GPlates tutorial: Time-dependent rasters and age-based masking of raster images

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2010-10-23

This tutorial aims at teaching the user to utilise the use of time-dependent raster imagery and the new age-based masking functionality of GPlates as introduced with version 0.9.10 of the software (September 2010). It describes the basic methodology to use time-dependent images as well as utilising the age-based masks for reconstructing raster data in plate tetonic simulations.

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1. Introduction

With the release of version 0.9.10 of GPlates, functionality to do age-based masking of raster data was included. This means any age-grid can be used to mask underlying rasters which in turn can be cookie-cut by polygons and rotated to their position in the past.

In this tutorial we will be working on importing and visualising raster data in GPlates and rotating and masking raster data back through time. The tutorial will use the data included in the GPlates distribution in the Sample data folder (see the “Sample data” section under Appdx. A).

2. Files

For this tutorial we will be using a few different sets of files:

1. The bundled tutorial data set includes time-depedent raster sequences of reconstructed ocean floor age at 1 Ma timesteps as well as regional depth slice images of seismic tomography which have been age-coded (c.f. Appdx. B).

2. Sample raster images of time-dependent dynamic topography, global gravity and topography/bathymetry. The global gravity image can be found in sample-data/Rasters, called DNSC08GRA_6m.jpg. The dynamic topography images are located in sample-data/Rasters/Time-dependent raster sequences/dynamic topography. Additionally, users might want to load the global 1' resolution topography ETOPO1, called color_etopo1_ice_low.jpg which is bundled with this tutorial or available at the NGDC website. Download the image and save it in the Rasters directory of the sample data folder. You can interrogate the images using any image viewer on your computer and check how they look outside of GPlates.
3. Digital age of the ocean floor grid for age-based masking. This grid is the age of the ocean floor as published by Müller et al. [2008] from the EarthByte group. It will be used to mask other rasters based on their age. The file is found in sample-data/Rasters and called agegrid_6m.nc. It is a netCDF grid created by GMT v4.
4. A set of global polygons to cookie-cut plates. The corresponding data set is located in the sample data folder at the following location: sample-data/FeatureCollections/StaticPolygons/Global_EarthByte_GPlates_PresentDay_StaticPlatePolygons_20100927.gpml.
5. A rotation file which provides the plate kinematic model, allowing us to rotate features back through time. The file is located here: sample-data/FeatureCollections/Rotations and is called Global_EarthByte_GPlates_Rotation_20100927.rot.

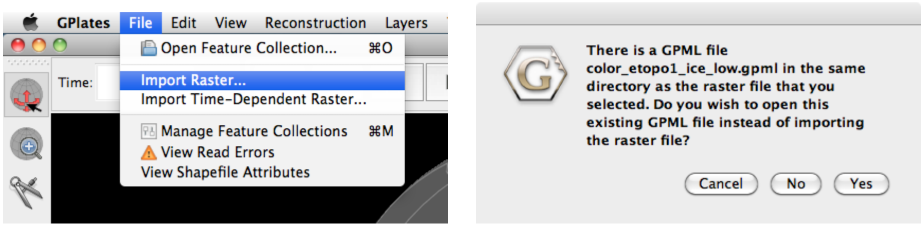
All these files (apart from the ETOPO1 image) are available in the Sample data folder (see Appdx A) along with your GPlates installation. Make sure that you know where you can find the Sample data folder and how to navigate to the (sub-)directories.

3. Working with raster data

3.1. Loading raster data

Loading rasters in GPlates is very easy. Just use `File` → `Import raster...` as shown in Fig. 1a. In case the file has already been loaded in GPlates previously, a new window will pop up and ask you whether you'd like to load the *.gpml instead. Once a raster has been loaded into GPlates, the application will automatically create a *.gpml file with the same basename as the original raster file. The next time you try to load the raster file, you can just open it as feature collection instead of importing it.

