Tutorial C (Forward & Inverse Modelling of Potential Fields)

Parent topic:
User Manual and Tutorials

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Introduction to Tutorial C

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

Why are we interested in potential field data as an aid to geological mapping? There are generally insufficient geological observations to unambiguously construct the boundaries between formations to form a 3D geological map. Observations are generally in short supply at depth, and relationships between formations may be unclear. Variations in potential field response are related to the 3D distribution of physical properties. If we can sensibly relate physical properties to the units used in the geological map, then the potential field data can provide additional insight into the 3D distribution of the mapped units. Potential field data are often readily available and uniformly sampled, enhancing the value of these data.

The purpose of this tutorial is to show the functionality available in the 3D GeoModeller geophysics modules. This will enable you to apply this powerful technique to your own project. In this section:

- Definitions and references
- Interpretation phases
- Overall strategy
- Introduction to litho-constrained inversion of gravity and magnetics
- Physical properties
- Prior geological information
- The need for a close initial 3D geology model
- Strategies for achieving successful inversions of geophysical data
- Inversion analysis flowchart
- Overview of steps for this Tutorial

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Definitions and references

Parent topic: **Introduction to Tutorial C**

In geophysics, the term **forward modelling** refers to the process of calculating a response given a physical property model. You can carry these calculations out relatively quickly and accurately to predict the gravity and magnetic response, given a 3D model of density and magnetisation respectively.

Property optimization is a term used to describe a simple way to improve the overall fit of your geology model to any observed geophysics grids you may have. Often your rock property knowledge, especially of deeper units is very poor. With this technique, you can easily come up with average properties that make a best fit overall for each unit. With this, it is much easier to judge if your geology model is giving a reasonable first fit to the geophysics.

Inverse modelling or **inversion** is the reverse operation to forward modelling; attempting to derive a physical property model given a set of observations. With potential field data, this is a much more challenging process than forward modelling because there is more than one possible solution. To circumvent this characteristic—termed **non-uniqueness**—you can define some preferred characteristics for the solution. The inversion program can then find one or more solutions that not only reproduce the observations but satisfy your preferences as well. In this instance, these preferences or 'constraints' are in the form of the 3D geological map and the physical property distributions that you define for each geological formation in the map.

References

The following references contain additional background information about the mapping and inversion modules in 3D GeoModeller.

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Forward modelling and inversion with 3D GeoModeller (The 3D GeoModeller Reference Manual).

Interpretation phases

Parent topic: **Introduction to Tutorial C**

The flowchart shows the basic phases for production of an integrated interpretation of geological, physical property and geophysical data. Operations that you can carry out using 3D GeoModeller are shown in cyan.

Following acquisition, geological observations are assessed and assigned to categories ('formations'). The mapping module is used to compile boundary and orientation information into a 3D map that shows the geometrical arrangement of boundaries between the formations. Physical property measurements are assigned to formations, and statistical methods are then used to determine the characteristics of these properties at the scale of the elements used in the inversion phase.

Overall strategy

Parent topic: **Introduction to Tutorial C**

These tutorials guide you through practical demonstrations, beginning with a forward modelling exercise and progressing to a litho-constrained, joint inversion of gravity and magnetic datasets.

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Put simply (see illustration below), the idea is to begin with a starting 3D geology model that honours all geology observations (somewhere in green space). Then, use the observed gravity and magnetic data sets to drive an inversion result to deliver only 3D geology models which also honour the gravity and magnetic data, i.e., in the overlapping space between red, green and blue 3D GeoModeller uses the principles of statistical sampling to drive the inversion process, so the approach can be thought of as a Monte Carlo, Markov Chain simulation. For more details see Forward modelling and inversion with 3D GeoModeller.

Introduction to litho-constrained inversion of gravity and magnetics

Parent topic: **Introduction to Tutorial C**

Because of the non-uniqueness associated with both geological and potential field observations, we cannot tell whether the 3D geological map in the current project and the estimates of the physical properties are a good approximation of the 'truth' or not. The most we can say is that this combination of geometry from the 3D map and properties from the supplied distributions is one of many solutions that would be consistent with all of the observations. However, if this combination of inputs produces a response that is significantly different to the geophysical observations, we can conclude that combination is extremely unlikely to be present.

The inversion method implemented in 3D GeoModeller begins with linked lithology and property models, which we assume to be close to the 'true' models. The algorithm generates a sequence of linked models that are similar to these starting models by making small random changes to the lithological boundaries and physical properties.

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After each change is made, the likelihood of this combination of models is assessed by comparing the predicted potential field response to the observed (measured) response. The proposal is then accepted or rejected.

The algorithm preferentially samples models that have greater likelihood. It is, however, important to decide if this likelihood equates to reproduction of the observations within a reasonable uncertainty envelope during the monitoring stage of the inversion. If this is not the case, then you must make changes to one or more of the following:

- The starting lithology model
- The physical property distributions assigned to each formation
- The uncertainty levels associated with the geophysical data

You can run another inversion session using the modified inputs.

At the conclusion of an inversion session, 3D GeoModeller carries out an analysis of the ensemble of models that was generated. Although this analysis is restricted to models that reproduced the observations to an acceptable degree, there may be many millions of models involved.

We use statistical methods to distil and simplify the information contained within these models. It is important to recognise the difference between statistical entities such as the 'most probable model' from the models that were actually sampled during the inversion. The statistics highlight general features of the samples, but do not necessarily represent a 'true' configuration of lithologies and properties.

Physical properties

Parent topic: **Introduction to Tutorial C**

It is unrealistic, given our knowledge of the real world, to assign a single constant physical property to each geological formation. It is also well known that the bulk properties of rocks vary considerably from those measured in a laboratory, on a small scale, or say from a sample gathered in a borehole. We tend to measure the properties of the most durable portion of the population and ignore the more friable fraction. Every formation shows some degree of heterogeneity. We simulate this in the inversions by defining a 'distribution' or spread of physical properties for each formation. Our convention for recording the spread is to ask you to define a probability distribution function or PDF. In the simplest of cases, this can be a Normal population with a mean and standard deviation. In a forward model, the mean is adapted for the single run.

Before spending time on inversion, we recommend you spend some time checking the bulk properties. This can be done using a new property optimization method. You take your geology model, give your formations a property distribution. You also allow a lower bound and an upper bound for each property. These bounds should be conceived and constrained by reasonableness. If the results show that some properties required to explain the geophysics are consistently at one end of the bounds, your model may not be as good as it needs to be.

During an inversion session, 3D GeoModeller selects properties at random from the supplied distribution. The algorithm is more likely to retain a selection that improves the fit between the observed and predicted geophysical response than one that increases the misfit between these two quantities.

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Note that the distributions supplied for each formation are for samples having a volume equal to the volume of the cells used in the models. These cells typically have volumes that are many orders of magnitude greater than the volume of drill core or hand specimen samples (for example, a model cell 100 x 100 x 50 m in size has a volume 1 billion times larger than a sample 100 x 50 x 50 mm in size).

Much of the local heterogeneity seen in collections of drill core or hand specimen measurements is averaged out when considering the variability between samples having large volumes. This issue of estimating the variability between samples with different volumes is analogous to the problem of estimating the grade for a mine stope from assays of drill core samples. The variability in the grades for stopes is always much less than the variability observed in small volume samples.

Unfortunately, it is very difficult to estimate the correct variability (spread of values) for specifying in 3D GeoModeller without measurements from a large number of samples from many locations within the project area. However, if you have some confidence in the volumes of the main units, Property optimization (Tutorial C2—Potential field forward calculation) can help.

Prior geological information

Parent topic: **Introduction to Tutorial C**

Prior to commencing forward or inverse modelling, methodical investigation of all available datasets is crucial to building a realistic starting 3D geology model.

The following illustration shows progressive investigation of gravity and magnetic data via a range of interpretation methods. In combination with all available geological observations (surface and sub-surface), completing some or all of these methods can provide best-available knowledge for building your starting 3D geological model.

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The need for a close initial 3D geology model

Parent topic: **Introduction to Tutorial C**

Most successful use of the fully constrained lithological inversion method is achieved by first creating a starting or reference geology model that is consistent with all of the geological observations, and also closely honours the observed geophysics signals for most of the study area. This is necessary because the Monte Carlo techniques adopt very detailed processes for changing individual properties or geometries, and a close starting model will ensure you minimize the time needed to explore probability space and maximize your chance of converging quickly to an acceptable misfit; allowing time to continue on gathering good statistical results.

Below is a histogram illustration of a non-viable reference model prior to any inversion. The left hand population from a forward model of the gravity response has a completely different distribution to the observed response. The model misfit is more than 200 mGal and far too large for this model to be considered as a starting model for inversion.

Left is observed, right is calculated (units in mGal)

Taking the example case here where we have an observed gravity grid and a forward model of the gravitational response (above figure), you should compare the two grids in a spatial and a statistical manner. In this case the likelihood of your starting model migrating to the observed while honouring the known constraints is very low.

One extra complication to be considered is the issue of detrending in order to remove a regional response. If the observed geophysics grid contains a contribution from a larger, deeper source which is not represented in your model, then you can either high pass filter your grid to remove the regional or allow 3D GeoModeller to automatically detrend the observed grid during inversion to improve the model misfit.

By analogy it is very important to build an initial 3D geology model that is as close as possible to the real situation. To check this, forward modelling of the gravity and magnetic responses of your initial geology model (using measured or assumed physical property values for each geology formation) is strongly recommended. This way you can compare the 'predicted' with 'observed' gravity and magnetic responses, and manually make changes to your 3D GeoModeller model or changes to the assigned physical properties (if these are not known with high-level certainty). Forward geophysical modelling, followed by revisions to the geology model (geometry) and physical properties (densities and magnetic susceptibilities) may need to be repeated to achieve a close starting model. These are considered to be the gross-scale, necessary modifications to carefully complete before embarking on inversion.

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Strategies for achieving successful inversions of geophysical data

Parent topic: **Introduction to Tutorial C**

Overall strategy for building robust 3D geology models-Sequential evolution

This section describes a recommended strategy for achieving successful inversions of geophysical data directly from 3D geology models.

Whilst it is not required to complete all of the following cases in sequential order, the following list gives ideal cases, which if carried out and verified separately, gives the user the best chance of achieving a desired inversion that will be robust from all points of view (good convergence, realistic geology outcomes, tight statistics, etc.).

1. Forward Model, Propose a starting model,
   - compute gravity response - **[Tutorial C2]**
   - compute a magnetic response
   - compute a seismic section response
2. Property Optimization (Solve for properties using a bounded least-squares fit) - **[Tutorial C3]**
3. Bi-Modal Property Only Inversion (No proposed body, just a proposed density contrast)
   - A very simple geology model with perhaps just 2 units such as basement and an intrusive to see where the blobs form - similar to the deterministic methods
4. Fixed Geology Model Property-Only Inversion (an alternative approach to property optimization).
5. Prior Only Inversion (Fixed Properties Geology-Only Inversion) explores only the probability space implied by the geological constraints that have been set and does not use geophysics to drive geological evolution. **[Tutorial C4]**
6. Joint gravity and magnetics **[Tutorial C5]**:
   - explore geometry-only; (0% probability of property change)
   - explore properties-only; (100% probability of property change)
   - explore both geometry & properties; (50/50 equal chance of a change in either)
7. Joint gravity and magnetics including the possibility of magnetic remanence.
8. Forward modelling of the gravity full tensor response **[Tutorial C6]**
9. Inversion of observed full tensor gradients with 5 independent observations or more, driving the changes.

At all stages, the user should examine the computed geophysical response grids and compare them to the observed grids. They should also confirm the main features are present; especially in the early stages,

Once there is a near starting model, all the inversion methods above will produce quite a good fit.

The statistical analysis of thousands of equally viable models will assist you to learn more about how good the model is at explaining the geology.

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Inversion analysis flowchart

Parent topic: **Introduction to Tutorial C**

This flow chart illustrates the way an inversion session progresses. Each pass through the central loop is one iteration. There are generally millions of iterations in each session.

At the beginning of an iteration, 3D GeoModeller makes a small change to a boundary between different formations, to physical properties, or to both. It assesses the suitability of the change against criteria such as whether this has preserved the network of interconnections between formations (the 'topology' of the model).

If the change fails the test, 3D GeoModeller rejects it and concludes the iteration. If it passes, the forward potential field response of the modified model is calculated.

3D GeoModeller applies a second set of tests, favouring acceptance of models that reduce the misfit between the predicted and observed response. It does not, however, completely exclude the possibility of accepting a change that increased this misfit. This important aspect of the algorithm enables us to explore many different model configurations.

If the modified model passes all tests, the changes are accepted. The modified model becomes the input for the next iteration. This loop continues until 3D GeoModeller has reached the maximum number of iterations specified, or you stop the program.

This is not a deterministic solver (the misfit does not determine when the solver will stop), but rather when the solver has converged to a point where all subsequent models will fit the data with the same likelihood and from which point, statistical records and movies can start to be made capturing the results with equal probability of being good answers. There can be millions of equally plausible answers.

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Overview of steps for this Tutorial

Parent topic: **Introduction to Tutorial C**

Review the existing geology model (Tutorial C1)

1. To understand the geological scenario and familiarize ourselves with the starting geology model, you will load the current 3D geological project without making any changes. Using the menus for geological editing and viewing, you will explore the geological data constraining the model, repeat the model compute (run the 3D interpolators to build surfaces) and visualise 2D and 3D aspects of the model and geological pile.

Forward modelling (Tutorial C2)

2. Associate physical property distributions with each geology formation. They are required for both forward and inverse modelling.
3. Carry out a gravity forward calculation (using the spatial method) to see whether the combination of the geological model and the choice of physical properties produces a response that broadly corresponds with the measured geophysical observations.
4. Examine the forward calculation products in the Results Viewer and the geophysical response grids in the 2D and 3D viewers. Manage the colour table and data range clipping to enhance the details.

Property Optimisation (Tutorial C3)

5. If the results of the forward calculation are broadly similar with the measured observations, then you can skip property optimisation.

   However, if the predicted response of the 'starting model' is a poor fit to the measured geophysics (i.e. it may have a similar shape but much larger amplitude) then this violates a fundamental assumption of the inversion methodology (must have a close starting model) and points to problems with formation property estimates. Your end results will be poor and you should try to optimise the properties in some way (one method is demonstrated here).

   New optimised estimates of your formation rock properties are returned based on your model geometry and the observed geophysics. These will assist you in making sensible adjustments to your rock properties prior to inversion.

Prior-only Inversion (Tutorial C4)

6. Perform prior only inversion to see what probability space is implied by the geological constraints ("geology tests") that you are going to set.

   In this case we are not concerned with reduction of the calculated misfit between the predicted and observed geophysics. The likelihood of the new proposal is not calculated after each iteration nor is it compared with the reference geophysics grids.

Joint magnetic-gravity inversion with stochastics (Tutorial C5)

7. You will supply suitable parameters and carry out the joint litho-constrained inversion calculations. The inversion program searches for models that:
   - Satisfactorily reproduce the measured geophysical observations,
   - Have a physical property distribution close to what you have assigned, and
   - Obey the geology tests.

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8 Next, you will use a number of tools to visualise and analyse the inversion results. These enable:

- Viewing of the misfit evolution curve.
- Running of the super summary statistics, collation & analysis tool, after first deciding the "burn-in point" or earliest point of convergence during inversion.
- To create histograms, combining the initial, final, and post-SuperSummaryStats output MeshGrids or results-voxets.
- To create histograms, combining and computing with the MeshGrids or results- voxets, as required. For example:
- To create histograms of the mean & standard deviations of rock properties from the accepted proposals considering every single voxel or cell grouped on a per-lithology basis (this could either be from the final iteration, or from all accepted proposals between burn-in and the last iteration).

9 Forward calculation of the gravity full tensor response (using a Fast Fourier Transform in 3D) - Also, visualisation of the component tensors **(Tutorial C6)**

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Tutorial C1—Review the existing geology model 'BuriedGranite'

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

In this tutorial:

- C1—Introduction
- C1 Stage 1—Load and examine the 'BuriedGranite' 3D geology project / model
- C1 Stage 2—Examine the project metadata
- C1 Stage 3—Re-compute and review the 2D and 3D views of the geology model

C1—Introduction

This simple 3D GeoModeller project / model has already been created for you.

In this tutorial we will explore the existing 3D geology model using menus for **viewing the project properties, geological editing and visualisation** without making changes to the model.

C1 Stage 1—Load and examine the 'BuriedGranite' 3D geology project / model

Parent topic: **Tutorial C1—Review the existing geology model 'BuriedGranite'**

C1 Stage 1—Steps

View the pre-created 3D geology project in 3D GeoModeller

1 Launch the 3D GeoModeller software, to reveal the splash screen.

2 From the main menu choose **Project > Open** OR

From the **Project** toolbar choose **Open** OR Press CTRL+O.

3 Browse to the pre-created 3D GeoModeller project:

`Tutorial_C\Tutorial_C1\C1Beginning_Project\C1Beginning_Project.xml`

4 Save your own copy of this project, so that you don't accidentally overwrite the original project files. **Warning: The name of the project you choose must not contain any spaces.** Use an '_' instead (eg. **My_Tutorial_C1**)! It is important to progressively Save (and Save As), as you progress with the exercises

From the main menu choose **Project > Save as** OR

from the toolbar choose **Save As** or press CTRL+SHIFT+S.

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5 View the already-computed 3D geology model as rendered in the 2D viewer

6 Examine the main elements of the 3D GeoModeller workspace, labelled above.

- 2D Viewer contains 2D sections. This tutorial C1 project contains several sections, C3 and C2 which are already rendered when the project opens.
- We use 2D sections for storing and/or digitising geological data input, and for rendering 2D plots of our 3D model.
- You can also open section: SurfaceTopography (the "Topographic" or "Map" section). This is a special type of "2D section" in that it retains the information of the draped grid of the digitial elevation model (DEM) if one has been used to build the project. If not, then this section will be a horizontal plane of a specified height, as used in this case study (sea level). Check this by moving the mouse over the SurfaceTopography section, and observing the x,y,z mouse-location in the lower left corner of the workspace (z is constantly -1.0m in this project).
- Note the topography section (SurfaceTopography here) defines the rock-air interface of your model. Generally we recommend using a DEM to assign the correct topographic shape as this allows more accurate mapping of geology on surface.
- 3D Viewer contains a 3D view of your project, or a wireframe bounding box if the model is not yet visualised. At the stage opened (see above) a "Visualise 3D Formations and Faults" has not yet been done (we will do this later).

7 Also note the Project Explorer, located to the left of the 2D Toolbar:

- **Project Explorer** — has a tree structure containing details about the objects making up your 3D geology model:
  - **Formations** in the stratigraphic pile, and what data-type the contraints exist in (by 2D-data on individual sections; or by 3D data; or by drill holes)
  - **Faults** in the project and what data-type the contraints exist in (by 2D-data with the section identified; or by 3D data)
  - **Sections** (names & any associated geo-located images)

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- **Drillholes** (ID and geology intercepts)
- **3D Geology** ("+" if a 3D model or 3D grid is built / visualised in the 3D Viewer)
- **Meshes and grids** ("+" if one or more is loaded in the 3D Viewer)

The image above shows **contact / interface** data for the tops of 2 formations in our model - this is an example of **data-type: 2D**. They were added to the section using the "pencil/create" tool, from the 2D Toolbar.

8 View the stratigraphic pile for the 'BuriedGranite' 3D model. From the main menu choose **Geology > Stratigraphic Pile: Visualise**.

- Every aspect of the way the stratigraphic pile is set up will have an impact on the way that the interpolators will run, and how the resulting geology shapes and lines will be built. We call this "rule-based-modelling". It is intuitive for geologists and geophysicists, and unique to 3D GeoModeller.

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C1 Stage 2—Examine the project metadata

Parent topic: **Tutorial C1—Review the existing geology model 'BuriedGranite'**

C1 Stage 2—Steps

1 From the menu choose **Project > Properties**

Examine the project metadata.

For this project the dimensions and Coordinate System are:

- **Projection:** Local
- **Height Datum:** Local
- **Extents:**

	Minimum	Maximum	Range
East (X)	0	10,000	10,000
North (Y)	0	10,000	10,000
Z-axis	-2,000	2,500	4,500

Some further comments about the 3D GeoModeller project work space:

- X (East), Y (North) and Z (Elevation, positive upwards) are a standard coordinate framework according to a right-hand rule
- X, Y, Z are all in the same units - meters (they cannot be degrees of latitude or longitude).
- X and Y would typically be real world projected coordinates but could be a local grid (this is the case for the "BuriedGranite" model).
- Z is elevation, and is positive upwards. It also would typically use a real world vertical datum such as mean sea level.
- If possible you should define the Projection (actually a Coordinate System, consisting of a Datum and Projection). Geolocation of your project is essential if you are to properly create and integrate with geoscientific data from many sources.

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- All data must be within the 3D project limits. Data outside of the limits will be ignored when importing (a report will be given listing them as excluded).
- Likewise all modelled results - geology lines, polygons and surfaces - reside within those limits.

When you create your own project, make the project dimensions large enough to:

- include all your data
- include a margin above your highest point of your topography
- allow sufficient project space at the bottom of the model to cover the entire range of modelled geology and geophysical data that you are interested in.

C1 Stage 3—Re-compute and review the 2D and 3D views of the geology model

Parent topic: **Tutorial C1—Review the existing geology model 'BuriedGranite'**

C1 Stage 3—Steps

Compute the 3D geology

Compute the 3D geology model for the project that we have loaded (to be constrained by the geological data and pile we have reviewed).

1 From the **Model** toolbar, choose **Compute** or (press CTRL+M).
In the Compute the Model dialog box:

- Series to interpolate—Select All
- Faults to interpolate—Select All
- Sections to take into account—Select All
- Faults only—Clear (therefore DO compute faults)
- Choose **OK**

3D GeoModeller computes the model. (Nothing to see yet.) The model is a mathematical model-a set of interpolator equations that are computed from the geology contacts and orientation data. There is an interpolator equation for each series in the stratigraphic pile, and also an equation for each fault.

View the modelled geology

To see the modelled geology, we need to interrogate the model equations. We can:

- Plot the modelled geology on any section in the model
- Create a new section, and plot the modelled geology on it
- Build the 3D shapes of the modelled geology, and view in the 3D Viewer

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2 Select **C3 section** in the **2D Viewer** (click the window & a tick appears in the top left corner)

3 From the **Model** toolbar, choose **Plot the model settings** (or press CTRL+D) In the Plot the model settings dialog box:

- Check all 3: "Show Fill" and "Show Lines"
- Choose **OK**

The fill/lines of the modelled geology are plotted on the vertical 2D Section (C3).

4 Repeat these steps and plot the modelled geology on some of the other sections.

5 Save your project

From the main menu choose **Project > Save** or from the toolbar choose **Save** (or press CTRL+S)

Explore model plotting options

Experiment with other options in the Plot the model settings dialog box:

- Check "Show Trend Lines"
- Choose "Apply to All" to render the 3D model on all (open) 2D sections.
- For "Show Trend Lines" or "Show Fill", select or de-select various combinations of formations
- Choose "Show Trend Lines" in combination with Show Lines &/or Show Fill
- Modify the Plotting resolution from the default u=50, v=50 to, say, 100 x 100

6 Experiment with the three plot buttons in the **Model** toolbar:

- Model > Plot the model settings (or press CTRL+D)
- Model > Plot the model on the current section
- Model > Plot the model on all sections

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7 Experiment with the **Section display parameters**:

- **Right-click** on the **background** of an active 2D section
- Choose for example **C3 > Display parameters**

This allows you to toggle between different views which are already rendered. For example: **Model geology > geology - lines** (tick) OR **geology - fill** (tick)

Explore the 3D Viewer - 'Build' the model in 3D

8 From the Model toolbar choose Build 3D Formations and Faults

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In the Build 3D Formation and Fault Shapes dialog box:

- Check **Build—Formations**
- Check **Build—Faults**
- Select **Type—Volume**
- Check **Draw Shapes after building**
- Adjust the **Resolution—Render quality** to Medium
- Choose **OK**

Use Project Explore to Manage the 3D Viewer - 'View' the model in 3D

3D GeoModeller computes the 3D shapes of the geology model as solid 'volumes' defined by triangle mesh surfaces, which it displays in the 3D Viewer.

Use the **Project Explorer** (typically on the left-side of your work space) to manage the display of modelled objects in the 3D Viewer.

9 Experiment with change "whole" model appearances

- In the Project Explorer right-click **3D Geology >** and select **Hide**—to hide the entire modelled geology
- In the Project Explorer right-click **3D Geology >** and select **Show**—to show again the entire modelled geology
- In the Project Explorer right-click **3D Geology >** and select **Wireframe**—to change the displayed 3D volumes to wireframes
- In the Project Explorer right-click **3D Geology >** and select **Shading**—to toggle the 3D display of geology, back to shaded

10 Change individual geology units of the model, in the same ways as above:

- In the Project Explorer click the "+" symbol to expand the list within **3D Geology**.
- Again, expand the "+" symbols for each series in the model

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11 For the series3 unit, Right-click on **Volume: Cover** to **>Hide** from the 3D viewer.

