Tracking Crustal Thickness Changes

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Updated for GPlates 2.2 and the reconstructions of Müller et al. (2019) by Christopher Alfonso and Behnam Sadeghi

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Aim

This tutorial is designed to introduce the user to the functionalities that allow changes in crustal thickness to be visualised in deforming areas.

Included files

Click here to download the data bundle for this tutorial.

The tutorial dataset (8.4-Crustal_Thickness.zip) includes the following files:

1. GPlates project file:
   - 8.4-Crustal_Thickness.gproj
2. Rotation file:
   - Muller_etal_2019_CombinedRotations.rot

3. Coastlines file:
    - Muller_etal_2019_Global_Coastlines.gpmlz
4. Plate boundaries and deforming meshes file:
    - Muller_etal_2019_PlateBoundaries_DeformingNetworks.gpmlz

Background

Deforming networks are useful for modelling plates that do not remain rigid. Crustal thickness does not remain constant during this deformation, and it can be useful to track and visualise in different ways how the crust changes thickness through time.

There are three ways to visualise crustal thickness changes in GPlates 2.2. The first of these is the absolute crustal thickness (gpml:CrustalThickness). When a network of crustal thickness points is generated, an initial uniform crustal thickness value is assigned. By default, this value is set to 40 km, although any value can be specified. Areas which have experienced compression will have increased crustal thickness values, while areas which have experienced extension will have thinner crust.

Relative changes in crustal thickness can be visualised using one of two parameters (gpml:CrustalStretchingFactor and gpml:CrustalThinningFactor). These parameters are defined as follows:

$$Crustal\ Stretching\ Factor = \frac{T_i}{T_t}$$

$$Crustal\ Thinning\ Factor = \frac{T_i - T_t}{T_i} = \frac{-\Delta T}{T_i} = 1 - \frac{T_t}{T_i}$$

Where:

T_i = initial crustal thickness

T_t = crustal thickness at time *t*

ΔT = change in crustal thickness (i.e. $T_t - T_i$)

Thus the Crustal Stretching Factor has the range (0, ∞), with values < 1 indicating thickened crust and values > 1 indicating thinned crust. A value of

1 indicates no change in crustal thickness.

Meanwhile, the Crustal Thinning Factor has the range $(-\infty, 1)$, with values < 0 indicating thickened crust and values > 0 indicating thinned crust. A value of 0 indicates no change in crustal thickness.

In all of these cases, the initial time ($t = 0$) is crucially important, as all calculations are relative to the crustal thickness at this time.

Exercise 1 – Visualising crustal thickness changes in the North Atlantic

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This exercise is designed to introduce you to how GPlates represents and tracks changes to crustal thickness in a forward modelling sense, whereby relative changes to crustal thickness are calculated with respect to a time in the past.

1. Open GPlates and load in the project file '8.4-Crustal_Thickness.gproj' by either dragging and dropping it onto the globe, or File → Open Project...

2. Rotate the globe such that the North Atlantic is in view at 120 Ma (Figure 1).

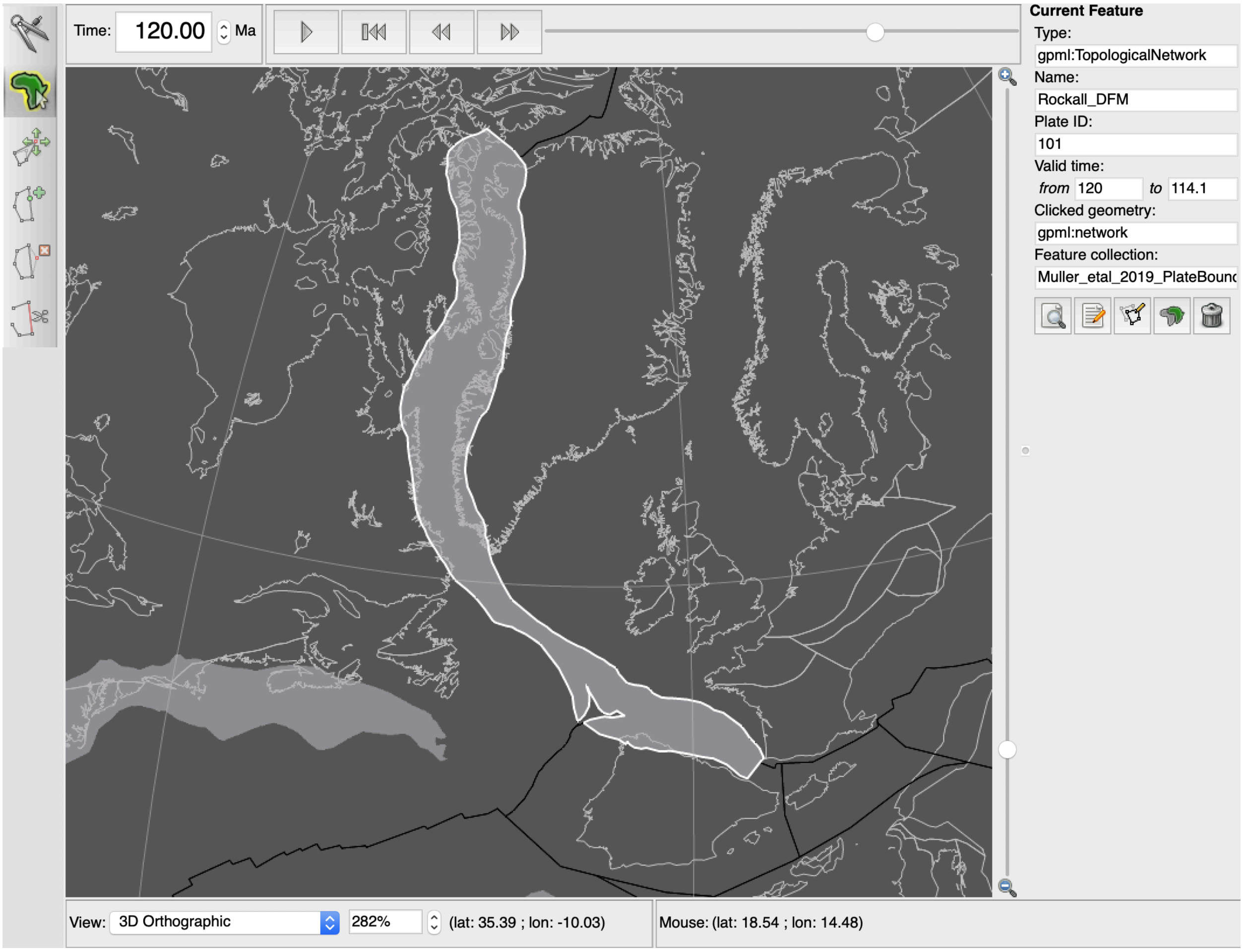

Figure 1: Screenshot of globe focused on North Atlantic at 120 Ma. Deforming meshes are shaded grey, and the North Atlantic deforming mesh ('Rockall_DFM') is selected.

Note the highlighted polygon (outlined in white, shaded in grey). This is a deforming network for the North Atlantic, which we will use to visualise changes in crustal thickness through time.

3. **Ensure that the reconstruction time is set to 120 Ma**. This is the time we want to calculate relative changes in crustal thickness with respect to and your results will look different if you don't begin at 120 Ma.

4. Using the select feature tool, select the deforming network region by clicking anywhere in the grey shaded area (the boundary of the region should turn white once selected).

5. Go to Features → Generate Deforming Mesh Points

A new dialog should open where we will specify the parameters for the calculations to be performed on the deforming mesh (Figure 2). These parameters are defined separately for each deforming region.

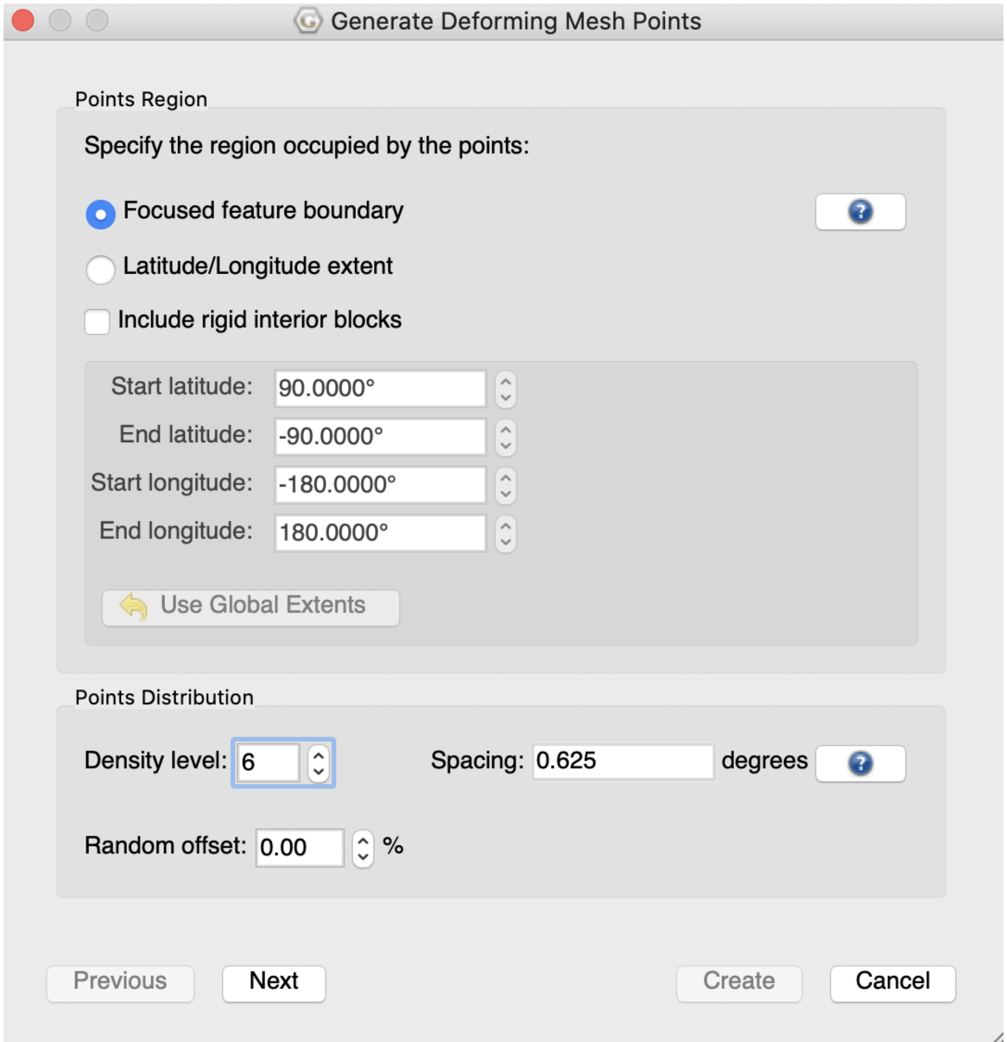

Figure 2: Generate Deforming Mesh Points window (Step 5).

Now we will generate the points inside the deforming region that will be used to represent relative changes in crustal thickness.

