An integrated and interoperable platform enabling 3D stochastic geological modelling

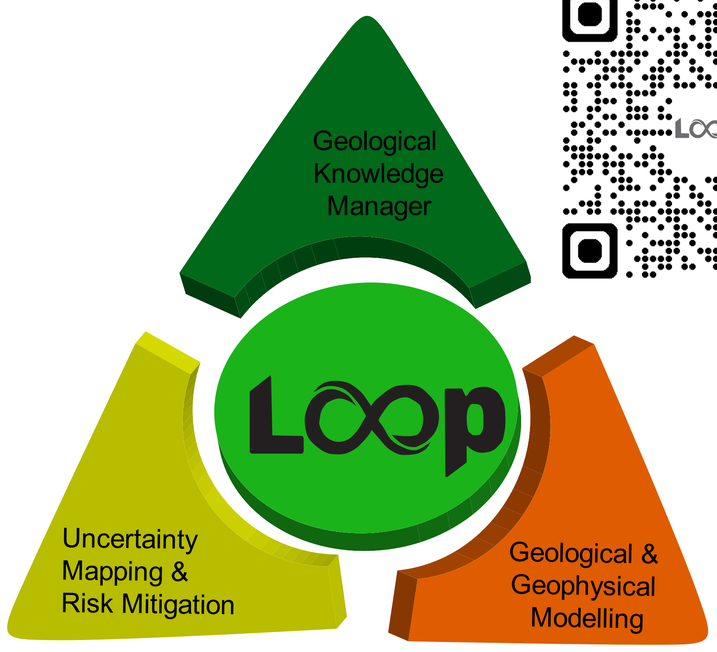
Loop: achievements, vision and a Foundation

Laurent Ailleres[1], Lachlan Grose[1], Mark Jessell[2], Rabii Chaarani[1], Guillaume Pirot[2], Noelle Cheng[1], Angela Rodrigues[1], Vitaliy Orgarko[2], Michel Nzikou[2] and Jeremie Giraud[2]

[1]School of Earth, Atmosphere and Environment, Monash University

[2]Centre for Exploration Targeting, University of Western Australia and MinEx Cooperative Research Centre

Loop – a vision for better management of sub-surface resources



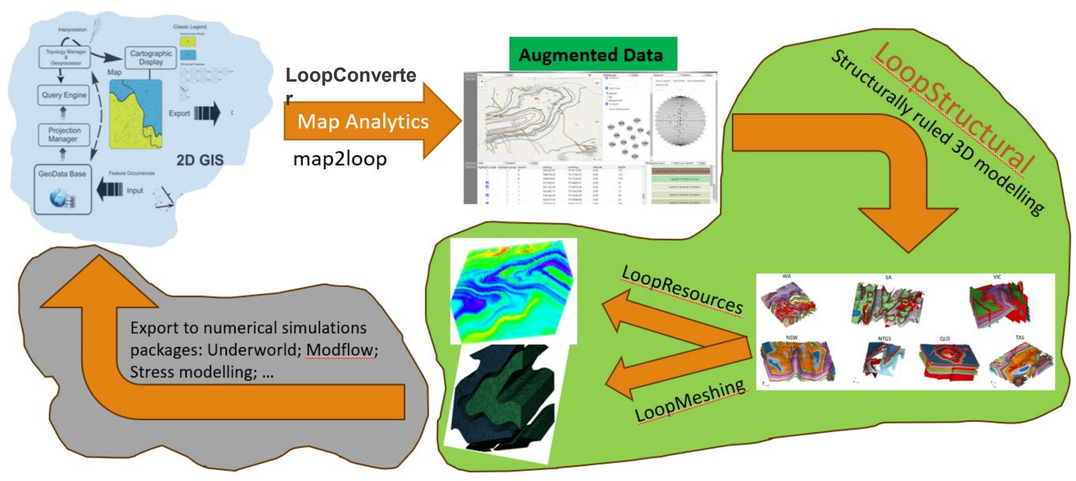
Loop3d.org /

Open-source is the future
github.com/Loop3D/

Developing digital-twins of our subsurface is essential to better manage our natural resources (metals, water and waste disposal).

