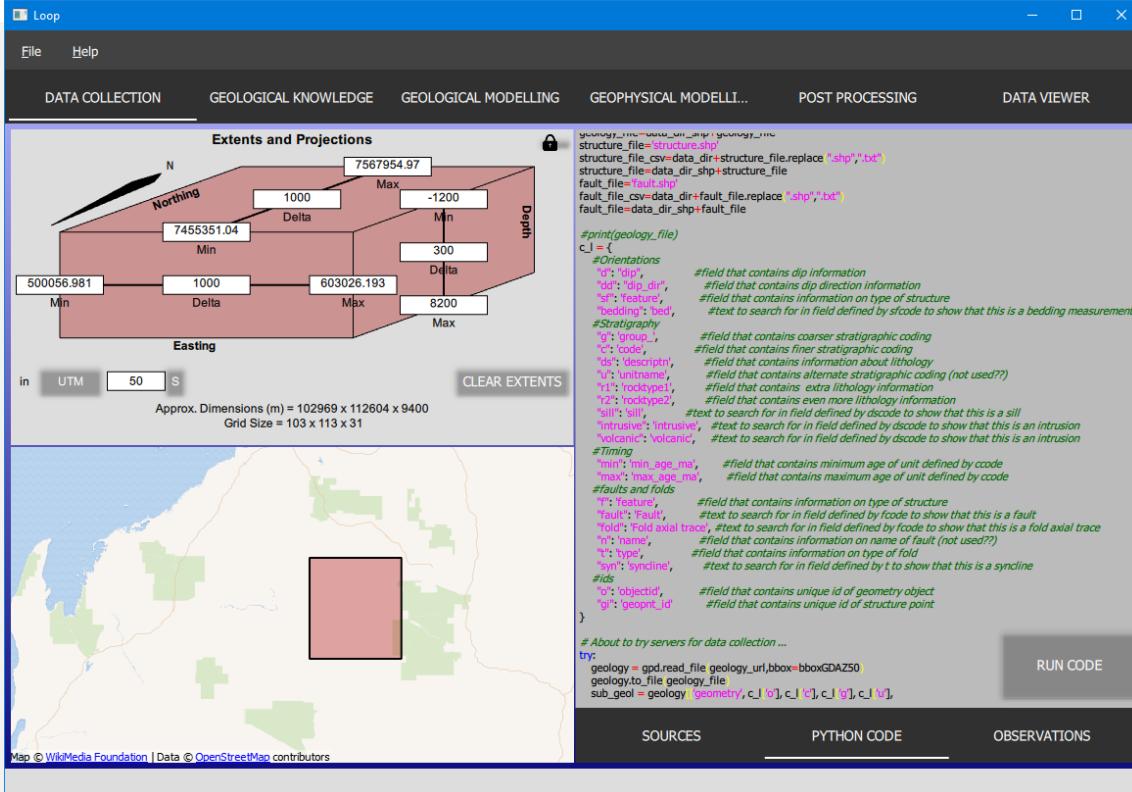
Python version of NetCDF data structures completed

Further progress towards inclusion of WP1 & WP5



Loop

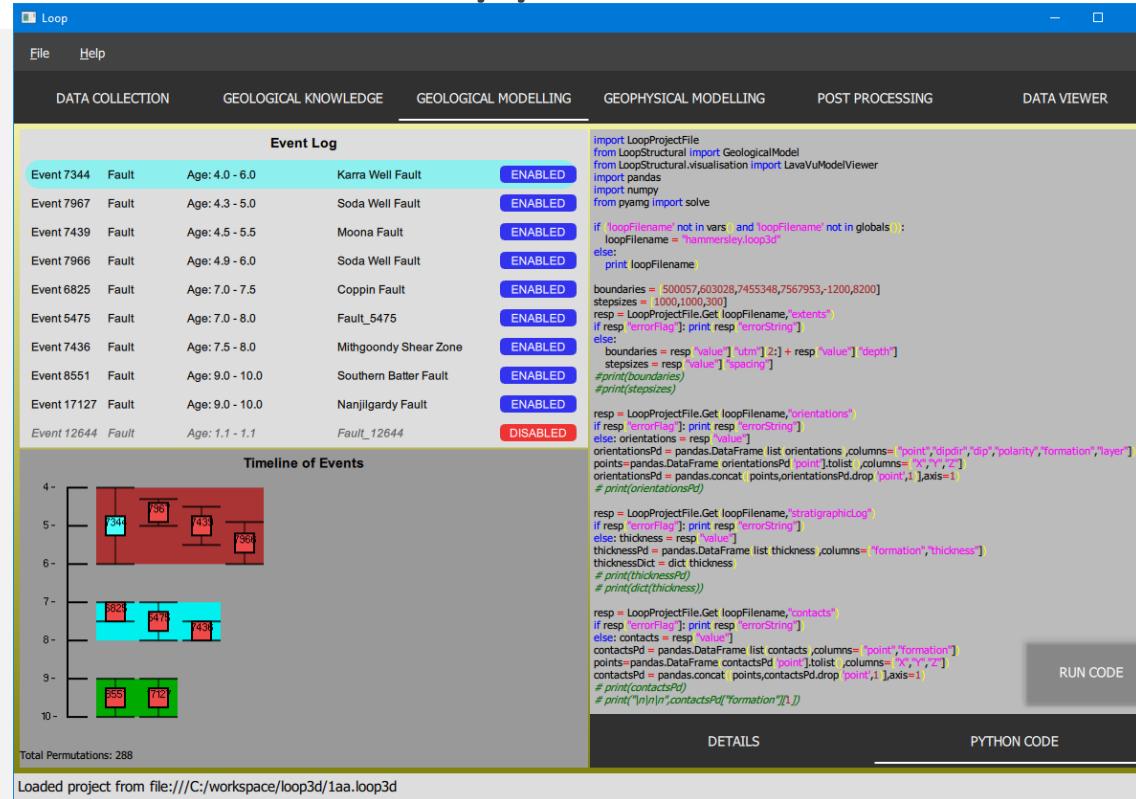
WP #0 – Infrastructure // Software Development



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

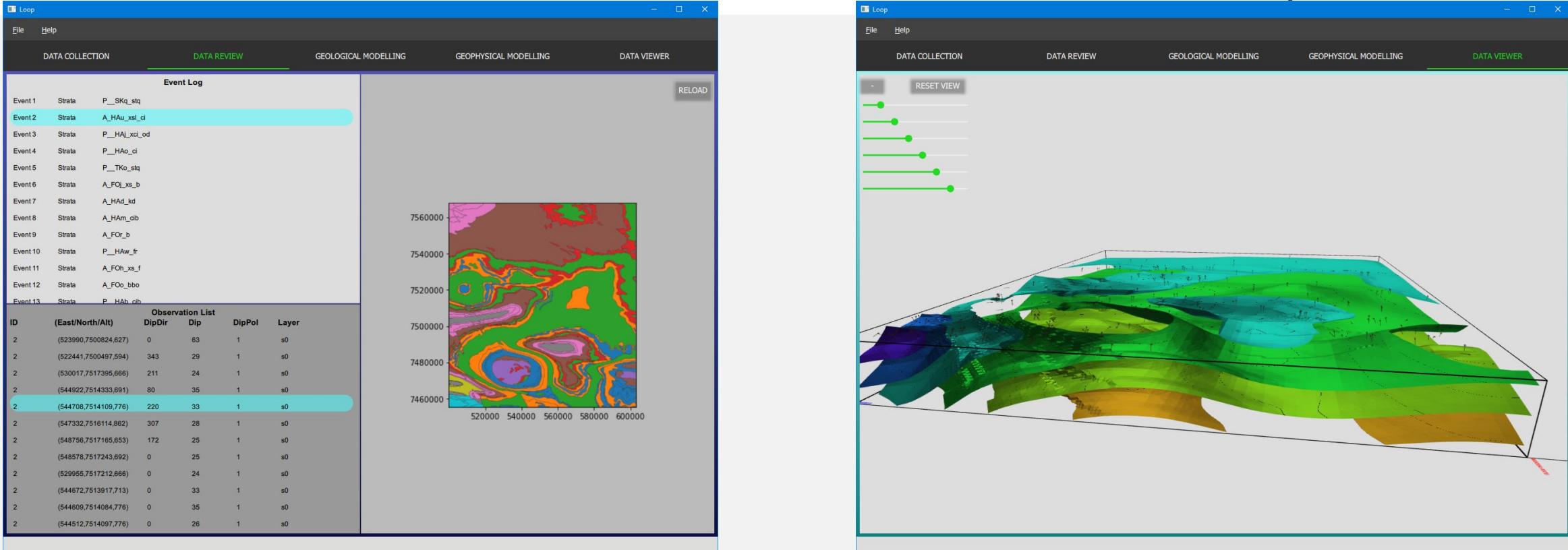
WP #0 – Infrastructure // Software Development



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



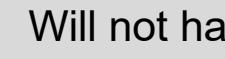
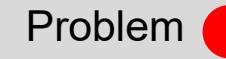
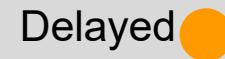
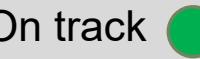
GUI Image showing first pass of data review/update UI as well as an updated 3D viewer of the same region with observation arrows

Loop

WP #1 – Geoscience Knowledge Manager

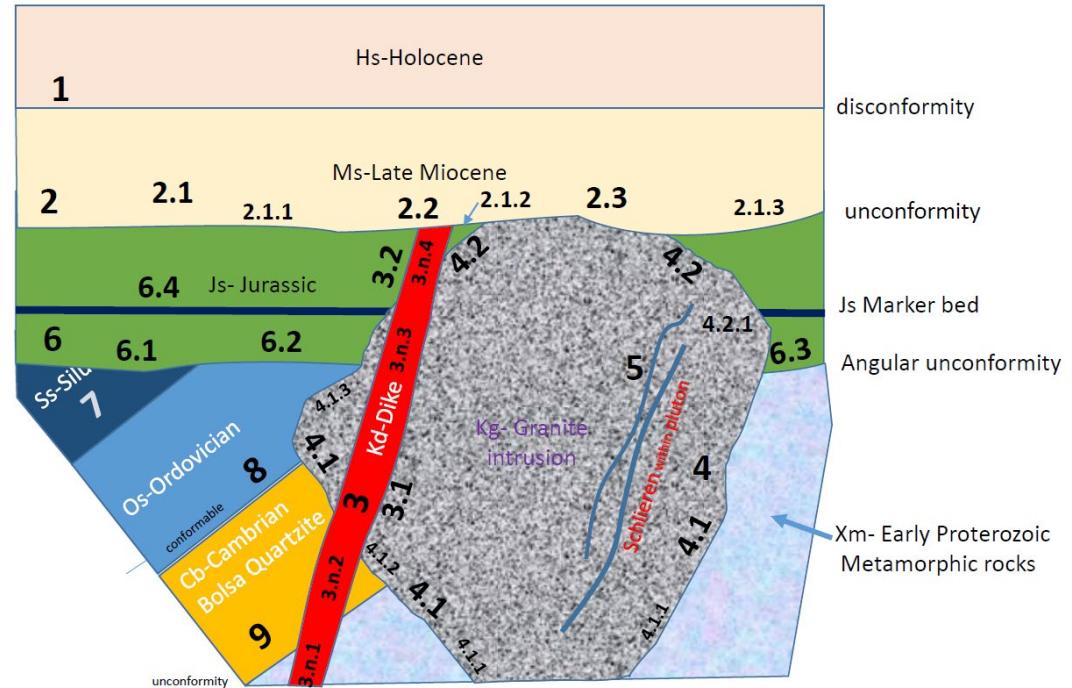
Is work on track against plan? update all deliverables