6. Specify the following parameters (Figure 2), then click "Next":
    - Points Region: Focused feature boundary
    - Density level = 6 (default - specifies point density in the deforming region. See note at end of this exercise for more information)
        - Spacing will be automatically determined based on density level

- Random offset = 0 % (default)

7. In the next window, specify the following parameters (Figure 3), then click “Next”:
    - Thickness = 40.0 km (default)
    - Plate ID = 0 (default)
    - Begin time = 120 Ma (the time we reconstructed to when we generated the points)
    - End time = 0 Ma (default)
    - Name = North_Atlantic_Crustal_Thickness (or whatever name you would like to give it)

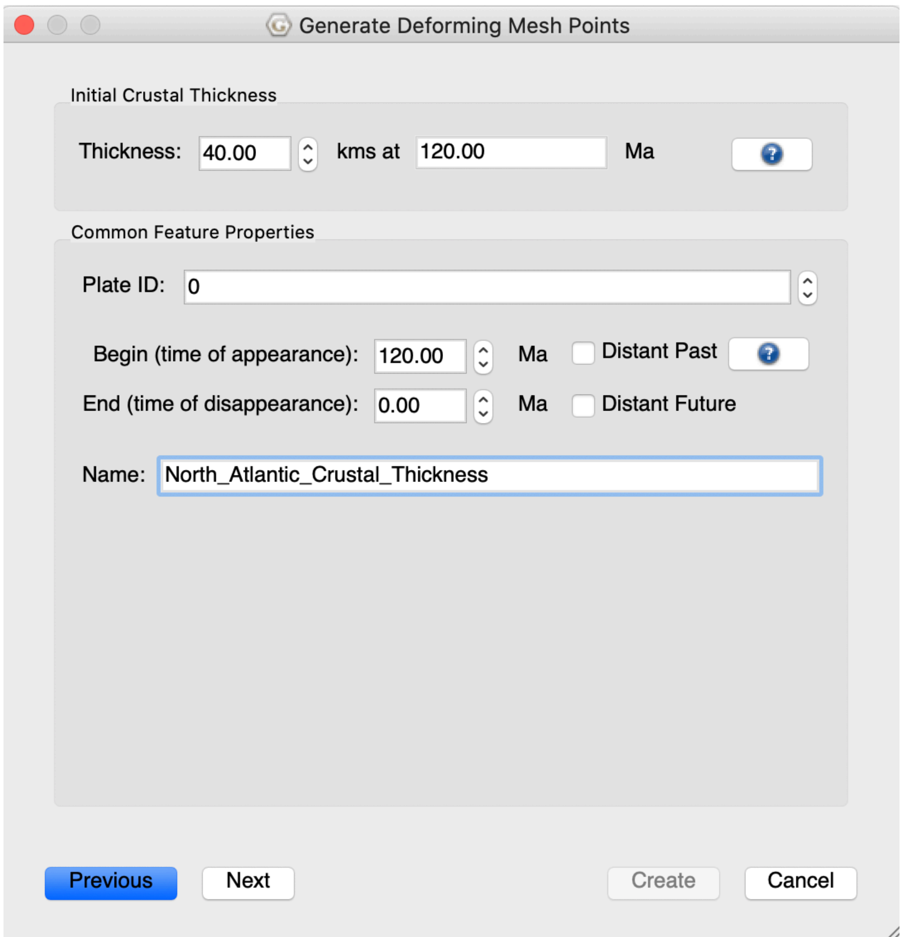

Figure 3: Entering deforming mesh parameters, as described in Step 6.

8. In the next window, click “< Create a new feature collection >”, then “Create”

9. In the next window (Figure 4), we need to specify some final parameters:

- Youngest Age = 0 Ma (default)
- Oldest Age = 120 Ma
- Select "Deactivate points that fall outside a network"
- Leave other options as defaults

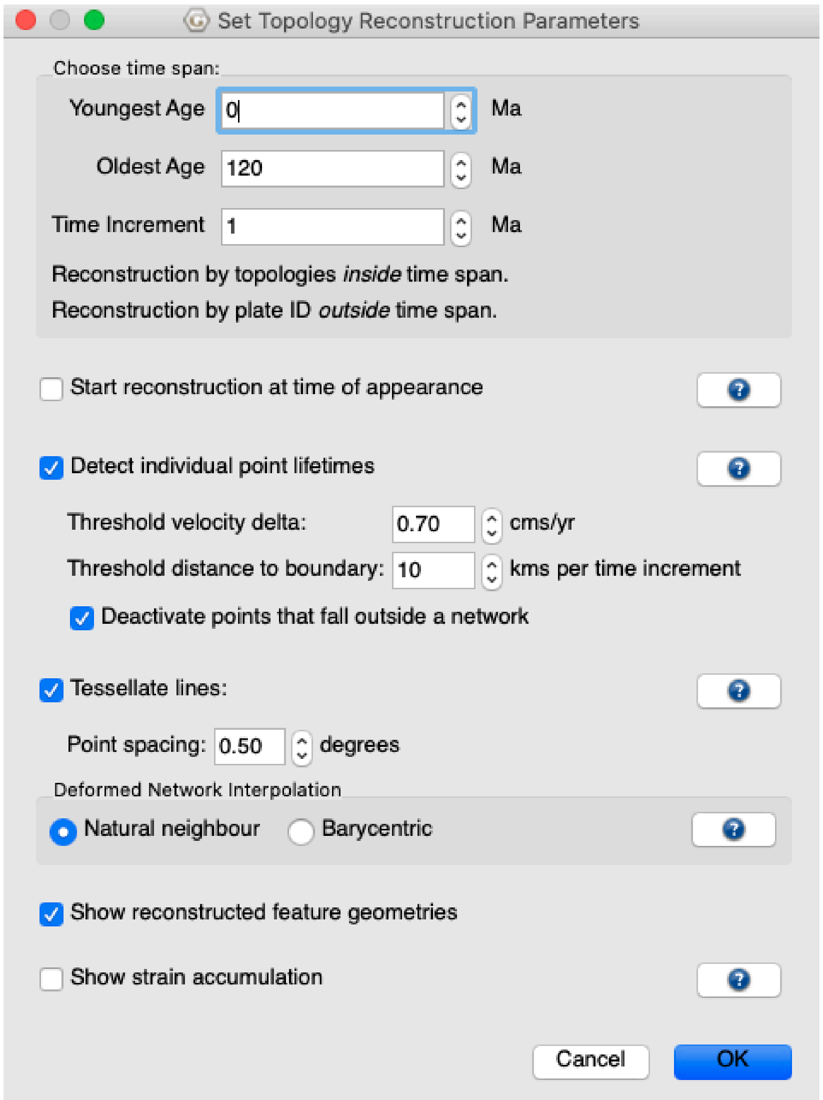

Figure 4: Entering further deforming mesh parameters, as described in Step 8.

10. Click "OK", and your network of points will be created (this may take a moment)

You should now notice that there are green points within our deforming network region (Figure 4).These are the points that will represent crustal thickness and are confined to within the deforming region.

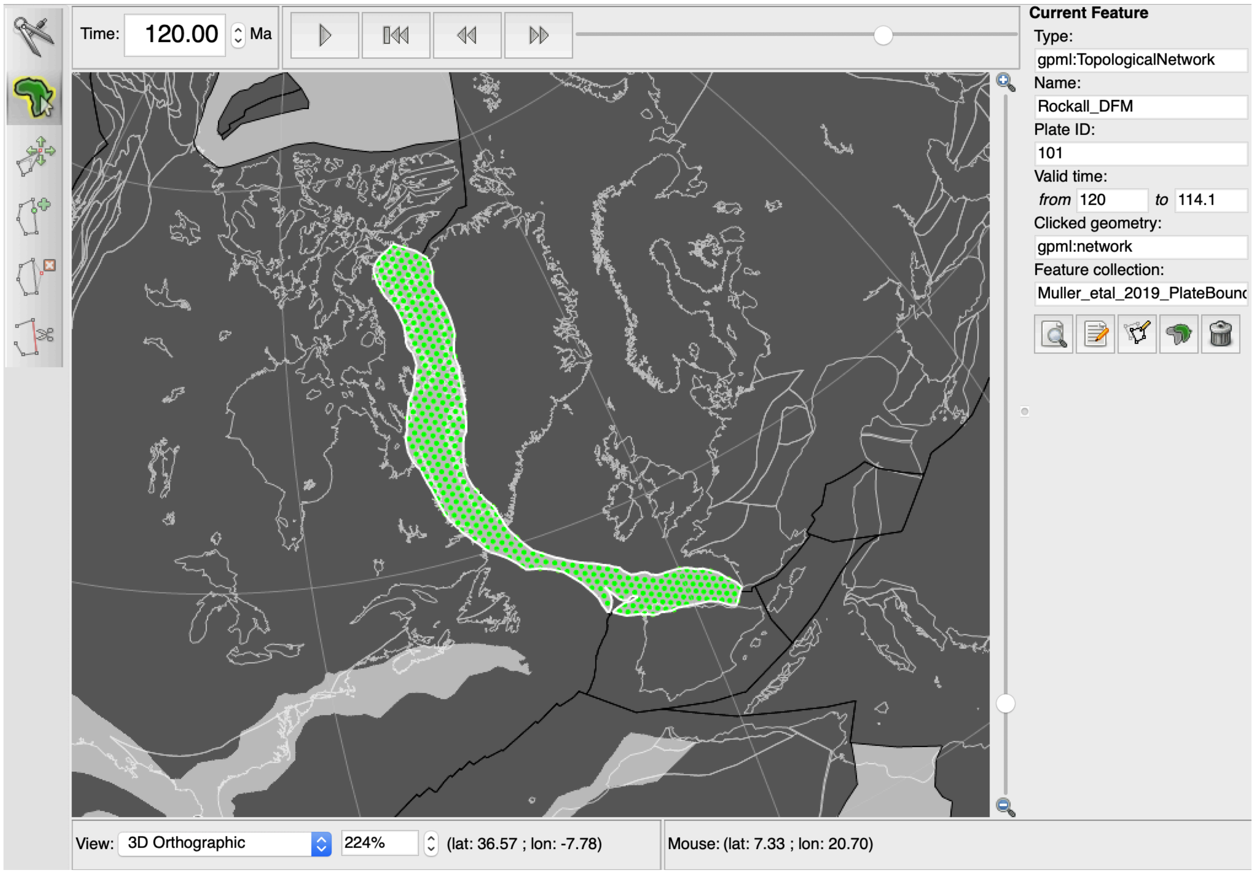

Figure 5: Newly generated crustal thickness points (green) within the deforming region (grey).

11. If it is not already visible, open the Layers window (Window → Show Layers… or Cmd/Ctrl+L)

You should notice that two new layers have been produced - a green one (reconstructed geometries) and a dark grey one (reconstructed scalar coverages). These will have automatically been assigned generic names (e.g. “Layer [n]”) for the moment.