12 For the series2 unit, Right-click on **Volume: Host-rock** to **> Wireframe**

To Show modelled geology polygons (or lines) in the 3D Viewer:

13 Select a 2D section (for example, C3) (ensure a green tick appears top-left).

14 Use the shortcut menu: right-click the background of the 2D viewer, and choose: "**Show Modelled Geology Polygons in 3D Viewer**".

15 Save your project

From the main menu choose **Project > Save**

NOTE: Managing the Geological Editor is not the main objective of Tutorial C, and a brief overview has only been given here for this reason.

For further instruction on the Geological Editor functions of 3D GeoModeller, go to Tutorial Case Study A, in the **Main Menu > Help > Manual & Tutorial (PDF)**.

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Tutorial C2—Potential field forward calculation

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

This tutorial takes the user through a typical sequence of tasks for forward modelling of potential field data directly from 3D geology models.

In this tutorial:

- C2—Steps overview
- C2 Stage 1—Enter physical properties
- C2 Stage 2—Forward calculation
- C2 Stage 3—2D seismic calculation

C2—Steps overview

Parent topic: **Tutorial C2—Potential field forward calculation**

1. The first task, whether we are going to carry out forward or inverse modelling, will be to associate physical property distributions with each formation.
2. We then carry out a forward model calculation to see whether the combination of the geological model and the choice of physical properties will produce a response that broadly corresponds with the measured observations.

You need to perform the following operations on the geophysical observations:

3. 3D GeoModeller expects the observed geophysics to be in a regular 2D grid format and observed on a horizontal plane or a drape surface.
4. A variable Z cell option is provided to help reduce any aliasing of the response due to topography effects. If this is insufficient, you may wish to further reduce aliasing effects by upward continuing the data. For vertical gravity and TMI, a terrain clearance of half to one vertical cell height, respectively, should be sufficient.
5. Make adjustments to the geophysical observations to remove the response of material that will not be considered during the inversion phase. This process is generally called 'regional removal'.
6. 3D GeoModeller inversion obtains formation and geological boundary information from the current project. Enter the parameters that define the distributions of properties for each formation into a table in 3D GeoModeller.
7. Supply a grid containing processed geophysical data for each data type.
8. Run the forward modelling calculation either for magnetism, gravimetry or both.
9. When 3D GeoModeller has finished, you can view the observed geophysical grids, the calculated grids and the misfits.
10. In the light of outcomes, you can revise geology boundaries (including adding new units) and physical properties and repeat the forward modelling.

C2 Stage 1—Enter physical properties

Parent topic: **Tutorial C2—Potential field forward calculation**

In this section:

- Physical Properties—Introduction
- Display physical properties in the geological formation dialog box - Information
- Set single mode magnetic susceptibility properties—Steps
- Set bi-model mean density properties—Steps
- Finalise density and magnetic susceptibility properties—Steps

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Physical Properties—Introduction

It is unrealistic, given our knowledge of the real world, to assign a single constant physical property to each formation. Every formation shows some degree of heterogeneity. We simulate this in the inversions by defining a 'distribution' or spread of physical properties for each formation. In a forward model, the mean is adapted for the single run.

Display physical properties in the geological formation dialog box - Information

1 If it is not already open, open your project or the supplied start-point 3D GeoModeller project for Tutorial C2.

From the main menu choose **Project > Open** OR

From the **Project** toolbar choose **Open** OR Press CTRL+O.

(For the start-point project supplied) In the **Open a project** dialog box navigate to the 3D GeoModeller Project .xml file

`Tutorial_C\Tutorial_C2\C2Beginning_Project\C2Beginning_Project.xml`

2 (If you have not already done so) Save your own copy of this project, so that you don't accidentally overwrite the original project files

From the main menu choose **Project > Save as** OR

from the toolbar choose **Save As** or press CTRL+SHIFT+S.

Save your project work in a folder outside the original folder.

3 From the main menu choose **Geophysics > Define physical properties**. 3D GeoModeller displays the **Physical properties of geological formation** dialog box. Some default values are shown as we have not set 'considered' values yet.

In each of the five tabs of the dialog box, the top section contains a table of physical properties for each formation in the geological pile. Double click within the appropriate cell to view or modify the parameters.

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In the lower half of each tab of the dialog box you can set parameters that apply to all formations in the model.

- In the **Gravity** tab, use the **Reference density** to convert absolute density values from the table to relative density for the calculations. The reference density is often, but not always, related to the density used for the Bouguer or terrain corrections applied to gravity data. The standard density used for this purpose is 2.67g/cm3. **No changes to be made here yet.**
- In the **Magnetic** tab, note that the **Total field (nT)**, Declination and Inclination are default values. This is due to a "local" co-ordinate system being set in this project (see Main Menu: Project > Properties). A real world co-ordinate system for the model would result in appropriate fields being automatically filled here. Just provide the date of the observed geophysics survey using the IGRF calculator, and these will adjust accordingly. Alternatively, you can manually enter the Total field (nT), Declination and Inclination from independent sources. **No changes to be made here yet**.

Set single mode magnetic susceptibility properties—Steps

1 In the menu tab for **Magnetic > Susceptibility (SI)**, double-click on the value-field for **Cover** to display details of the current **magnetic susceptibility** for **Series3 - Cover**. Enter/change them to the values below:

Series	Mean Susceptibility	Standard Deviation	Statistical Law	Percentage of Population
3 - Cover	0.00002	0.000002	**LogNormal**	100

2 **OK** to close and save the new Mean and SD values.

In the **Magnetics** tab there are 3 fields below the **IGRF Calculator** where you must enter the Earths's magnetic field properties for the current location: **Total Magnetic Field (nT), Declination (degrees)** and **Inclination (degrees)**.

The **IGRF calculator** will automatically complete these 3 fields based on the Datum/Projection assigned to the 3D GeoModeller Project. (See **Project > Properties**).

Note: In this case the projection is set to Local so the IGRF values must be assigned manually

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3 The "BuriedGranite" model is fictitious, but nominally located in the north of South Australia in WGS 84 zone 54S. Our geophysics survey was acquired on 1st Jan 2010. Therefore please enter:

Total magnetic field (nT)	Declination (degrees)	Inclination (degrees)
56 600	7.6	-62.0

Note:

- The magnitude of the induced magnetisation is the product of induced susceptibility and the magnitude of the ambient field.
- Inclination is positive below the horizontal and declination is positive east of true north.

4 **OK** to close and save the new values.

Further Information

Settings

- Number of modes
- Statistical 'law' or distribution type
- Parameters to define the distribution
- Proportions (if more than 1 mode)

For each formation and property, you can select the number of modes, the statistical law (for each mode if multi-modal), then assign two parameters, **Mean value** and **Standard deviation**. These define the distribution (for each mode if multi-modal). For multi-modal options, you also specify the proportions for each mode.

- For a **Normal** distribution, the **Mean value** and **Standard deviation** have a meaning that is well understood.
- For a **LogNormal** distribution, the **Mean value** is the natural logarithm of the mean, and the **Standard deviation** is the standard deviation of the natural logarithm transformed values.

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- For an **Equal** distribution, the **Mean value** is the central value and the **Standard deviation** is half the range (in other words, the limits of the distribution are **Mean value** ± **Standard deviation**).
- A **Poisson** distribution is completely defined by the **Mean value** (in other words, the **Standard deviation** is not required).
- An **Equal Plus** distribution is an equal distribution where the **Mean value** is the minimum value and the **Standard deviation** is the range.
- An **Equal Minus** distribution is an equal distribution where the **Mean value** is the maximum value and the **Standard deviation** is again the range.

At present, the properties are initialised when performing either a forward or inverse calculation using the mean value. This is the reason for having three different ways of defining an equi-probable distribution (that is, where the distribution is defined with a 'mean' that relates to the central, minimum and maximum values respectively for the equal, equal plus and equal minus distributions).

Supply **Density** values in units of g/cm^3.

Supply **Magnetisation** values in SI units. We assume that the magnetisation is entirely induced. 3D GeoModeller obtains the orientation from the ambient field information.

$$1 \text{ cgs or emu unit of susceptibility} = 4\pi \text{ SI units of susceptibility}$$

$$\text{magnetisation} = \text{susceptibility}\,(\kappa) * \text{field_intensity}\,(H)$$

$$\text{magnetisation} = \text{susceptibility}\,(\kappa) * \text{induction}\,(B) / \mu_0$$

Hence, if you know the susceptibility 'susc' in SI * 10^{-5}, and the ambient field 'amb' in nT, then the magnetisation is:

$$\frac{(\text{susc} * 10^{-5} * \text{amb} * 10^{-9})}{(4 * \pi * 10^{-7})}$$

Multi-modal options

The multi-modal options enable you to define complex distributions as a random mixture of samples from populations that are defined by simple uni-modal distributions.

Specify the proportions for each mode. Since these are constrained to add up to 100%, 3D GeoModeller automatically assigns the proportion of samples for one of the modes based on the proportions specified for the other modes.

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Set bi-model mean density properties—Steps

Create a bi-modal distribution with 70:30 proportions. We suspect from the observed geophysics that there are two separate units with different properties within this **Host_rock** series but we don't have enough data to be able to geologically model them.

1 In the **Gravity > Mean density properties** dialog box for **Host_rock**, select **Bi-modal** from the **Modes** option buttons.

Set the parameters as shown in this table:

Components of Series 2	Mean Density	Standard Deviation	Statistical Law	Percentage of Population
Host_rock	3.1	0.1	**LogNormal**	30-component1
Host_rock	2.5	0.1	**NormalDistribution**	70-component2

2 Set each component in turn. Use the slide bar for the first component, to set 70% of the population. The other 30% will automatically assign to the 2nd population.

3 Choose **OK**. 3D GeoModeller updates property definitions in the table with the revised 'mean', 'standard deviation' and percentage values.

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Finalise density and magnetic susceptibility properties—Steps

Even though the first exercise (forward modelling) is for gravity only, we will also estimate the magnetic susceptibilities for all 3 geological formations in our model. The magnetic properties are not well known so we allow them a relatively large standard deviation. We run magnetic Property optimisation using these values in the next Tutorial C3 and then revise them prior to inversion.

Densities

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Series3-Cover	2.2	0.1	**NormalDistribution**	100
Series2-Host_rock	3.1	0.1	**LogNormal**	30-component1
Series2-Host_rock	2.5	0.1	**NormalDistribution**	70-component2
Series1-Granite	2.9	0.1	**LogNormal**	100

Magnetic Susceptibilities (we will not be setting Remanent Magnetization)

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Series3-Cover	0.0002	0.0001	**LogNormal**	100
Series2-Host_rock	0.02	0.01	**LogNormal**	100
Series1-Granite	0.04	0.02	**LogNormal**	100

1 Ensure all of the values in the above tables are entered and then choose **OK** and **Save** your project

C2 Stage 2—Forward calculation

Parent topic: **Tutorial C2—Potential field forward calculation**

We perform a forward model calculation to verify that the combination of a geological model and the properties assigned to each formation produces a response that broadly corresponds with a set of observations.

We do this as a prelude to the inversion session because we base interpretation of the inversion results on an assumption that the starting model was a reasonable first guess for a model that would be consistent with geological, physical property and geophysical observations.

In this section:

- Configure and run a forward calculation—Steps
- Lateral padding of a model — Information
- Summary images of the response for gravity forward calculation
- Analyse the forward calculation—Steps

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Configure and run a forward calculation—Steps

1 Select the data type to calculate.

From the main menu choose **Geophysics > 3D Geophysics > Forward wizard**. 3D GeoModeller displays the forward calculation area of the **3D Geophysics** tool.

2 Change the name to **Case 1_FM_Gz** and choose **Create a new case**

3 Choose **Gz (vertical gravity)** in the **Fields to compute** area.

Gz is the vertical component of gravity in mGal (the quantity normally measured with ground gravity instruments). **TMI** is total field magnetic intensity in nT (the quantity normally measured in an aeromagnetic survey).

Gravity Tensors (and the following 6 separate components; **Gxx**, etc.) and **Magnetic Tensors** (and the following 9 separate components, **Mx**, etc.) ... are the gravity and magnetic field gradients in the x, y and z directions (correspond to east, north and up). See **Tutorial C6** for further details and a demonstration exercise.

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Below is an image of the observed gravity: 10km x 10km 17.8 to 28.5 mGals. Linear colour stretch.

The aim of our forward modelling exercise is to achieve a close fit of the gravity response from our current geology model, compared with the *observed* response above. The observed response is the "unknown geology" which is our target, and that which we seek to discover during the course of this tutorial.

Our investigation is typical of an exploration approach adopting geophysical inversion. Our starting geology model begins as a best guess at the true sub-surface geology (which in nature is never known with complete certainty). As more geological data can be added to the model (through drilling, sampling and mapping) - and /or potential field geophysics can be interpreted through forward and inverse techniques as demonstrated in this tutorial - then the starting geology model will be driven towards reality and will more closely match the observed geophysics.

4 Select **Specify an Observed Grid**

5 **Browse** for and load the **observed Gz grid** file:

`Tutorial_C\Tutorial_C2\Data\Observed_Boug_Grav_2p2.ers`

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6 Choose a **calculation surface** that best describes the same surface as your grid of observed responses. **Choose Drape - Terrain clearance= 0 m**. This assumes the data was collected on a ground level. It creates a calculation surface which mimics the shape of your DEM, but for a set terrain clearance height

- Alternatively you can select to compute on a constant elevation that will ignore terrain effects in the response i.e. on the zero height datum (eg. sea level).
- The final option allows you to load an external "drape grid" that you want your model response estimated upon. This is the closest option to being able to compare your model response calculations to what might be given to you from an airborne geophysics contractor grid.

7 Choose **NEXT**.

Supported reference grid formats - Information

The default grid format is ERMapper *.ers format. Beneath the "hood" we use the generic Intrepid GridIO drivers capable of auto detecting a range of industry standard geophysical grids.

Some formats support multi-band grids, ie there are multiple data fields within the same grid. An example of a 4 band geophysics grid would be radiometrics data, with bands 1, 2, 3 for K,Th, U and the fourth band for the Total Count. Choose the band that you want to use as an observed grid. Tensor grids are stored in 6 bands by Intrepid.

The *.semi format is a very simple ASCII XY value format that can be used if you are having trouble obtaining a standard grid.

With the Kriging capability within 3D GeoModeller, you can also import gravity point data, or an airborne survey magnetic channel and grid the observations prior to this step (see the reference manual).

The extent of the grid of forward calculations is the intersection of the extent of the supplied grid and the plan view extent of the current project. The spacing between observations in the forward model output is identical to that of the voxet used to calculate the forward response.

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Voxet properties and variable Z

1 Verify the number of cells in the X, Y direction. n=20; leave them as defaults.

2 Tick the vertical resolution **Variable Z**.

By selecting the Variable Z option the user can create a semi-regular voxet instead of a regular voxet (See image below). This allows the user to define a voxet geometry where the cell size can vary with depth. The cell size near the surface can be small and then after a nominated depth becomes progressively larger. This gives a more accurate forward model of the stronger shallow geological response and decreases cell aliasing at the topographic surface while allowing faster computation in the deeper less sensitive parts of the 3D model than if the smaller cell size was used throughout the voxet.

3 When you choose **Variable Z** the only processing option available is the **Spatial** convolution method. This method is thread-safe and will use more than one CPU on a local machine.

The other Fast Fourier method does not support Variable Z requiring a constant vertical sub-cell resolution for topography modelling. It is recommended to use half the vertical cell size as a starting position but this choice depends upon how rugged your topography is.

3D GeoModeller positions the mesh elements laterally, such that the observation locations in the supplied grid coincide in plan view location with the **centre** of each mesh element.

4 Choose **NEXT**

5 Setting the Variable Z Resolution.

- **Location of geology cross-section**

  Choose a Cross-Section visual of your model with topography profile in black. You can display a section of your model in either the XY or YZ directions.

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- **Z Resolution of topography**

  Set the max elevation (**ZMax**) of the voxet above the highest topographic elevation in this project.

  - **Zmax = 2180m** - Elevation of the upper limit of highest voxet resolution.
  - **Upper dZ = 100m** - Highest voxet resolution or cell size
  - **Boundary At = 780m** - Base elevation of the highest voxet resolution; below the lowest topographic elevation

- **Z Cell Resolution below topography**

  Below the base elevation defined above the voxet can be of lower resolution with a cell size increasing with depth.

  Set the

  - **Lower dz = 204.721** -the starting cell size below the base elevation.
  - **Geometric factor to 1.1** - the cell size increases by this factor with depth.
  - **Zmin = -2000** - the base elevation of the voxet to be modelled.

- **Number of cells in z direction**

  3D GeoModeller gives you a summary of the number of cells in the Z direction and an estimation of the memory required to compute the forward model.

  - **Topography part** - number of cells in upper part of model
  - **Lower part** - number of cells in lower part of model
  - **Required memory**

- Click **NEXT**

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Review or edit your lithology properties

Review (or edit) your rock properties. In this case, we are doing a gravity simulation, so we are just asked to review densities. **Leave the set values** which are derived from the Physical Properties table as entered in the previous section.

Click on each coloured formation in the left hand side of the panel, and the tool will show each property as you select the formation. If you wish to change a value, double click on the property law, and the editor will appear.

A background or regional density must be set.

- Select Bouguer Anomaly
  - Set Reference density = **2.2**
  - Set Above-topo density = **2.2**.

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6 Click **NEXT** to launch the Spatial method forward computation.

Note on the last page you are prompted for the number of CPUs to commit to this task. You also have the option for an interactive session or a batch session in the background. In this case, the time to compute is small, so interactive is OK.

7 Click **FINISH**.

Monitoring the forward calculation - Information

The program discretises the geological model (extracts the lithology at the centre of each cell).

To make the forward model calculations tractable, especially as 3D GeoModeller uses the forward model calculation many millions of times during inversion, we must 'discretise' the geological model. This means that we need to convert the continuous form of the geological model (created in the mapping module) to a mesh or block model form. We assume the lithology at all points within each mesh element to be the same as the lithology we calculated (based on the continuous geological model) at the centre of the cell.

3D GeoModeller announces when it has started the re-sampling operations required to discretise the model. The time required for these calculations depends on the number of elements in the mesh. The time may be only a few seconds for a mesh with a few tens of thousands of elements (for example, 40 x 40 x 20 cells) or many minutes for a mesh with several million elements (for example, 200 x 200 x100 cells).

3D GeoModeller initialises the appropriate physical property model, density for gravity calculations and magnetisation for magnetic calculations using the 'mean' value for each formation.

3D GeoModeller announces when the forward calculations are ready to start. The forward calculation for a typical mesh (for example, 100 x 100 x 50 elements) should take no more than a few minutes.

3D GeoModeller displays the results in the **3D Geophysics-> Results Explorer** window.

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Lateral padding of a model — Information

The illustration below shows a plan-view of padded litho-model arrangement used in the forward model response calculation.

Before undertaking forward model calculation using either spatial or FFTmethods, we pad the model volume by surrounding it with 8 copies of the model.

We create these copies by reflecting the model about the vertical sides of the model and performing a double reflection to produce the corner tiles. This strategy results from the thought that the region adjacent to the volume under consideration is most likely occupied by material similar to that of the model volume. 3D GeoModeller calculates the forward model response of the entire padded model at grid points above the core model volume.

This simple strategy reduces the need to remove the effect of sources adjacent to the model volume. However, we still need to exclude the response of material below the model volume from the observed data before comparing these data with the forward model response.

Lateral Padding of the Model

Plan view of the litho-model

Plan-view of the padded litho-model arrangement used in the forward model response calculation

Summary images of the response for gravity forward calculation

3D GeoModeller displays the images of the response of our gravity forward calculation in the **Results Explorer** window.

To remove a DC shift or regional trend from your calculated response go to the bottom left hand-corner: select a **degree** from the regional settings available.

0-Constant is a DC shift,

1-linear is the simplest regional trend.

2-linear, a more complex regional trend type.

1 For this case study, select **0-Constant**

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2 Next select **Solve** (bottom right hand side

3D GeoModeller displays several images and some basic statistics when the forward model calculations have been completed. The images are:

- Top Left-the observed grid
- Top Centre-the response of the 'current model' that you have calculated
- Top Right-the 'current misfit' or difference in response between the response of the 'current' model and the observed grid.
- Bottom Left is the result of choosing a DC shift and asking the tool to **solve** for a best fit degree. The surface is horizontal, so no grid is apparent here. (The solved degree is displayed on bottom-bar, in "Regional" field.)
- Bottom Middle is the computed response with the DC shift added.
- Bottom Right is the redone misfit plot, to see if this extra regional has improved the misfit to the observed.

Note: that the colour scales are typically different for each of the images as they are the result of a linear colour mapping between the minimum and maximum values in the range for each grid.

3 It is clear from the forward model misfit that we are not fitting the higher density feature in the SE corner of the project. We try to resolve this later using inversion. The bimodal properties of the Hostrock_series allow us to seek out the lithology geometry and properties responsible for this misfit.

4 Use **File > Exit** to leave this tool.

All grids are saved in a folder within the 3D GeoModeller project folder called "Case1".

5 Use **Project > Save**.

You can return at any time later to see these results again, by going to: **Geophysics >3D Geophysics > Results explorer**

The left hand panel provides a data explorer for all the cases you may have created. The convention is to use the GREEN arrow to indicate Forward model result cases and RED arrows to the left, to indicate inversion cases.

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Analyse the forward calculation—Steps

3D GeoModeller saved the results of the forward gravity calculation in the project folder in **Case 1_FM_Gz > Run1**. You can examine the grids in more detail by viewing the files.

Load 2D grids to 2D sections of the geology model

1 Back in the 2D viewer of the main 3D GeoModeller workspace, go to the **Explorer** Window.

2 Left-click on the **Grids and Meshes** item, or from the main menu choose **Import> Grid and Mesh > 2D Grid**.

3 Browse to **Tutorial_C2 > C2Completed_Project > Case 1_FM_Gz > Run1**. For this C2 training exercise, the file to load is "**`calculated_Gravimetry_1.ers`**"

4 Ensure your 2D section called "**Surface Topography**" is open and active

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5 Expand the Explore tree by clicking the "+" symbol which has appeared next to **Grids and meshes** in the Explorer so that you can select and then right-click on **calculated_Gravimetry_1**

6 Check the "**Field Visualization Manager**"

Also, you can see all available mechanisms for displaying, colour table matching, statistical analysis, cross plots, contouring and general manipulation of fields within any grid or surface. Special purpose geophysical options are also available for micro-seismic analysis.

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7 Check **View on section** for **Topography surface**

The **calculated** grid of gravity is now geolocated in the 2D map section of the current geology model. (Note the "**observed_Gravimetry_1**" can be loaded in addition:- Repeat steps 5, 6, and 7 above). Toggle between different 2D grids on the section: In **Explorer** menu, right-click on the grid name then > **Hide all views of this field**.

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8 Finally, to see a colour table for the loaded grid **Select Calculated_Gravimetry_1** in the **Explorer** tree

9 Right-cick > **Display Colour Table**

Remember that interpolated geology boundaries/lines can be switched on/off in this view to aid interpretation:- Right-click in the background of the 2D window **display parameters.** (This MTN surface geology section is dominated by the Cover unit hence only the fault iso-line is rendered in blue, lower right.)

Next we will view a histogram of the forward modelled gravity grid (2D)

1 In **Explorer**, choose **calculated_Gravimetry_1** below **Grids and meshes**

2 Right click, and choose **Histogram**. (The y axis is in **mGal**.)

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You can also examine the completed project folder (to view the grid files directly) as stored in your project directory:

`Tutorial_C\Tutorial_C2\C2Completed_Project\Case1\Run1`

Grid file	Description
observed_Gravimetry_1	A copy of the supplied grid. 3D GeoModeller may have resampled the observed grid and trimmed its extent if the supplied grid was not wholly within the plan view extent of the current project.
calculated_Gravimetry_1	Response grid of the starting geology model using the density values set in the physical properties table.

3D GeoModeller writes results from the forward model calculation to standard ERMapper geophysical grids.

