

# Deforming Plate Models and Crustal Thickness

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Authors: Samantha Ross<sup>1</sup>, Simon Williams<sup>1</sup>, Mike Gurnis<sup>2</sup>, Ting Yang<sup>2</sup>

<sup>1</sup>EarthByte Research Group, School of Geosciences, The University of Sydney, Australia

<sup>2</sup>Division of Geological and Planetary Sciences, California Institute of Technology

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

EarthByte Research Group, School of Geosciences, The University of Sydney, Australia

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## **Aim**

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This tutorial is designed to introduce the user to deforming plate models and visualising crustal thickness.

## **Included files**

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Click [here](#) to download the data bundle for this tutorial.

The tutorial dataset includes the following files:

- Coastlines: Muller\_etal\_2019\_Global\_Coastlines.gpmlz
- Static plate polygons:  
Muller\_etal\_2019\_Global\_StaticPlatePolygons.gpmlz
- Plate boundaries:  
Muller\_etal\_2019\_PlateBoundaries\_DeformingNetworks.gpml
- Rotation model: Muller\_etal\_2019\_CombinedRotations.rot
- GPlates project: 9.4-Deforming\_Models.gproj
  - This file loads all of the above files
- Global sediment thickness raster:
  - crust1\_SedimentThickness\_15m.gpml and
  - crust1\_SedimentThickness\_15m.nc

**NOTE:** This tutorial requires functionalities that are only available in GPlates 2.0 or newer versions.

## Exercise 1 - Cretaceous Rift Basins in Africa

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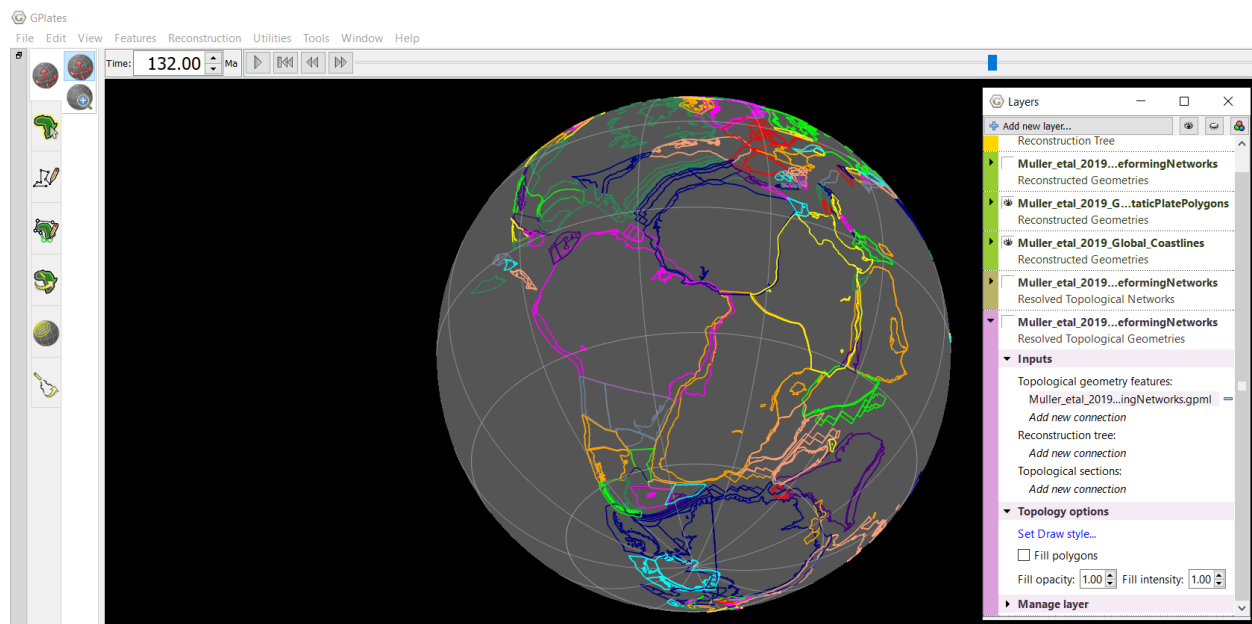
### Part 1: Understanding the deformation inherent within existing reconstruction models

Firstly, we will load the files from the Muller et al. (2019) plate motion model, and look at how deformation is represented within a rigid, topological plate model. Within this global model, the poles of rotation that describe South Atlantic rifting are taken from the studies of Nürnberg and Müller (1991) and Torsvik et al (2009).

1. From the tutorial data, load the included GPlates project file (9.4-Deforming\_Models.gproj).
2. Set the reconstruction time to 132 Ma, and focus on the region of Africa and South America (Figure 1).

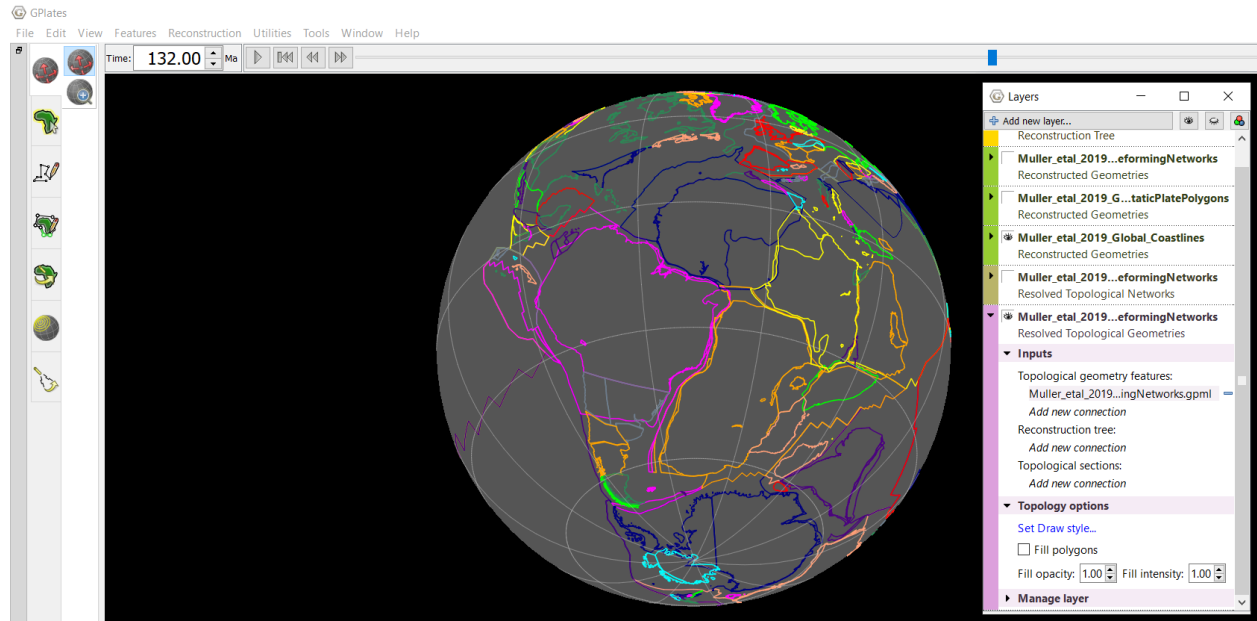
3. You may wish to colour your coastlines in a single colour to avoid confusion - we choose silver in this exercise (Features → Manage Colouring).

Note the overlap between the static polygons that represent NW Africa, NE Africa, Southern Africa, South America, and the two subplates in Southern South America (labelled Colorado and Parana subplates) (Figure 1). The overlap represents the fact that these plates will move away from each other at some point between this reconstruction time and present day (you can compare what you are looking at with Figure 10 of Torsvik et al., 2009).



**Figure 1:** Overlap between static polygons in Africa and South America at 132 Ma.

4. Play the reconstruction forward to see how this extension develops. This extension is finished earlier in South America than Central Africa, where the relative motion continues until 83.5 Ma in this reconstruction.
5. Turn off the green static polygon Reconstructed Geometries layer and turn on the purple Resolved Topological Geometries layer (Figure 2).



**Figure 2:** Extensional boundaries within Africa and South America at 132 Ma (Step 5)

Within the Muller et al (2019) topologies, the extensional boundaries within Africa and South America are represented as lines. Our aim will be to modify these boundaries to be more analogous to more diffuse zones of continental rifting. Note that in this tutorial we will only deal with the intracontinental rifts.