12. Expand the options for the green reconstructed geometries layer (Figure 6).

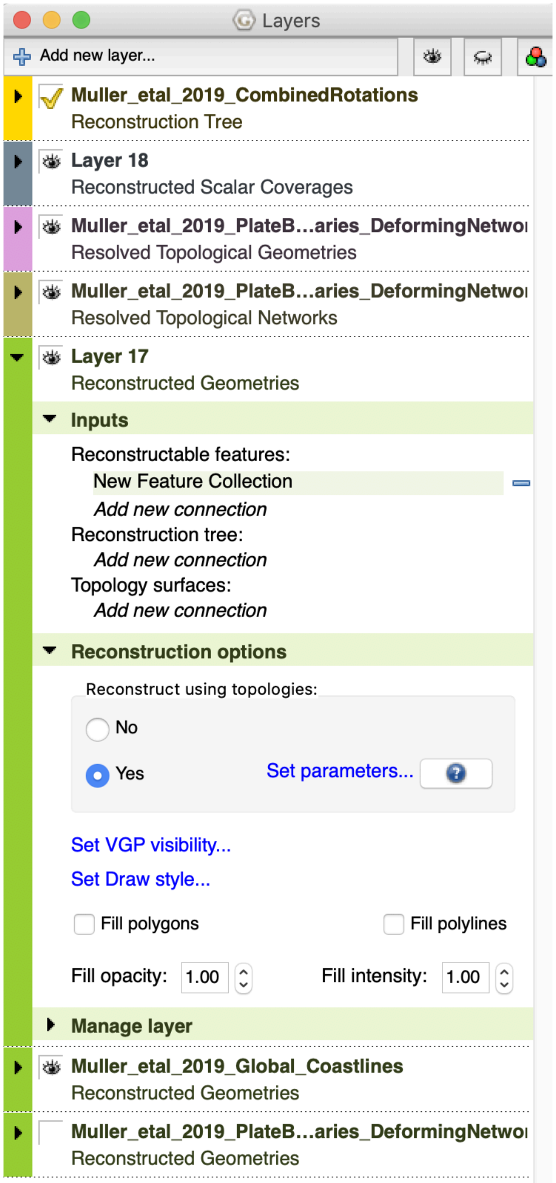

Figure 6: Layer options for our crustal thickness points.

13. Under Inputs → Topology surfaces, add a new connection to the gold-coloured Muller_etal_2019_PlateBoundaries_DeformingNetworks (Figure 7).

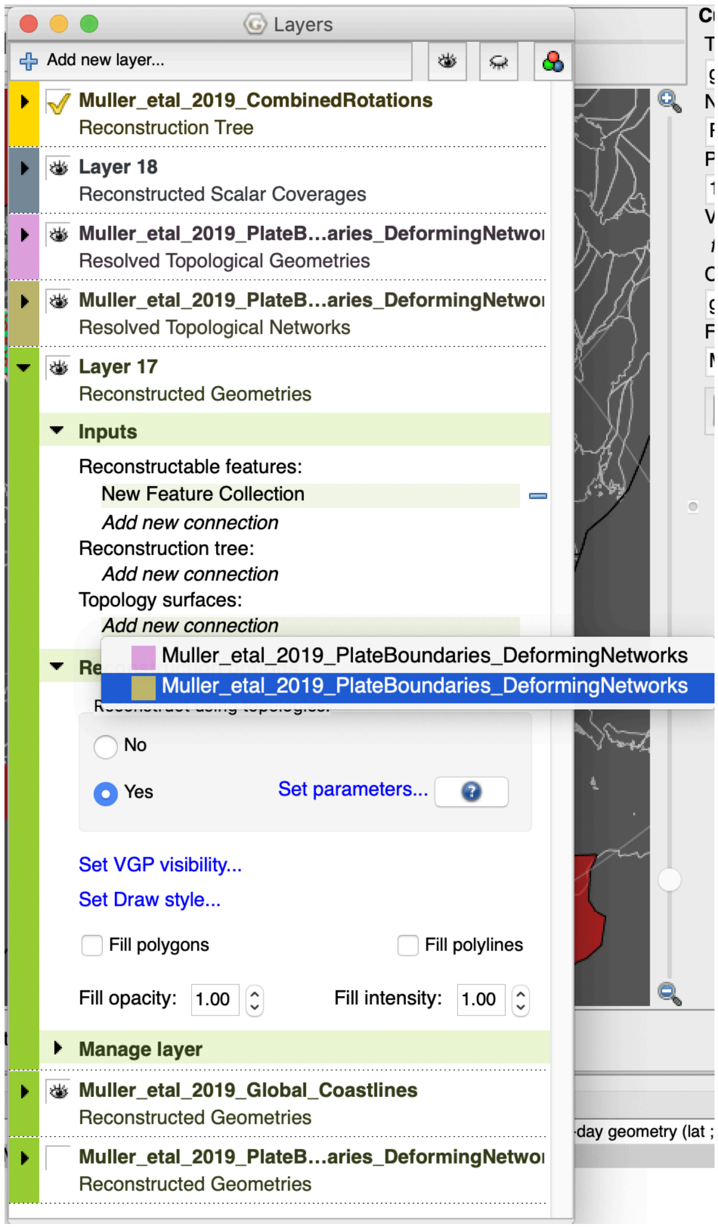

Figure 7: Connecting the crustal thickness points to the topology surface

Note: Although we connect a deforming network in this tutorial, rigid topologies (pink layers) can also be used.

14. Expand the options under the dark grey Reconstructed Scalar Coverages layer (Figure 8). Under Scalar Coverage options, set the Scalar Type to gpml:CrustalStretchingFactor. Change the Palette Range to 0.0–2.0, since we are looking at relative changes in crustal thickness, where the original value is defined as 1.

Note: the palette range can be changed to any range you'd like however it is recommended that 1 is in the middle since it represents the original crustal thickness at 120 Ma and the colours diverge appropriately.

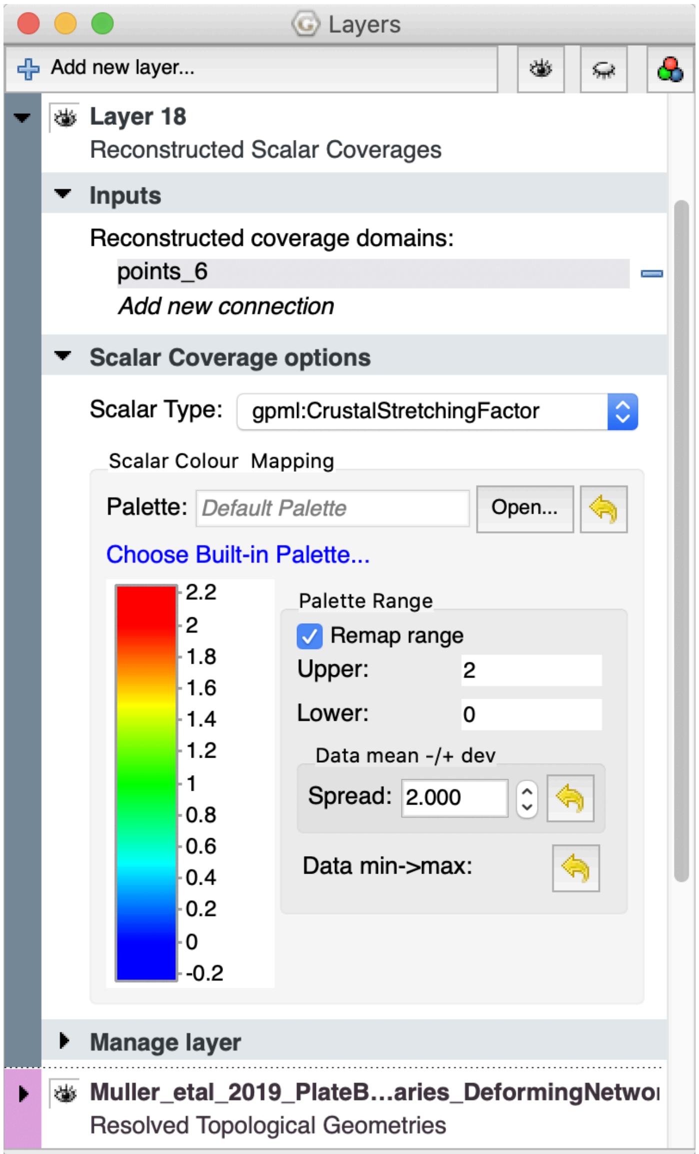

Figure 8: Changing the colour palette range (Step 13).

With the default colour palette, crust that has thickened since 120 Ma will be blue, while crust which has thinned will be yellow–red.

15. Change the reconstruction time to 62 Ma (Figure 9).

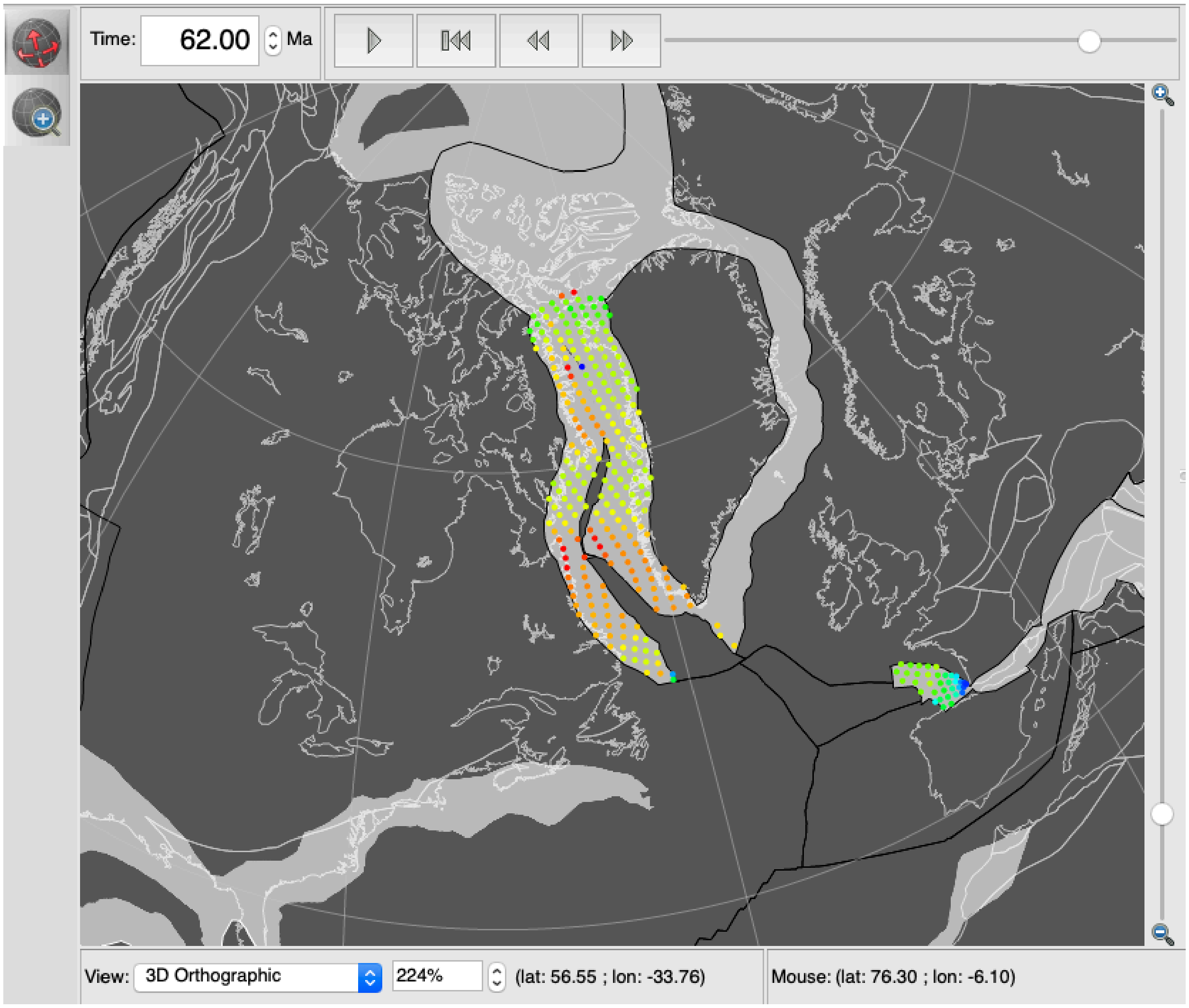

Figure 9: Crustal thickness in the North Atlantic at 62 Ma.

