Plate Reconstructions

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Aim

This is a condensed version of the tutorials designed to introduce the user to creating plate reconstructions with GPlates

Included files

Click here to download the data bundle for this tutorial.

The tutorial dataset (9.2-Plate_Reconstructions.zip) includes the following files:

Global Coastlines: Seton_etal_ESR2012_Coastlines_2012.1_Polygon.gpmlz

Global Rotation File: Seton_etal_ESR2012_2012.1.rot

Australia Antarctica Rotation File: AusAnt_ExampleRotation.rot

Rotation File: Global_EarthByte_GPlates_Rotation_AusAnt_Example.rot

Australia - Antarctica Fracture Zones: AusAnt_FZs.gpml

List of Plate IDs for Seton et al (2012) Plate model: Seton_etal_ESR2012_PlateIDs.pdf

Background to Plate Rotation Models

If you do not have a background in plate motions, we recommend that you read Cox and Hart (1986). Below are some definitions used in this tutorial (see GPlates User Manual for further details):

Plate ID

A Plate ID assigns a feature to a plate or tectonic element that has moved relatively to other plates for some period during its geological history. A Plate ID is a non-negative integer number. Tectonic elements can include anything from large plates to island arcs and relatively small blocks or terranes in regions experiencing complex deformation. In GPlates we also assign separate Plate ID's to pieces of oceanic crust that were transferred from one plate to another by a ridge jump or propagation. Even though such pieces of crust were always part of one plate or another, we need to assign it a separate plate ID to model this process. The fixed reference frame of the Earth's spin axis is assigned Plate ID 0, whereas sections of the Earth's mantle that appear to have moved relatively coherently to other portions of the mantle can be assigned Plate IDs as well.

Finite Rotations

Euler's Displacement Theorem specifies that any displacement on the surface of the globe can be modelled as a rotation about some axis. This combination of axis and angle is called a finite rotation and can be expressed as a latitude, longitude and angle of rotation. Finite rotations are used by GPlates as the elementary building blocks of plate motion.

Total Reconstruction Poles

Total Reconstruction Poles tie finite rotations to plate motion. A total reconstruction pole is a finite rotation which "reconstructs" a plate from its present day position to its position at some point in time in the past. It is expressed as the combination of a "fixed" Plate ID, a "moving" Plate ID, a point in time and a finite rotation.

Reconstructions are defined in a relative fashion; A single total reconstruction pole defines the motion of one plate id (the "moving" Plate ID) relative to another (the "fixed" Plate ID) at a specific moment in geological time. A sequence of total reconstruction poles is needed in order to fully model the motion of one particular plate across the surface of the globe throughout time.

Anchored Plate ID

A sequence of total reconstruction poles is used to model the motion of a single plate across the surface of the globe. Total reconstruction poles describe the relative motion between plates, but ultimately this motion has to be traced back to a single Plate ID which is considered "anchored". GPlates calls this the Anchored Plate ID. Generally, this Plate ID corresponds to an absolute reference frame, such as a hotspot, paleomagnetic, or mantle reference frame. The convention is to assign the anchored Plate ID to 000, but GPlates allows any Plate ID to be used as the anchored Plate ID.

The Rotation Hierarchy

To create the model of global plate rotations that is used in GPlates, total reconstruction poles are arranged to form a hierarchy, or tree-like structure. At the top of the hierarchy is the anchored Plate ID. Successive Plate IDs are further down the chain and linked by total reconstruction poles. To calculate the absolute rotation of a Plate ID of a feature with a given Plate ID (relative to the fixed reference defined by the anchored plate ID, at a given time), GPlates starts at that point in the hierarchy and works its way up to the top - to the root of the tree.

For example, in the GPlates-compatible 2008 EarthByte Global Rotation

Model, the South American plate (also known by the abbreviation “SAM”, with plate ID 201) moves relative to the African plate (“AFR”, 701), as does the Antarctic plate (“ANT”, 802), while the Australian plate (“AUS”, 801) moves relative to the Antarctic plate. This is illustrated in Figure 1.

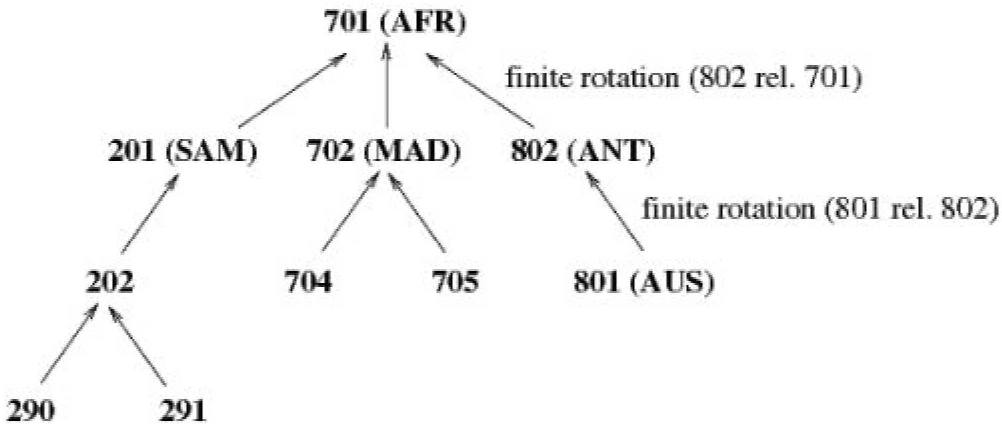


Figure 1: Sample of a simple rotation tree.

Content of a rotation file

Figure 2 is a section from a rotation file. The basic content is the same in other file formats e.g. GPML.

Column 1: “Moving” Plate ID e.g. 652

Column 2: Time e.g. 0.0 (Ma)

Columns 3, 4, 5: Rotation poles. The first two are the coordinates of the pole of rotation (latitude, longitude), the third is the angle of rotation.

Column 6: Conjugate or “fixed” Plate ID (Rotations relative to this plate) e.g. 609

Column 7: Abbreviation of Plate and Conjugate Plate and name, and sometimes the relevant reference e.g. WPV-NPS West Parece Vela Basin – North Philippine Sea.

There are usually multiple entries for the same Plate ID, but with different times and rotation poles and, sometimes, different conjugate plates, to capture the rotation history of a given plate relative to neighboring, or conjugate plates. Which plate is assigned as a given plate’s conjugate depends on the user. Generally this choice is determined by where most of the constraints for reconstructing the relative motion history are, and this can be time-dependent.

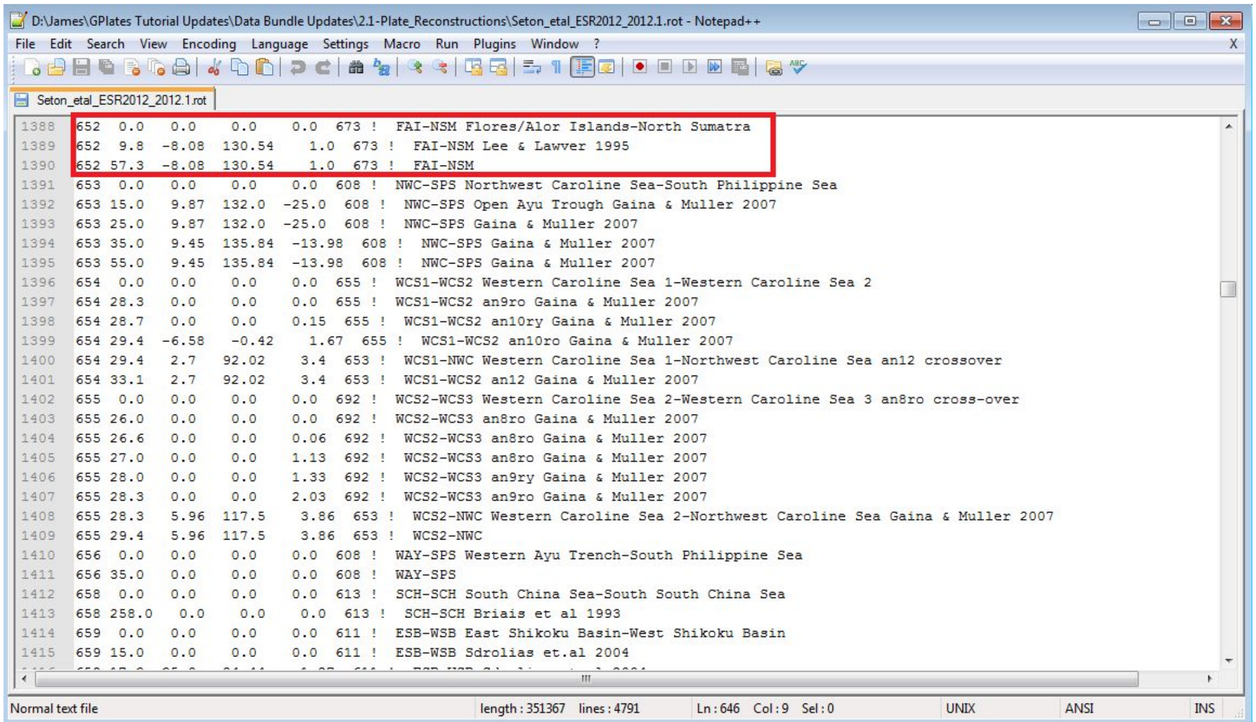


Figure 2: Sample of a rotation file.

Exercise 1 - Plate Hierarchy

Here we will see what the plate hierarchy looks like in GPlates.

1. Open GPlates

2. File > Open Feature Collection… > Open the following files:
   - Coastlines: Seton_etal_ESR2012_Coastlines_2012.1_Polygon.gpmlz
   - Rotation: Seton_etal_ESR2012_2012.1.rot

3. Click and drag the globe to rotate it such that it is centred on the South Atlantic (Figure 3). You will see that all the plates are coloured according to their Plate ID.