By digital twins, we mean a realistic representation of the subsurface including the estimation of relevant physical and geochemical properties at an appropriate scale - in other words: a useful series of models allowing for risk mitigation via uncertainty characterization.

Loop Modelling Workflow



The ideal workflow starts with your own database.

1. The LoopConverter, currently developed at the NTGS by Rabii Chaarani transforms your data into a loop-digestible input subsequently analysed and augmented by map2loop.

2. map2loop (Jessell et al., 2021) is a library that automatically extracts geological information from maps and generates parameters for the modelling library.

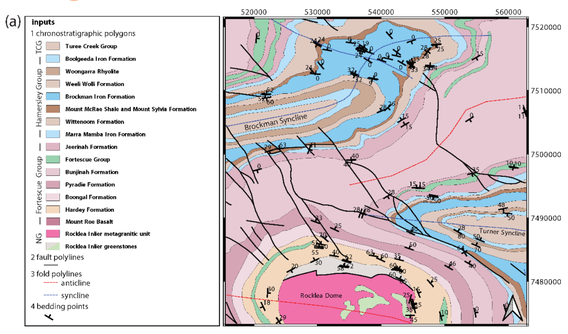
Download Jessell et al., 2021 , Geoscientific Model Development

Loop Modelling Workflow (continued)

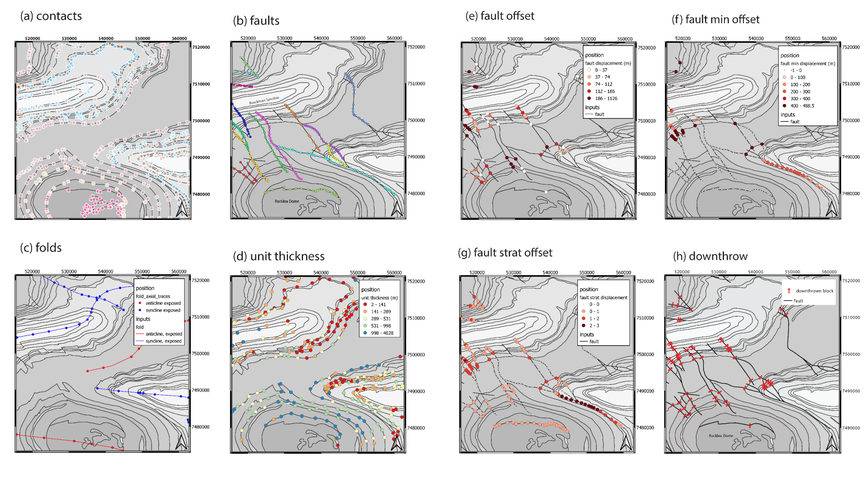
3. LoopStructural (Grose et al., 2021; Alvarado-Neves et al., 2024) allows the building of structurally consistent 3D geological models based on a time-aware parameterisation of a series of events. Each event is modelled sequentially and is associated to a structural frame which put simply is defining a curvilinear coordinate system within each event-related geological object. Each structural frame consists of 3 perpendicular scalar fields that loosely represent the finite-strain ellipsoid directions of each object. The frames are fitted to structural data in 3D and then combined according to the geological history.

4. LoopResources utilises the curvilinear coordinate systems to enable geostatistical estimation of properties throughout the entire model.