Load the initial lithology & density 3D voxet, and view histograms

The process of running a forward model requires that a "Case" or initial lithology voxet is created at the cell-size defined in **Create Forward Case > Voxet Properties** (See page 32). Other attributes of the initial case are stored in the same voxet, such as densities. The voxet files can be viewed directly in **Windows**, in the path containing your tutorial project:

`Tutorial_C2\C2Completed_Project\Case 1_FM_Gz\run1\initial.vo`

1 In **Explorer**, choose **Grids and meshes** and right-click.

2 Choose **Import > Geophysical Results > Case 1_FM_Gz > Run1**

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3 In **Explorer** under the **Grids and Meshes** tree, two Mesh Grids (one 2D and one 3D) will be imported and created. Their names will be:

- **Case 1_FM_Gz_Run1_2D**
  - Clicking on the + will reveal three 2D fields
    - ***calculated_Gravimetry_1***
    - ***compute_Surface_1***
    - ***observed_Gravimetry_1***
- **Case 1_FM_Gz_Run1_3D_initial**
  - clicking on the + will reveal two 3D voxet fields:
    - ***Lithology***
    - ***Density***

4 Choose the **Lithology** field, then right click.

5 Check the "**Field Visualization Manager**" and then "**View grid in 3D**".

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The Lithology voxet appears in 3D viewer as shown below. If the interpolated 3D geology model is also in the same space, select **Explorer > 3D Geology > Hide**

6 Under Grids and Meshes, right click on:

Case 1_FM_Gz_Run1_3D_initial > Lithology and choose **Histogram**.

The three Lithology units are shown together with the Above Topo (white). You can remove **Above Topo** by ticking **Exclude Above Topo.** The volumes of the individual Lithology units are displayed in the right hand panel.

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7 Under Grids and Meshes, right click on:

Case 1_FM_Gz_Run1_3D_initial > Density and choose **Histogram**.

The Histogram for the **Density** field of the selected voxet will be displayed.

Right Click in the histogram panel and choose **Zoom Out >Domain Axis**

Note the spikes in the histogram occur because only the mean values of lithology densities were used in forward modelling gravity. The density values correspond to the mean value density minus the reference density 2.2. To get the real density add 2.2 to the values on the X axis of the histogram.

Setting the Clipping Parameters of a 3D voxet in the 3D Viewer

A 3D voxet can be sliced or clipped in the 3D viewer in the X, Y, and Z directions

Under Grids and Meshes clear the 3D Display, right click on:

1 **Grids and Meshes >Remove All Views**

2 **Choose Case 1_FM_Gz_Run1_3D_initial > Density** and display in **3D Viewer**

3 Select the **Set Clipping Parameters** 3D tool on the 3D toolbar.

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C2 Stage 3—2D seismic calculation

Parent topic: **Tutorial C2—Potential field forward calculation**

The first job is to set a seismic velocity for each geological formation.

1 Do this in the main menu by choosing **Geophysics > Define physical properties**.

2 Choose the **Seismic** tab. Create velocity contrasts between the 3 geology units in our model, by entering the values for a log-normal distribution in the table below.

Enter by clicking on each number field.

Geology unit	velocity m/s	standard deviation m/s	Percentage of Population
Cover	1200	20	100
Host_rock	1800	20	100
Granite	2500	20	100

After entering each new velocity value, press Enter on the keyboard to ensure the value sticks.

3 Under **General Parameters** above set **Reference Velocity (Vp)** to **2500** m/s

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4 Now choose **Geophysics > 2D geophysics** from the **Main menu**. The following dialog will open:

5 Select Vertical section **C3** from the top dropdown. We will calculate a predicted seismic response for this section.

6 Select the **Seismic** tab and toggle **Compute Seismic**.

7 The "**Physical Properties**" status is shown as **Defined.** Physical Properties can be further edited here by clicking on the Cog wheel glyph

8 The **Time**, **Space** and **Frequency** sampling parameters allow you to adjust the resolution of the predicted response. Set the parameters as shown below:

- **Number of Samples = 3000**
- **Interval (ms) = 2 ms**
- **X stepping (m) = 100m**
- **Z stepping (m) = 10m.**
- **Frequency Sampling: From (Hz) = 5 Hz.**
- **Frequency Sampling: To (Hz) = 40 Hz**

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9 Click **Compute**.

After a minute or two's pause the right hand panel displays the calculated 2D synthetic seismograph for section **C3** in the upper panel with the model geology below. The dialog is shown below.

10 You can save the predicted synthetic seismograph to a SEGY format file or as an image snapshot by clicking on the buttons below the Geology Cross-Section.

- Click **Save as SEGY (*.sgy)** or
- Click **Save as Image (*.jpg, *.png, *.bmp, *.tif);**
- for examples see **`Sec_C3_Seismograph.png`** in the **`Tutorial_C2\Data`** directory

Note: A SEGY file can be used to create a vertical cross-section in 3D GeoModeller from the Section menu. Generally the SEGY file would need to be depth converted for effective use in 3D GeoModeller.

11 Save your project
From the main menu choose **Project > Save** or
from the toolbar choose **Save** or press CTRL+S.

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Discussion

We enable rapid creation of a 3D geology model in an off-shore continental margin setting by:

- using the 2D seismic picks that are interpreted in a time based context then depth converted
- these picks are imported as 3D points into 3D GeoModeller and directly used to compute a geological model
- we use the potential field interpolator of 3D GeoModeller to rapidly create 3D bodies that fill the whole project volume.

The gravitational response of a body is easily computed, so that any misfit with observed marine gravity data becomes obvious. This then leads to queries for the seismic picking team to mull over and perhaps re-think some of the horizon returns.

To do something similar with either Gravity or Magnetic profiles is quite easy. Any geophysical database that is line based, and has field observations, can be used to create sections down each line, and have its profile tested for a fit with the underlying 3D geology model.

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Tutorial C3—Potential field rock property optimisation

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

In this section:

- C3 Stage 1—How it works
- C3 Stage 2—Running a property optimisation on the Magnetic properties

Your 3D geology model must not only be consistent with the known geology but must also fit the observed geophysical data such as a Free Air gravity or a Total Magnetic Intensity grid.

To achieve this you must assign rock properties for each formation as described in Tutorial C2.

After you have run your initial forward models you will be able to observe in the Results Viewer how well your geology and property estimates reproduce the shape and amplitude of the observed geoophysics.

If you are confident of your geology model and the forward models do not fit the observed geophysics then you can use property optimization to refine your rock properties and improve the geophysical misfit.

C3 Stage 1—How it works

Parent topic: **Tutorial C3—Potential field rock property optimisation**

Spatial discretisation

We provide an algorithm that computes a bounded least squares optimization of the property estimates for your proposed model. We run it using relatively coarse cells in X and Y and finer cells in the Z direction.

Response kernel

A response kernel for each lithology is required for property optimisation. The kernels are calculated automatically when you choose the **Run Property Optimisation** option in the forward wizard. Once the response kernels have been calculated, property optimisation is run and a report file is displayed with the optimised property values. To be most effective at least three lithology units are recommended.

Bounds

The standard Property Law Standard Deviation is used to constrain the property optimisation run. The algorithm uses +/- 2 times the lithology Standard Deviation to define the minimum and maximum property bounds. This constrains the resulting estimates to be within bounds which are reasonable.

If you find some or all of the estimated property values are at the minimum or maximum of the bounds then your formation standard deviations may be too small and do not allow sufficient freedom for the algorithm to locate the optimum property value.

Alternatively your chosen rock properties are not correct or you do not have a good geology model. You will need to investigate this aspect in more detail before continuing with the inversion.

Spike rejection

You may have a genuine very high observed reading in your data that will distort the general background properties for a lithology unit. To make sure you use representative values from the observed geophysical data, a *maxAbsoluteObserved* field value can be defined so that the algorithm ignores these outliers.

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Solver method

The solver uses a weighted least-squares approach over the whole 3D assembly of cells and properties to best fit the observed data. The response from each individual unit is summed by its response kernels.

C3 Stage 2—Running a property optimisation on the Magnetic properties

Parent topic: **Tutorial C3—Potential field rock property optimisation**

1. If it is not already open, open your project, or the supplied start-point 3D GeoModeller project for Tutorial C3.

   From the main menu choose **Project > Open** OR

   From the **Project** toolbar choose **Open** OR Press CTRL+O.

   In the **Open a project** dialog box navigate to the 3D GeoModeller Project `.xml` file

   `Tutorial_C\Tutorial_C3\C3Beginning_Project\C3Beginning_Project.xml`

2. *(If you have not already done so)* Save your own copy of this project, so that you don't accidentally overwrite the original project files

   From the main menu choose **Project > Save as** OR

   from the toolbar choose **Save As** or press CTRL+SHIFT+S.

Check the Magnetic properties of the geological formations set in Tutorial C2:

3. In the Main Menu Select **Geophysics > Define Physical Properties**.
4. Select the menu tab for **Magnetic > Susceptibility (SI)**.

   In Tutorial C2 the formation susceptibilities were set as shown below:

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Series3- Cover	0.0002	0.0001	**LogNormal**	100
Series2-Host_rock	0.02	0.01	**LogNormal**	100
Series1- Granite	0.04	0.02	**LogNormal**	100

   For a property optimization the standard deviation plays an important role. The (Mean +/- 2*StdDev) defines the lower and upper bounds of the optimised properties. The standard deviation must allow enough variation for the property optimization to converge. The estimated StdDev you set will depend on confidence in your data. We choose for this tutorial a 50% variation each side of the mean value as we have a low very low confidence in our susceptibility estimates.

5. Choose **Close** when finished with the **Define Physical Properties** menu tab.

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Configure and run Property optimisation

Property optimization follows the same wizard as forward modelling

1 From the main menu choose **Geophysics > 3D Geophysics > Forward Wizard**. 3D GeoModeller displays the forward calculation area of the **3D Geophysics** tool.

2 Choose **Create a new case** and call it "**`Case1_POpt_TMI`**"

3 Choose **TMI (total magnetic intensity)** in the **Fields to compute** area.

4 Choose **NEXT**

5 Select **Specify an Observed Grid**

6 **Browse** for and load the **observed TMI grid** file:

`Tutorial_C\Tutorial_C3\Data\Observed_Mag.ers`

7 Choose an **Obervation/Modelling surface** that best describes the surface your magnetic survey was collected on.

Choose **Drape - Terrain clearance = 40 m**.

This assumes the data was collected in an airborne survey at a constant clearance of 40m above your DTM.

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8 Choose **NEXT**

Voxet properties

9 Change the number of cells in the X, Y direction to nX=40, nY=40; leave nZ as the default nZ=20

10 In Processing Options tick **Property Optimisation**

11 Choose **NEXT**

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12 Choose **NEXT**

Review (or edit) your rock properties. In this Magnetic case we are just asked to review susceptibilities.

Leave the set values which are derived from the Physical Properties table as discussed previously above. We have low confidence in our susceptibilities and have set StdDevs of +/- 50% to ensure convergence.

Click on each coloured formation in the left hand side of the panel, and the tool will show each property as you select the formation. If you wish to change a value, double click on the property law and the editor will appear.

The **Geomagnetic Reference Field** must be set.

- Total Magnetic Field = 56600 (nT)
- Declination is 7.6 (Degree)
- Inclination is -62.0 (Degree).

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13 Choose **NEXT** and in the last window of the wizard choose **Finish**

On completion of the process the property optimisation report pops up. The report will also now be available in your Case directory:

`Tutorial_C\Tutorial_C3\C3Completed_Project\Case1_POpt_TMI\Run1\Property_Optimization.rpt`

```
*******************************
Property Optimization Report:
Optimizing model susceptibilities
IGRF used for this run
Magnitude: 56600.00 nT  Inc: -62.00  Dec: 7.60
X component:   3514.33 nT
Y component:  26338.67 nT
Z component:  49974.83 nT

Observed geophysics grid used: Observed_Mag.ers
Number of formations considered: 3

Model response grids used:
 Layer 3, Cover:
  calculated_bylitho_TMI_E_3.ers
  calculated_bylitho_TMI_N_3.ers
  calculated_bylitho_TMI_D_3.ers

 Layer 2, Host_rock:
  calculated_bylitho_TMI_E_2.ers
  calculated_bylitho_TMI_N_2.ers
  calculated_bylitho_TMI_D_2.ers

 Layer 1, Granite:
  calculated_bylitho_TMI_E_1.ers
  calculated_bylitho_TMI_N_1.ers
  calculated_bylitho_TMI_D_1.ers

Number of valid grid cells used: 400, rejected spikes 0, nulls 0

Initial properties:

Formation, PileNo,     Mean,   StdDev, LowBound,  UpBound
    Cover,      3, 0.000200, 0.000100, 0.000000, 0.000400
Host_rock,      2, 0.020000, 0.010000, 0.000000, 0.040000
  Granite,      1, 0.040000, 0.020000, 0.000000, 0.080000

Levenberg-Marquardt returned after 20 out of 100000 iterations.
Reason: Stopped by small incremental improvement
Initial misfit: 49.736728
Final misfit:   0.869128

Optimised properties:
Formation, PileNo,Recommend,Input Mean,   StdDev, LowBound,  UpBound
    Cover,      3, 0.000012,  0.000200, 0.000100, 0.000000, 0.000400
Host_rock,      2, 0.001830,  0.020000, 0.010000, 0.000000, 0.040000
  Granite,      1, 0.004251,  0.040000, 0.020000, 0.000000, 0.080000

Trend added to optim'd grid:+0.000288768*x - 3.95524e-005*y - 1.21043

Creating trend-matched, optimised response grid: optimized_TMI_1.ers
Optimization finished
```

The report includes a summary of the parameters used for the property optimisation and also a table of the initial rock properties. If you scroll down you will find the optimised properties suggested by 3D GeoModeller for the observed magnetic grid and the initial properties you entered.

In our case we get:

Formation	Recommended	Input Mean	StdDev	Lower Bound	Upper Bound
Cover	0.000012	0.0002	0.0001	0.000000	0.0004
Host_rock	0.001830	0.02	0.01	0.000000	0.04
Granite	0.004251	0.04	0.02	0.000000	0.08

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Note: When the property optimisation is finished, 3D GeoModeller will open the Results Explorer. This has no meaning for the property optimisation and can be closed.

We will now change the mean and stddev susceptibility values of our geological formations with those proposed by the property optimisation.

14 Do this in the main menu by choosing **Geophysics > Define physical properties**.

15 Save your project

From the main menu choose **Project > Save** or

from the toolbar choose **Save** (or press CTRL+S)

Configure and run a forward calculation to check the results of the Magnetic Property Optimisation

We use the same parameters that were used for the Property optimisation but we use the new optimised properties entered above and select Spatial rather than Property Optimisation in Step 8.

1 From the main menu choose **Geophysics > 3D Geophysics > Forward Wizard**. 3D GeoModeller displays the forward calculation area of the **3D Geophysics** tool.

2 Choose **Create a new case** and call it "`Case1_Fwd_TMI`"

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3 Choose **TMI (total magnetic intensity)** in the **Fields to compute** area.

4 Choose **NEXT**

5 Specify an **Observed Grid**

Browse for and load the **Observed TMI grid** file:

`Tutorial_C\Tutorial_C3\Data\Observed_Mag.ers`

6 Choose an **Obervation/Modelling surface** that best describes the surface your magnetic survey was collected on.

Choose **Drape - Terrain clearance = 40 m**.

This assumes the data was collected in an airborne survey at a constant clearance of 40m above your DTM.

7 Choose **NEXT**

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8 Click **NEXT**

9 Review (or edit) your rock properties. We have just updated the Properties using the property optimisation results.

Check the Lithology Susceptibility Properties are correct then continue.

10 Click **NEXT**

11 Choose the default **Interactive**

12 Increase **Number of Cores** to 4

13 Click **Finish**

14 When completed the **Results Viewer** will open.

15 Click **Solve** to remove any linear trend and examine the Misfit in the Top Right panel. The Misfit is ~ +/- 2 nT which is a big improvement over the Misfit which would have been obtained using the original properties. If you have time you could examine these results which have been saved in the C2CompletedProject in the Tutorial_C2 folder (Case1_Fwd_TMI). The Misfit is an order of magnitude larger.

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16 Save your Project

17 We have repeated the above steps for Vertical Gravity using the following starting densities.

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Series3-Cover	2.5	0.5	**LogNormal**	100
Series2-Host_rock	3.0	0.5	**LogNormal**	100
Series1-Granite	2.5	1.0	**LogNormal**	100

18 Set Reference Density = 2.2 (The Observed Grid bouguer density)

19 The only difference in this gravity case is: we use a drape on the topography with a clearance of 0 as we did for the forward modelling.

20 We show the results of the optimised densities in the table below.

```
******************************
Property Optimization Report:
Optimizing model densities
Observed geophysics grid used: Observed_Boug_Grav_2p2.ers

Number of formations considered: 3
Model response grids used:
 Layer 3, Cover:      calculated_bylitho_Gravimetry_3.ers
 Layer 2, Host_rock:  calculated_bylitho_Gravimetry_2.ers
 Layer 1, Granite:    calculated_bylitho_Gravimetry_1.ers

Number of valid grid cells used: 400, rejected spikes 0, nulls 0
Initial properties:

Formation, PileNo,     Mean,   StdDev, LowBound,  UpBound
     Cover,     3, 2.500000, 0.500000, 1.500000,  3.500000
Host_rock,      2, 3.000000, 0.500000, 2.000000,  4.000000
   Granite,     1, 2.500000, 1.000000, 0.500000,  4.500000
Reference density: 2.200000

Levenberg-Marquardt returned after 25 out of 100000 iterations.
Reason: Stopped by small incremental improvement
Initial misfit: 36.123161
Final misfit:   0.407294

Optimised properties:
Formation, PileNo,Recommend,     Mean,   StdDev,  LowBound,  UpBound
     Cover,     3, 2.283305, 2.500000, 0.500000,  1.500000,  3.500000
Host_rock,      2, 2.631513, 3.000000, 0.500000,  2.000000,  4.000000
   Granite,     1, 3.045903, 2.500000, 1.000000,  0.500000,  4.500000

Trend added to optimized grid: +0.000268665 * x -0.000113805 * y -11.7116
Creating trend-matched, optimised response grid: optimized_Gravimetry_1.ers
Optimization finished
```


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21 We set the densities for our inversion run as follows not accepting the Cover density as being representative. Because of the terrain and an assumed Bouguer density it is difficult for the algorithm to obtain an accurate estimate for the Cover unit. We might be better off using a Free Air calculation for the Cover optimisation estimate although the terrain signal may be very large and mask small differences in densities of depper units.

22 We also decide to return to the bimodal definition for Host_rock as discussed previously. This is analysed in more detail in Tutorial C5

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Cover	2.2	0.05	**NormalDistribution**	100%
Host_rock (unit1)	2.5	0.05	**NormalDistribution**	94%
Host_rock (unit2)	2.9	0.05	**LogNormal**	6%
Granite	3.1	0.10	**LogNormal**	100%

23 As a final test of these results we suggest adjusting the Physical Properties in your model to the suggested optimised values for both Gravity and TMI.

24 Save to a new project and rerun the Forward model as described in Tutorial C2.

25 Finally compare the misfits in Results Explorer for the original and optimised Cases. The optimised Case will have much reduced misfits for both Bouguer Gravity and TMI.

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Tutorial C4—Prior Only Inversion (geology-only inversion)

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

The aim of this tutorial is to design a series of Prior Only inversions that illustrate how geological constraints affect the geometry of your project. The reference manual contains further references and detailed explanations.

In this tutorial:

- C4—Introduction
- C4—Steps overview
- C4 Stage 1—Propose a suite of Prior Only geology inversions to evaluate the Geological Constraints; Run the No_Tests Example.
- C4 Stage 2—Visualise and Analyse Super Summary Statistics for the No_Tests Example
- C4 Stage 3—Run the PVR Prior Only test, Visualise and Analyse
- C4 Stage 4—Run 3 Commonality, Prior Only tests, Visualise and Analyse.
- C4 Stage 5—Run 3 Shape Ratio, Prior Only tests, Visualise and Analyse.
- C4 Stage 6—Run 3 Volume Ratio, Prior Only tests, Visualise and Analyse.
- C4 Stage 7—Conclusions

C4—Introduction

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

Forward modelling (Tutorial C2—Potential field forward calculation) demonstrated a reasonable fit to the observed gravity potential field was achieved with our initial 3D geology model. Refinements to the magnetic properties were achieved in Tutorial C3 through Property Optimization.

Our next objective before running the joint inversion (which will explore both properties and geology space) is to explore how the available geometric constraints influence the location, coherence, shape and volume of geological formations during an inversion. We do this without reference to the geophysics (properties remain unchanged).

We are not concerned here with the reduction of the calculated misfit between predicted and observed geophysics. No likelihood of the new proposal will be calculated at each iteration or compared with the observed geophysics grids.

We perform prior-only inversions to see what probability space is implied by the geological constraints ("geology tests") that we are proposing.

C4—Steps overview

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

1. A 3D GeoModeller project has already been created for you. You can use the same model/project from the completed Tutorial C3, or Load the Beginning project of Tutorial C4 from your installation directory.
2. First, we propose a set of geological tests which explore how the "tightness or looseness" of the available constraints effect the geological boundaries during an inversion.
3. Next, we run the test suite of stochastic simulation calculations.
4. Finally, we evaluate whether our chosen geological tests result in appropriate geometric changes to the 3D geology model. Are they geologically reasonable?

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C4 Stage 1—Propose a suite of Prior Only geology inversions to evaluate the Geological Constraints; Run the No_Tests Example

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

1 Open the provided 3D geology project in 3D GeoModeller

Launch 3D GeoModeller

From the main menu choose **Project > Open** OR

From the **Project** toolbar choose **Open** OR Press CTRL+O.

Browse to the pre-created 3D GeoModeller project:

`Tutorial_C\Tutorial_C4\C4Beginning_Project\C4Beginning_Project.xml`

2 We will now set up the basic framework for our suite of **Prior Only** inversion tests.

We make an initial run with **no geological constraints** and then one with just the **Preserve Vertical Relationship** constraint which is always recommended where there are no overturned strata as in this project example.

We then clone the PVR example and add tests one at a time for **Commonality, Shape Ratio** and **Volume Ratio** to examine the behaviour of each.

Finally we choose an optimum combination and run a full test inversion to evaluate the results

The Prior Only suite of tests is summarised in the Table below. This table is repeated at **C4 Stage3** for clarity.

In these tests we concentrate mostly on the granite geometry as this is the geological body which is most prominent in this inversion study.

Case	Litho	PVR	Commonality	Shape Ratio	Volume Ratio
No_Tests	NA	No	Off	Off	Off
PVR_only	NA	Yes	Off	Off	Off
Comm1 Tight	Granite	Yes	{Weib, 0.02, 1}, bias: none Other Fm's 0.2 default	Off	Off
Comm2 Moderate	Granite	Yes	{Weib, 0.20, 1}, bias: none Other Fm's 0.2 default	Off	Off
Comm3 Loose	Granite	Yes	{Weib, 2.00, 1}, bias: none Other Fm's 0.2 default	Off	Off
Shape1 Tight	Granite	Yes	Off	{Log, 1, 0.01}, bias: none Other Fm's 0.05 default	Off

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Case	Litho	PVR	Commonality	Shape Ratio	Volume Ratio
Shape2 Moderate	Granite	Yes	Off	{Log, 1.0, 0.05}, bias: none Other Fm's 0.05 default	Off
Shape3 Loose	Granite	Yes	Off	{Log, 1.0, 0.10}, bias: none Other Fm's 0.05 default	Off
Vol0p7 Smaller	Granite	Yes	Off	Off	{Log,0.7, 0.01}, bias: none Other Fm's {Log,1.0,0.03} def
Vol1p0 Same	Granite	Yes	Off	Off	{Log,1.0, 0.01}, bias: none Other Fm's {Log,1.0,0.01} def
Vol1p3 Bigger	Granite	Yes	Off	Off	{Log,1.3, 0.01}, bias: none Other Fm's {Log,1.0,0.03} def

Note: The Commonality, Shape Ratio, Volume Ratio default formats and options are:

Commonality {type: Weibull; mean: 0.2; stddev: 1.0}, bias: none, Local Abundance, Local Commonality, Global Commonality.

Shape Ratio {type: Lognormal; mean: 1.0; stddev: 0.05}, bias: none, Local Abundance.

Volume Ratio {type: Lognormal; mean: 1.0; stddev: 0.05}, bias: none, Local Abundance.

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Order of Application of Geological Constraints

It is important to be aware that the **Geological Constraint** tests are applied sequentially in the following order. If a test fails then none of the tests later in the order are applied. Tests 3, 4 and 5 compare the Proposed Model with the Reference Model according to a chosen mean and distribution

Note: The geophysical Misfit tests are completed last, after the Geology tests, in a full inversion. Although we try to influence the geological proposal with our geological constraints, it does not mean that the proposal will pass the Geophysical acceptance tests and it could be rejected. The corollary of this is that we need to be careful not to be too restrictive with our Geology tests as this might cause too few Geophysical acceptances and not allow our model to converge or result in a poor misfit.

Order	Geological Constraint	Description
1	Preserve Topology	NA in GUI; Not Considered Here.
2	Preserve Vertical Relationship (PVR)	Honours Stratigraphic Pile
3	Commonality (Weibull distribution)	No of voxels in common between the Proposed and Reference models
4	Volume Ratio (Lognormal)	Volume Proposed/Volume Reference
5	Shape Ratio (Lognormal) where Shape= $(\sqrt[2]{SurfArea})/\sqrt[3]{Volume})$	Shape Proposed/Shape Reference

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1 Choose **Geophysics > 3D Geophysics > Inversion Wizard**

The wizard suggests a new Case and a new Run labelled with the next sequentially available name.