Work completed



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

WP #1 – Geoscience Knowledge Manager



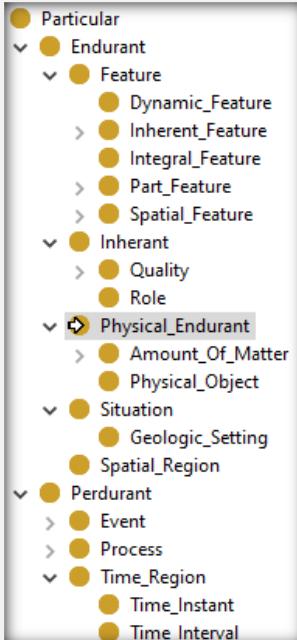
```
ejs:JsFormation
  rdf:type geo:Formation;
  rdfs:label 'Js Formation';
  rdfs:comment 'upper part is massive limestone';
  geo:hasTemporalProperty [
    rdf:type geo:Chronostratigraphic_Age;
    geo:hasYoungerAge
      tim:Lower_Jurassic_Epoch;
    geo:hasOlderAge
      tim:Lower_Jurassic_Epoch
  ];
  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 smrTucson@gmail.com
Boyan Brodaric, Geological Survey of Canada boyan.brodaric@canada.ca

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GSO documentation v1

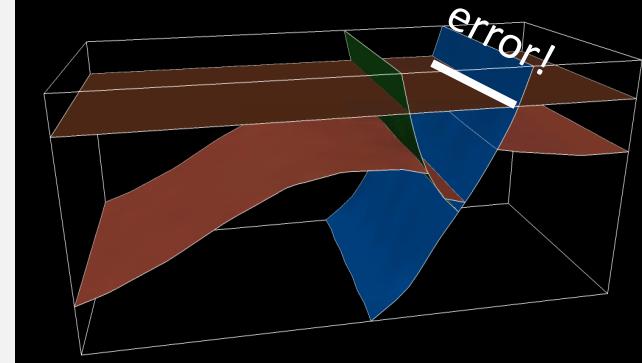
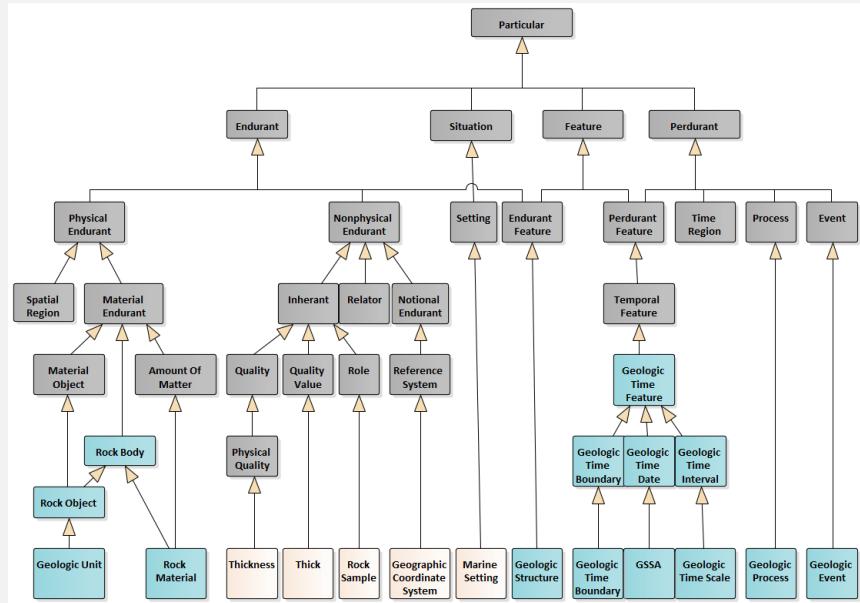
Task 4: progress on GSO development – refinements made post-LOOP workshop Mar 2020; v1 document draft.

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

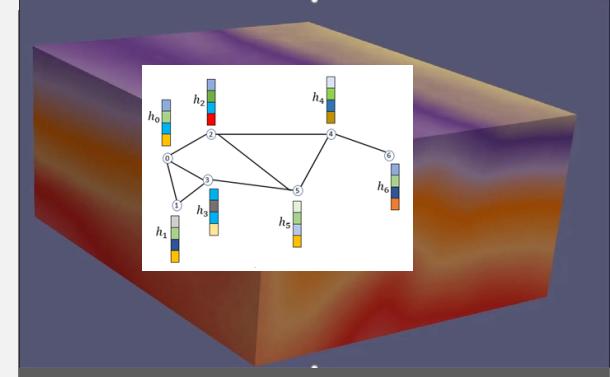
Task 6: evaluate GKM access and explore *usage scenarios* – **petrophysical** testing scenario in progress.



WP #1 – Geoscience Knowledge Manager



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.

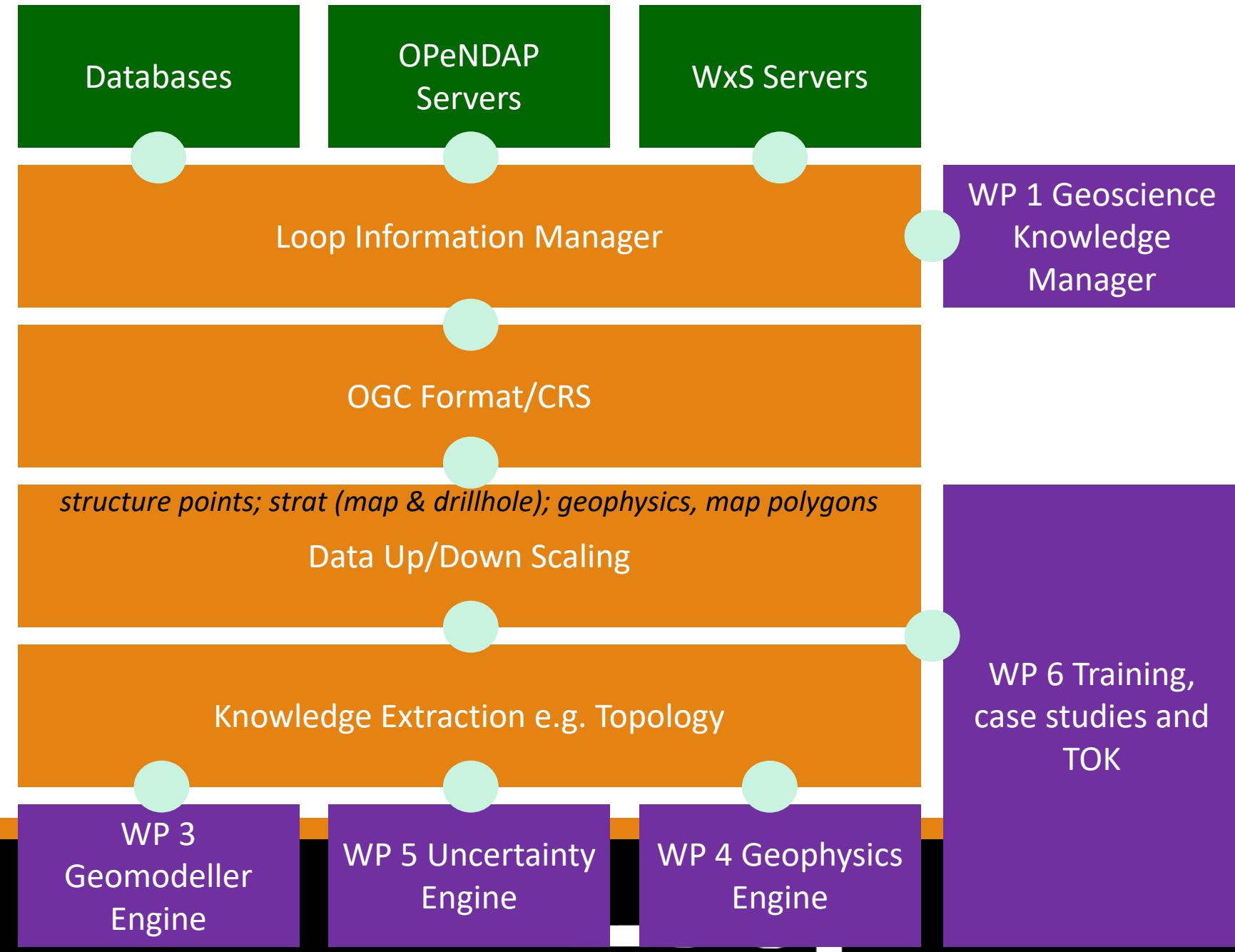
WP #2 – Data Pre-Processing & input

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

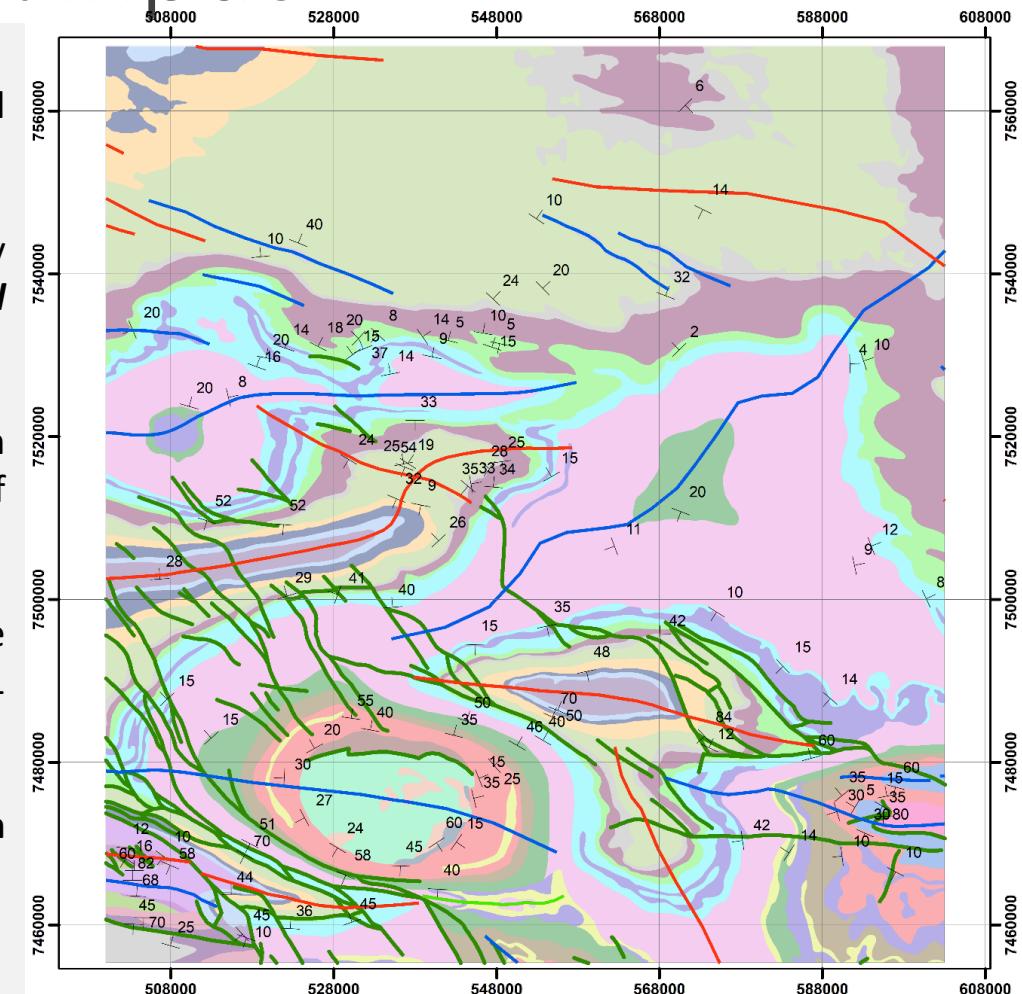
WP #2 – Data Pre-Processing & input



WP #2 – Data Pre-Processing & input

Map2loop proof of concept

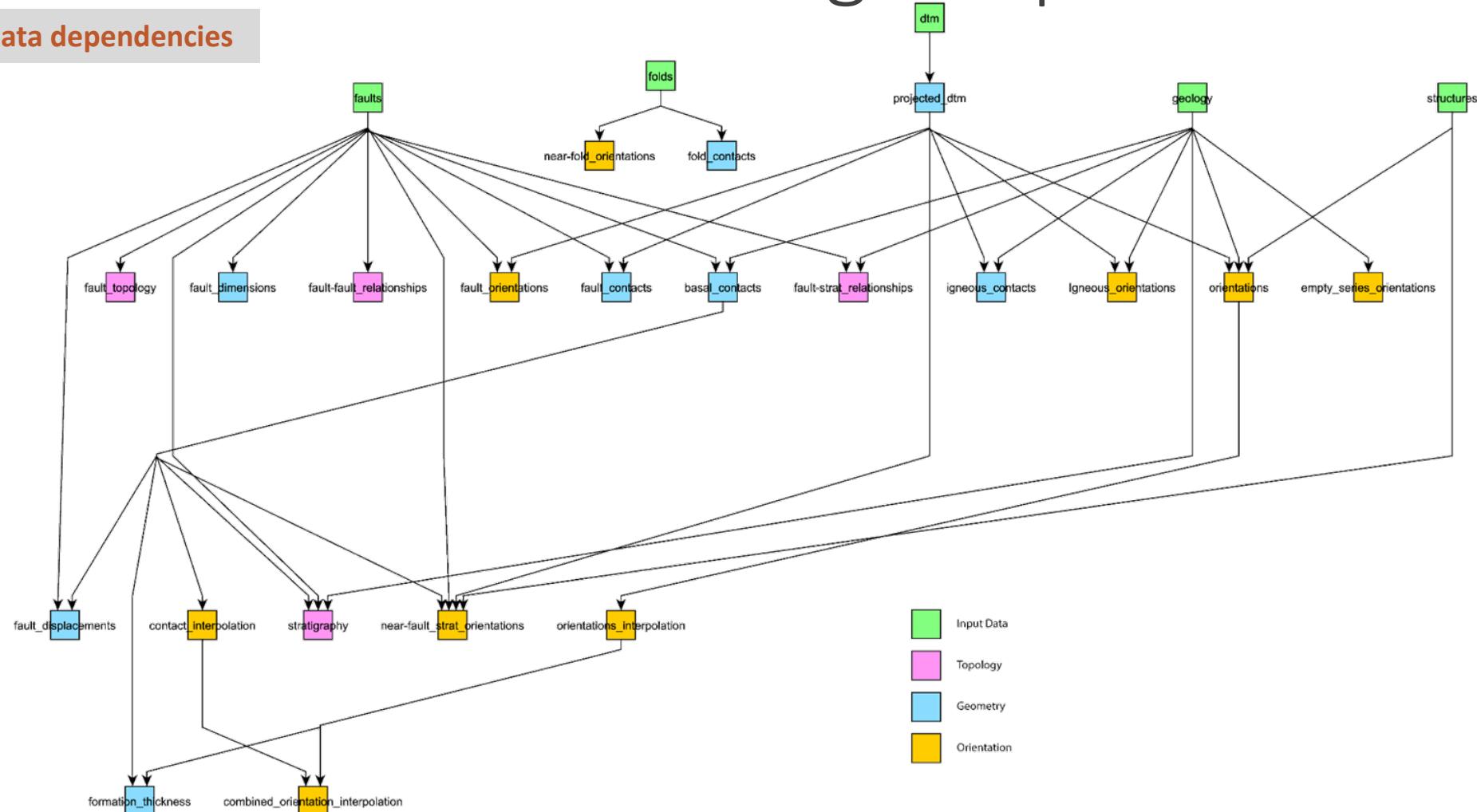
- One of the aims of WP2 is to automate as much as possible the input of data and transformation in appropriate inputs to Loop 3D modelling codes
- In this (first) example we have developed python & C++ codes to automatically derive the input data needed to produce ***gempy, geomodeller and LoopStructural (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

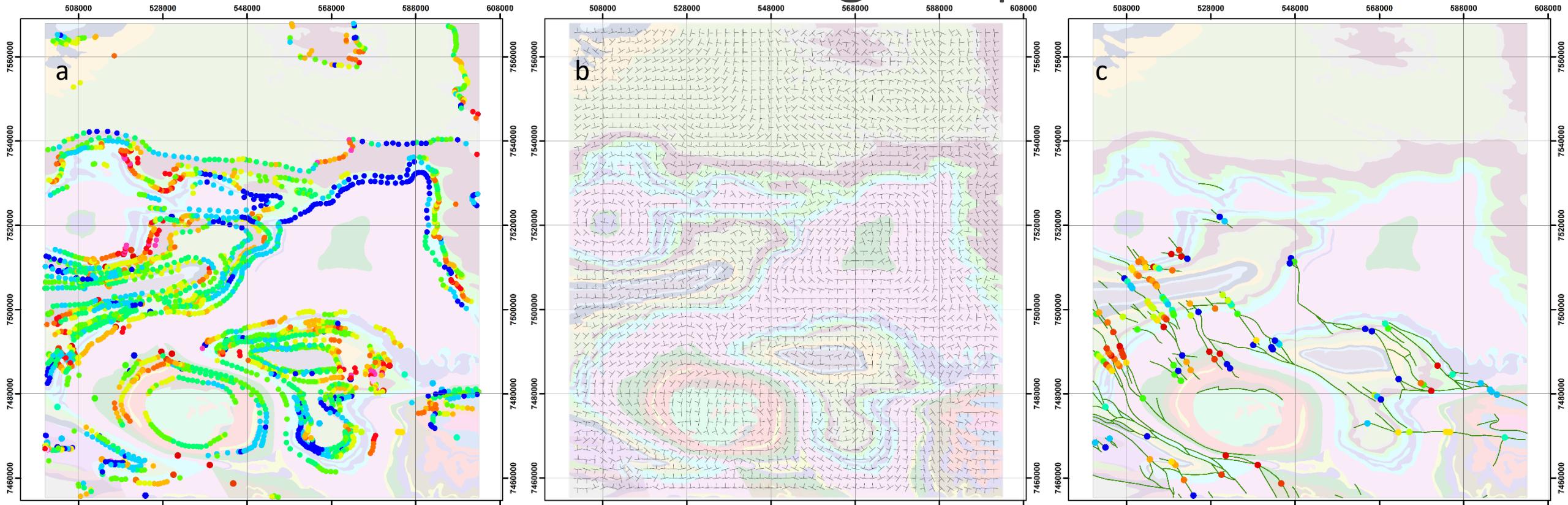
WP #2 – Data Pre-Processing & input

Map2loop // Data dependencies



Loop

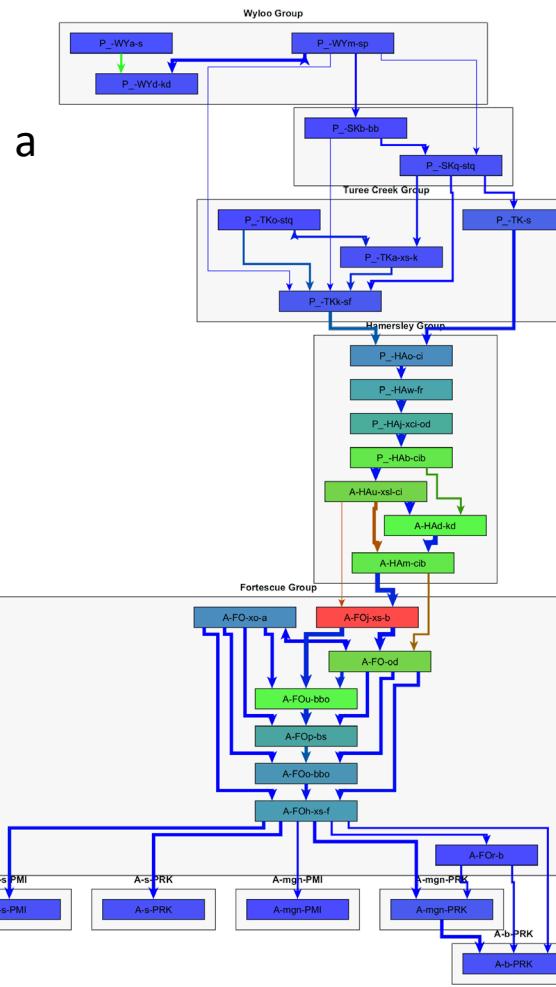
WP #2 – Data Pre-Processing & input



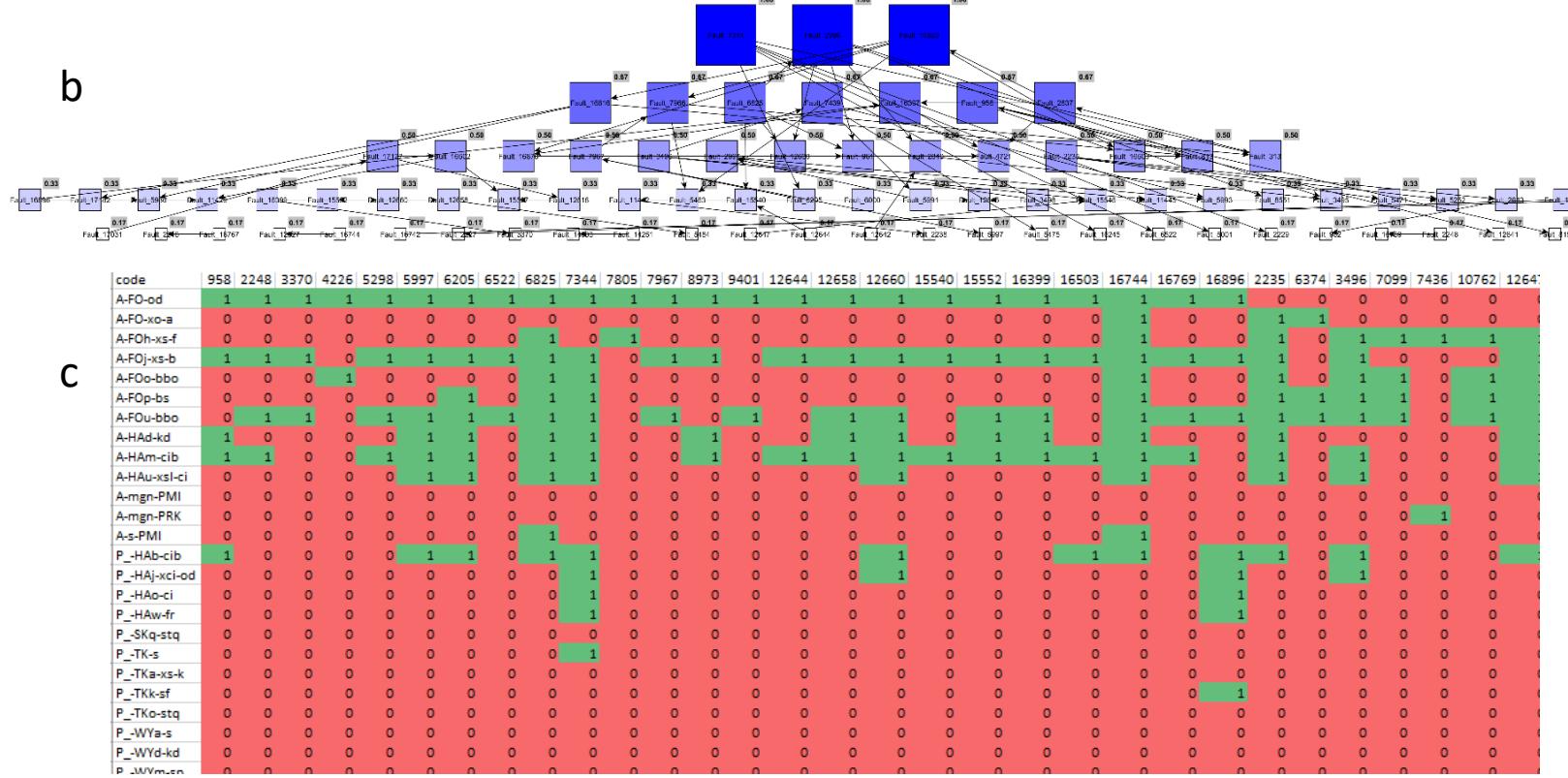
Map2loop // Secondary geological information automatically derived from maps. a) Normalised local formation thickness (hotter colours show thicker formations) b) Interpolated estimated bedding orientations for the Hamersley and Fortescue Groups c) Apparent fault throw (hotter colours show larger throw)