If you are loading a raster the first time into GPlates, the "Import raster" wizard will walk you through three main steps in order to allow GPlates to properly digest the data:



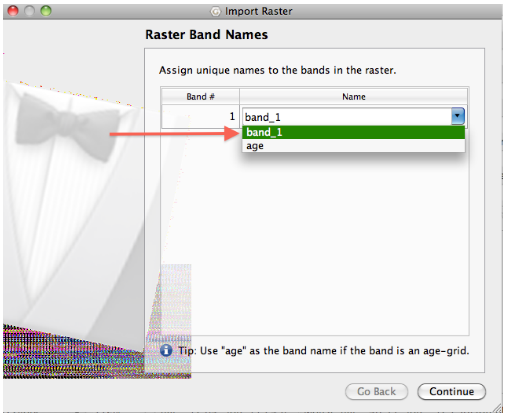
(a) Import raster menu **(b)** Previously loaded rasters

Figure 1: Loading rasters in GPlates. (a) Importing rasters in GPlates. (b) In case the raster has already been loaded into GPlates, a GPML feature collection is automatically generated (`*.gpml`) and the user is presented a dialogue which allows to chose from either, re-importing the raster or using the existing `*.gpml` file.

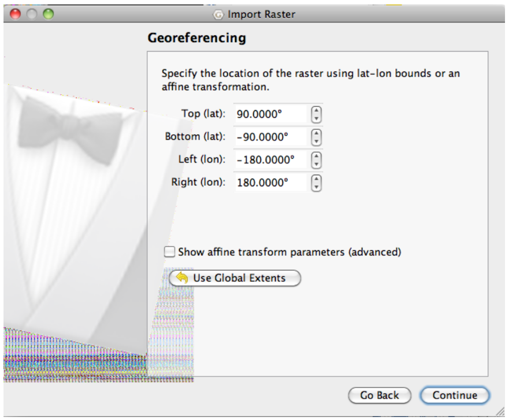
1. Raster Band Names: This dialogue ask you to assing a certain band to the raster image. You can chose between the normal band in the raster "`band_1`" or "`age`" when the raster you are loading is an age grid. Chose "`band_1`" if you are loading a standard raster image without age information. See Sec. 5.2 for how to handle age-based masking. Click `Continue` when you have assigned the information.
2. Georeferencing: At the moment, GPlates allows you to load either global rasters or rectangular rasters covering certain regions of the world. Adjust the georeferencing information accordingly. For most of the sample data used in this tutorial you can mostly use the default settings (global extend). Click `Continue`. If you have non-global raster imagery, Sec. 4.3 will introduce georeferencing of raster imagery in GPlates.
3. Feature Collection: Lastly, GPlates will create a new feature collection with your imported raster. You can select to save the new feature collection once the raster data has been imported, so the next time you can simply "Open" the `*.gpml` file (see above, Fig.1b) instead of importing it again. Click `Done` once you're happy.

3.2. Managing raster data

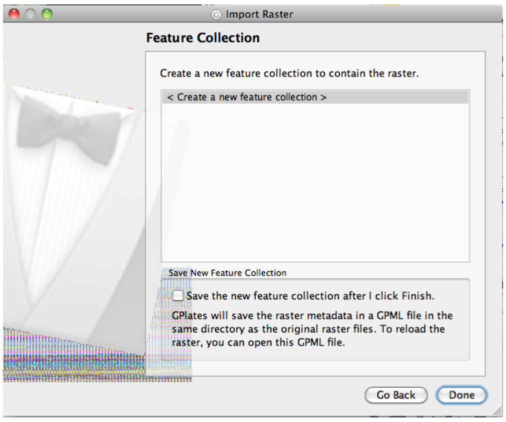
There are two ways to manage raster data in GPlates, which can be confusing at first. The main distinction between those two options is that one works directly on the files, whereas the second one operates on the layers from loaded feature collections only (there might be cases when a `*.gpml` file contains different layers). The first option being the file-centric "Feature manager", which can be accessed through `File` → `Manage features` or `ctrl+m`. The second option is the "Layer" tool (`Layers` → `Show layers`) which controls



