MONASH University

Monash Structural Geophysics Group

School of Earth, Atmosphere and Environment

Loop

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brgm

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Providing geoscience data globally

ONE Geology

Why is Loop needed?

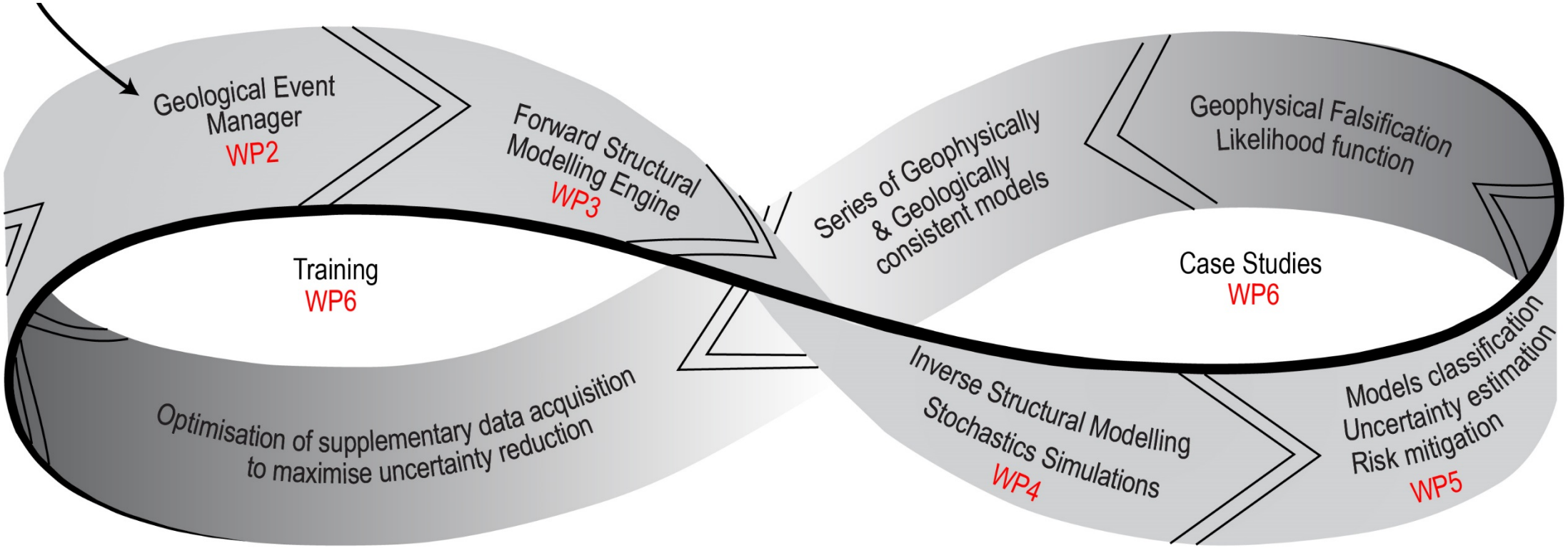
Need to produce an new open-source software to allow 3D Implicit Geological Structural Modelling and Simulate Geological scenarii to quantify/map geological uncertainties.

- Current 3D modelling packages do not handle complex hard rock geological terranes
- Uncertainty of models is high and needs to be robustly quantified/mapped
  - Input data sampling and upscaling methods are ignored
  - geological simulations / scenarii
- Better integration with geophysical data/models – especially to falsify
- Better integration with downstream modelling packages – better meshing tools.
- Project is timely: needs are there and the team is available with members are already working together

What is Loop?

Geological Knowledge Manager

An artificial intelligence method to extract geological knowledge from publicly available documents

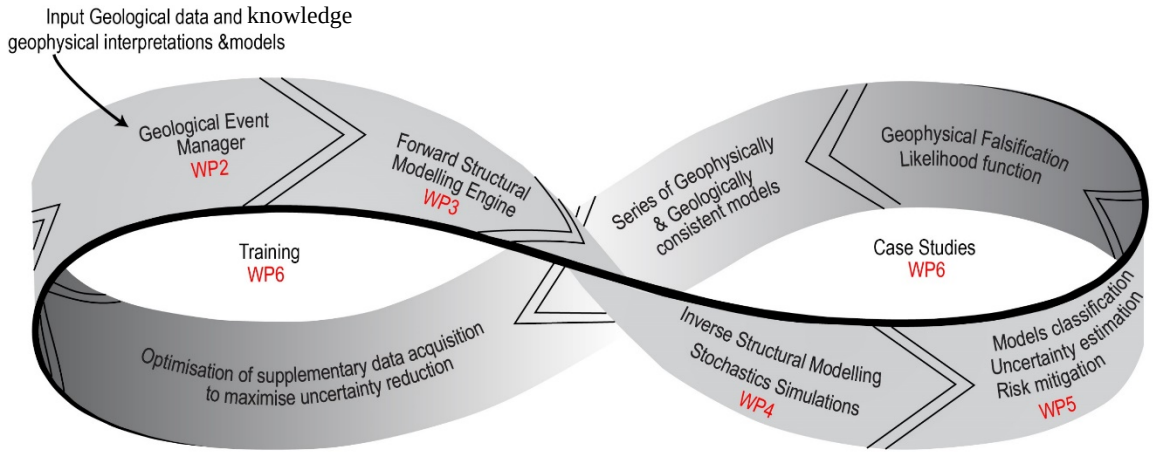


Loop – WP1 // Infrastructure and data structure

Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

Work package 1: Loop Architecture and Data Model:
In order to build a new Open Source platform we require a dedicated Work Package that will oversee:

- the software engineering of the Loop platform,
- the integration of available research codes,
- the management of the open source library and website and
- the facilitation of research and applications using Loop
  - Interoperability,
  - Python support,
  - Versionning (software, data)
  - Etc…

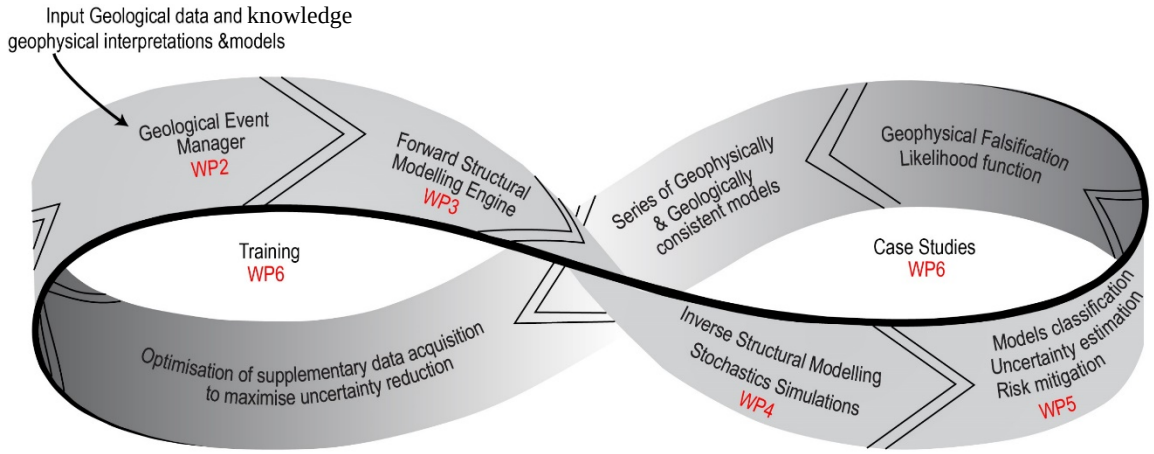


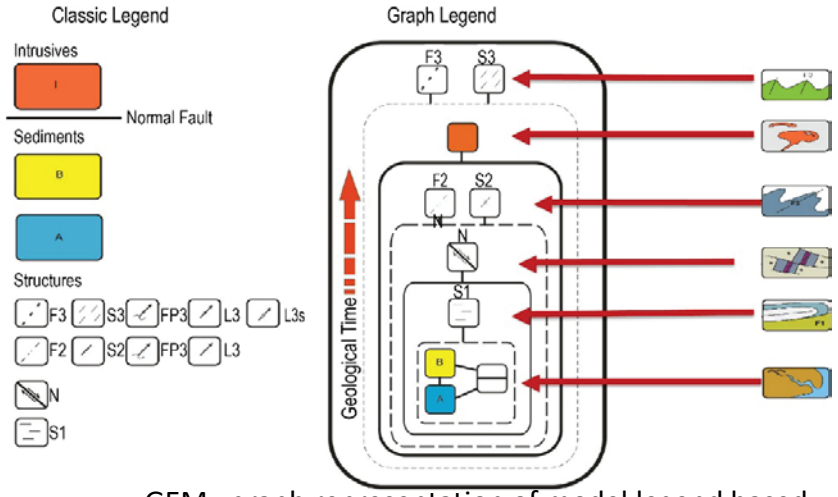
Loop - WP2 // Geological Event Manager

Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

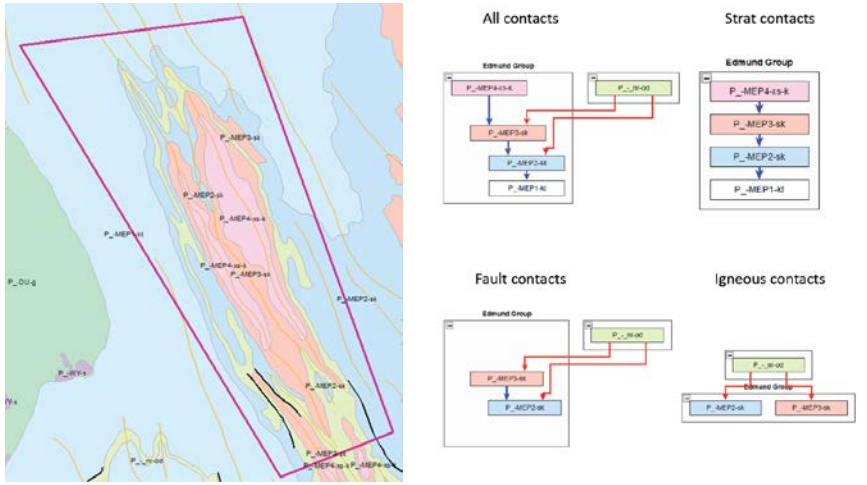
Work package 2: Geological Event Manager (GEM)

- development of methods to mathematically encode knowledge of temporal and spatial relationships of geological features. The GEM will capture and encode all the possible geological process based events that appear in a geological history. This has implications on the topology (mutual relationships of multiple geological objects) of the models which is dependent on the relative timing of the geological events.
- Sets the rules for the “forward structural modelling engine”. The GEM will also captures inherent uncertainty associated with data and observations.





GEM: graph representation of model legend based on geological history



Map2model: ArcGIS plugin to extraxct topological relationship automatically from maps

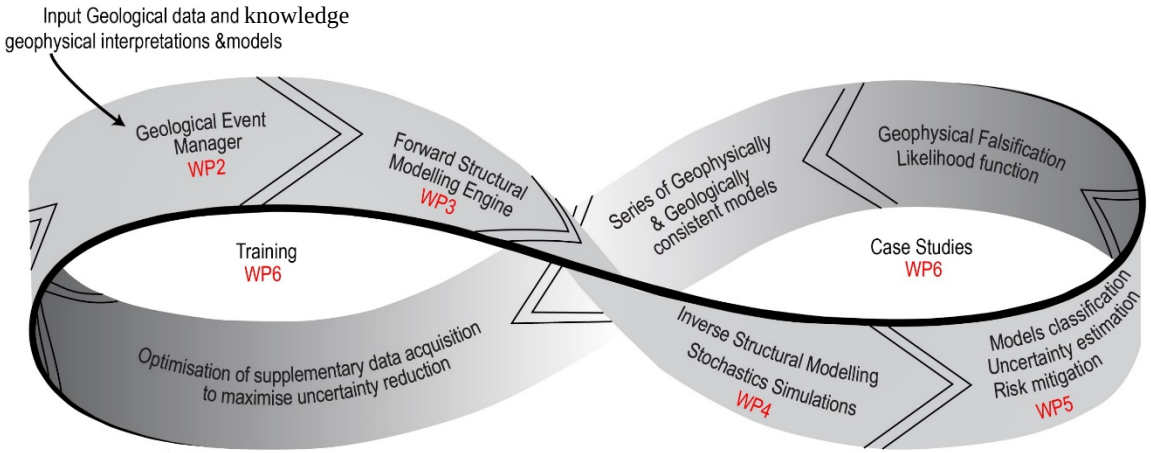
Loop - WP3 // Forward Structural Modelling Engine