Notice that the points are now all different colours. Based on our colour palette, points that are yellow/red denote a thinner crust than at 120 Ma, those that are blue denote a thicker crust than at 120 Ma, and those that are still green denote that the crustal thickness has not changed since 20 Ma.

16. Play the animation from 120 Ma - 62 Ma and see how the points move and show changes in crustal thickness.

We can see that the deforming region illustrates rifting between North America and Greenland, where the crust is thinned.
There is also a range of other colour palette options to choose from other than default red–green–blue:

17. Expand the Scalar Coverage options under the dark grey layer in the Layer window, and select 'Choose Built-in Palette...' (Figure 10).

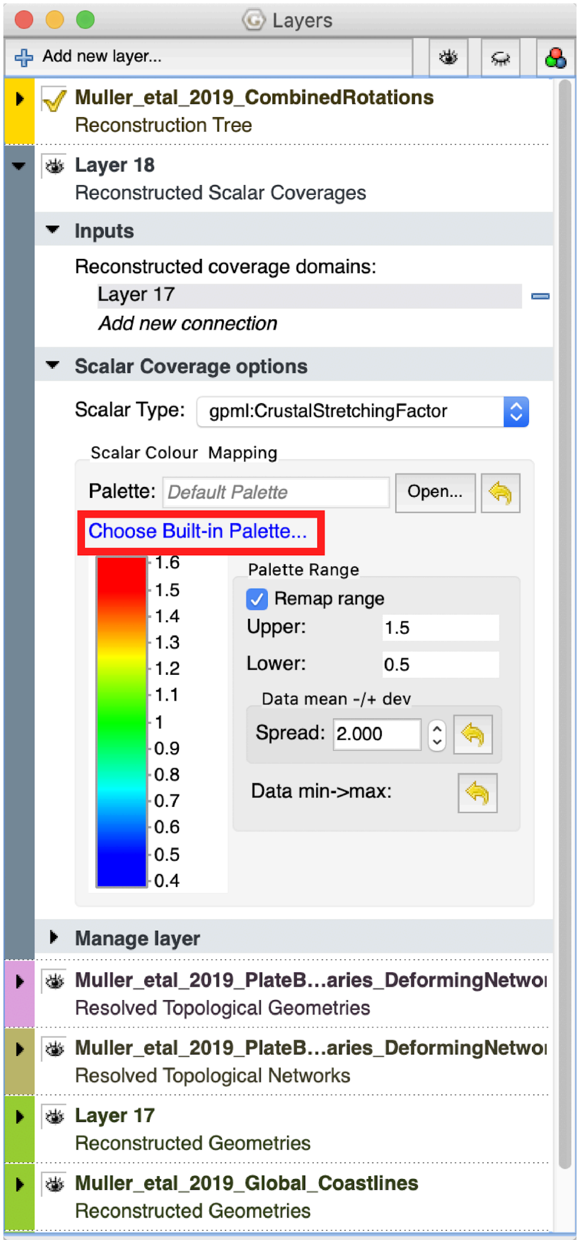

Figure 10: Layer window showing 'Choose Built-in Palette…' option.

This will open the Choose Built-in Palette window (Figure 11), where you can choose from a range of different colour palettes. You can also choose to invert the colour palette (tick 'Invert'), as well as making the colour palette discrete, with a given number of classes (tick 'Discrete' and enter a value for 'Classes').

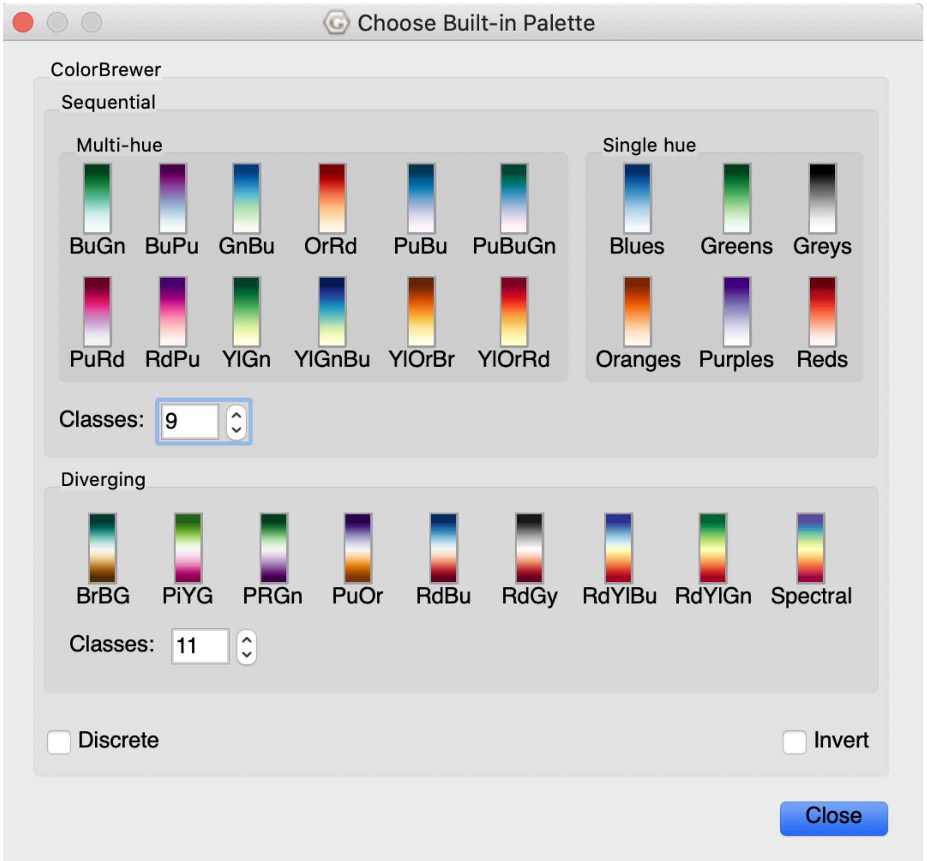

Figure 11: The Choose Built-in Palette window, showing the range of colour palette options.

18. Experiment with the different colour palette options, then when you are satisfied with your choices, click "Close".

Don't forget to save your new feature collection containing the crustal thickness points!

Note: when specifying the point density in Step 6, we used a value of 6 and got a rather sparse coverage. Although it may take longer to compute, using a point density of 8 gives us a more detailed coverage (Figure 12).

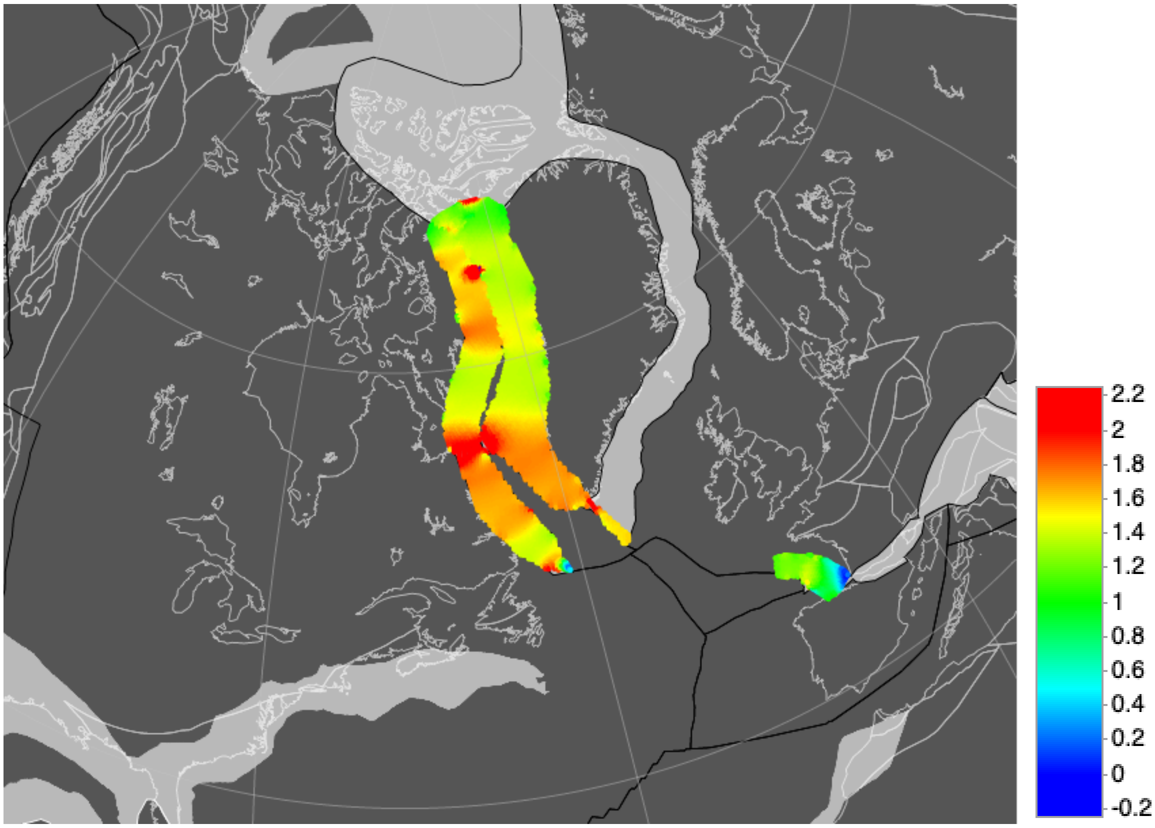

Figure 12: Crustal thickness of North Atlantic deforming region with point density of 8 with default colour palette showing relative crustal thickness changes.

Using a denser point coverage can also make the visualisation of relative crustal thickness change easier, especially if a discrete colour palette is used (Figure 13).

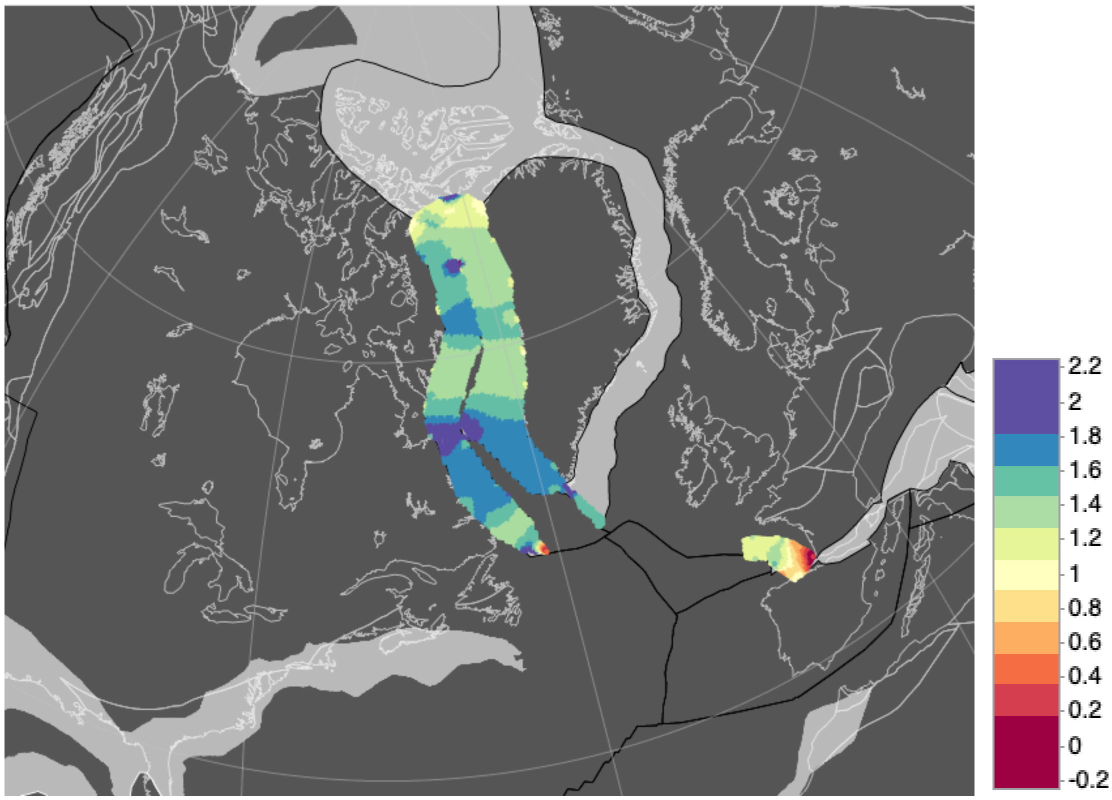

Figure 13: Crustal thickness of North Atlantic deforming region with point density of 8 and modified colour palette (Discrete, Spectral).