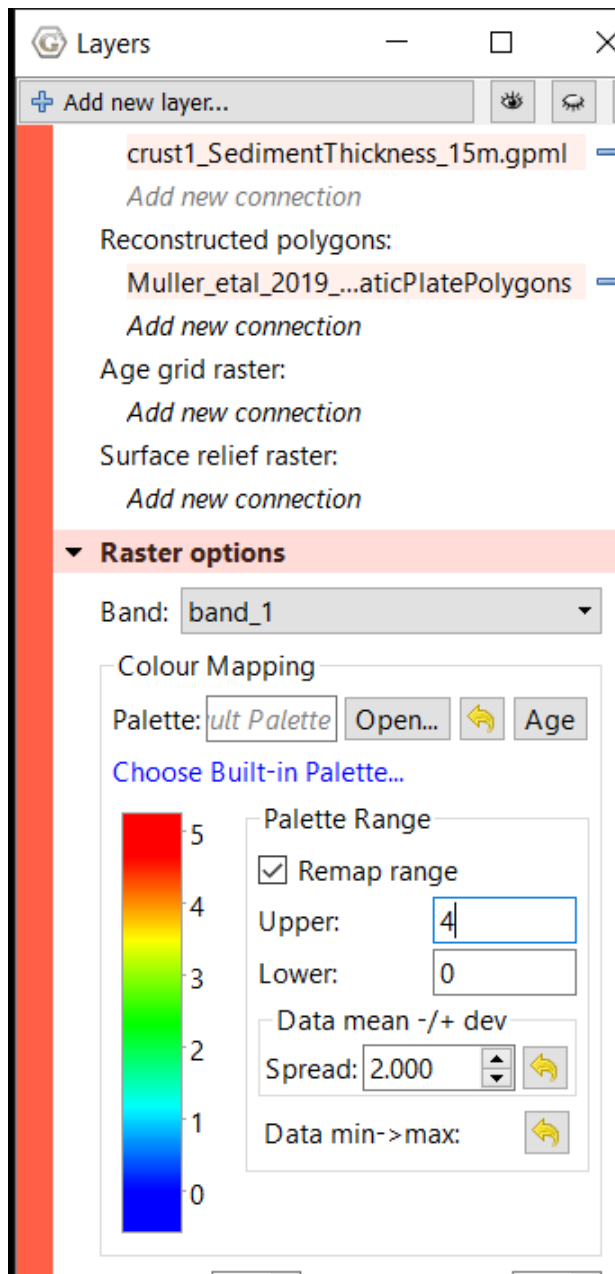
## Part 2: Deciding where the deformation should be distributed

Before we modify the topologies to include deforming regions, we first need some basis for where the deformation is distributed. For the purposes of this tutorial we will focus on one such example, sediment thickness. We will use the global, 1 degree resolution sediment thickness included in the CRUST1.0 model of global crustal structure.

A global grid file (and associated .gpml file) has been included in the tutorial data (resampled to 15 minute resolution).

1. Load this .gpml file into GPlates  
("crust1\_SedimentThickness\_15m.gpml")
  
2. Connect the raster layer to the Static Polygons – open the layers

window if it is not already visible (Window → Show Layers), then expand the options beneath the raster layer. Under Inputs → Reconstructed Polygons, click Add new connection and select the green Muller\_etal\_2019\_Global\_StaticPlatePolygons layer (Figure 3) - see Tutorial 3.2 for a full description of this process.



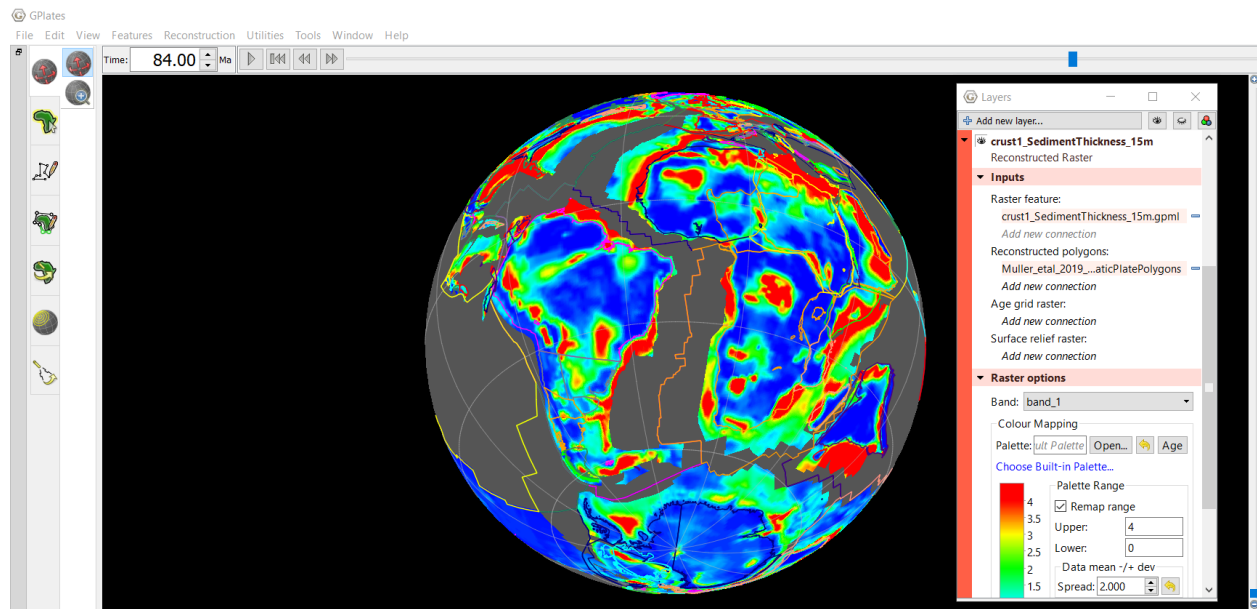
**Figure 3:** Adding the connection to the static polygons layer for the sediment thickness raster (Step 2).

As you reconstruct back through time, you should now notice that the raster

layer moves with the static polygons.

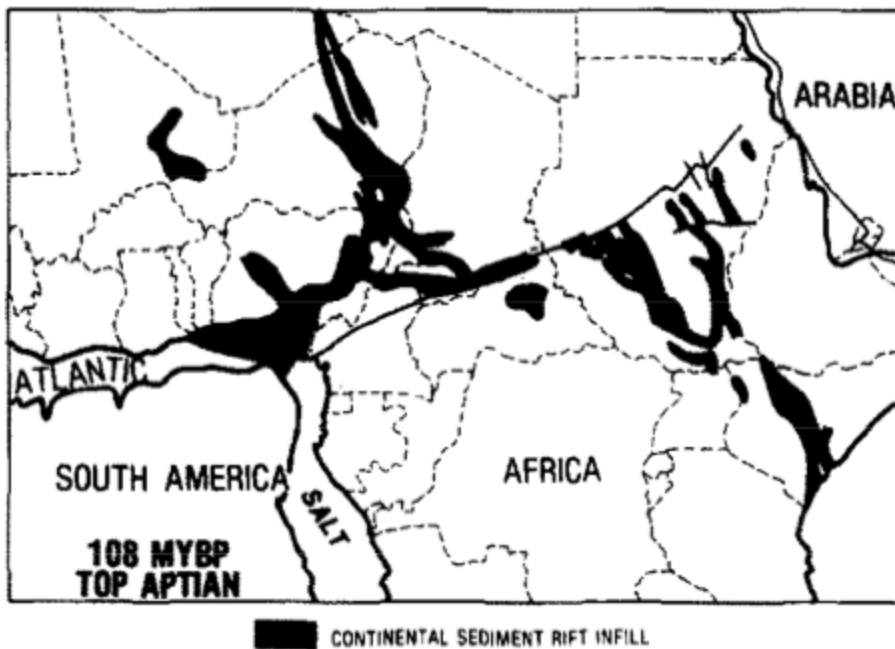
3. Restrict the colour palette range to 0-4 (Figure 3).

