

Deforming Plate Models and Crustal Thickness

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Aim

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

Included files

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

The tutorial dataset (9.4-Deforming_Models.zip) includes the following files:

Coastline File: Seton_etal_ESR2012_Coastlines_2012.1.gpmlz

Static Plate Polygon File:

Seton_etal_ESR2012_StaticPolygons_2012.1.gpmlz

Dynamic Plate Polygon File: Seton_etal_ESR2012_PP_2012.1.gpmlz

Rotation File: Seton_etal_ESR2012_2012.1.rot

Sediment Thickness Raster: crust1_SedimentThickness_15m.gpml

Input Raster grid: crust1_SedimentThickness_15m.nc

NOTE: This tutorial requires functionalities that are only available in GPlates 2.0 and not earlier versions

Exercise 1 - Cretaceous Rift Basins in Africa

Part 1: Understanding the deformation inherent within existing reconstruction models

Firstly, we will load the files from the Seton et al. (2012) 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 Coastline, Static Plate Polygons, Dynamic Plate Polygons and rotation file for the Seton et al (2012) model.

- Seton_etal_ESR2012_Coastlines_2012.1_Polyline.gpmlz
- Seton_etal_ESR2012_StaticPolygons_2012.gpmlz
- Seton_etal_ESR2012_PP_2012.1.gpmlz
- Seton_etal_ESR2012_2012.1.rot

2. Set the reconstruction time to 132 Ma, and focus on the region of Africa and South America.

3. Turn off the resolved topology layer temporarily (Seton_etal_ESR2012_PP_2012.1.gpmlz), so we can focus on the static polygons (Figure 1).

4. 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're looking at with Figure 10 of Torsvik et al, 2009).

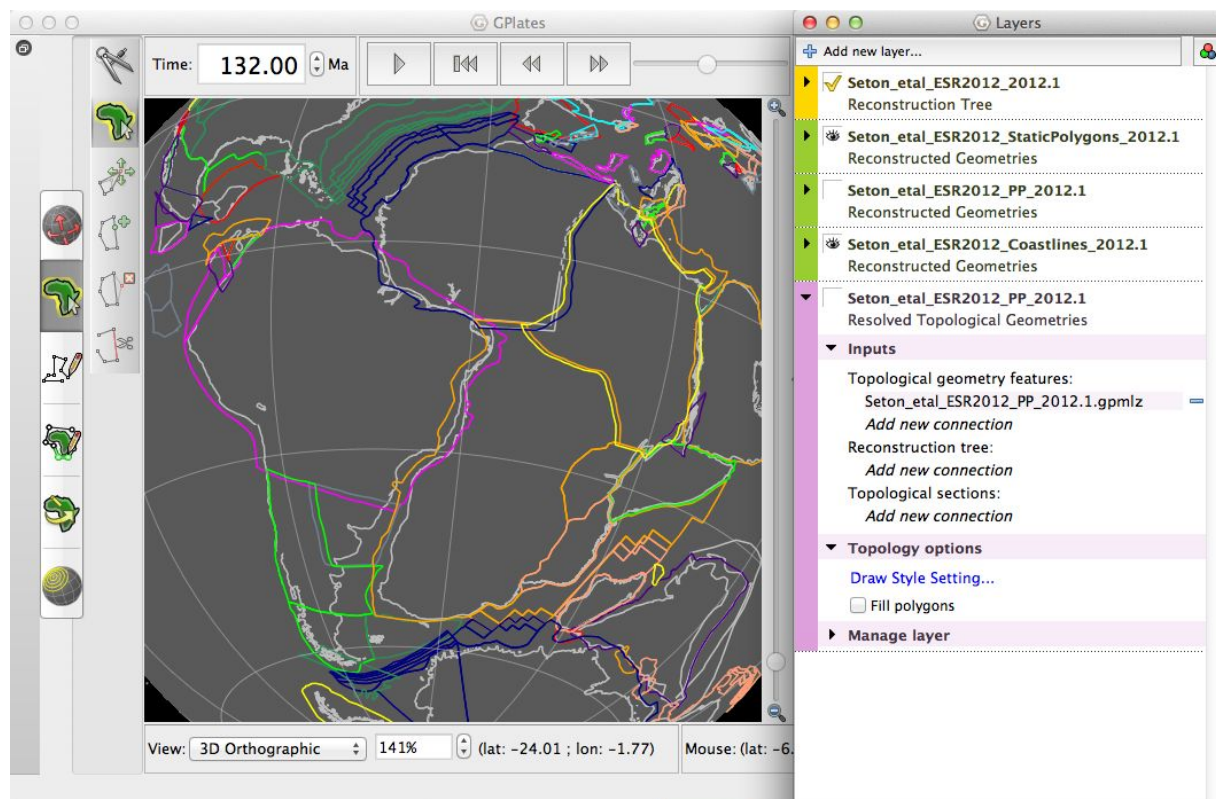


Figure 1: Overlap between static polygons (Step 3), coastlines coloured silver

5. 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.

6. Turn off the static polygon layer and turn on the Resolved Topology layer (Figure 2).

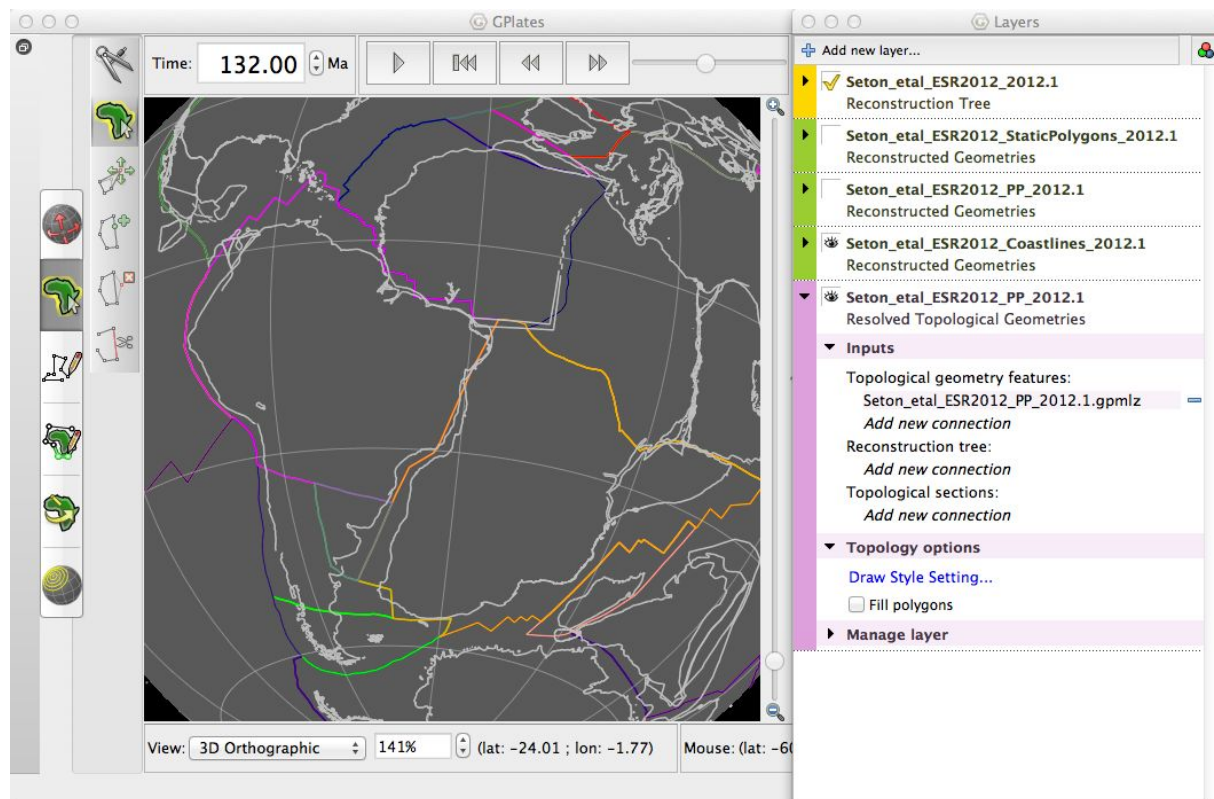


Figure 2: Extensional boundaries within Africa and South America at 132 Ma (Step 5)

Within the Seton et al (2012) 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 recently revised 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 (Window > Show Layers), expand the options beneath the raster layer.