(a) Import rasters: Assign band



(b) Import rasters: Georeferencing



(c) Import rasters: New Feature collection

Figure 2: Import raster wizard. If you load a new raster into GPlates, the "Import raster" wizard will ask you to chose a band in the raster to be assigned (a), questions about the georeferencing information of the raster image (b), and whether you want to save your imported raster into a new `*.gpml` file (c).

the individual features (instead of working with the files on disk directly) and allows for functionality similar to layers in vector-graphic applications like Inkscape, Corel Draw or Adobe Illustrator.

3.2.1. Feature manager

Once you have loaded features (rasters, vector data from shape files or other GPML data), these will reside in GPlates' memory as feature collections. These individual loaded files can be shown using the "Feature manager" (see Fig.??).

For the following tutorials, you need to be aware that files can be enabled/disabled by checking/unchecking the tickbox in the "Layer types" column.

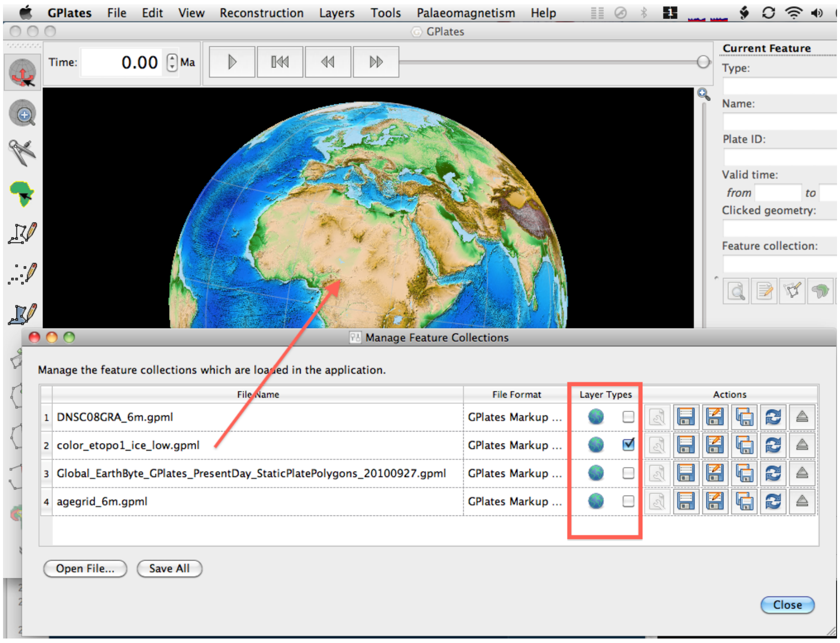
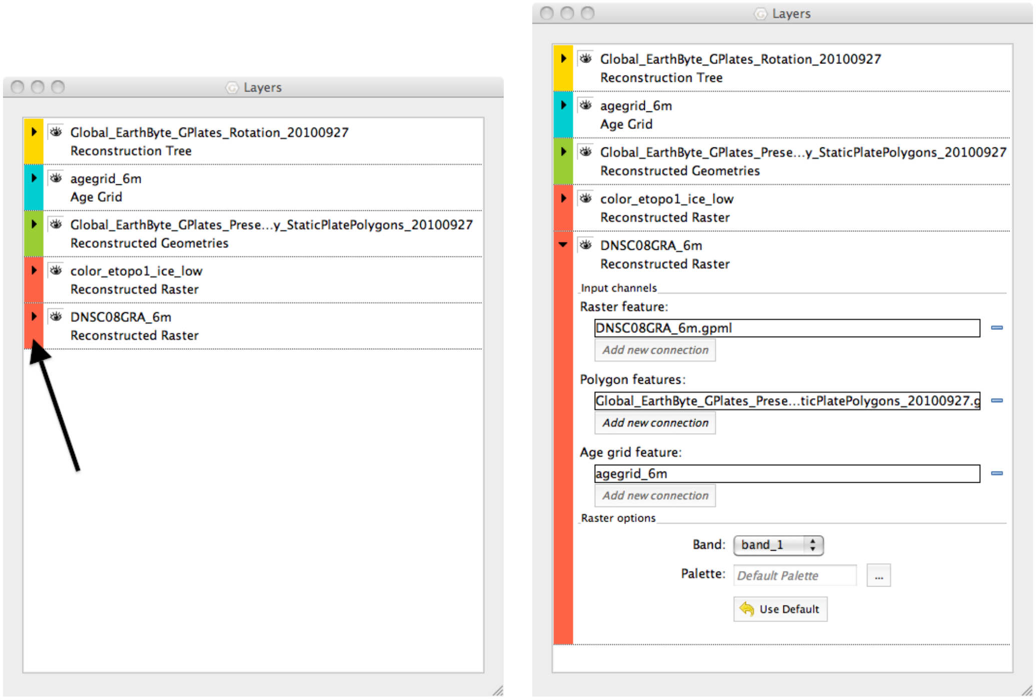