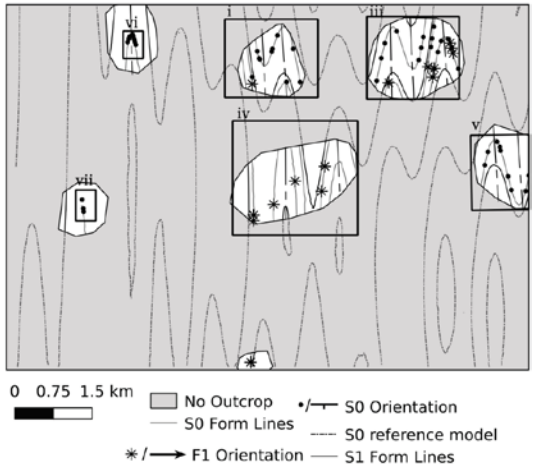
Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

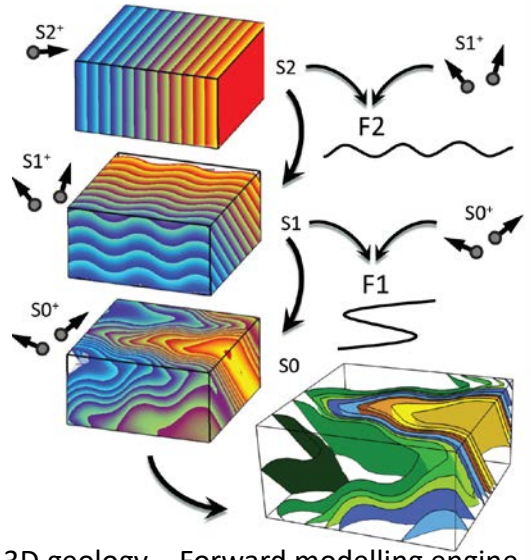
Work package 3: Forward Structural Modelling Engine:
The Forward Structural Modelling Engine will utilise information derived from the GEM to build 3D geological models by fitting interfaces between geological observations.
Methods will be developed to model all types of geological objects:

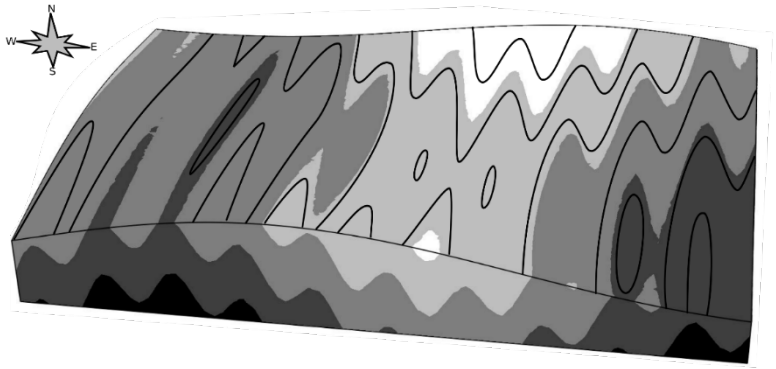
- faults and fault network (including estimating fault throws, amplitude and direction of offset),
- unconformities,
- intrusions.

The modelling will be time-aware in order to account for topological constraints.







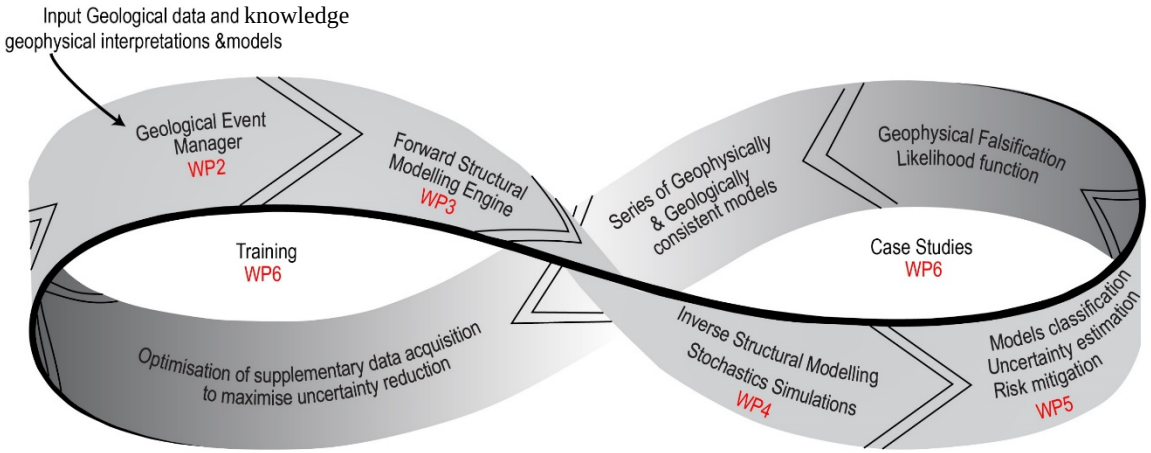


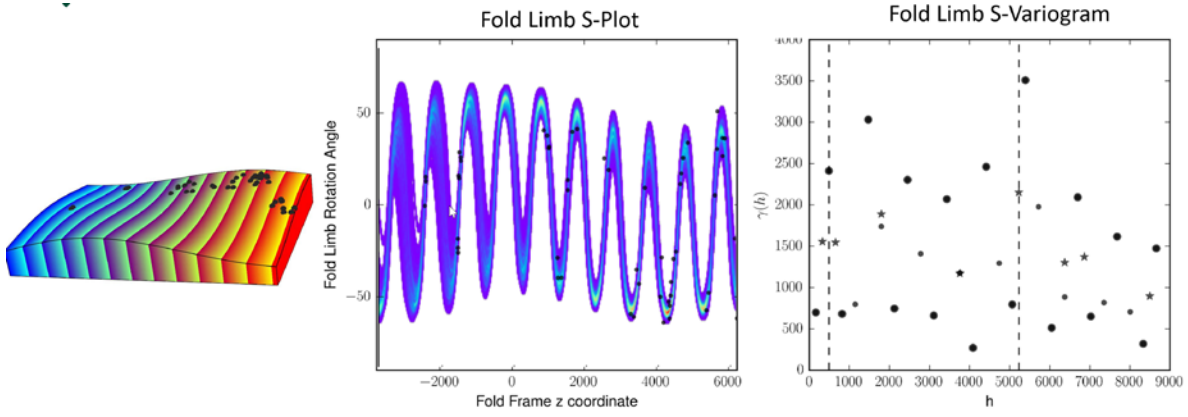
From structural maps to one realization of the 3D geology – Forward modelling engine

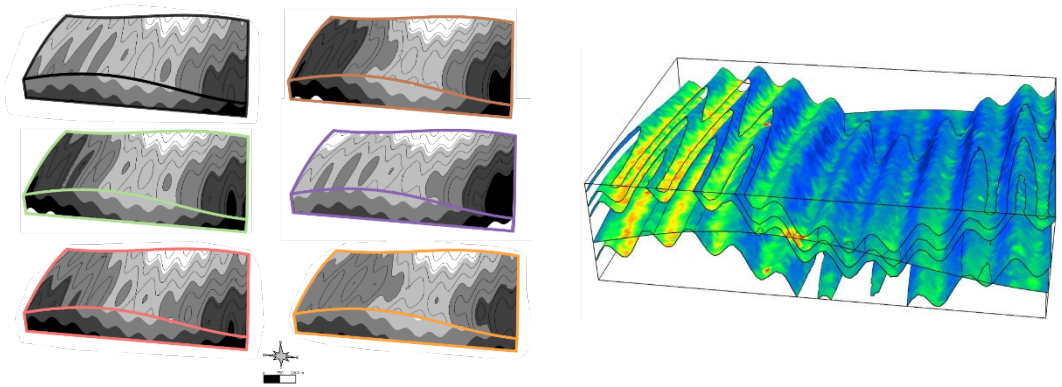
Loop – WP4 // Structural Inversions

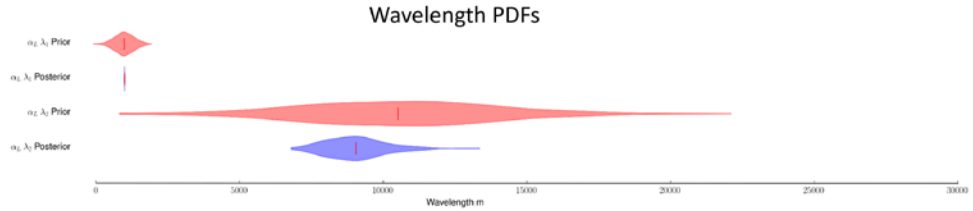
Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

Work package 4: Structural Inversion and Stochastic Simulations Engine: The Forward Structural Modelling Engine will be developed while ensuring that the parameters of the structural interpolants can be fitted through Bayesian inferences and inversion using Markov Chain Monte Carlo sampling. This is similar to the method recently developed by Grose et al. (2017 Tectonophysics and inc. Bayesian modelling recently accepted to JGR) for folds and fold overprinting and Wellmann et al. (2017). We consider that the creation of 3D geological models can be framed as an inverse problem where the aim is to infer parameter values for the interpolation algorithm given geological observations and knowledge.







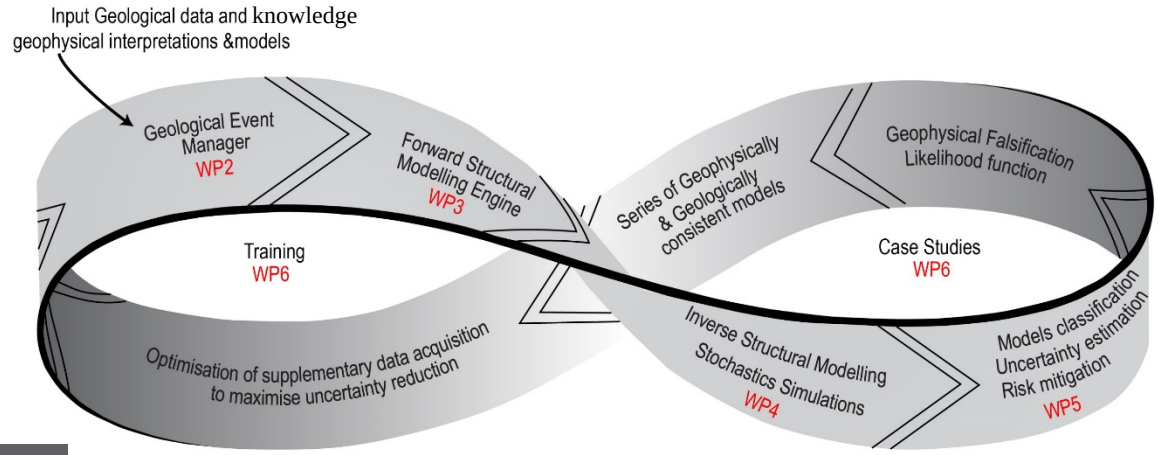


From left to right: Probabilistic modelling (Bayesian modelling) to fit multiple fold wavelengths to structural data. Both fold axis fields and folded foliation fields are fitted simultaneously. The probabilistic modelling results in a series of structural models and characterisation of structural uncertainty.

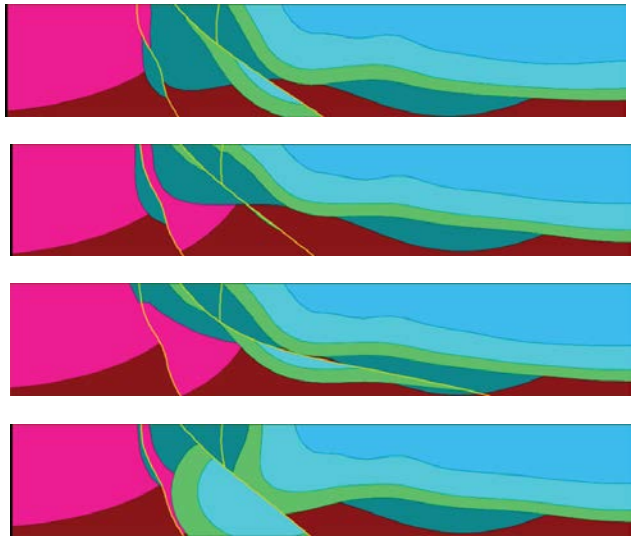
Loop - WP5 // Characterising 3D Uncertainty

Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

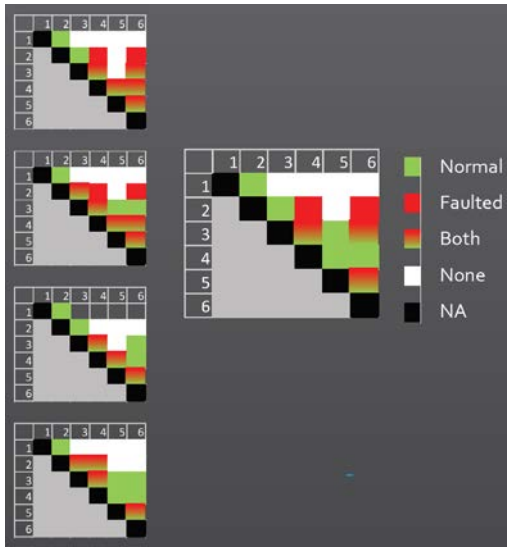
Work package 5: Uncertainty Analysis and Automatic Model Classification:
The aim of this module is to be able to simulate data uncertainty throughout the modelling workflow and to classify models according to their geometrical and topological characteristics using the concept of geo-diversity developed by Lindsay et al. (2013a; b; 2014) and Thiele et al. (2016a & b).
These characteristics will allow the falsification of model classes that display characteristics not consistent with the input data and knowledge.