Under Inputs > Reconstructed Polygons > Add new connection >

Seton_etal_ESR2012_StaticPolygons_2012.1 (Figure 3) - see [Tutorial 3.2](#) for a full description.

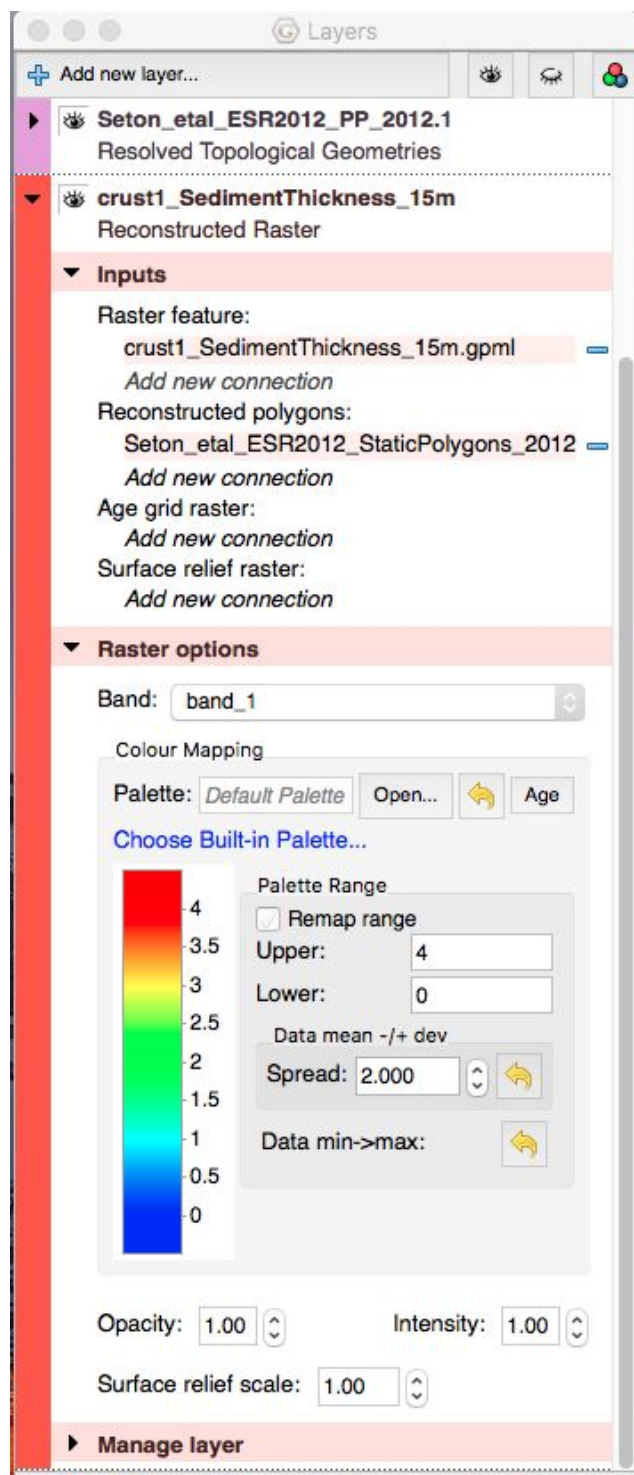


Figure 3: Adding the connection to the static polygons layer for the sediment thickness raster (Step 2)

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)

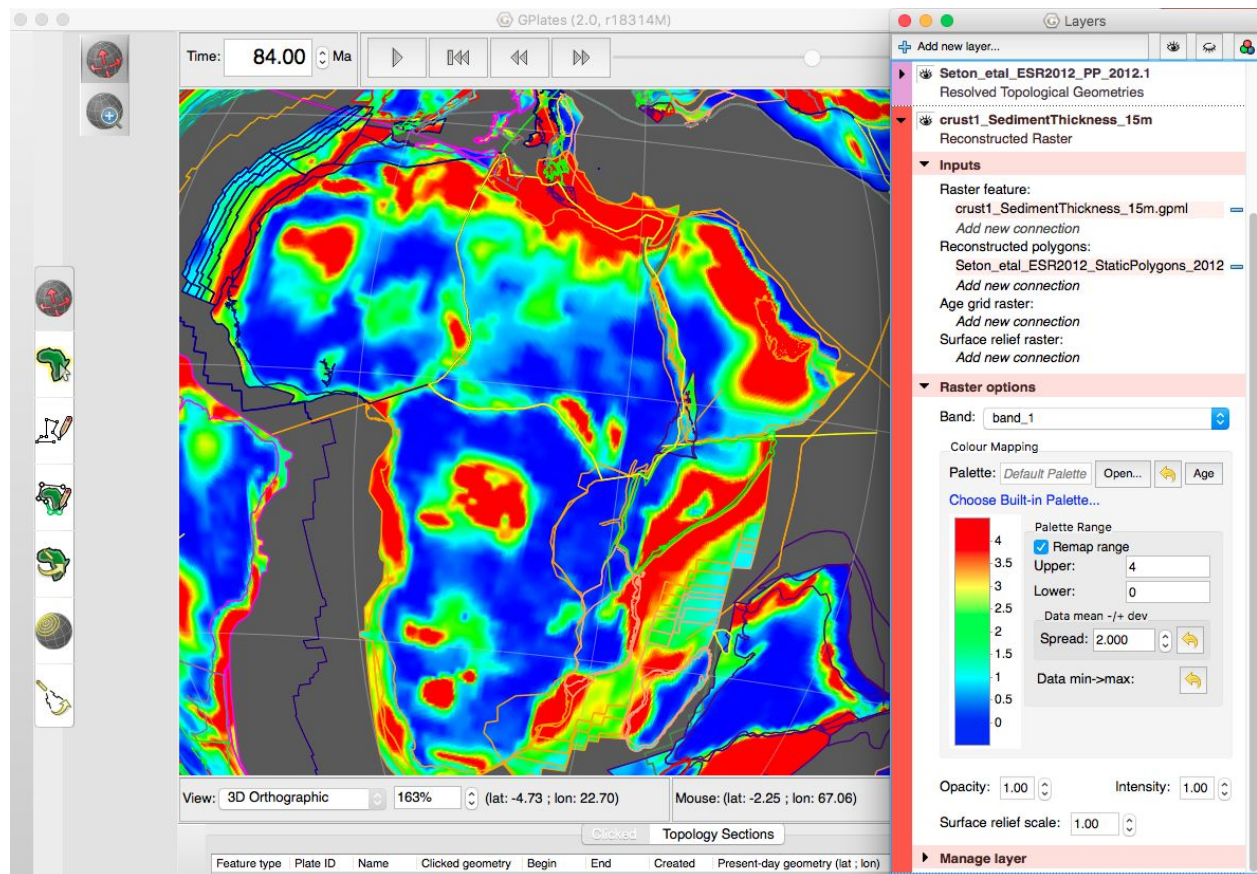


Figure 4: Sediment thickness reconstructed to 84 Ma (the raster layer is connected to the Static Polygons layer)

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 sediment 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).