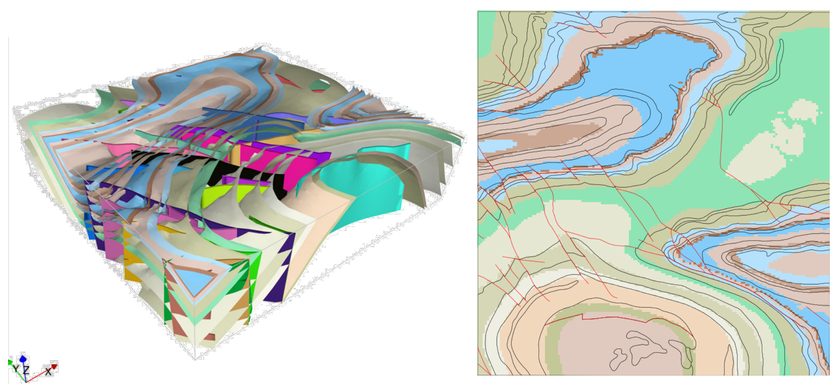
Map2loop – automatic map analysis and data augmentation



Input information
- Geological map
- Stratigraphic relationships (can be estimated automatically)
- DTM



Augmented dataset
- sampled basal contacts
- faults, apparent displacements and minimal fault offsets
- fold axial traces (not yet implemented)
- unit thicknesses