Figure 3: All loaded files in GPlates will show up in this dialogue window, listed by their original file name, the file format, whether they are enabled and GPlates offers a set of actions which the user can perform on them.

3.2.2. Layer tool

The "Layer" tool (`Layers` → `Show layers`) acts more like what you are used to from vector-graphic applications. It allows loaded and enabled feature collections to be displayed or hidden (click the "eye" button to toggle the display of the feature), and other feature collections can be "connected" to the respective layer as "Input channels". Furthermore, dragging individual layers by the colored rectangle (grab it below the black triangle) allows you to change the visual order (stacking) of active feature collections. Different colored rectangles at the side illustrate different layer types.



(a) Layer manager (collapsed) menu **(b)** Layer manager (expanded) menu

Figure 4: All loaded files in GPlates will show up in the layer window (a). You can toggle the visibility on/off by clicking the "eye", drag them into a new order (change the visual stacking) by clicking and dragging the area pointed out by the the black arrow (a) and expand them to perform actions/attach "Connections/Input channels" to respective layers (b).

4. Tutorial 1: Time-dependent rasters

In this first tutorial we will used time-dependent rasters, e.g. snapshots of geodynamic models of dynamic topography (see Appdx. A) and depth slices from seismic tomography models which are coded to geological age, and visualise them in GPlates.

4.1. Time-dependent rasters: global dynamic topography

Dynamic topography is vertical motion of the Earths surface attributed to mantle processes. For example, subducting slabs viscously drag down overlying crust as they sink through the upper mantle, whereas hot upwellings push up overlying crust. For an informative overview of dynamic topography, the 2001 Scientific America article Sculpting the Earth from Inside Out by Professor Mike Gurnis is a good place to start.

In this exercise we will be importing a sequence of time-dependent raster images showing geodynamic model results of dynamic topography since the Mid-Cretaceous (0–100 Ma), provided by Bernhard Steinberger (GFZ Potsdam). These images have been generated at 1 Myr intervals.

1. Load the time-dependent rasters using the following sequence of commands: `File` → `Import Time-Dependent Raster` (Fig. 5). Select the `Add directory` button and locate and select folder called "Dynamic Topography" in the *tutorial* data bundle. Press `Continue` (you cannot select an individual JPEG when loading a Raster Sequence) and leave the band name as "band_1". Press `Continue` again and as our rasters are global, ensure that the lat-lon bounds are 90° to -90° and -180° to 180°. Press `Continue` again and create a new feature collection by selecting `Done`. You can also tick the checkbox in the last dialogue to save a *.gpml file storing your settings.