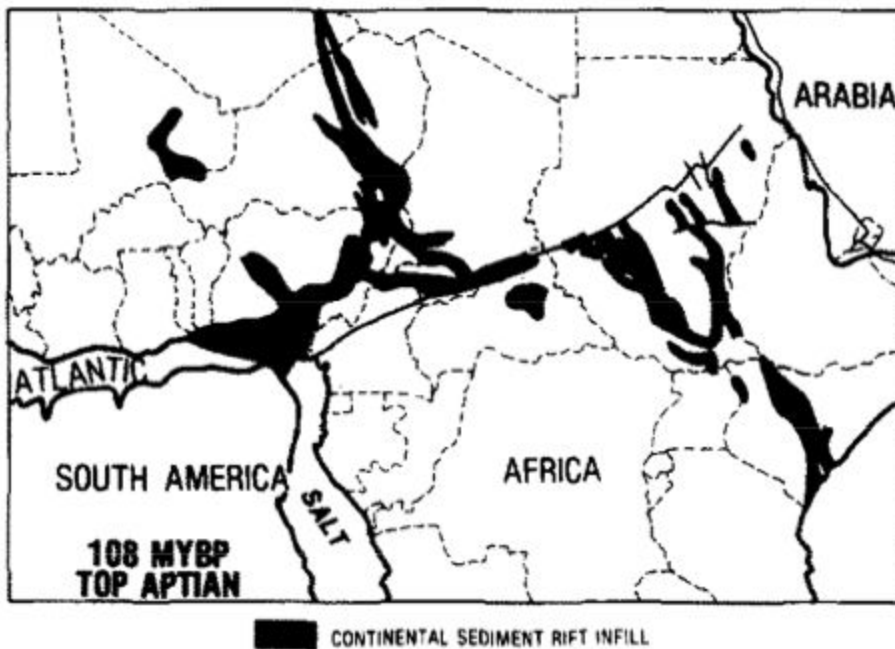


Figure 5: Development of major rift basins at 108 Ma (Genik et al, 1992)

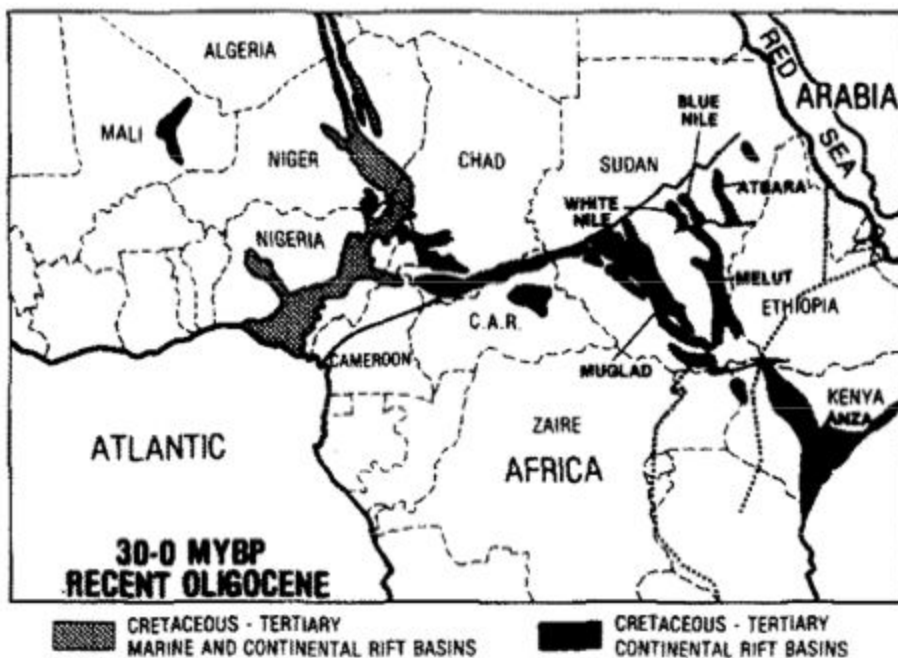


Figure 6: Rift configuration at 30 Ma (Genik et al, 1992)

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 is not thought to be related to South Atlantic rifting and is 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 ("Seton_etal_ESR2012_2012.1.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).

| Plate ID | Time (Ma) | Rotation (°) | Reference Frame |
|----------|-----------|--------------|-----------------|
| 710 | 600.0 | 15.0 | 37.2 |
| 712 | 0.0 | 0.0 | 0.0 |
| 713 | 0.0 | 0.0 | 0.0 |
| 714 | 0.0 | 0.0 | 0.0 |
| 715 | 0.0 | 0.0 | 0.0 |
| 718 | 0.0 | 0.0 | 0.0 |

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 networks over the deformation regions is to define line geometries that will define the boundaries of the deformation zone.

1. Select the 'Digitization' menu from the toolbar on the left of the GPlates window, then select the 'Digitize 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'll also have to modify the Begin and End times - based on Genik et al., (1992) set this to 132 Ma and 0 Ma.

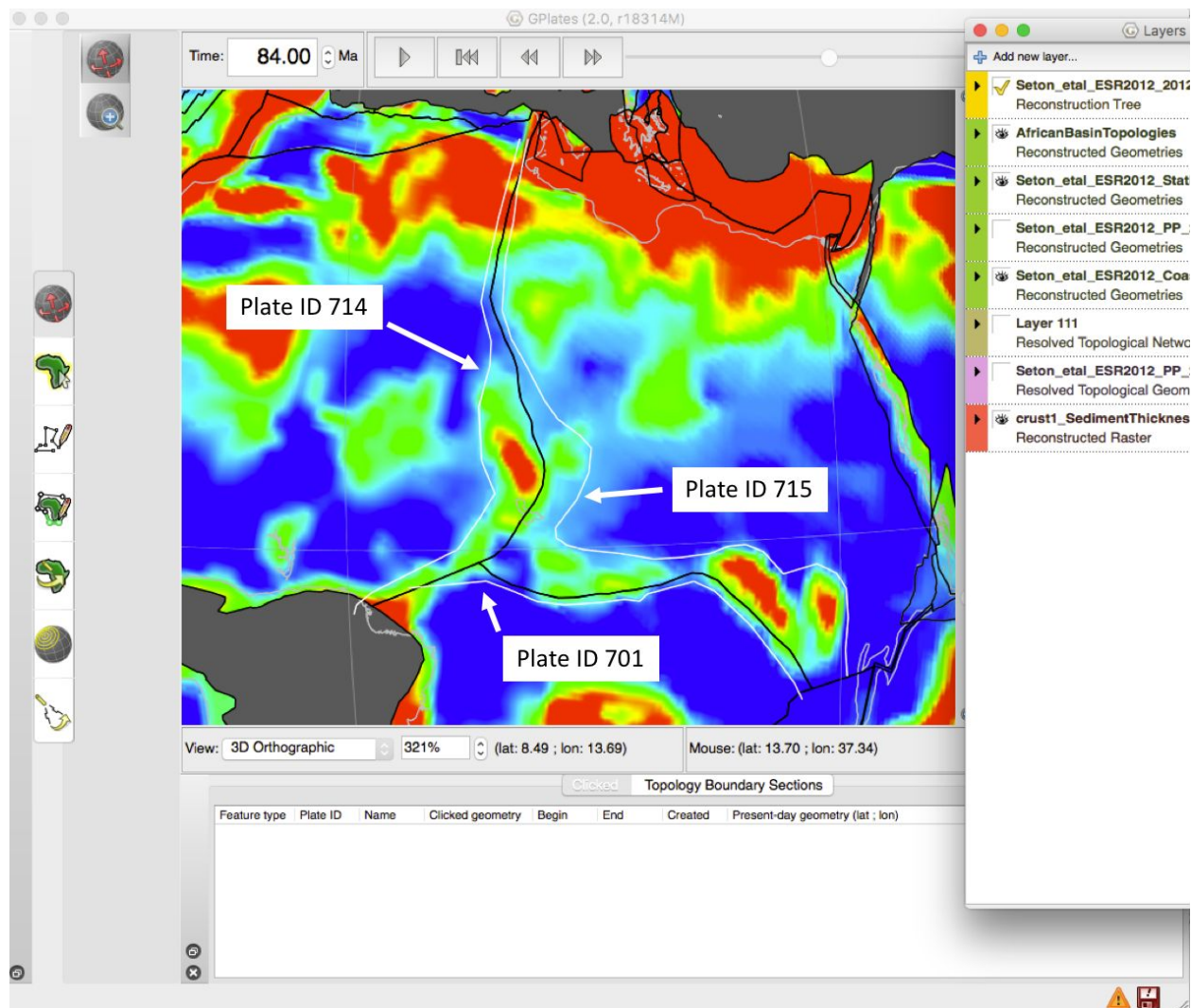


Figure 8: Example of the three new boundaries (white lines) which encompass the regions of the Central African Rift System Basins. The appropriate Plate IDs that they should be assigned are also shown. Static polygons are coloured black to avoid confusion with new lines, Coastlines are in silver.