2 Create a new case called **"Case1_NoTests"**

We also need to select a single geophysical observational grid data type from the Components list although geophysics will not be used in this Case. **Tick Gz**.

3 Choose **NEXT**

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4 Specify an **Observed Grid:**

Click on **Browse** and navigate to:

`Tutorial_C4\Data\Observed_Boug_Grav_2p2.ers`

5 **> Open**

6 Choose an **Obervation/Modelling surface**:

Set **Drape - Terrain Clearance** to **0m**. Leave the other options as their defaults.

7 Choose **NEXT**

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8 Choose the **Voxet Properties** for the proposed inversion.

Change the number of cells in the X, Y and Z directions only.

Set **nX, nY and nZ = 20**;

The memory required for this resolution is indicated below the wizard Voxet extents panel.

9 Choose **NEXT** - the **Geophysical Properties** wizard dialog appears; we do not want to modify any Properties; they are irrelevant for a Prior Only inversion

10 Choose **NEXT** - the **Shared Geological Settings** wizard dialog opens.

Set the shared geological constraints for the current inversion case

11 We are interested only in the following parameter:

Probability of Property Change Only (%)

In order to calibrate the "tightness or looseness" of geological boundaries explored during an inversion we need to run an inversion with the properties fixed. We have no interest in the geophysical misfit in this process

- Set **Probability of Property Change Only:** to **0%**

12 Under **Fix Individual Cells Containing:**

- **Accept the defaults - all untoggled**

The options here are:

- **Surface Intersections** - fix the computed surface geology - do not change cells intersecting the surface topography section.
- **Any Defined Contact** - do not change cells containing any defined contact data.
- **Points from CSV File** - fix cells at x, y, z locations defined in loaded CSV file.

  Further explanation of these options is covered in Tutorial C5—Joint Gravity-magnetics litho-constrained inversion.

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13 Under **Contacts with Provenance**:

- **Accept the defaults - all untoggled**

The options here allow the user to fix contacts with certain Provenance attributes:

- **Unspecified** - a contact for which Provenance is not specified **(All contacts in this project are Unspecified - this is the default when new contacts or orientation data are created)**.
- **Observed** - a contact or orientation data based on an actual observation - outcrop/oriented drillhole/mine opening etc.
- **Inferred** - a contact or orientation data inferred from other related information i.e. two widely spaced outcrops
- **Interpreted** - a contact or orientation data interpreted from another source such as geophysical data.
- **ModelConstructor** - a contact or orientation data derived from 3D GeoModeller's implicit function or an alternate 3D model builder.

See "Provenance Editor dialog box" in 3D GeoModeller reference on recording Provenance attributes.

14 Drillholes

- Multiselect drillholes from the list to fix the lithologies of intersecting cells.
- Choose a **Radius of Influence** (distance from drillhole to fix cell lithologies).
- Use **Invert All; Select All; Deselect All** operators to make global list selections

15 Choose **NEXT**

The **Lithology Specific Geological Settings** wizard dialog appears.

This panel is where we set the lithology specific geological constraints that will impact our Prior Only inversion cases.

16 **Geological Constraints - Leave defaults for Cover, Host_rock and Granite**

For this case we do not use any geological constraints. We want to see how this impacts the geometry of our Formations during inversion.

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17 Choose **NEXT**

18 **Change** the number of **Iterations to 400,000**

400,000 iterations are enough in this exercise. This number of iterations will allow the impact of the geological constraints on the formation geometry to be visualised.

- **Tick off** "Allow Geophysical Misfit Tests"
- **Tick off** "Allow Formation Geometry Tests"
- **Tick off** "Allow Commonality Test". Bias option to the right: default "none".
- **Tick off** "Allow Volume Ratio Test". Bias option to the right: default "none".
- **Tick off** "Allow Shape Ratio Test". Bias option to the right: default "none".
- Choose **Finish**

Weighting or bias options are explained in the manual Forward modelling and inversion with 3D GeoModeller.

When the 400,000 iterations are complete you will be asked "**Do you want to compute the Summary Voxets now?**".

The Super Summary Statistics process computes statistics for a user-selected range of inversion lithology models derived from each inversion Run. It collates these as a set of probabilities - the probability of each lithology - in each voxel of the voxet model. This set of probabilities is recorded in a 3D GoCAD voxet format.

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19 Choose **Yes** to immediately **Compute the Summary Voxets**.

The following dialog will open.

If you decline the first time, or wish to calculate SSS for a different Case or iteration range, you can return to this option by selecting:

Geophysics > 3D Geophysics > Summary Voxets from Inversion

20 To calculate **Super Summary Statistics,** choose the default burn-in range of **0 to 400,000** and a **Threshold** of **90** (%).

We want to study statistics for the full range of iterations as their is no indication of convergence in a Prior Only run of this type.

The **Threshold** value is the percentage Probability used when computing the **MostProbable_Thresholded** lithology field in the output voxet. Voxels where the lithology has a probability <90% are removed (set to Null) in this field.

Note: When we do this computation with no lithology constraint tests the results are purely random and the Probability of a particular formation being assigned correctly will generally be less than ~60% so the **MostProbable_Thresholded** field will be empty (null) i.e. <90%.

Choose **OK**.

21 Save your Project.

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C4 Stage 2—Visualise and Analyse Super Summary Statistics for the No_Tests Example

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

We will analyse and visualise the Super Summary Statistics voxet for Prior Only inversions using the following methods:

- Visualise the MostProbable formations in 2D and 3D to ensure the geological constraints produce acceptable formation shapes, sizes and locations, using the Grids and Meshes tools.
- Display the formation probability voxet fields (i.e. Prob_Granite) in 2D and 3D to examine the probability distributions of the selected formations.
- Examine the voxel counts relative to the starting model to see if the relative proportions and overlap constraints are being met.
- Generate a video of selected sections to observe how the formations change as the iteration count increases.

We run through this sequence in detail for the Case1_NoTests Prior Only test case and then we summarise the results for each of the other Prior Only tests to save some time.

Note: Batch task files are provided for each of the Prior Only tests to illustrate how the whole test sequence can be automated. The task files are stored in your main project directory and can be run by choosing:

Geophysics > 3D Geophysics > Shell Window from the Main menu

This opens a CMD shell.

At the CMD prompt type:

```
invbatch 001_Case1_NoTests_Run1_inversion.task
```


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Visualise the MostProbable and Prob_Granite voxels in a 2D Section or in 3D

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

Load the **Prior Only** Inversion results into the **Grids and Meshes** tree

1. From the **Explorer** tree, select **Grids & Meshes**
2. Right-click **Import > Geophysical Results > Case1_NoTests>Run1**

   A 3D voxet mesh grid is created: **"Case1_NoTests_Run1_3D_Stats_1_400K_T90"**

   The fields in this voxet are described in the table below. The shaded items are not relevant in Prior Only tests as **Probability of Property Change Only:** is set to **0%**

   .

File(s)	Description
Entropy	Records the volatility of the particular voxel (how often it changed) during inversion. Computed as a number from 0 (low volatility) to 1 (high volatility).
ChangeCount	The number of times this particular voxel has changed.
MeanDensity	The mean density as derived from the accumulated accepted inversion proposals/models which occurred during the chosen range of iterations.
StdDevDensity	Related to the above mean and derived from initial PDF.
MeanSusceptibility	The mean magnetic susceptibility as derived from the accumulated accepted inversion proposals/models which occurred during the chosen range of iterations.
StdDevSusceptibility	Related to the above mean and derived from initial PDF.
MostProbable	For each voxel location, this field records the lithology index ***most often assigned*** to that voxel over the iteration range selected. The lithology index is an integer starting at 1 and incrementing by 1 from the base of the stratigrapic pile up. The AboveTopo unit is assigned the number 0.
MostProbableThresholded	As above, but the ***most often assigned*** lithology for a voxel location must have been accepted as that lithology for “>= the threshold (90%) of the number of proposals” over the iteration range selected, otherwise a “Null” is recorded instead of a lithology index. Areas of uncertainty will appear as Null gaps around geological boundaries.
Prob_AboveTopo	Within the whole model space, the probability of finding “AboveTopo” varies between 0 and 100%. Display values in a black/grey/white colour scale.
Prob_Granite	Within the whole model space, the probability of finding “Granite” varies between 0 and 100%. Display values in a black/grey/white colour scale.
Prob_Host_rock	Within the whole model space, the probability of finding “Host_rock” varies between 0 and 100%. Display values in a black/grey/white colour scale.
Prob_Cover	Within the whole model space the probability of finding “Cover” is between 0 and 100%. Display values in a black/grey/white colour scale.

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There are 3 other mesh grids imported during this process including a 2D multifield geophysics grid (initial and final), a 3D initial lithology and property voxet and a 3D final lithology and property voxet. These are of no interest in our Prior Only tests and will be discussed in more detail in Tutorial C5—Joint Gravity-magnetics litho-constrained inversion

3 In **Explorer** under **Sections** double click on **C2** or select section **C2** in the **2D Viewer** if already open. We will display the results on this section.

4 Expand the **Case1_NoTests_Run1_3D_Stats_1_400K_T90**. Click on the **+** to display the individual voxet fields

Before we can display the **Most Probable** field using Lithology colours we must unset the Lithology alias for the **MostProbableThresholded** field and then set the Lithology alias for the **MostProbable** field. Proceed as follows:

5 Right click on **MostProbableThresholded** and select **Properties** then change the text in the **Alias** field from **Lithology** to **?**

6 Right click on **MostProbable** and select **Properties** then change the text in the **Alias** field from **?** to **Lithology**

Steps 5 and 6 above are illustrated in the following Dialogs

7 Right click on **MostProbable** and Select **Field Visualisation Manager**.

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8 In **Field Visualisation Manager**, Toggle **C2** in the **View on Section** column.

9 Click OK andtThe MostProbable voxet will be displayed as shown below.

The **MostProbable** field records the lithology index most often assigned to that voxel over the iteration range selected. We can see that the formations have disintegrated into randomly distributed patches.

We can also look at the reliability of the results of the Granite formation for example by displaying **Prob_Granite** (the probability of voxels being Granite in our voxet).

10 Right click on **Prob_Granite** and Select **Field Visualisation Manager**.

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11 In **Field Visualisation Manager**, Toggle **C2** in the **View on Section** column.

The initial formation boundaries are shown over the voxel image below. It is clear that the probability of finding Granite at any of the voxels assigned to Granite is mostly less than 50% (not good odds). If we were to look at the **MostProbableThresholded** voxet we would find no Granite voxels were assigned as we set a probablity threshold of 90% when we calulated the super summary statistics.

At this point we can make use of the Image Manager controls to make the Prob_Granite and the MostProbable images transparent to enhance the formation boundaries and examine the relationships between the them.

12 Right click outside the boundary of section C2 and select Image Manager

We can use the transparency controls to highlight the initial computed boundaries and also allow the MostProbable image to be seen through the Prob_Granite.

13 Toggle on MostProbable, click on Prob_Granite and pull the Transparency slider to the left and back to see the relationship between the two on the C2 section.

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Finally display the MostProbable voxet in 3D to obtain a more complete view of the results of No Tests.

1 In Explorer Right Click on 3D Geology to remove the 3D Geology shapes from the 3D Viewer.

2 Right click on **MostProbable** and Select **Field Visualisation Manager**.

3 In **Field Visualisation Manager**, Toggle **View Mesh Grid in 3D,** then Toggle **3D Volume** or **3D Points**.

4 Select the 3D Slicing tool from the 3D Viewer toolbar and adjust as shown below.

5 Alternatively in **Field Visualisation Manager**, Toggle **View Mesh Grid in 3D,** then Toggle **3D Points**. This allows some transparency.

6 Right click on the voxet field MostProbable and choose Appearance and increase the Point size to 5

7 In **Explorer > 3D Geology** Right Click on Granite and Display as Wireframe. Select the Transparency slider and slide to the left to make it ~50% transparent.

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8 Your display should appear as below allowing you to see the Initial computed Granite through the MostProbable voxet point cloud.

Examine the voxel counts relative to the starting model

During our Prior Only analysis we may want to know if the relative formation proportions and overlap constraints are being met. We can see this qualitatively in simple situations but sometimes we may want to quantify this in a statistical sense using pixel counts.

We can do this using the following steps:

1 First we must calculate the voxel counts for our initial (starting) lithology model. We import the initial model from our Case1_NoTests inversion run.

2 In **Explorer,** Right Click on **Grids and Meshes** and choose **Import>3D Grid** as shown below

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3 Navigate to **`Case1_NoTests\Run1`** within your project directory and select voxet **`Initial.vo`**

4 In the Grids and Meshes tree open the initial mesh tree, Right Click on Density and choose Histogram

5 Right Click on the Formation dropdown at bottom right and choose each formation in turn and record the **n-Effective** cell count for each. You should obtain the following results:

Lithology	InitCellCnts
Cover	3235
Host	2170
Granite	416
AboveTopo	2179

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6 To compare this with the cell counts for your **Case1_NoTests** inversion:

- Right Click on the **MeanDensity** field in your voxet **Case1_NoTests_Run1_3D_Stats_1_400K_T90** and select Histogram
- Repeat Step 5 above to obtain the counts for each formation after 400000 iterations with no tests selected.
- Results are shown below

  The impact of no geological constraints is to gradually equalise the counts for the 3 formations and distribute them with a random spatial geometry if run for an infinite number of iterations.

Lithology	InitCellCnts	No_Tests
Cover	3235	2383
Host	2170	2443
Granite	416	995
AboveTopo	2179	2179
Cover	CountRatio	0.74
Host	CountRatio	1.13
Granite	CountRatio	2.39

Creating an Inversion Movie on Section C2

Another useful method for the visualisation of Prior Only results is to generate a movie of one or two well placed sections to show how formations evolve during an inversion as geological geometry constraints are varied.

1 In Main Menu **Geophysics > 3D Geophysics > Create Movies From Inversion**

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2 Accept the default parameters and Choose **OK**.

When the video is created, a pop-up message appears.

3 Select **YES** to view

The Video is stored in your case directory:

`Tutorial_C\Tutorial_C4\C4Completed_Project\Case1_NoTests\Run1\C2_Lithology_1_400000.mpg`

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4 The figure below is an evolution summary (1 frame every 20000 iterations up to iteration 140000) of the above video with an outline of the initial granite lithology superimposed.

5 Save your project

From the main menu choose **Project > Save** or

from the toolbar choose **Save** (or press CTRL+S)

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C4 Stage 3—Run the PVR Prior Only test, Visualise and Analyse

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

The Suite of tests is repeated below. So far we have run & reviewed the No Tests case

Case1	Litho	PVR	Commonality	Shape Ratio	Volume Ratio
NoTests	NA	No	Off	Off	Off
PVR_only	NA	Yes	Off	Off	Off
Comm1 Tight	Granite	Yes	{Weib, 0.02, 1}, bias: none Other Fm's 0.2 default	Off	Off
Comm2 Moderate	Granite	Yes	{Weib, 0.20, 1}, bias: none Other Fm's 0.2 default	Off	Off
Comm3 Loose	Granite	Yes	{Weib, 2.00, 1}, bias: none Other Fm's 0.2 default	Off	Off
Shape1 Tight	Granite	Yes	Off	{Log, 1, 0.01}, bias: none Other Fm's 0.05 default	Off
Shape2 Moderate	Granite	Yes	Off	{Log, 1.0, 0.05}, bias: none Other Fm's 0.05 default	Off
Shape3 Loose	Granite	Yes	Off	{Log, 1.0, 0.10}, bias: none Other Fm's 0.05 default	Off
Vol0p7 Smaller	Granite	Yes	Off	Off	{Log,0.7, 0.01}, bias: none Other Fm's {Log,1.0,0.03} def
Vol1p0 Same	Granite	Yes	Off	Off	{Log,1.0, 0.01}, bias: none Other Fm's {Log,1.0,0.01} def
Vol1p3 Bigger	Granite	Yes	Off	Off	{Log,1.3, 0.01}, bias: none Other Fm's {Log,1.0,0.03} def

Run the Preserve Vertical Relationship (PVR) Only test

1 Choose **Geophysics > 3D Geophysics > Inversion Wizard**

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2 Clone the Case1_NoTests and rename Case1_PVR_Only

3 Continue through the wizard panels to **Shared Geological Settings**

Under **Fix Individual Cells Containing:**

- Toggle **Surface Intersections OFF** - don't fix the surface geology map.
- Click **Next**

4 In the the new wizard panel - **Lithology Specific Geological Settings**

- Click on **Stratigraphic Order**

  This will automatically Preserve Vertical Relationships between formations. An older formation cannot occur above a younger formation and vice versa.

  The results in the interface are:

  For **Cover** - both **Host_rock** and **Granite** are toggled **ON**.

  For **Host_rock** - **Granite** is toggled **ON**.
- Click **Next**

5 In the new wizard panel - **Run Settings**

- Toggle **Apply Geological Constraints ON**

  Only the **Allow Preserve Vertical Relationship Test** should be toggled ON (it is shaded out in this panel - as it is not selectable here).
- Click **Next**

6 In the new wizard panel - **Runtime Settings**

- set **Number of Cores** to the maximum i.e **4**
- Click **Finish**

7 The Inversion Misfit graph pops up. When the 400000 iterations is completed a popup dialog appears asking:

8 **Do you want to compute the Summary voxets now .....** :

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9 Click **Yes**; the following dialog pops up

10 Accept defaults and click **OK;** when stats calc is complete this dialog pops up.

11 Import the results by selecting the Case/Run as below:

`Import > Geophysical Results > Case_PVR_Only > Run1`

12 Delete the 2D voxet and the Initial and Final 3D voxets. We are only interested in the 3D Stats voxet.

Repeat C4 Stage 2—Analysis and Visualisation of Super Summary Statistics

1 In **Explorer** under **Sections** double click on **C2** or select section **C2** in the **2D Viewer** if already open. We will display the results on this section.

2 Expand the **Case1_PVR_Only_Run1_3D_Stats_1_400K_T90**. Click on the **+** to display the individual voxet fields

Before we can display the **Most Probable** field using Lithology colours we must unset the Lithology alias for the **MostProbableThresholded** field and then set the Lithology alias for the **MostProbable** field. Proceed as follows:

3 Right click on **MostProbableThresholded** and select **Properties** then change the text in the **Alias** field from **Lithology** to **?**

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4 Right click on **MostProbable** and select **Properties** then change the text in the **Alias** field from **?** to **Lithology**

5 Right click on **MostProbable** and Select **Field Visualisation Manager**.

6 In **Field Visualisation Manager**, Toggle **C2** in the **View on Section** column. Adjust the transparency to highlight the initial formation boundaries using Image Manager.

We see the power of PVR in maintaining the stratigraphic pile order but the initial shape and volume attributes of the formations are lost

We can also look at the reliability of the results of the Granite formation for example by displaying **Prob_Granite** (the probability of voxels being Granite in our voxet).

7 Right click on **Prob_Granite** and Select **Field Visualisation Manager**.

8 In **Field Visualisation Manager**, Toggle **C2** in the **View on Section** column.

The initial formation boundaries are shown over the voxel image below. It is clear that the probability of finding Granite at any of the voxels assigned to Granite has improved significantly compare with the first example Case1_NoTests.

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Also if we look at the **MostProbableThresholded** voxet we now find there are a few Granite voxels assigned in spite of the a high probablity threshold of 90%. You must reset the Lithology alias to visualise this, see page 70.

9 We conclude that the PVR test is worthwhile in preserving some important characteristics of our initial lithology model.

10 We now display the **MostProbable** voxet in 3D to obtain a more complete view of the results of the **PVR** test. Set the Lithology alias to the MostProbable field. We examine the Granite only (mask the MostProbable field to Granite only using the LUT visibility clip).

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11 Note in 3D that the actual volume of the Granite has increased significantly in the PVR test

12 We compare the cell counts for the **Case1_PVR_Only** inversion with the initial counts as we did for Case1_NoTests on page 75:

- Right Click on the **MeanDensity** field in your voxet **Case1_PVR_Only_Run1_3D_Stats_1_400K_T90** and select Histogram
- Select each formation from the Histogram drop down to obtain the counts for each formation after 400000 iterations.
- Results are shown below

  The impact of the PVR_Only constraints is to decrease the cell counts for the Cover formation and increase the Granite. The spatial coherence is still reasonable but the shape is poorly preserved.

Lithology	InitCellCnts	PVR_Only 0.4K
Cover	3235	2494
Host	2170	1973
Granite	416	1354
AboveTopo	2179	2179
Cover	CountRatio	0.77
Host	CountRatio	0.91
Granite	CountRatio	3.25

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13 We now generate a video for section C2 of the PVR_Only test as was done for Case1_NoTests, pages 76 - 77

We provide an evolution summary (1 frame every 20000 iterations up to iteration 140000) of the above video with an outline of the initial granite lithology superimposed.

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C4 Stage 4—Run 3 Commonality, Prior Only tests, Visualise and Analyse.

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

We run the remaining Prior Only tests with the PVR test turned on since we believe PVR is valuable in constraining our basic geology geometry. We append the Commonality test using a variety of constraints to test some end member settings.

Commonality

Description of Commonality

In this project we want to maintain the integrity of the Granite intrusive. We allow it to move but it must maintain some overlap with the initial proposal. This will be ***at the expense of*** the **Cover** and **Host_rock** units.

By definition: **Commonality** *is the extent to which a formation's voxels in the* ***initial*** *model remain 'in common' with that formation's voxels in the* ***proposed*** *model.*

Viewing/modifying the Weibull PDF is the same as for lithology properties, except there is no provision for multiple populations. The PDF's you choose are appropriate for shapes, not properties. The advantage of Weibul is that it is a very conservative PDF. The probability of a radical change at any one step is minimized, whereas for a Normal distribution, there is always a 50/50 chance of a larger change.

The Commonality constraint has 4 Bias correction methods that can be applied:

- none
- Local Abundance
- Local Commonality
- Global Abundance

Testing on this project shows that Local Abundance and Local Commonality have the effect of reducing overlap for moderate constraints (k = 0.2 ; overlap decreases from 80% to 50%). Also a much higher number(much higher numbers of proposals are rejected) of proposals are rejected.

Global Abundance is even more extreme and results in a severe reduction in volume of the smallest formation i.e. Granite in this example almost disappears in all 3 tests. It should not be used in its current form.

Since a Bias setting of "none" has the most predictable behaviour it is generally preferred when used with PVR.

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The three Commonality tests from the main test suite table appear below.

PVR_Comm1 - Tight	Granite {Weib, 0.02, 1}, bias: none, Other Fm's 0.2 default
PVR_Comm2 - Moderate	Granite {Weib, 0.20, 1}, bias: none, Other Fm's 0.2 default
PVR_Comm3 - Loose	Granite {Weib, 2.00, 1}, bias: none, Other Fm's 0.2 default

1. Choose **Geophysics > 3D Geophysics > Inversion Wizard**
2. Clone the Case1_PVR_Only and rename as Case1_PVR_Comm1
3. Step through the wizard to the 5th panel **Lithology Specific Geological Settings**
4. Select Lithology < Granite and for Commonality click on the Pencil glyph to open the Weibull distribution editor.
5. Set the λ***(Scale)***: parameter to **0.02** as shown below and click **OK**
6. Leave all other Lithology settings as the defaults.

7. Click **Next** to open the **Run Settings** wizard panel
8. Toggle **Allow Commonality Test ON**

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9 Accept default associated **Bias correction Method** of "**none**"

10 In the final wizard panel - **Runtime Settings**

- set **Number of Cores** to the maximum i.e **4**
- Click **Finish**

11 Repeat **Steps 1 to 10** for the other two Commonality tests, **PVR_Comm2** and **PVR_Comm3** by cloning **PVR_Comm1**.

The only change to the **PVR_Comm1** test is at **Step 5**

For **PVR_Comm2**, for Granite set the λ***(Scale)***: parameter to **0.20**

For **PVR_Comm3**, for Granite set the λ***(Scale)***: parameter to **2.00**

12 Calculate the Super Summary Stats for the 3 tests

- **Geophysics>3D Geophysics>Summary Voxets From Inversion**

13 Import the 3 Super Summary voxets using a Right Click from the Grids and Meshes tree

- **Import > Geophysical Results > Case1_PVR_Comm1>Run1**
- **Import > Geophysical Results > Case1_PVR_Comm2>Run1**
- **Import > Geophysical Results > Case1_PVR_Comm3>Run1**

Repeat C4 Stage 2—Analysis and Visualisation of Super Summary Statistics

We now compare the results of the three Commonality tests to see which if any of these tests will help with our inversion:

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Compare the MostProbable results on section C2:

In Summary:

Commonality test with Granite k = 0.02 (Tight) has a 90% overlap with initial.