Loop

WP #2 – Data Pre-Processing & input



b

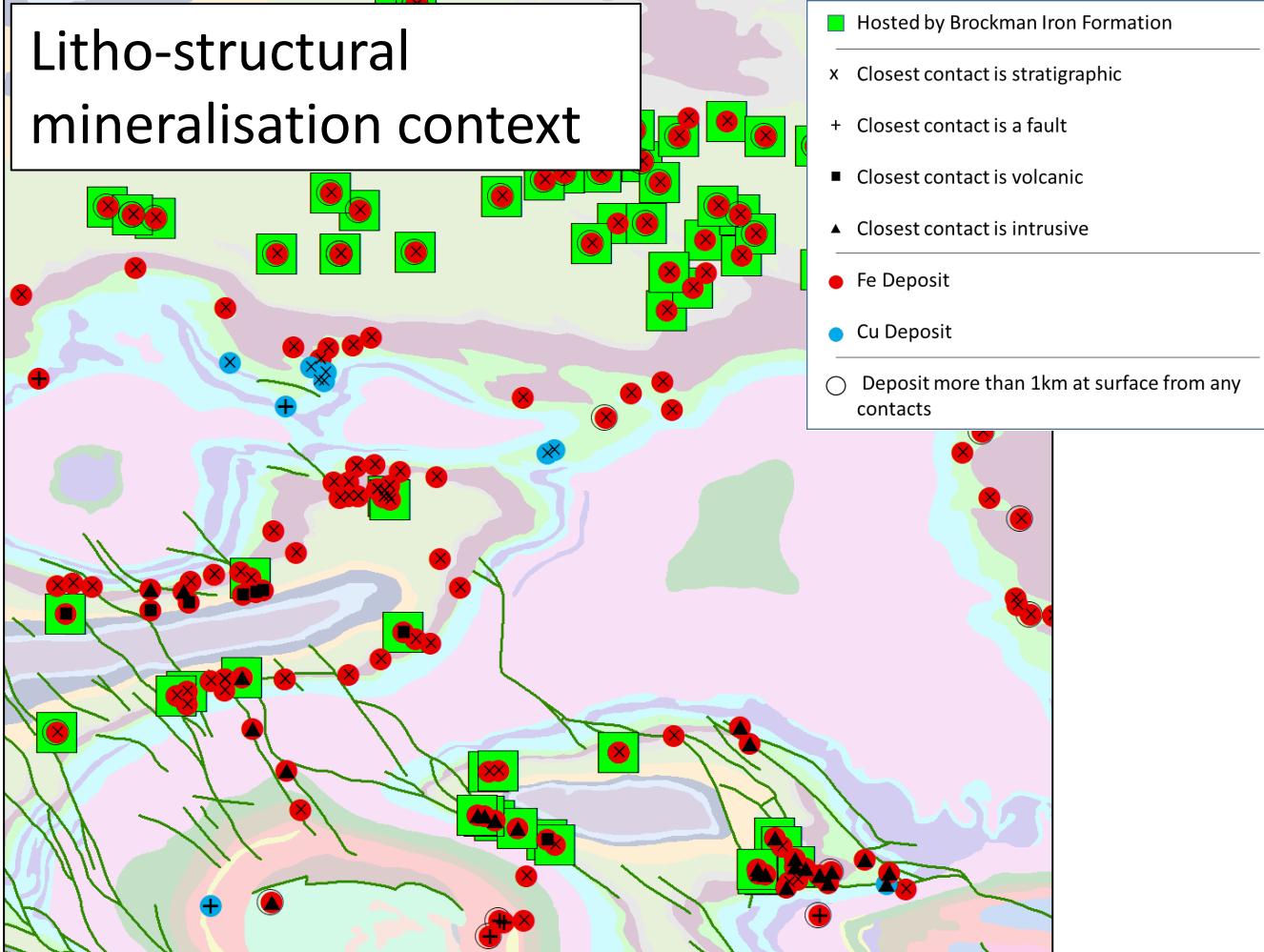


c

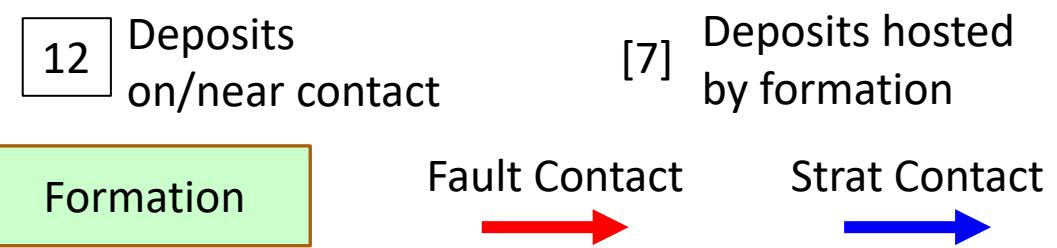
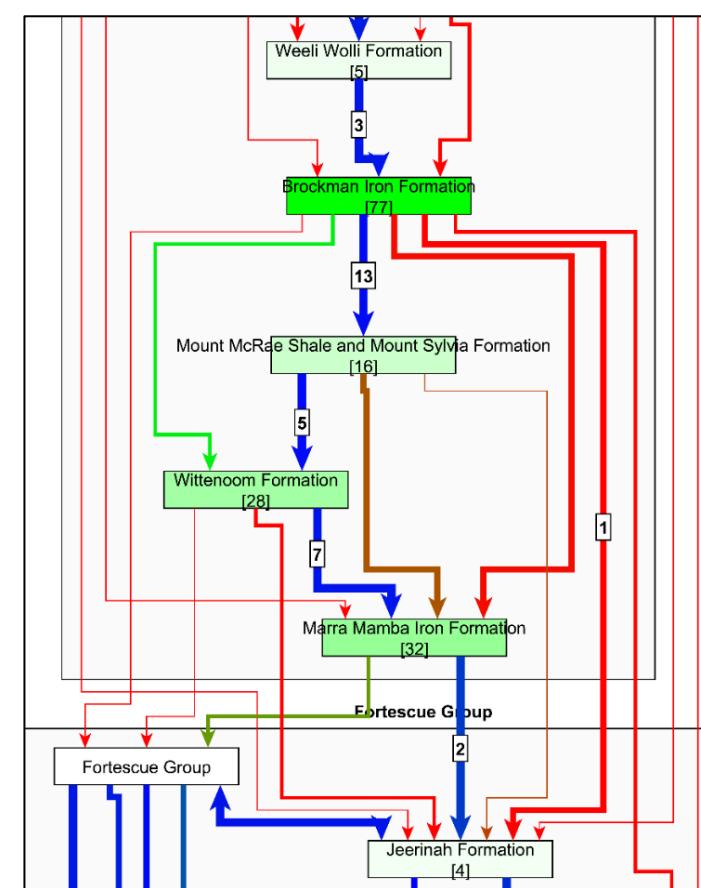
code	958	2248	3370	4226	5288	5997	6205	6522	6825	7344	7805	7967	8973	9401	12644	12658	12660	15540	15552	16399	16503	16744	16769	16896	2235	6374	3496	7099	7436	10762	1264
A-FO-od	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	
A-FO-xo-a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	
A-FOh-xs-f	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1
A-FQj-xs-b	1	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
A-FQo-bbo	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1
A-FOp-bs	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1
A-FQo-bbo	0	1	1	0	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
A-HAd-kd	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A-HAm-cib	1	0	0	0	0	1	1	0	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0
A-HAu-xsl-ci	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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A-mgn-PRK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A-s-PMI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_HAb-cib	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
P_HAj-xci-od	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
P_HAO-ci	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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P_TK-s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_TKa-xs-k	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_TKk-sf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_TWk-stq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_WYs-s	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_WYd-kd	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P_WYm-en	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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



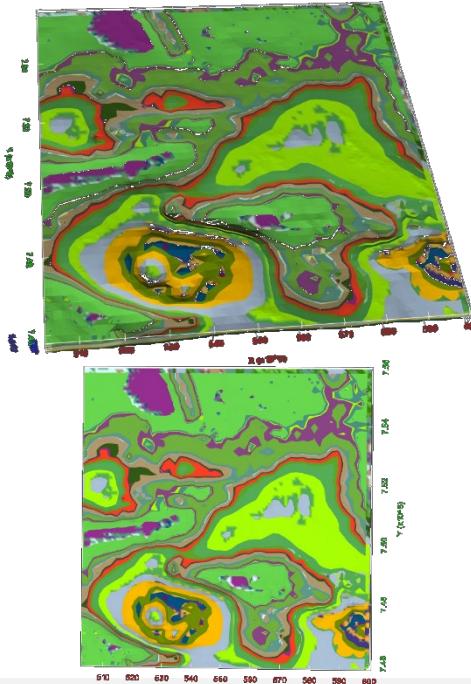
Functionality added to *map2loop* to analyse the litho-structural context of mineral deposits, which will help in defining which elements to retain for modelling



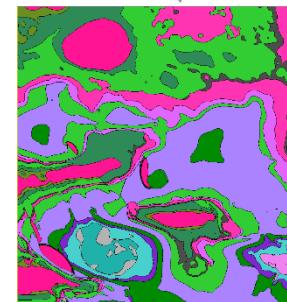
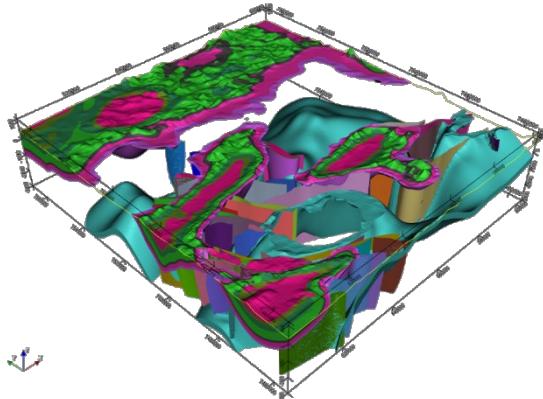
Loop

WP #2 – Data Pre-Processing & input

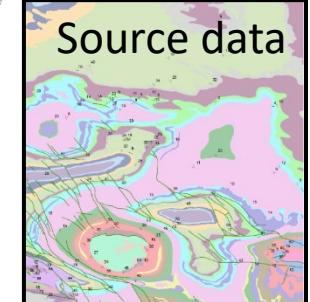