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 (ie in a logical clockwise or anticlockwise progression), and then click on 'Add To Boundary' (Figure 9).

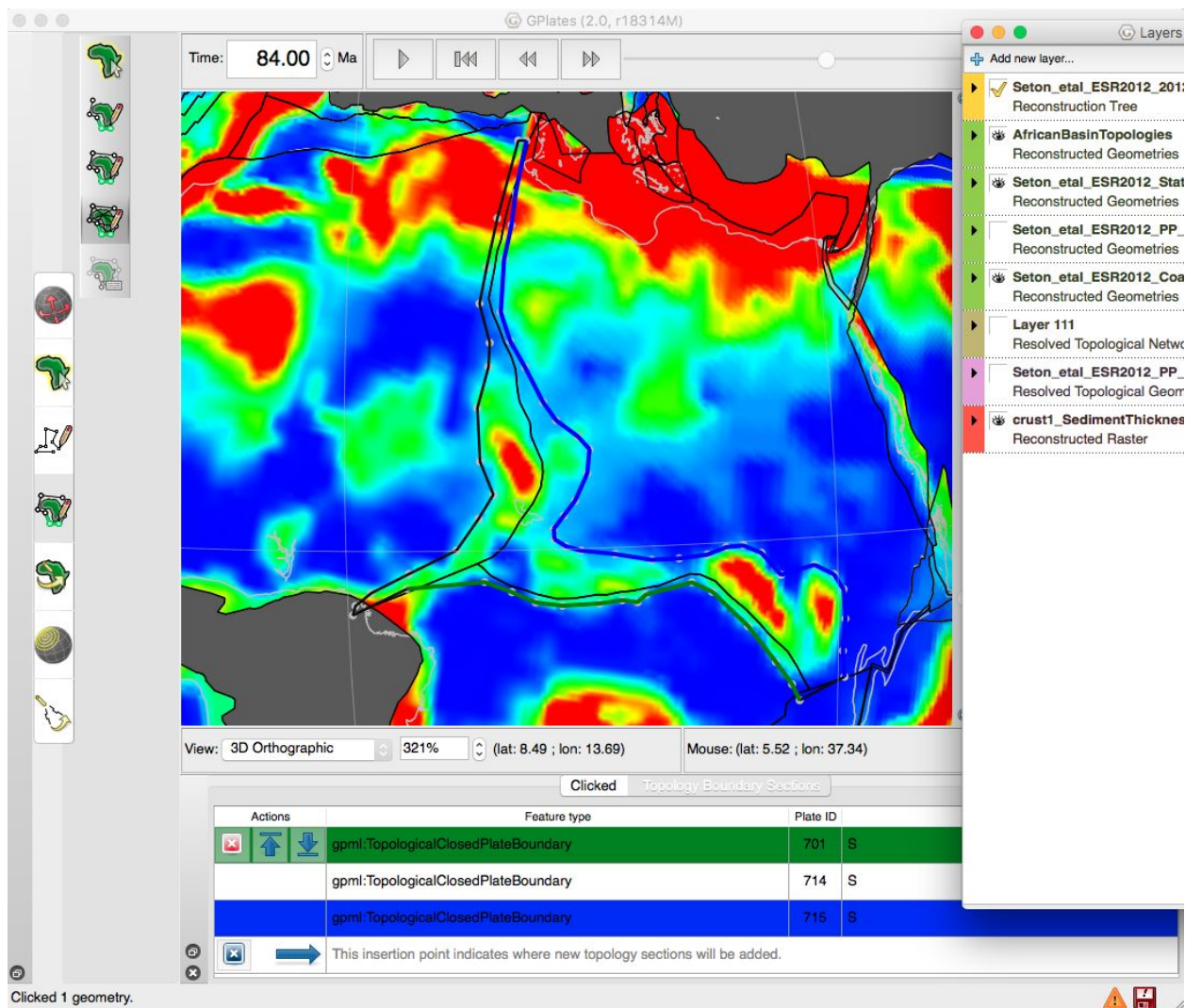


Figure 9: Building the network topology with line segments (Step 3).

4. Once we've added all the line segments (the 3 we just digitised), 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've 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).

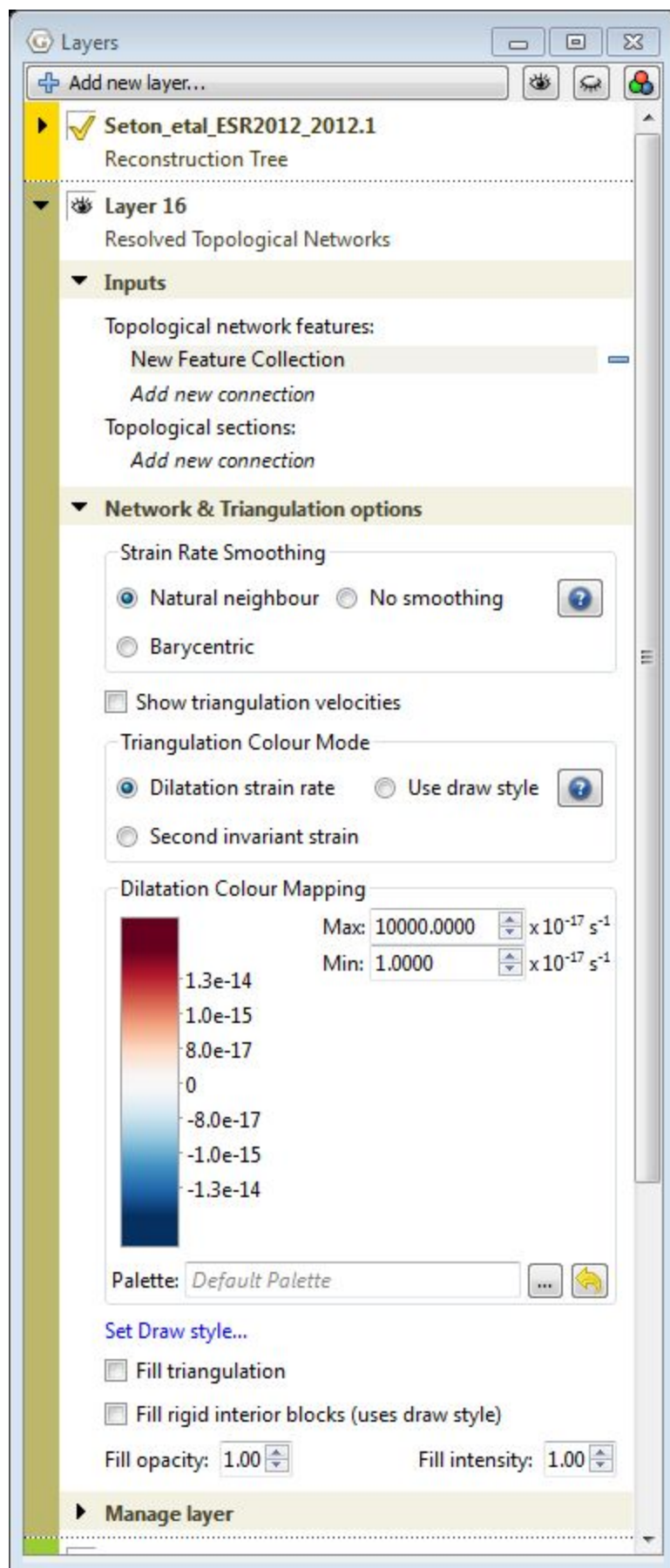


Figure 10: Layer options when Resolved Topological Networks Layer is expanded

7. 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)