Commonality test with Granite k = 0.20 (Moderate) has an 83% overlap with initial.

Commonality test with Granite k = 2.00 (Loose) has a 75% overlap with initial.

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On the other hand the relative volumes of the Formations show the following behaviour with the Granite growing very significantly relative to other formations.

Lithology	InitCellCnts	PVR_Comm1 0.4M	PVR_Comm2 0.4M	PVR_Comm3 0.4M
Cover	3235	2324	2409	2317
Host	2170	1986	1987	2113
Granite	416	1511	1425	1391
AboveTopo	2179	2179	2179	2179
Cover	CountRatio	0.72	0.74	0.72
Host	CountRatio	0.92	0.92	0.97
Granite	CountRatio	3.63	3.43	3.34

The video evolution summaries for each of these tests (1 frame every 20000 iterations up to iteration 160000) with an outline of the initial granite lithology superimposed are displayed below.

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C4 Stage 5—Run 3 Shape Ratio, Prior Only tests, Visualise and Analyse.

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

Introduction

Shape is defined as the dimensionless number **square_root (boundary_counts) / cube_root (volume_counts)** where "boundary_counts" is the number of faces of voxels occupied by a particular formation that are in contact with voxels of another formation.

ShapeRatio

ShapeRatio is the ratio of the Shape of the Proposed model formation divided by the Shape of the same formation in the Reference model.

For **ShapeRatio** we always use a Log-normal distribution.

> **Log-normal(central measure, spread measure)** where
>
> Central Measure is the (**Mean**) and the
>
> Spread Measure is the (**Standard Deviation**)

Central Measure (Mean)

If we want a 'shape' to be the same as the 'shape' in our Reference Model then the ratio is 1. Although we use a log-normal distribution, we enter the 'arithmetic ratio value 1' for the central measure and an arithmetic standard deviation for the spread measure.

Increasing the ShapeRatio Mean tends to increase the model roughness

For example a very likely case is that my Reference Model is a slightly simplified, smoother model ('smoother' and thus pushing the 'shape-ratio' down to a relatively lower value). In practice, the evolving voxel-model of the inversion should have some nooks and crannies and edges and protuberances and holes (i.e. tendency towards a higher shape-ratio). In the real geology world it is likely that geology reality will also have these same 'rough' characteristics compared to an idealised, smooth Reference Model.

Thus the ShapeRatio 'mean' could usefully be set to, say, 1.20 - meaning "I expect that the geology is actually rougher than my idealised starting model" … rougher to the tune of 20% higher shape-ratio. Specifying this mean will actually push the evolving (inversion) model away from the reference shape-ratio, and towards a rougher model.

You could also set the 'mean' to be 0.80 … meaning I want to force the model in the direction of becoming smoother than my starting model.

Spread Measure (Standard Deviation)

This is the parameter that should be tuned when doing a series of Prior Only inversions. The current ShapeRatio implementation is very sensitive to the standard deviation.

ShapeRatio Bias Settings

The ShapeRatio constraint has 2 Bias correction methods that can be applied:

- **none**
- **Local Abundance**

Note: Testing with this version of 3D GeoModeller shows that use of the **Local Abundance** bias setting causes the target formation, Granite to almost disappear. We recommend that it not be used with the ShapeRatio!

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ShapeRatio Test Sequence

We run the series of tests described in the table below and adjust the Granite by varying its ShapeRatio, Standard Deviation while holding the Stddev of the other formations constant. We do this because the Granite has a relatively well defined shape which we would like to maintain during our inversions. The other formations are relatively uniform slabs.

Shape1 Tight	Granite {Log, 1, 0.01}, bias: none; Other Fm's 0.05 default
Shape2 Moderate	Granite {Log, 1.0, 0.05}, bias: none; Other Fm's 0.05 default
Shape3 Loose	Granite {Log, 1.0, 0.10}, bias: none; Other Fm's 0.05 default

We set up the tests and run them using the same sequence as for the Commonality tests in the previous section.

1. Choose **Geophysics > 3D Geophysics > Inversion Wizard**
2. Clone the **Case1_PVR_Only** and rename as **Case1_PVR_Shape1**
3. Step through the wizard to the 5th panel **Lithology Specific Geological Settings**
4. Select **Lithology > Granite** and for **ShapeRatio** click on the Pencil glyph to open the PDF editor.
5. Set the **Standard Deviation** parameter to **0.01** as shown below and click **OK**
6. Leave all other Lithology settings as the defaults.

7. Click **Next** to open the **Run Settings** wizard panel

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8 Toggle **Allow Shape Ratio Test ON**

- Toggle **Include Faces on Topography ON**
- Toggle **Include Faces On Project Boundaries ON**

  We do this because the Granite is in contact with base of project box and forms part of the Granite shape and the Cover intersects the Topography.

9 Accept default associated **Bias correction Method** of "**none**"

10 In the final wizard panel - **Runtime Settings**

- set **Number of Cores** to the maximum i.e **4**
- Click **Finish**

11 Repeat **Steps 1 to 10** for the other two ShapeRatio tests, **PVR_Shape2** and **PVR_Shape3** by cloning **PVR_Shape1**.

The only change to the **PVR_Shape1** test is at **Step 5**

For **PVR_Shape2**, for Granite set the **StdDev**: parameter to **0.05**

For **PVR_Shape3**, for Granite set the **StdDev**: parameter to **0.10**

12 Calculate the Super Summary Stats for the 3 tests

- **Geophysics>3D Geophysics>Summary Voxets From Inversion**

13 Import the 3 Super Summary voxets using a Right Click from the Grids and Meshes tree

- **Import > Geophysical Results > Case1_PVR_Shape1 > Run1**
- **Import > Geophysical Results > Case1_PVR_Shape2 > Run1**
- **Import > Geophysical Results > Case1_PVR_Shape3 > Run1**

Repeat C4 Stage 2—Analysis and Visualisation of Super Summary Statistics

We now compare the results of the three ShapeRatio tests to see which if any of these tests will help with our inversion:

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Compare the MostProbable and the Probability of Granite results on section C2:

It is clear that the first ShapeRatio test is probably too restrictive, allowing very little change to the Granite shape or position. It also gives high probabilities that the Granite exists in this area which is not so bad since we expect this to be true in the centre where they are highest.

On the other hand the relative volumes of the formations show the following behaviour with the Granite growing very significantly relative to other formations.

The tests run are highlighted with red headers. The last test PVR_Shape01 was run with Bias set to Local Abundance. The Granite volume drops to only 8 Cells!

Lithology	InitCellCnts	PVR_Shape01 Bias none Gr 1.0, 0.01; Oth 1.0, 0.05	PVR_Shape01 Bias none; Fix surf Gr 1.0, 0.01; Oth 1.0, 0.05	Bias none Gr 1.0, 0.02; Oth 1.0, 0.05	Bias none Gr 1.0, 0.03; Oth 1.0, 0.05	PVR_Shape02 Bias none Gr 1.0, 0.05; Oth 1.0, 0.05	PVR_Shape03 Bias none Gr 1.0, 0.10; Oth 1.0, 0.05	PVR_Shape01 Bias Loc Abund Gr 1.0, 0.01; Oth 1.0, 0.05
Cover	3235	2675	2757	2366	2237	2351	2335	3678
Host	2170	2347	2202	1945	2086	2088	2162	2135
Granite	416	799	862	1510	1498	1382	1324	8
AboveTop	2179	2179	2179	2179	2179	2179	2179	2179
Cover	CountRatio	0.83	0.85	0.73	0.69	0.73	0.72	1.14
Host	CountRatio	1.08	1.01	0.90	0.96	0.96	1.00	0.98
Granite	CountRatio	1.92	2.07	3.63	3.60	3.32	3.18	0.02

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The video evolution summaries for each of these tests (1 frame every 20000 iterations up to iteration 160000) with an outline of the initial granite lithology superimposed are displayed below.

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This ShapeRatio test although probably too restrictive, does allow some expansion. This is better seen in 3D as the section C2 is not representative of the full picture.

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C4 Stage 6—Run 3 Volume Ratio, Prior Only tests, Visualise and Analyse.

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

Introduction

VolumeRatio

VolumeRatio is the ratio of the Volume of the Proposed model formation divided by the Volume of the same formation in the Reference model i.e. Proposed Volume/ Reference Volume.

For **VolumeRatio** we always use a Log-normal distribution.

> **Log-normal(central measure, spread measure)** where
>
> Central Measure is the (**Mean**) and the
>
> Spread Measure is the (**Standard Deviation**)

Central Measure (Mean)

If we want the new formation 'volume' to be the same as the 'volume' in our Reference Model then the ratio is 1. Although we use a log-normal distribution, we enter the 'arithmetic ratio value 1' for the central measure and an arithmetic standard deviation for the spread measure.

Increasing the VolumeRatio Mean of a formation will result in an increase in Volume relative to the Reference or Initial model

Spread Measure (Standard Deviation)

This parameter allows the chosen VolumeRatio to vary around the chosen VolumeRatio Mean. Since we do not know exactly what the new volume will be, we do not want to be too restrictive in our prior prediction.

VolumeRatio Bias Settings

The VolumeRatio constraint has 2 Bias correction methods that can be applied:

- **none**
- **Local Abundance**

Note: Testing with this version of 3D GeoModeller shows that use of the **Local Abundance** bias setting causes the target volume to taper for Volume ratios greater then 1 but has little impact on VolumeRatios less than 1.We recommend using a Bias of **none** as it appears to be more predictable in ths mode.

VolumeRatio Test Sequence

We run the series of tests described in the table below and adjust the Granite by varying the VolumeRatio, Mean. We keep the Standard Deviation small for the Granite to test whether we can achieve the proposed outcome. We allow a higher StdDev for the other formations except in the “Vol1p0 Same” case.

Vol0p7 Smaller	Granite {Log,0.7, 0.01}, bias: none ; Other Fm’s {Log,1.0,0.03}
Vol1p0 Same	Granite {Log,1.0, 0.01}, bias: none; Other Fm’s {Log,1.0,0.01}
Vol1p3 Larger	Granite {Log,1.3, 0.01}, bias: none; Other Fm’s {Log,1.0,0.03}

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We set up the tests and run them using the same sequence as for the ShapeRatio tests in the previous section.

1 Choose **Geophysics > 3D Geophysics > Inversion Wizard**

2 Clone the **Case1_PVR_Only** and rename as **Case1_PVR_Vol0p7**

3 Step through the wizard to the 5th panel **Lithology Specific Geological Settings**

4 Select **Lithology > Granite** and for **VolumeRatio** click on the Pencil glyph to open the PDF editor.

5 Set the **Mean** to **0.7** and the **Standard Deviation** to **0.01** and click **OK**

6 Select the other lithologies, **Cover** and **Host_rock** and set their **Standard Deviations** to **0.03;** leave their default **Mean's** as **1**

7 Click **Next** to open the **Run Settings** wizard panel.

8 Toggle **Allow Volume Ratio Test ON**

9 Accept default associated **Bias correction Method** of "**none**"

10 In the final wizard panel - **Runtime Settings**

- set **Number of Cores** to the maximum i.e **4**
- Click **Finish**

11 Repeat **Steps 1 to 10** for the other two VolumeRatio tests, **PVR_Vol1p0** and **PVR_Vol1p3** by cloning **PVR_Vol0p7**.

The only changes to the **PVR_Vol0p7** test are at **Step 5**

For **PVR_Vol1p0**, for **Granite** set the **VolumeRatio Mean** parameter to **1.00**
for **Cover** and **Host** set the **VolumeRatio StdDev's** to **0.01**

For **PVR_Vol1p3**, for **Granite** set the **VolumeRatio Mean** parameter to **1.30**
for **Cover** and **Host** set the **VolumeRatio StdDev's** to **0.03**

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12 Calculate the Super Summary Stats for the 3 tests

- **Geophysics>3D Geophysics>Summary Voxets From Inversion**

13 Import the 3 Super Summary voxets using a Right Click from the Grids and Meshes tree

- **Import > Geophysical Results > Case1_PVR_Vol0p7 > Run1**
- **Import > Geophysical Results > Case1_PVR_Vol1p0 > Run1**
- **Import > Geophysical Results > Case1_PVR_Vol1p3 > Run1**
-

Repeat C4 Stage 2—Analysis and Visualisation of Super Summary Statistics

We now compare the results of the three VolumeRatio tests to see which if any of these tests will help with our inversion:

3D Distribution of Granite for the 3 Volume Ratio tests. Volume increases with Mean

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Compare the MostProbable results on section LevelPlan -1700m:

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Numerical table shows volume changes in Cell counts for the VolumeRatio tests

Lithology	InitCellCnts	Gr 0.7, 0.01; Oth 1.0, 0.03	Gr 1.0, 0.01; Oth 1.0, 0.01	Gr 1.0, 0.01; Oth 1.0, 0.03	Gr 1.3, 0.01; Oth 1.0, 0.03
Cover	3235	3171	3265	3189	3024
Host	2170	2350	2205	2279	2232
Granite	416	300	351	353	565
AboveTopo	2179	2179	2179	2179	2179
Cover	CountRatio	0.98	1.01	0.99	0.93
Host	CountRatio	1.08	1.02	1.05	1.03
Granite	CountRatio	0.72	0.84	0.85	1.36

Prior Only Summary - Proposal Acceptance/Rejection Statistics - All Tests

The following tables contain a summary of the Acceptance/Rejection statistics for all the Prior Only tests described above. These tables are built from the **`Summary.txt`** files which are written to each **`Case>Run`** directory.

They are included here for reference and they show the number of rejections that occurred for each test. This information is important as a test with a large number of rejections means that very few proposals will then make it through to the geophysical misfit test. This may be undesirable depending on the accuracy of the initial/reference geological model as it can restrict the convergence of an inversion to a good solution.

Prior Only Inversion Summary	Case		Case		Case		Case		Case	
Proposals Accept/Reject Summary	No Tests		PVR Only		PVR/Comm1 Gr 0.02 Oth 0.20		PVR/Comm2 Gr 0.20 Oth 0.20		PVR/Comm3 Gr 2.00 Oth 0.20	
Total Iterations/Seed	400000	1234	400000	1939	400000	1234	400000	1234	400000	1234
Total Proposals	400000		400000		400000		400000			
InterFormation (Formation Changed)	400000		400000		400000					
	Counts	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*
TotalAcceptanceCount	**400000**		**108890**		**108385**		**110251**		**109071**	
InterFormation (Formation Changed)	400000	400000	108890	400000	108385	400000	110251	400000	109071	400000
InterFormation (Formation UnChanged)	0	400000	0	0	0	0	0	0	0	0
IntraFormation	0	0	0	0	0	0	0	0	0	0
TotalRejectCount (All GeologyRejects)	**0**	400000	**291110**		**291615**		**289749**		**290929**	
PreserveTopology										
PreserveVerticalRelationship			291110	400000	290571	400000	289285	400000	290568	400000
Commonality					1044	109429	464	110715	361	109432
CommonalityVolume										
Volume										
Shape										
Overlap for Granite (Inside,TotalCount)					376	416	344	416	313	416

Table 3: No Tests, PVR and Commonality Proposals Summary

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Prior Only Inversion Summary	Case		Case		Case		Case		Case	
Proposals Accept/Reject Summary	No Tests		PVR Only		PVR/Shape1 Gr 1.0, 0.01 Oth 1.0, 0.05		PVR/Shape2 Gr 1.0, 0.05 Oth 1.0, 0.05		PVR/Shape3 Gr 1.0, 0.10 Oth 1.0, 0.05	
Total Iterations/Seed	400000	1234	400000	1939	400000	1234	400000	1234	400000	1234
Total Proposals	400000		400000				400000			
InterFormation (Formation Changed)	400000		400000							
	Counts	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*
TotalAcceptanceCount	**400000**		**108890**		**92484**		**113445**		**113299**	
InterFormation (Formation Changed)	400000	400000	108890	400000	92484	400000	113445	400000	113299	400000
InterFormation (Formation UnChanged)	0	400000	0	0	0	0	0	0		
IntraFormation	0	0	0	0	0	0	0	0		
TotalRejectCount (All GeologyRejects)	**0**	400000	**291110**		**307516**		**286555**		**286701**	
PreserveTopology										
PreserveVerticalRelationship			291110	400000	290571	400000	279747	400000	290568	400000
Commonality										
CommonalityVolume										
Volume										
Shape					19885	112369	6808	120253	4794	118093
Overlap for Granite (Inside,TotalCount)										

Table 4: No Tests, PVR and ShapeRatio Proposals Summary

Prior Only Inversion Summary	Case		Case		Case		Case		Case	
Proposals Accept/Reject Summary	No Tests		PVR Only		PVR/Vol0p7 Gr 0.7, 0.01 Oth 1.0, 0.03		PVR/Vol1p0 Gr 1.0, 0.01 Oth 1.0, 0.01		PVR/Vol1p3 Gr 1.3, 0.01 Oth 1.0, 0.03	
Total Iterations/Seed	400000	1234	400000	1939	400000	1234	400000	1234	400000	1234
Total Proposals	400000		400000				400000			
InterFormation (Formation Changed)	400000		400000							
	Counts	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*	*Counts*	*Out of*
TotalAcceptanceCount	**400000**		**108890**		**17309**		**34250**		**34547**	
InterFormation (Formation Changed)	400000	400000	108890	400000	17309	400000	34250	400000	34547	400000
InterFormation (Formation UnChanged)	0	400000	0	0						
IntraFormation	0	0	0	0						
TotalRejectCount (All GeologyRejects)	**0**	400000	**291110**		**382691**		**365750**		**365453**	
PreserveTopology										
PreserveVerticalRelationship			291110	400000	295214	400000	288640	400000	265430	400000
Commonality										
CommonalityVolume										
Volume					87477	104786	77110	111360	100113	134660
Shape										
Overlap for Granite (Inside,TotalCount)										

Table 5: No Tests, PVR and VolumeRatio Proposals Summary

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C4 Stage 7—Conclusions

Parent topic: **Tutorial C4—Prior Only Inversion (geology-only inversion)**

The Prior Only tests before inversion let you check whether the chosen geological constraints ("geology tests") allow appropriate lithology geometry variation during the full joint Inversion but still respect the geology history (pile order) and your field or drillholes observations (i.e. The granite has an inverted rounded conical shape and doesn't come to the surface).

Note: The geophysical Misfit tests are completed last, after the Geology tests, in a full inversion. Although we try to influence the geological proposal with our geological constraints, it does not mean that the proposal will pass the Geophysical acceptance tests and it could be rejected. The corollary of this is that we need to be careful not to be too restrictive with our Geology tests as this might cause too few Geophysical acceptances and not allow our model to converge or result in a poor misfit.

Order	Geological Constraint	Description
1	Preserve Topology	NA in GUI; Not Considered Here.
2	Preserve Vertical Relationship (PVR)	Honours Stratigraphic Pile
3	Commonality (Weibull distribution)	No of voxels in common between the Proposed and Reference models
4	Volume Ratio (Lognormal)	Volume Proposed/Volume Reference
5	Shape Ratio (Lognormal) where Shape= $(\sqrt[2]{SurfArea})/\sqrt[3]{Volume})$	Shape Proposed/Shape Reference

Once we are confident of our geophysical properties and our geological constraints, we can run a joint Gravity and Magnetic inversion.

From the above tests we conclude in this case that the tests we should use in our full joint inversions should be one of the following combinations:

1

- PVR - preserve the geological pile order.
- Commonality - select the Comm2 example; use a higher k (mean) value of 0.4 for all formations
- ShapeRatio - select the Shape2 example; use a lower standard deviation for Granite i.e. StdDev = 0.01

  AND/OR
- VolumeRatio - select the Vol1p0 example to maintain roughly the same formation volumes.

Recommend using only 3 tests so that the proposal rejection rate is not too high; 4 tests in combination may be too restrictive

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Tutorial C5—Joint Gravity-magnetics litho-constrained inversion

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

This tutorial is designed to walk you through a simple, practical example of how to set up and run a joint gravity-magnetics litho-constrained inversion. Inversion of your 3D geology model is designed to improve your knowledge about the geology-geometry and rock properties of your project.

Forward modelling and inversion with 3D GeoModeller contains more detailed references and explanations of the methods used in this section.

In this tutorial:

- C5—Introduction
- C5—Steps overview
- C5 Stage 1—Create a new Case
- C5 Stage 2—Check rock properties distributions
- C5 Stage 3—Shared Geological Settings
- C5 Stage 4—Enter run control parameters
- C5 Stage 5—Monitoring the misfit and computing post burn-in summary statistics
- C5 Stage 6—View the final 2D grids for magnetics and gravity (quality check)
- C5 Stage 7—Statistical results analysis
- C5 Stage 8—Analyse 2D & 3D composite views of resulting geology-geometry
- C5 Stage 9—Create 3D points of inversion-driven geology (Export Shells - cvs)

C5—Introduction

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

To set-up and run a litho-constrained inversion. You only need to access the **Geophysics** menu.

The **Geophysics** menu operations directly access the geological information in the current project, including the physical properties tables, so there is only a modest amount of additional information to supply in the Inversion wizard.

Some of the pages of the Inversion wizard are similar to the Forward Modelling wizard (such as the need to set properties, choose grids, and set the run environment). The main differences appear on wizard pages 3 & 4.

C5—Steps overview

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

1. Set up the new Case and Run number and select observed geophysical datasets.
2. Check associated physical property distributions for each formation.
3. Set the exploration-bounds on geology boundaries to be explored during inversion.
4. Set iterations, boundary conditions, and the aspects of lithology that will be fixed.
5. Carry out a stochastic simulation, exploring all allowed bounds of the geology, gravity and magnetics "data sets".
6. When 3D GeoModeller has finished, a misfit trend can be analysed to see the progression towards converged solutions. You judge this by observing where the misfit becomes more or less constant, despite best efforts to perturb the model.
7. Calculate the "Super Summary Stats” from the iteration where the inversion run misfit curve flattens to a minimum - the "burn-in point - to the final iteration.

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This includes all valid, equally probable models from the simulation but excludes the iterations before burn-in.

8 Next we view the final calculated geophysics grids, the statistically compiled geophysical-results voxets, the per-lithology rock property distributions, and thresholded surfaces of probability of the geology.

9 In the light of outcomes, you can revise geology boundaries and physical properties.

C5 Stage 1—Create a new Case

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

Open the existing 3D geology project in 3D GeoModeller

1 From the main menu choose **Project > Open** OR

From the **Project** toolbar choose **Open** OR Press CTRL+O.

Browse to the existing 3D GeoModeller project:

`Tutorial_C\Tutorial_C5\C5Beginning_Project\C5Beginning_Project.xml`

2 Choose **Geophysics > 3D Geophysics > Inversion Wizard**

The wizard will suggest creating a new Case with the next sequentially available name i.e. Case1, Case2 etc.

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3 Select **Create a new case** and name it: **Case1_JointInv_FixCov_Shp**

Note: Once you have run your first Case you can use it to clone the next Case by toggling, **Clone an existing case.** A list of existing cases is available from the drop down list on the right**.**

The new Case is initialised with the same modelling parameters as the cloned Case. You can modify the original Case parameters as required. This saves considerable setup time. By default the new case is named **Case_cloned1** but the name can be edited to a name of your choice.

4 Select the geophysical observational grid data types to use from the **Components** list. In this case for a joint inversion,

Tick

- **Gz** (Vertical Gravity) and
- **TMI** (Total Magnetic Intensity).

5 Choose **NEXT**

6 Browse to the Observed grids for each component selected.

Click on **Browse...** and navigate to :

`Tutorial_C5\Data\Observed_Boug_Grav_2p2.ers`

7 **> Open**

8 Set the **Observational Error: = 0.1** mGal

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9 Leave the **Match Trend** option unselected.

The options here are:

- **Degree** (the trend polynomial order) and
- **Rate** (how often to trend match in no. of iterations; 0 is once only at the start)

  At the specified iteration and polynomial order we determine the trend of the computed '*Ti(computed)*' and the trend of the observed *Ti(observed)* grids

  - Compute the difference : *tdiff* = *Ti(computed)* - *Ti(observed)*
  - ADD this difference to the 'observed': *Ti(observed)* + *tdiff*

10 Under **Observation/Modelling Surface** choose the option that best describes the observed measurement height for the vertical gravity grid:

- Select **Drape - Terrain Clearance: = 0.0 m**. (i.e. ground survey)

  The other options are:

- **Constant Elevation:** A flat surface defined by a project elevation (NOT height above the DTM - referenced to the project Z)
- **Drape - Load from dataset:** From a grid containing the aircraft flight or computed Drape surface for the survey in elevation units (Altitude NOT height above the DTM)

  When this latter option is selected then two other parameters are required:

  - **Vertical contour interval**

    To save computation time in computing the inverted field value on a variable height surface we quantise it into a number of equidistant surfaces above the DTM. We compute kernels for each surface and then interpolate between them to obtain accurate field estimates at any drape elevation. This step results in a linear increase in memory requirements for each level but is done only once at the start of an inversion.