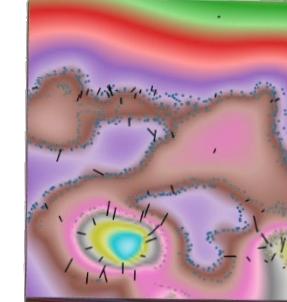
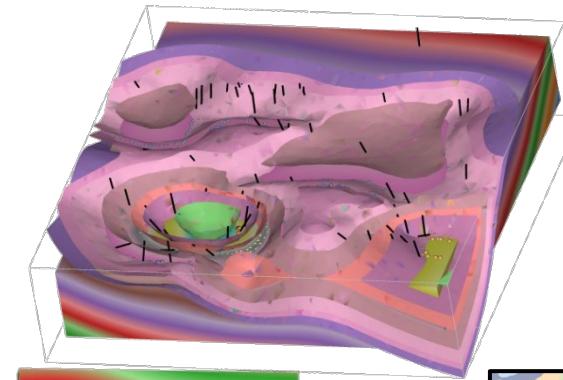
gempy



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.

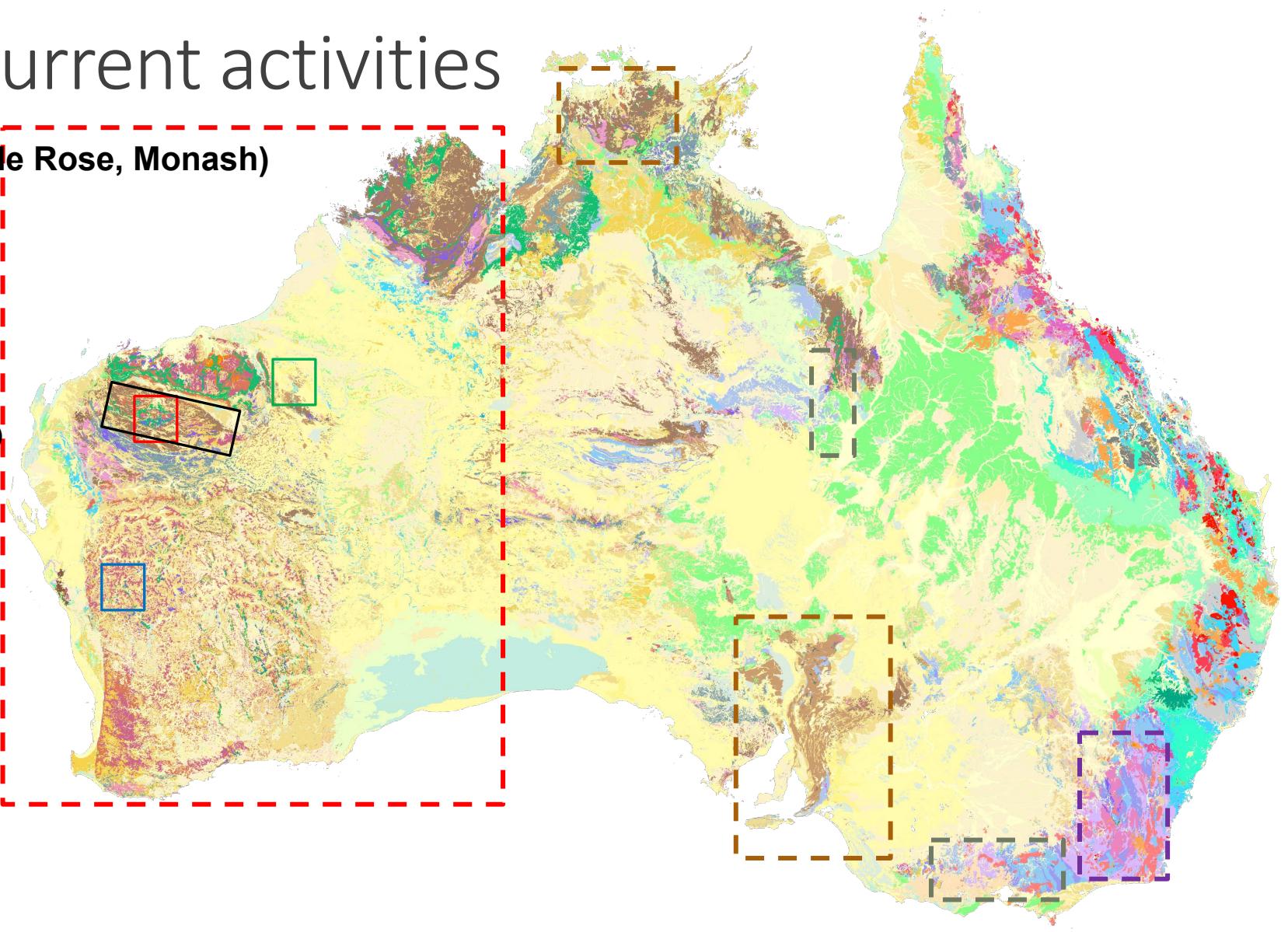
WP #2 – Map2loop-current activities

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

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

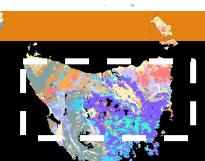
b) Testing of map2loop code

- 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

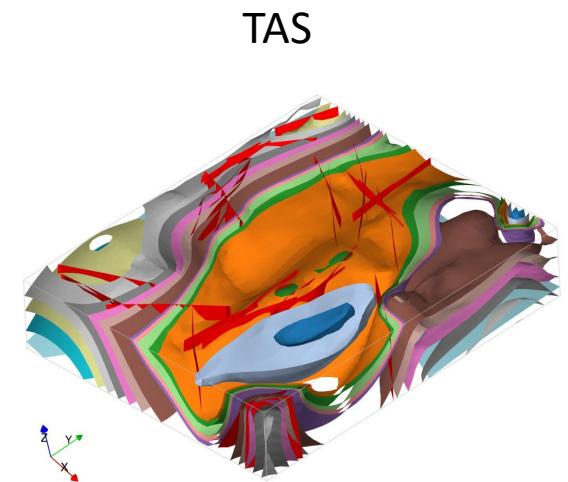
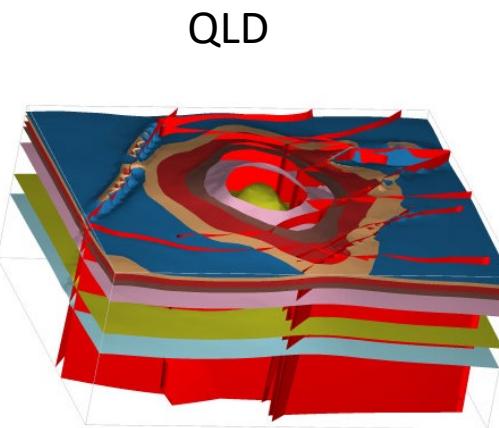
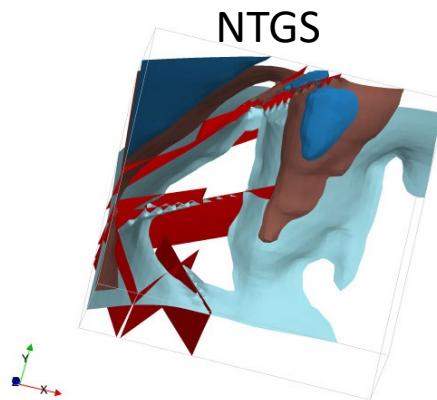
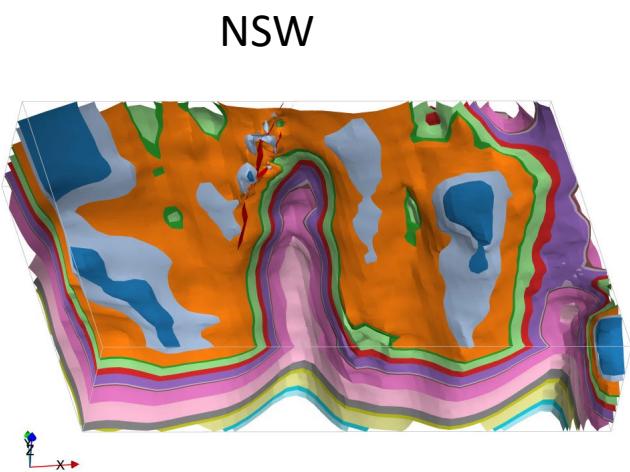
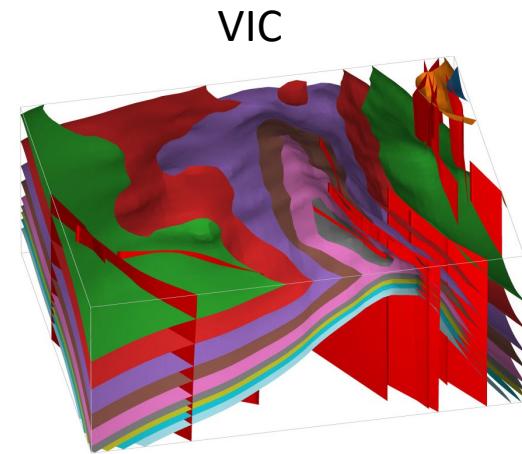
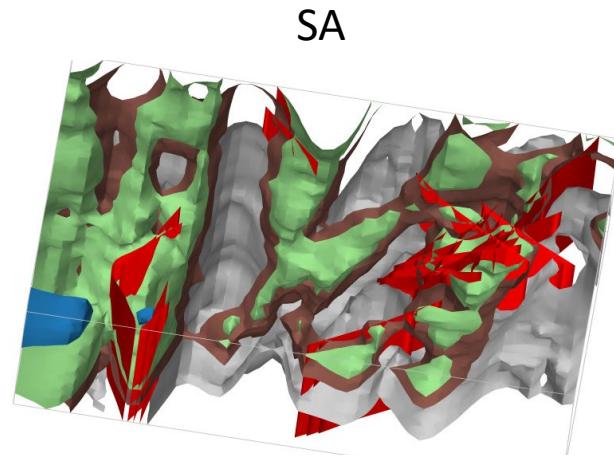
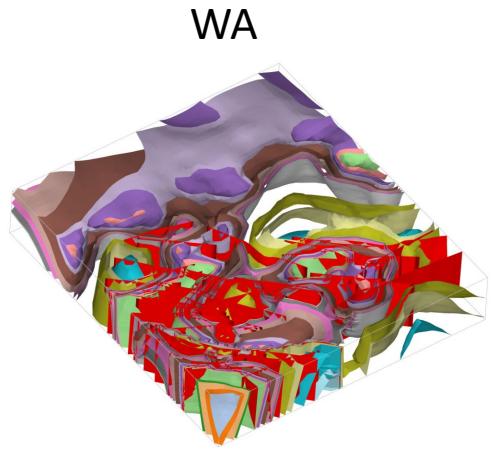


c) Seeking additional funding for drillhole analysis from Auscope & MinEx CRC Opportunity funds

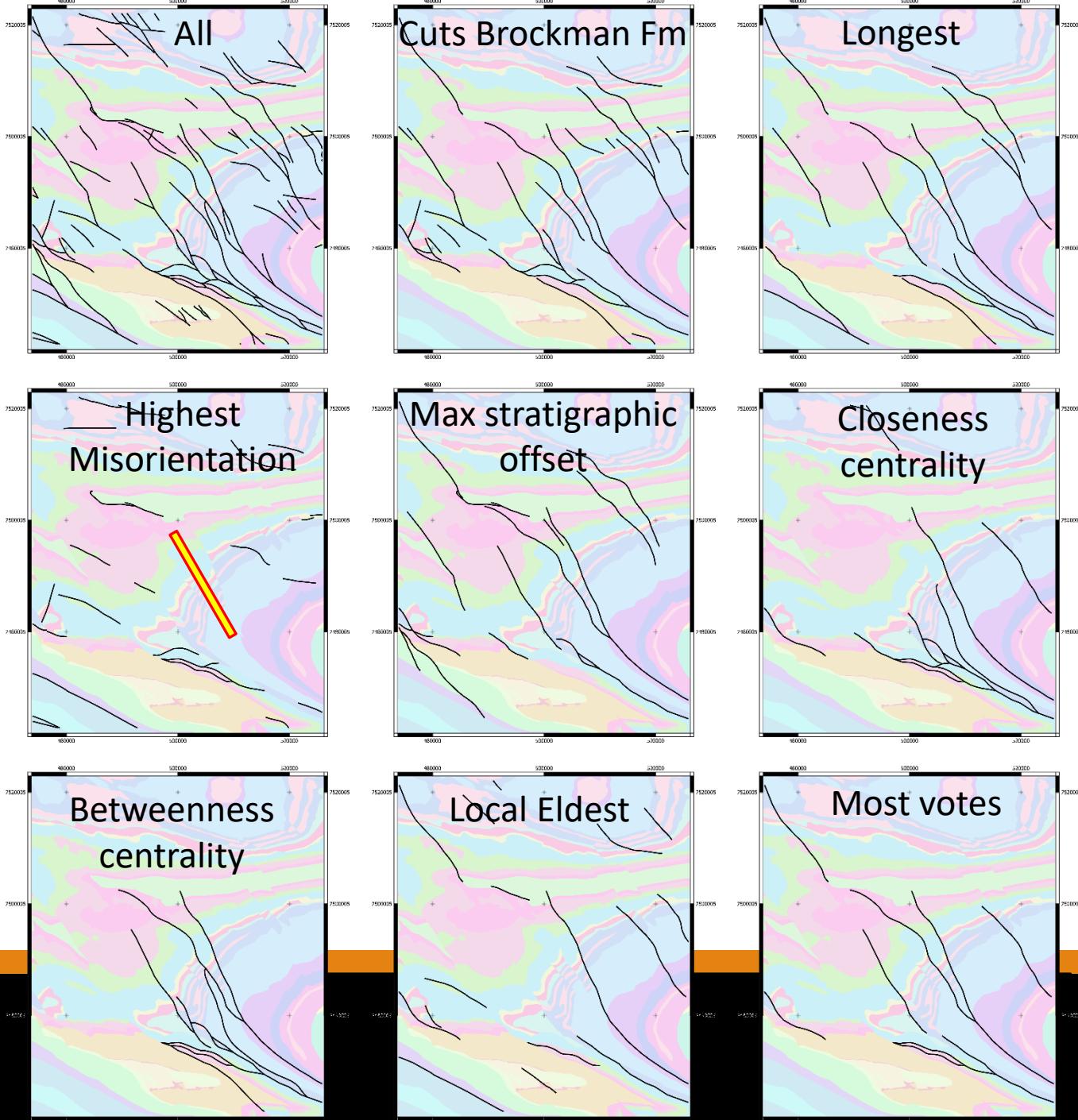
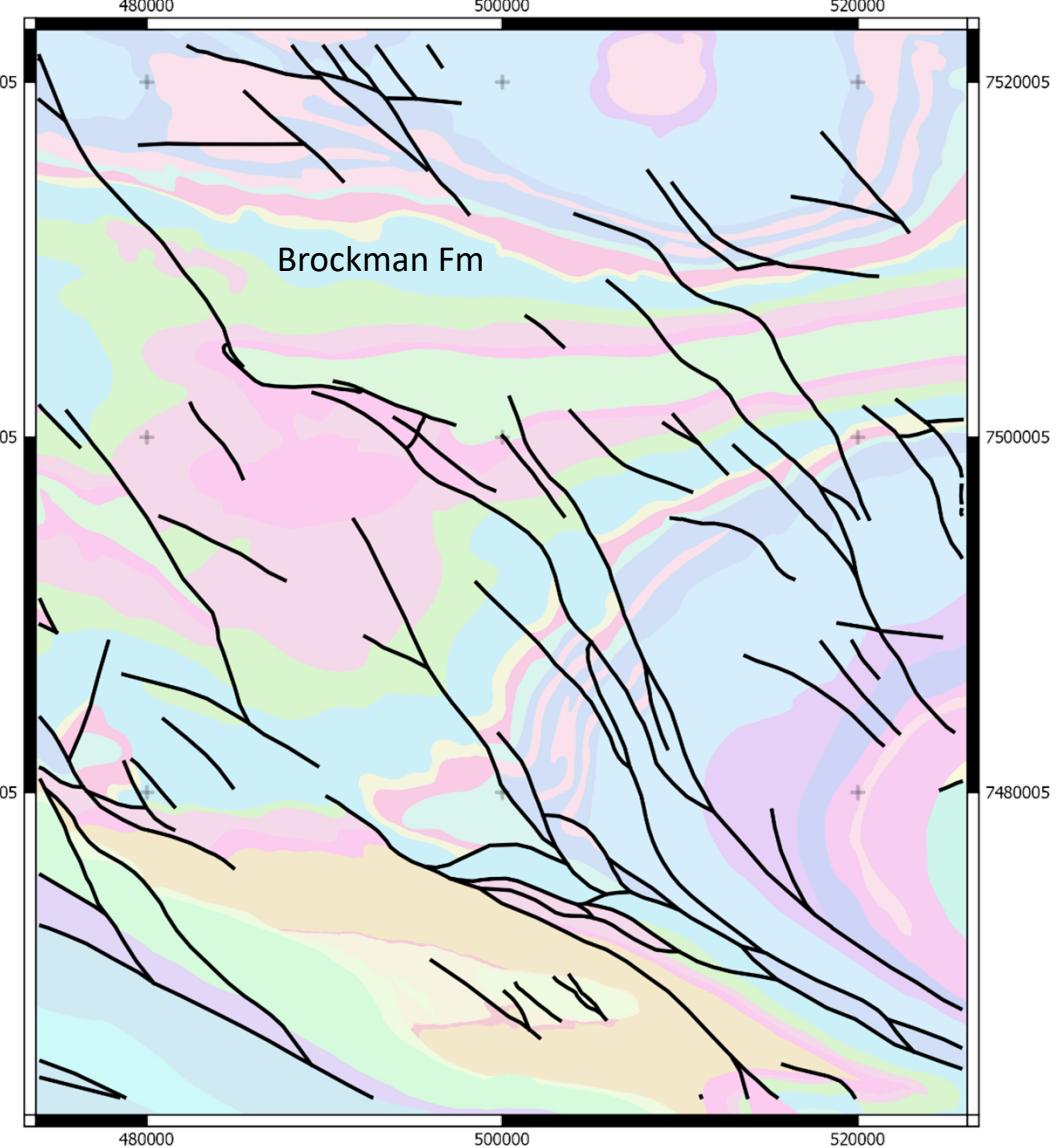
Loop



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 LoopStructural

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 (<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 and map2loop_v2
- 17. 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

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

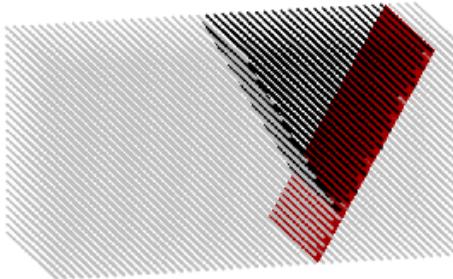
- 30. Quadratic interpolation using triangular mesh – paper in prep, figure showing comparison to linear
- 31. Probability branch of LoopStructural created including Theano wrapper for gradient evaluation
- 32. Testing inversion of fault geometry
- 33. Conda, pip and docker builds + loopstructural works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

WP #3 – LoopStructural

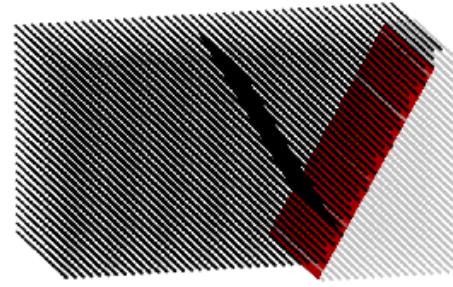
A. Fault network



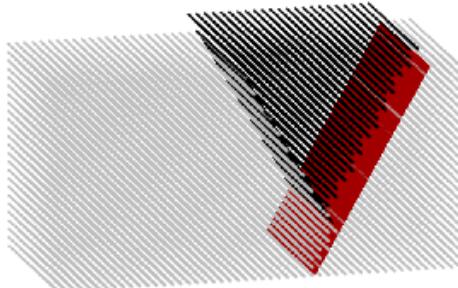
B. Model support before restoration



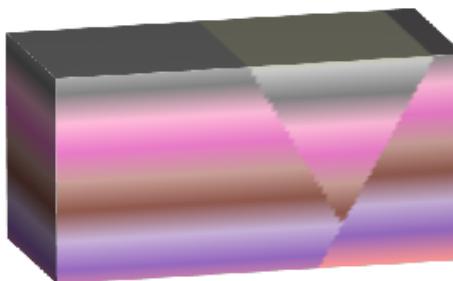
C. Model support restored by main fault



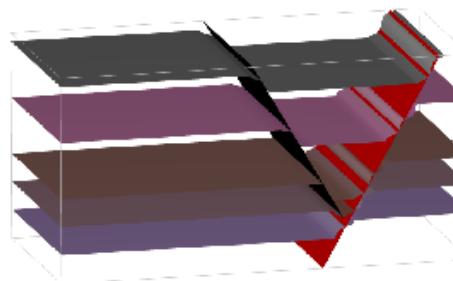
D. Model support restored by antithetic fault



E. Interpolated stratigraphy scalar field



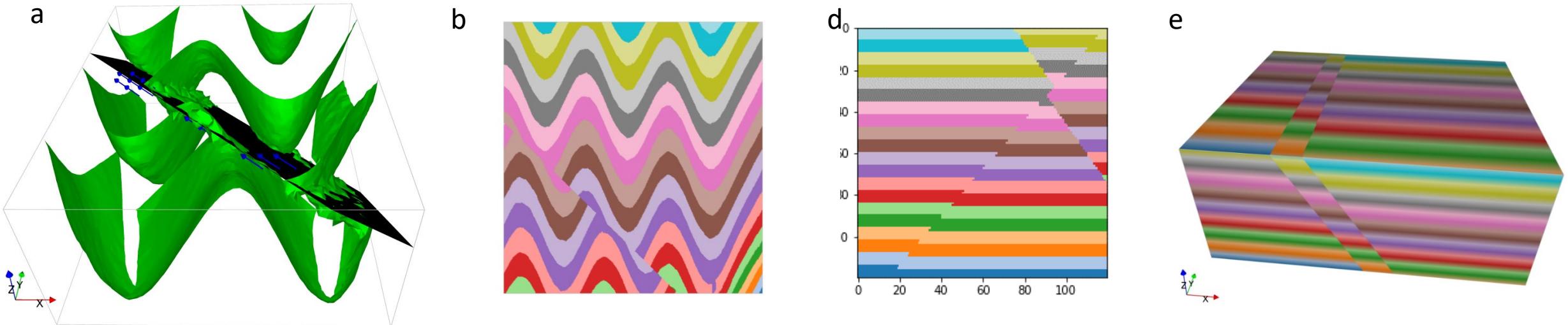
F. Isosurfaces extracted from scalar field



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.

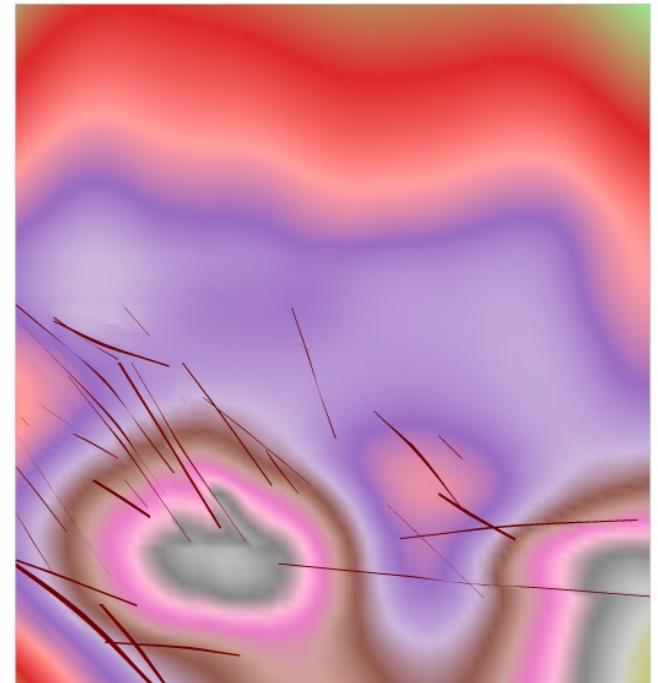
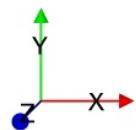
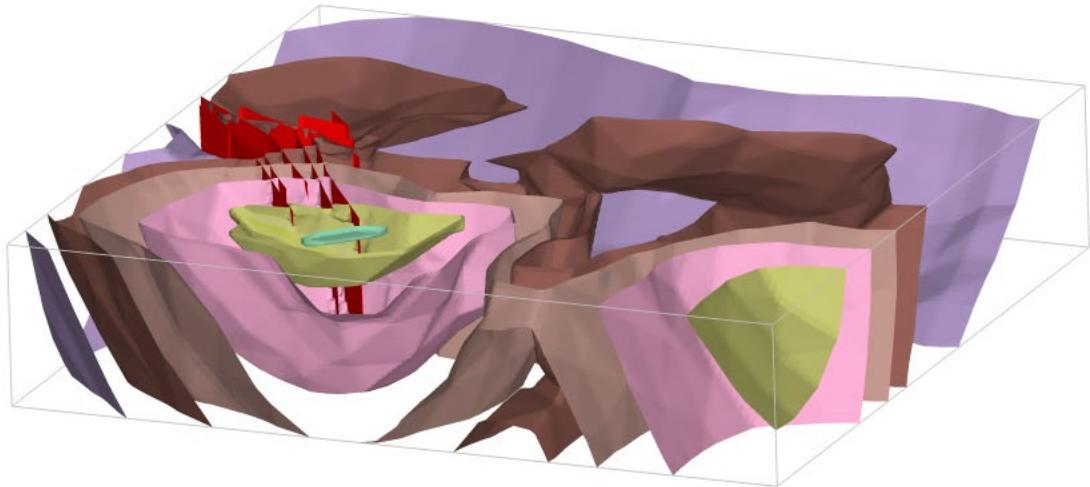
WP #3 – LoopStructural