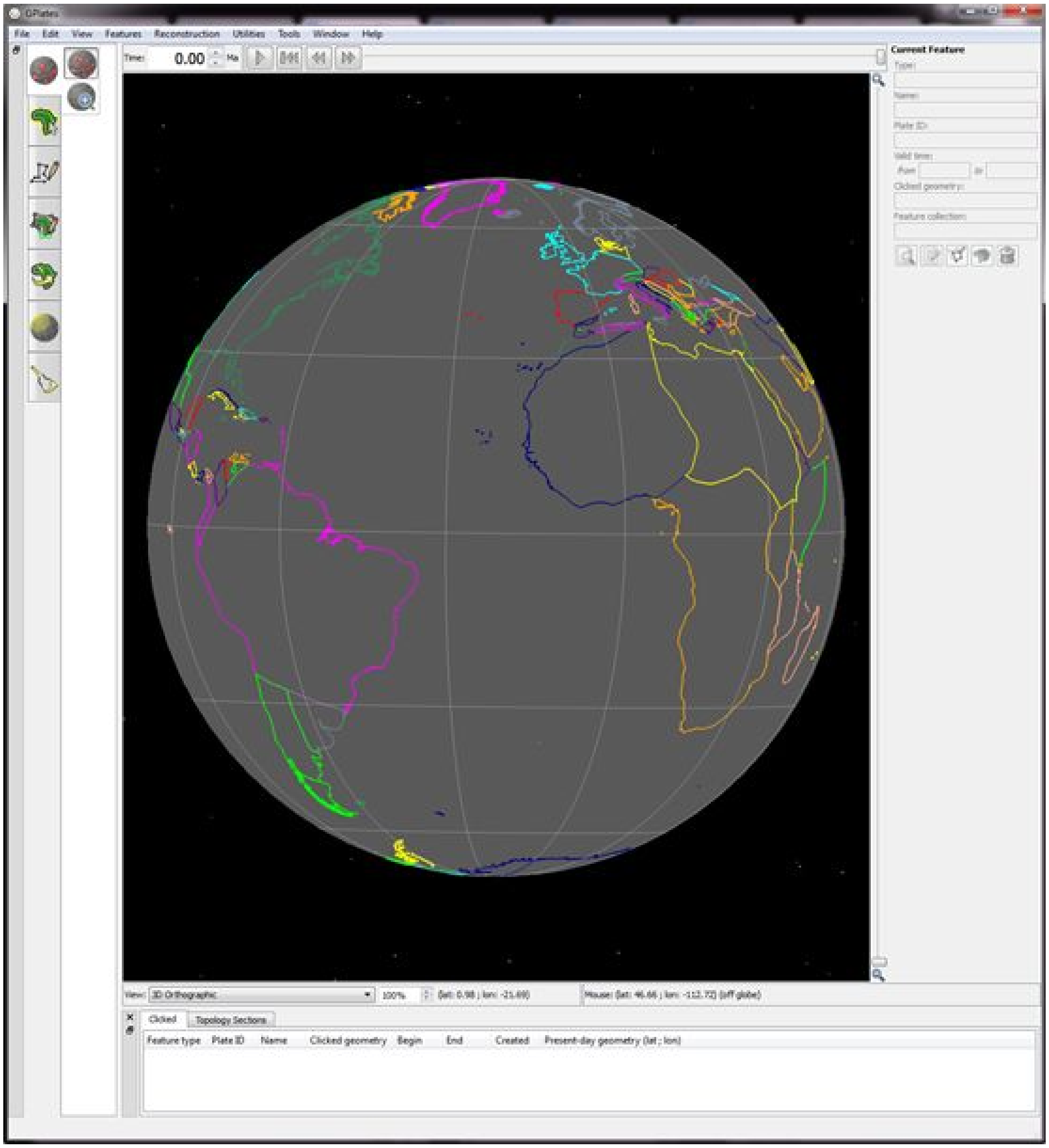


Figure 3: Coastlines of the world, globe centred on the South Atlantic

We will now view the plate hierarchy of the files loaded

4. Reconstruction > View Total Reconstruction Poles (Figure 4) > Reconstruction Tree (third tab, Figure 5).

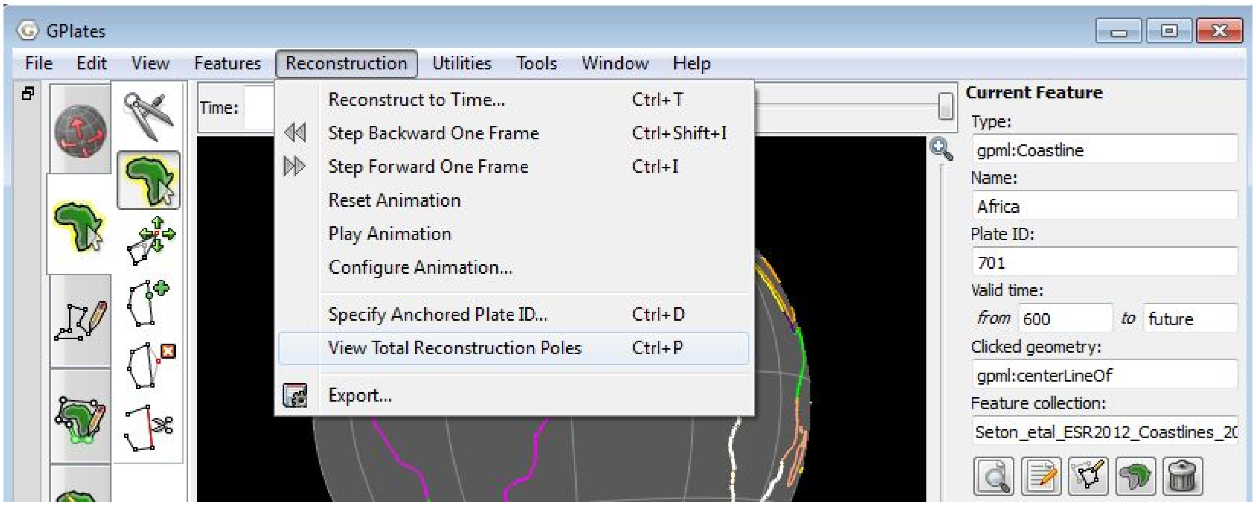


Figure 4: Navigating to View Total Reconstruction Poles from the Main Menu.

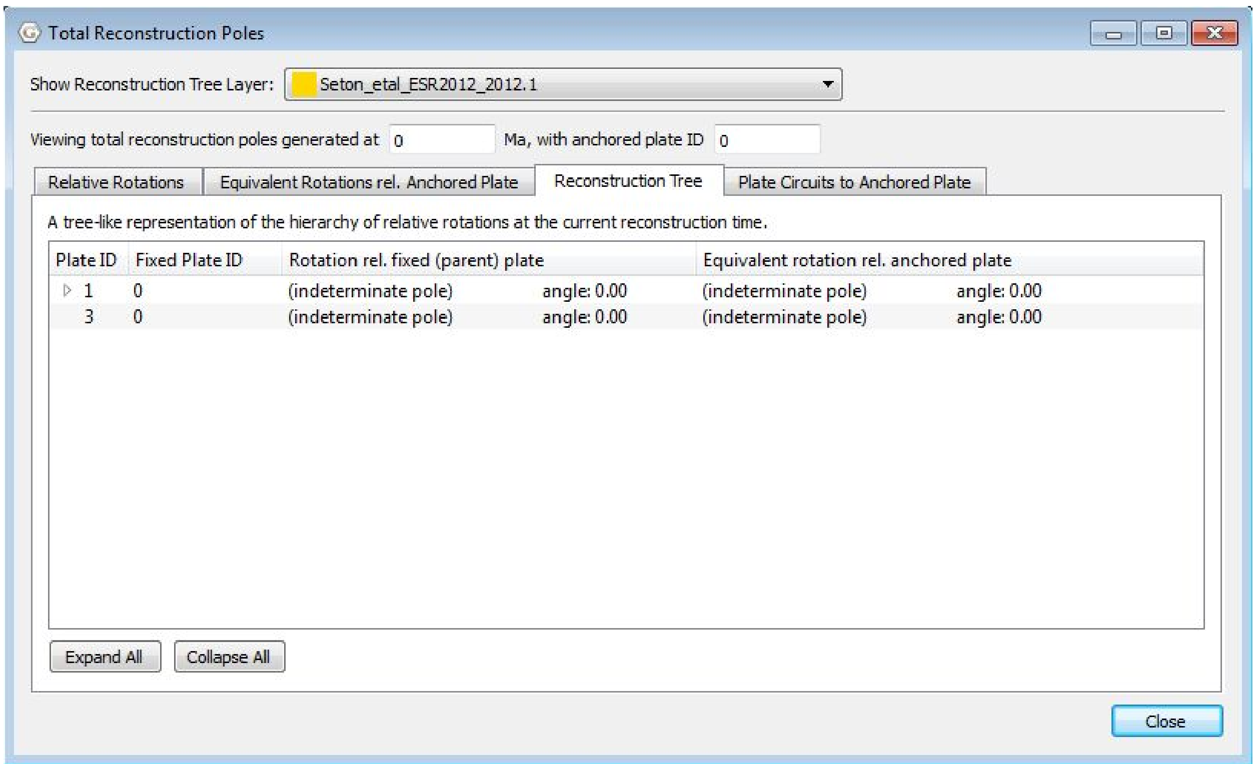


Figure 5: The plate hierarchy is found under the Reconstruction Tree tab in the Total Reconstruction Poles window (third tab).

You will see that the highest entry id is Plate ID 1 (001 – Atlantic-Indian hotspots) which is fixed to 0 (000 – Earth's spin axis).

5. Click the small triangle to the left of the '1', this will reveal the next highest plate in the plate hierarchy - Plate 701 (Africa) (Figure 6).

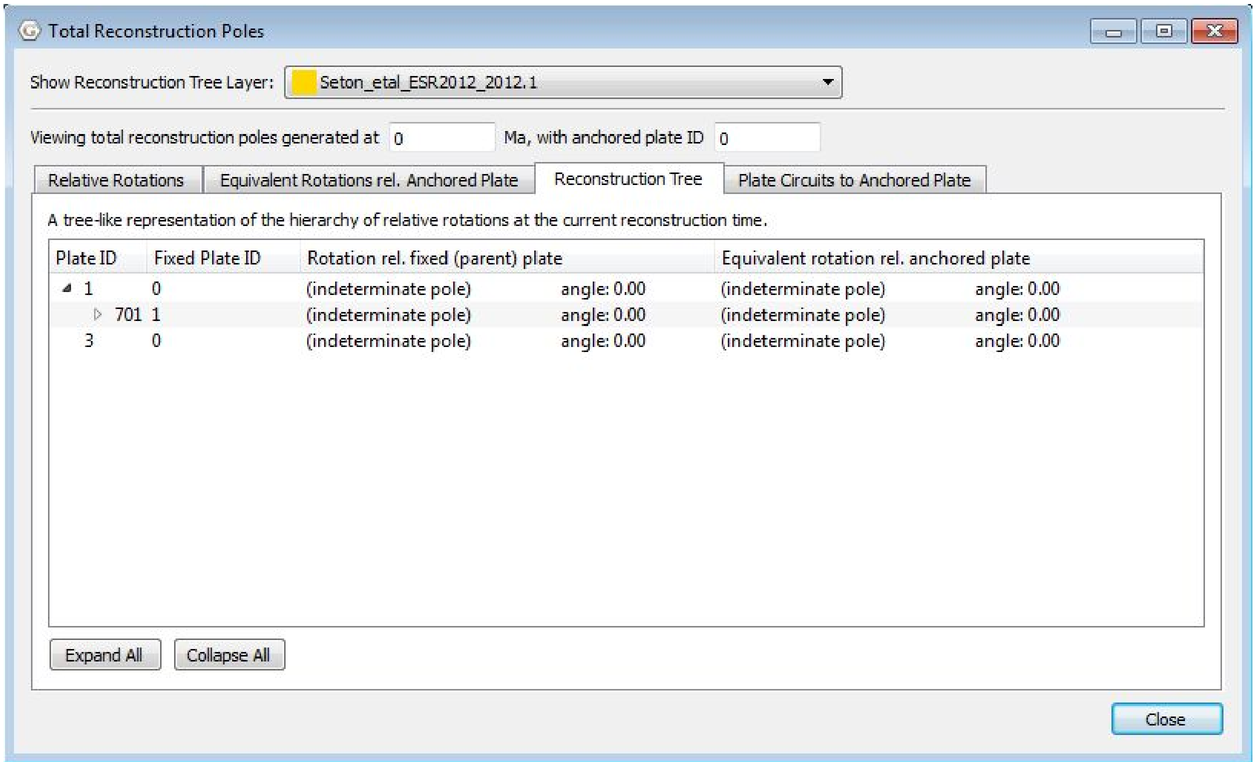


Figure 6: Expanding Plate ID 1, you reveal the next highest plate in the plate hierarchy.

6. Now expand the tree even further by clicking the small triangle next to Plate ID 701 (which plate is this?). You will see that plates 201, 307 503, 507 etc move relative to 701, which in turn moves relative to 001, which in turn is fixed to 000 (Figure 7).