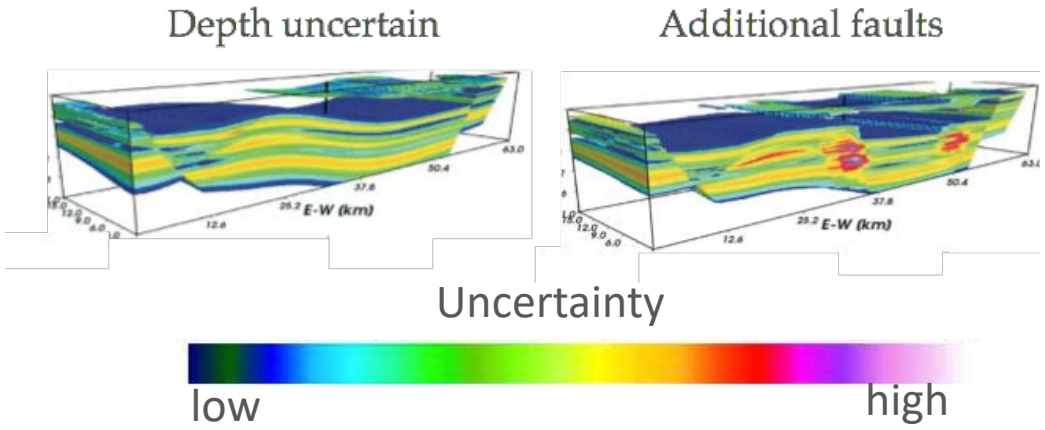
Extreme models



Topological classification



Giraud et al., 2017 - Geophysics

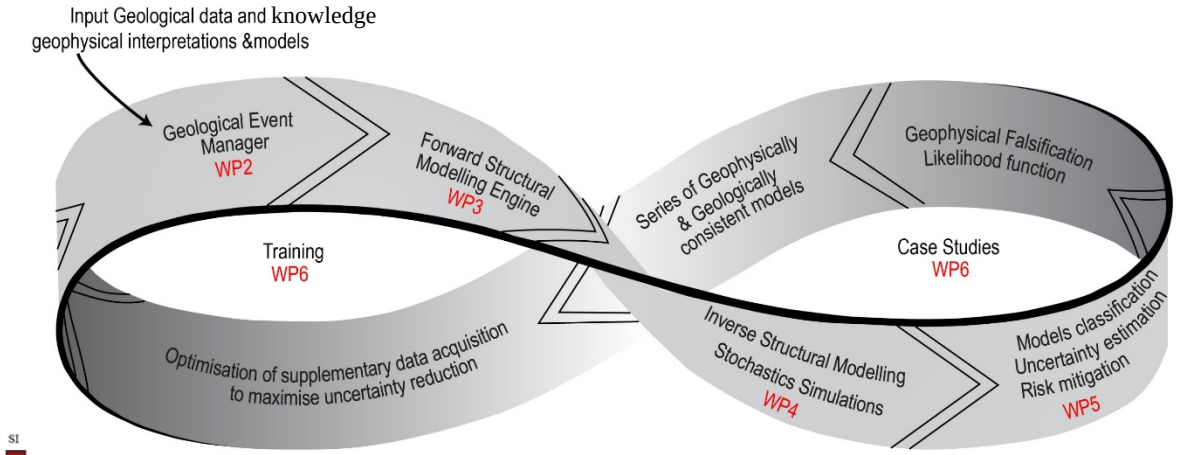


Wellmann et al., 2012 - Tectonophysics

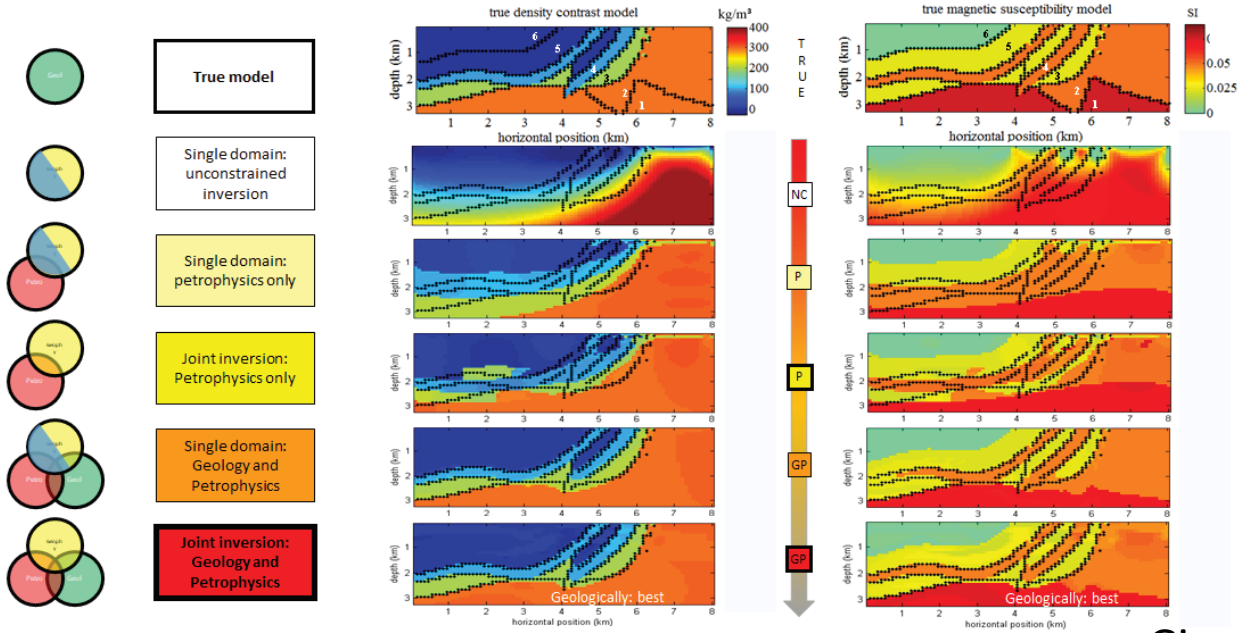
Loop - WP5 // Geophysical Inversions and Modelling

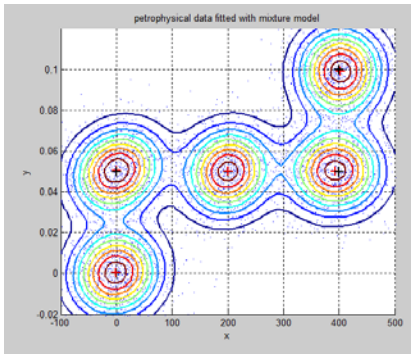
Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

Work package 5: Uncertainty Analysis and Automatic Model Classification: Geophysical inversions will be used to both provide key inputs to the modelling, and falsify model classes. The research in geophysical modelling will build on recent method utilising lithological uncertainty as an inference for petrophysical property during joint magnetic-gravity inversions.



2D Geophysical Inversions





Probability density functions for multiple petrophyical properties per lithology. Lithologies are also defined throughout the model with a PDF for each voxel.

Giraud et al., 2017 - Geophysics

Loop - Funding

Loop : an new open-source software for 3D Geological & Geophysical Modelling and Simulations

GSC: 2 post-doctoral positions [interpolants + geological knowledge manager] +/- 4 staff

BRGM: 1 PhD position [anisotropic interpolants] + /- 4 staff

BGS: 1 post-doctoral position [geological knowledge manager] +/- 4 staff

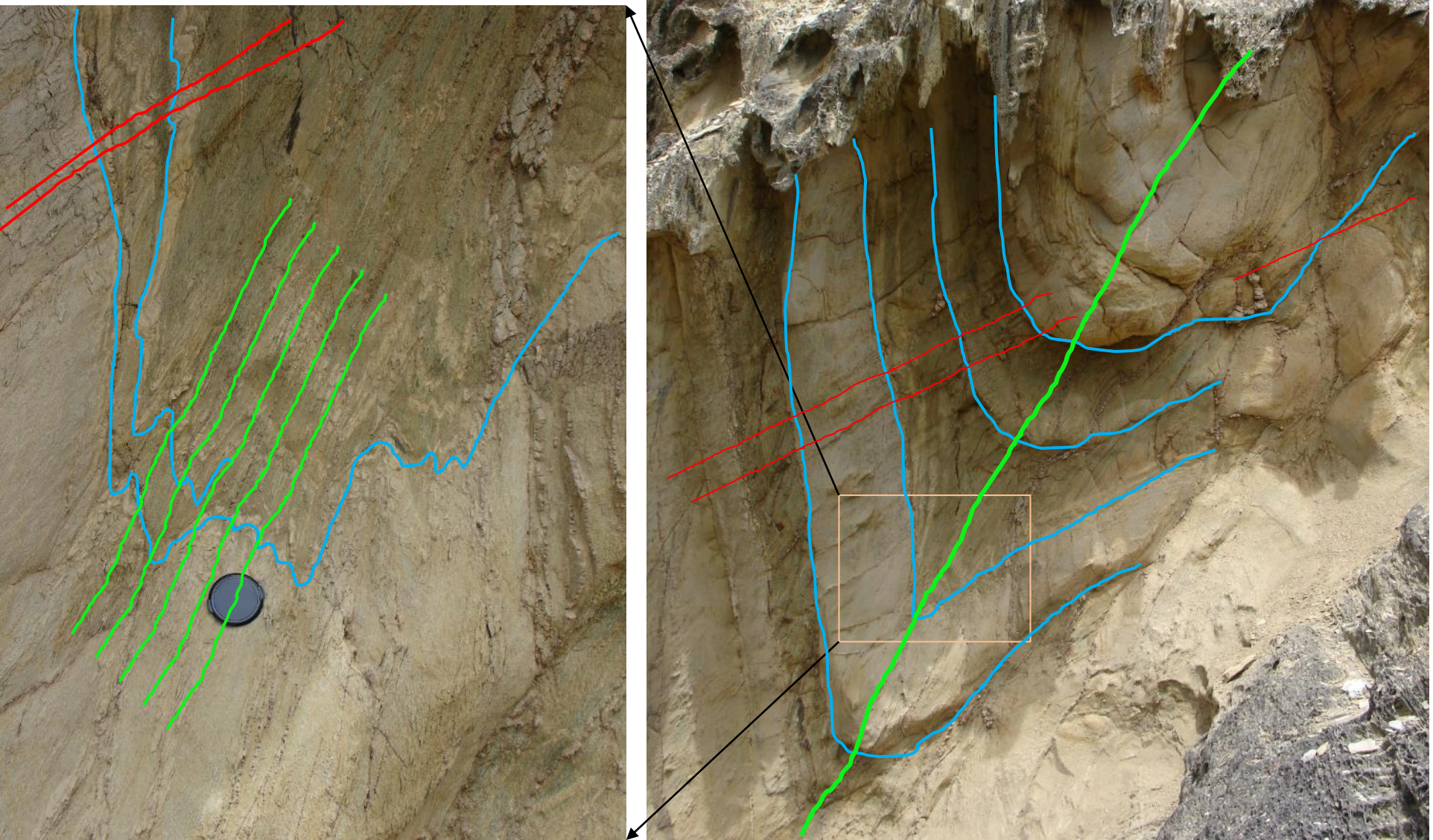
Geoscience Australia + GSWA + NTGS + GSNSW + GSSA + Auscope:

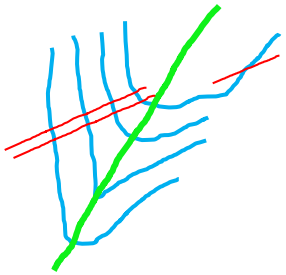
- >$1M cash; >$1.3M in-kind leveraged against ARC Linkage grant: FUNDED ☺ $711K
- Announced yesterday
- This would fund over 3 years:
  - 1 software architect
  - 1 software programmer
  - 2 post-doctoral positions [forward structural engine / uncertainty characterisation
  - Collaborative research funding