```
: 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

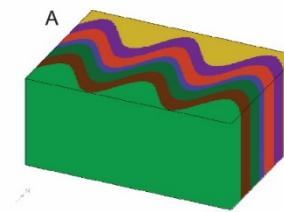
Sampling structural data

Form-surface sampling vs Across structure sampling.

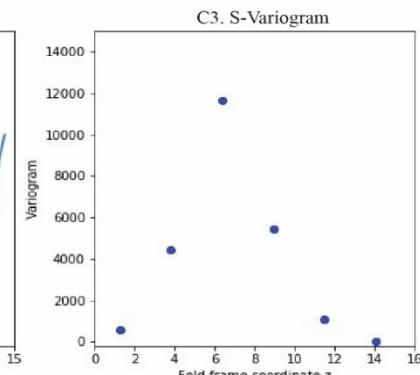
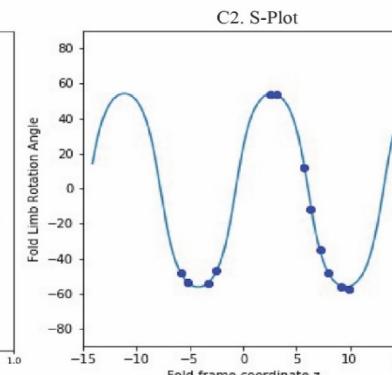
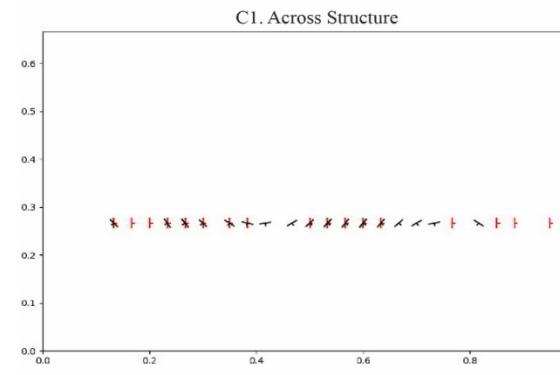
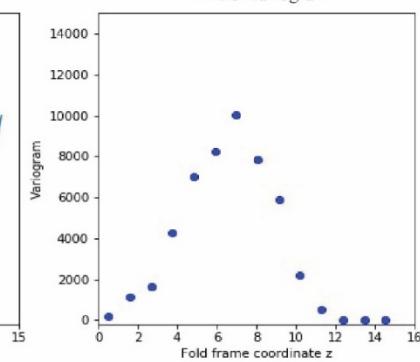
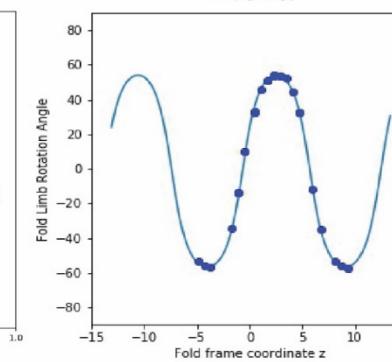
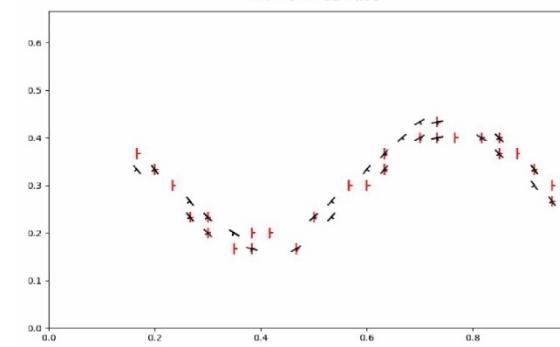
The reference model generated using Noddy (A) is an upright cylindrical fold with a fold axis plunging vertically.

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

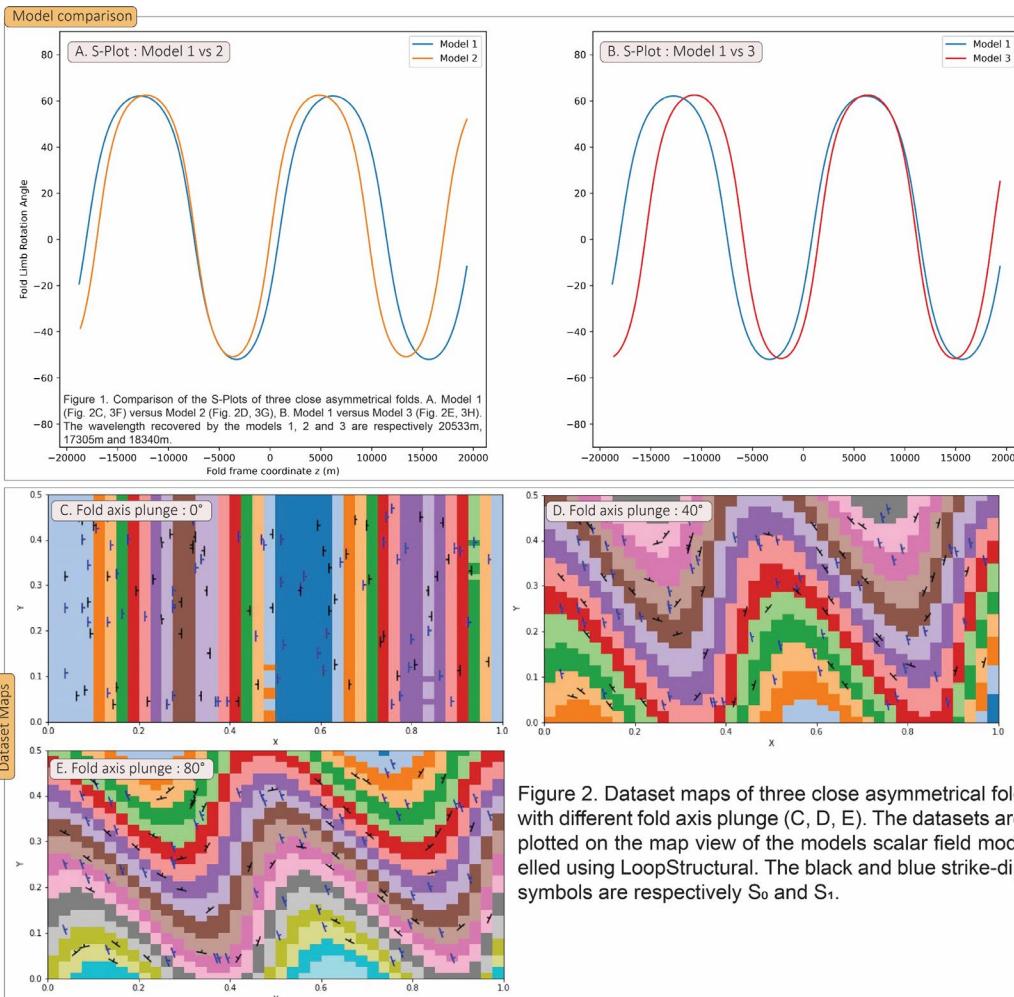


Form surface sampling
versus
Across structure sampling

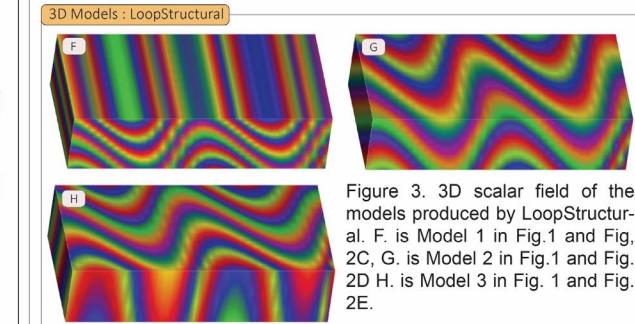
Loop

WP #3 – LoopStructural

Figure showing LoopStructural sensitivity to data sampling for folded structures.



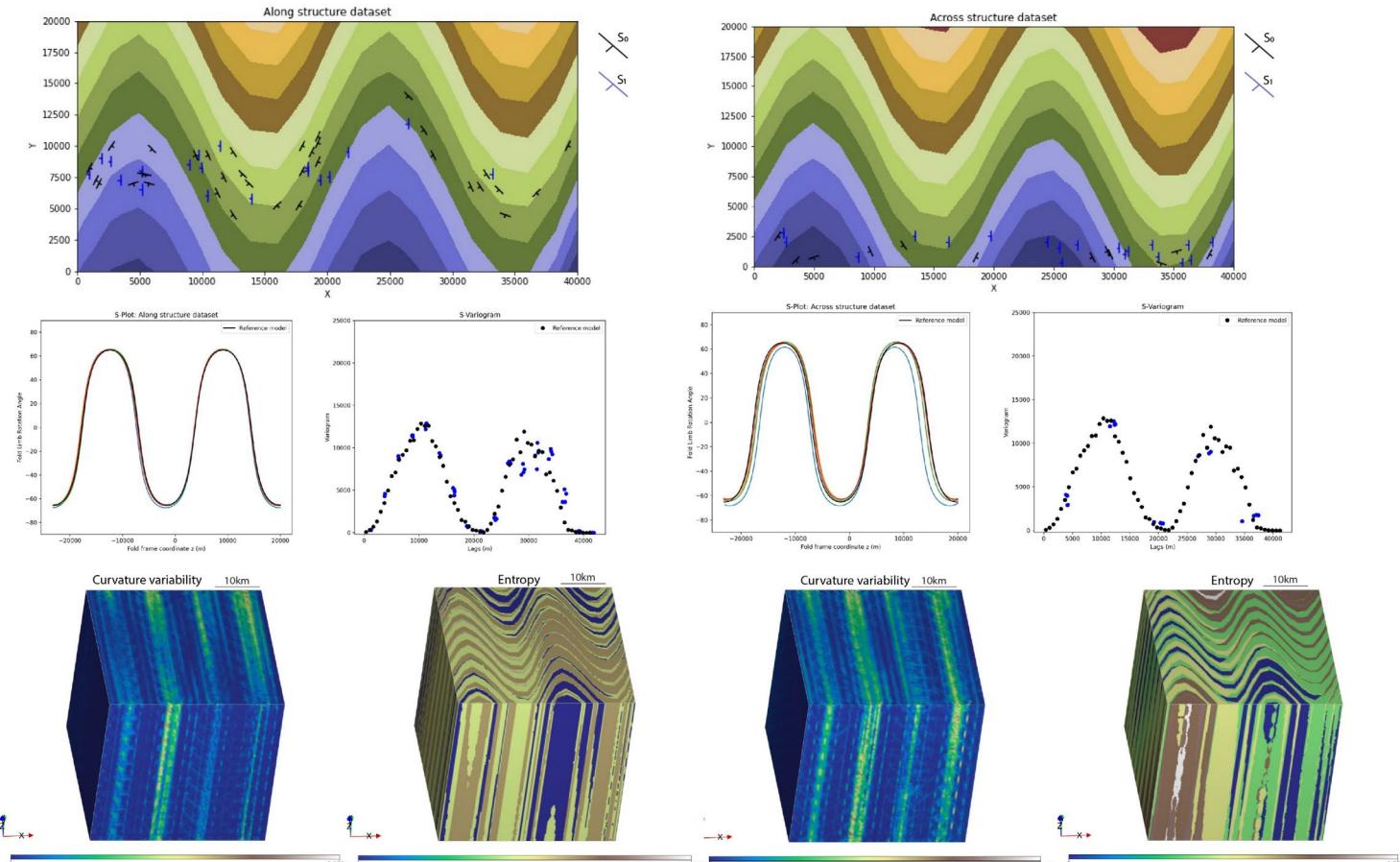
Wavelength Recovery : Cylindrical folds



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



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.

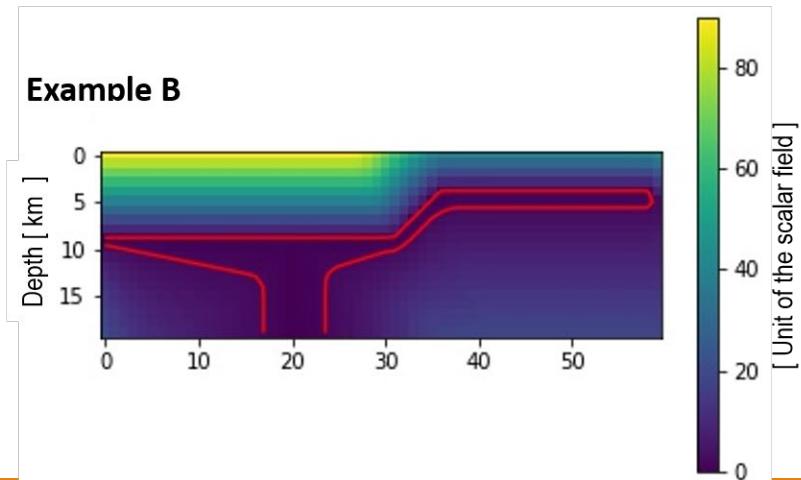
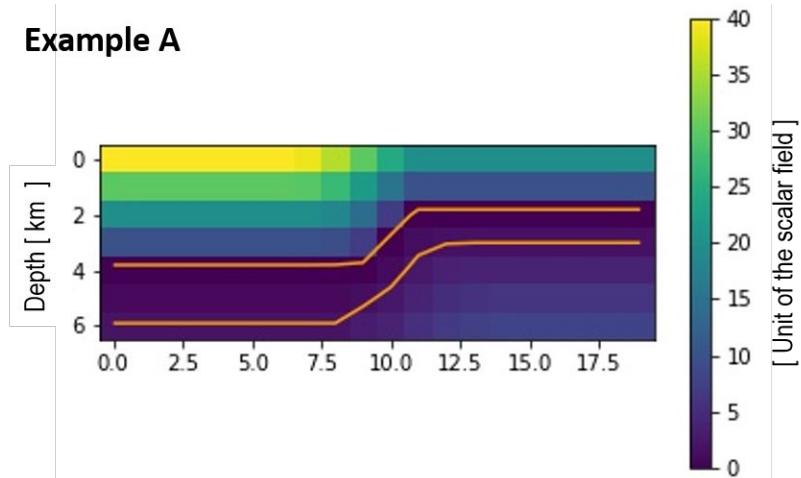
WP #3 – LoopStructural

Modelling intrusions

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

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

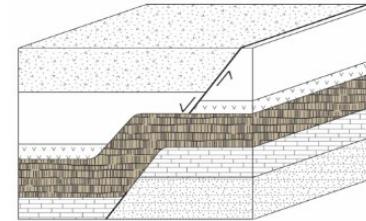
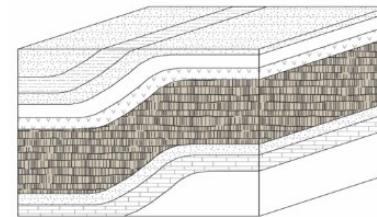
Example B. Feeder-sill-dyke-sill transition. Red contour shows scalar field $\phi(p) = 2$



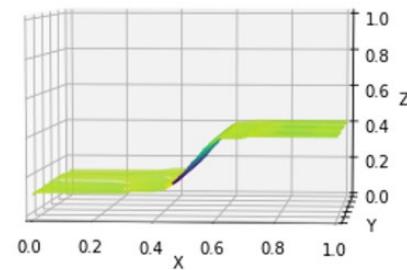
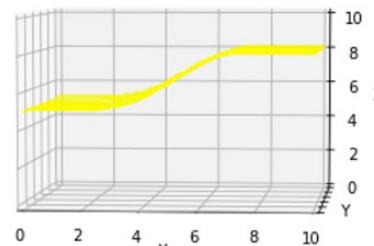
WP #3 – LoopStructural

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).