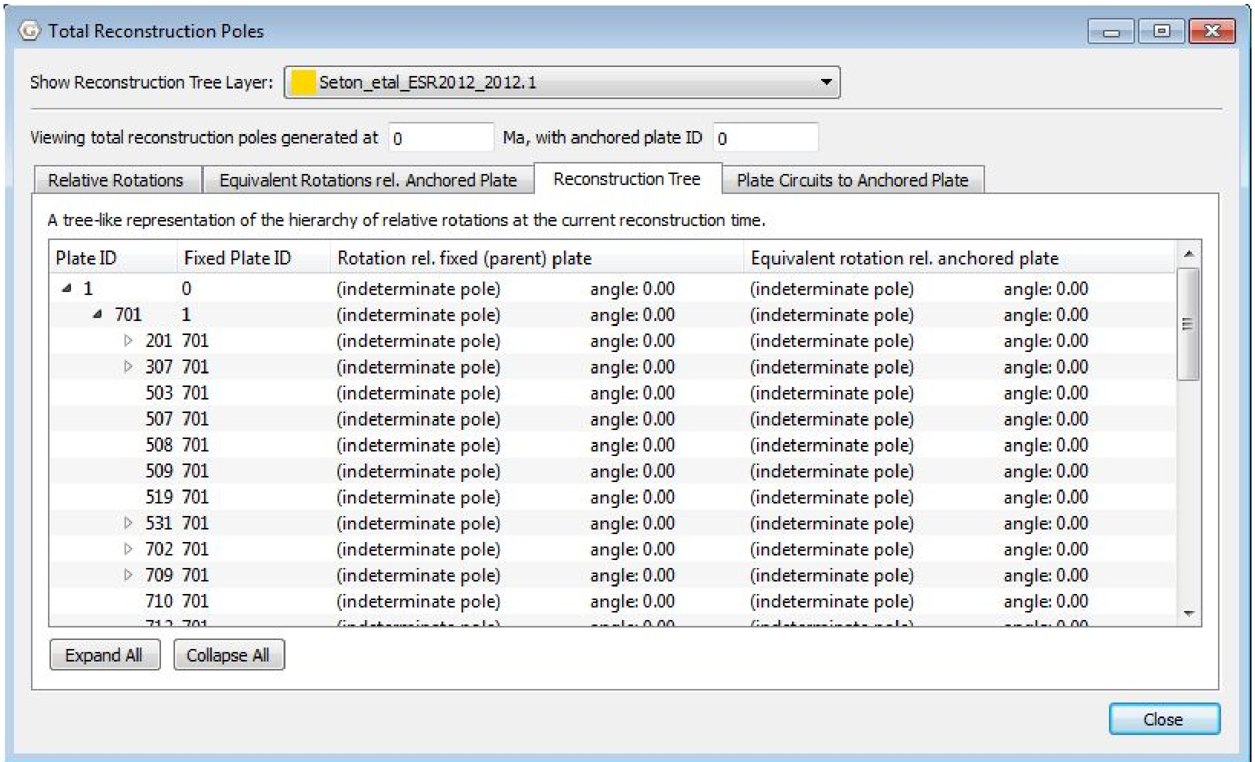


Figure 7: The plate hierarchy tree for our loaded files.

7. Click Expand All, and you can see how all the plates in the Coastline file move at the reconstructed time, i.e. which plates they move relative to.

Changing something high in the rotation tree will affect the absolute rotations of all lower plates (relative motions will remain the same). You can always check the conjugate plate by looking at the information of a particular plate, or checking the reconstruction tree as above.

For more detailed information about plate hierarchy, see [Tutorial 2.1] or the [GPlates User Manual]

Exercise 2 - Reconstructing Data on the Globe

Now that you have some understanding of how a plate hierarchy works, it is a good idea to spend some time actually reconstructing the coastline data. We will now employ the rotation file to reconstruct our coastlines back to 100 Ma, The easiest way to reconstruct data is by using the Time (Figure 8) and Animation tools (Figure 9).

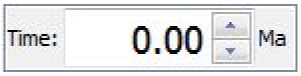


Figure 8: The Time tools enable you to jump to a certain time.

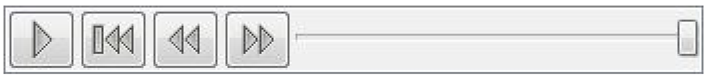


Figure 9: The Animation tools in the Main Window enable you to reconstruct data back and forth through time.

1. In the Time Controls box (Figure 8) type 100 Ma > Enter. Rotate the globe and have a look at where the continents were 100 Ma (Figure 10).

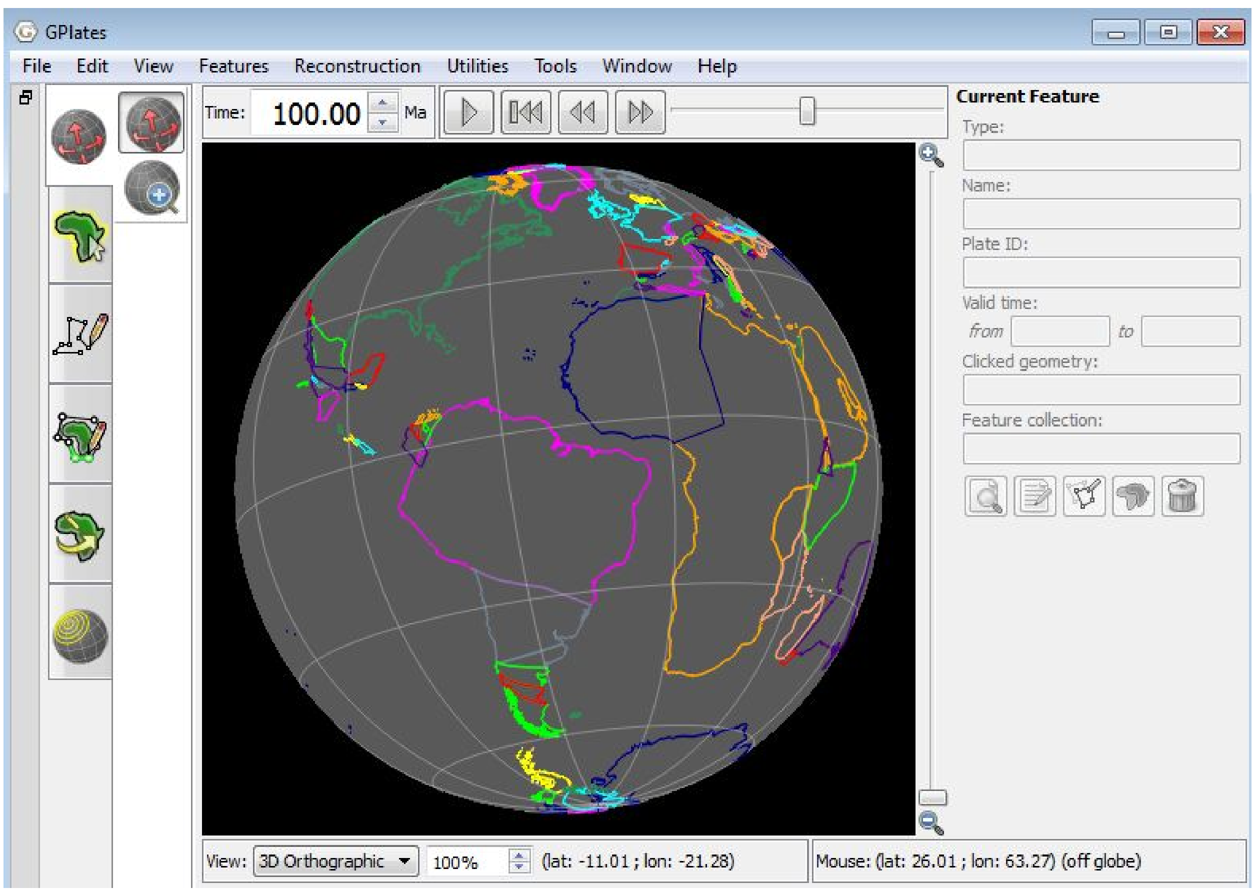
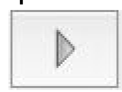
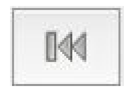


Figure 10: View of the coastlines at 100 Ma. Note that in the Time Controls box (top left) the time says 100.00 Ma.

An alternative way to reconstruct your data is by using the Animation controls. You can simply click and manually move the time slider (notice that in Figure 10, the slider is no longer at the far right but is a third of the way along) or you may jump to a certain time and then “play” an animation of the feature data reconstructing.

2. Make sure that you are still at 100 Ma (or jump to any time in the past) > press the play button in the Animation Controls  and watch the coastlines rotate back to their present-day positions. To animate the entire time period you have rotations for, first use the Reset button  to take you back to the oldest time you have rotations for and then press play.

You may also watch animations of your data by using the Configure Animation option from the Reconstruction menu (Figure 11).

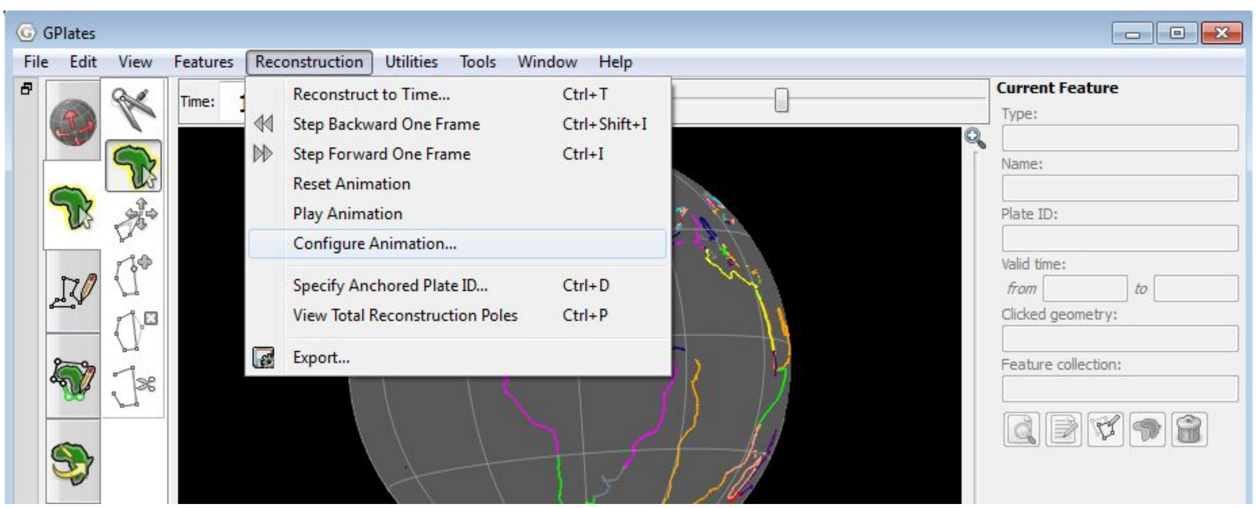


Figure 11: Animations can be manually configures from the Reconstruction menu.

The Animate window provides you additional control over your animation (Figure 12). For example, you can specify whether you want to watch a reconstruction run backwards or forwards through time by clicking the Reverse the Animation button.