4. Change the reconstruction time to 84 Ma, and concentrate on central Africa (Figure 4).

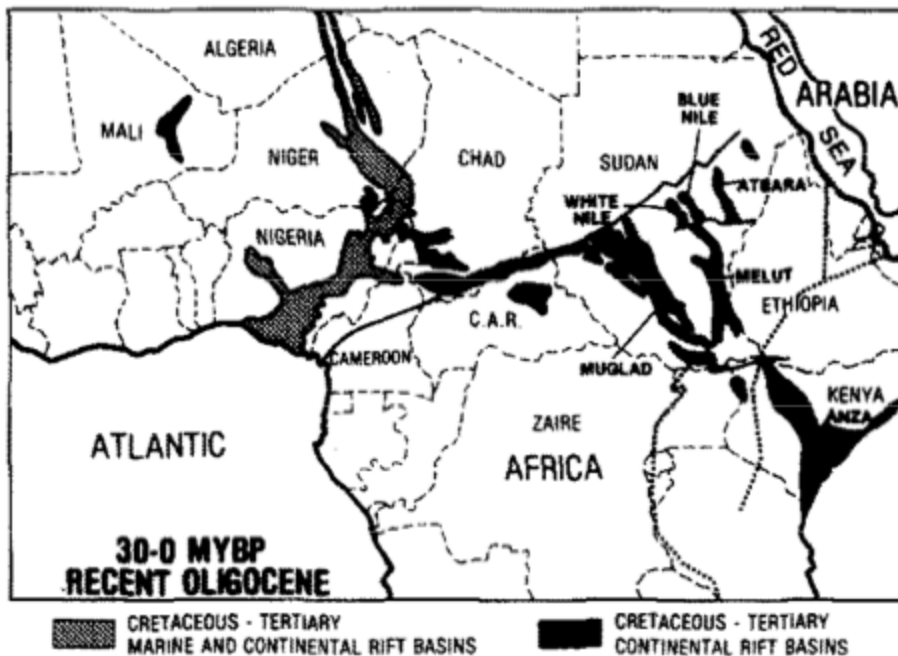


**Figure 4:** Sediment thickness reconstructed to 84 Ma (the raster layer is connected to the Static Polygons layer).

The rationale for using a map of sediment thickness to guide our definition of deforming regions is fairly simple - if the deforming regions are extensional basins, then we might expect the zones of high extension and crustal thinning to correlate with thick sediment accumulations. The sediment thickness map alone provides no indication of the timing that these sediments accumulated, or whether the accumulations correspond to rift basins or some other mechanism. For the thick sediments along the boundaries separating NW, NE and Southern Africa, we can check against the locations of rift basins defined in different literature (Figures 5 & 6).



**Figure 5:** Development of major rift basins at 108 Ma (Genik et al, 1992).



**Figure 6:** Rift configuration at 30 Ma (Genik et al, 1992).

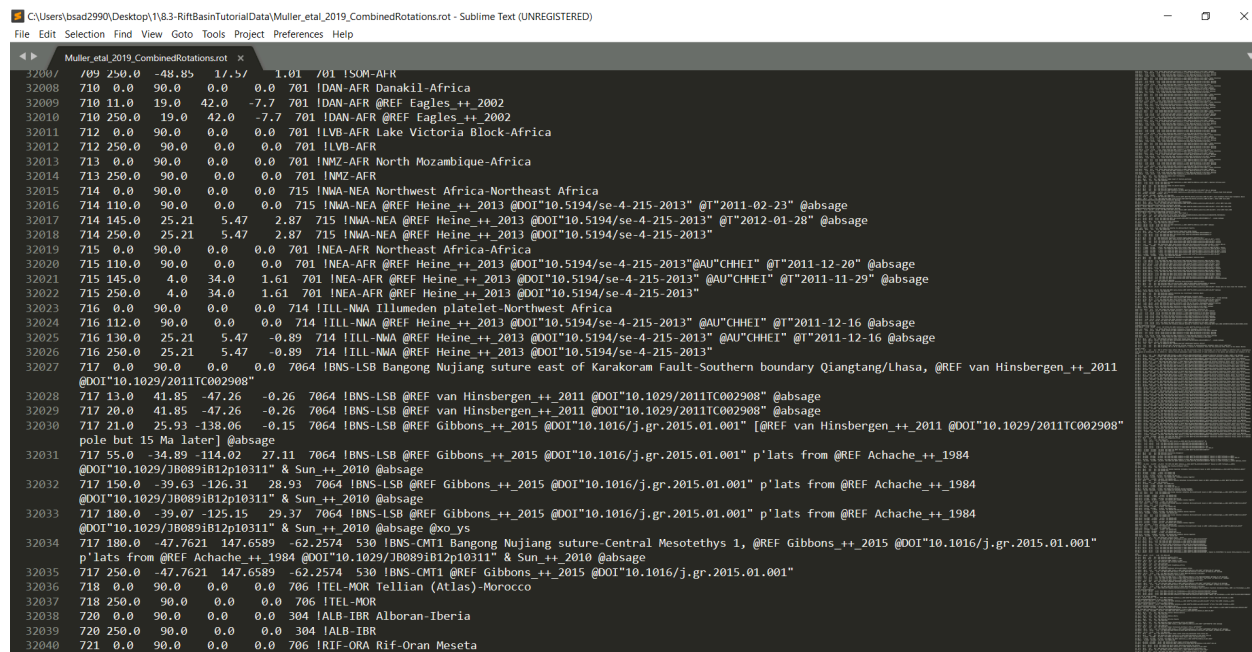
If we compare the distribution of Cretaceous basins in this interpretation (Figure 5) to the sediment thickness grid and the plate boundaries in the topological model (Figure 4), we can see that there is a pretty good correlation between all three for the basins of the Central African Rift

System. The sediment thickness grid also includes additional significant accumulations in other areas (e.g., the Congo Basin within southern Africa, or the Taoudeni Basin within NW Africa), which are not thought to be related to South Atlantic rifting, and are therefore not represented in the topological plate boundaries.

It is also worth considering the timing of the motion between the different blocks. The three plate polygons in question have plates IDs of 714 (NW Africa), 715 (NE Africa) and 701 (Southern Africa).

5. Open the rotation file (Muller\_etal\_2019\_CombinedRotations.rot) in a text editor, and then navigate to the section that contains the rotations for these plates (Figure 7).