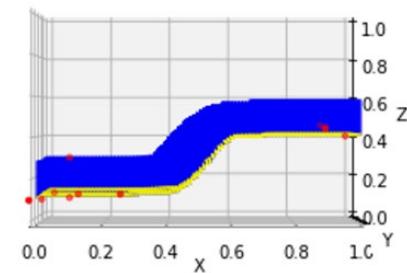
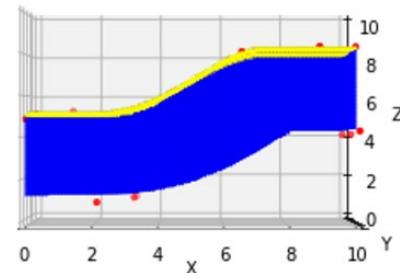
(A) Schematic representation of synthetic cases



(B) Outcome of Step 1

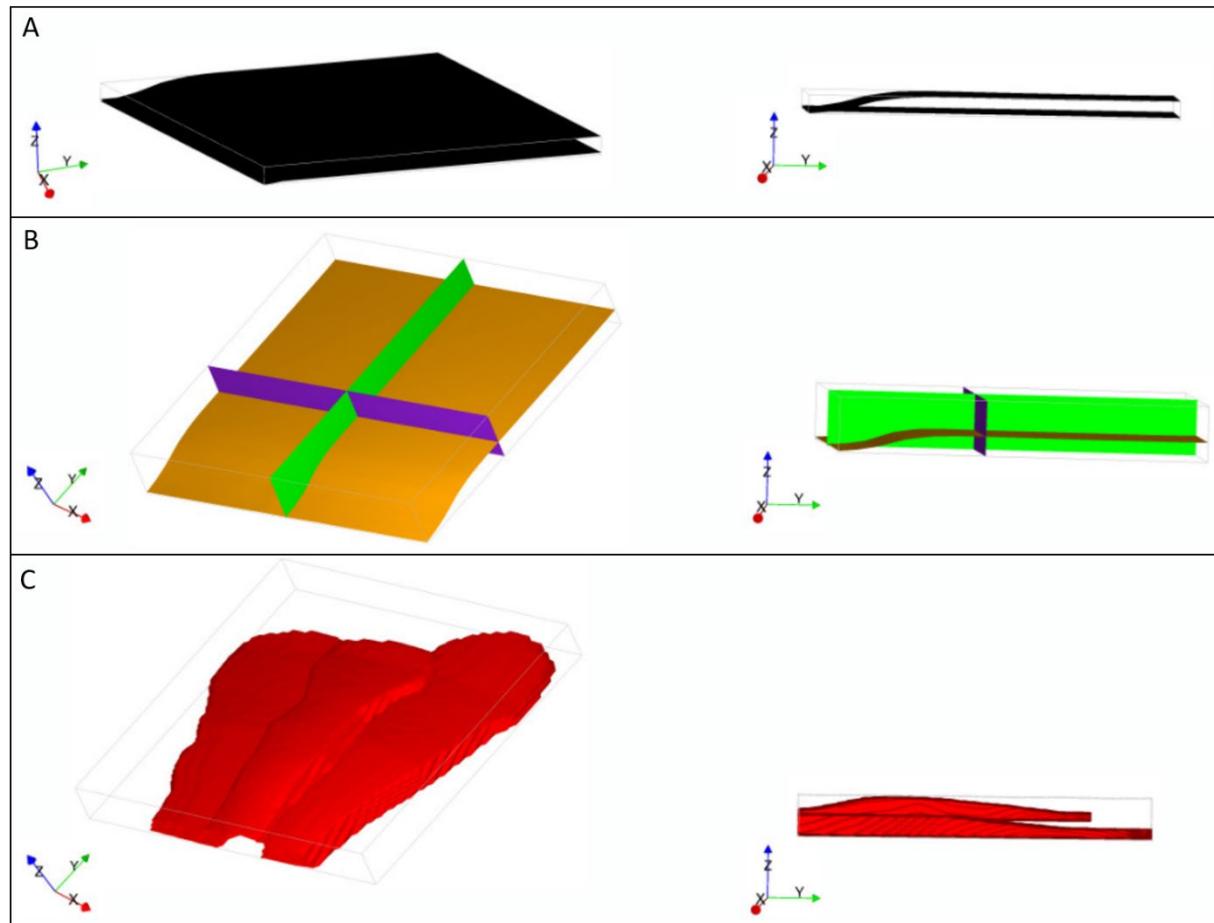


(C) Outcome of Step 2



WP #3 – LoopStructural

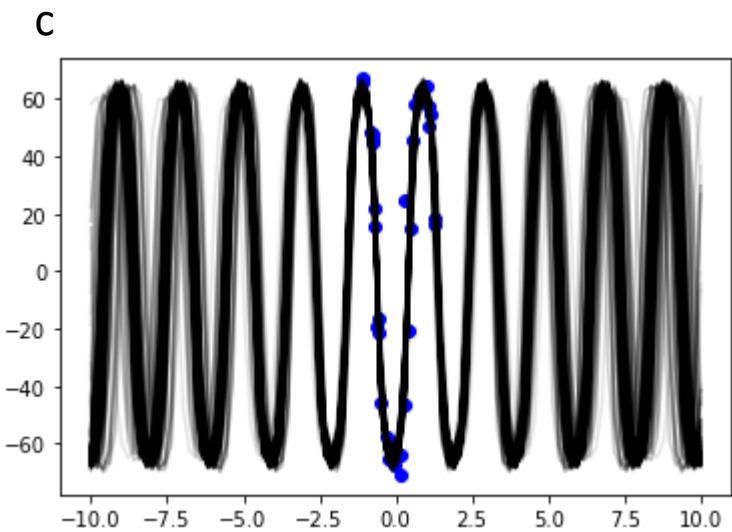
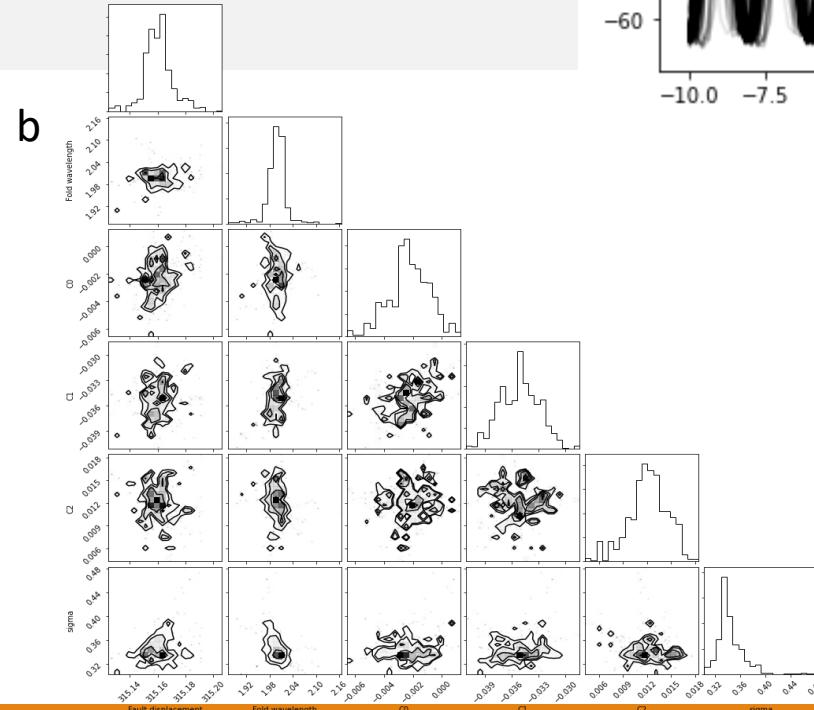
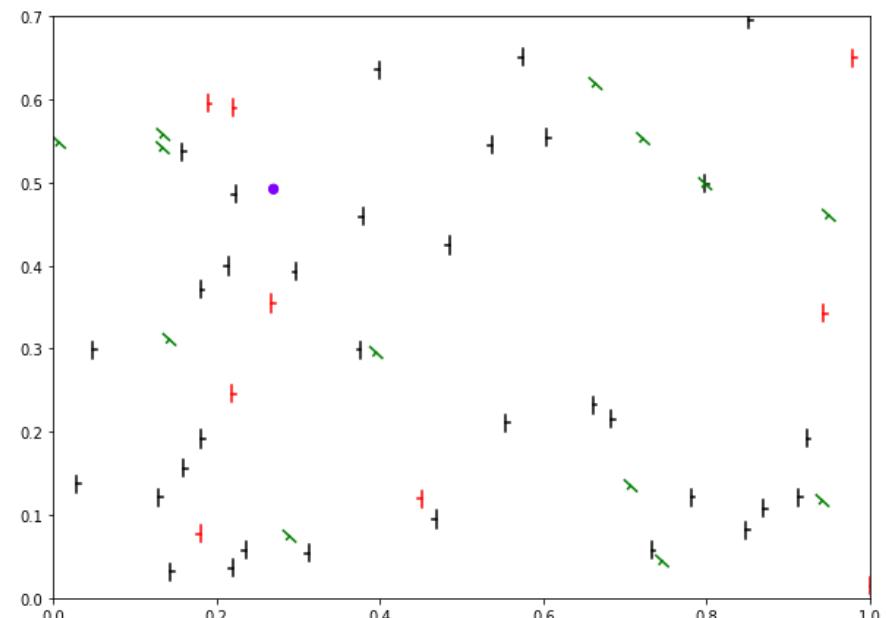
Synthetic example representing the main features of a sill complex and sill segmentation. The middle intrusion exploits a pre-existing structure and propagates through a higher stratigraphic level. Closer to the source, the intrusions coalesce and develop broken bridges structures. At distal locations, 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

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.

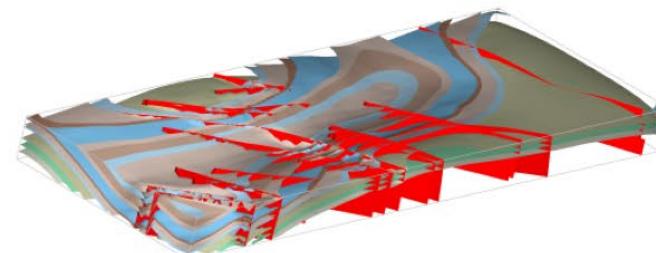
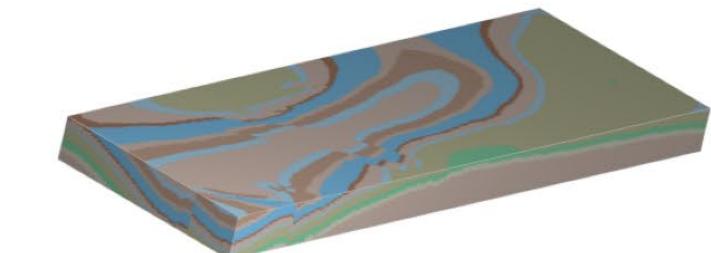


Loop

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



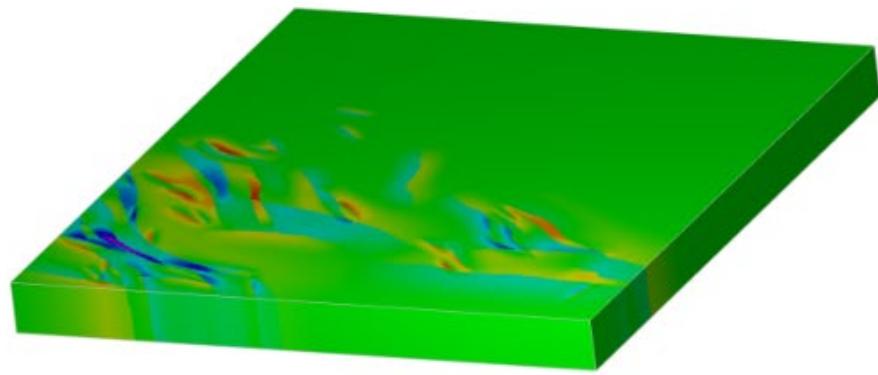
Loop

WP #3 – LoopStructural

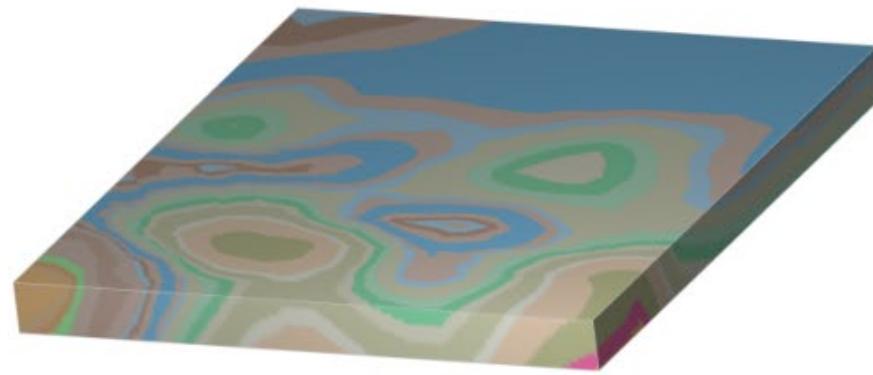
Fault displacement map

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

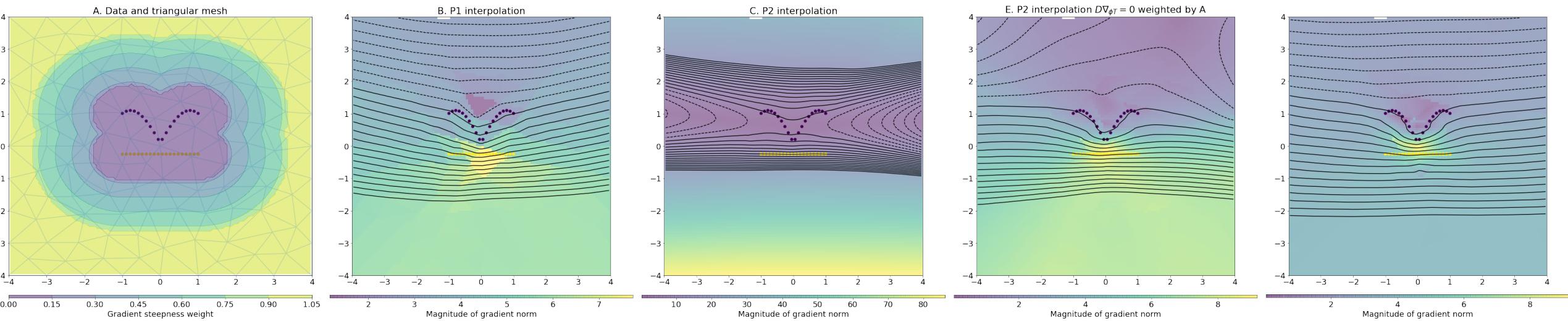


WP #3 – LoopStructural

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 #4 – Integrated Geophysical Inversion

Is work on track against plan? update all deliverables

Work completed  On track  Delayed 

Problem 

Will not happen 

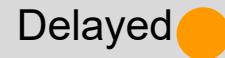
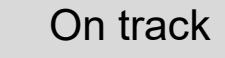
New 

-  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



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



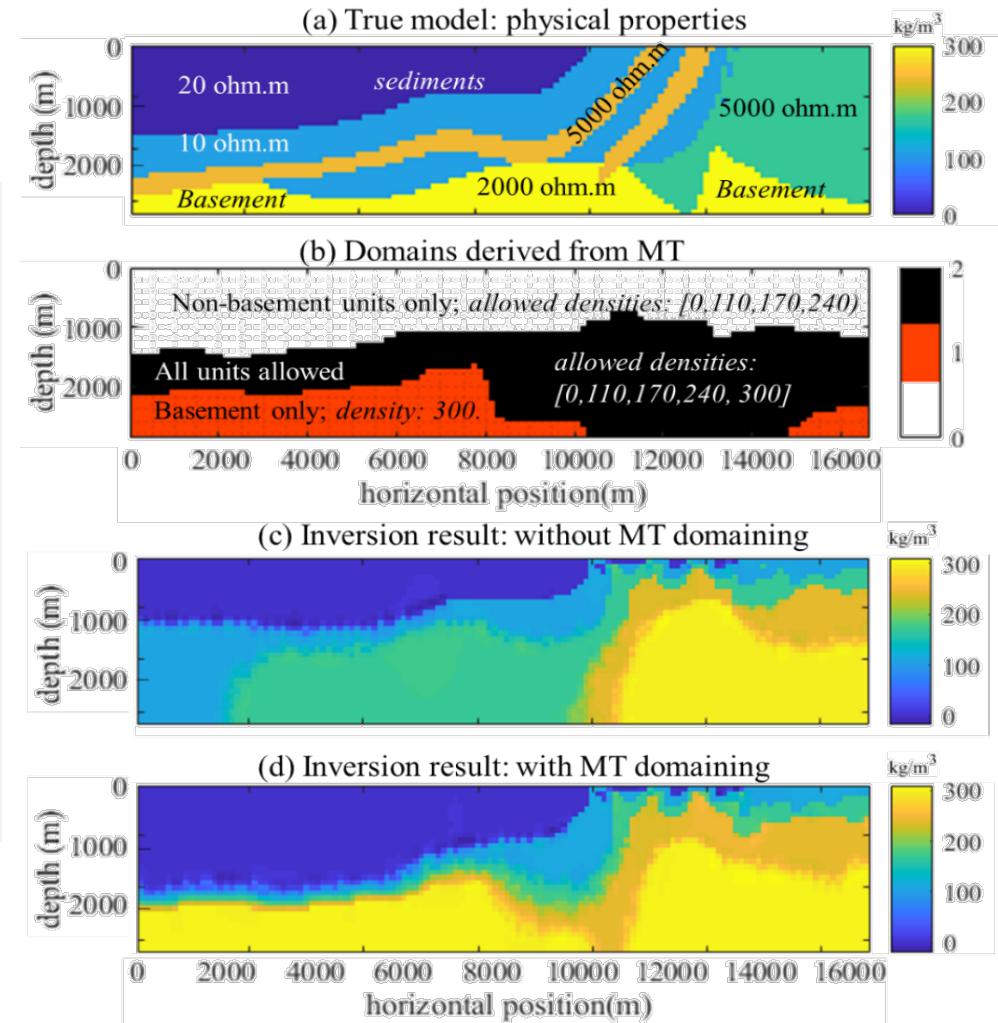
- 12. Case study using data from Yamarna region using 3D geometrical inversion of gravity data constrained by sparse 2D seismic modelling.
- 13. Developed methodology for integration of 1D MT + passive seismic for depth to basement modelling.
- 14. Started case study in collaboration with GTK (Finnish geological survey) for shallow seismically-constrained geometrical gravity inversion in vicinity of ore body.