MinEx CRC (ARC Collaborative Research Centre): 2 post-doctoral positions [uncertainty and geophysical modelling/inversions]

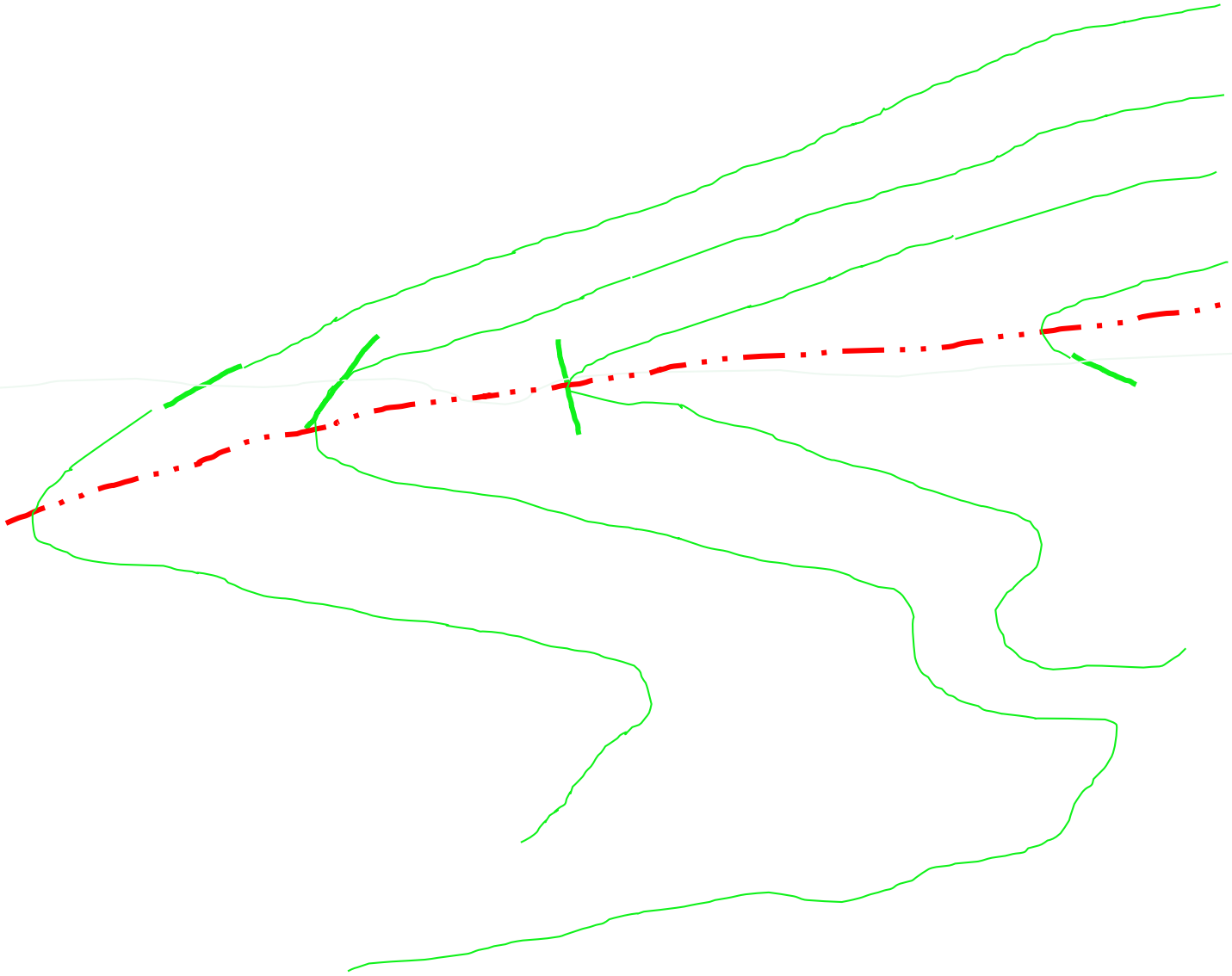
A time aware interpolator for foliations and structural information

Looking South into Bermagui Heads, stratigraphy dipping steeply West

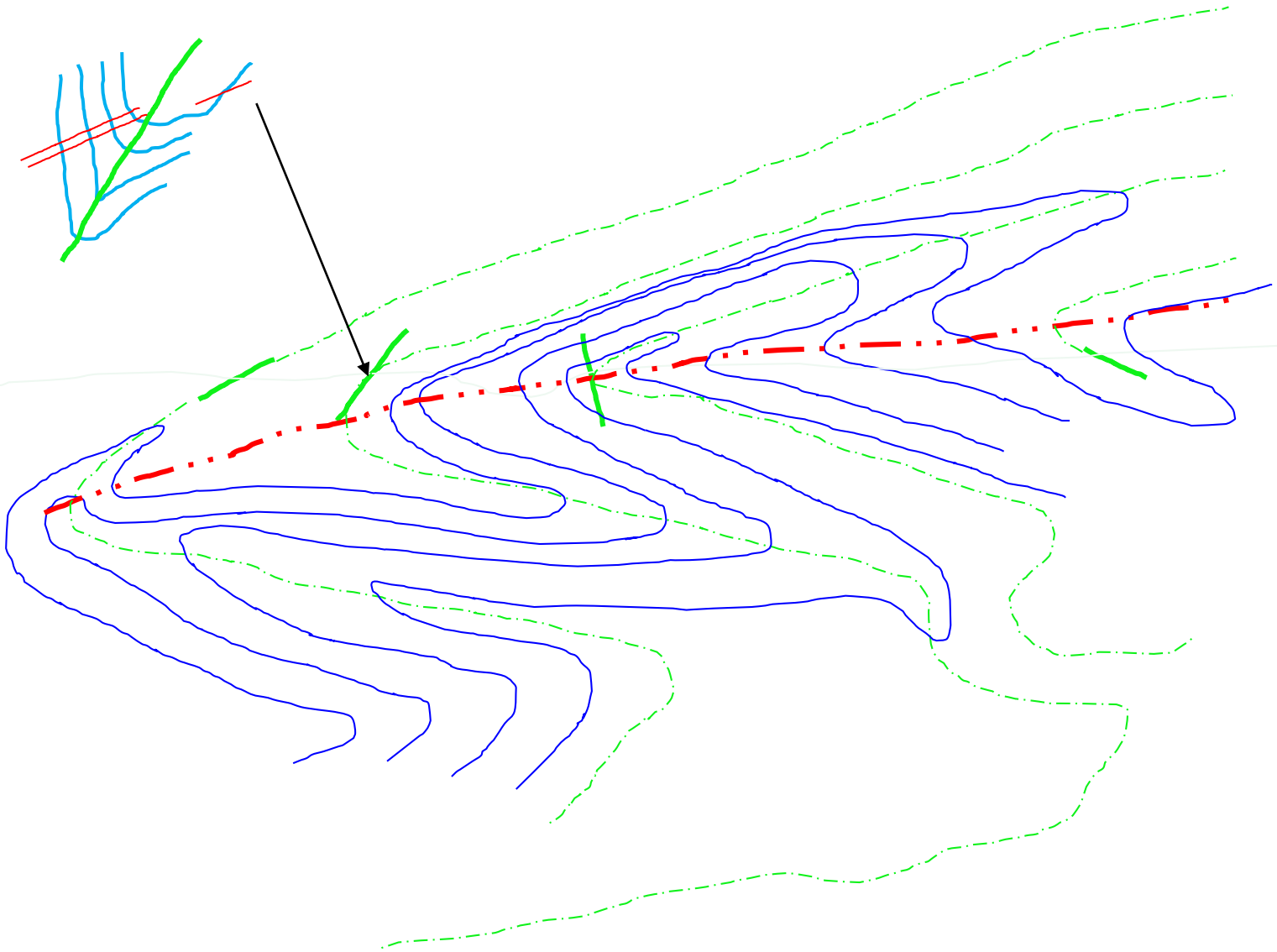




Topography



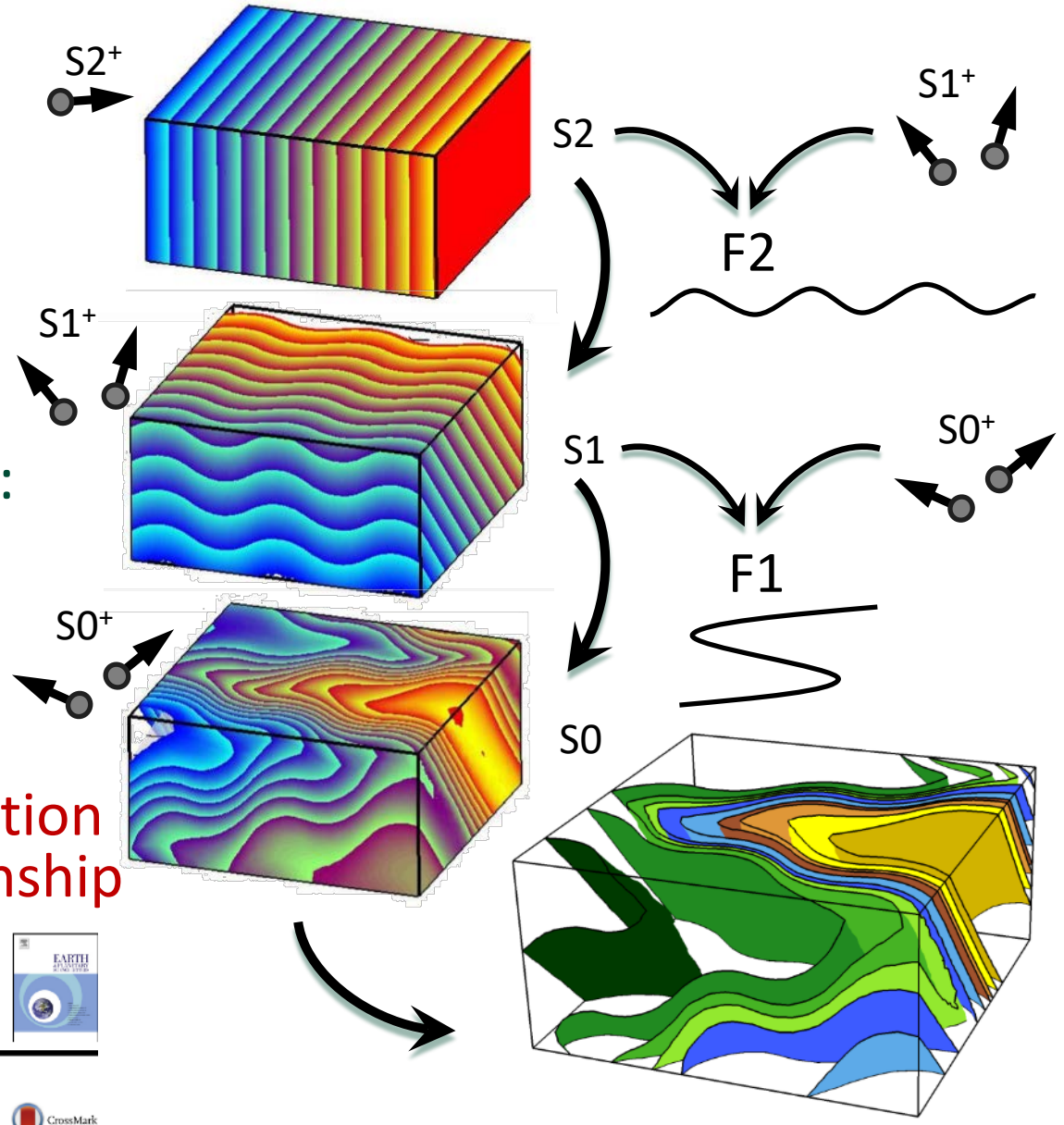
Topography



1. Poly-deformation:
   - Model step by step
   - Restoration approach
     - going backward in time
   - Fold operator:
     - $S_{i-1} = Fi(S^{+}_{i-1} \mid P_i)$