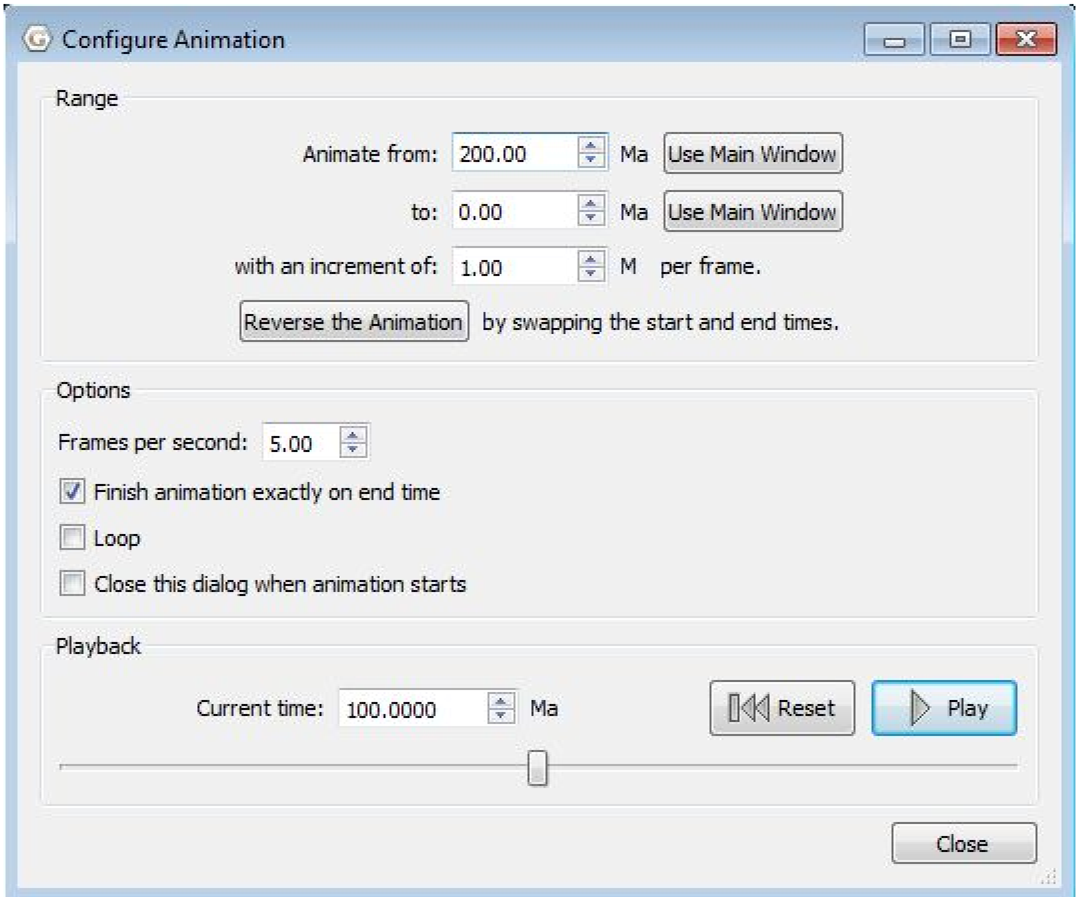


Figure 12: The Animate window allows you to specify details about your animations.

GPlates also enables you to change the anchored plate so that you can reconstruct data keeping different plates fixed.

3. Reconstruction > Specify Anchored Plate ID… > 201 > OK (Figure 13).

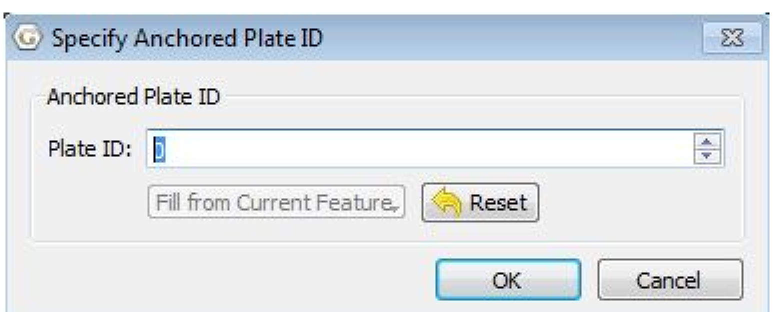


Figure 13: Nominating which plate to keep fixed.

Now that we have fixed the South American plate, change the animation time to 100 Ma and see how this influences the plate motions.

4. Once you have finished experimenting, set your anchored plate back to 000 (the spin axis – default).

For more detailed information about reconstructing data, see Tutorial 2.1 or the GPlates User Manual

Exercise 3 - Applying Rotations

When creating tectonic reconstructions, it is more likely that you will want to change or apply a rotation to a feature back in time, rather than changing anything at the present-day. Using a simple example, we will learn how to apply a rotation.

Australia started to move away from Antarctica ~83 Ma. According to Tikku and Cande (1999), Australia moved in a northward direction relative to a fixed Antarctica. You will implement this rotation in the provided rotation file, AusAnt_ExampleRotation.rot. For simplicity, this file contains rotations for Australia and Antarctica only.

1. Open AusAnt_ExampleRotation.rot in a text editor so you can see what it looks like (Figure 14):

a. Plate ID 000 = Spin axis

b. Plate ID 001 = Atlantic hotspots

c. Plate ID 701 = Africa

d. Plate ID 801 = Australia

e. PlateID 850 = Tasmania

f. Plate ID 802 = Antarctica

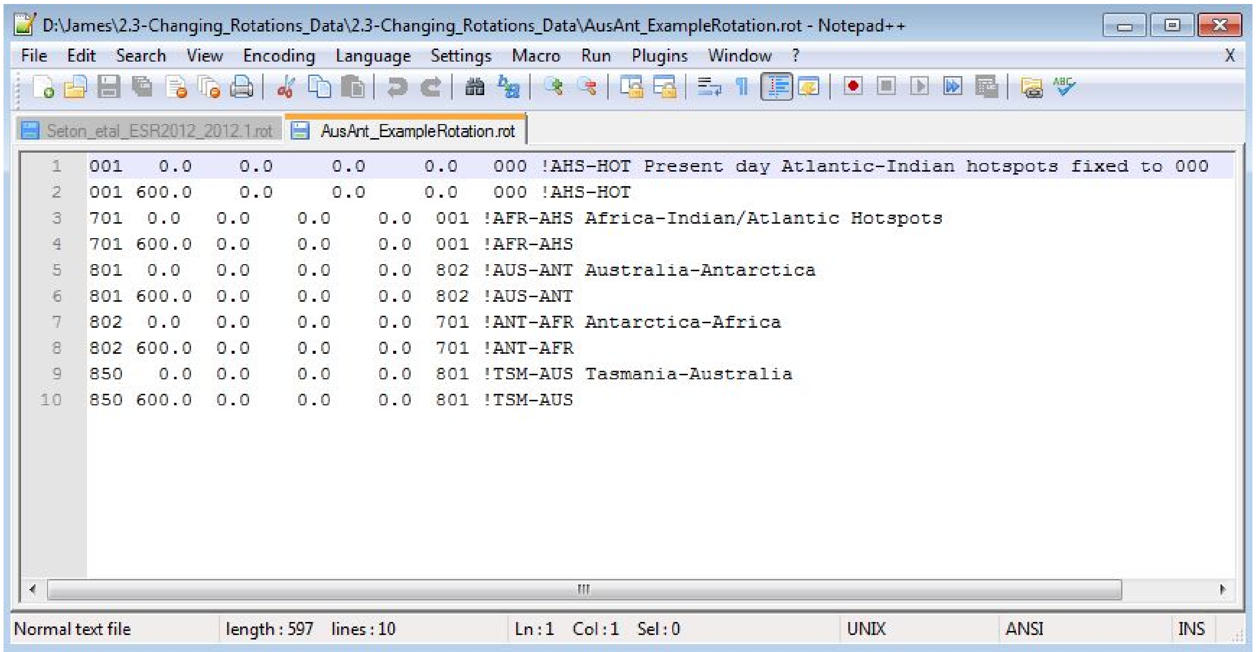


Figure 14: The contents of our example rotation file.

You will notice that Australia moves relative to Antarctica, Antarctica moves relative to Africa, Africa moves relative to the hotspot reference frame which is fixed to the spin axis.

2. If you are proceeding from Exercise 2, File > Manage Feature Collections…
   - Eject the global rotation file (Seton_etal_ESR2012_2012.1.rot)
   - Click Open File… > Select AusAnt_ExampleRotation.rot

(If you are coming directly to this tutorial, open the coastlines file as well as the AusAnt_ExampleRotation.rot file by File > Open Feature Collection…)

3. Rotate the globe so that it is centred on Australia. Now reconstruct backwards through time. You will notice that the features fixed in their present-day locations (this is because they have no relative rotations). The only thing that changes is that features will disappear if you reconstruct to before their 'appear time'.

It is generally believed that Australia moved northwards, relative to a fixed Antarctica, between ~83 Ma and the present (Tikku and Cande, 1999). We will implement this rotation.

5. Centre your globe so that Australia and the coastline of Antarctica nearest Australia are in view (Figure 15).

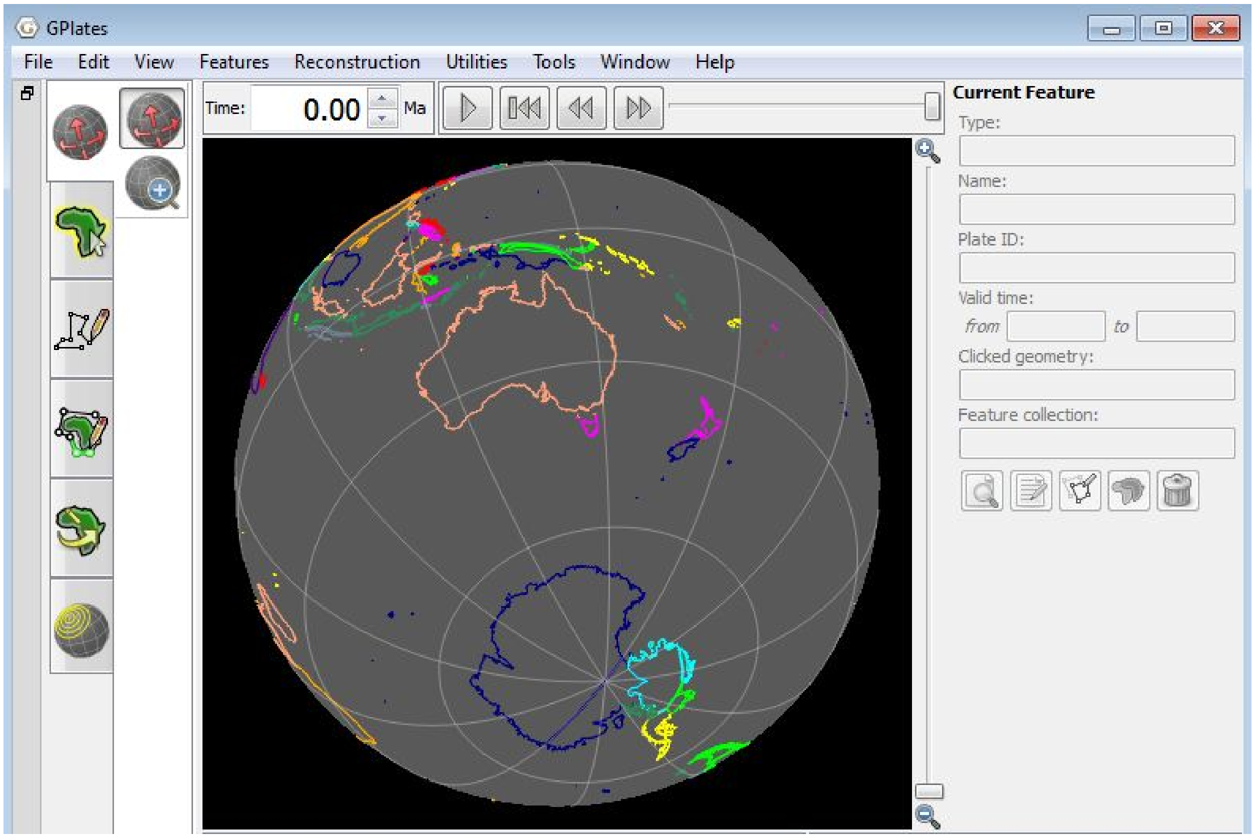


Figure 15: View of Australia and Antarctica.