WP #4 – Integrated Geophysical Inversion

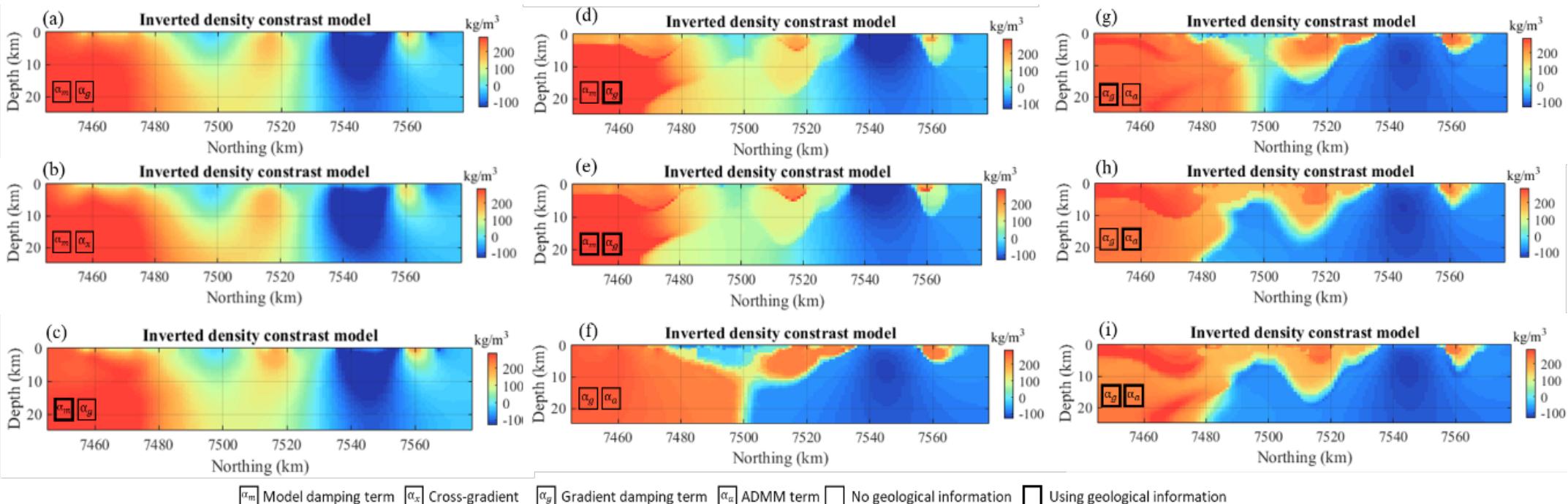
Feasibility study of proposed workflow for the integration of gravity and magnetotellurics data.

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

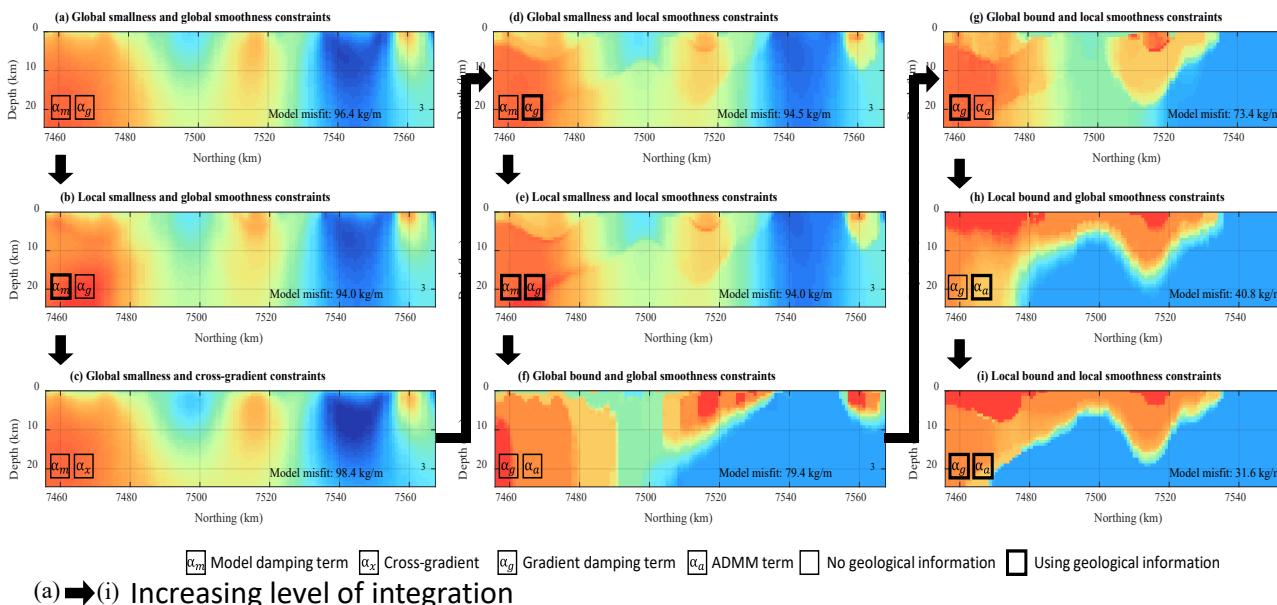


Comparison of inversion results for density contrast models recovered using different kinds of constraints from petrophysics and/or geology and/or structural prior information.

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

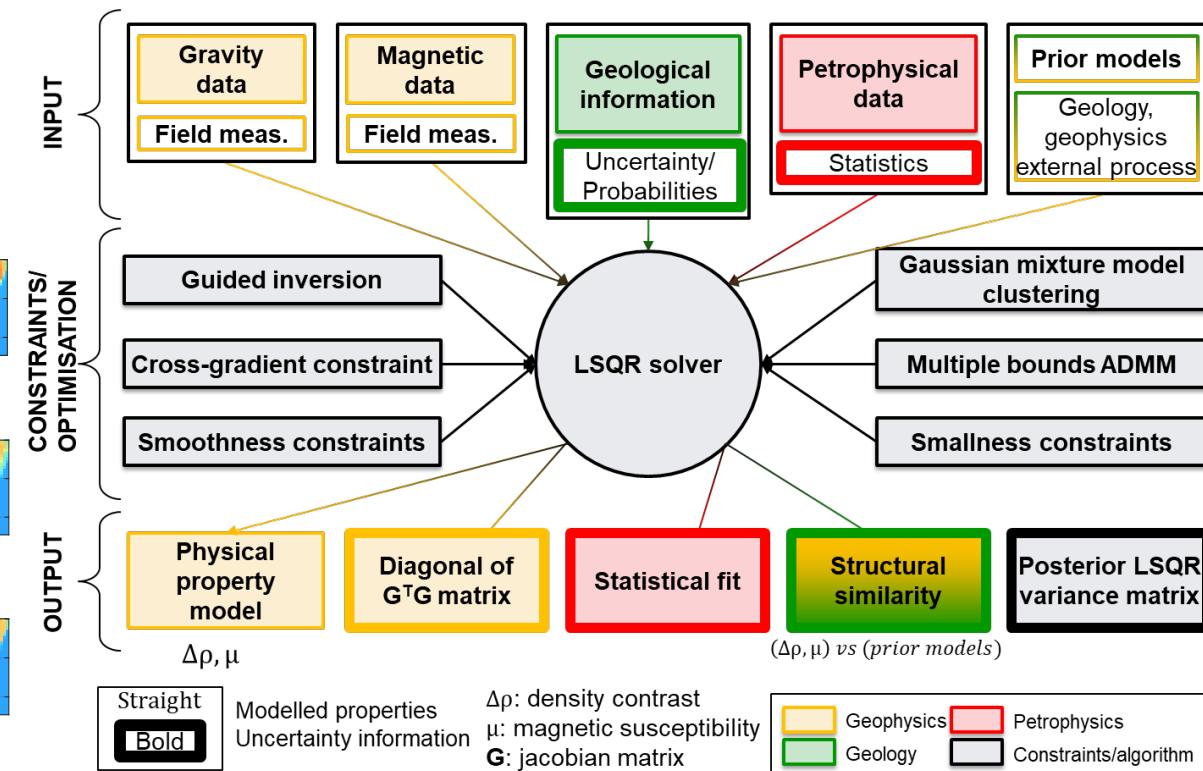
WP #4 – Integrated Geophysical Inversion

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

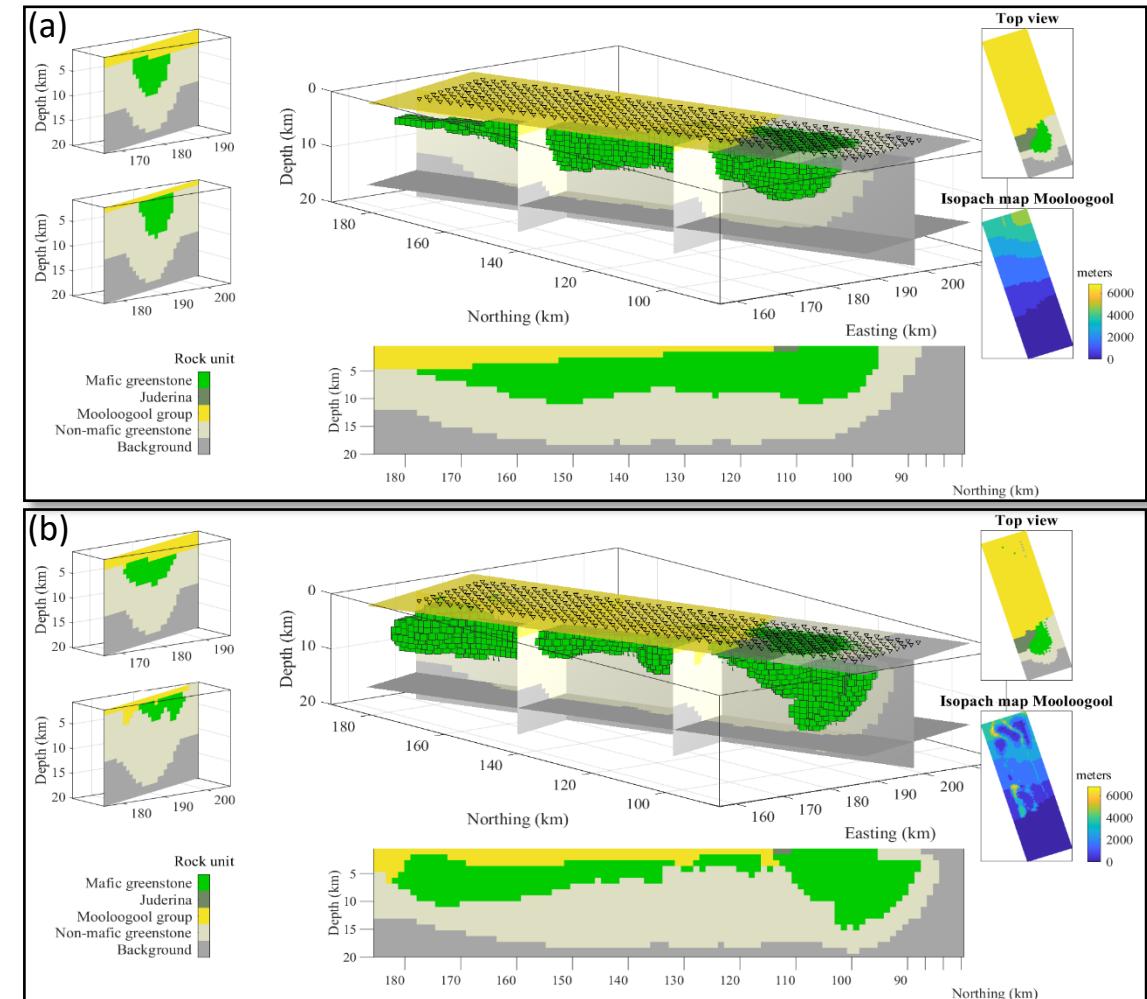
Results of gravity data inversion using level-set formulation of geometries to adjust geological bodies' shapes. Application to greenstone belt from Yerrida basin (WA)

(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.



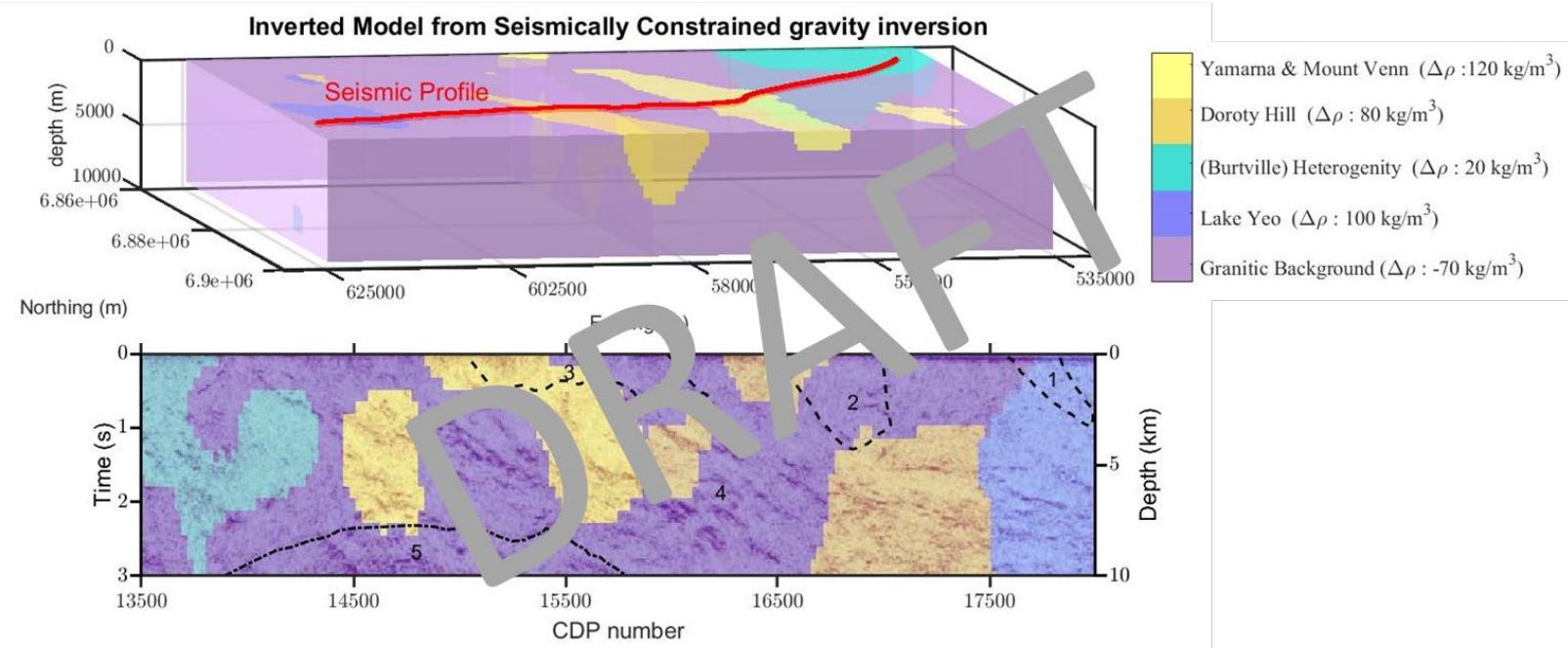
WP #4 – Integrated Geophysical Inversion

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.



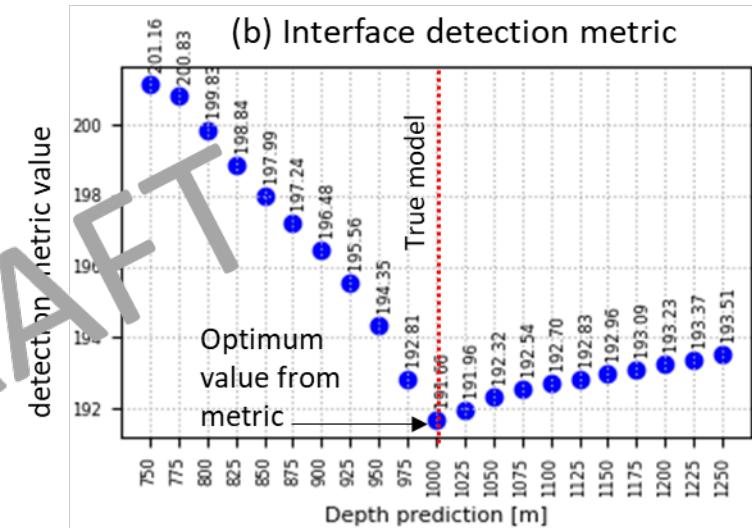
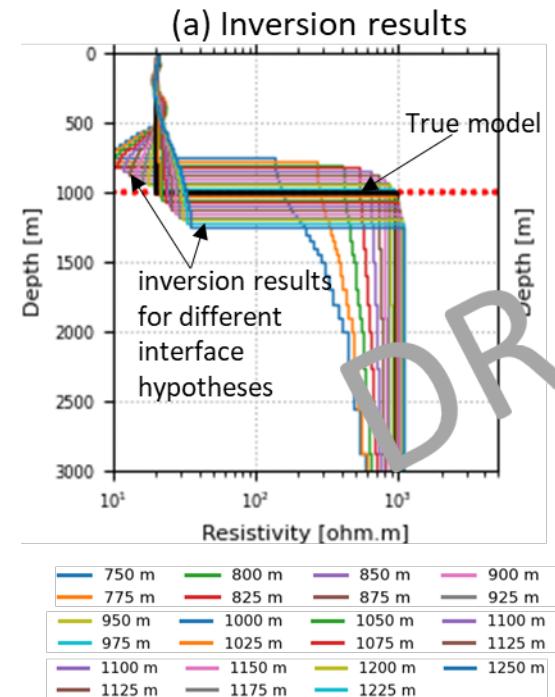
WP #4 – Integrated Geophysical Inversion

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.