2. Fold characterisation:
   - Statistics from data
   - Fold Frames
     - Using structural elements
   - Fold Profiles

‼ No deformation simulation
‼ Only geometric relationship



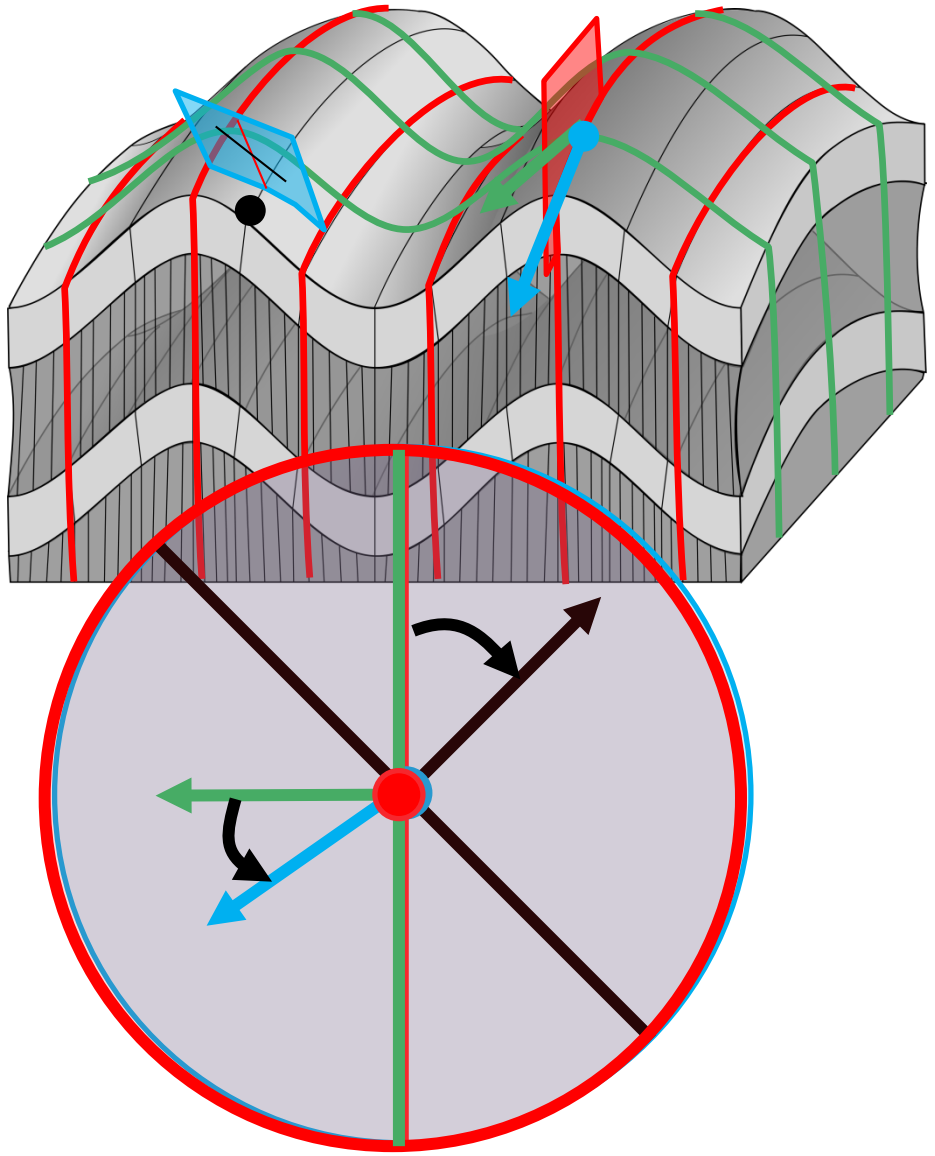
Contents lists available at ScienceDirect
Earth and Planetary Science Letters
www.elsevier.com/locate/epsl
ELSEVIER

Implicit modeling of folds and overprinting deformation

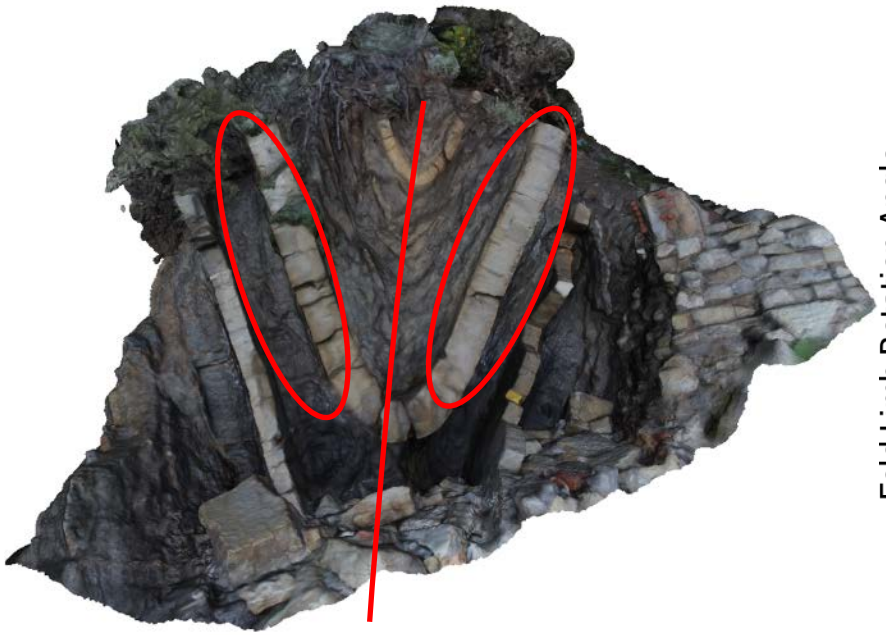
Gautier Laurent [a,b,*], Laurent Ailleres [a], Lachlan Grose [a], Guillaume Caumon [b], Mark Jessell [c], Robin Armit [a]

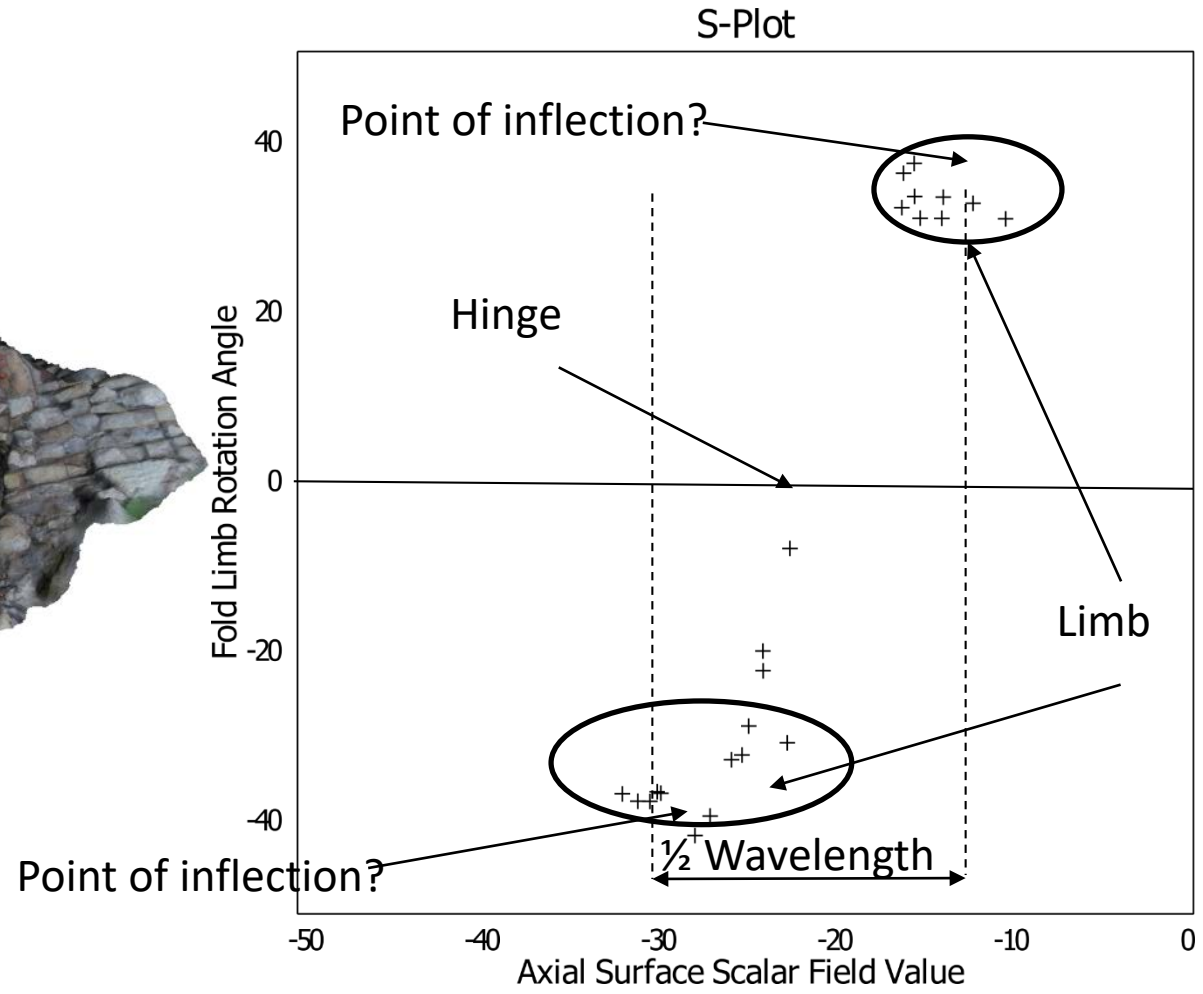
Implicit Fold Modelling: Quantifying fold geometry locally

- Fold Axis Rotation Angle
  - Fold axis observation
  - Gradient of Y field
  - In (axial foliation) XY plane
- Fold Limb Rotation Angle
  - Folded foliation observation
  - Gradient of axial foliation (Z field)
  - Looking down plunge