  - **Interpolate between contours**

    For accurate calculations of the computed field on the drape surface this must always be ON!

11 Click **NEXT**.

Do the same for the Magnetic data:

12 Click on **Browse...** and navigate to:

`Tutorial_C5\Data\Observed_Mag.ers`

13 **> Open**

14 Set the **Observational Error: = 0.1 nT**

The TMI range is small (~14nT) so an Observational Error of 1.0, which might normally be chosen, is too large and will result in unstable convergence.

15 Leave the **Match Trend** option unselected.

16 Under **Observation/Modelling Surface** choose the option that best describes the observed measurement height for the TMI grid:

- Select **Drape - Terrain Clearance: = 40.0 m**. (i.e. helicopter survey)

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17 Click **NEXT**

The **Voxet Properties** wizard panel opens:

18 Choose the **3D voxet extents** and **X, Y, Z cell sizes** with which to discretise the lithologies and properties for this inversion Case. For a rapid inversion, accept the **defaults**.

The defaults initialise the inversion for the full project area at a relatively coarse voxel resolution. A project subset volume can be selected by changing the X,Y,Z extents. Cell dimensions for X, Y and Z can each be different but a constant set of X, Y cell dimensions must apply throughout the voxel model. The same applies to Z unless the user Toggles the **Variable Z** option. This option allows the user to increase the Z cell size with depth as described for Forward modelling in C2 Stage 2—Forward calculation pages 32 - 34. We do not use **Variable Z** here.

Choose the default discretisation scheme of 20 x 20 x 20 divisions in each direction. This results in the cell dimensions x=500m; y=500m, and z=225m.

Note the indicator, **Memory Requirements** shows the estimated memory required to run the inversion.

19 Choose **NEXT**

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C5 Stage 2—Check rock properties distributions

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

This wizard page allows you to check and alter the initial set of rock property distributions for **each** lithology.

We have set our formation rock properties to values very close to the ones suggested by the Property Optimisation results in Tutorial_C3. However as mentioned in Tutorial_C3, a monomodal distribution must be selected when running Property optimisation; the estimate will be the average if more than one population is present.

We are aware from observations outside our project that the Host_rock unit is made up of at least two different rocktypes of which one has a higher density; so we have modified the optimised values. We adopt a bimodal distribution for density and susceptibility to give the inversion an opportunity to spatially locate the much less abundant unit. The ratio between the two volumes is set to 94/6. We don't believe that it makes up a large percentage of the volume. We err on the low volume side. We have also decided to keep our property standard deviations small; we believe the bulk properties do not vary as much as was allowed previously. We also want to minimise any overlap in the property distributions beweeen lithologies to minimise any ambiguity in the inversion. We can test these assumptions by alternating between mostly geology to mostly property style inversions as discussed later in this tutorial.

The following table shows the properties adopted:

Densities

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Cover	2.2	0.05	**NormalDistribution**	100%
Host_rock (unit1)	2.5	0.05	**NormalDistribution**	94%
Host_rock (unit2)	2.9	0.03	**LogNormal**	6%
Granite	3.1	0.03	**LogNormal**	100%

Magnetic Susceptibilities (we will not be setting Remanent Magnetization)

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Cover	0.000024	0.000001	**LogNormal**	100%
Host_rock (unit1)	0.0016	0.0001	**LogNormal**	94%
Host_rock (unit1)	0.003	0.00015	**LogNormal**	6%
Granite	0.005	0.0001	**LogNormal**	100%

You can change the Probability Distribution Function (PDF) for each lithology by double clicking on the **Value** field text for each **Property** i.e. `NormalDistribution(2.2,0.1,100)`. This is the same procedure as described in the Forward Wizard.

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In the General Properties panel in the lower half of the wizard page, under the **Gravity** and **Magnetic** Tabs you choose how density and magnetic susceptibility will be initialised in the initial model. The options are:

- **From Law Mean**—this is the **Default** and sets every cell of a lithology to its mean value.
- **From Law Random**—this initialises each cell of a lithology with a random sample from its chosen PDF.
- **From voxet**—this option allows you to browse to and load an external GoCAD format voxet of rock properties from a previous inversion or another external source. The voxet MUST have the same project extent and cell size specified for this inversion in Page 2 of this wizard.

It is important to remember that each lithology has its own unique property law (PDF). If you want to fix the geology-geometry of a model and run a property-only inversion, the properties generated for each lithology are still randomly selected from the defined PDF for each.

1 For GRAVITY, set **FromLawRandom**

- Toggle Bouguer Anomaly
- Set Reference density = **2.2** g/cm^3;
- **Toggle Above-topo density** and ensure it is also set to **2.2** g/cm^3.

  Note: This is the default for a Bouguer correction

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2 For MAGNETIC, set **FromLawRandom**
   - Set **Total Magnetic Field**: 56,600 nT
   - **Declination:** 7.6 degrees
   - **Inclination:** –62 degrees
3 Toggle between the Gravity and Magnetic tabs again to check the field settings are appropriate for both:
4 Choose **NEXT**.

C5 Stage 3—Shared Geological Settings

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

The **Create Inversion Case - Shared Geological Settings** wizard page is for setting the geology constraints during inversion.

Proposal

The first panel titled **Proposal,** controls how property change and lithology boundary proposals are mixed and managed during the evolution of the new model.

1 Toggle **Allow Property Change on Fixed Cells - OFF**. This prevents the properties of a cell with the lithology fixed to change its properties within the constraints of its property law (PDF).
2 Toggle **Treat Cells with the same Property Law as the same Lithology - OFF -** (the default).

If selected, the inversion process does not change the lithology of neighbouring cells that belong to different formations if their properties laws are the same. The physical properties of a cell are still allowed to change.

OR in other words when toggled ON:

If the properties of two voxels are the same, it is determined that there is no effective boundary between those two voxels, and so any boundary perturbing option cannot be proposed for the target voxel.

3 Accept the default: **Probability of Property Change Only = 50%**

Discussion

Probability of property change only: 50%

- **MCMC Case**

  For this tutorial, keep the default at: **50/50**. For Monte Carlo/Markov Chain (MCMC), the natural case is to allow at any one iteration a 50/50 split between changing the model at the lithology boundaries and changing the properties of a unit.

Probability of property change only: 100%

- **Property Only Case**

  When you feel very confident about your geology model and you have bulk physical properties that do a reasonable job of reproducing the observed geophysical response from that model you can try to locate property subclasses (i.e. bimodality) within lithologies if you allow a **Probability of Property Change Only: 100%** run. You can restrict which units to explore this way, by setting the Standard Deviation to zero for those units you want to exclude from the study.

  This approach, which locks-down the geology, ccan be thought of as a more controlled type of "Property Optimisation".

Probability of property change only: 0%

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- **Geology Only Case**

  The other extreme is similar to the algorithms used in more traditional gravity/mag inversions for solving depth to basement. You hold all the properties constant and force geology-boundary changes as the only way to reduce the misfit in the study.

  Note, however when a lithology boundary changes and a cell adopts a new lithology, a new property will be assigned by randomly sampling from the new lithology's PDF.

  Locking-down the properties, can be thought of as a type of "Prior-only" run (see Tutorial C4—Prior Only Inversion (geology-only inversion) with important differences! Prior Only seeks to control acceptable levels of geology-boundary variation (based on your geological knowledge and data sets) without reference to the geophysics. A Geology-Only inversion refers only to geophysics to drive solutions from your previously established geology model and should only be tried once a close starting model is confirmed.

Fix Individual Cells Containing:

This wizard panel allows you to fix parts of your geological model.

The options here are:

- **Surface Intersections** - fix the computed surface geology - do not change cells intersecting the surface topography section. Choose this option if you have a good surface geological map based on outcrop, costeans or shallow drilling.
- **Any Defined Contact** - do not change cells containing any defined contact data. These might be based on open pit or underground mapping that have a high level of confidence.
- **Points from CSV File** - fix cells at x, y, z locations defined in a loaded CSV file. These could represent any of the above geolgical entities that have not been used in the building of the model i.e. drillholes although better to use the more recent drillholes option if the drillholes make up part of your model.

1 Toggle **ON Surface Intersections**

We know from field mapping that "Cover" exists everywhere on surface, although "contact" datapoints for Cover are not actually required on surface to build it that way. See Tutorial C1—Review the existing geology model 'BuriedGranite'.

Contacts with Provenance

This wizard panel also allows you to fix parts of your geological model. It is based on a more conventional characterisation of geological reliability often used on published maps.

The options here allow the user to fix contacts with certain Provenance attributes:

- **Unspecified** - a contact for which the Provenance is not specified **(All contacts in this project are Unspecified - this is the default when new contacts or orientation data are created)**.
- **Observed** - a contact or orientation data based on an actual observation - outcrop/oriented drillhole/mine opening etc.
- **Inferred** - a contact or orientation data inferred from other related information i.e. two widely spaced outcrops
- **Interpreted** - a contact or orientation data interpreted from another source such as geophysical data i.e. seismic picks of formation tops or faults

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- **ModelConstructor** - a contact or orientation data derived from 3D GeoModeller's implicit function or an alternate 3D model builder.

See "Provenance Editor dialog box" in 3D GeoModeller reference for information about recording Provenance attributes.

1 Toggle **OFF** all of the above options (the default). Provenance attributes have not been used in this project

Drillholes

This wizard panel allows you to fix the cells surrounding drillholes within your project. The options are:

- Multiselect drillholes from the list to fix the lithologies of intersecting cells.
- Choose a **Radius of Influence** (distance from drillhole to fix cell lithologies).

Use **Invert All; Select All; Deselect All** operators to make global list selections

1

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2 Choose **Next**.

The **Lithology Specific Geological Settings** wizard panel opens. This is the wizard which allows us to assign the properties of the Geological Constraints to each of our Project Lithologies. We discussed this panel in detail during Tutorial C4 Prior Only

Discussion:

Setting up Geological Constraints for a litho-constrained inversion

As well as fixing parts of our geological model as discussed above, we can also choose constraints which govern how the geometry of our project's lithology units change during inversion.

Without any Geological Constraints, inversion may still converge and achieve a good fit with the geophysics, but the resulting models will probably be geologically unrealistic and include fragmented formations that bear little relationship to our starting model.

In 3D GeoModeller, specifications of certain geometric constraints ("geology tests") are available on a lithology-by-lithology basis. For example high-confidence geology units can be "locked down" while lower-confidence units are allowed more freedom for the geometry to change. Hence an inversion can be set-up to minimise the chance that unrealistic geology will be created, i.e. the geological constraints limit totally random changes to the initial geology model.

In 3D GeoModeller, the following geological constraints are available to control the geometrical changes of the initial lithology units during inversion. They are:

Fix Lithology Frontier, **Preserve Vertical Relationship (PVR)**, **Commonality, Shape Ratio** and **Volume Ratio**. PVR, Commonality and Shape Ratio are the parameters often used to geologically constrain a stochastic inversion.

This tutorial demonstration uses these common geological constraints.

Select each Lithology unit in turn when setting up the geological constraints. A highlight box is drawn around the chosen unit as shown in the wizard panel dialog above.

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Three control mechanisms are available per lithology:

- **Fix lithology frontier** — to fix the boundary of a unit (you might have good near-surface seismic control of this layer).
- **Constraints** — to modify the constraints which control how a lithology unit's shape and volume is constrained as it changes with successive proposals.

  Note: In this wizard page we are setting the constraint properties only, i.e. the PDF's. Each constraint can be turned On or Off in the next "RUN" page of the wizard.
- **Always above these lithologies** — also known as **Preserve Vertical Relationship**. When selected using the dialog button, this option prevents overturning of the younging direction for your whole geological sequence. However it can be set for each individual unit; the PVR relationship is recorded as an array of on/off switches for all the other units in the geological pile. Note, it is accepted that gaps/missing units are allowed when applying this test.

1 **Fix lithology frontiers:**

- Select **Cover** and **Toggle ON - Fix Lithology Frontier**.

  We want to refine the deeper part of our model; we are more confident of the Cover unit geometry and properties. If we allow the Cover to vary it may dominate our inversion i.e. the inversion can tend to fit the geophysics by varying the properties of the shallow cover; we could also prevent this by setting the Cover property standard deviations to be very small or even zero

2 **Constraints**:

- **Commonality**
  - Accept the default settings for **Cover**; since Cover is fixed above Constraints will not be applied during inversion
  - Set the **Host_rock** k(scale) to **0.4**
  - Set the **Granite** k(scale) to **0.4** as shown below.

    We want both the Granite and Host_rock to adjust so we allow fewer voxels in common with the reference model. A Weibull scale of 0.4 equates to a 70% similarity with the reference model allowing more freedom than the default of 0.2 which equates to an 84% similarity with the reference model.

i.e. Granite {Weib, 0.40, 1}, bias: none, Host_rock {Weib, 0.40, 1}, bias: none

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- **ShapeRatio**
  - Accept defaults for **Cover;** Cover is fixed, Constraints are not applied.
  - Set the **Host_rock StdDev** to **0.01**
  - Set the **Granite StdDev** to **0.01**

  i.e. Granite {Log, 1, 0.01}, bias: none; Host_rock {Log, 1, 0.01}, bias: none
- **VolumeRatio**
  - Accept the defaults for **Cover;** Cover is fixed, Constraints are not applied.
  - Set **Host_rock Mean** to **1.1** and **StdDev** to **0.01**. We want the **Host_rock** to increase in volume by ~10% to accommodate the change in Granite below.
  - Set **Granite Mean** to **0.7** and **StdDev** to **0.01**. We want the **Granite** to reduce in volume by ~70% relative to the reference model.

  i.e. Granite {Log,0.7, 0.01}, bias: none ; Host _rock {Log,1.1, 0.01}, bias none;

3 **Click** on **Stratigraphic Order** to preserve the stratigraphic pile sequence.

4 Choose **Next**.

Note for users completing Tutorial C6

If you are using the instructions in this section for Tutorial C6 (Tutorial C6—Calculations using gravity gradients (forward and inversion)), follow this link to return and go to the next stage: C6 Stage 4.4—Enter run control parameters.

C5 Stage 4—Enter run control parameters

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

Here you control the specifics of the inversion run: number of iterations, how to influence convergence, and switches for geology constraint tests (set but not on yet).

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For this tutorial,:

1 **Change** the number of **Iterations to 500,000**

500,000 iterations is enough in this exercise, to get convergence to a uniform misfit between the model geophysics responses and the observed geophysics grids. The iterations after the initial convergence (after "Burn-in") allow for an exploration of all the equally probable models that follow. Millions of equally probable models, each with a small variation in a property or geology boundary, can explain the observed data sets.

2 **Tick ON Allow Formation Geometry Tests**"

3 **Tick ON Allow Commonality Test**. Set the Bias option on the right to **"none"**.

4 **Tick ON Allow Shape Ratio Test**. Set the Bias option on the right to **"none"**.

- **Tick On Include Above Topo Faces in Shape Ratio**
- **Include Outside Faces in Shape Ratio**

AND/OR (i.e. choose ShapeRatio and VolumeRatio together or separately; check differences in geometry & geophysics misfit between the 3 possible cases)

5 **Tick ON Allow Volume Ratio Test**. Set the Bias option on the right to **"none"**.

6 **Tick ON Allow Geophysical Misfit Tests**

7 Choose **Next**

The Bias options are explained in Tutorial C4—Prior Only Inversion (geology-only inversion) and in Forward modelling and inversion with 3D GeoModeller)

C5 Advanced Tuning Options:

The advanced options are available for testing and for influencing the speed of the solver in the initial convergence stage. For this tutorial, leave **Advanced Tuning Options** unadjusted.

Options in this dialog are:

- **Seed:** Set the Random number Seed for the inversion. We keep this constant for testing purposes (reproducibility).

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- **Large Misfit RMS Threshold Factor**

  A parameter that is used during the initial stages of an inversion, allowing the user to adjust the likelihood function used in the geophysical data acceptance tests.

- **Large Misfit Entropy**

  Another startup parameter, allowing the user to adjust the likelihood function used in the acceptance tests

  If the misfit of the proposed model is greater than the standard deviation assigned to this geophysical data type multiplied by the **SetLargeMisfitRMSThresholdFactor value**, the variance for this geophysical data type is multiplied by the value of **SetLargeMisfitTemperature**. This has the effect of modifying the probability of acceptance. A temperature value less than 1 decreases the probability of acceptance for a given misfit value. This tends to force a “steepest descent” behavior to the Run, with proposals being accepted only in the situation where the misfit decreases (at least until the misfit equals the product of the standard deviation assigned to this geophysical data type and the SetLargeMisfitRMSThresholdFactor value). If the appropriate standard deviation values have been specified for the Case, this is unnecessary (and undesirable).

- **Dual Entropy Mode**

  Mode 1

  - **Entropy Factor**
  - **Duration**

  Mode 2

  - **Entropy Factor**
  - **Duration**

  The Dual Temperature Mode allows the user to alternate between two temperatures of the likelihood function used in acceptance tests. What we have here is a means of accelerating the convergence of the initial burn-in period of the inversion, while seeking a minimum misfit. The default is false.

For more details on these parameters see "Temperature" in Version 4.0

Note: If you are currently running Tutorial C6 and have finished referring to the information in this section, use this link to return: C6 Advanced Tuning Options

Execution of Environment Settings

Just prior to running an inversion, you must make a decision about where to run the job and how many Cores/Threads to use.

The default uses your local machine interactively. You may have more than one CPU and the operating system is designed to allow you to continue to work interactively, while "number crunching" continues in separate process(es).

1. Accept the default **Interactive ON**
2. **Accept the default maximum number of cores** to run on your computer. In general the more you choose the faster the inversion will run.

   If you need other processes to current concurrently, choose a lesser number of cores to dedicate to the inversion task.
3. Choose **Finish**

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C5 Stage 5—Monitoring the misfit and computing post burn-in summary statistics

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

When running interactively, a progress bar in the form of a current misfit vs iterations graph pops-up.

As the inversion gets underway, the pop-up graph shows us a high initial misfit which rapid settles lower and then constant. When the 500,000 iterations are complete you will be asked if you wish to compute Summary Voxets (also known as "Super Summary Statistics"[SSS]) which collates all results in attributed voxets (3D grids) for a post burn in iteration range of your choice.

1 Choose **Yes** to immediately **Compute the Summary Voxets**.

If you decline the first time, or wish to calculate SSS for a different burn-in point, you can return to the misfit screen, by selecting:

Geophysics > 3D Geophysics > Summary Voxets from Inversion

2 **Choose a burn-in point of 300,000**; **type 300000** in the **From box** (lower left).

This is where the misfit becomes more or less constant (at ~1.1), as shown by the graph below. Your burn in point may be different depending on the settings applied.

Note the mouse is interactive with the misfit plot to display a label.

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Setting the burn-in gives the starting iteration for statistical analysis of that portion of the inversion corresponding to simulations that are all equally plausible (usually, through to and including the last iteration). Burn-in is judged by observing where the misfit becomes more or less constant, despite best efforts to perturb the model.

3 Choose **OK**, to create a summary statistics mesh grid (voxet) for re-compiled results and settings captured between 300,000 & 500,000 iterations.

Note that we left the default Threshold at '90'. This is the percentage probability measure used to produce the MostProbableThresholded field. Voxels assigned a lithology that have a probability <90% are set to Null. See C5 Stage 7—Statistical results analysis below, and the Table therein for further details.

When the Summary Voxet calculations are finished, you will see the following pop-up:

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View the list of your joint inversion output files

Here is a summary of the inversion output files which now exist in your project directory folder: **Case1_JointInv_FixCov_Shp> Run1**:

File(s)	Description
misfit.csv	Numeric record of the misfit evolution (Misfit value for gravity and magnetics as a function of iteration number where misfit is the least squares differences between the observed and the current computed geophysics grid, [dist = sqrt(dist / count);].
Summary.txt	A summary of proposal acceptances and rejections for each geological and geophysical constraint for the full inversion.
compute_Surface_1.ers	2d grid of the surface on which to compute the Gravimetry response
observed_Gravimetry_1.ers	2d grid of the measured gravity.
initial_Gravimetry_1.ers	2d grid of the computed gravity response from the initial iteration of the inversion.
final_Gravimetry_1.ers	2d grid of the computed gravity response from the final iteration of the inversion.
compute_Surface_2.ers	2d grid of surface on which to compute the TMI response
observed_TMI_2.ers	2d grid of the measured gravity.
initial_TMI_2.ers	2d grid of the computed gravity response from the initial iteration of the inversion.
final_TMI_2.ers	2d grid of the computed gravity response from the final iteration of the inversion.
initial.vo	Initial voxet (3D grid) for the state of the model at the final iteration - 4 attributes: final lithologies; fixed cells; final densities; final susceptibilities.
final.vo	Voxet (3D grid) for the state of the model at the final iteration - 4 attributes: final lithologies; fixed cells; final densities; final susceptibilities.
reference.vo	The geophysical response kernel voxet model (3D grid), discretised at the same cell size as the voxet models above. Deleted on completion to save space.
Stats_300K_500K_T90.vo	A summary statistics mesh grid (voxet) for inversion iterations 300,000-500,000 (post burn-in). For further details see E5 Stages 8 & 9.
Case2_JntInv_Run1.txt	Log of changes to the geology model voxet. Used to reconstruct the state of the inversion during its evolution. For headings, and further information see the Inversion Manual.

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C5 Stage 6—View the final 2D grids for magnetics and gravity (quality check)

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

We compare the **observed** and **final** geophysics grids to evaluate whether the inversion geometry and rock property changes produced a close fit with the geophysics.

- If the geology tests were too tight or,
- The initial geology model was not good enough or,
- The rock properties were poor and not improved by property optimisation

THEN poor matches between observed and final grids may occur. On the other hand, good agreement between observed and final grids does not guarantee that the inversion regime was appropriate or has necessarily given us good results. Before concluding this we must also investigate the changes that were driven by the proposed properties and geology geometry constraints.

Load the summary final geophysical grids via EXPLORER

Similar to the Forward Modelling tool (Tutorial C2—Potential field forward calculation), Inversion also creates and stores summary results which can be viewed in the Results explorer. Select:

Geophysics > 3D Geophysics > Results explorer

The left hand panel provides a data explorer for all the forward and inversion cases you may have run. The convention is to use GREEN arrows to indicate Forward model cases, and RED arrows to indicate Inversion cases. The other main function available here is the ability to delete cases that are of no further interest.

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3D GeoModeller displays several grid images including the calculated misfit grids. The images are:

- Top Left—Observed: the observed grid
- Top Centre—**Final:** the computed response at the final inversion iteration
- Top Right—**Misfit:** the misfit or difference; *(Observed - Computed at the Final iteration)*.
- Bottom Left—**Regional Trend**: the trend removed if you choose to solve and remove a regional trend from the Observed grid. (No detrending was applied in this case).
- Bottom Middle—**Final + Regional Trend:** the Computed Final grid after adding back the Regional Trend i.e. *(Final + Regional Trend)*.
- Bottom Right—**Misfit - Regional Trend:** The Misfit after adjusting for the regional trend *(Observed - Regional Trend - Computed Final)*.

Note that the colour scales are different for each of the images as they are the result of a linear colour mapping between the minimum and maximum values for each grid.

1. **Select** the **Gravity** or **Magnetic** Tabs to view the results for Gravity or Magnetic data.
2. Use the **Options** dropdown on the left to **Load** or **Remove** an **Observed grid**
3. Use **File > Open Results** or **Save Results** to Open or Save the inversion.xml file which records all executed inversion Cases for the current project. This allows you to save the current inversion.xml file with the new observed grid or simply save the inversion.xml to a new name for Case archival purposes.
4. Save your Project.

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Load the Inversion output products and display 2D geophysics grids (observed & final) in the 2D geology workspace

1 Ensure your **Topography Section** is open in the **2D Viewer**

2 From the **Explorer** tree, select **Grids & Meshes** > Right-click **Import > Geophysical Results > Case1_JointInv_FixCov_Shp> Run 1**

All the grid/voxet products from the Inversion run are imported into the Grids and Meshes tree in Explorer.

3 In the **Explorer** tree, **Expand** the "+" for the 2D Mesh **Case1_JointInv_FixCov_Shp_Run1_2D**

4 **Right Click** on `final_Gravimetry_1.ers` with the grid selected, right-click Field Visualisation Manager

5 **Tick Surface Topography** underneath **View on Section**

6 Choose **OK**. The grid is displayed in the 2D Viewer on the **SurfaceTopography** section

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7 Click **Display Colour Table** to view the colour table legend.

OR

Click on the same grid in **Explorer**, and right-click > **Display Colour Table**

- **Visualise the other 2D grids and display the colour table** by repeating Steps 4 to 7 above.
- Use the **Image Manager** to explore multiple 2D mesh grids and image backdrops using the ON/OFF selectors and transparency slider; reorder the image list as required.
- Right click on **Grids and Meshes > Hide all Views** to clear your Surface Topography Viewer before viewing the next grid.