3D models
- Discrepancies with the original map due to sampling of contacts and more importantly lack of faults' parameters knowledge
- rapid and automatic

Acknowledgments

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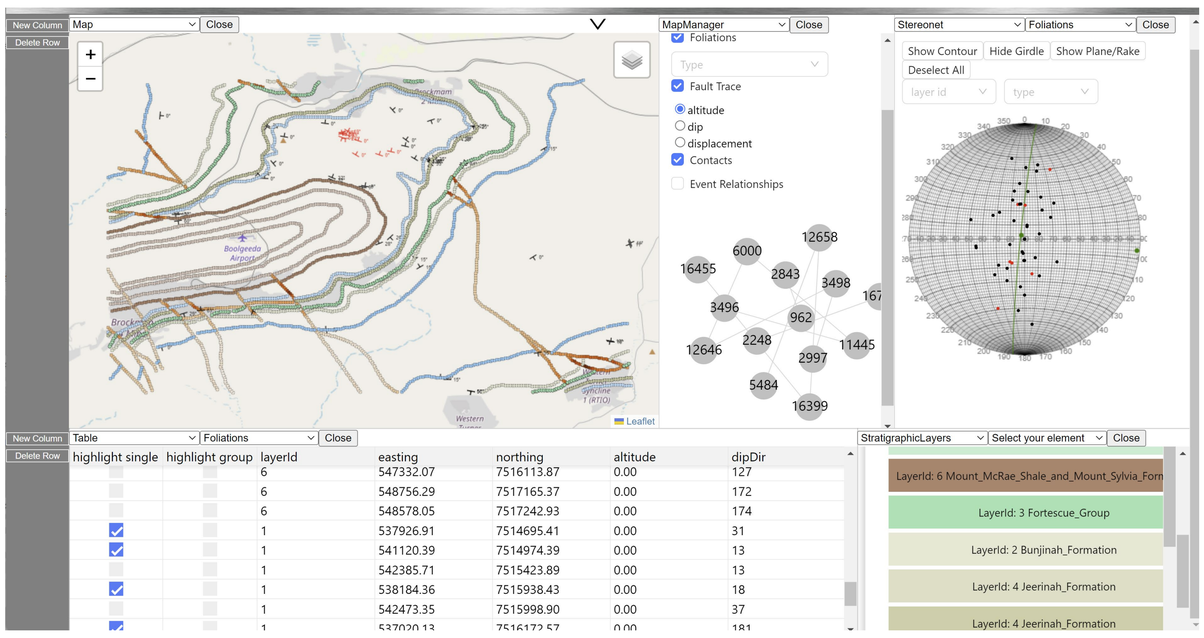
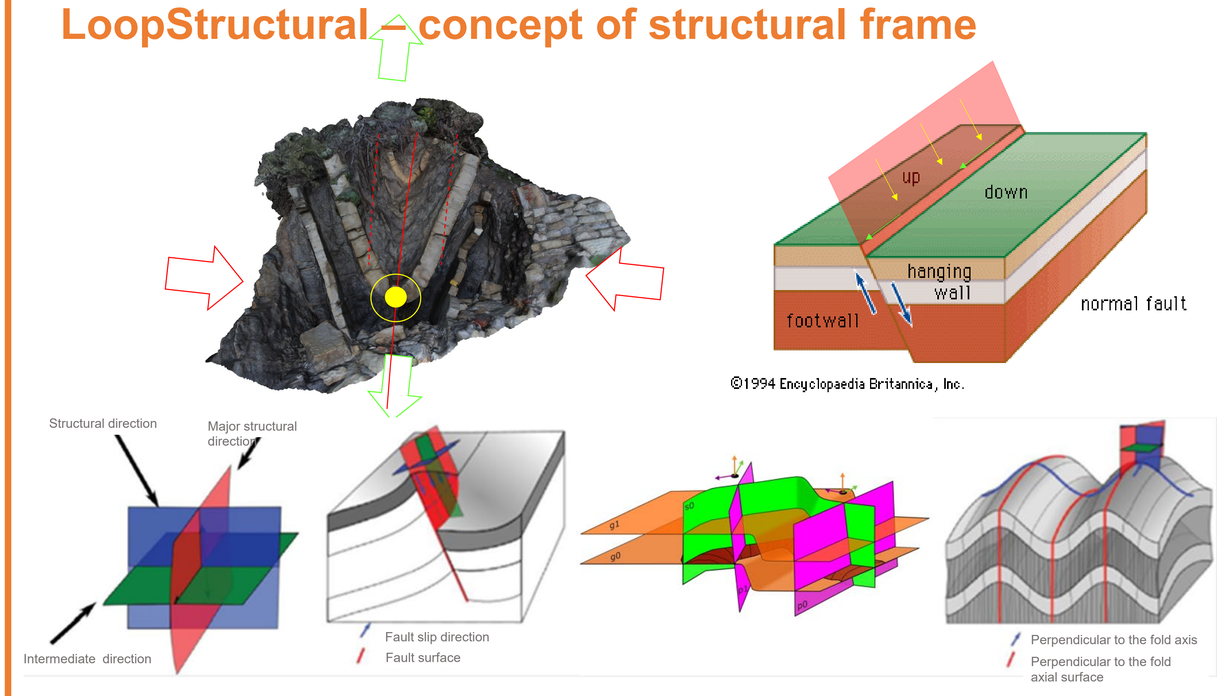
Visualising and editing augmented data (output of map2loop)