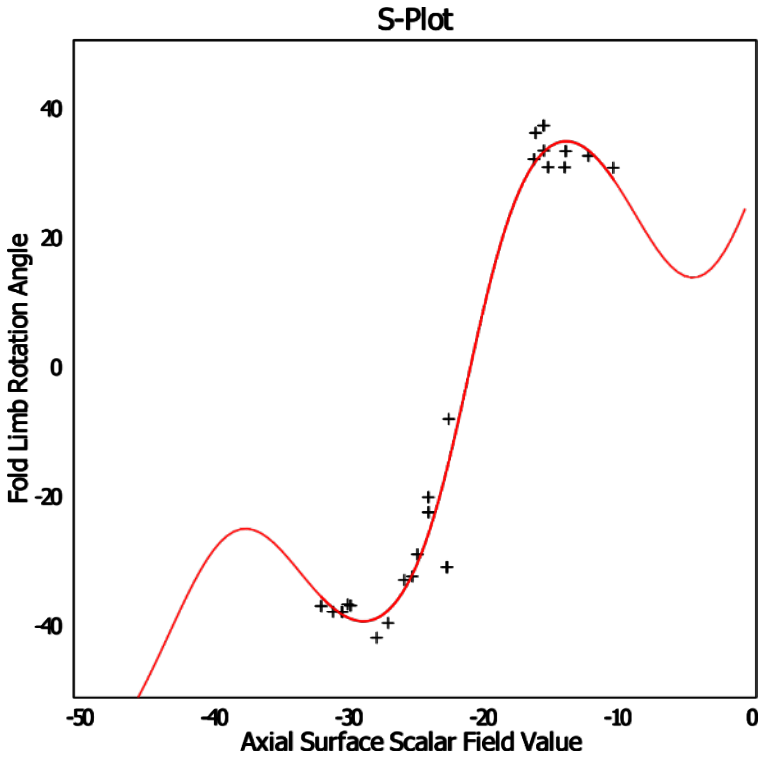
Fold geostatistics

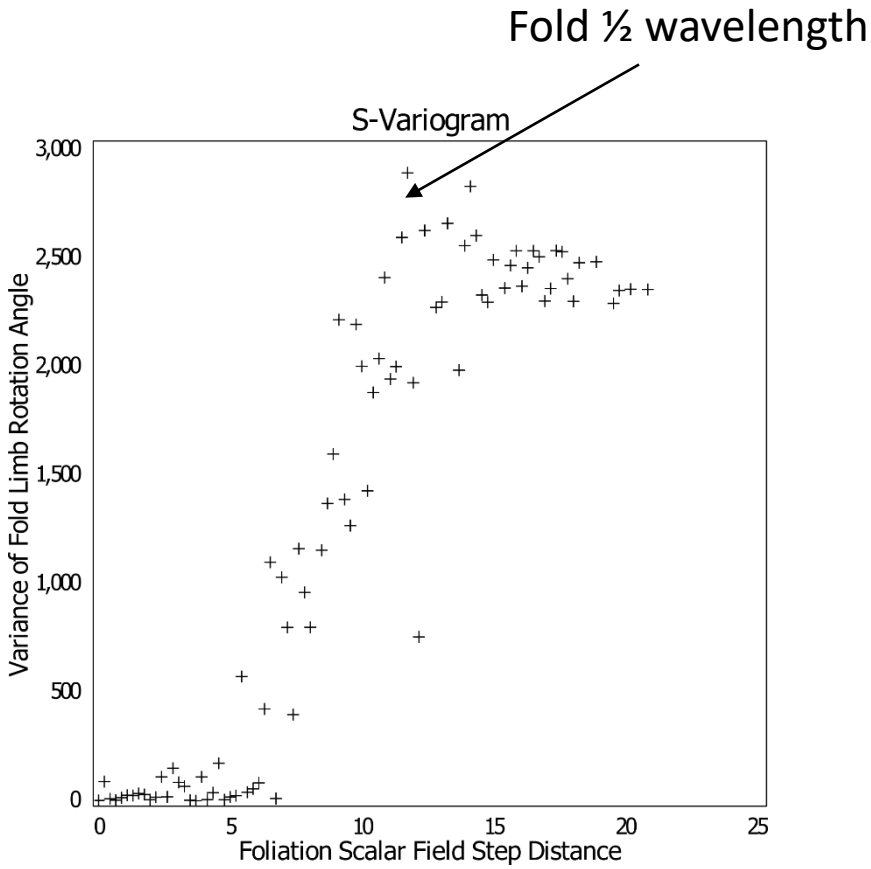




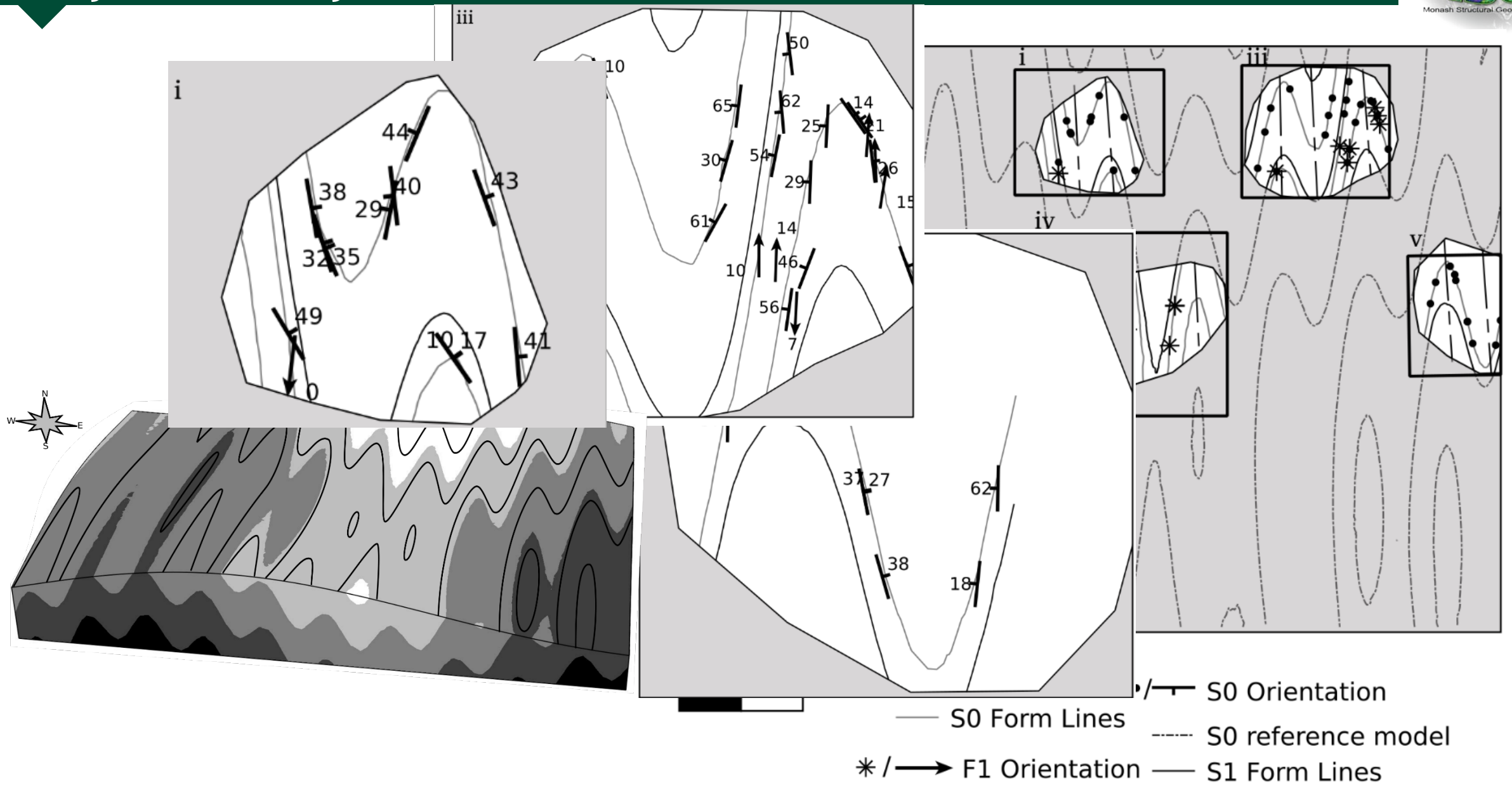
Fold geostatistics

- Interpolate gradient directly instead of angle
- Use fold wavelength as shape parameter



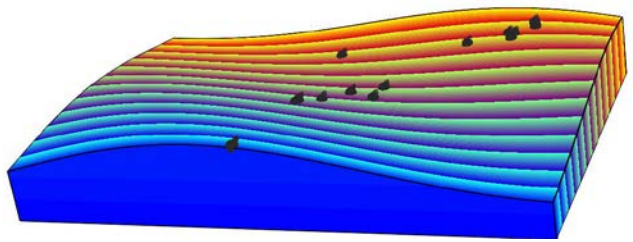


Todays case study

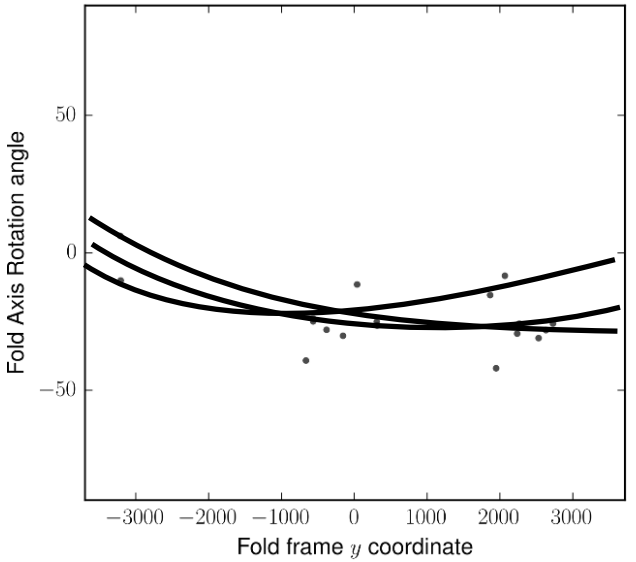


Fold Geostatistics

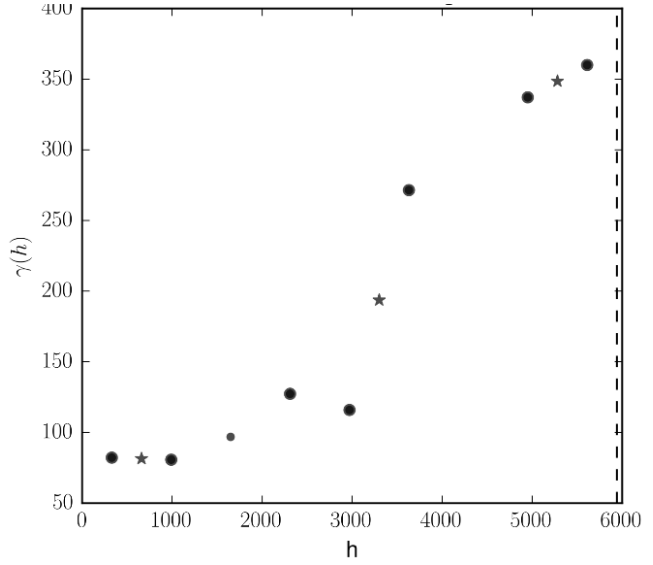
Fold frame y coordinate



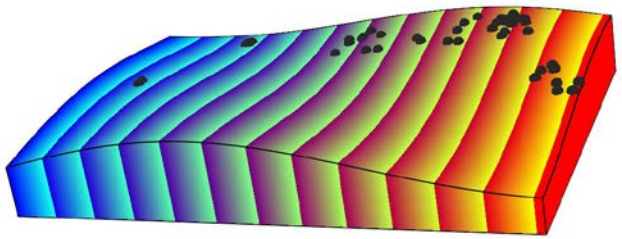
Fold Axis S-Plot



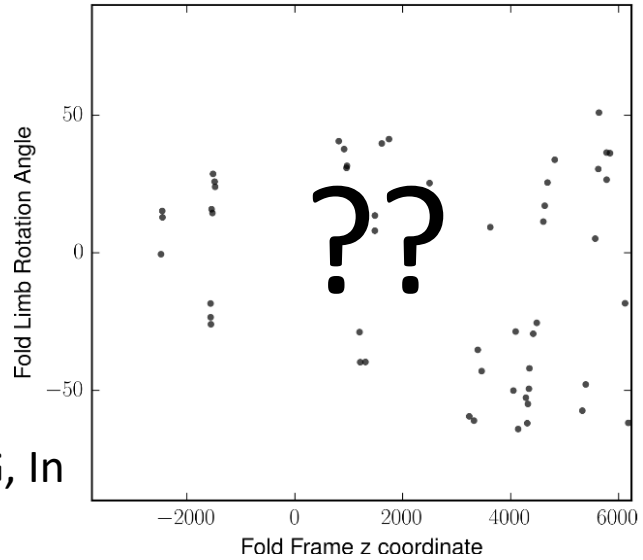
Fold Axis S-Variogram



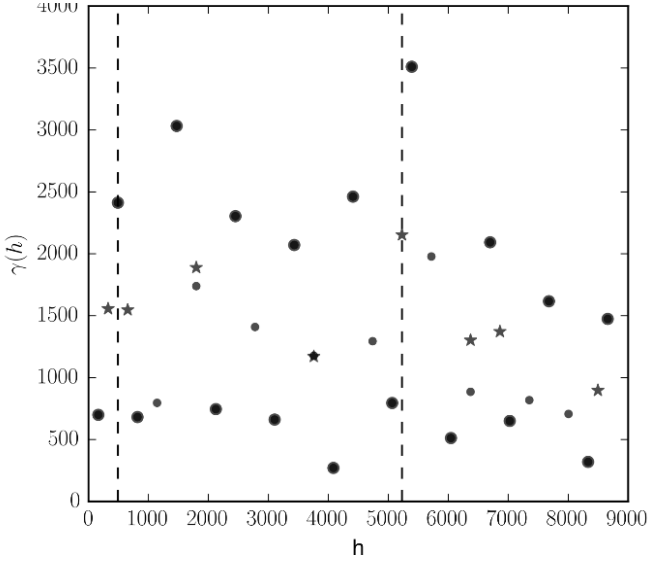
Fold frame z coordinate



Fold Limb S-Plot



Fold Limb S-Variogram



(Grose et al., 2017, JSG, In Press)

Bayesian Inference for Fitting Fourier Series Fold Geometry Model

- Parasitic folds modelled specifying multiple wavelength parameters

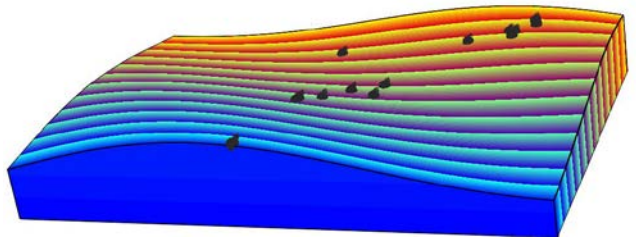
$$\hat{y}\left(x_i|A_0, A_{1..n}, \lambda_{1..n}\right) = A_0 + \sum_{n=1}^{N} B_n \cos\frac{2\pi}{\lambda_n}x_i + \sum_{n=1}^{N} A_n \sin\frac{2\pi}{\lambda_n}x_i + \text{uncertainty}$$