701 moves relative to the absolute reference frame, and the relative motion between the different African blocks is described by the relative motions of 714 and 715 (as the moving plates, column 1) relative to 701 (as the fixed plate, column 6).



```

32007 /09 250.0 -48.85 1.5/ 1.01 701 ISOM-AFR
32008 710 0.0 90.0 0.0 0.0 701 IDAN-AFR Danakil-Africa
32009 710 11.0 19.0 42.0 -7.7 701 IDAN-AFR @REF Eagles_++ 2002
32010 710 250.0 19.0 42.0 -7.7 701 IDAN-AFR @REF Eagles_++ 2002
32011 712 0.0 90.0 0.0 0.0 701 ILVB-AFR Lake Victoria Block-Africa
32012 712 250.0 90.0 0.0 0.0 701 ILVB-AFR
32013 713 0.0 90.0 0.0 0.0 701 INMZ-AFR North Mozambique-Africa
32014 713 250.0 90.0 0.0 0.0 701 INMZ-AFR
32015 714 0.0 90.0 0.0 0.0 715 INWA-NEA Northwest Africa-Northeast Africa
32016 714 110.0 90.0 0.0 0.0 715 INWA-NEA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @T"2011-02-23" @absage
32017 714 145.0 25.21 5.47 2.87 715 INWA-NEA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @T"2012-01-28" @absage
32018 714 250.0 25.21 5.47 2.87 715 INWA-NEA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013"
32019 715 0.0 90.0 0.0 0.0 701 INEA-AFR Northeast Africa-Africa
32020 715 110.0 90.0 0.0 0.0 701 INEA-AFR @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @AU"CHHEI" @T"2011-12-20" @absage
32021 715 145.0 4.0 34.0 1.61 701 INEA-AFR @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @AU"CHHEI" @T"2011-11-29" @absage
32022 715 250.0 4.0 34.0 1.61 701 INEA-AFR @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013"
32023 716 0.0 90.0 0.0 0.0 714 IILL-NWA Iliumedden platelet-Northwest Africa
32024 716 112.0 90.0 0.0 0.0 714 IILL-NWA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @AU"CHHEI" @T"2011-12-16" @absage
32025 716 130.0 25.21 5.47 -0.89 714 IILL-NWA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013" @AU"CHHEI" @T"2011-12-16" @absage
32026 716 250.0 25.21 5.47 -0.89 714 IILL-NWA @REF Heine_++ 2013 @DOI"10.5194/se-4-215-2013"
32027 717 0.0 90.0 0.0 0.0 7064 IBNS-LSB Bangong Nujiang suture east of Karakoram Fault-Southern boundary Qiangtang/Lhasa, @REF van Hinsbergen_++ 2011 @DOI"10.1029/2011TC002908"
32028 717 13.0 41.85 -47.26 -0.26 7064 IBNS-LSB @REF van Hinsbergen_++ 2011 @DOI"10.1029/2011TC002908" @absage
32029 717 20.0 41.85 -47.26 -0.26 7064 IBNS-LSB @REF van Hinsbergen_++ 2011 @DOI"10.1029/2011TC002908" @absage
32030 717 21.0 25.93 -138.06 -0.15 7064 IBNS-LSB @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001" @REF van Hinsbergen_++ 2011 @DOI"10.1029/2011TC002908" pole but 15 Ma later] @absage
32031 717 55.0 -34.89 -114.02 27.11 7064 IBNS-LSB @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001" p'lats from @REF Achache_++ 1984 @DOI"10.1029/JB089iB12p10311" & Sun_++ 2010 @absage