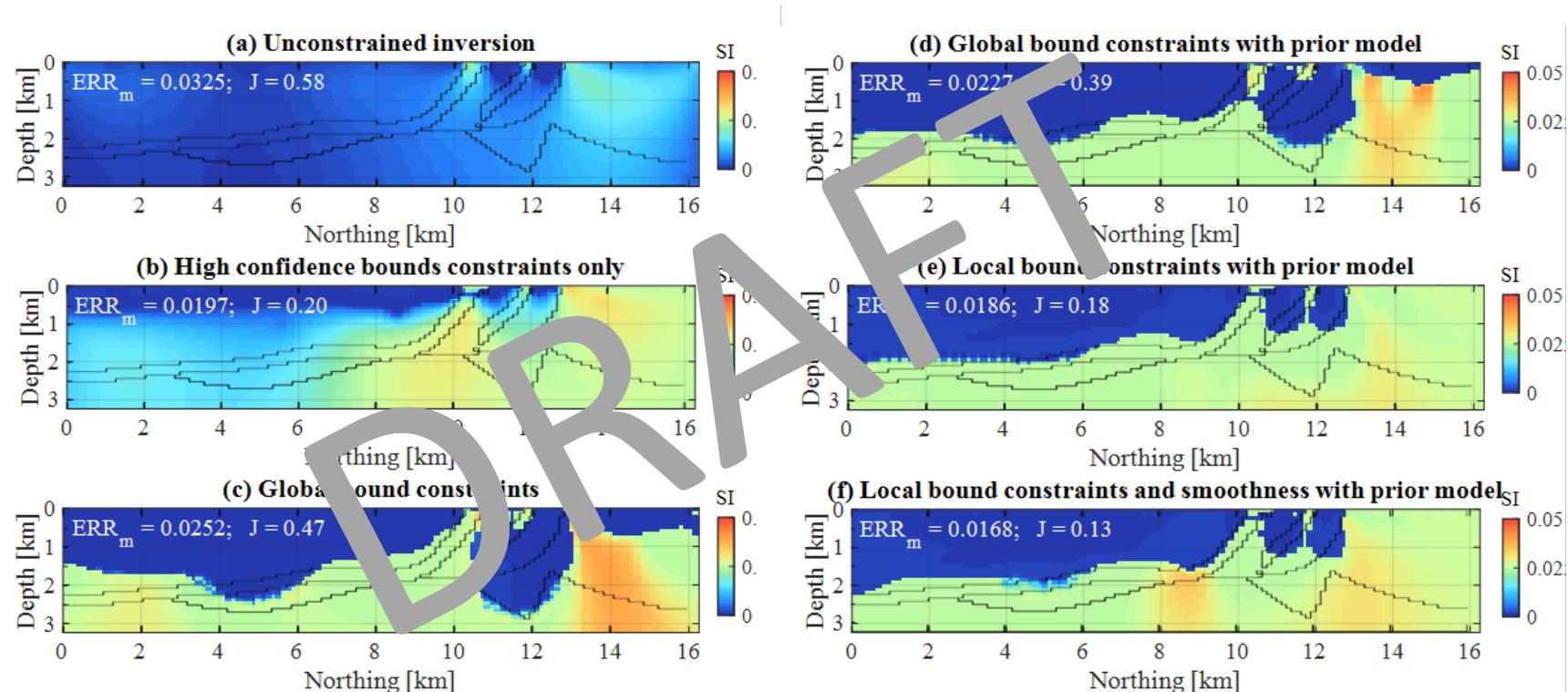


WP #4 – Integrated Geophysical Inversion

Utilisation of probabilistic MT to constrain magnetic inversion.

The grey lines materialise the interfaces between geological units in the true model. 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 2nd 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
- 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 

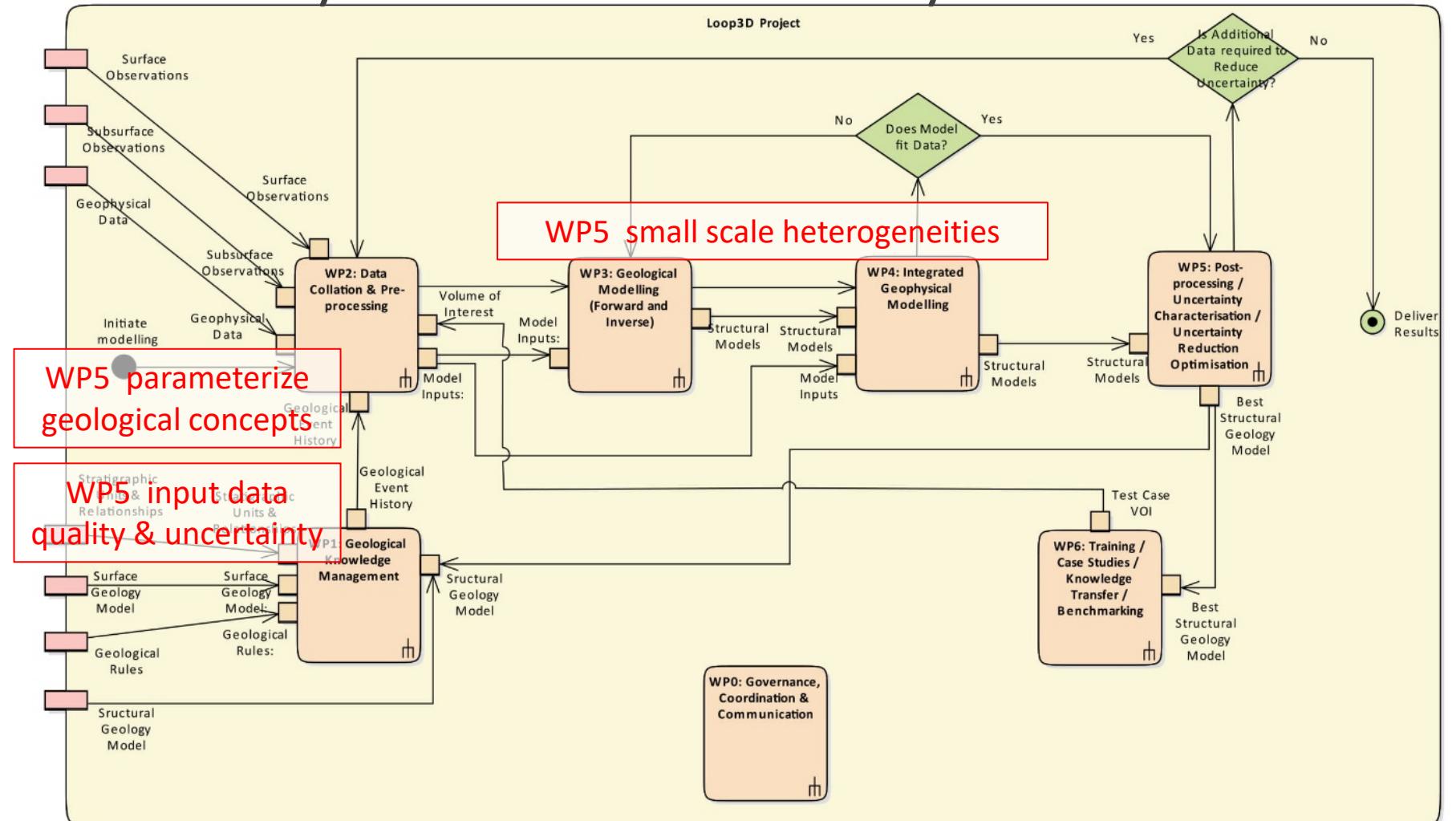
Problem 

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

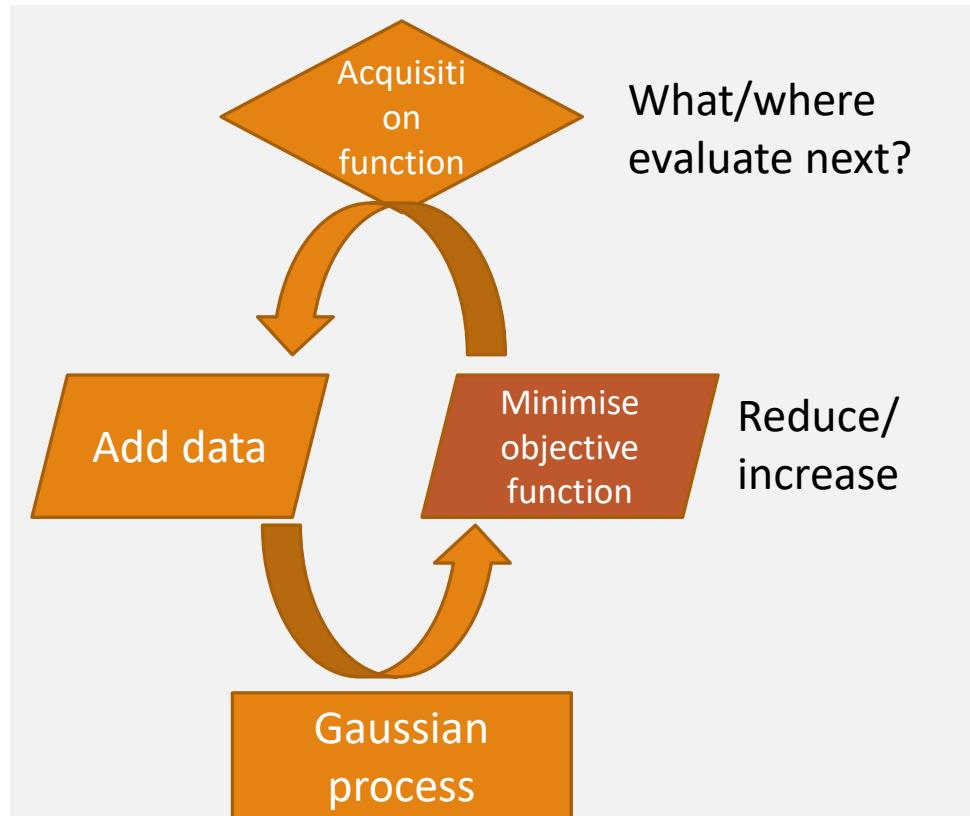
OLS - Global/Local

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 < σ
Markets > σ

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

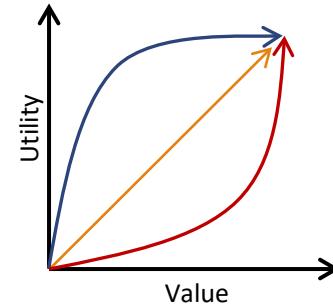
Decision analysis

- 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

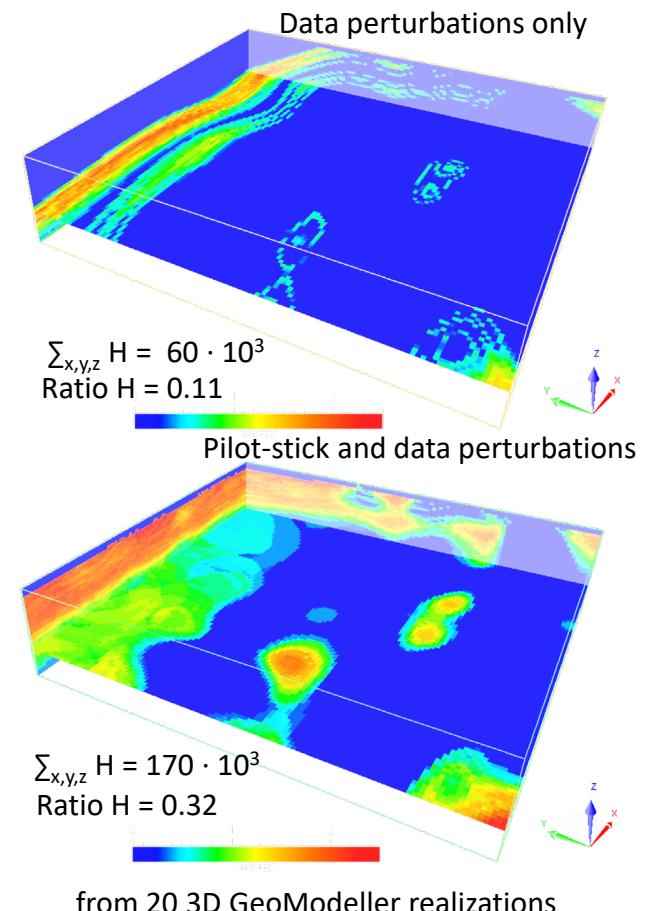
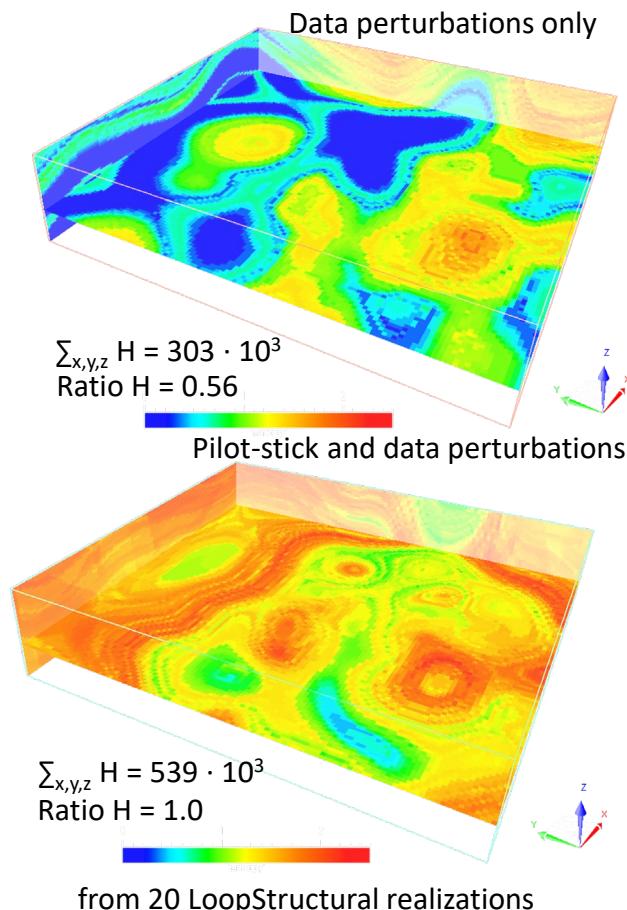
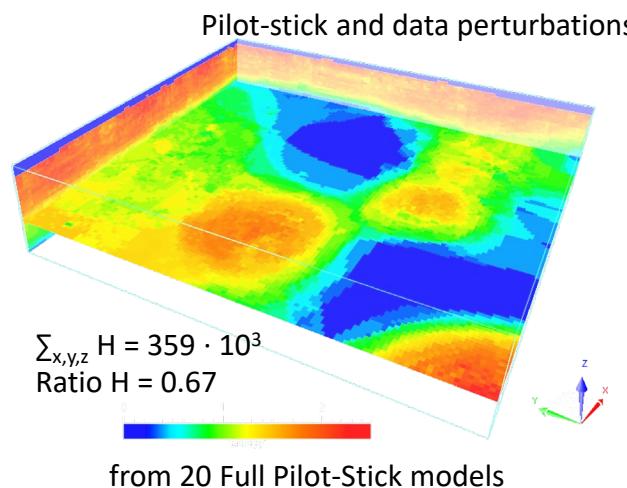
- Define a synthetic reference and prior information (Done)
- Implement pilot drillhole perturbations (Done, improvement in progress)
- Select (Done) and implement the optimization algorithm (Done)



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

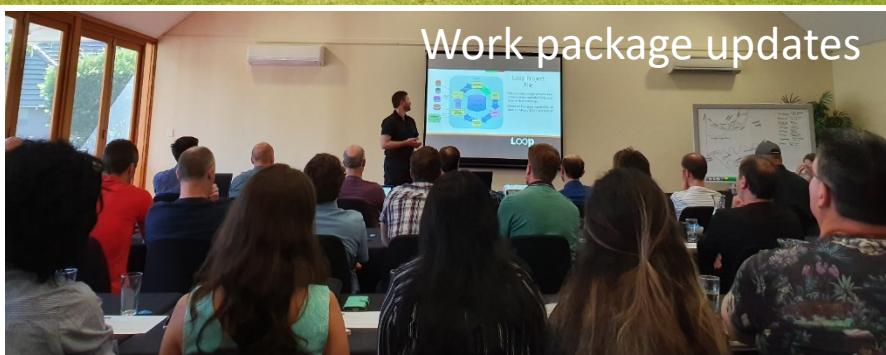
Will not happen

New

- 23. Website – 2nd version went live 9th 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

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

Loop Papers and Conference presentations

■Papers

- Geoscientific Model Development – Special Issue: The Loop 3D stochastic geological modelling platform – development and applications (Laurent Ailleres coordinator)
 - Grose, L., Ailleres, L., Laurent, G., Jessell, M., 2020. LoopStructural 1.0 time aware geological modelling. *Geosci. Model Dev. Discuss.*, <https://doi.org/10.5194/gmd-2020-336>
 - 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

- 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.
- 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

Submitted Papers

- de Kemp, E. Submitted. Spatial Agents for Geological Surface Modeling. Submitted – Geoscientific Model Development
- Hillier, M. et al., Three Dimensional Structural Geological Modelling using Graph Neural Networks. Submitted – Math. Geosciences
- 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., 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.

■ 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 belt
- Grose, L. LoopStructural – Structural frame for the geometrical modelling of polydeformed terranes
- Giraud, J. Use of prior information to constrain geophysical inversions in Tomofast



Loop Papers and Conference presentations

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

- 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
- 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

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 Prospectivity
- 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

■ 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

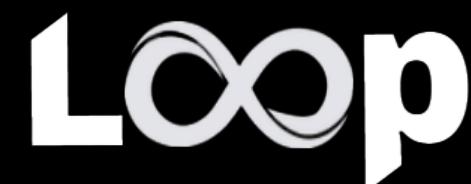
- Grose et al., Fault modeling kinematics

■ 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 - Submitted**

- 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 Prospectivity, 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 Prospectivity 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: <https://github.com/Loop3D/LoopStructural>
- map2loop: <https://github.com/Loop3D/map2loop-2>
- dh2loop: <https://github.com/Loop3D/dh2loop>