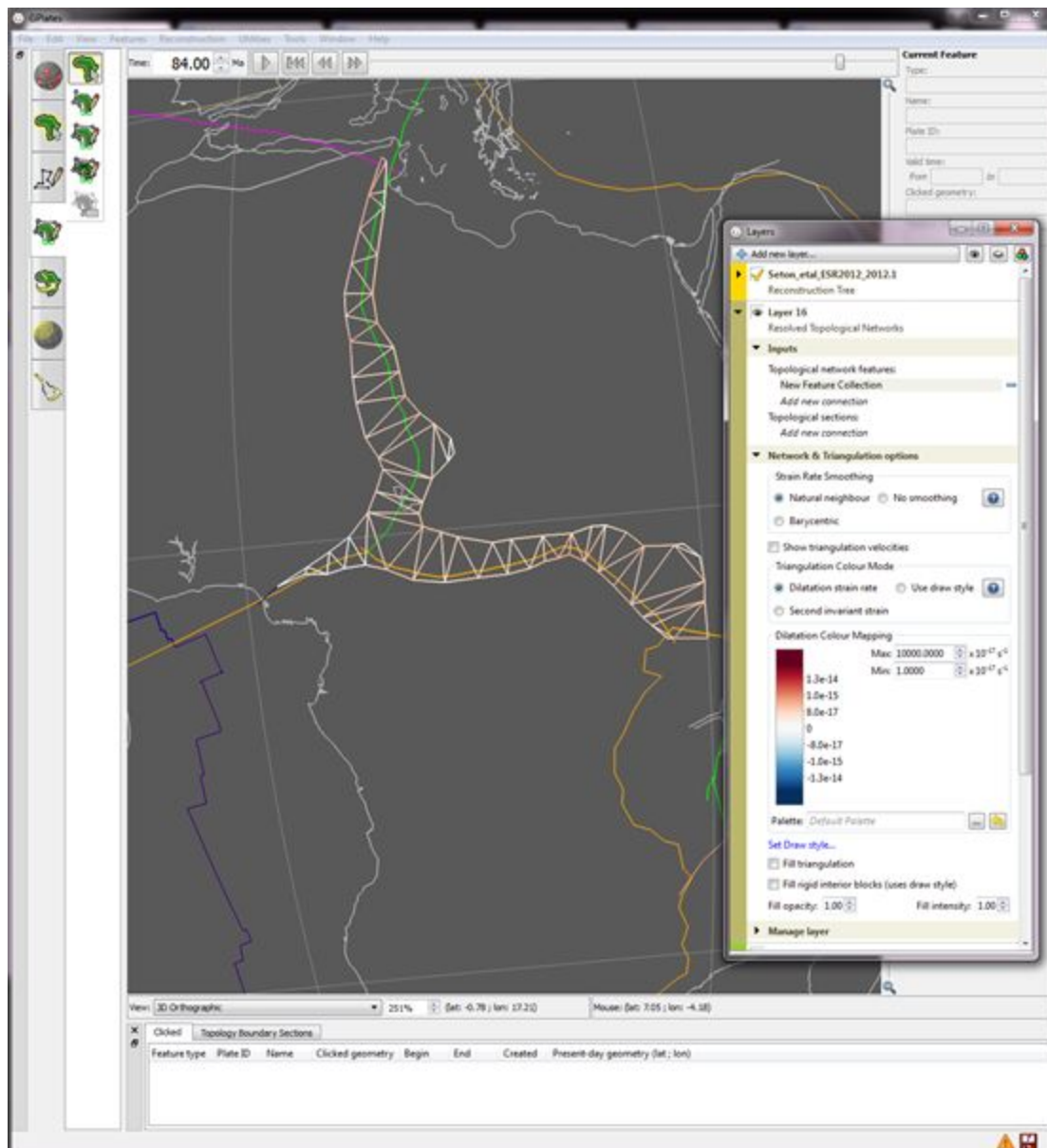


Figure 11: African Rift Basin network topologies

(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 (ie 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, Triangulation Draw Mode > select 'Fill triangulation'

10. Now reconstruction from 132-84 Ma and 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

GPlates 2.0 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. Change the reconstruction time to 132 Ma - very important!

3. Using the Feature Inspection Tool, select the deforming network region by clicking anywhere on the white space.

It may be difficult to see due to the colouring, but the outline of this network will now be highlighted in white (indicates that we have selected it).

4. Features > Generate Crustal Thickness Points (Figure 12)

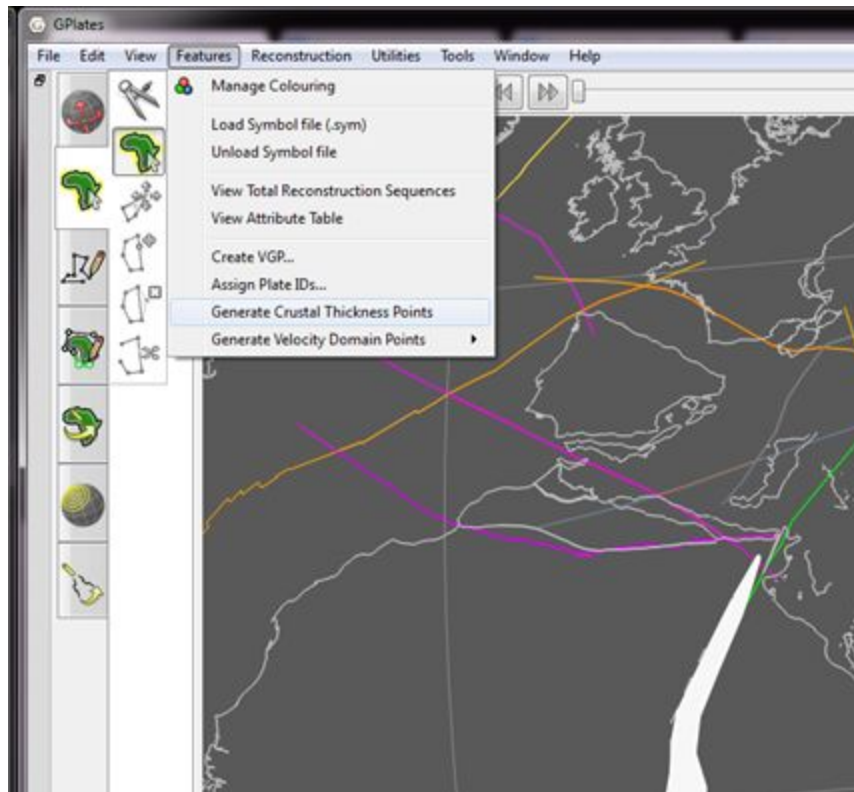


Figure 12: Features > Generate Crustal Thickness Points

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

Generate Crustal Thickness Points

Initial Crustal Thickness

Scalar Type: ?

Thickness: kms

Uniform Point Distribution

Density level: Spacing: degrees ?