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- **Right Click** on **`observed_TMI_2.ers`** as in step 4 and right-click Field Visualisation Manager and display as below

Note: the resolutions of the Observed grids have been resampled to the lower resolution discretisation scheme that was selected in the inversion settings. We have turned on **Interpolate** (smooth resampling) in the **Image Manager** to enhance the display.

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C5 Stage 7—Statistical results analysis

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

Topics covered in C5 Stage 7 include:

- Check Final Inversion 3D Voxet Grid Histogram properties
- Compare the volumetric changes of the granite body in the initial vs final inversion models

Check Final Inversion 3D Voxet Grid Histogram properties

1 In the **Explorer** > **Grids and Meshes**, expand the 3D voxet **Case1_JointInv_FixCov_Shp_Run1_3D_final** to show the four fields:
   - Lithology
   - Fixed Cell
   - Density
   - Susceptibility

2 Right click on **Susceptibility** and select **Histogram**

3 Using the **bottom right-hand-corner dropdown** which shows the default **ALL,** select each lithology in turn to display its susceptibility statistics.

4 Select **Host_rock**, as shown below

5 Select each lithology in turn and note the **Mean** Susceptibility and **standard deviation** for each,. The table below shows a summary of the distributions that were recorded in the final iteration of the inversion.

Note - The following table gives an indication of the expected values:

Lithology	Mean Susceptibility	Standard Deviation
Cover	0.000024	0.000001
Host_rock	0.001702	0.000382
Granite	0.004998	0.000104

More informative statistics can be studied for densities/susceptibilties in the Super Summary voxet, **Case1_FixCov_Shp_Run1_3D_Stats_300K_500K_T90,** rather than those shown here which relate to the final iteration-only,

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Case1_JointInv_FixCov_Shp_Run1_3D_final .

6 Do the same for the Density Host Rock. Repeat steps 3 to 5; choose the field Density in the same final voxet .

Note: The distribution of densities for the Host Rock is Bi-Modal.

Compare the volumetric changes of the granite body in the initial vs final inversion models

1 Select the **Lithology** field of the 3D initial grid **Case1_JointInv_FixCov_Shp_Run1_3D_initial**, and right-click **> Histogram**

2 **Tick Exclude Above Topo** (In the lower right corner)

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3 Repeat Steps 1 and 2 to also view the histogram for the **Lithology** field in final.vo: **Case1_JointInv_FixCov_Shp_Run1_3D_Final**

Key observations:

Granite in:	% of litho-model	Volume	Change
initial.vo	7.15	$2.34E^{10}$	
final.vo	5.72	$11.87E10^{10}$	Reduced volume

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C5 Stage 8—Analyse 2D & 3D composite views of resulting geology-geometry

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

In Meshes and Grids, select **Super Summary Stats** voxet: **Case1_JointInv_FixCov_Shp_Run1_3D_Stats_300K_500K_T90**

1 **Expand this directory** to reveal 12 different property fields of the attributed 3D grid. (Description of each field are located in Tutorial C4—Prior Only Inversion (geology-only inversion))

2 From the **Explorer** tree, select the **MostProbableThresholded** property field > right-click **Properties** (bottom of list)

3 Change **Alias** to "**Lithology**" (type) - should be already set.

4 Choose **OK**

5 In Explorer > **MostProbableThresholded**, right-click > **Edit Colours & Clips**

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6 Select a Visibility Clip from 0.5 to 1.5 to isolate granite (pink); and the zero field (white) which represents cells which resided below the threshold of 90% c.l.)

7 Choose **Close**

8 Next ensure that **section C1, C2, C3 are** open in the 2D Viewer. If necessary Erase all model Geology .

9 Again with **MostProbableThresholded** selected, right-click **> Field Visualisation Manager**

10 Select View on Sections "**C1, C2, C3**" and View Mesh Grid in 3D with 3D Points.

11 Right Click on **MostProbableThresholded,** select **Appearance** and set the **Vertex Symbol Size** to **5;** Click **OK**

12 Click **OK**

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The MostProbableThresholded Granite at 90% confidence limits for Section **C3** is displayed below together with the Probability of Granite. This is directly compared in the 2D Viewer with the initial (starting) model. Notice an outlier of granite which is probably related to the high density component of Host_rock (Bimodal) rather than Ganite. Ignoring this outlier the Granite shrinks in volume as expected. All the Granite in this section passes the MostProbable threshold. The low probability cells at the base and either side of the Granite are not assigned a unit as they fall below the 90% threshold for all lithologies. This is shown in the third figure where the lithology mask has been removed.

MostProbableThresholded Granite Only

Probability of Granite

MostProbableThresholded All

Below we show the 3D Points view of the MostProbableThresholded Granite superimposed on the initial 3D Granite rendered in the 3D Viewer. To obtain the rendered 3D Granite view:

13 Right Click on **3D Geology** and select **Hide**

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14 Right Click on **3D Geology>Series_1** and select **Appearance**

15 Set **Transparency** to ~50%; Select **Display Mode>Shading**

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Compute a New Field to view the granite post-burn in density distribution

1 In **Explorer** select **Meshes and Grids > Hide all Views**

2 With SummaryStats : **Case1_JointInv_FixCov_Shp_Run1_3D_Stats_300K_500K_T90** selected, right-click > **Compute new Field**

All fields to be computed must be within the same grid. (Functions such as: "Merge this grid with Another" can assist manipulation)

3 In the Calculator type/click select:

If ("MostProbable" == 1; **MeanDensity**; **NaN**)

Give the new field a name, (top right of Calculator): say, "**GraniteBYDensitycontrast**"

4 **Evaluate**, then **Save and exit.**

5 From Explorer menu, select **3D Geology > Hide**

6 From Explorer menu, select the new field **GravityBYDensitycontrast**, then right-click **> Field Visualisation Manager**

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7 Select **View Meshgrid in 3D > OK**

The View below opens in 3D

8 Aditionally, you can open the colour table: from Explorer **> Grids and Meshes > GraniteBYDensitycontrast > Display Colour Table**

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C5 Stage 9—Create 3D points of inversion-driven geology (Export Shells - cvs)

Parent topic: **Tutorial C5—Joint Gravity-magnetics litho-constrained inversion**

A key method for re-importing the post-inversion geology geometry is demonstrated in this section. First, we **export** the "tops" of the MostProbable Geology as a point cloud and then re-import them as primary geology constraints ("new granite").

1. From the Main menu open **Geology > Formations: Create or Edit**
2. Select a colour and type a name say, "**NewGranite**" (RGB; 0,153,8) No spaces! **> Add**
3. Choose **Close**
4. The Create Formation dialogue box will appear. Select **Yes, Start Stratigraphic Pile editor**
5. Delete the old formation Granite from the Pile; Select **Granite** and click **Delete**
6. In the **Stratigraphic Pile Editor** Select > **New Series**
7. Highlight > **NewGranite > Commit > Close > Close**

8. In **Explorer** select **Meshes and Grids > Hide all Views**

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9 For mesh grid **Case1_JointInv_Run1_3D_Stats_300K_500K_T90** select, **MostProbable** Right-click and select **> Export Surface Shells**

10 Choose query type "**Equal**"

Select **Tops only(cvs file)** output (which can be re-imported into 3D GeoModeller as a cloud of contact data points)

Choose value type **1** (1=Granite)

11 From the Right-side "... " Browse to the directory of your choice to save the file

12 Name the file say, "**Tops_NewGranite**" > choose **OK**.

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Import the 3D contact points for the top of NewGranite into the model

1 From the Main menu **Import > 3D Geology > interfaces**
The WIZARD will lead you through the importation of the points from the .cvs file to be assigned to the geology object called "NewGranite"

Step 1 of 4: Browse in your directory "**`Tops_NewGranite.cvs`**" **> Open> Next**

2 **Step 2 of 4**: Observe 3 separate columns are recognised for x, y and z. > **Next**

	X	Y	Z	Value
1	2750.000000	3750.000000	-1550.000000	1.000000
2	2750.000000	4250.000000	-1550.000000	1.000000
3	2750.000000	4750.000000	-1550.000000	1.000000
4	2750.000000	5250.000000	-1550.000000	1.000000
5	3250.000000	3250.000000	-1550.000000	1.000000
6	3250.000000	3750.000000	-1550.000000	1.000000
7	3250.000000	4250.000000	-1550.000000	1.000000
8	3250.000000	4750.000000	-1550.000000	1.000000
9	3250.000000	5250.000000	-1550.000000	1.000000
10	3750.000000	2750.000000	-1775.000000	1.000000
11	3750.000000	3250.000000	-1550.000000	1.000000
12	3750.000000	3750.000000	-1550.000000	1.000000
13	3750.000000	4250.000000	-1550.000000	1.000000
14	3750.000000	4750.000000	-1325.000000	1.000000
15	3750.000000	5250.000000	-1325.000000	1.000000

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3 **Step 3 of 4**: Sorts the columns: For **Source Style** choose **Project** and for **Source** select = **NewGranite**; X=X; Y=Y; Z=Z then choose **> Next**

4 **Step 4 of 4**: Under dropdown **ALL:** select **Merge to Existing Formation. NewGranite** will display in green in the **Merge To** column dropdown.

5 **Click Finish**

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6 A report on the importing of points is given

7 From the Main menu **View > 3D Viewer > Show interface data**

Select **NewGranite > OK**

- The points viewed (below) define the top of the "MostProbable" granite body as an outcome of the joint geophysical inversion.

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- They are currently committed to a new geology object (NewGranite), and included in the geological pile.

8 We want to remove the isolated cluster of points on the east side of the model as we have decided they do not represent the main granite body

9 Double click on a 3D contact point in the 3D Viewer to select the group then Right Click and select Edit

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10 A table editor will pop up. Select the points with East coordinates >6750.0 and click on the Delete button at bottom left. The points will be removed from 3D Viewer

	Formation/Fault	X	Y	Z
61	NewGranite	6750.0	5750.0	-1325.0
62	NewGranite	6750.0	6250.0	-1100.0
63	NewGranite	7250.0	750.0	-1325.0
64	NewGranite	7250.0	1250.0	-1325.0
65	NewGranite	7250.0	1750.0	-1550.0
66	NewGranite	7750.0	750.0	-1550.0
67	NewGranite	8250.0	3250.0	-1550.0
68	NewGranite	8250.0	3750.0	-1550.0
69	NewGranite	8750.0	1250.0	-1550.0
70	NewGranite	8750.0	1750.0	-1550.0
71	NewGranite	8750.0	2250.0	-1550.0
72	NewGranite	8750.0	2750.0	-1550.0
73	NewGranite	8750.0	3250.0	-1550.0
74	NewGranite	8750.0	3750.0	-1550.0
75	NewGranite	8750.0	4250.0	-1550.0
76	NewGranite	8750.0	4750.0	-1775.0
77	NewGranite	9250.0	1250.0	-1550.0
78	NewGranite	9250.0	1750.0	-1550.0
79	NewGranite	9250.0	2250.0	-1550.0
80	NewGranite	9250.0	2750.0	-1550.0
81	NewGranite	9250.0	3250.0	-1775.0
82	NewGranite	9250.0	3750.0	-1550.0
83	NewGranite	9750.0	1250.0	-1550.0
84	NewGranite	9750.0	1750.0	-1550.0
85	NewGranite	9750.0	2250.0	-1550.0

11 Click OK

12 Save your project

Re-compute the 3D granite iso-surface in the model, with post-inversion constraints

In this step we modify the initial geology model - replacing the "old" granite contact points, with the NewGranite contact points.

The first step is to add some orientation data for NewGranite. We have already imported and edited our 3D contact points so orientation data is all we need to compute the NewGranite

1 From Main menu, select **Model > Project Data onto Sections in 2D Viewer**

2 Select All Sections except **SurfaceTopography** and Select "**NewGranite**"

3 Type **Maximum Projection distance: "400" > OK**

4 With **Section C2** active (tick in the top left), select the **"Create"** tool from the 2D toolbar (pencil tool)

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5 Guidance for the shape of the **NewGranite** is needed on **Section C2**:

Use the **Create tool** to click in 2 places, and select > **Create Geology Orientation data** (from the top toolbar Menu)

6 For each of the 3 orientations, check **NewGranite is selected > Create** (bottom)

Guidance is also required for the shape of the **NewGranite** surface on **Section C3**:

7 Repeat Steps 1 to 6 above for **Section C3**.

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8 New orientation data, in the approximate locations as show below, are recommended.

9 You can also import already created Orientation data from: **`Tutorial_C5\Data\NewGranite_Orientation_Foliations.csv`**

In the Main Menu **Import > 3D Geology > 3D Orientation and Project to Sections**

Browse the file in the data directory and choose **Next** until **Step 3**.

10 In Step 3 change Source style to **Project** and to **NewGranite**.

Choose **NEXT**.

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11 In Step 4 Select **Sections C1, C2, C3, C5**.

In the Final Step verify that the points are Imported as **NewGranite** and press on **Finish**.

Check the 4 sections to make sure the orientation data has been projected to each 2D section

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Compute the New Model

Compute the 3D geology model for the project that we have loaded (to be constrained by the geological data and pile we have reviewed).

1 From the **Model** toolbar, choose **Compute** or (press ctrl+M)

In the Compute the Model dialog box:

- Series to interpolate—Select "**Series_2**" and "**NewGranite Series**" (Series_3 is Cover. This will be automatically generated between series 2 and the topographic surface.
- Faults to interpolate—Select All
- Sections to take into account—Select All
- Faults only—Clear (therefore DO compute faults)

2 Choose **OK**

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Explore the 3D Viewer - 'Build' the model in 3D

3 From the **Model** toolbar choose **Build 3D Formations and Faults**

In the Build 3D Formation and Fault Shapes dialog box:

- Check **Build—Formations**
- Check **Build—Faults**
- Select **Type—Volume**
- Check **Draw Shapes after building**
- Adjust the **Resolution—Render quality** to High
- Click the **More** button
- Set **Cell Dimension** to **Fixed**
- Set **Size** to **200m**

4 Choose **OK**

The full model in built in the 3D Viewer, but let's now reveal the NEW granite

5 From Explorer > Expand the (+) **3D Geology**

6 Expand +Series3 > Volume: Cover > **Hide**

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7 Expand +Series2 > Volume: Host_rock > **Hide**

Conclusion: the inversion outcomes for the NewGranite body are now fully integrated in the revised geology model.

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Tutorial C6—Calculations using gravity gradients (forward and inversion)

Parent topic: **Tutorial C (Forward & Inverse Modelling of Potential Fields)**

This tutorial introduces the user to full tensor gravity grids, as a precursor exercise to performing inversion with observed full tensor potential field data (the basis of an extension Tutorial currently under development).

In this tutorial:

1 C6—Introduction
2 C6 Stage 1—Load and review the "BuriedGranite" 3D model
3 C6 Stage 2—Forward calculation of a gravity full tensor grid
4 C6 Stage 3—Visualisation of the component tensor grids
5 EITHER:
- C6 Stage 4 (FTG)—Inversion of an FTG gravity gradiometer full tensor grid
  - C6 Stage 4.1—Create a new Case
  - C6 Stage 4.2—Check rock properties distributions
  - C6 Stage 4.3—Shared Geological Settings
  - C6 Stage 4.4—Enter run control parameters

OR:
- C6 Stage 4 (Falcon)—Inversion of Falcon gravity gradiometer full tensor grid

6 EITHER:
- C6 Stage 5 (FTG)—Analysis—monitoring the misfits and computing post burn-in summary statistics

OR:
- C6 Stage 5 (Falcon)—Analysis—monitoring the misfits and computing post burn-in summary statistics

7 C6 Stage 6—View the final 2D grids for gravity gradients (quality check)
8 C6 Discussion—Comparing FTG with vertical gravity inversion constraint

C6—Introduction

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

1. In this tutorial we forward model an airborne gravity gradiometer (FTG) full tensor from our preliminary 3D geology model, using a **3D Fourier** method and the **Spatial** method. Our initial geology model is the same as the starting model used in Tutorial C5—Joint Gravity-magnetics litho-constrained inversion i.e. prior to our refinements from inversion
2. The result is output as a Double Precision, 6 band ERMapper grid in BIL (band interleaved by line) format.
3. We visualise the full tensor grid by the cube root of its determinant (default view).
4. Next we visualize separate components and derived products of the tensor by querying the full tensor grid in the Results Viewer and in the Grids and Meshes environment
5. We invert the FTG full tensor grid and compare the inversion results with gravity only.
6. We repeat 5. above, but this time we invert using a Falcon tensor grid

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C6 Stage 1—Load and review the "BuriedGranite" 3D model

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

1. At this point you cannot continue with your current project from C5 as we are going to back track and repeat C5 but this time we will model a gravity gradiometer tensor grid. You need to load the **`C6Beginning_Project`**
2. From the main menu choose **Project > Open** OR

   From the **Project** toolbar choose **Open** OR Press CTRL+O.
3. **Browse and open** the pre-created 3D GeoModeller project:

   `Tutorial_C\Tutorial_C6\C6Beginning_Project\C6Beginning_Project.xml`
4. From the main menu choose **Geophysics > Define physical properties**.

Densities

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Cover	2.2	0.05	**NormalDistribution**	100%
Host_rock (unit1)	2.5	0.05	**NormalDistribution**	94%
Host_rock (unit2)	2.9	0.03	**LogNormal**	6%
Granite	3.1	0.03	**LogNormal**	100%

Ensure the above values are entered for densities. We will only be modelling a **gravity** full tensor grid, so only densities need to be checked..

C6 Stage 2—Forward calculation of a gravity full tensor grid

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Now we will set up and compute a full tensor gravity field from the 3D geology model. We are modelling terrain corrected tensor gradients. Together they can be thought of as a Bouguer equivalent product; comparable to a complete bouguer in vertical gravity terms since a bouguer slab has no gradient signal.

In this simple case where the surface cover is a constant density the terrain effect is cancelled by assigning the Above_Topo unit (Air) with the same density as Cover. In the real world where the density of terrain can be variable this becomes a more complex problem.

We simulate an FTG airborne survey which is flown with a mean drape clearance of 80m above the terrain.

We have modified the DTM by adding 100m of elevation then low pass filtered the resulting grid at a wavelength of 1km to simulate a typical survey drape with a mean clearance of 80m.

1. From the main menu choose **Geophysics > 3D Geophysics > Forward wizard**. 3D GeoModeller displays the forward calculation area of **3D Geophysics** tool.

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2 Choose **Gravity Tensor** in the **Fields to compute** area. All six tensor components will be automatically selected. Call your case : "**Case1_FFT_GravTenBg_80m**"

The six separate components of the Gravity Tensors

- **Gxx**: second derivative of the gravity potential purely in the x (east) direction
- **Gxy** or **Gyx**: second derivative of the gravity potential in the composite directions x and y; a curvature gradient
- **Gxz** or **Gzx**: second derivative of the gravity potential in the composite directions x and z
- **Gyy**: second derivative of the gravity potential purely in the y direction
- **Gyz** or **Gzy**: second derivative of the gravity potential in the composite directions z and y
- **Gzz**: second derivative of the gravity potential purely in the z (depth) direction

3 Now press **NEXT** and go to the second page of the wizard.

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Forward Model Parameters

4 Browse for/load observed (reference) Gravity Tensor grid.

`Tutorial_C6\Data\FreeAir_GravityTensors_TC2p2_Drp80m.ers`

5 **Observation Modelling Surface:**

- Choose **Drape Load from dataset**:
- Browse up one level to `Tutorial_C6\Data` and load the Drape surface elevation grid, `FTG_Drape_80m.ers`
- Toggle **Interpolate between contours**
- Enter a **Vertical Contour Interval** of **50**m

  The last two parameters control the speed and accuracy with which the calculation of the gravity response on the variable height Drape surface is computed. A response kernel is calculated at each contour level. Gravity responses at heights between these levels are then interpolated between them. For accurate results the Interpolate parameter should always be on.

  This type of calculation carries a significant memory and storage requirement (linear by contour level). The kernels are computed prior to the commencement of modelling or inversion and removed on completion unless otherwise requested.

6 Choose **NEXT**.

7 **Voxet Properties**

- Set Zmax to 2200; the Elevation maximum is ~2170m
- Choose Voxet resolution of Dx= 250, Dy=250, and Dz=100

8 Select **Fast Fourier Method**

9 Set the **vertical expansion to 1500%.**

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10 Accept all the remaining defaults in the remaining part of this window.

11 Choose **NEXT**

12 Accept the current Lithology Densities checked earlier; any changes here will overide the settings of in the Physical Properties table.

13 We are forward modelling Terrain corrected gravity gradients so we set the Above-Topo density to the density of our surface geology to remove the effects of terrain.

- **Reference density = 2.2**
- **Above-Topo Density = 2.2**

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14 Now choose **NEXT**.

15 Finally, accept the default **Interactive** mode.

16 The number of CPU's minus 1 is selected for this run. This allows 1 processor for other programs that you may want to use during the modelling. You can incease this value by 1 to improve runtime.

17 Choose **FINISH**

Summary images of the full tensor response for gravity

By default 3D GeoModeller displays the **Tensor Cube Root of Determinant** response of the full tensor gravity forward calculation in the Results Explorer window.

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Individual tensor components or tensor transformations can be selected from the Options menu at top left (see below).

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This Results Explorer can be returned to later by selecting:

Geophysics > 3D Geophysics > Results Explorer

i.e. We show the Full Tensor Gzz component below.

When the forward model calculations have been completed 3D GeoModeller displays several full tensor grid images (by a Cube Root Determinant function) and some basic statistics. The images are:

- Top Centre—the response of the 'current model' that you have calculated
- Top Right—the 'current misfit' (meaningless without an observed grid)
- Bottom Middle—same as Top Centre - detrending is not valid for tensors.
- Bottom Right—same as Top Right - detrending is not valid for tensor.

Regional Detrending is not valid for tensor grids so those options are removed from the Results Explorer.

1 Use **File > Exit** to leave this tool.

2 **Project > Save**

All grids are saved in a folder within the 3D GeoModeller project folder called **Case1_FFT_GravTenBg_80m**.

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C6 Stage 3—Visualisation of the component tensor grids

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Import the results of the Forward Model case as described in previous Tutorial sections.

1 From the **Explorer** tree, select **Grids & Meshes** > Right-click **Import > Geophysical Results > Case1_FFT_GravTenBg_80m> Run 1**

One 2D grid and one 3D voxet product from the Forward FFT run are imported into the Grids and Meshes tree in Explorer as shown below.

2 In the **Explorer** tree, **Expand** the "+" for the 2D Mesh **Case1_FFT_GravTenBg_80m_Run1_2D**

3 Right click on the two tensor grids:

`observed_GravityTensors_1` and

`calculated_GravityTensors_1`

- Select Field Visualisation Manager
- Under View on Section toggle SurfaceTopography

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- Click on Edit Colours and Clips and choose Colour Pseudocolor (PITS)

- The new colour LUT is applied immediately; Click Cancel to close
- Right click in SurfaceTopography section and select Image Manager

- In Image Manager toggle Interpolate for both displayed images
- Toggle the top image on/off to flick between the two displays or use the transparency slider on the top image
- Use the Query dropdown in Image Manager or

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- Right Click one the Tensor component in the Mesh Grid tree to select the Tensor ZZ components

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4 Examine the differences between the Observed and Calculated images. It is clear that our forward model is a moderately close fit to the observed data and suitable for an initial model for inversion.

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5 Finally examine the Tensor Trace components. The tensor Trace component should be ~0. It is apparent in the images that the Calculated tensor trace contains a significant amount of signal. This is a known issue with the Fourier forward modelling process and relates to difficulties with accurate computation on a Drape surface. We show the image and histogram differences between the Observed and Calculated Trace products below.

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6 We run a Spatial forward model using the same parameters and show the differences below.

7 You can also examine the completed case folder as stored in your project directory:
`Tutorial_C\Tutorial_C6\C6Completed_project\Case3\Run1`

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C6 Stage 4 (FTG)—Inversion of an FTG gravity gradiometer full tensor grid

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Note: This section describes how to process FTG gravity gradiometer data. See also C6 Stage 4 (Falcon)—Inversion of Falcon gravity gradiometer full tensor grid

Steps preview for Stages 4–6

1. Set up the new Case and Run number and select observed geophysical datasets.
2. Check associated physical property distributions for each formation.
3. Set the exploration-bounds on geology boundaries to be explored during inversion.
4. Set iterations, boundary conditions, and the aspects of lithology that will be fixed.
5. Carry out a stochastic simulation, exploring all allowed bounds of the geology, gravity "data sets".
6. When 3D GeoModeller has finished, a misfit trend can be analysed to see the progression towards converged solutions. You judge this by observing where the misfit becomes more or less constant, despite best efforts to perturb the model.
7. Calculate the "Super Summary Stats" from the iteration where the inversion run misfit curve flattens to a minimum - the "burn-in" point - to the final iteration. This includes all valid, equally probable models from the simulation but excludes the iterations before burn-in.
8. Next we view the final calculated geophysics grids, the statistically compiled geophysical-results voxets, the per-lithology rock property distributions, and thresholded surfaces of probability of the geology.
9. In the light of outcomes, you can revise geology boundaries and physical properties.