The visualization webApp (developped by Noelle Cheng) allows the visualisation of the augmented data via a UI and a flask server accessing the “LoopProjectFile” (output of m2l). The app allows users to edit the augmented data and call LoopStructural functions to build and visualize 3D models.

LoopStructural differentiates itself from other 3D modelling platforms by interpolating 3 scalar fields perpendicular to each other and representing geologically significant directions.

LoopStructural – concept of structural frame



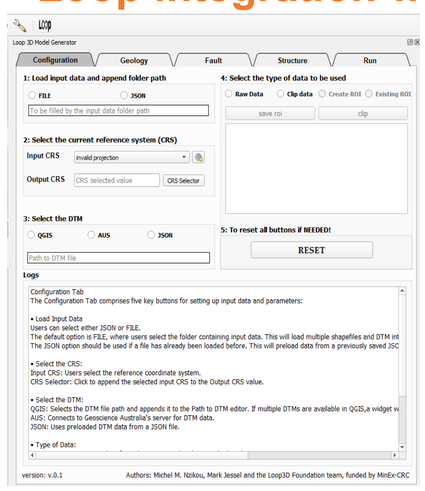
The three orthogonal scalar fields define a structural frame that is fitted to observations and represent an element of the finite strain ellipsoid of that event.

Folds: perpendicular to 1) the axial surface field, 2) the fold axis and 3) the extension direction

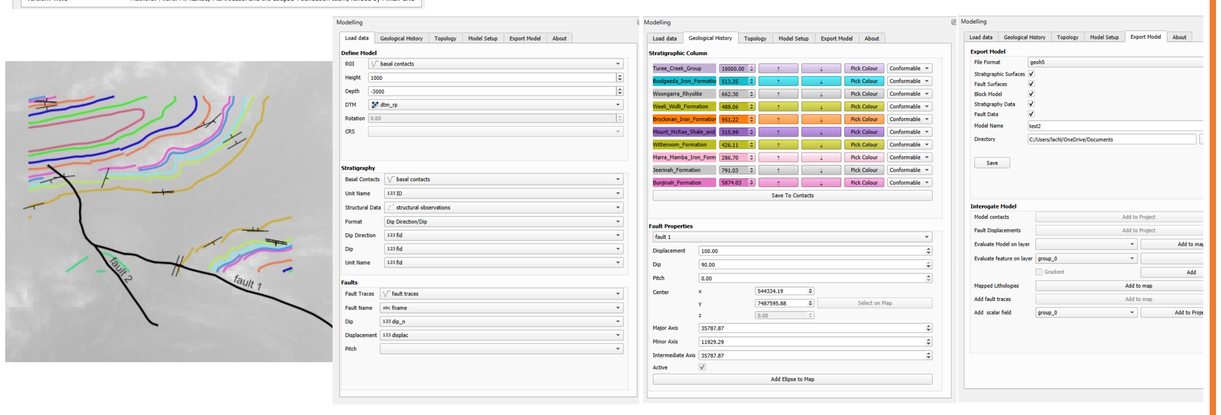
Faults: perpendicular to 1) the fault surface, 2) the offset direction and 3) the lateral extent of the fault

Intrusions: perpendicular to 1) the propagation direction, 2) the growth/inflation direction and 3) the lateral extent.

Loop integration with QGIS



Map2loop plugin for QGIS, developed by Michel M. Nzikou. The plugin allows users to select input data for map2loop and generate an augmented dataset which can then be used in LoopStructural to automatically built a 3D model. The output augmented dataset can also be visualised in the above WebApp.

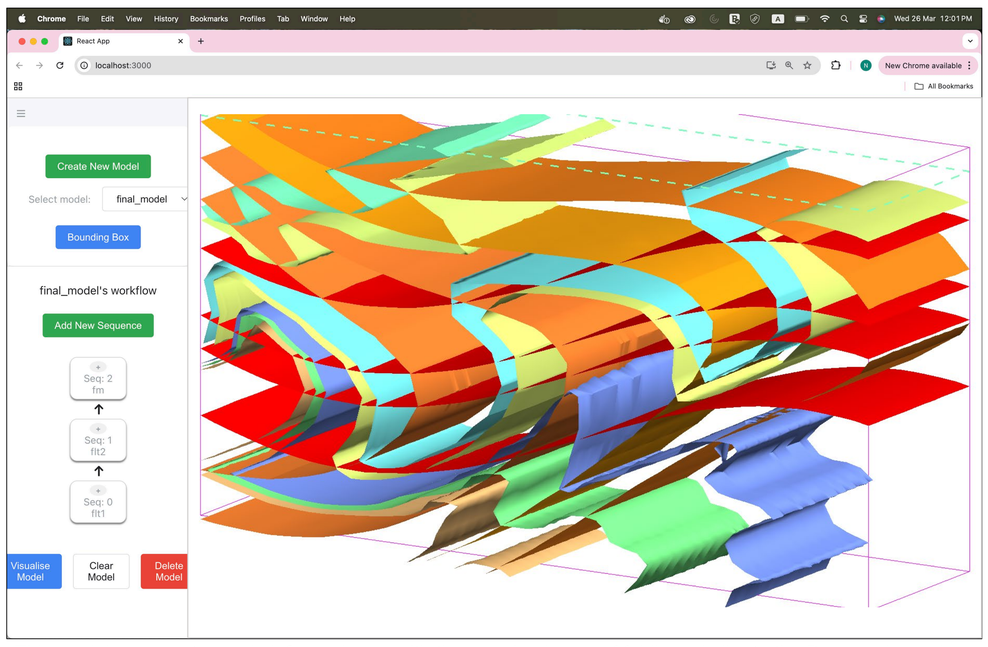


LoopStructural plugin for QGIS, developed by Lachlan Grose, allows to 1) select input data to LoopStructural, 2) setup model parameters including topology and geometric parameters for faults and horizons 3) set up interpolation parameters and 4) calculate a 3D model and export it to common formats.