Random offset: %

Common Feature Properties

Plate ID:

Begin (time of appearance): Ma ☒ Distant Past ?

End (time of disappearance): Ma ☐ Distant Future

Name:

Figure 13: Generating Crustal Thickness Points Window

5. Specify (Figure 14):

- Scalar Type = gpml:CrustalStretchingFactor
- Density level = 7
- Plate ID = 0 (default)
- Begin time = 132 Ma
- End time = 84 Ma
- Name = whatever you'd like! (or African Rift Basin)

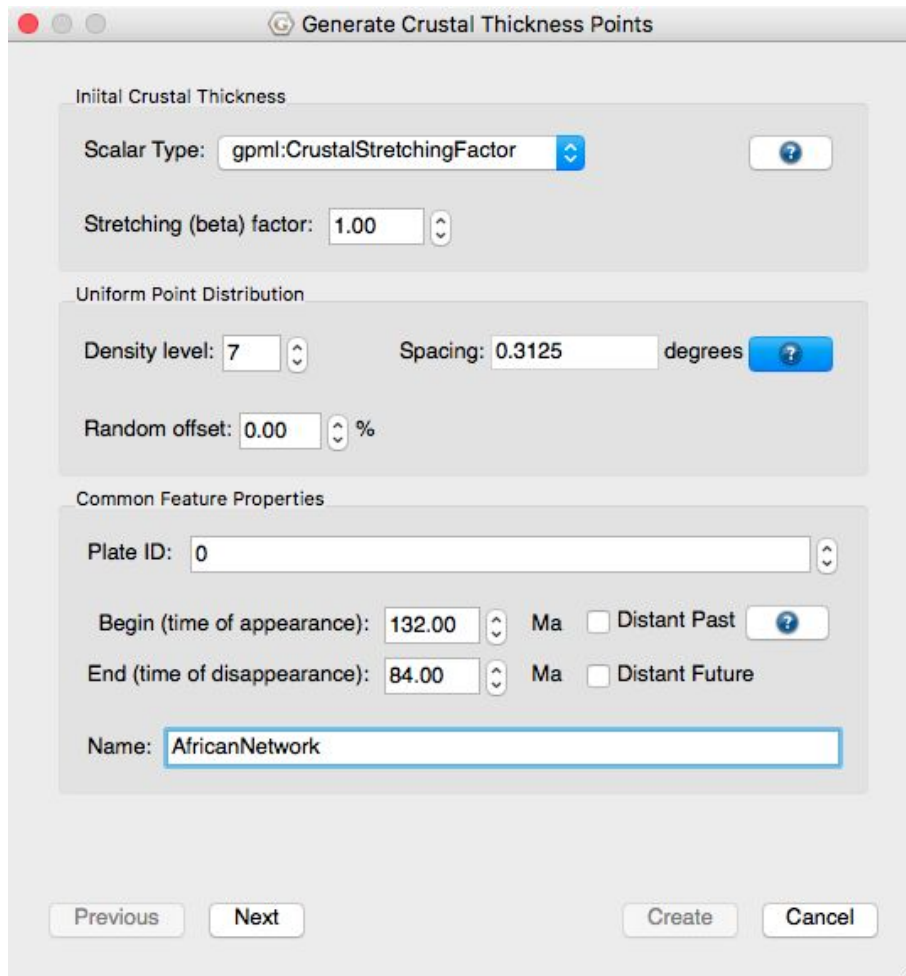


Figure 14: Generating Crustal Thickness Points Window

Since we are selecting `gpml:CrustalStretchingFactor`, we will be generating points that will track relative changes in crustal thickness according to the beta factor.

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!).

6. Next > Create a new feature collection > Create

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).

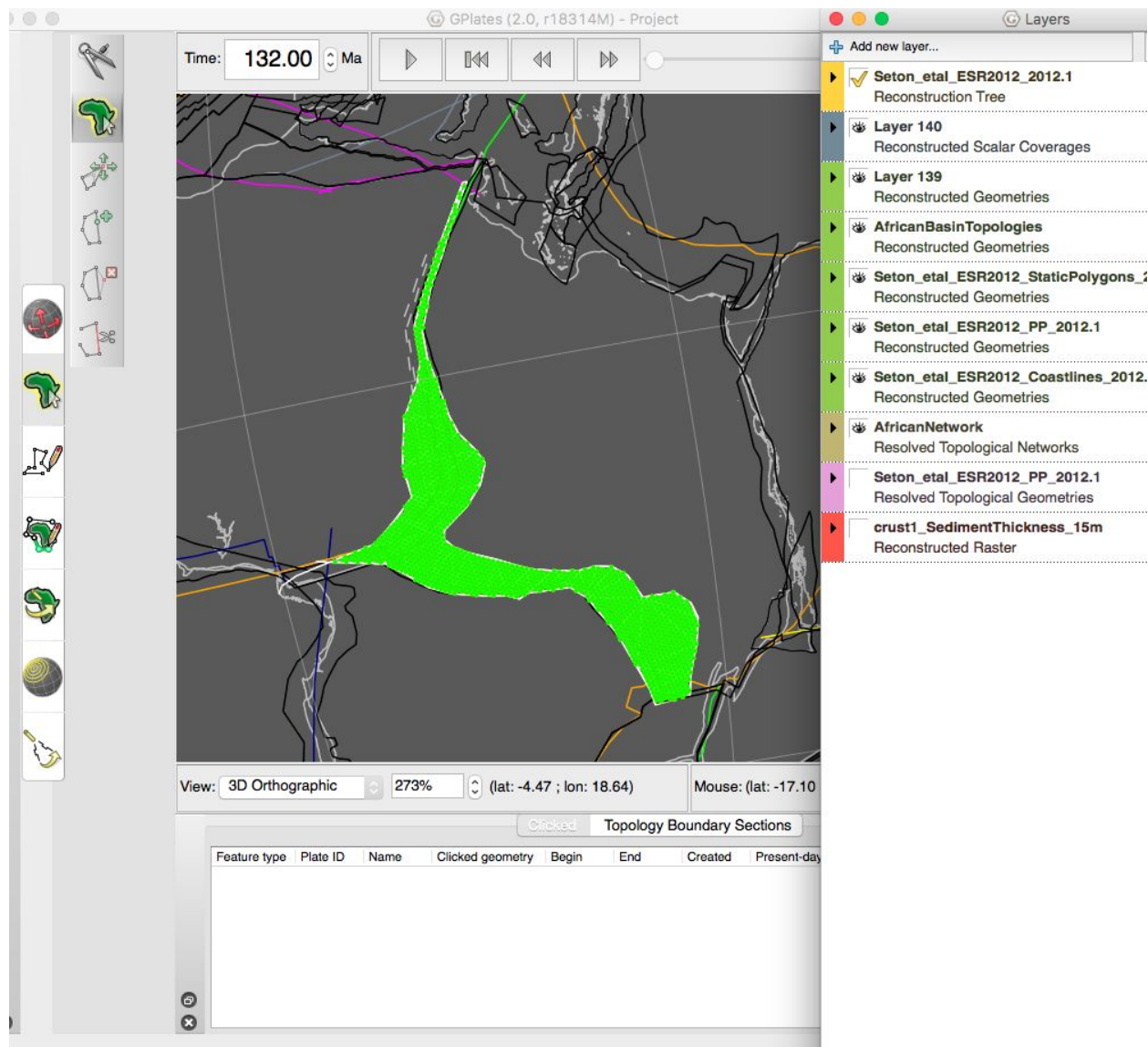


Figure 15: Newly generated crustal thickness points

7. Expand the options beneath the new green Reconstructed Geometries layer and under Inputs > Topology surfaces > Add new connection > select the gold topological network layer (Figure 16).