6. As we want to implement a rotation at 83 Ma, jump to this time using the Time controls.

7. Use the Choose Feature tool  to select Australia (click somewhere on the coastline - it should go white once selected) and then click Modify Reconstruction Pole .

8. Drag Australia in a southward direction so that it approximately lines up with Antarctica (Figure 16).

If at first you are not happy with the new location of Australia, just click and drag again as appropriate. The feature can also be rotated about its axis by holding down SHIFT and dragging.

Note: the globe can still be re-oriented whilst holding down the Command (Mac)/Control(PC) key while in the “Modify Reconstruction Pole” mode. Information regarding the reconstruction pole is displayed in the task panel to the right. This includes the Plate ID of the feature you are moving and the new rotation pole that will be applied if this location is confirmed by pressing Apply.

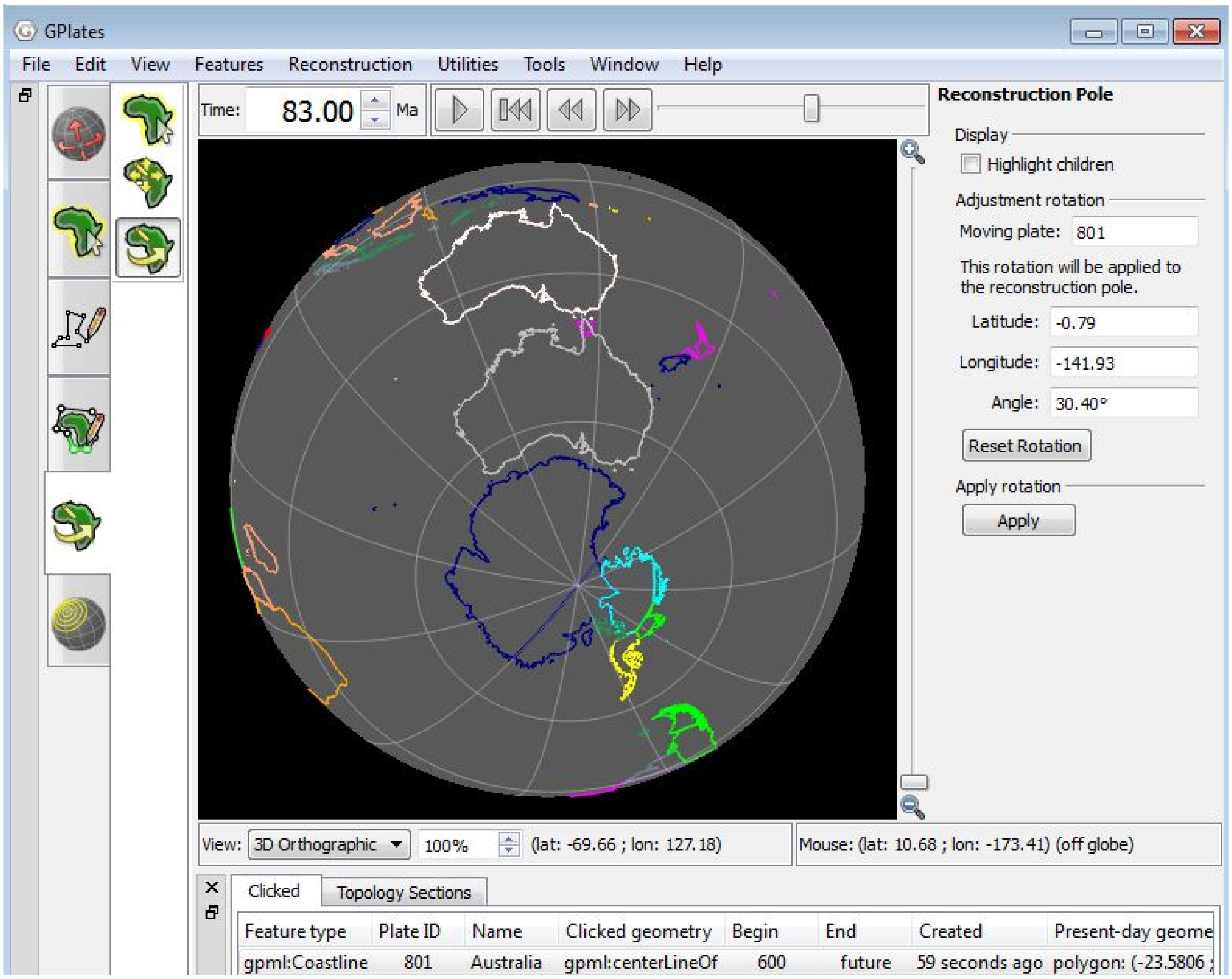


Figure 16: Australia has been dragged southward at 83 Ma to line up with Antarctica.

9. Once the feature attains the desired position and orientation, click Apply (right of the globe). This will open up Apply Reconstruction Pole Adjustment window, where you can review the details of your implemented rotation (Figure 17).

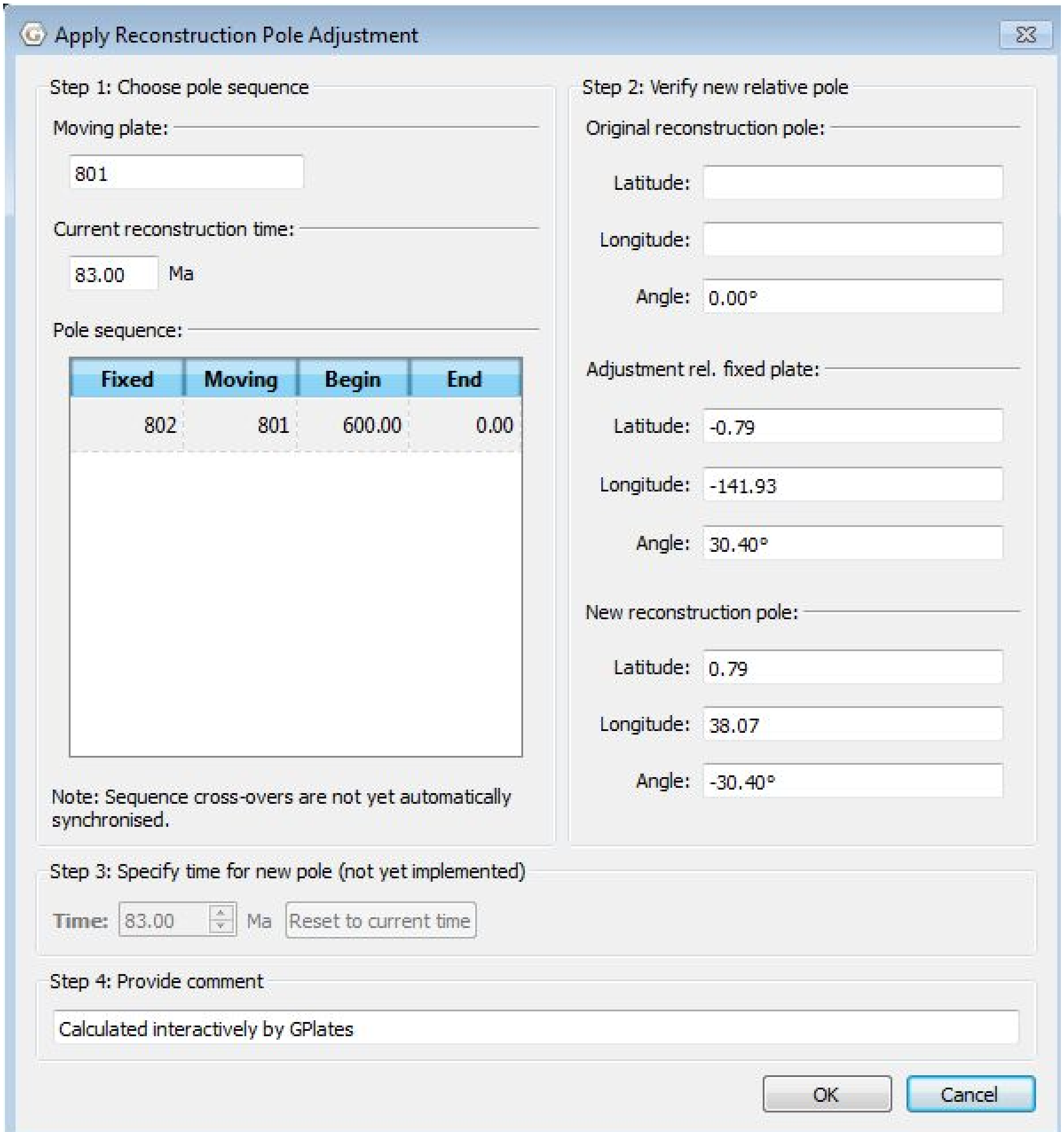


Figure 17: Apply Reconstruction Pole Adjustment window, where you can review the details of your rotation implementation.

9. In this window you can verify the new relative pole and details (Figure 17). Click OK (this will implement your rotation)

You will notice that Australia is now positioned adjacent to Antarctica at 83 Ma (Figure 18).

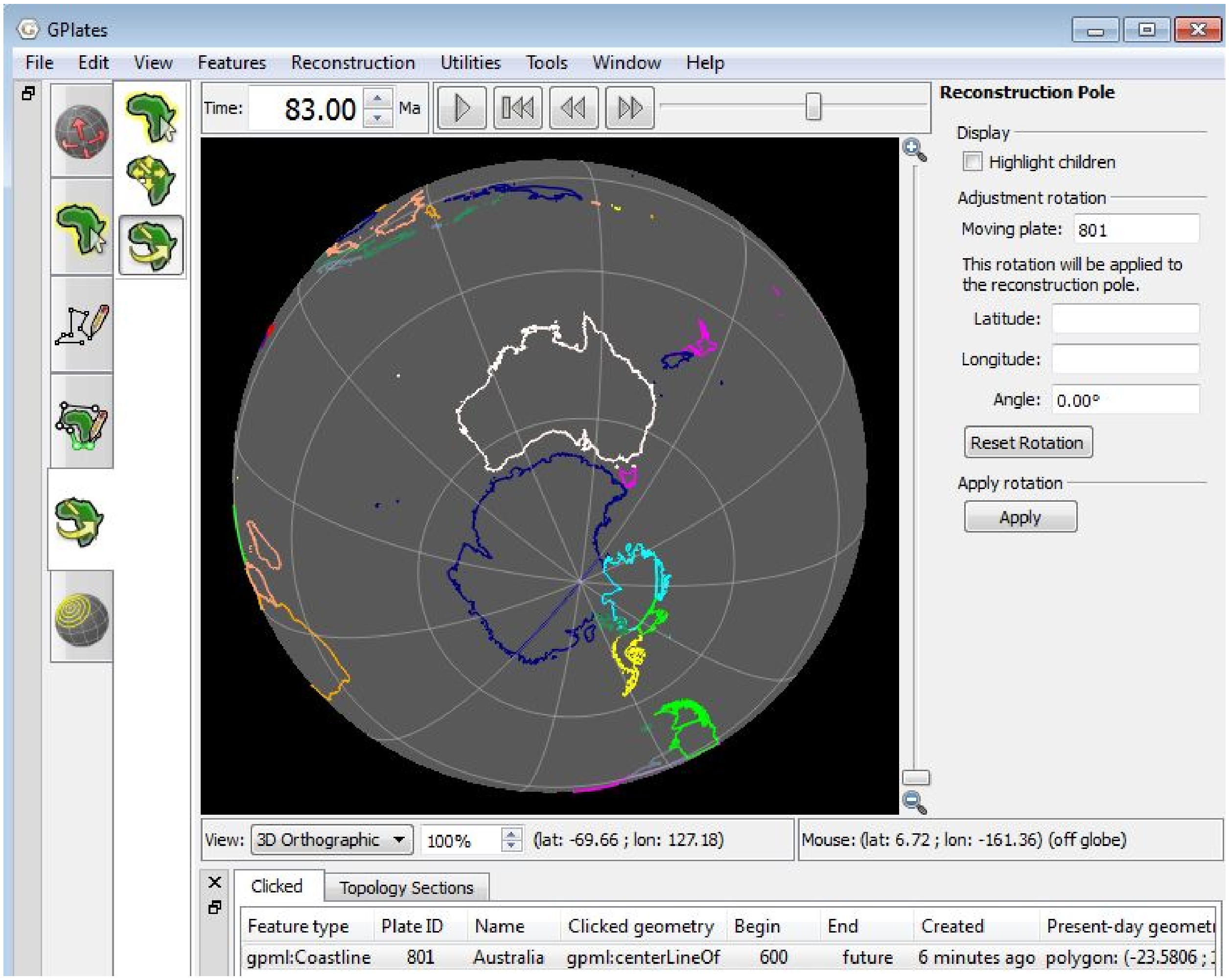


Figure 18: Australia is now positioned adjacent to Antarctica at 83 Ma. It is south of its present-day position.