Notes

You will note a number of 2D grids (**`.ers` grid files**), 3D grids (**`.vo` voxet files**).

Also, as we have used the spatial method (rather than the FFT method), a **`.task file`** is also present that captures the process used to do the 3D inversion model. This is typically called **`Case1_Falcon_Inversion.task`**).

In the folder **`Case_FTG_INV/Run1`**, 3D GeoModeller has spawned this separate process as a batch process.

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File	Description
`Case_FTG_INV_Run1.txt`	Running changes by cell of the inversion progress
`Summary.txt`	text summary
`compute_Surface_1.ers`	Copy of the drape surface grid
`final.sg`	This is for the variable interval Z, otherwise final.vo

`final_Gdd_1.ers`
`final_Ged_1.ers`
`final_Gee_1.ers`
`final_Gen_1.ers`
`final_Gnd_1.ers`
`final_Gnn_1.ers`
	Tensor components as separate grids

`final_GravityTensors_1.ers`	Final estimate of the gravity, as a tensor grid
`ftgmisfits.csv`	Misfit evolution
`initial.sg`	Starting voxet

`initial_Gdd_1.ers`
`initial_Ged_1.ers`
`initial_Gee_1.ers`
`initial_Gen_1.ers`
`initial_Gnd_1.ers`
`initial_Gnn_1.ers`
	Initial/starting tensor components

`initial_GravityTensors_1.ers`	Starting estimated tensor grid

`observed_Gdd_1.ers`
`observed_Ged_1.ers`
`observed_Gee_1.ers`
`observed_Gen_1.ers`
`observed_Gnd_1.ers`
`observed_Gnn_1.ers`	

`observed_GravityTensors_1.ers`	Copy of the observed tensor grid

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File	Description

`reference_1.vo`
`reference_10.vo`
`reference_11.vo`
`reference_12.vo`
`reference_13.vo`
`reference_14.vo`
`reference_15.vo`
`reference_16.vo`
`reference_17.vo`
`reference_18.vo`
`reference_19.vo`
`reference_2.vo`
`reference_20.vo`
`reference_21.vo`
`reference_22.vo`
`reference_23.vo`
`reference_24.vo`
`reference_3.vo`
`reference_4.vo`
`reference_5.vo`
`reference_6.vo`
`reference_7.vo`
`reference_8.vo`
`reference_9.vo`
	Computed response kernels

C6 Stage 4.1—Create a new Case

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Open the existing 3D geology project in 3D GeoModeller

1 From the main menu choose **Project > Open** OR

From the **Project** toolbar choose **Open** OR Press CTRL+O.

Browse to the existing 3D GeoModeller project:

`Tutorial_C\Tutorial_C6\C6Beginning_Project\C6Beginning_Project.xml`

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2 Choose **Geophysics > 3D Geophysics > Inversion Wizard**

The wizard will suggest creating a new Case with the next sequentially available name i.e. Case1, Case2 etc.

3 Select **Create a new case** and name it: **Case1_FTG_INV**

Note: Once you have run your first Case you can use it to clone the next Case by toggling, **Clone an existing case.** A list of existing cases is available from the drop down list on the right**.**

The new Case is initialised with the same modelling parameters as the cloned Case. You can modify the original Case parameters as required. This saves considerable setup time. By default the new case is named **Case_cloned1** but the name can be edited to a name of your choice.

4 Select the geophysical observational grid data types to use from the **Components** list. In this case for a joint inversion,

Tick **Gravity Tensors**

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5 Choose **NEXT**

6 Browse to the Observed grids for each component selected.

Click on **Browse...** and navigate to :

`Tutorial_C6\Data\FreeAir_GravityTensors_TC2p2_Drp80m.ers`

7 **> Open**

8 Set the **Observational Error: = 0.1** mGal

9 Leave the **Match Trend** option unselected.

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10 Under **Observation/Modelling Surface** choose the option that best describes the observed measurement height for the vertical gravity grid:

Select **Drape - Load from dataset:** From a grid containing the aircraft flight or computed Drape surface for the survey in elevation units (Altitude NOT height above the DTM)

When this latter option is selected then two other parameters are required:

- **Vertical contour interval**

  To save computation time in computing the inverted field value on a variable height surface we quantise it into a number of equidistant surfaces above the DTM. We compute kernels for each surface and then interpolate between them to obtain accurate field estimates at any drape elevation. This step results in a linear increase in memory requirements for each level but is done only once at the start of an inversion.

- **Interpolate between contours**

  For accurate calculations of the computed field on the drape surface this must always be ON!

The other options are:

- **Drape - Terrain Clearance: = 0.0 m**. (i.e. ground survey)
- **Constant Elevation:** A flat surface defined by a project elevation (NOT height above the DTM - referenced to the project Z)

11 Click **NEXT**.

The **Voxet Properties** wizard panel opens:

12 Choose the **3D voxet extents** and **X, Y, Z cell sizes** with which to discretise the lithologies and properties for this inversion Case. For a rapid inversion, accept the **defaults**.

The defaults initialise the inversion for the full project area at a relatively coarse voxel resolution. A project subset volume can be selected by changing the X,Y,Z extents. Cell dimensions for X, Y and Z can each be different but a constant set of X, Y cell dimensions must apply throughout the voxel model. The same applies to

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Z unless the user Toggles the **Variable Z** option. This option allows the user to increase the Z cell size with depth as described for Forward modelling in C2 Stage 2—Forward calculation pages 32 - 34. We do not use **Variable Z** here.

Choose the default discretisation scheme of 20 x 20 x 20 divisions in each direction. This results in the cell dimensions x=500m; y=500m, and z=225m.

Note the indicator, **Memory Requirements** shows the estimated memory required to run the inversion.

13 Choose **NEXT**

C6 Stage 4.2—Check rock properties distributions

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

This wizard page allows you to check and alter the initial set of rock property distributions for **each** lithology.

We have set our formation rock properties to values very close to the ones suggested by the Property Optimisation results in Tutorial_C3. However as mentioned in Tutorial_C3, a monomodal distribution must be selected when running Property optimisation; the estimate will be the average if more than one population is present.

We are aware from observations outside our project that the Host_rock unit is made up of at least two different rocktypes of which one has a higher density; so we have modified the optimised values. We adopt a bimodal distribution for density and susceptibility to give the inversion an opportunity to spatially locate the much less abundant unit. The ratio between the two volumes is set to 94/6. We don't believe that it makes up a large percentage of the volume. We err on the low volume side. We have also decided to keep our property standard deviations small; we believe the bulk properties do not vary as much as was allowed previously. We also want to minimise any overlap in the property distributions beween lithologies to minimise any ambiguity in the inversion. We can test these assumptions by alternating between mostly geology to mostly property style inversions as discussed later in this tutorial.

The following table shows the properties adopted:

Densities

Series	Mean Value	Standard Deviation	Statistical Law	Percentage of Population
Cover	2.2	0.05	**NormalDistribution**	100%
Host_rock (unit1)	2.5	0.05	**NormalDistribution**	94%
Host_rock (unit2)	2.9	0.03	**LogNormal**	6%
Granite	3.1	0.03	**LogNormal**	100%

You can change the Probability Distribution Function (PDF) for each lithology by double clicking on the **Value** field text for each **Property** i.e. `NormalDistribution(2.2,0.1,100)`. This is the same procedure as described in the Forward Wizard.

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In the General Properties panel in the lower half of the wizard page, under the **Gravity** tab you choose how density will be initialised in the initial model. The options are:

- **From Law Mean**—this is the **Default** and sets every cell of a lithology to its mean value.
- **From Law Random**—this initialises each cell of a lithology with a random sample from its chosen PDF.
- **From voxet**—this option allows you to browse to and load an external GoCAD format voxet of rock properties from a previous inversion or another external source. The voxet MUST have the same project extent and cell size specified for this inversion in Page 2 of this wizard.

It is important to remember that each lithology has its own unique property law (PDF). If you want to fix the geology-geometry of a model and run a property-only inversion, the properties generated for each lithology are still randomly selected from the defined PDF for each.

1 For GRAVITY, set **FromLawRandom**
   - Toggle Bouguer Anomaly
   - Set Reference density = **2.2** g/cm^3;
   - **Toggle Above-topo density** and ensure it is also set to **2.2** g/cm^3.

     Note: This is the default for a Bouguer correction

2 Choose **NEXT**.

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C6 Stage 4.3—Shared Geological Settings

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

If you need to review shared geological settings, refer to the steps in C5 Stage 3—Shared Geological Settings.

C6 Stage 4.4—Enter run control parameters

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Here you control the specifics of the inversion run: number of iterations, how to influence convergence, and switches for geology constraint tests (set but not on yet).

For this tutorial:

1. **Change** the number of **Iterations to 100,000**

   100,000 iterations is enough in this exercise, to get convergence to a uniform misfit between the model geophysics responses and the observed geophysics grids. The iterations after the initial convergence (after "Burn-in") allow for an exploration of all the equally probable models that follow. Millions of equally probable models, each with a small variation in a property or geology boundary, can explain the observed data sets.

2. **Tick ON Allow Formation Geometry Tests**"
3. **Tick ON Allow Commonality Test**. Set the Bias option on the right to **"none"**.
4. **Tick ON Allow Shape Ratio Test**. Set the Bias option on the right to **"none"**.
   - **Tick On Include Above Topo Faces in Shape Ratio**
   - **Include Outside Faces in Shape Ratio**

   AND/OR (i.e. choose ShapeRatio and VolumeRatio together or separately; check differences in geometry & geophysics misfit between the 3 possible cases)

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5 **Tick ON Allow Volume Ratio Test**. Set the Bias option on the right to **"none"**.

6 Tick ON **Allow Geophysical Misfit Tests**

7 Choose **Next**

The Bias options are explained in Tutorial C4—Prior Only Inversion (geology-only inversion) and in Forward modelling and inversion with 3D GeoModeller)

C6 Advanced Tuning Options

The advanced options are available for testing and for influencing the speed of the solver in the initial convergence stage. For this tutorial, leave Advanced Tuning Options unadjusted.

For more information about the options in this dialog box, if needed, see C5 Advanced Tuning Options:

Execution of Environment Settings

Just prior to running an inversion, you must make a decision about where to run the job and how many Cores/Threads to use.

The default uses your local machine interactively. You may have more than one CPU and the operating system is designed to allow you to continue to work interactively, while "number crunching" continues in separate process(es).

1 Accept the default **Interactive**

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2 **Accept the default maximum number of cores** to run on your computer. In general, the more you choose the faster the inversion will run.

If you need other processes to current concurrently, choose a lesser number of cores to dedicate to the inversion task.

3 Choose **Finish**

Next

If you are using the FTG gravity gradiometer, go next to C6 Stage 5 (FTG)—Analysis—monitoring the misfits and computing post burn-in summary statistics

C6 Stage 4 (Falcon)—Inversion of Falcon gravity gradiometer full tensor grid

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Note: This section describes how to process Falcon gravity gradiometer data. See also C6 Stage 4 (FTG)—Inversion of an FTG gravity gradiometer full tensor grid

The convention for constructing a Falcon tensor grid is designed so that we preserve the same 6 band BIL scheme that is used for FTG. It is adapted in a systematic way to contain the Falcon duplicate A and B horizontal curvature gradient measurements, Gne and Guv where Guv = (Gee - Gnn)/2. We can convert the FTG forward model grid created above into a form that is compatible with an observed Falcon tensor grid. This process must be followed before proceeding to any visual comparison of an observed Falcon gridded dataset, and the response from your model. The options for visualizing a Falcon tensor grid are adapted to the components available in the measured data.

You will note a number of 2D grids (`.ers` **grid files**), 3D grids (`.vo` **voxet files**).

Also, as we have used the spatial method (rather than the FFT method), a `.task file` is also present that captures the process used to do the 3D inversion model. This is typically called `Case1_Falcon_Inversion.task`).

3D GeoModeller has spawned this separate process as a batch process.

File	Description
`calculated_GravityTensors_1.ers`	2D full tensor grid computed by FFT forward modelling (6 bands)
`final_GravityTensors.vo`	Resulting 3D grid - 6 attributes (one for each tensor component)
`initial.vo`	Initial 3D grid - 2 attributes (one for each Lithology, density)
`Observed_GravityTensors_1.ers`	empty grid, as we did not use a supplied/or reference grid
`vfilt_GravityTensors.task`	The FFT process captured ready for batch or multi-threading environments.

Next

If you are using the Falcon gravity gradiometer, go to C6 Stage 5 (Falcon)—Analysis—monitoring the misfits and computing post burn-in summary statistics

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C6 Stage 5 (FTG)—Analysis—monitoring the misfits and computing post burn-in summary statistics

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Note: This section describes how to process FTG gravity gradiometer data. See also C6 Stage 5 (Falcon)—Analysis—monitoring the misfits and computing post burn-in summary statistics

Analysis of an FTG gravity gradiometer full tensor grid inversion

When running interactively, a progress bar in the form of a current misfit vs iterations graph pops-up.

As the inversion gets underway, the pop-up graph shows us a high initial misfit which rapid settles lower and then constant. When the 50,000 iterations are complete you will be asked if you wish to compute Summary Voxets (also known as "Super Summary Statistics"[SSS]) which collates all results in attributed voxets (3D grids) for a post burn in iteration range of your choice.

1 Choose **Yes** to immediately **Compute the Summary Voxets**.

3D GeoModeller displays the **Summary statistics from inversion result** dialog box.

Note: If you decline the first time, or wish to calculate SSS for a different burn-in point, you can return to the misfit screen, by selecting:

Geophysics > 3D Geophysics > Summary Voxets from Inversion

2 Set a burn-in point of 30,000—type **30000** in the **From** box (lower left).

This is where the misfit becomes more or less constant (at ~1.1), as shown by the graph below. Your burn in point may be different depending on the settings applied.

Note that the mouse is interactive with the misfit plot to display a label.

Setting the burn-in gives the starting iteration for statistical analysis of that portion of the inversion corresponding to simulations that are all equally plausible (usually, through to and including the last iteration). Burn-in is judged by observing where the misfit becomes more or less constant, despite best efforts to perturb the model.

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3 Choose **OK**, to create a summary statistics mesh grid (voxet) for re-compiled results and settings captured between 30,000 & 50,000 iterations.

Note that we left the default Threshold at '90'. This is the percentage probability measure used to produce the MostProbableThresholded field. Voxels assigned a lithology that have a probability <90% are set to Null. See C5 Stage 7—Statistical results analysis below, and the Table therein for further details.

When the Summary Voxet calculations are finished, you will see the following message:

View the list of your joint inversion output files

Here is a summary of the inversion output files which now exist in your project directory folder: **`Case1_FTG_INV\Run1`**:

File(s)	Description
`misfit.csv`	Numeric record of the misfit evolution (Misfit value for gravity as a function of iteration number where misfit is the least squares differences between the observed and the current computed geophysics grid, [dist = sqrt(dist / count);].
`Summary.txt`	A summary of proposal acceptances and rejections for each geological and geophysical constraint for the full inversion.
`compute_Surface_1.ers`	2d grid of the surface on which to compute the Gravimetry response
`observed_Tensor_1.ers`	2d grid of the measured gravity.
`initial_Tensor_1.ers`	2d grid of the computed gravity response from the initial iteration of the inversion.
`final_Tensor_1.ers`	2d grid of the computed gravity response from the final iteration of the inversion.
`compute_Surface_2.ers`	2d grid of surface on which to compute the TMI response
`initial.vo`	Initial voxet (3D grid) for the state of the model at the final iteration - 4 attributes: final lithologies; fixed cells; final densities; final susceptibilities.
`final.vo`	Voxet (3D grid) for the state of the model at the final iteration - 4 attributes: final lithologies; fixed cells; final densities; final susceptibilities.
`reference.vo`	The geophysical response kernel voxet model (3D grid), discretised at the same cell size as the voxet models above. Deleted on completion to save space.

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File(s)	Description
`Stats_300K_500K_T90.vo`	A summary statistics mesh grid (voxet) for inversion iterations 300,000-500,000 (post burn-in). For further details see E5 Stages 8 & 9.

Next

If you are using the FTG gravity gradiometer, go to C6 Stage 6—View the final 2D grids for gravity gradients (quality check)

C6 Stage 5 (Falcon)—Analysis—monitoring the misfits and computing post burn-in summary statistics

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

Note: This section describes how to process Falcon gravity gradiometer data. See also C6 Stage 5 (FTG)—Analysis—monitoring the misfits and computing post burn-in summary statistics

Analysis of an Falcon gravity gradiometer tensor grid inversion.

The operations are currently available in 3D GeoModeller.

Please contact our technical support service for further information. This section of the tutorial remains unfinished.

C6 Stage 6—View the final 2D grids for gravity gradients (quality check)

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

We compare the **observed** and **final** geophysics grids to evaluate whether the inversion geometry and rock property changes produced a close fit with the geophysics.

- If the geology tests were too tight or,
- The initial geology model was not good enough or,
- The rock properties were poor and not improved by property optimisation

THEN poor matches between observed and final grids may occur. On the other hand, good agreement between observed and final grids does not guarantee that the inversion regime was appropriate or has necessarily given us good results. Before concluding this we must also investigate the changes that were driven by the proposed properties and geology geometry constraints.

Load the summary final geophysical grids via EXPLORER

Similar to the Forward Modelling tool (Tutorial C2—Potential field forward calculation), Inversion also creates and stores summary results which can be viewed in the Results explorer. Select:

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Geophysics > 3D Geophysics > Results explorer

The left hand panel provides a data explorer for all the forward and inversion cases you may have run. The convention is to use GREEN arrows to indicate Forward model cases, and RED arrows to indicate Inversion cases. The other main function available here is the ability to delete cases that are of no further interest.

3D GeoModeller displays several grid images including the calculated misfit grids. The images are:

- Top Left—Observed: the observed grid
- Top Centre—**Final:** the computed response at the final inversion iteration
- Top Right—**Misfit:** the misfit or difference; *(Observed - Computed at the Final iteration)*.
- Bottom Left—**Regional Trend**: the trend removed if you choose to solve and remove a regional trend from the Observed grid. (No detrending was applied in this case).
- Bottom Middle—**Final + Regional Trend:** the Computed Final grid after adding back the Regional Trend i.e. *(Final + Regional Trend)*.
- Bottom Right—**Misfit – Regional Trend:** The Misfit after adjusting for the regional trend *(Observed - Regional Trend - Computed Final)*.

Note that the colour scales are different for each of the images as they are the result of a linear colour mapping between the minimum and maximum values for each grid.

1. **Select** the **Gravity** tab to view the results .
2. Use the **Options** dropdown on the left to **Load** or **Remove** an **Observed grid**
3. Use **File > Open Results** or **Save Results** to Open or Save the `inversion.xml` file which records all executed inversion Cases for the current project. This allows you to save the current `inversion.xml` file with the new observed grid or simply save the `inversion.xml` to a new name for Case archival purposes.

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4 Save your Project.

Load the Inversion output products and display 2D geophysics grids (observed & final) in the 2D geology workspace

5 Ensure your **Topography Section** is open in the **2D Viewer**

6 From the **Explorer** tree, select **Grids & Meshes** > Right-click **Import > Geophysical Results > Case1_FTGInv > Run 1**

All the grid/voxet products from the Inversion run are imported into the Grids and Meshes tree in Explorer.

7 In the **Explorer** tree, **Expand** the "+" for the 2D Mesh **Case1_FTG_Inv_Run1_2D**

8 **Right Click** on `final_Tensor_1.ers` with the grid selected, right-click **Field Visualisation Manager**

9 Tick **Surface Topography** underneath **View on Section**

10 Choose **OK**. The grid is displayed in the 2D Viewer on the **SurfaceTopography** section

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11 Click **Display Colour Table** to view the colour table legend.

OR

Click on the same grid in **Explorer**, and right-click > **Display Colour Table**

- **Visualise the other 2D grids and display the colour table** by repeating the steps above.
- Use the **Image Manager** to explore multiple 2D mesh grids and image backdrops using the ON/OFF selectors and transparency slider; reorder the image list as required.
- Right click on **Grids and Meshes > Hide all Views** to clear your Surface Topography Viewer before viewing the next grid.
- Tensor grid support is available in the **Image Manager**.

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C6 Discussion—Comparing FTG with vertical gravity inversion constraint

Parent topic: **Tutorial C6—Calculations using gravity gradients (forward and inversion)**

When we use tensors there are six signals instead of one. They converge more quickly, with fewer iterations. We find that tensors do a better job of constraining bodies. They are more efficient and work just as rapidly.

The FTG inversion has less mis-fit per component than the Vertical Gdd component (single component inversion). This is not surprising, as the scalar inversion wants to drive the mis-fits to zero, whereas the tensor mis-fit is reduced using the tensor algebra of potential fields towards each components natural noise floor.

The tensor finishes its path to the noise floor around 30000 iterations, while the Gdd keeps going, more slowly. The vertical component Gdd, within the tensor, is the most noisy, starting with a mis-fit of around 7 Eotvos, and reducing to 2. The exact same component, when used by itself starts at 12 Eotvos and reduces to 6, with more still to go.

The consequence of this is that the geology model for the scalar case is not as constrained in the horizontal plane, whereas with the tensor, it is. The tensor provides a more comprehensive forcing function to push the geology towards a better fit quicker.

Our linked tensor arithmetic ensures the physics of the potential field gradients are, at all times, honoured, and are also the most efficient computationally, in properly accounting for the full tensor gradients,.

This is better than doing the tensor components one at a time, and independently of each other.

Iterations	Proposals	Gee	Gen	Ged	Gnn	Gnd	Gdd
0	0	6.314256	1.708757	5.599489	5.306104	4.128572	7.021407
5000	5000	5.243386	1.309435	4.190322	4.539626	2.91464	5.327312
10000	10000	4.507285	1.065542	3.159284	4.134618	2.116988	4.174985
15000	15000	3.842734	0.830667	2.321168	3.719898	1.519336	3.313794
20000	20000	3.576017	0.691612	1.81041	3.618746	1.262282	2.837898
25000	25000	3.364548	0.573518	1.362955	3.542176	1.029081	2.417752
30000	30000	2.741128	0.494695	1.129268	2.97129	0.936215	2.122808
35000	35000	2.705944	0.41296	1.02824	2.928423	0.81117	2.078517
40000	40000	2.646371	0.428859	0.970126	2.85094	0.837379	2.013407
45000	45000	2.659886	0.39636	0.918026	2.823162	0.777424	1.93748
50000	50000	2.615182	0.41484	0.883669	2.797486	0.83565	1.822986

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Tensor vs single component convergence comparison

The following pair of tables and graphs show difference in the numbers and the convergence behaviour between Gdd or a single component, and the full tensor.

In this case, it is exactly the same geology model (Tutorial C), and exactly the same observed grid—the observed tensor grid, using all, or just the Gdd component.

The process behaves differently:

The full tensor case converges more quickly, and the overall misfit, taking all the components into account, is much less than the Gdd case.

This is not surprising, as the scalar case can not contribute to the horizontal changes in the model.

The time to do full tensor inversion is not very different to scalar inversion, in spite of earlier fears that it would be much slower.

Iterations	Proposals	Gee	Gen	Ged	Gnn	Gnd	Gdd
0	0	6.314256	1.708757	5.599489	5.306104	4.128572	7.021407
5000	5000	5.243386	1.309435	4.190322	4.539626	2.91464	5.327312
10000	10000	4.507285	1.065542	3.159284	4.134618	2.116988	4.174985
15000	15000	3.842734	0.830667	2.321168	3.719898	1.519336	3.313794
20000	20000	3.576017	0.691612	1.81041	3.618746	1.262282	2.837898
25000	25000	3.364548	0.573518	1.362955	3.542176	1.029081	2.417752
30000	30000	2.741128	0.494695	1.129268	2.97129	0.936215	2.122808
35000	35000	2.705944	0.41296	1.02824	2.928423	0.81117	2.078517
40000	40000	2.646371	0.428859	0.970126	2.85094	0.837379	2.013407
45000	45000	2.659886	0.39636	0.918026	2.823162	0.777424	1.93748
50000	50000	2.615182	0.41484	0.883669	2.797486	0.83565	1.822986

Iterations	Proposals	Gdd
0	0	12.65625
5000	5000	10.80218
10000	10000	9.613908
15000	15000	8.637774
20000	20000	7.796538
25000	25000	7.270731
30000	30000	6.833108
35000	35000	6.624582
40000	40000	6.421033
45000	45000	6.170153
50000	50000	6.072299

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