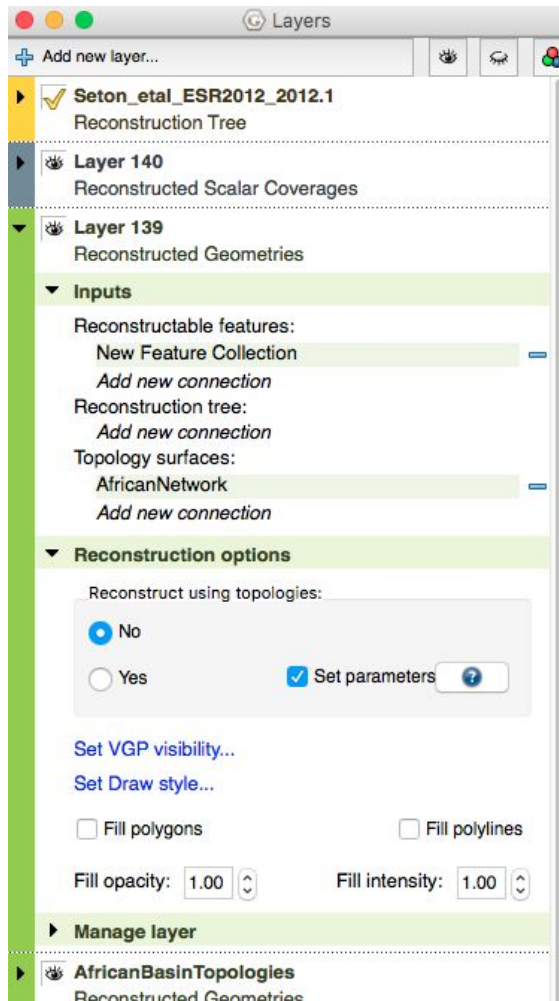


Figure 16: Layer options for new Reconstructed Geometries layer

8. Under Reconstruction options > Reconstruct using topologies > Select Yes

A new window should pop up (Set Topology Reconstruction Parameters)

9. Specify (Figure 17):

- Youngest Age = 84 Ma
- Oldest Age = 132 Ma

Then click OK

Set Topology Reconstruction Parameters

Choose time span:

Youngest Age 84 Ma

Oldest Age 132 Ma

Time Increment 1 Ma

Reconstruction by topologies *inside* time span.
Reconstruction by plate ID *outside* time span.

☐ Start reconstruction at time of appearance

☒ Detect individual point lifetimes

Threshold velocity delta: 0.70 cms/yr

Threshold distance to boundary: 10 kms/my

☒ Tessellate lines:

Point spacing: 0.50 degrees

Deformed Network Interpolation

☒ Natural neighbour ☐ Barycentric

☒ Show reconstructed feature geometries

☐ Show strain accumulation

Cancel OK

Figure 17: Setting the parameters for the topology (Step 9)

10. Now expand the options under the dark grey Reconstructed Scalar Coverages layer and change the colour palette range to 1-2 (Figure 18)

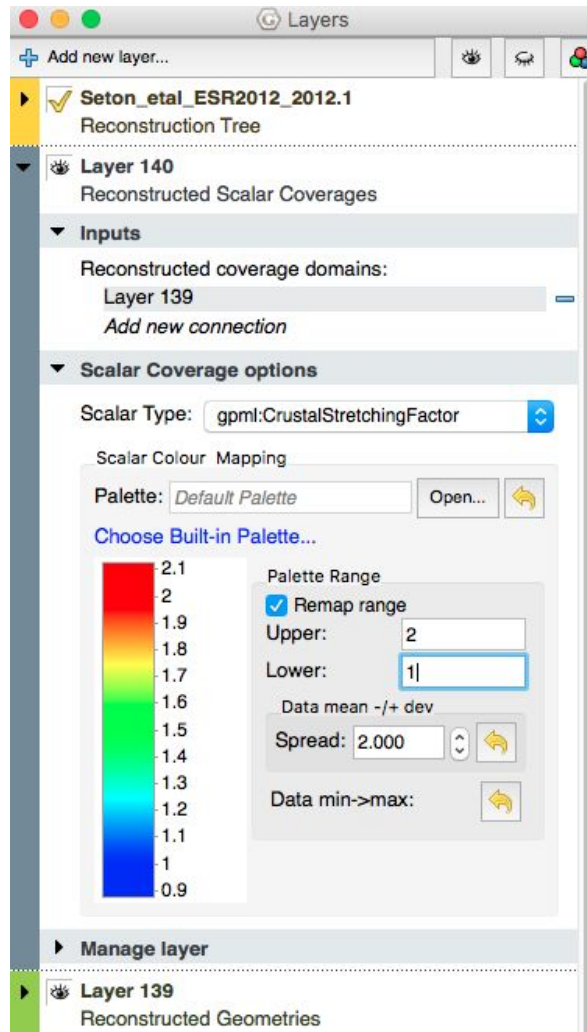


Figure 18: Redefining the colour palette range (Step 10)

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 19).

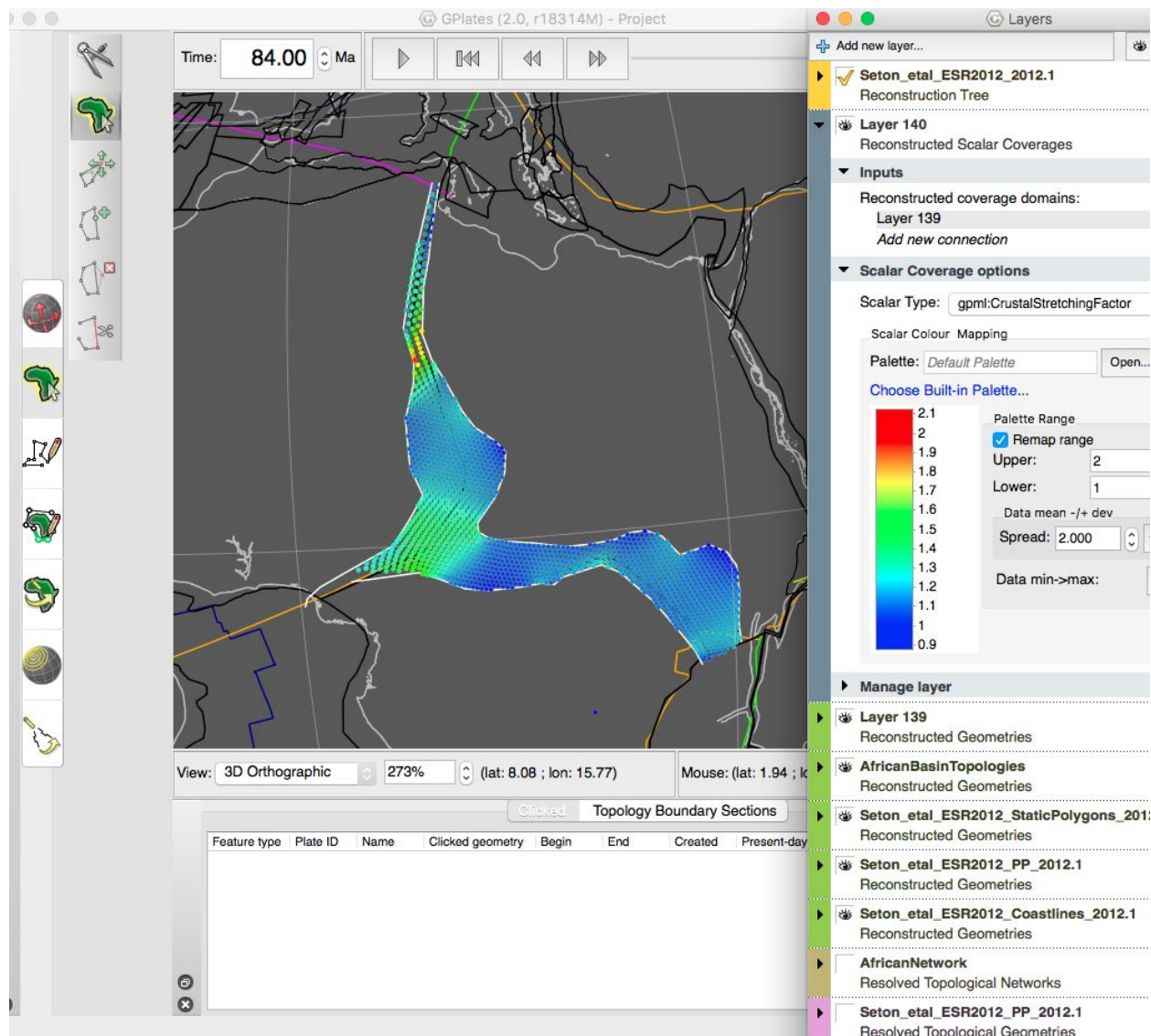


Figure 19: Stretching factor (beta factor) at 84 Ma with respect to 132 Ma

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 20).