Exercise 2 – Generate Velocity Points

It is also possible to show the velocities of deformed geometries.

1. Ensure that the project file and the crustal thickness points from Exercise 1 are loaded into GPlates.

2. Change the reconstruction time to 120 Ma.

3. At the top of the Layers window, select 'Add new layer…' and select the light blue Calculated Velocity Fields layer type, then click OK.

4. Expand the options under the newly created layer and under Inputs → 'Velocity domains', add a new connection to the green (reconstructed geometries) layer that represents your crustal thickness points.

5. Under Velocity & Interpolation options, select Calculate velocities ‘of domain points’.

Your options should look something like Figure 14

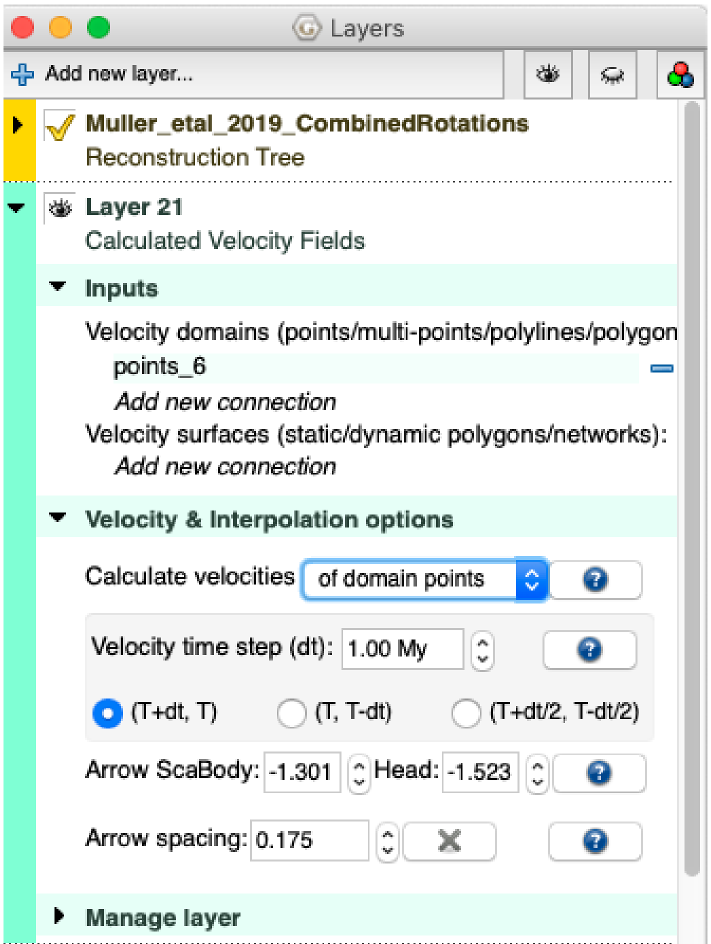

Figure 14: Layer window showing options of the new Calculated Velocity Fields layer.

6. Play the animation from 120–62 Ma and see the arrows that appear, describing the motion of the deforming network (Figure 15).

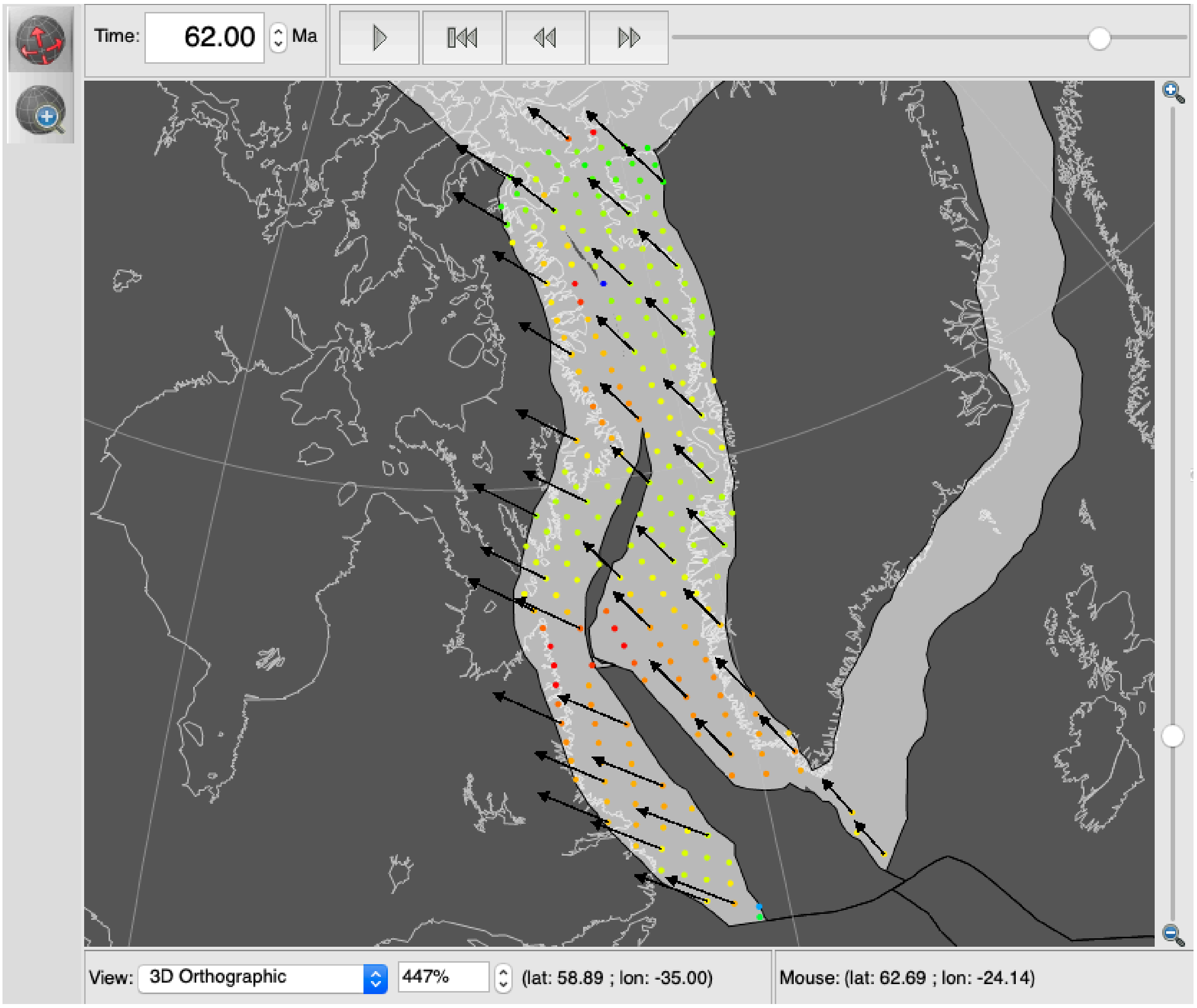

Figure 15: Deforming network and crustal thickness points at 62 Ma showing scalar velocities.

Exercise 3 – Export scalar coverage to files

After following the steps in Exercise 1 to generate scalar coverage points to show crustal thickness through time, we can then export these to files, which can be used at a later time.

1. Make sure that you have the appropriate files loaded into GPlates (dark grey Reconstructed Scalar Coverage layer).

2. Reconstruction → Export → + Add Export

3. Select (Figure 16):
    - A data type to export ('Scalar Coverages')
    - An output file format ('GMT' in this example)
    - Configure Export Options:
        - File Options (Export to a single file)
        - Domain Point Format Options (Longitude/Latitude GMT Default)
        - Include Strain Rate Options (Include dilatation strain rate)
    - Specify Output Filenames (you can change this or leave it as the default)

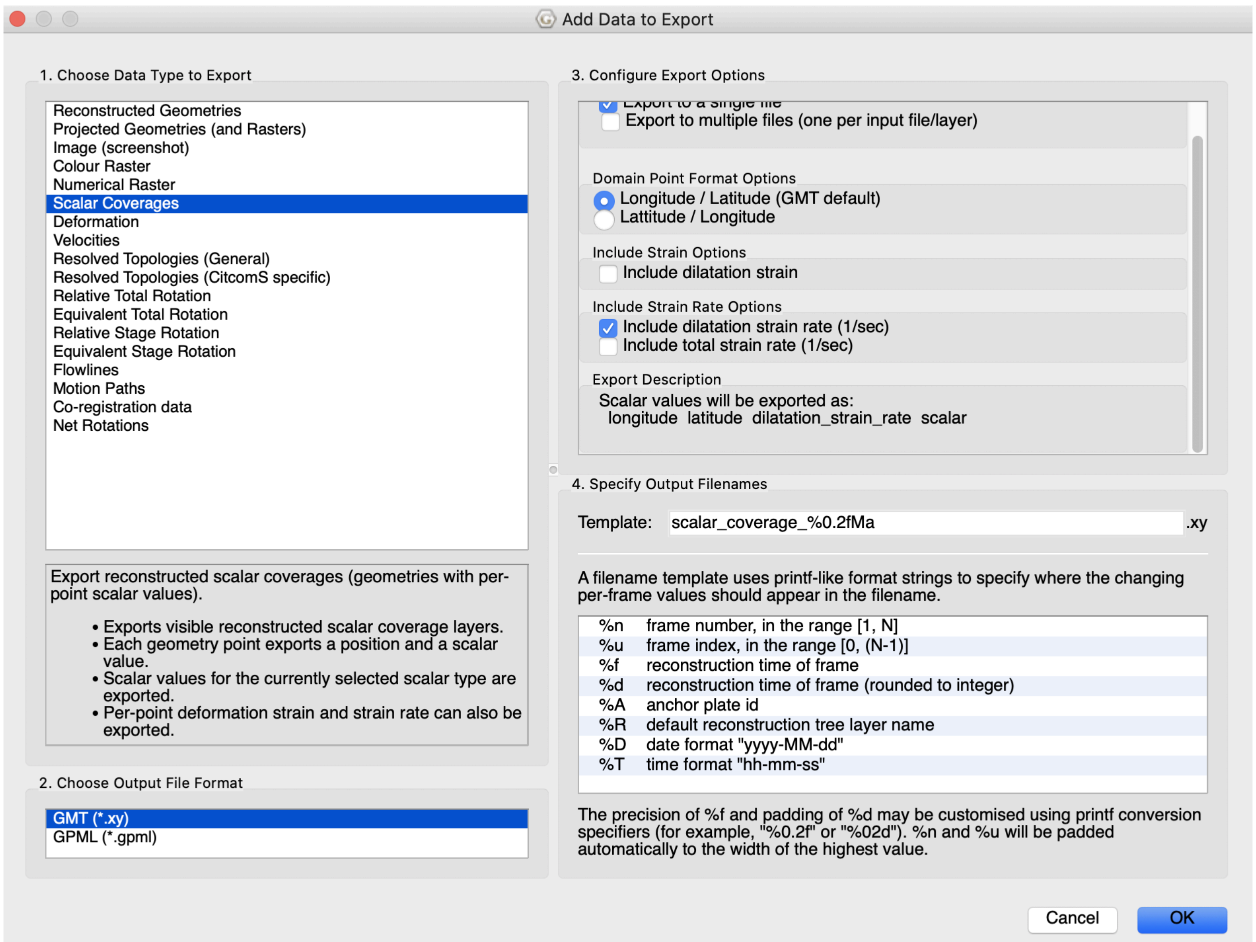

Figure 16: Add Data to Export window for scalar coverage crustal thickness points.