32032 717 150.0 -39.63 -126.31 28.93 7064 IBNS-LSB @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001" p'lats from @REF Achache_++ 1984 @DOI"10.1029/JB089iB12p10311" & Sun_++ 2010 @absage
32033 717 180.0 -39.07 -125.15 29.37 7064 IBNS-LSB @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001" p'lats from @REF Achache_++ 1984 @DOI"10.1029/JB089iB12p10311" & Sun_++ 2010 @absage @x0.y5
32034 717 180.0 -47.7621 147.6589 -62.2574 530 IBNS-CMT1 Bangong Nujiang suture-Central Mesothethys 1, @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001" p'lats from @REF Achache_++ 1984 @DOI"10.1029/JB089iB12p10311" & Sun_++ 2010 @absage
32035 717 250.0 -47.7621 147.6589 -62.2574 530 IBNS-CMT1 @REF Gibbons_++ 2015 @DOI"10.1016/j.gr.2015.01.001"
32036 718 0.0 90.0 0.0 0.0 706 ITEL-MOR Tellian (Atlas)-Morocco
32037 718 250.0 90.0 0.0 0.0 706 ITEL-MOR
32038 720 0.0 90.0 0.0 0.0 304 IALB-IBR Alboran-Iberia
32039 720 250.0 90.0 0.0 0.0 304 IALB-IBR
32040 721 0.0 90.0 0.0 0.0 706 IRIF-ORA Rif-Oran Meseta

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**Figure 7:** Rotation data for different African blocks (Step 4).

We can determine that NW Africa (714) moves relative to Southern Africa (701) from 131.7 Ma to 120.4 Ma in this model, while NE Africa (715) moves relative to Southern Africa from 120.4 Ma to 83.5 Ma (Figure 7). Note that, by implication, there is also relative motion between NW Africa and NE Africa during the 131.7 to 83.5 Ma time period.



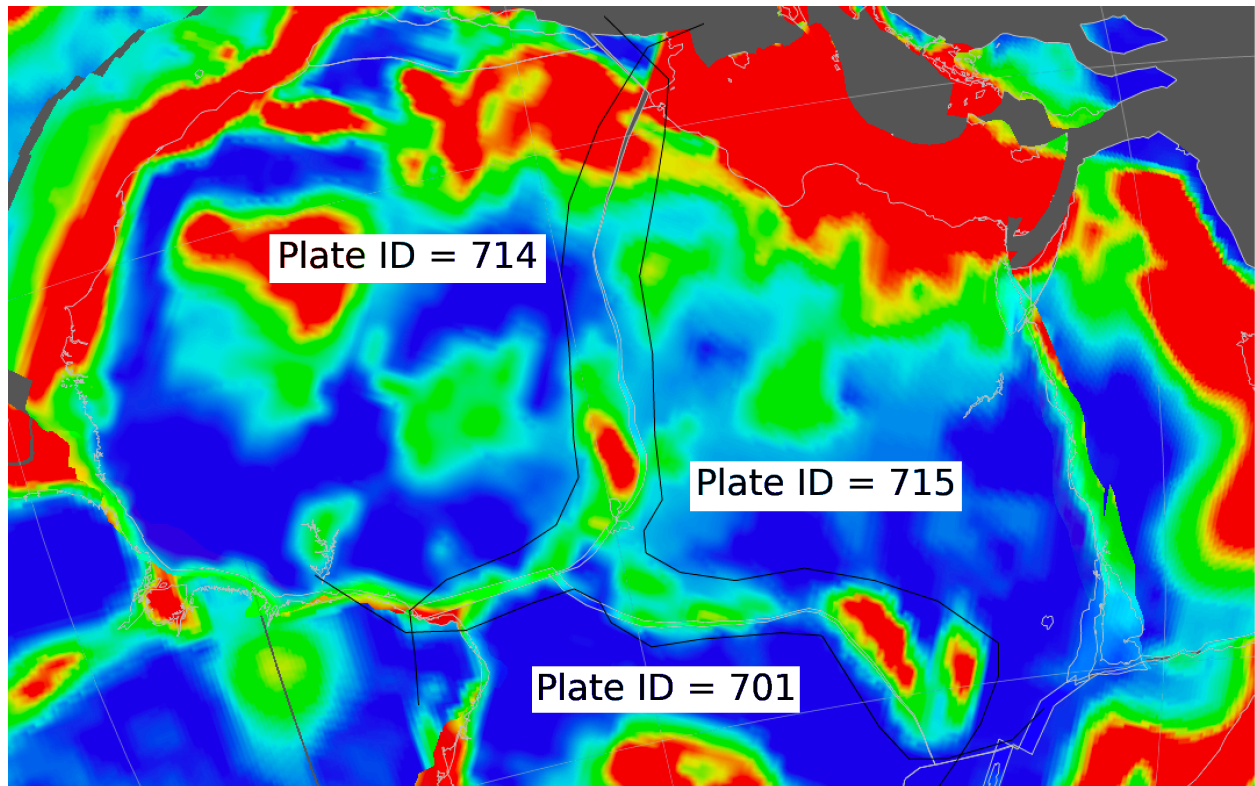
### Part 3: Build the Topological Boundaries and Network Topology

The first step to building a deforming network over the deformation regions is to define line geometries that will define the boundaries of the deformation zone.

1. Reconstruct to 132 Ma, then select the 'Digitisation' menu from the toolbar on the left of the GPlates window, then select the 'Digitise New Polyline Geometry'.
2. Digitize three new lines, which encompass the regions of the Central African Rift System basins as indicated by the sediment thickness map (Figure 8).

When constructing these lines, keep in mind the following:

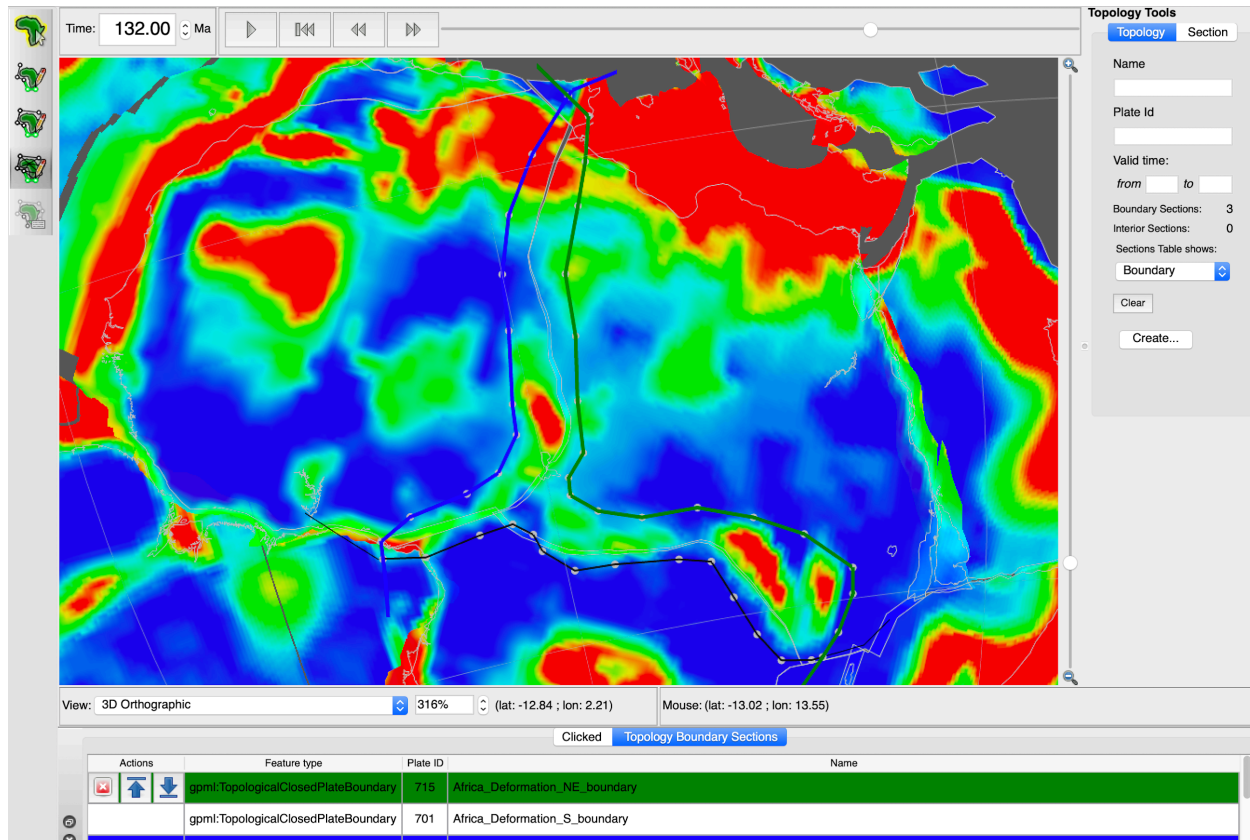
- Each line should be digitized so that it intersects with other (existing) lines such that we will be able to resolve the combination of lines into a single topological network polygon that encompasses the deforming region (and that can be added into the global set of topological polygons).
- Assign each line the Feature Type 'TopologicalClosedPlateBoundary'
- Each line should be assigned an appropriate Plate ID - for example, the boundary that marks the southern edge of the rift zone adjacent to Southern Africa should be assigned the Plate ID 701. The other appropriate Plate IDs are shown in Figure 8.
- For each line created, you will also have to modify the Begin and End times - based on Genik et al. (1992) set this to 132 Ma and 0 Ma.