- Bayesian inference

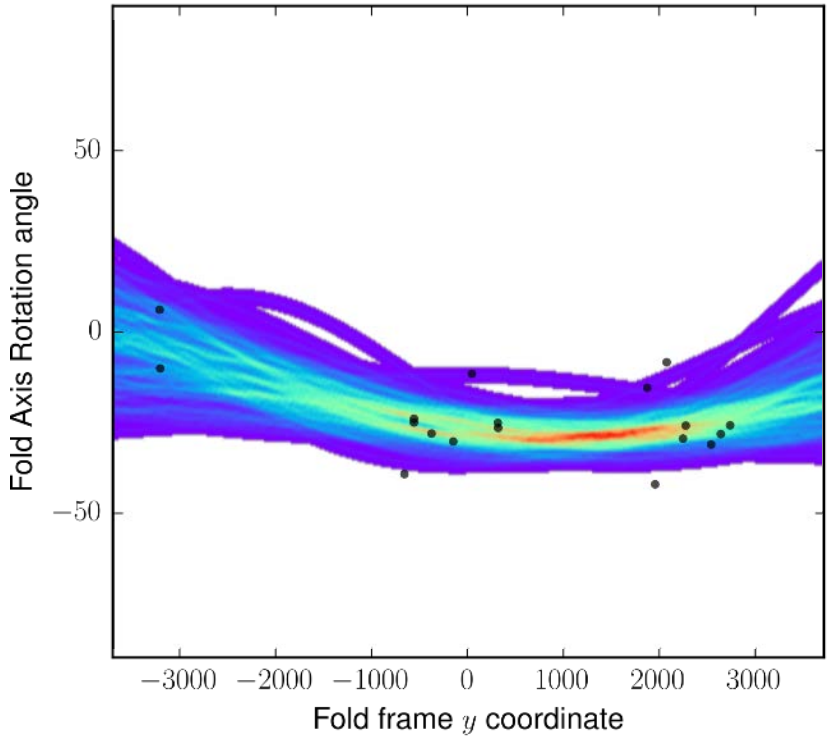
$$P(\theta|D) \propto P(D|\theta) \cdot P(\theta)$$

- Prior distributions:
  - Fourier coefficients – Normal distribution
  - Wavelength – Normal distribution
  - Uncertainty – Jeffery's prior (uninformative)
- Sample from joint posterior distribution using Gaussian likelihood function and Markov Chain Monte-Carlo sampler using PyMC2
- Find joint posterior distribution for BOTH rotation angles