Now you need to save your rotation file.

10. File > Manage Feature Collections > save a copy of the rotation file with a new name (this is so you can compare it to the old rotation file)

11. Remove the old rotation file (by clicking the eject button) and load this new rotation file by clicking Open File and navigating to the directory where it is saved > Open.

12. Use the Animation slider to reconstruct from 83 Ma to the present. You will see Australia move in a northward direction relative to Antarctica!

13. However there is one more thing we need to do. If you jump to 600 Ma for example and animate back to 0 Ma, you will notice that Australia starts in its present day coordinates, moves southward to its 83 Ma position and then

moves northwards again. This is because the location of Australia at 600 Ma is the same as present-day in our rotation file (Figure 19). We need to alter the rotation file so that there are not rotations between 600 Ma and 83 Ma.

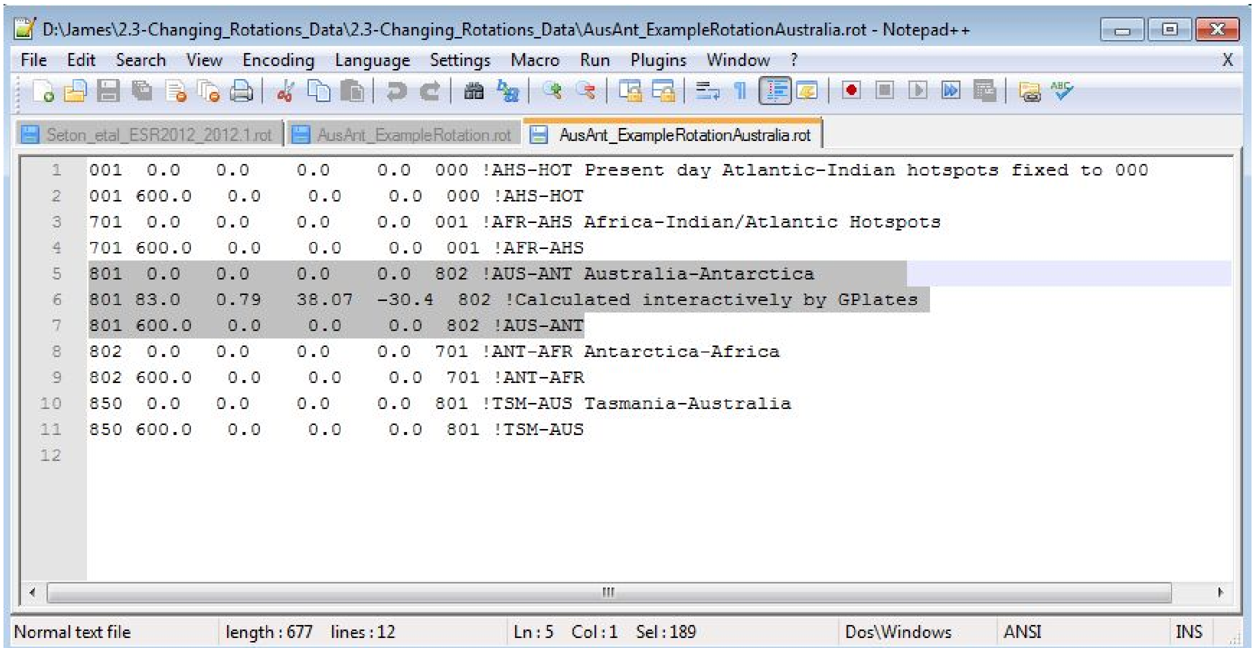


Figure 19: A rotation has been added for Australia at 83 Ma. However notice that the latitude and longitude of Australia at 600 Ma is the same as present-day.

14. Open the new rotation file in a text editor. And make the 600 Ma rotation data (lat., long., rotation angle) for Plate ID 801 the same as the 83 Ma rotation (ie duplicate the data) (Figure 20). This will result in no rotation between Australia and Antarctica until the period 83 Ma – 0 Ma.

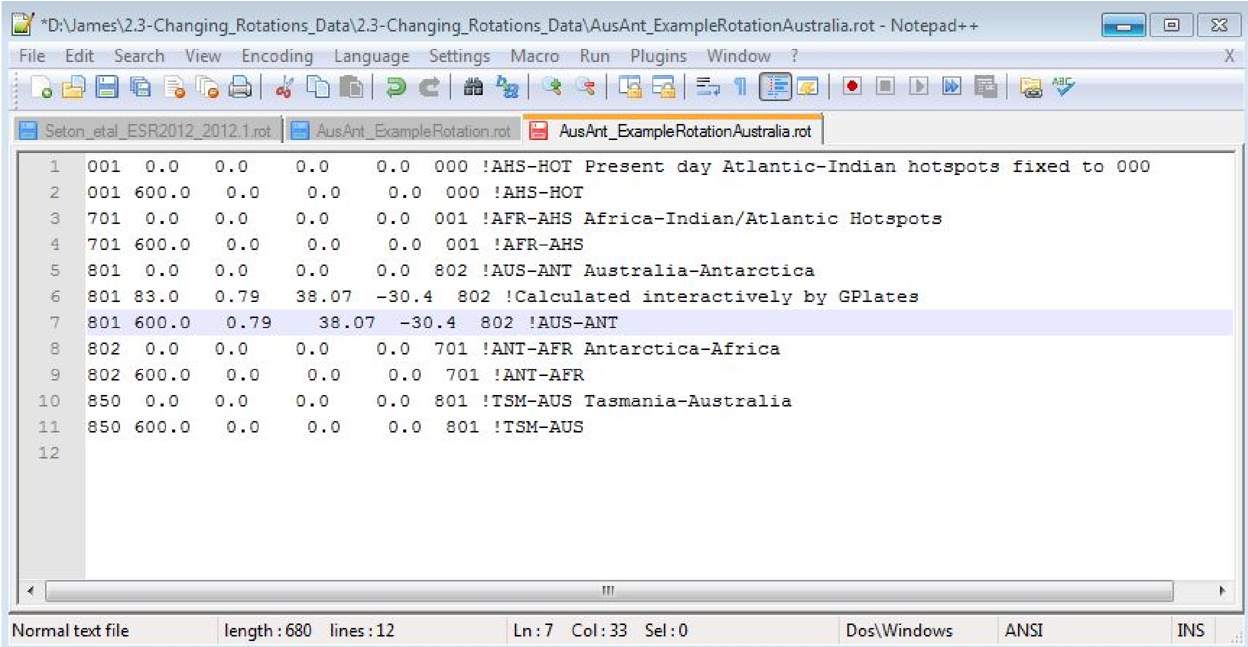


Figure 20: Modified rotation file, note that the 600 Ma and 83 Ma rotations for Plate ID 801 are the same.

15. Load your modified rotation file into GPlates and animate forward in time from say 150 Ma. You will notice that Australia stays attached to Antarctica until 83 Ma.

For more detailed information about rotation features, see Tutorial 2.1, or about applying rotations, see Tutorial 2.2 or the GPlates User Manual

Exercise 4 - Modifying Rotations

In this exercise we will learn how to modify an existing rotation file. Keeping with the theme of Australia and Antarctica we will implement a new rotation for Australia at 83 Ma. Whittaker et al. (2007) proposed that 83 Ma Australia was located further eastwards with respect to Antarctica than previously thought (e.g. Tikku and Cande, 1999). They suggest that from ~83 Ma to 50 Ma Australia moved northwest relative to a fixed Antarctica, before then commencing northward motion between 50 Ma and the present.

1. Eject all existing rotation files from GPlates but keep the Seton_etal_ESR2012_Coastlines_2012.1_Polygon.gpmlz file loaded. File > Manage Feature Collections > click the eject symbol  corresponding to

all loaded rotation files. Keep the Manage Feature Collections window open.

2. Open File > select the rotation file for this exercise Global_EarthByte_GPlates_Rotation_AusAnt_Example.rot > Open

The rotation file we have just loaded is significantly more complicated than that of the last exercise. Reconstruct the globe back through time and you will see that all the plates move. If you open this rotation file in a text editor you can see how much longer and more detailed it is compared to the last exercise.

3. Use the Time Controls to jump to 83 Ma.

We will use the fracture zones to help us constrain the position of Australia 83 Ma.

4. File > Manage Feature Collections > Open File > select AusAnt_FZs.gpml from the data bundle > Open

Following Whittaker et al. (2007) we will align the Antarctic fracture zone with the most westerly Australian fracture zone, whereby shifting Australia east relative to a fixed Antarctica.

5. Use the Choose Feature button  to select the Australian fracture zone > click Modify Reconstruction Pole  > drag the fracture zone eastward so that it is connected to the Antarctic fracture zone (Figure 21) > click Apply (right of globe) > you can then click OK in the Apply Reconstruction Pole Adjustment window once you have reviewed the details of your new reconstruction and are satisfied.