**Figure 8:** Example of the three new boundaries (black lines) which encompass the regions of the Central African Rift System Basins. The appropriate Plate IDs that they should be assigned are also shown. Coastlines are shown in silver.

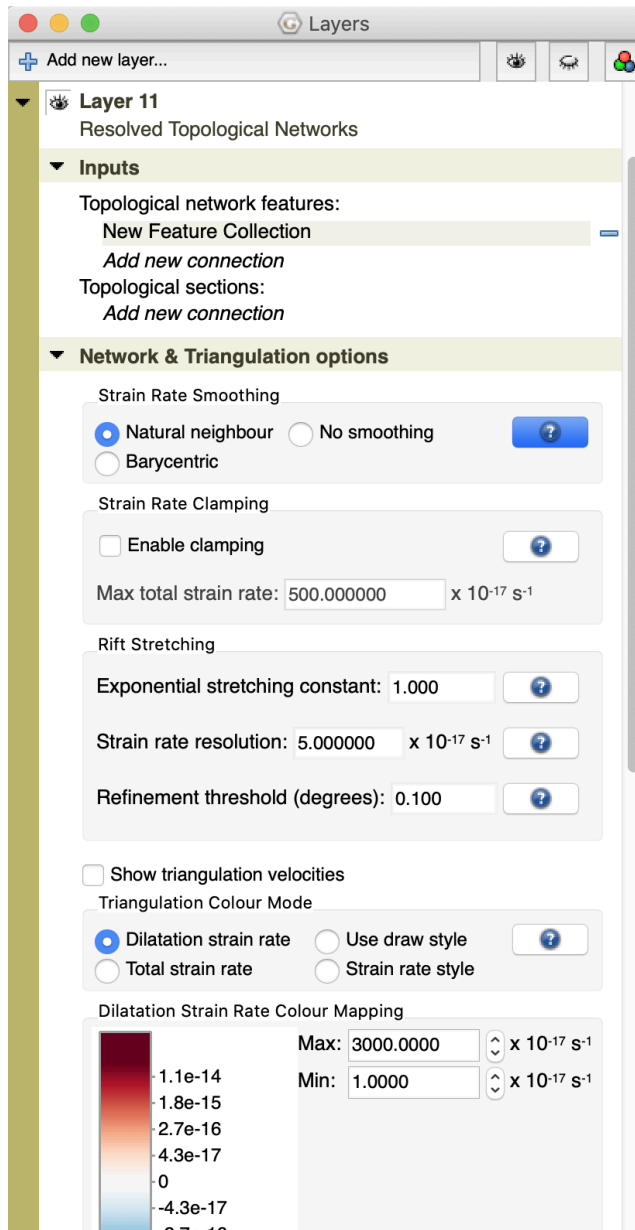
Note: Using this one dataset alone is somewhat approximate. In this case, we have no choice but to define boundaries that to some extent correspond to the rigid geometries in Torsvik et al (2009) model, even if the location of the implied deformation may not be immediately apparent from the sediment thickness. An example is the northern part of the boundary between NW and NE Africa. In practical cases, it is recommended to use as many alternative lines of available geological and geophysical data to refine these boundaries.

3. To build a network topology, select the Topology toolbar then select the 'Build New Network Topology' tool. Then, as with building any topological polygon or network, select each geometry you want to be contained in the boundary of the deforming region, in order (i.e., in a logical clockwise or anticlockwise progression), and then click on 'Add To Boundary' (Figure 9).



**Figure 9:** Building the network topology with line segments (Step 3).

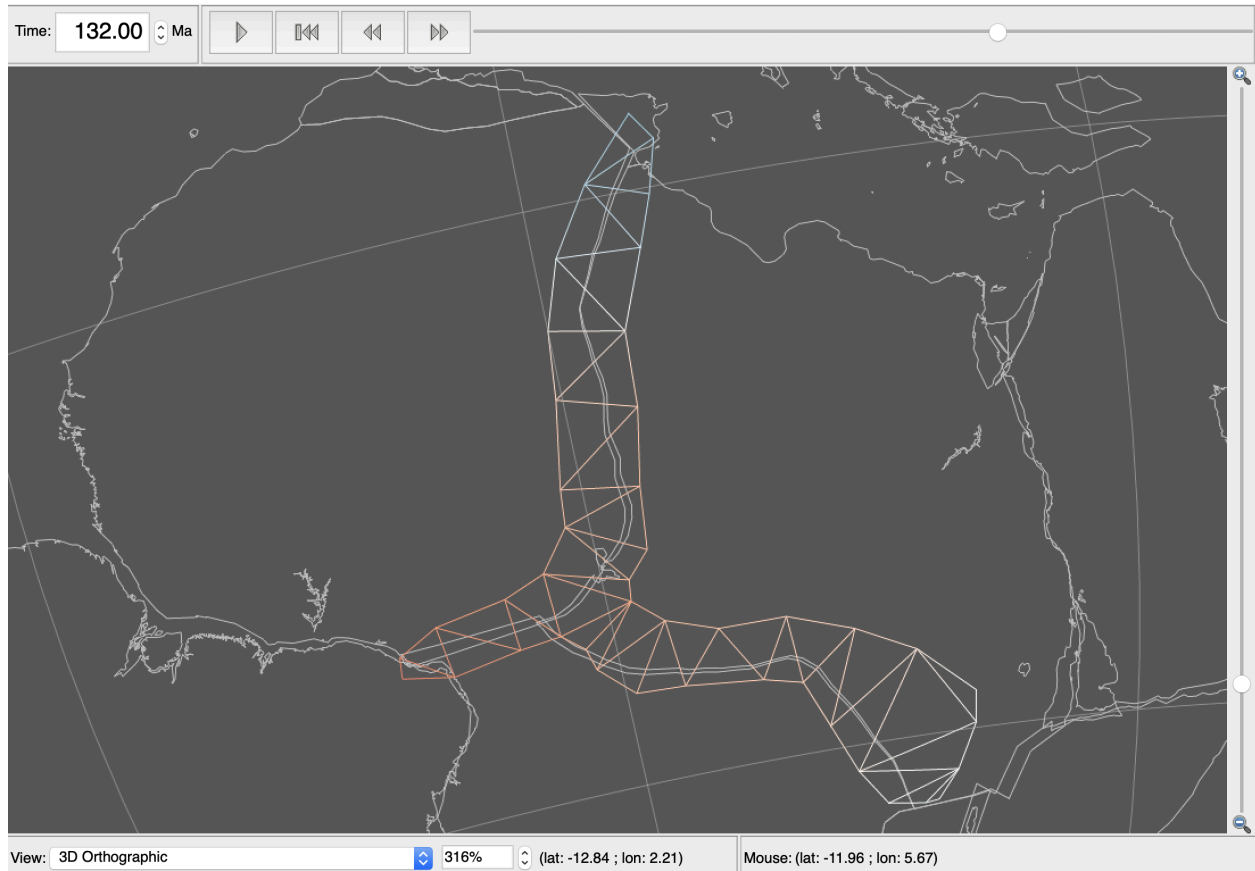
4. Once we have added all three line segments, we click 'Create...' and go through a series of dialogues to specify properties of the new feature. Define the feature type as gpml:TopologicalNetwork, and in the next window, set an appropriate Begin and End time. The network needs to exist for the same time period as the relative motion persists between the surrounding plates so in our case this is 132–0 Ma. Select the option of creating a new feature collection when prompted.
5. Once you have created the Resolved Topological Network layer, it may not initially appear - firstly make the raster layer and reconstructed geometry layers invisible.
6. Expand the options under the new gold Resolved Topological Networks layer (Figure 10).



**Figure 10:** Layer options when Resolved Topological Networks Layer is expanded.

7. Under Network & Triangulation options → Triangulation Colour Mode, select 'Dilatation strain rate'.

Notice that now the African rift basin appears like a network (Figure 11) (raster turned off for clarity).



**Figure 11:** African Rift Basin network topologies.

(Note that red = extension and blue = compression)

8. Try changing the reconstruction time to different times during the opening of the rift basins the networks represent (i.e., times between 132 and 84 Ma).

Another way to visualise the strain rate in a topological network is by filling the triangulations