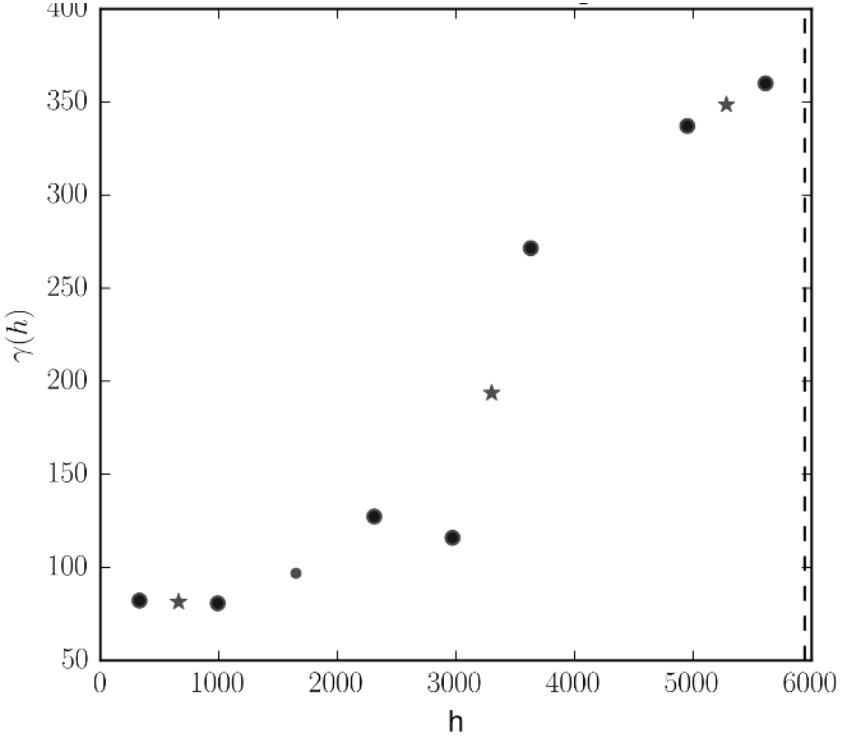
Fold axis rotation angle



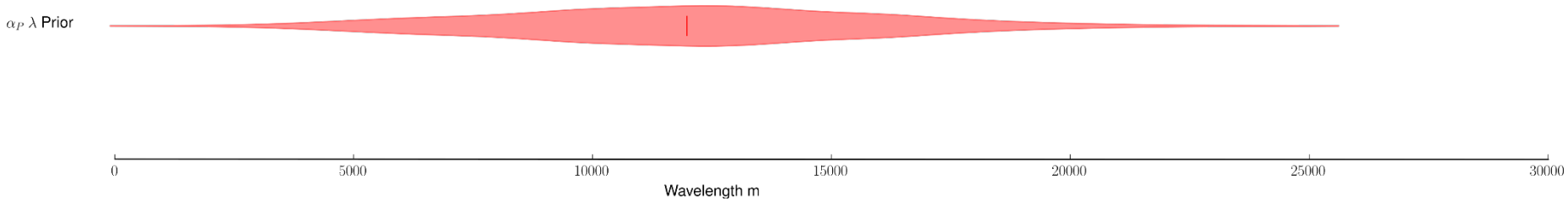
Fold Axis S-Plot



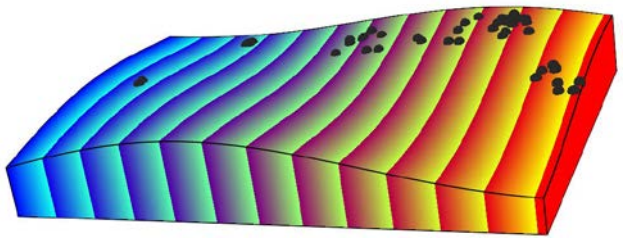
Fold Axis S-Variogram



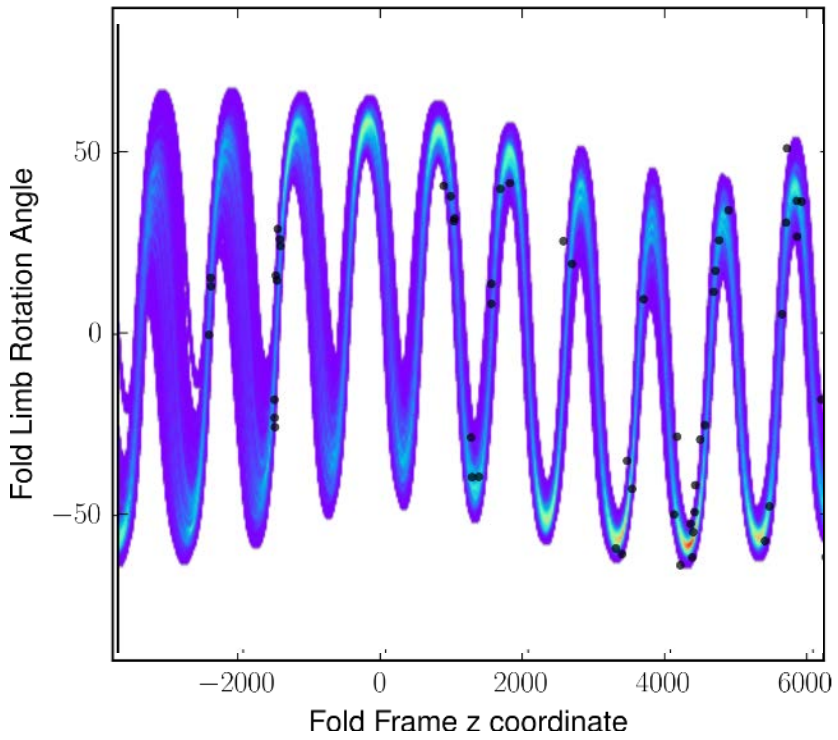
Wavelength PDF



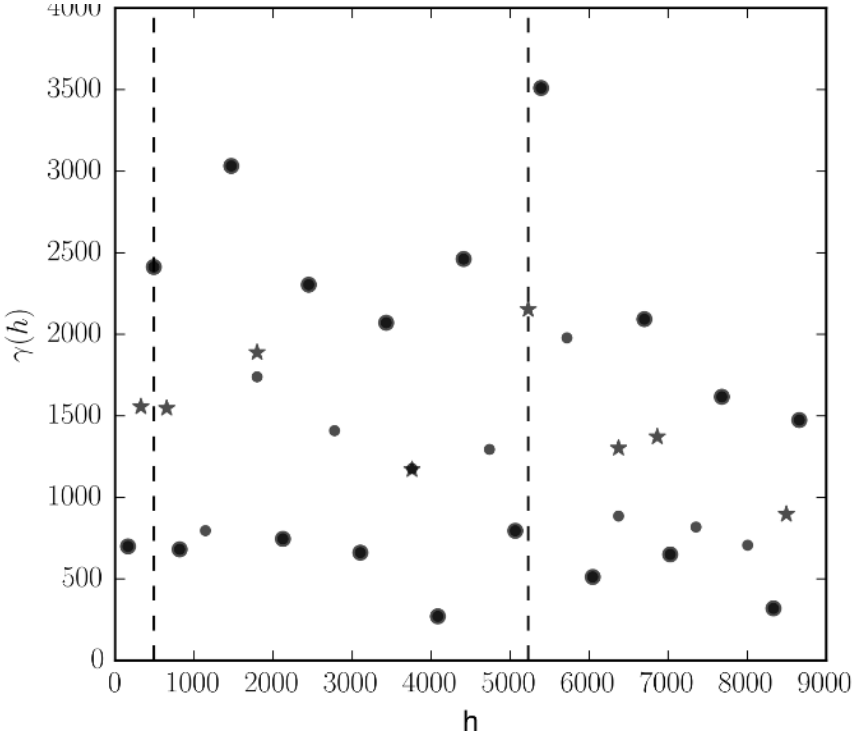
Fold Limb Rotation angle



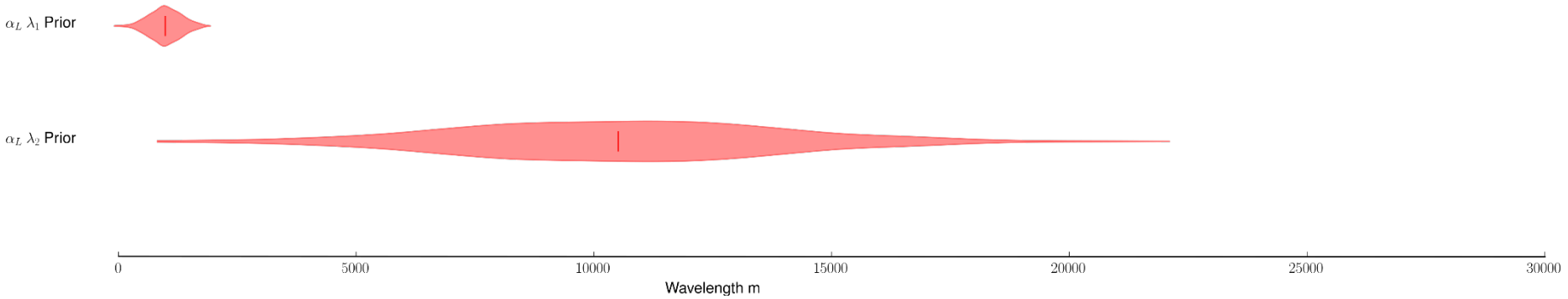
Fold Limb S-Plot



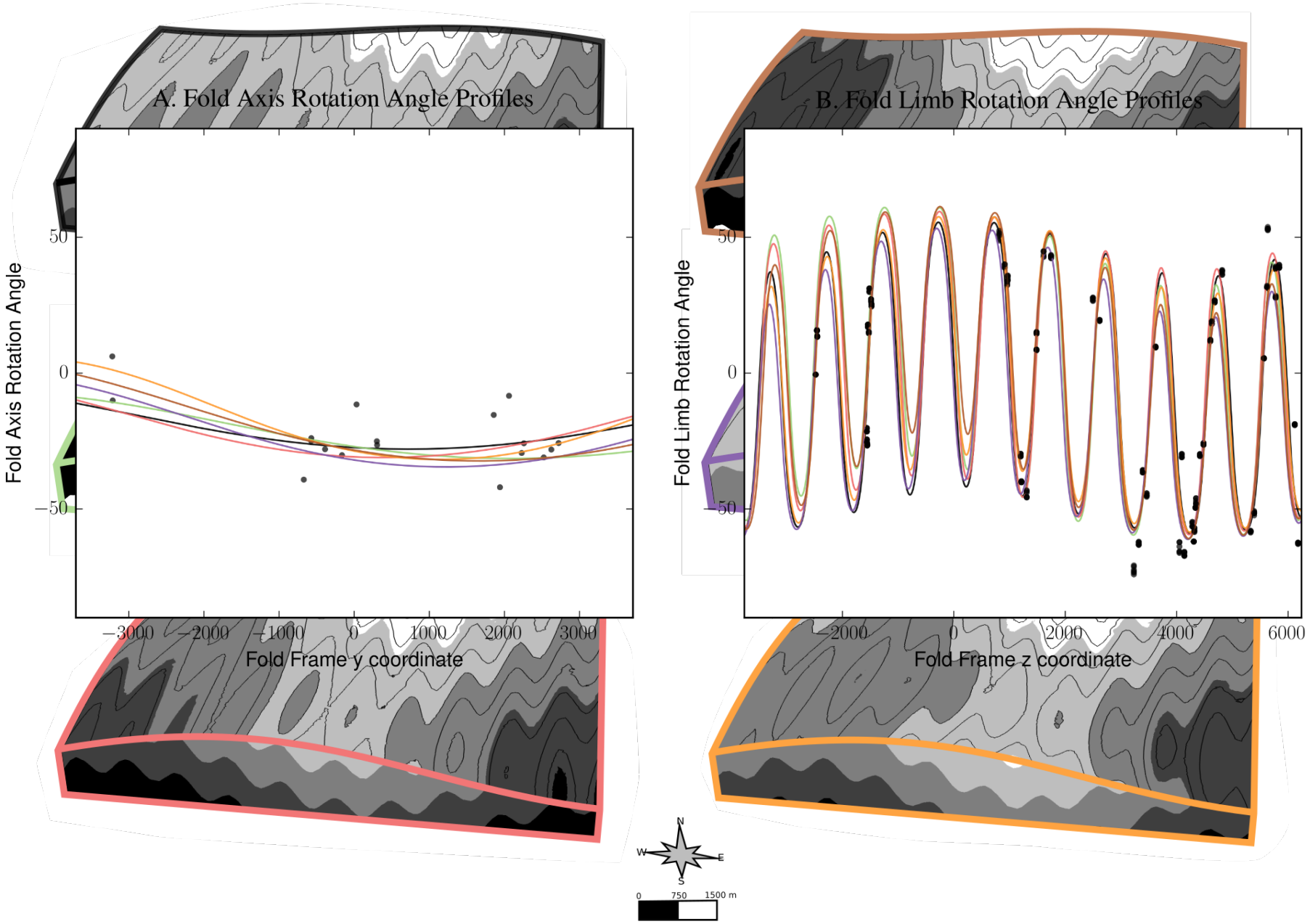
Fold Limb S-Variogram



Wavelength PDFs

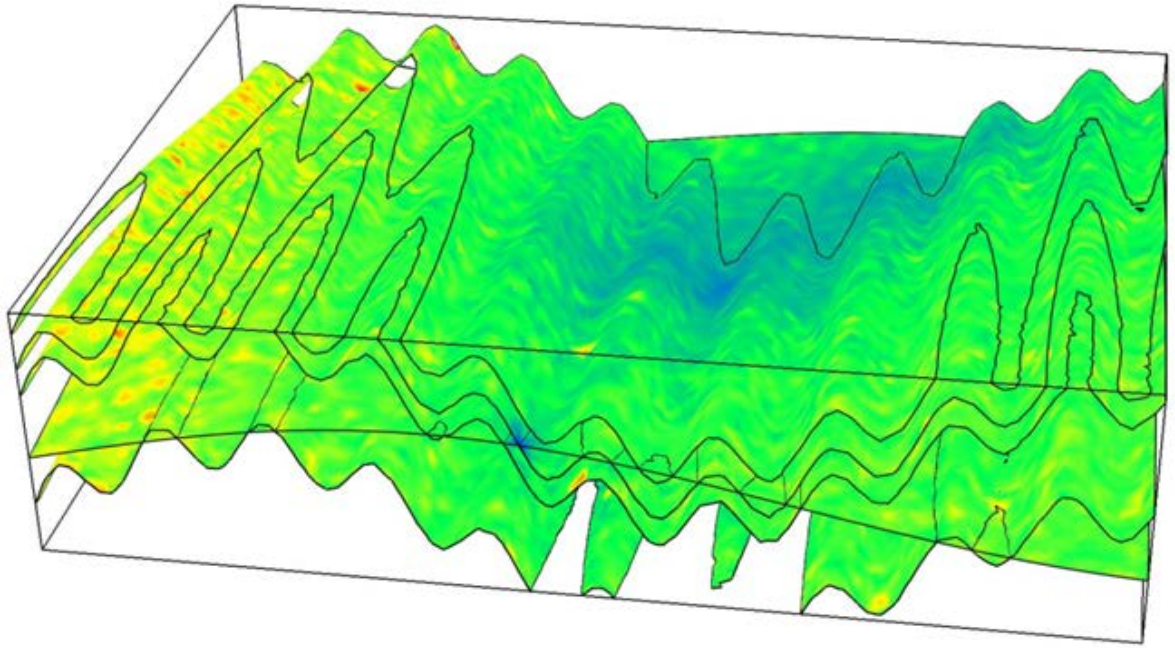


Sample models

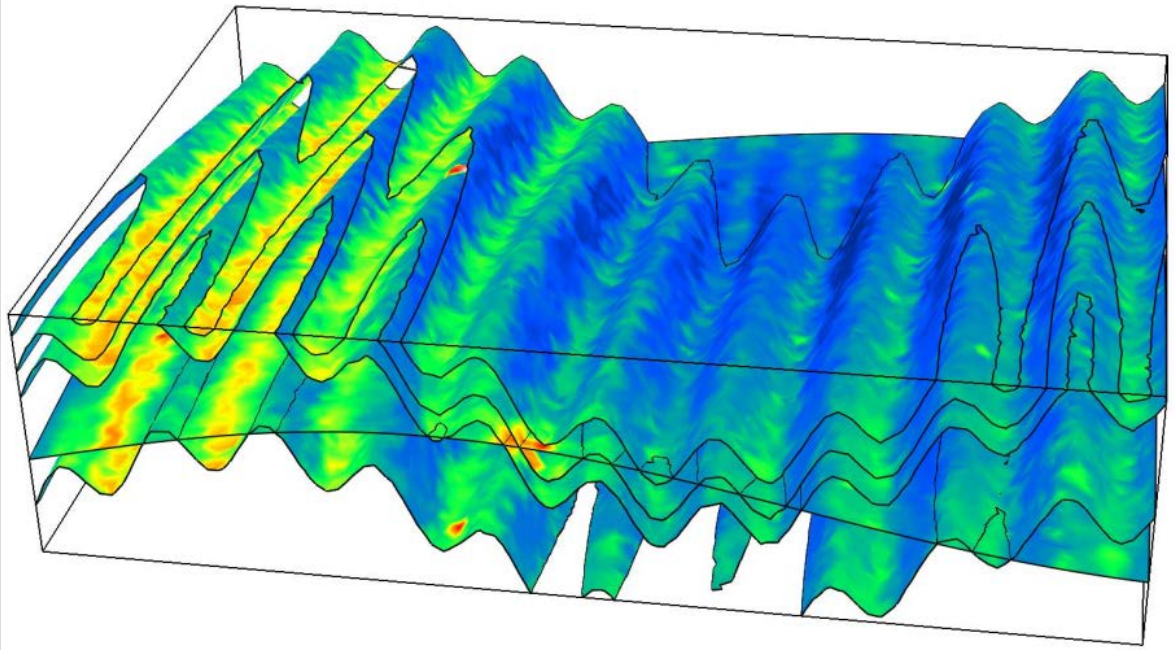


Comparing models

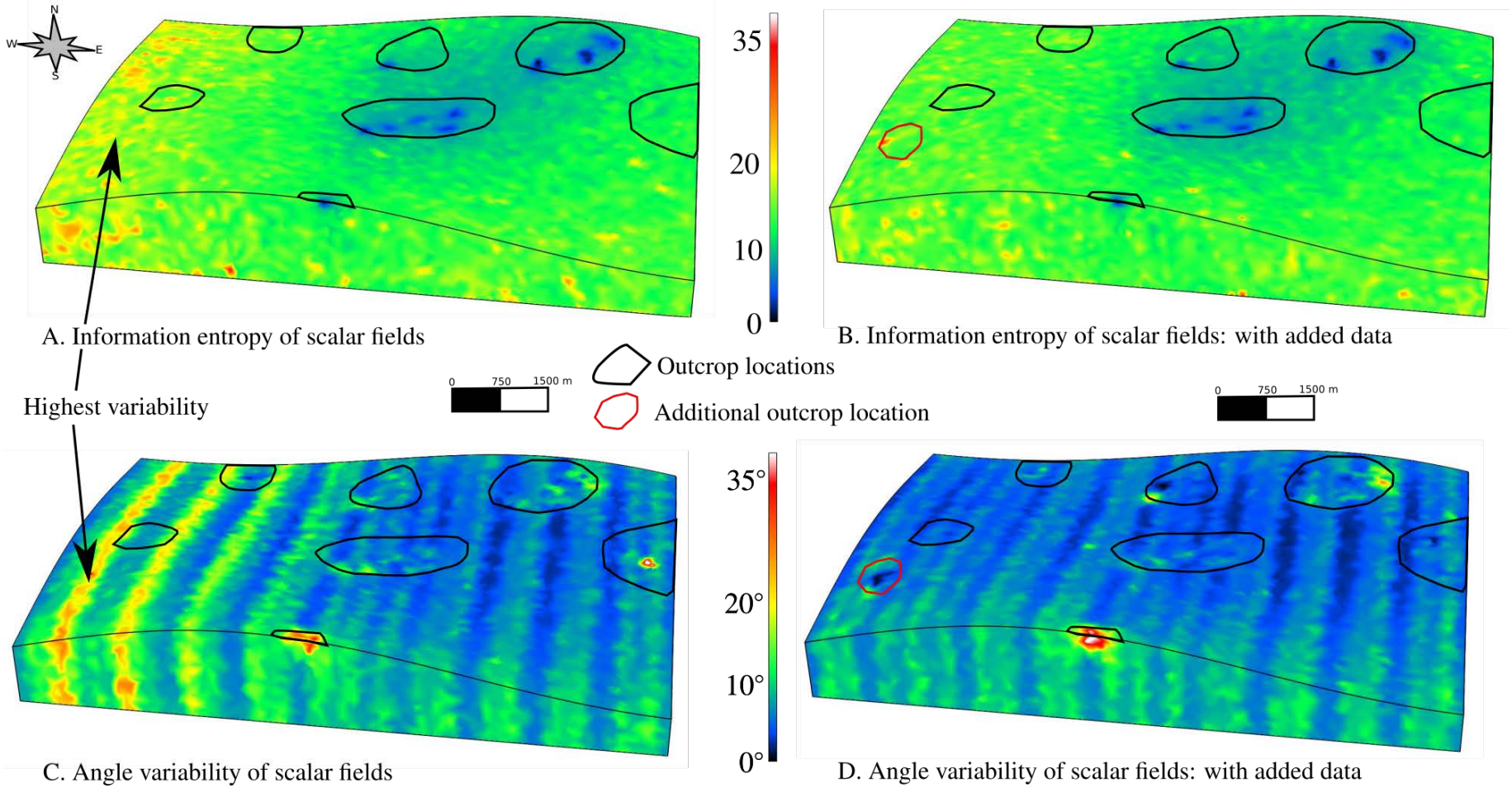
Uncertainty in scalar field value



Uncertainty in scalar field geometry



Reducing uncertainty



Loop - How can YOU be part of it?

Loop : **an new open-source software for 3D Geological & Geophysical Modelling and Simulations**

- Join the open-source community – be a beta user [when available]; tell us what you need.
- Fund in-house position to work on specific aspects of the developments to be contributed to the open-source repository
- Participate via WP6 – Training and Case Study although current participating orgs will be prioritised. Requires an in-house champion.
- I am sure there are others ways… let's talk!

Government of Western Australia
Department of Mines and Petroleum

Australian Government
Geoscience Australia

MONASH University

RWTH AACHEN UNIVERSITY

brgm

THE UNIVERSITY OF WESTERN AUSTRALIA
Centre for EXPLORATION TARGETING

NORTHERN TERRITORY GOVERNMENT

NSW GOVERNMENT Department of Industry Resources & Energy

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