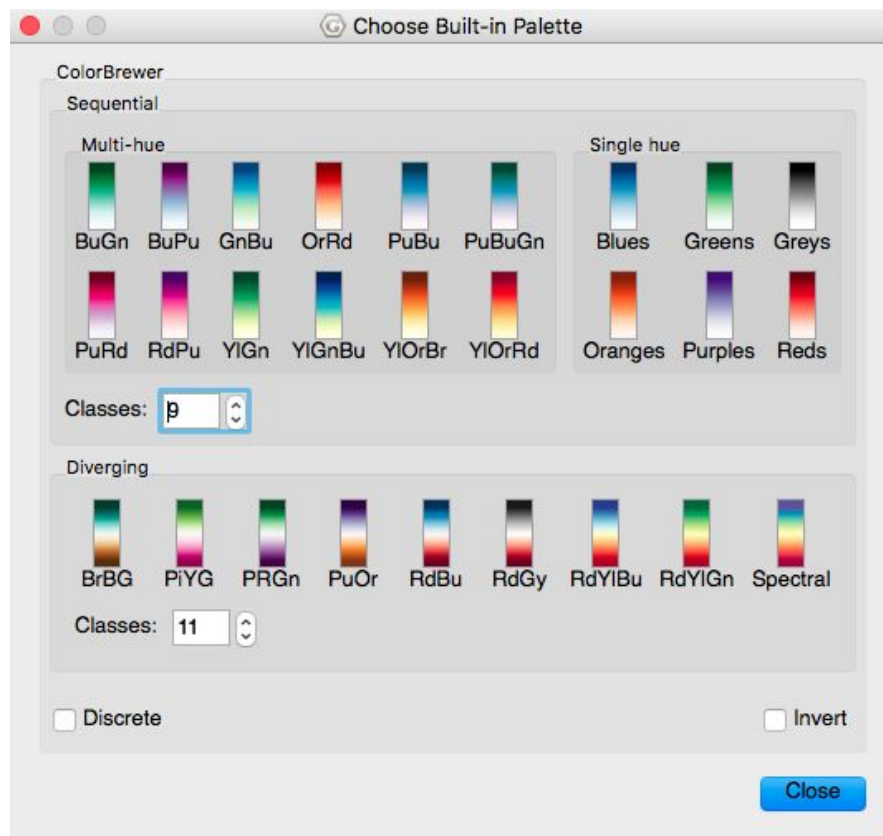


Figure 20: Choose colour palette from a range of built-in options

13. Have a go at changing the colour palette and/or change the range and see how this changes the colour of the points. An example is shown in Figure 21.

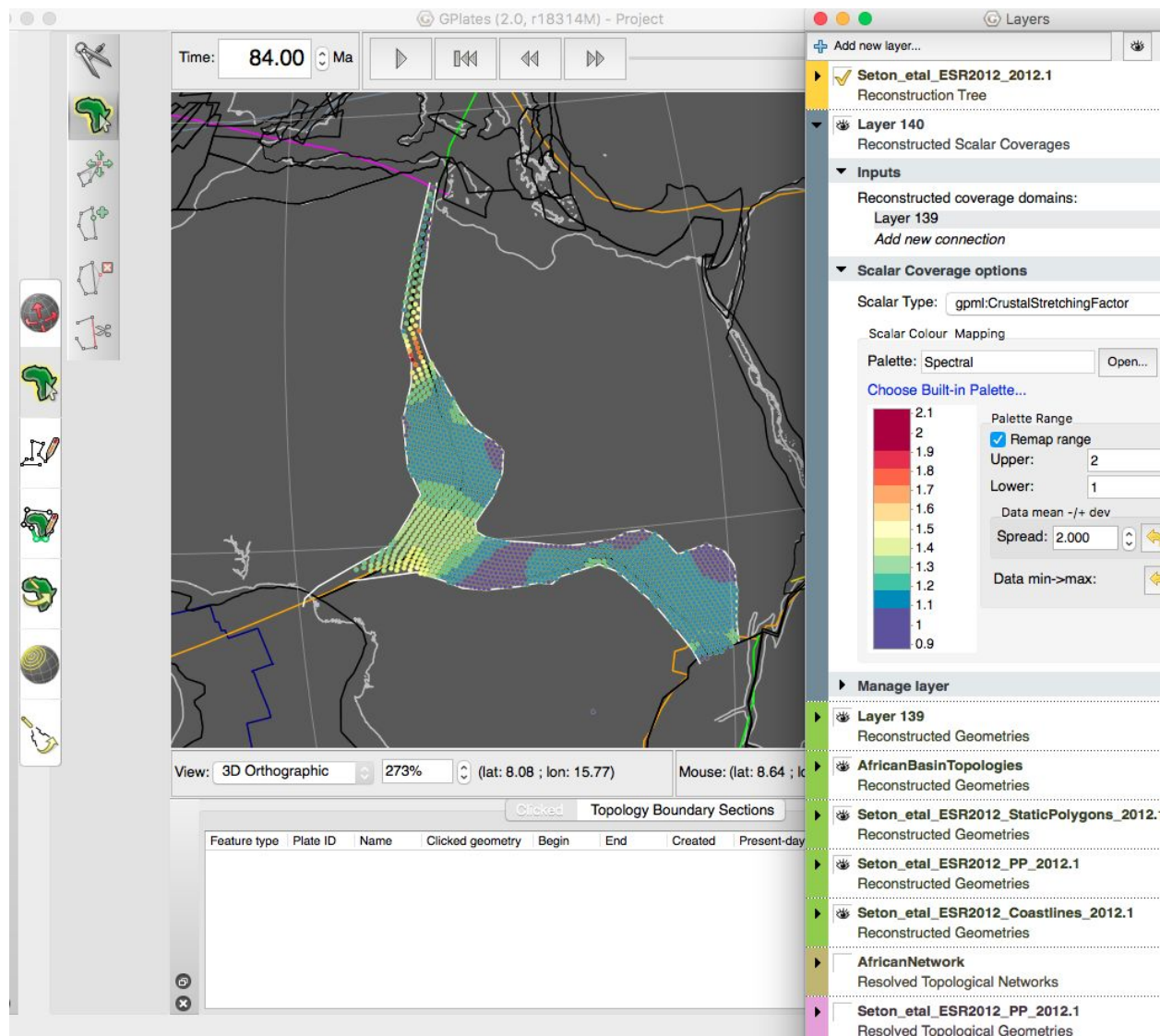


Figure 21: African Rift Basin with spectral colour palette (inverted and discrete)

For more detailed information about tracking crustal thickness changes, see [Tutorial 8.4](#).

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Genik, G. J. (1992). Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic (CAR). *Tectonophysics*, 213(1), 169-185.

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