9. In the layers window, under Triangulation Draw Mode, select 'Fill'
10. Now reconstruction from 132-84 Ma to see how we can visualise the strain rate in a different way.

Don't forget to save both the new line topologies and the topological network layer!

## Exercise 2 - Tracking Crustal Thickness Changes

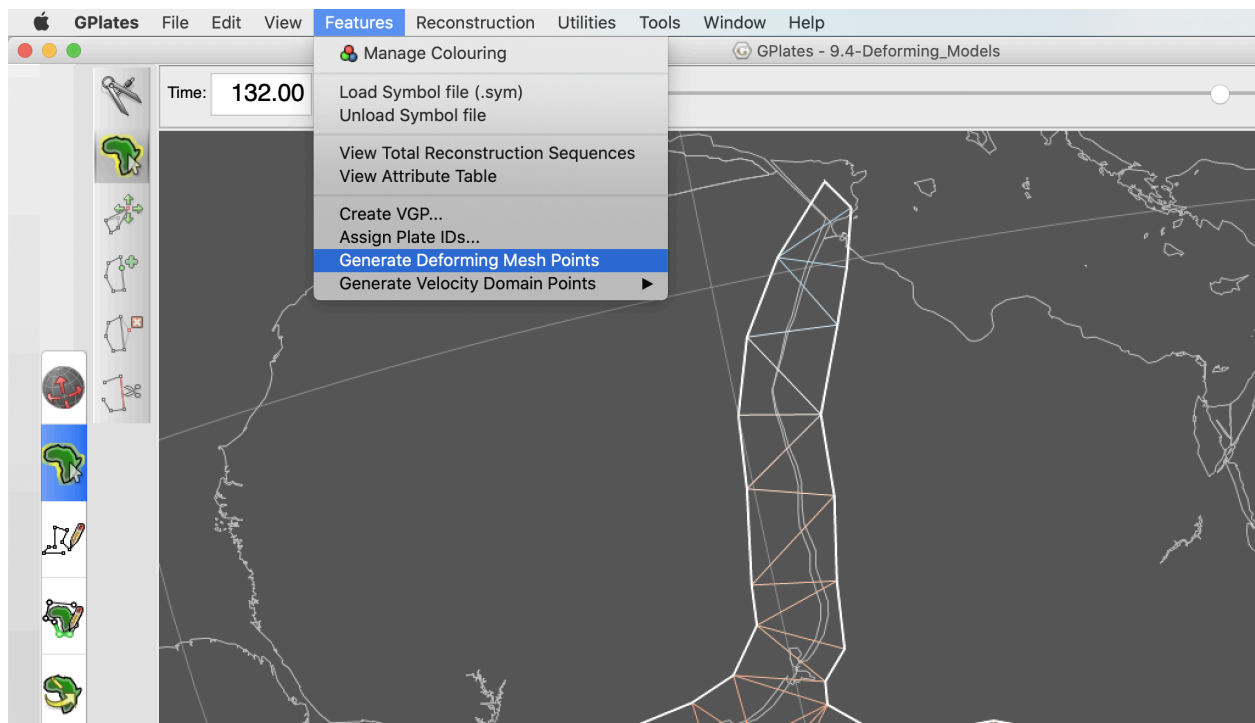
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GPlates has the functionality that allows points to be generated within a deforming region which then allow crustal thickness to be tracked.

1. Ensure that you have the deforming network loaded in from Exercise 1.
2. Set the reconstruction time to 132 Ma – this is very important!
3. Using the Feature Inspection Tool, select the deforming network.

The outline of the network should be highlighted in white once it has been selected.

4. Go to Features → Generate Deforming Mesh Points (Figure 12).



**Figure 12:** Features → Generate Deforming Mesh Points.

A new window will open where we specify properties of the points we will generate (Figure 13).

Generate Deforming Mesh Points

Points Region

Specify the region occupied by the points:

☒ Focused feature boundary ?

☐ Latitude/Longitude extent

☐ Include rigid interior blocks

Start latitude: 90.0000°

End latitude: -90.0000°

Start longitude: -180.0000°

End longitude: 180.0000°

Use Global Extents

Points Distribution

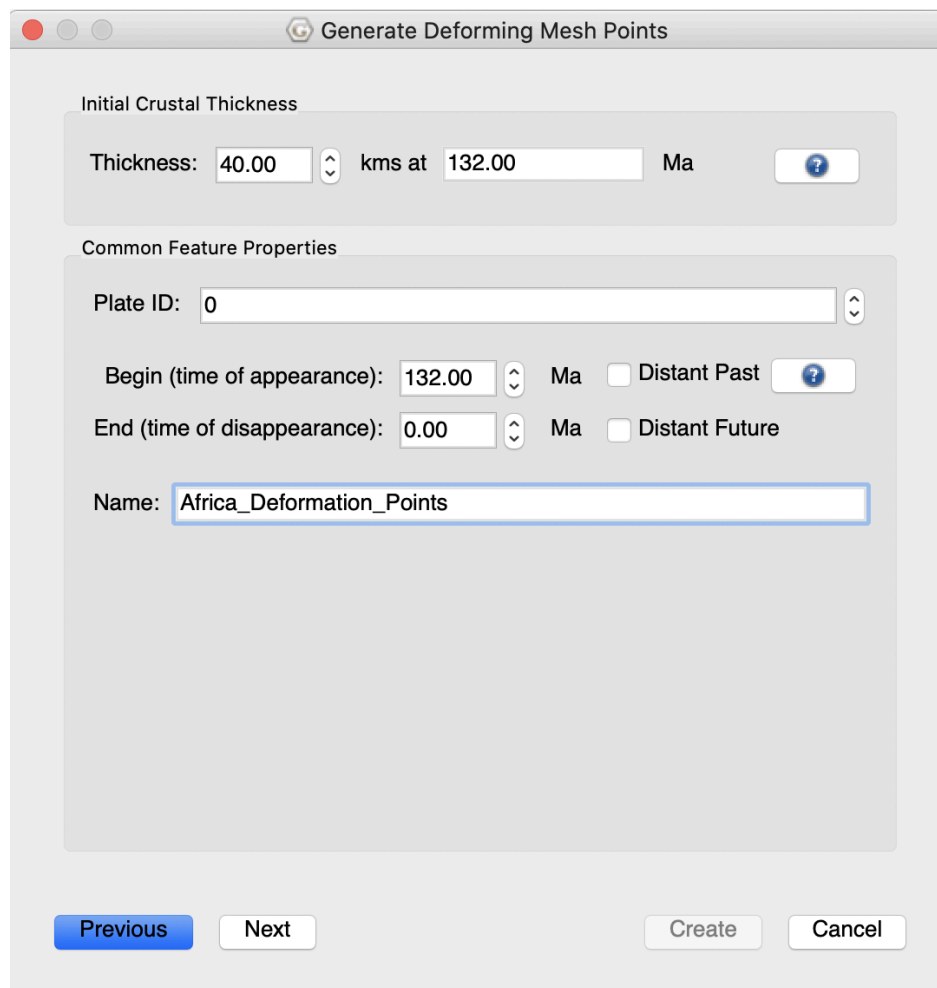
Density level: 7 Spacing: 0.625 degrees ?

Random offset: 0.00 %

Previous Next Create Cancel

**Figure 13:** Generating Crustal Thickness Points Window (Step 5).

5. Under 'Points Region', select 'Focused feature boundary'. Under 'Points Distribution', set 'Density level' to 7 (Figure 13). Click 'Next'.
6. In the next window, specify the following parameters, then click 'Next' (Figure 14):
  - Initial crustal thickness = 40 km (default)
  - Plate ID = 0 (default)
  - Begin time = 132 Ma
  - End time = 0 Ma (default)
  - Name = e.g. "Africa\_Deformation\_Points"



**Figure 14:** Generating Crustal Thickness Points Window (Step 6).

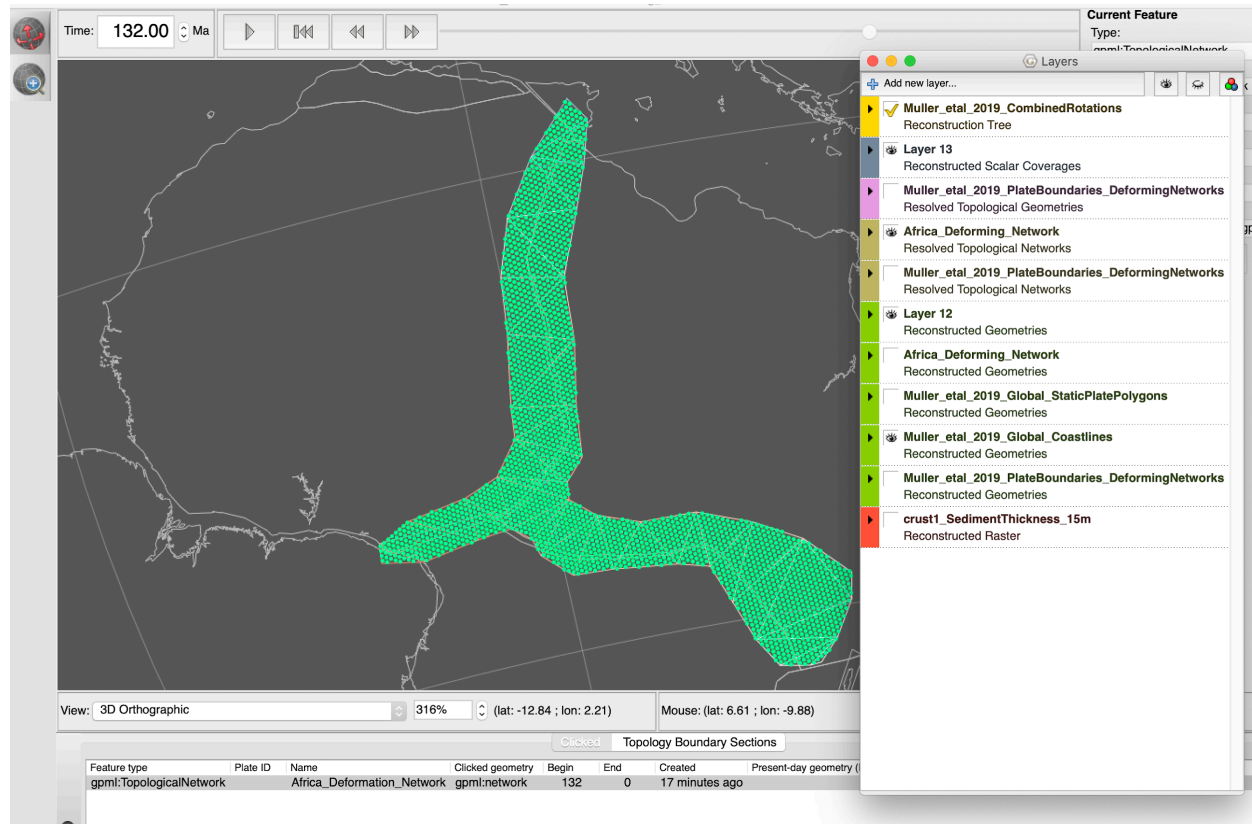
We are generating points at 132 Ma, so all changes to crustal thickness will be calculated relative to this time (hence it is very important to think about what time you generate your points at - check your reconstruction time now!).

7. Select < Create a new feature collection >, then click 'Create'.
8. In the next window, leave the options as defaults, but tick 'Deactivate points that fall outside a network'. Click 'OK' to create your points – this may take a few moments.

You will now notice that there are lots of green points within the deforming

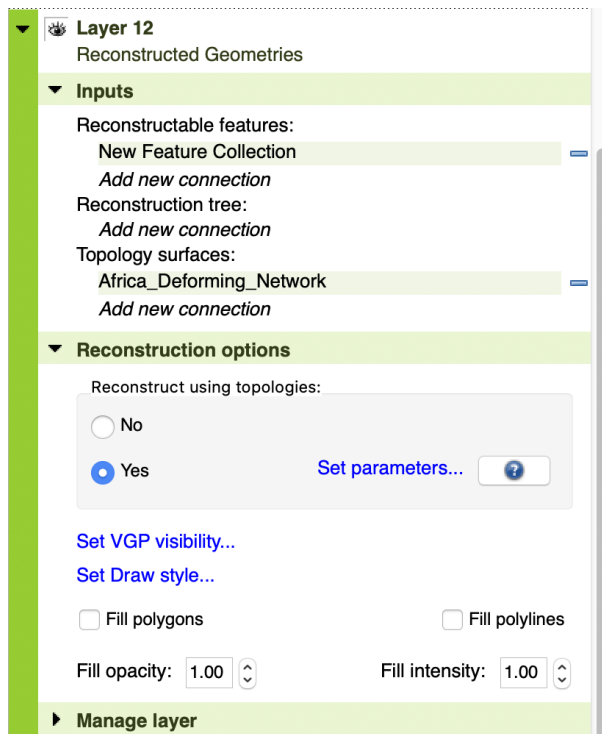


region (Figure 15), and that two new layers have been generated: a green Reconstructed Geometries layer and a dark grey Reconstructed Scalar Coverages layer.