LoopStructural - how to use it?

LoopStructural is time-aware and combines all the structural frames and associated scalar fields according to relative timing relationships. The youngest event is considered first and then we go back in time until the initial layering is modelled.

The more efficient way to use LoopStructural is to use your own python code. However for users with no coding knowledge, we have developed a series of applications that will allow users to build models in the WebApp or within QGIS.



This model represents a polydeformed area with three main phases of folding, similar to the Bermagui area in NSW. The model was build using a python notebook, however we expect the capabilities to be implemented in the LoopStructural WebApp in the near future.

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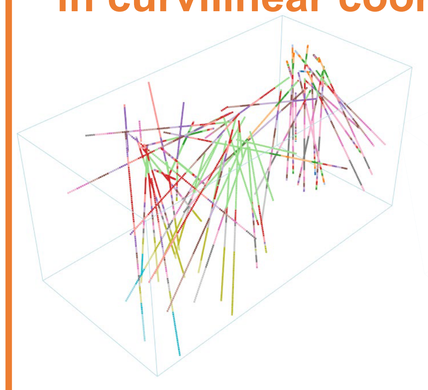
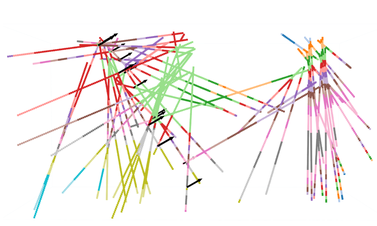
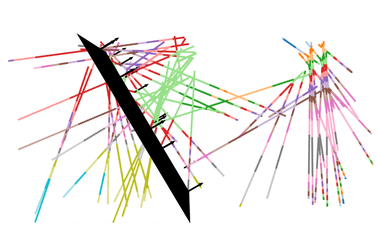
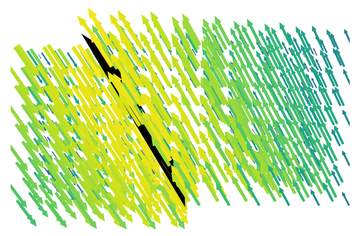
LoopResources – better property estimation in curvilinear coordinate systems



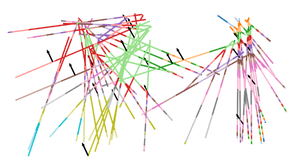
Synthetic set of drill holes with logs of structure, lithology and some assays. Let's use Loop structural frames to calculate the property model.

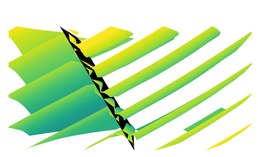


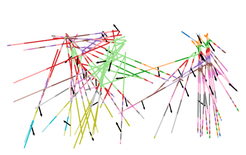


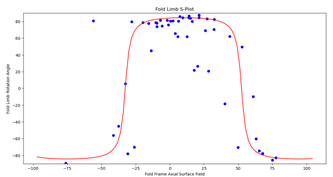


From the logged structures, let's recover a fault plane and assume we know the displacement (direction and amplitude).