4. Click OK and then ensure that we are animating the entire period that the crustal deformation is occurring (120-62 Ma) by changing the times in the Export window (Figure 17).

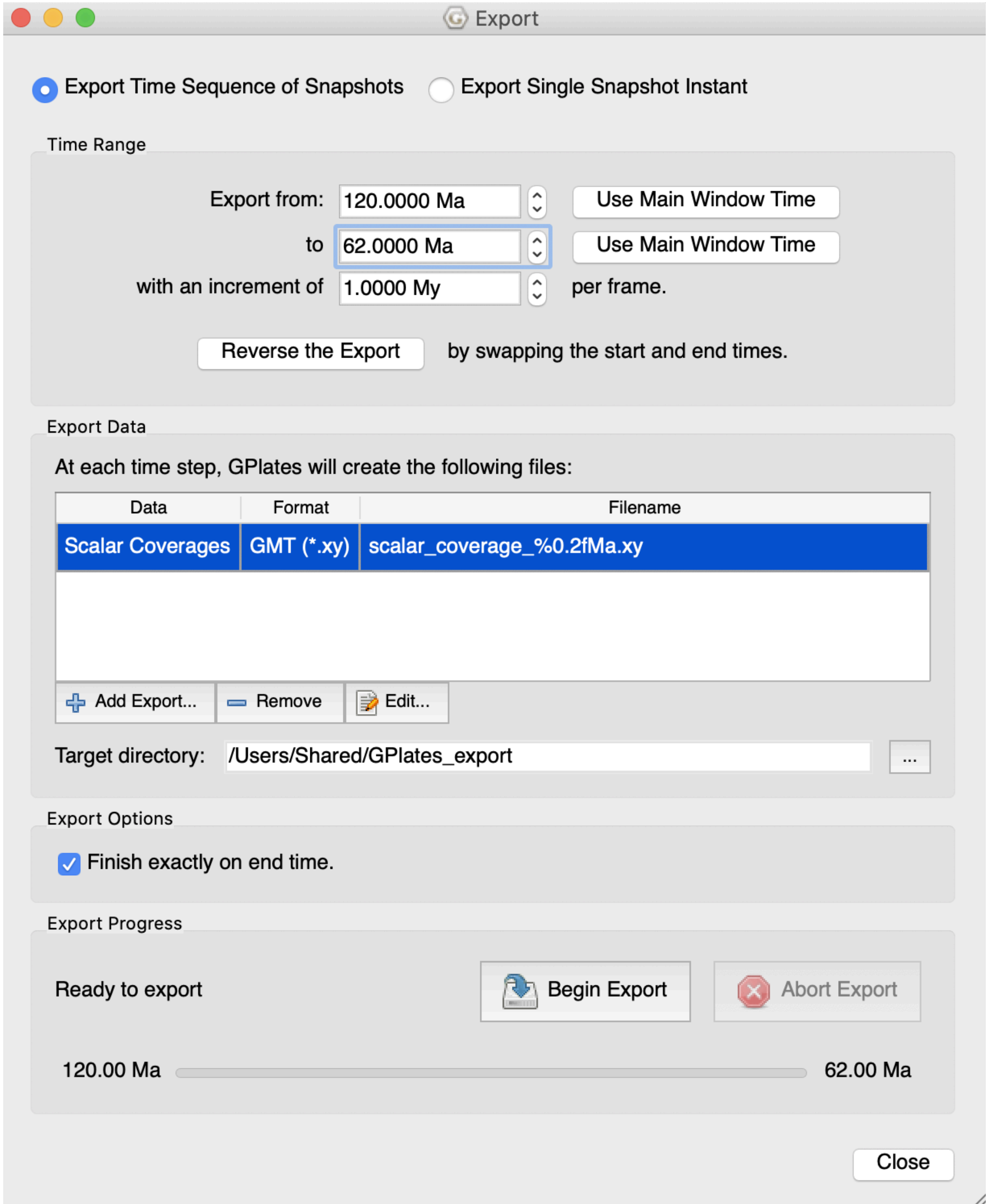

Figure 17: Export window for scalar coverage crustal thickness points.

5. Specify the directory where you would like to export these files to and then click 'Begin Export'.

6. These files should now be in the target directory for later use.

Exercise 4 – Visualising crustal thickness changes in the Arctic

We will now use a method similar to that in Exercise 1 to visualise changes in crustal thickness in the Arctic Region, based on the reconstruction of Müller et al. (2019).

1. If you have the files still loaded in GPlates from previous exercises, close and reopen GPlates, or go File → Clear Session.

2. As in Exercise 1, load the GPlates project file '8.4-Crustal_Thickness.gproj'.

3. Rotate the globe such that the Arctic region is in view, and change the reconstruction time to 68 Ma (Figure 18).

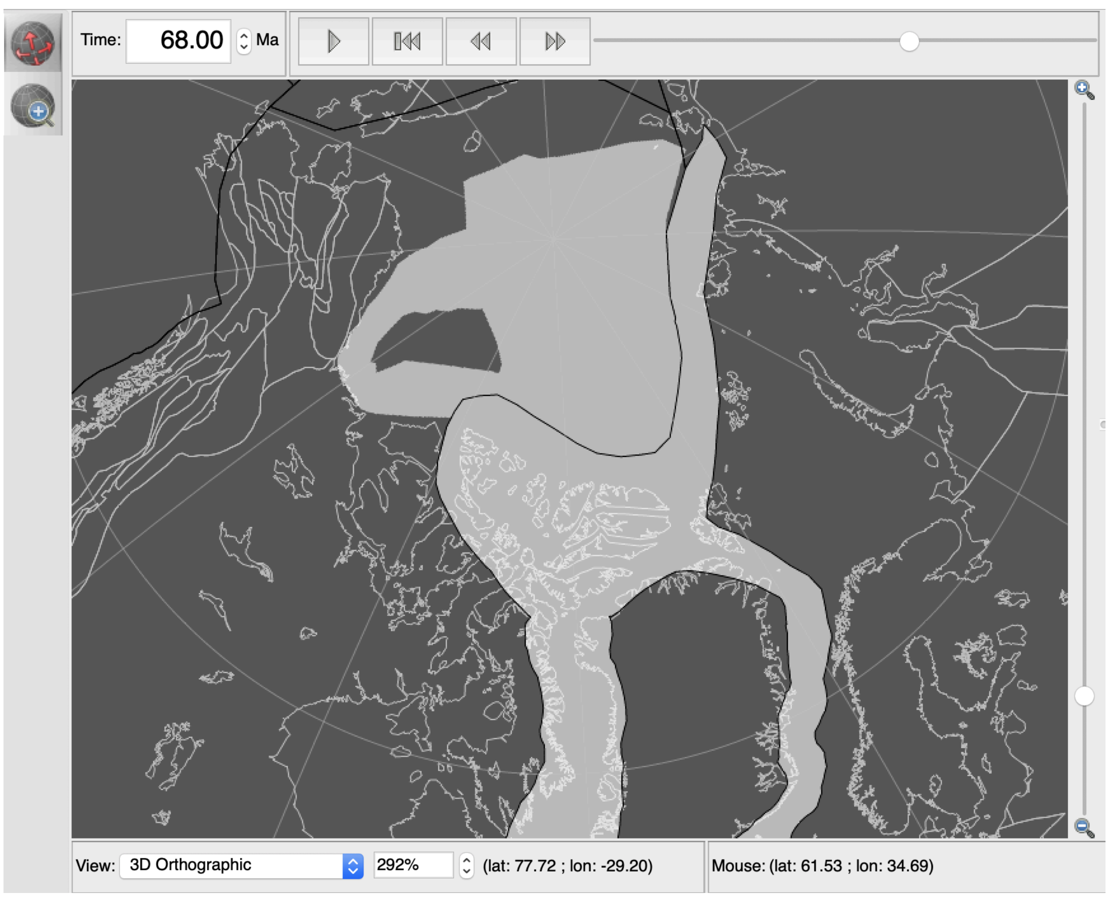

Figure 18: Deforming networks of the Arctic Region at 63 Ma.

4. Expand the options beneath the gold Resolved Topological Networks

layer and select the following options (Figure 19):

- Under Triangulation Draw Mode, select 'Mesh'
- Under Triangulation Colour Mode, select 'Dilatation strain'
- Under Strain Rate Clamping, select 'Enable clamping' (this will constrain the strain rate to remove extreme values and reduce computation time)

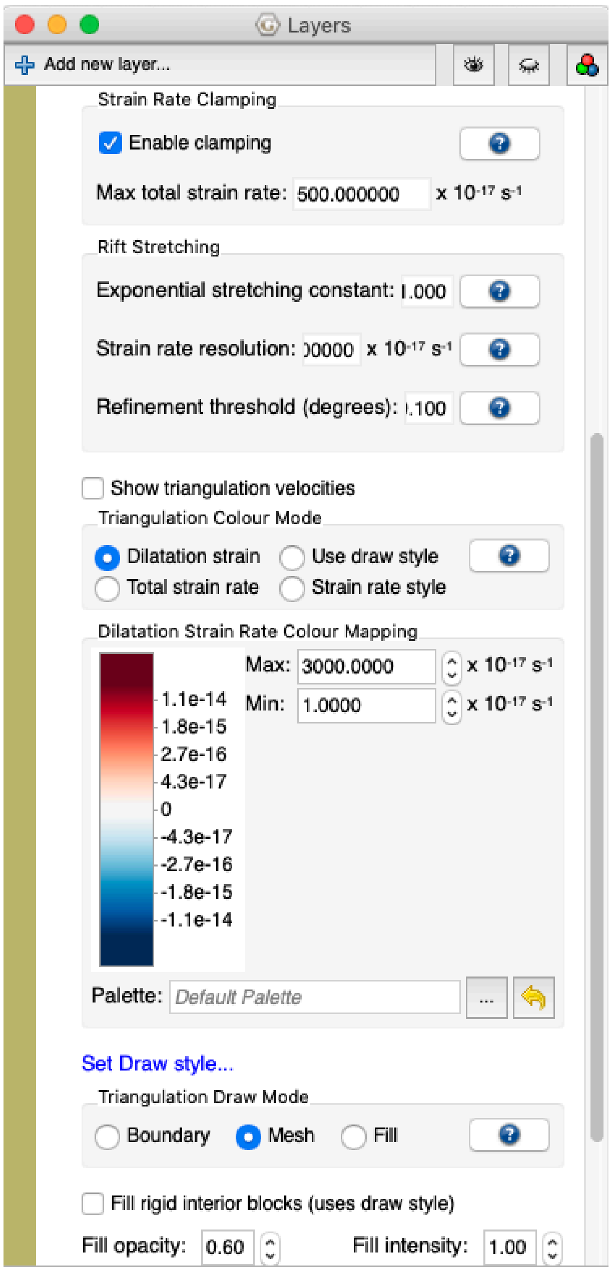

Figure 19: The options outlined in Step 4 have been selected.