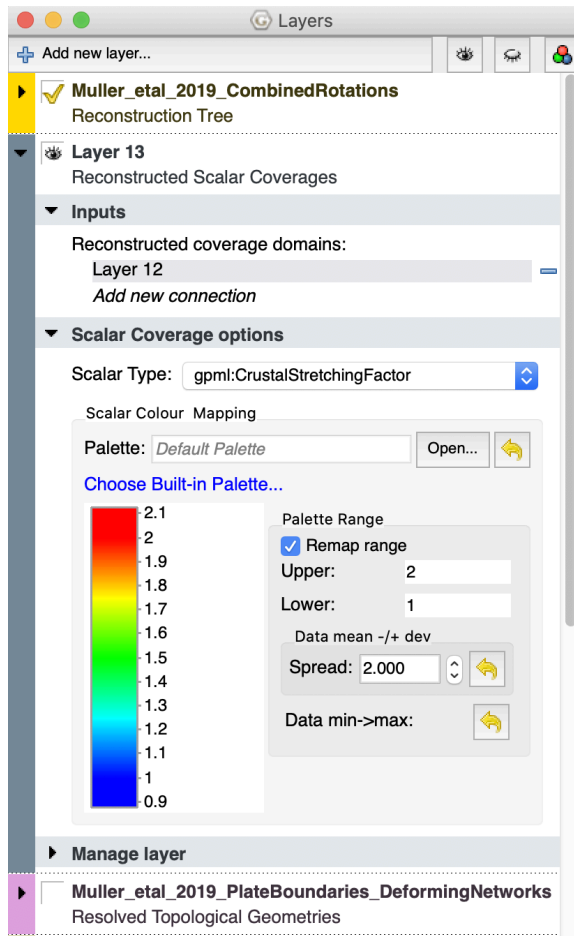
**Figure 15:** The newly generated crustal thickness points.

- Expand the options beneath the new green Reconstructed Geometries layer. Under Inputs → Topology surfaces, click Add new connection. Select the gold topological network layer you created in Exercise 1 (Figure 16).



**Figure 16:** Layer options for the new Reconstructed Geometries layer.

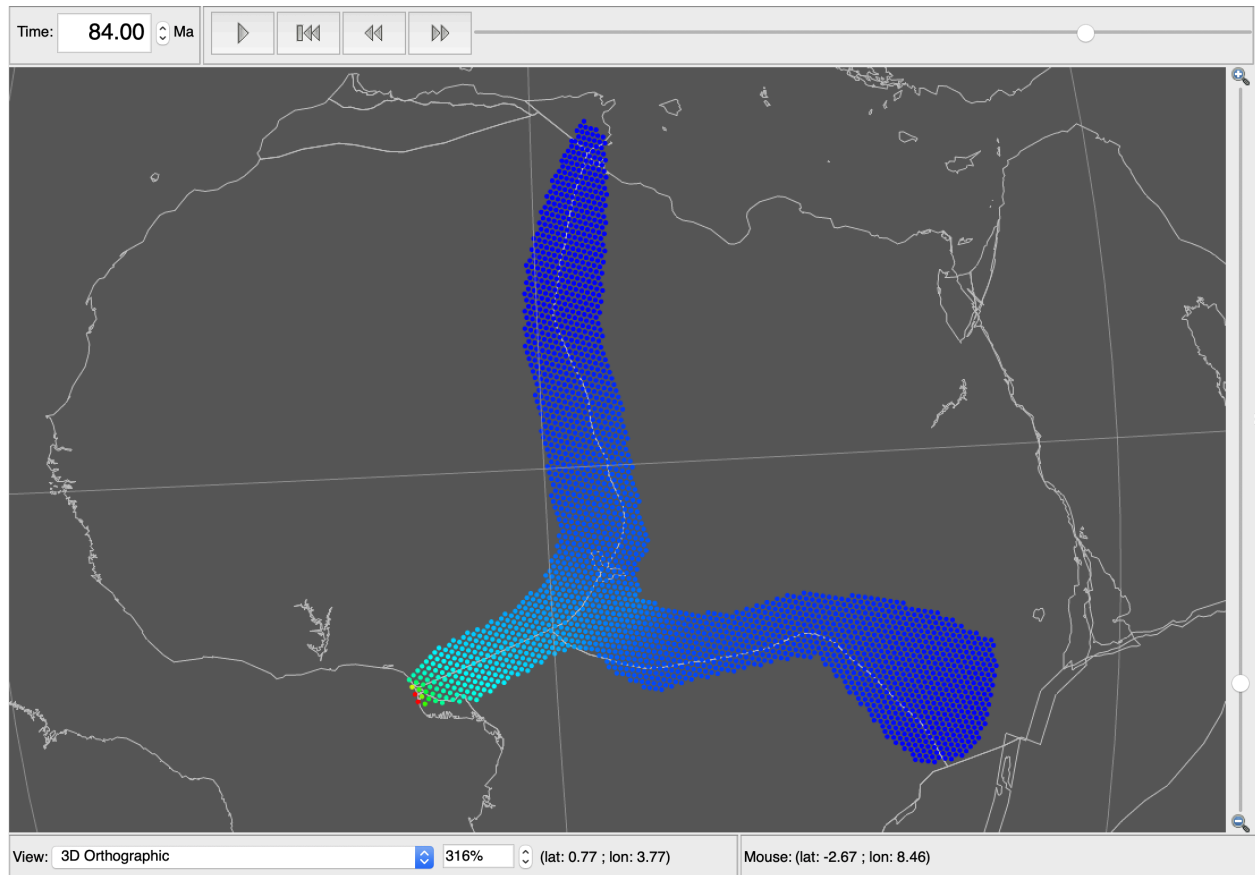
10. Now expand the options under the dark grey Reconstructed Scalar Coverages layer. Under 'Scalar Coverage options', make sure 'Scalar Type' is set to 'gpml:CrustalStretchingFactor', and change the colour palette range to 1-2 (Figure 17). For a more detailed explanation of the options available here, see Tutorial 8.4.



**Figure 17:** Redefining the colour palette range (Step 10).

11. Now play the animation through from 132–84 Ma (you may wish to hide the topological network layer as its colouring may interfere with the colouring of the crustal thickness points).

Notice how the scalar points have changed colour, reflecting changes in crustal thickness (Figure 18).



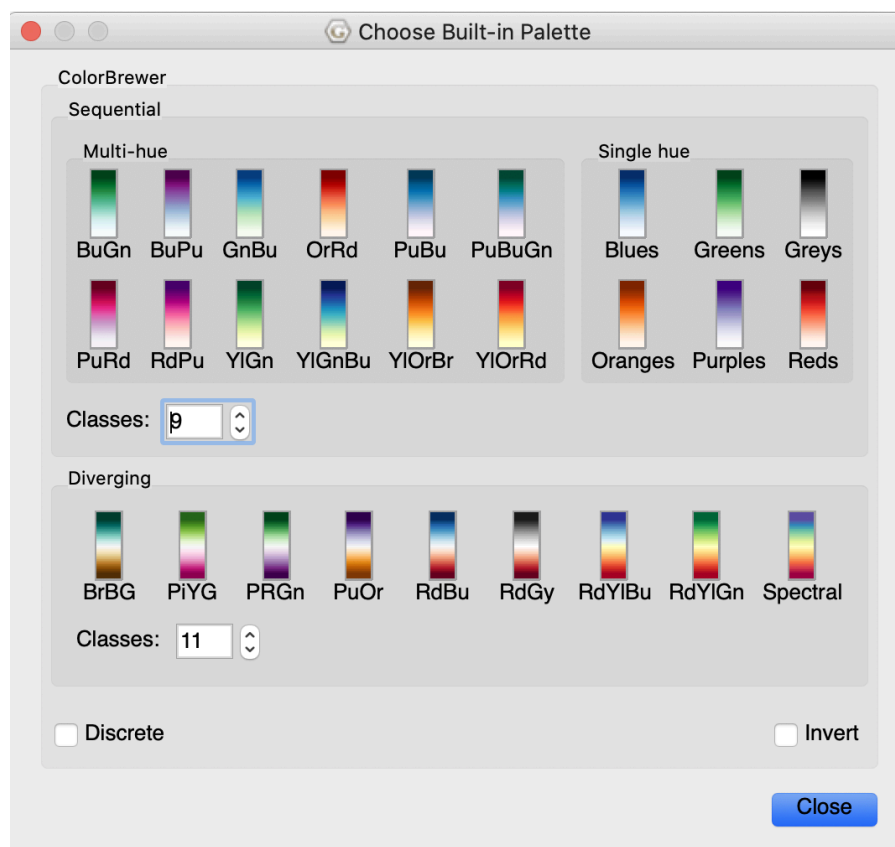
**Figure 18:** Stretching factor (beta factor) at 84 Ma relative to 132 Ma.

Since we are modelling a rift basin, it makes sense that the crust has thinned from 132-84 Ma due to rifting.

There are other options available to visualise changes to crustal thickness if you do not like the current colour palette.

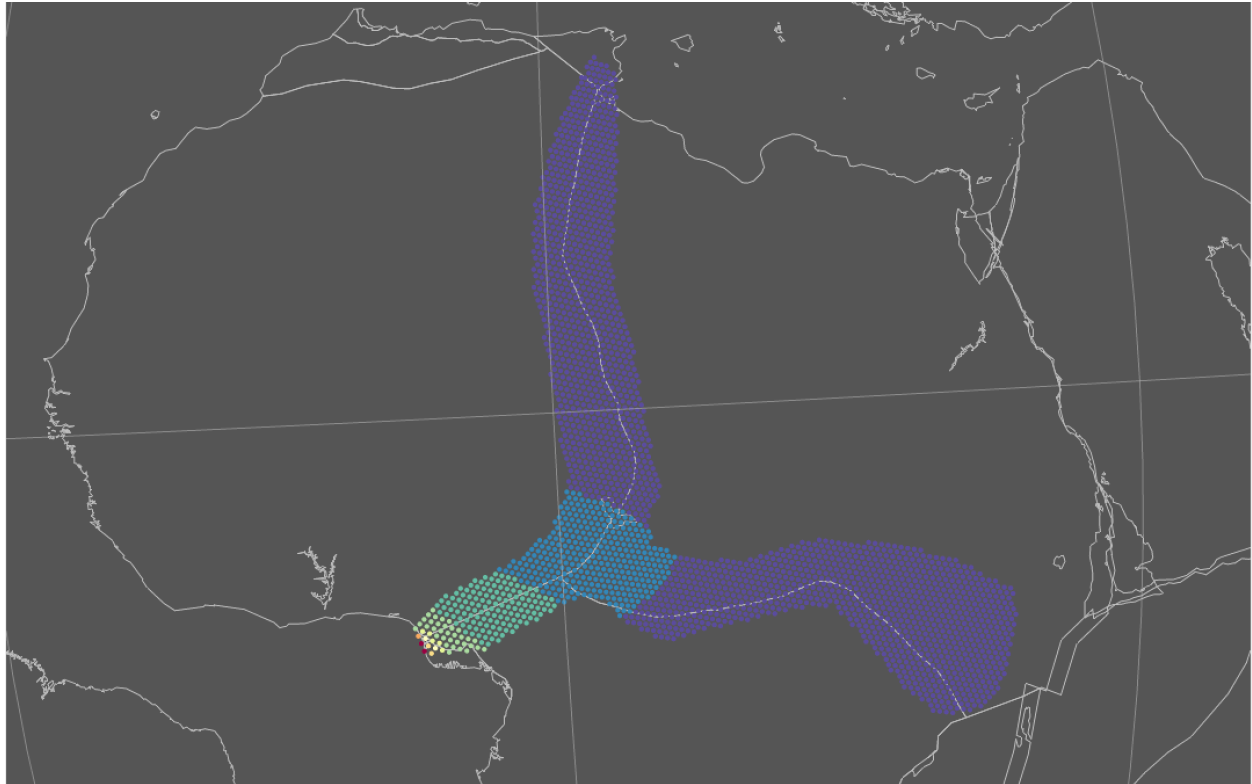
12. Expand the dark grey layer in the layer window and select 'Choose Built-in Palette...'.

A new window will open where you can choose from a range of colour palettes, choose the number of classes, whether the palette is discrete or whether you'd like to invert the palette (Figure 19).



**Figure 19:** Choose colour palette from a range of built-in options.

13. Experiment with changing the colour palette and/or range and see how this changes the colour of the points. An example is shown in Figure 20.



**Figure 20:** African Rift Basin at 84 Ma, visualised using the spectral colour palette (inverted and discrete).

For more detailed information about tracking crustal thickness changes, see Tutorial 8.4.

## References

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- Nürnberg, D., & Müller, R. D. (1991). The tectonic evolution of the South Atlantic from Late Jurassic to present. *Tectonophysics*, 191(1), 27-53.

Torsvik, T. H., Rouse, S., Labails, C., & Smethurst, M. A. (2009). A new scheme for the opening of the South Atlantic Ocean and the dissection of an Aptian salt basin. *Geophysical Journal International*, 177(3), 1315–1333. doi:10.1111/j.1365-246X.2009.04137.x

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