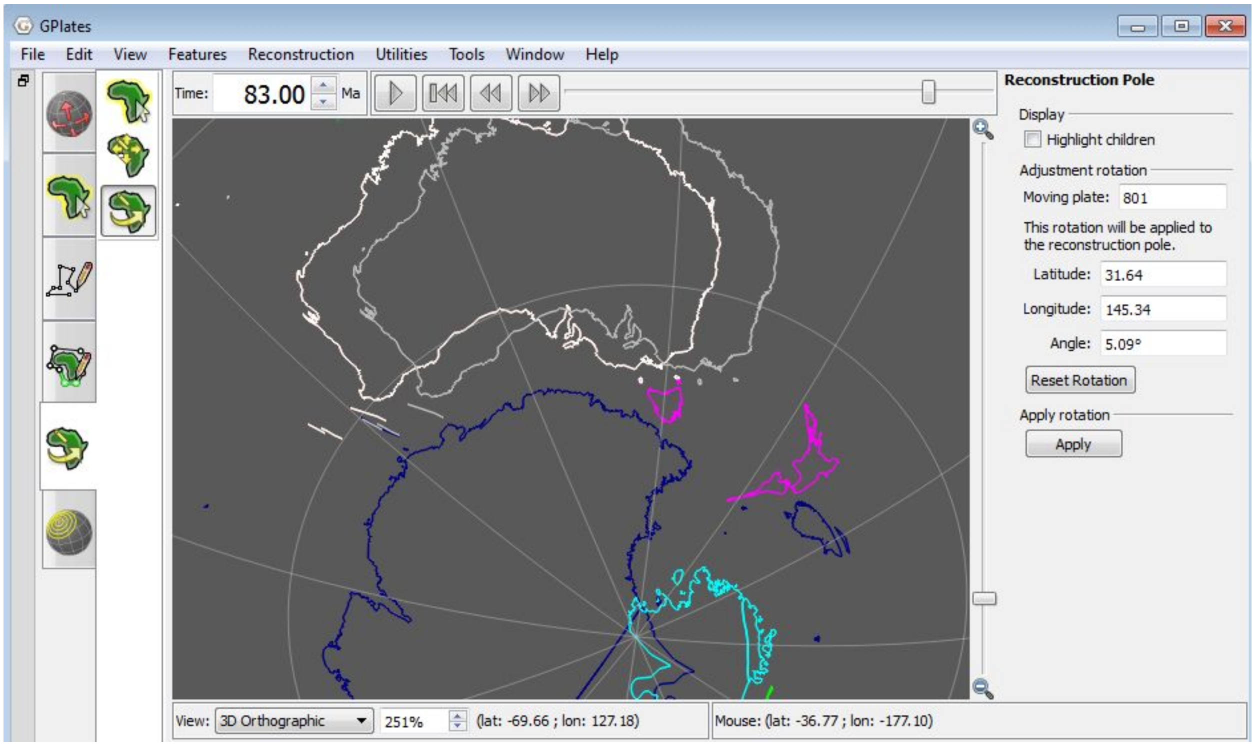


Figure 21: Australia shifted east using the Modify Reconstruction Pole tool.

When you return to the globe you will notice that Australia is located further east than when you started (Figure 22). We now need to save this data.

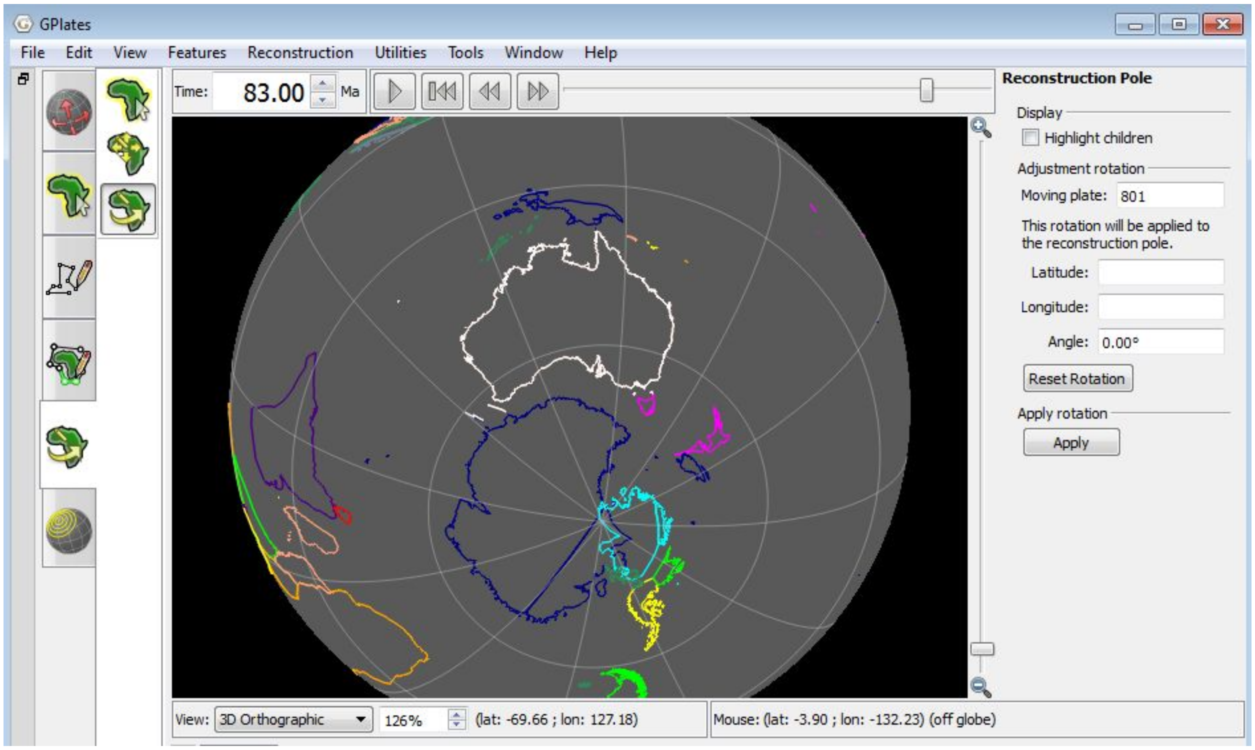


Figure 22: Australia shifted further east 83 Ma.

6. File > Manage Feature Collections > save your Global_EarthByte_GPlates_Rotations_AusAnt_Example.rot file with a new name  so that you preserve the old rotation file.

Now use the Time controls to watch Australia's motion from 83 Ma to present-day and you will see that there is northwest motion of Australia relative to a fixed Antarctica between 83 Ma and ~50 Ma. Then Australia commences northward motion.

7. Open your modified rotation file and the original rotation file using a text editor and scroll down to the entries for Plate ID 801, compare the two rotation files, you will see that they have different entries now for 83 Ma (Figure 23).

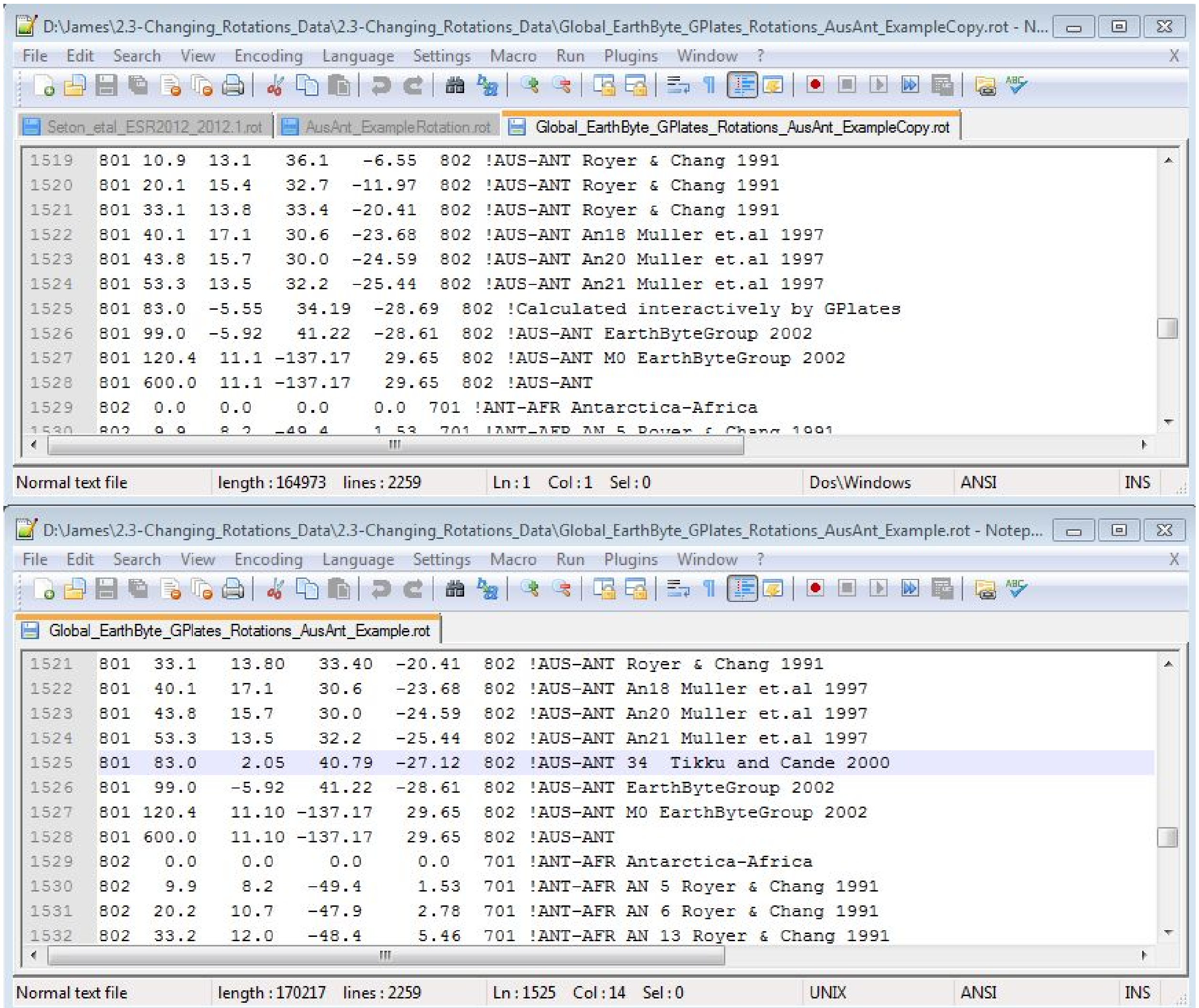


Figure 23: New (top) and old (bottom) rotation files showing entries for Plate ID 801. Entries for 83 Ma have changed.

Note: to better appreciate the change in motion of Australia relative to a fixed Antarctica you can specify Antarctica as the 'anchored plate' rather than the spin axis (default). Reconstruction > Specify Anchored Plate ID > enter 802. Now when you reconstruct the globe you can really notice that Australia moves in a northwest direction between 83 Ma and ~50 Ma.

Things to consider:

The cursor provides longitude and latitude locations to help with re-orienting. This is particularly useful when trying to replicate work from other literature.

Check the existing rotation file for the time increments for the plates. By reconstructing at these times will avoid jumps between two time steps. For example if the existing rotation file has rotations at 10 Ma and 20 Ma, by creating a new rotation at 16 Ma will only change the rotation between 10 Ma and 16 Ma. Between 16 Ma and 20 Ma the plate may jump erratically according to the old pole of rotation, unless you change it or an older timestep.

For more detailed information about changing rotations or other reconstruction options that are rotation-related, see Tutorial 2.2 or the GPlates User Manual

Exercise 5 - Exporting reconstructed geometries

GPlates allows you to export reconstructed geometries, either for a single snapshot or a sequence of snapshots. This functionality allows you to extract palaeo-coordinates for feature data that you have reconstructed back through time using a rotation model. Reconstructed geometries can be exported as a file containing longitudes and latitudes (i.e. in the GMT format, *.xy) or in the shapefile format to be used in GIS software.

To illustrate this procedure we will export reconstructed geometries for our coastlines.

1. Reconstruction > Export…

The Export Animation window is where you specify what type of data you are exporting and for which period of time (Figure 24). We will export our coastline geometries for the time period 50 Ma – 0 Ma, with an increment of 5 Myr.