The view should now appear as in Figure 20.

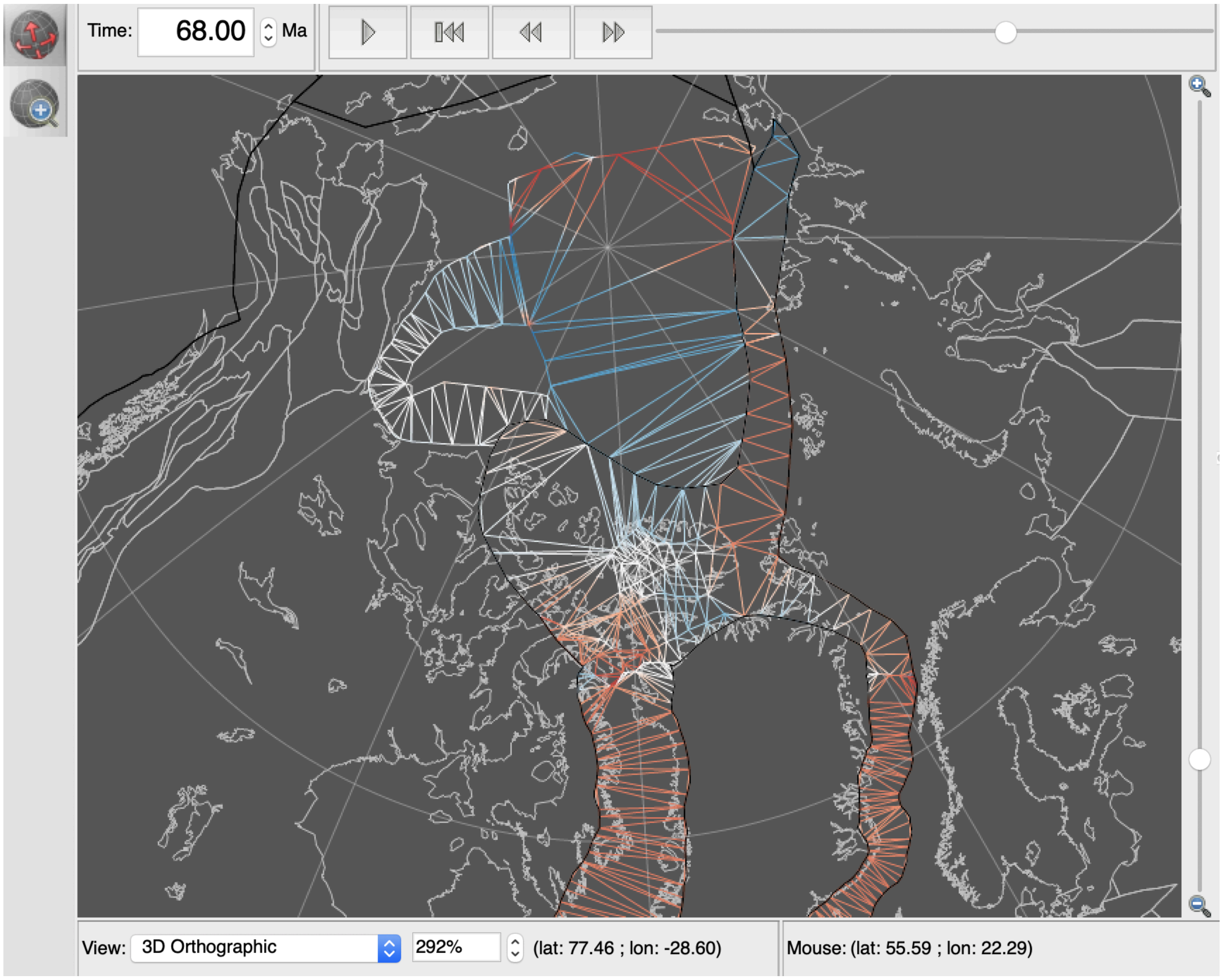

Figure 20: Deforming regions of the Arctic, visualised as meshes and coloured by dilatation strain.

5. Using the select feature tool, select the EllesmereIsland_Deformation_Network feature, to the north of Greenland, by clicking on the triangulated mesh (the boundary of the region should turn white).

6. After ensuring the reconstruction time is 68 Ma, go to Features → Generate Deforming Mesh Points.

As in Exercise 1, a new window will open, where we will specify the parameters for calculating crustal thickness.

7. Under 'Points Region', select 'Focused feature boundary'. Under Points Distribution, set 'Density level' to 8. Select 'Next'.

8. In the next window, specify the following parameters (Figure 21):
   - Initial crustal thickness = 40 km (default)
   - Plate ID = 0 (default)
   - Begin time = 68 Ma
   - End time = Distant Future
   - Name = whatever name you would like, e.g. "EllesmereIsland_Crustal_Thickness"

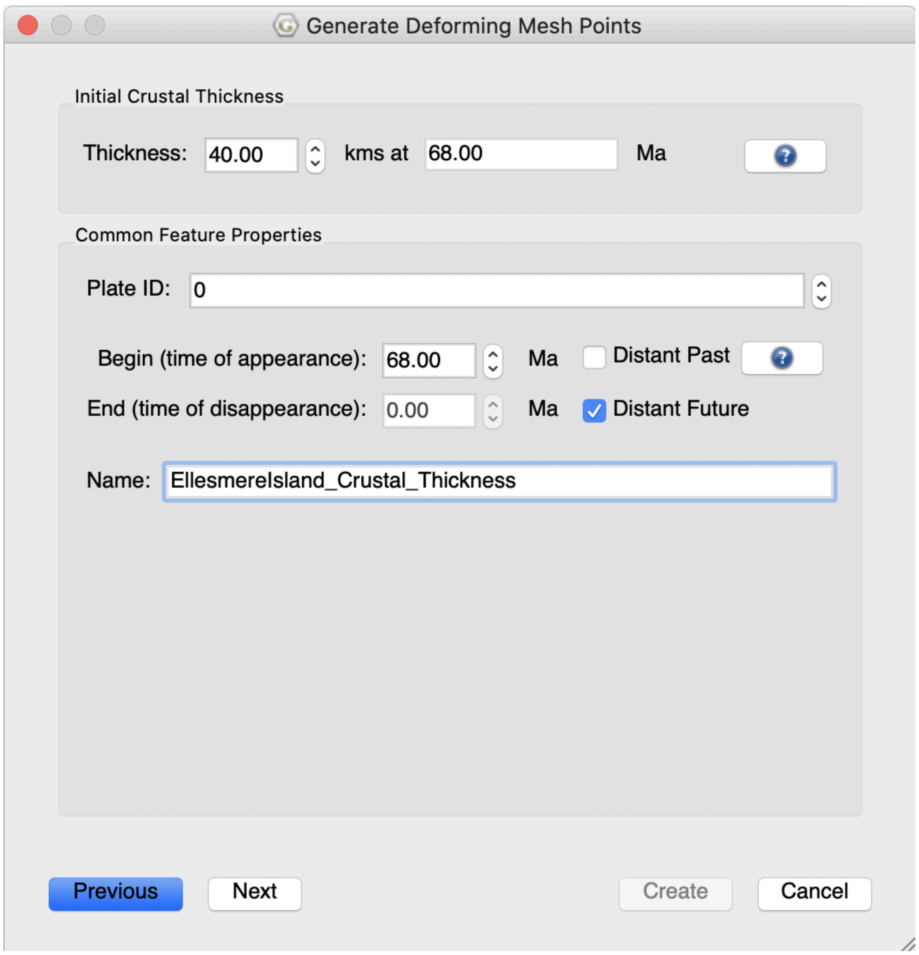

Figure 21: Specifying crustal thickness parameters (Step 8).

9. Click 'Next', select '< Create a new feature collection >', and click 'Create'.

10. In the next window, specify the following parameters, and leave the others as default:
    - Youngest Age = 0 Ma

- Oldest Age = 68 Ma
- Tick 'Deactivate points that fall outside a network'

11. Click 'OK'. The points may take a while to generate.

You should now have lots of green points within the deforming network region (Figure 22). As in Exercise 1, you should also note that there are two new layers that have been created - a green Reconstructed Geometries Layer and a dark grey Reconstructed Scalar Coverages Layer (Figure 22).

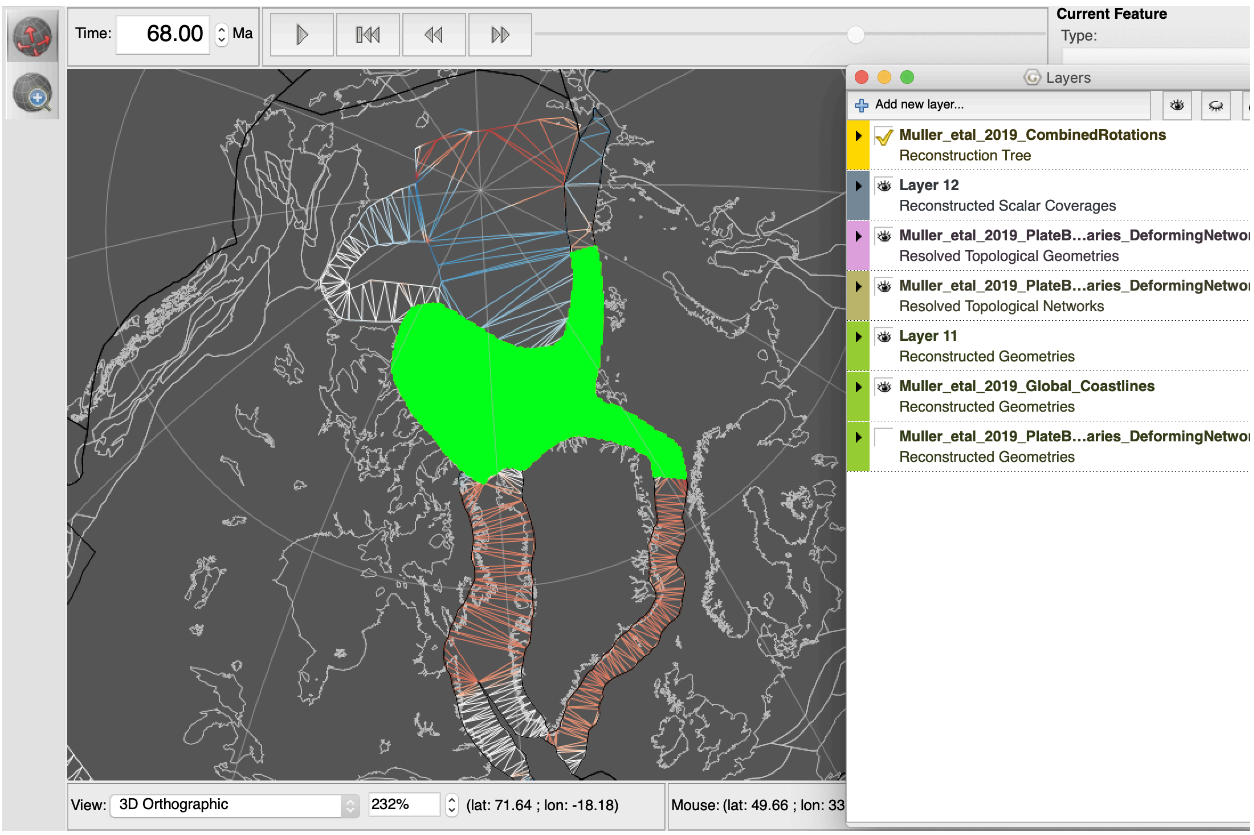

Figure 22: The newly-generated crustal thickness points.