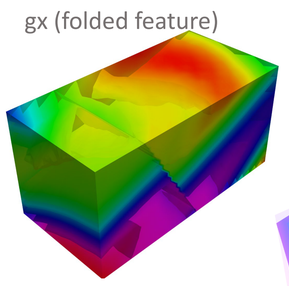


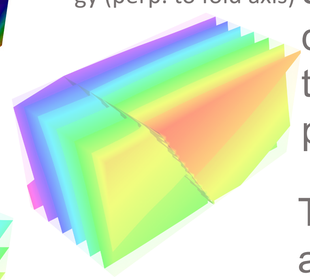


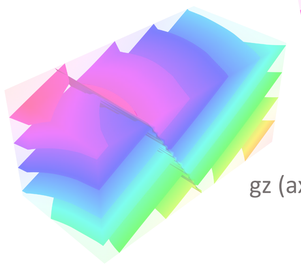




From the logged structures, let's model the faulted fold and estimate the fold profile using the axial surface scalar field and the rotation angle of the folded bedding (LoopStructural).

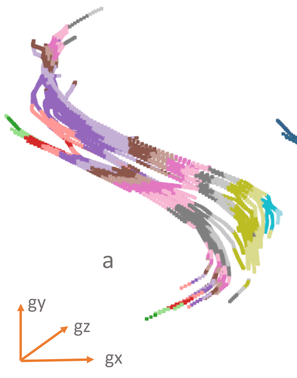


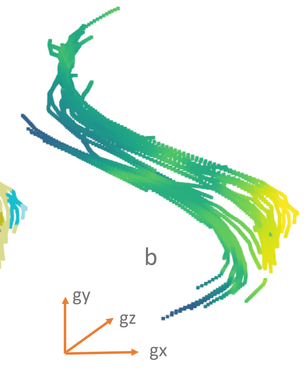


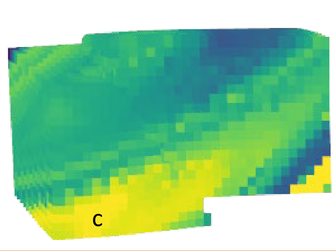


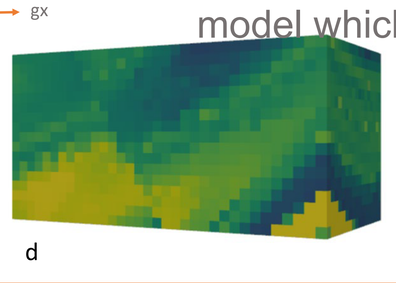
gx, gy, gz are the three axes of the unfaulted fold frame. These are defined in LoopStructural and fitted to the structural data (S1 and S0 profile within S1 scalar field).

The projection of the drill hole trace and of the lithological and assay data in gx, gy, gz are shown to the left (a and b). These images indicate that the faulted fold was not perfectly modelled due to lack of information (fault parameters, sampling of S0 and S1) and this will be used to estimate uncertainty in property models (e.g., simulation around the fold profile and/or fault offset direction and amplitude)
c & d show the recovered property model which is consistent with the data available.
Note c shows the unfaulted property model.



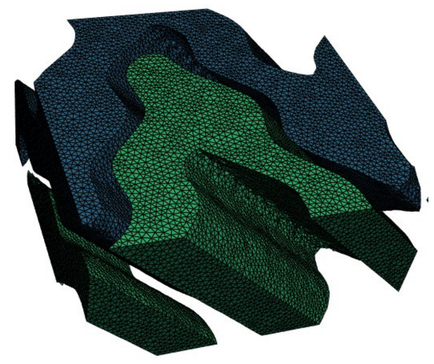


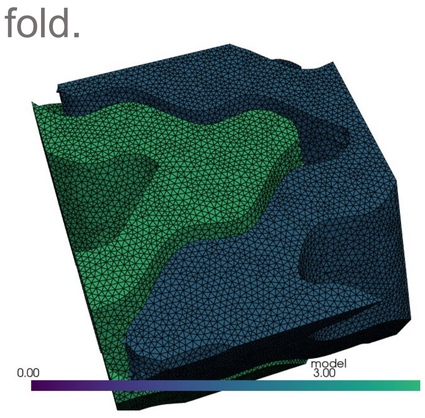




LoopStructural meshing

Using the structural frames, which define curvilinear coordinate systems conformable to layering and structures, it is possible to generate irregular meshes also conformable to layering and structures. A proof of concept has been developed although more testing and development may be required for more complicated geological settings. Below are two views from the Laurent et al., 2016 synthetic model of a refolded fold.