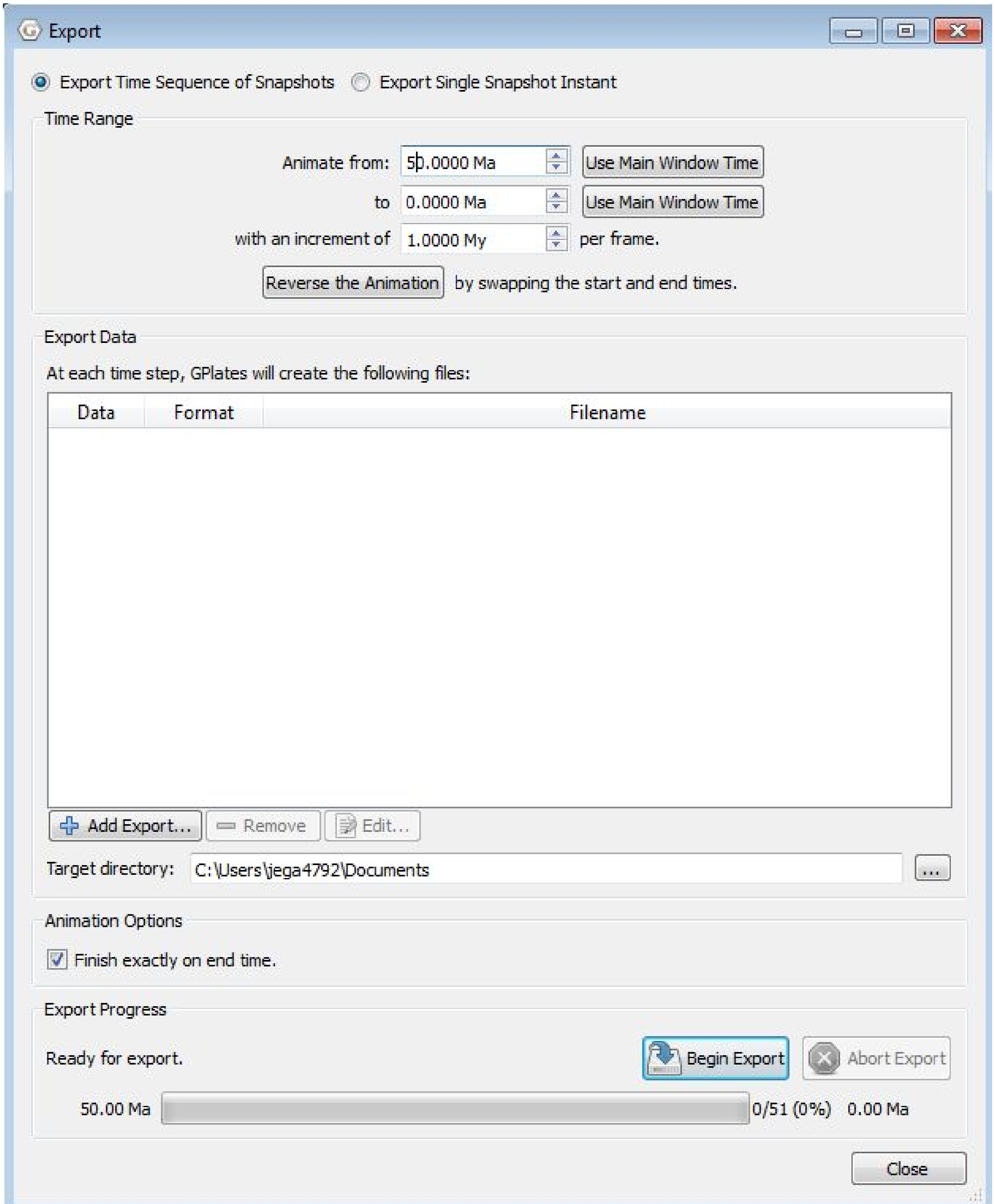


Figure 24: The Export Animation window.

2. Next we must select which files we want GPlates to create. Add Export > select the Reconstructed Geometries option from the top box > choose the GMT (*.xy) format > Select Export to multiple files> OK (Figure 25)

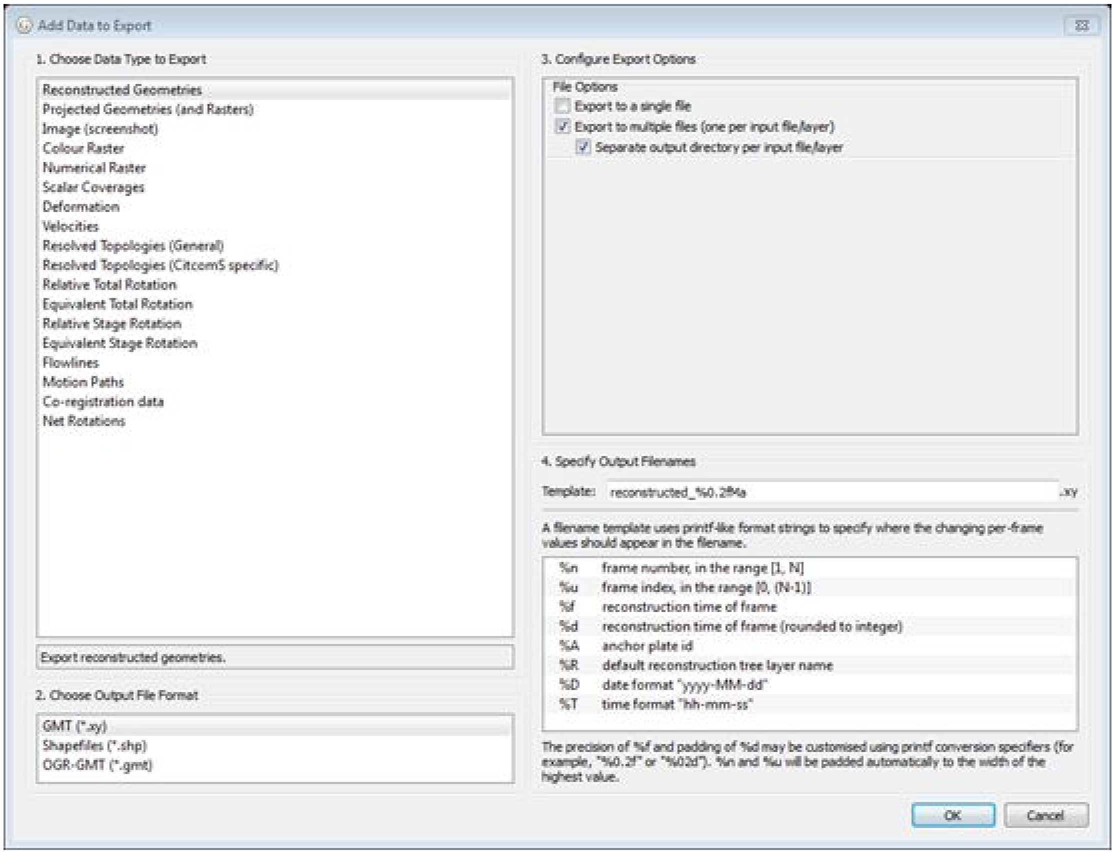


Figure 25: The Add Export window allows you to select which data you want to export, and in which format.

3. Now ensure that you have selected a target directory where your files will be created. When you are satisfied with all the criteria click Begin Animation (bottom) (Figure 26).

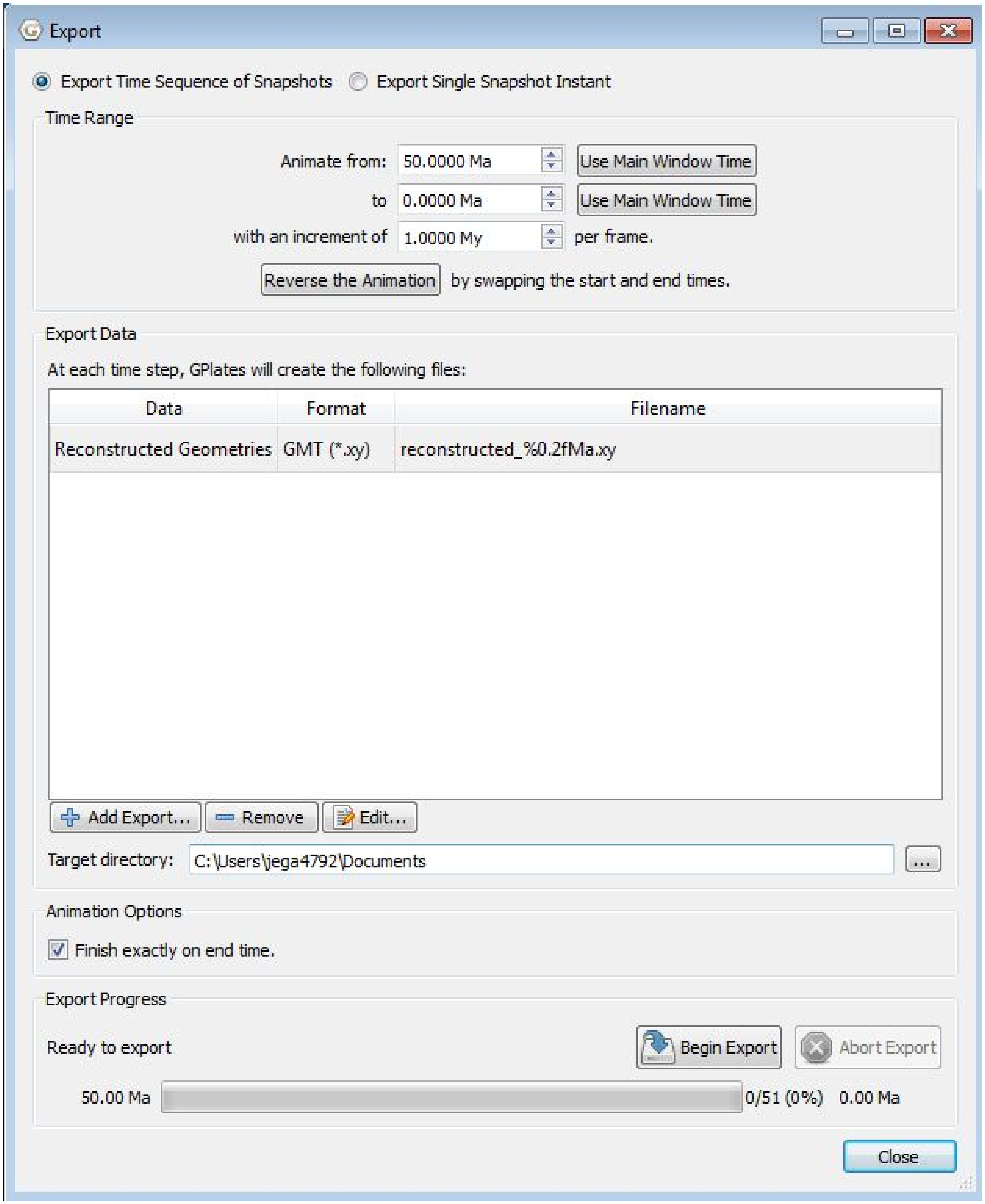


Figure 26. Once all the Export Animation fields have been filled hit Begin Export.

4. Go to the target directory where your files have been sent.

You will notice that GPlates has named the files according to the time the data is for and the number the file is in the sequence of files. The first file is named reconstructed_0.00Ma.xy, the second file is reconstructed_1.00Ma.xy etc.

5. Open one of the files and have a look at the output.

These data can now be plotted using GMT, for example. This GPlates function allows for quick and easy extraction of palaeo-coordinates for use outside of GPlates.

Note: GPlates will extract the reconstructed geometries of all feature data actively being displayed on the Globe. Therefore, turn off the data you do not wish to export the reconstructed geometries for. For example, if you also had the EarthByte Continent-Ocean Boundaries displayed on the globe but you did not wish to extract their reconstructed geometries, then you would go to File > Manage Feature Collections > and either Eject the unwanted files or in the "Layers" window (separate from the main GPlates window) uncheck the eye button, then follow the procedure above.

For more detailed information about exporting reconstructions, see Tutorial 2.1 or the GPlates User Manual

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