12. In the Layers window, expand the options beneath the new green Reconstructed Geometries Layer. Under 'Inputs', add a new Topology surfaces connection to the brown Resolved Topological Networks layer (Figure 23).

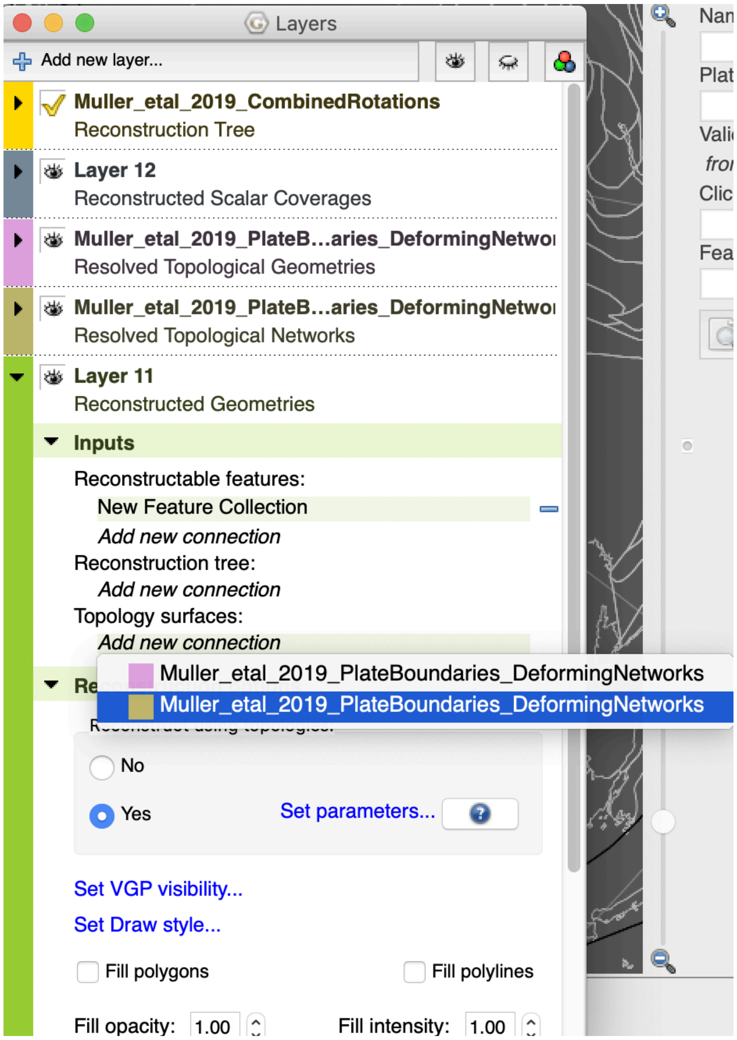

Figure 23: Adding the connection to the Resolved Topological Networks layer.

13. Expand the options under the dark grey Reconstructed Scalar Coverages layer. Set the Scalar Type to gpml:CrustalStretchingFactor and change the Palette Range to between 1.8 and 0.2, since we are looking at relative changes in crustal thickness and the original value is set as 1 (Figure 24).

N.B. the palette range can be changed to any range you'd like however it is recommended that 1 is in the middle since it represents the original crustal thickness at 68 Ma and the colours diverge appropriately.

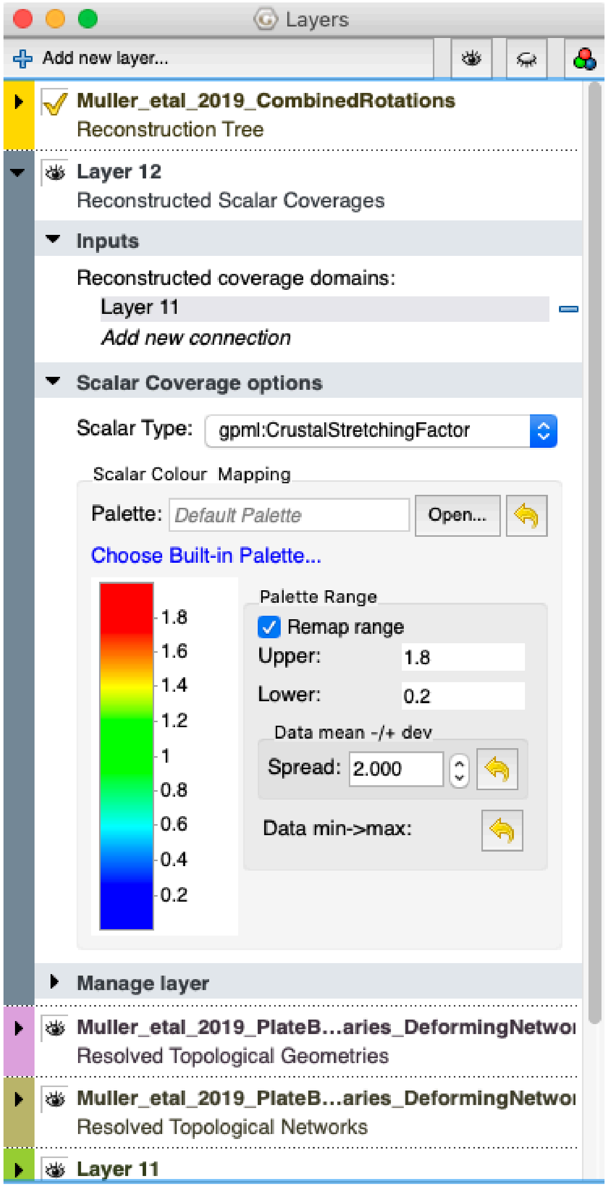

Figure 24: Changing the colour palette (Step 13).

With the default colour palette, points where the crust is thicker than it was at 68 Ma will be blue, while points where the crust is thinner will be yellow–red.

14. Play the animation from 63-33 Ma and see how the colours of the points change to reflect changes in crustal thickness (Figure 25).

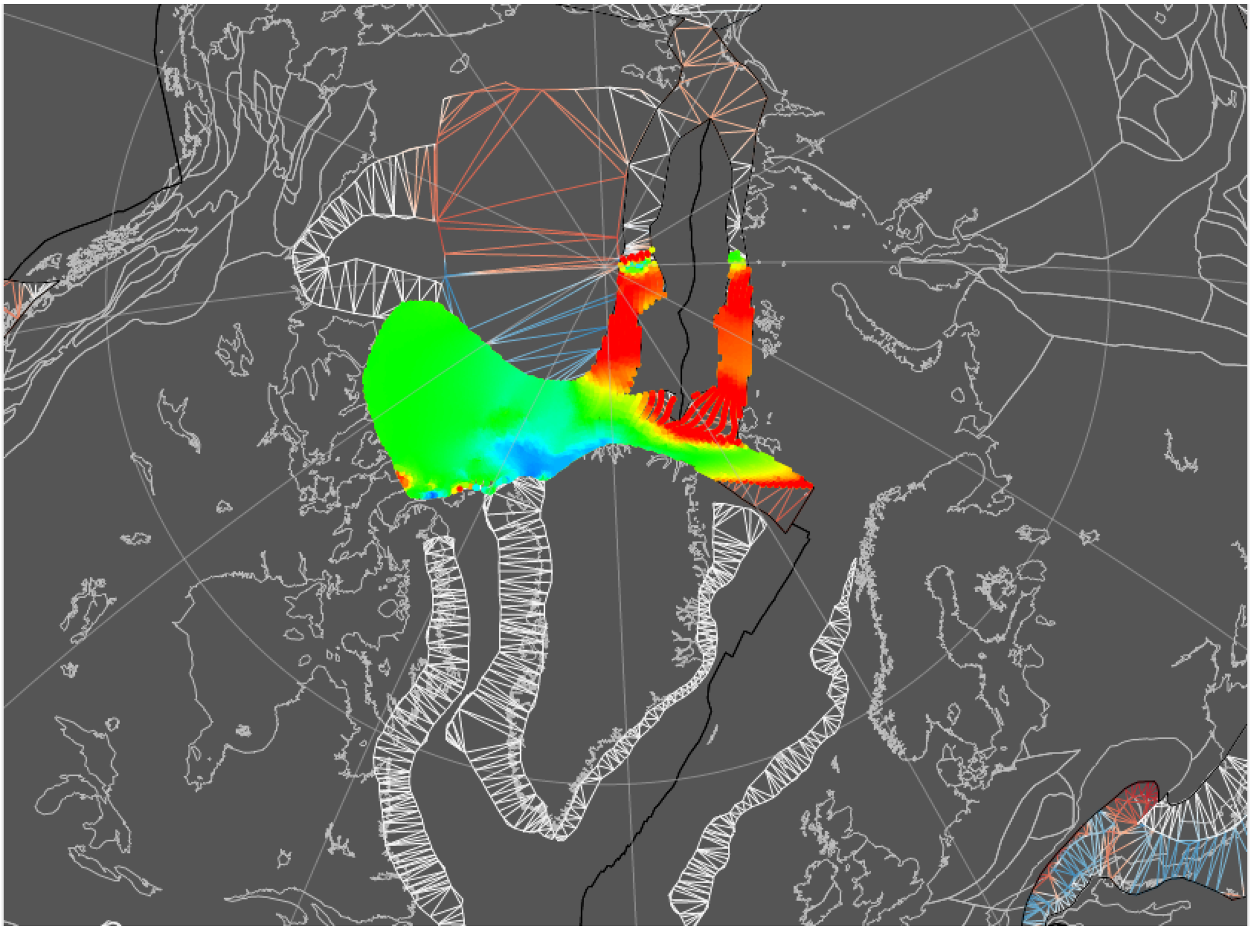

Figure 25: Crustal Stretching Factor in the Arctic region at 20 Ma.

15. Don’t forget to save the new layers you generated!

References

Müller, R. D., Zahirovic, S., Williams, S. E., Cannon, J., Seton, M., Bower, D. J., Tetley, M. G., Heine, C., Le Breton, E., Liu, S., Russell, S. H. J., Yang, T., Leonard, J., and Gurnis, M., 2019, A Global Plate Model Including Lithospheric Deformation Along Major Rifts and Orogens Since the Triassic: Tectonics, v. 38, no. 6, p. 1884-1907. doi: [10.1029/2018tc005462](https://doi.org/10.1029/2018tc005462)