Loop3D Foundation – a NFP company to support implementation of new R&D and maintenance of the Loop platform

- Loop3d Foundation's purposes are (extract from the constitution):
- to research, develop, maintain, and administer Loop software
- to make Loop freely and widely available
- to support and administer Loop
- to provide solutions for subsurface resources management
- to advance the natural environment through educating and/or promoting the education of the community about geological resources and related issues;
- to research, maintain, develop, review, collaborate and contribute knowledge concerning any or all of these purposes;
- to provide formal or informal training and supervision concerning Loop
- to provide services (commercial or otherwise) concerning Loop including training, consulting, and tailored application requirements; and
- to support members in connection with any of the above purposes

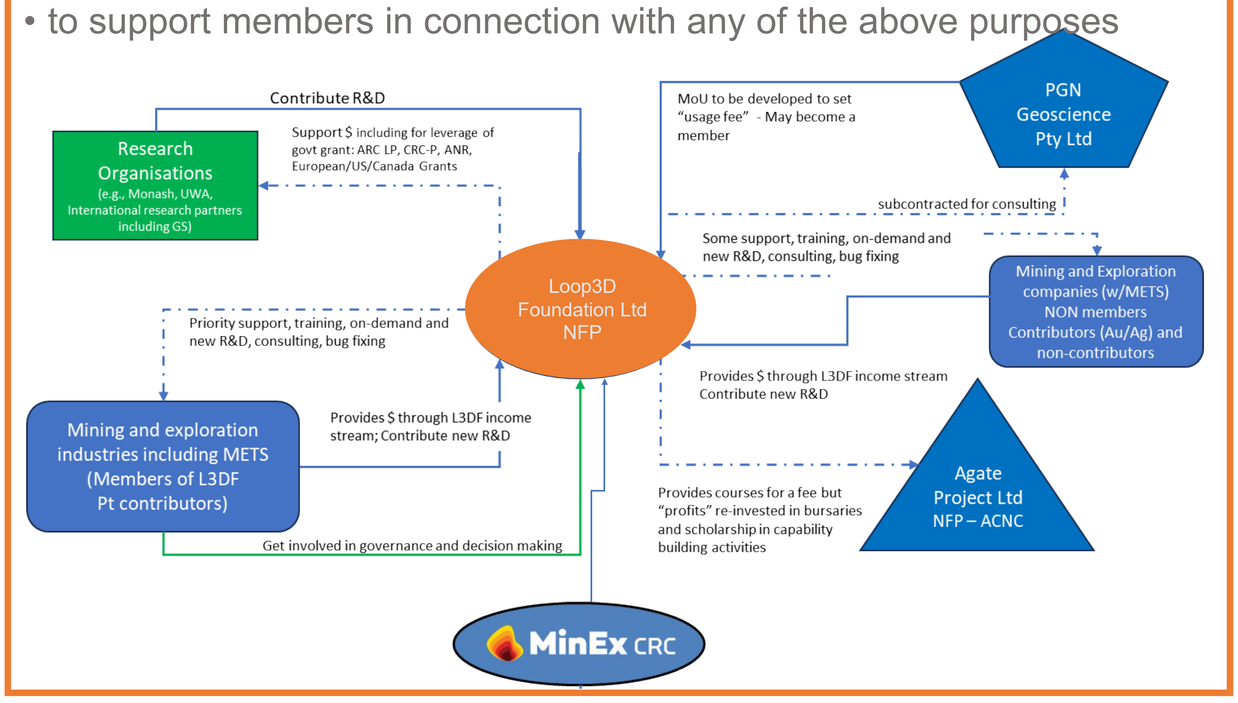
Custom code development

Embedding code in other platforms

Consulting

Support

Training



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