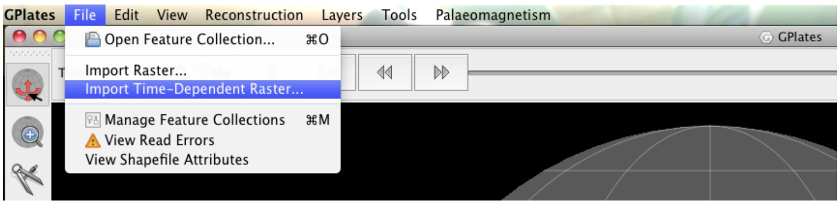


Figure 5: Navigating the menu bar to import time-dependent raster sequences.

2. To make these rasters more geographically meaningful, lets open a coastline file and add this to the GPlates main window: Go to `File` → `Open Feature Collection` and locate `Global_EarthByte_GPlates_Coastlines_20091014.gpml` in the tutorial data bundle. Click `Open` to add the file.

3. What are we missing? Unless we load a rotation file the coastlines (and any other datasets we want to visualise) will remain fixed in present-day coordinates. Use the same commands as in the previous step to load the file `Global_EarthByte_GPlates_Rotation_20091015.rot` of the tutorial sample data bundle to open the file.

4. Now use the Animation Controls and/or Time Controls (in the Main Window above the globe; Fig. 6) to reconstruct the image sequence back through time. Blues indicate negative dynamic topography, whereas reds indicate positive dynamic topography. To watch the evolution of

the dynamic evolution of the Earths surface since 100 Ma, set the Time to 100.00 and then press the Play button. See the Reconstructions section in the GPlates manual for more details about manipulating animations.

Figure 6: Time and Animation controls in the main window. You may use these controls to manually enter a time, move the slider to reconstruct the globe or animate from a selected time to the present.

4.2. Dynamic topography and tectonics in Australasia

Time-dependent raster sequences can be combined with other reconstructable datasets in order to analyse and investigate features in the geological record. We will now exploit this functionality in order to see why dynamic topography is reflected in the geological record of several Australian basins and oceanic plateau. Evidence for negative dynamic topography can be expressed as anomalous tectonic subsidence. By analysing stratigraphic data (obtained from exploration wells) we can calculate how a region has subsided over time. Anomalous subsidence can then be isolated by removing the predicted subsidence for the area, that is, subsidence expected from thermal cooling resulting from lithospheric stretching, or flexure due to the emplacement of a heavy load. Knowledge of the tectonic history of the region in question will further help determine if dynamic topography is a potential cause of the anomalous subsidence.

Cenozoic anomalous tectonic subsidence, induced by mantle convection processes, is recorded in wells north and northeast of Australia [e.g. DiCaprio et al., 2009, Heine et al., 2010, DiCaprio et al., 2010]. This dynamic topography, including a 300 m downward tilt of the continent to the northeast, is due to the Australian Plate migrating towards the subduction zones of Southeast Asia [DiCaprio et al., 2009]. We will now load into GPlates the outlines of the Carpentaria Basin (N of Australia), Queensland Plateau (NE of Australia) and Marion Plateau (NE of Australia); focus regions of the above authors.

1. Locate and open the files `CarpentariaBasin.gpml`, `QueenslandPlateau.gpml` and `MarionTerrane.gpml` from the tutorial data bundle.
2. We will also load in the locations of several wells that have recorded anomalous tectonic subsidence in the Cenozoic. We will do this using the option to load files also from the Feature Manager: `File` → `Manage Feature Collections`. Click on the `Open File` button and load the file `Wells_Australia.gpml`.

3. We will now adjust the colouring of the line and polygon data to make it easier to see: go to `Layers` → `Manage Colouring` and from the `Feature collection` drop down menu select `All` → `Single colour` and select "Black" (Fig. 7). Now we can clearly see the coastlines, wells and basin/plateau outlines

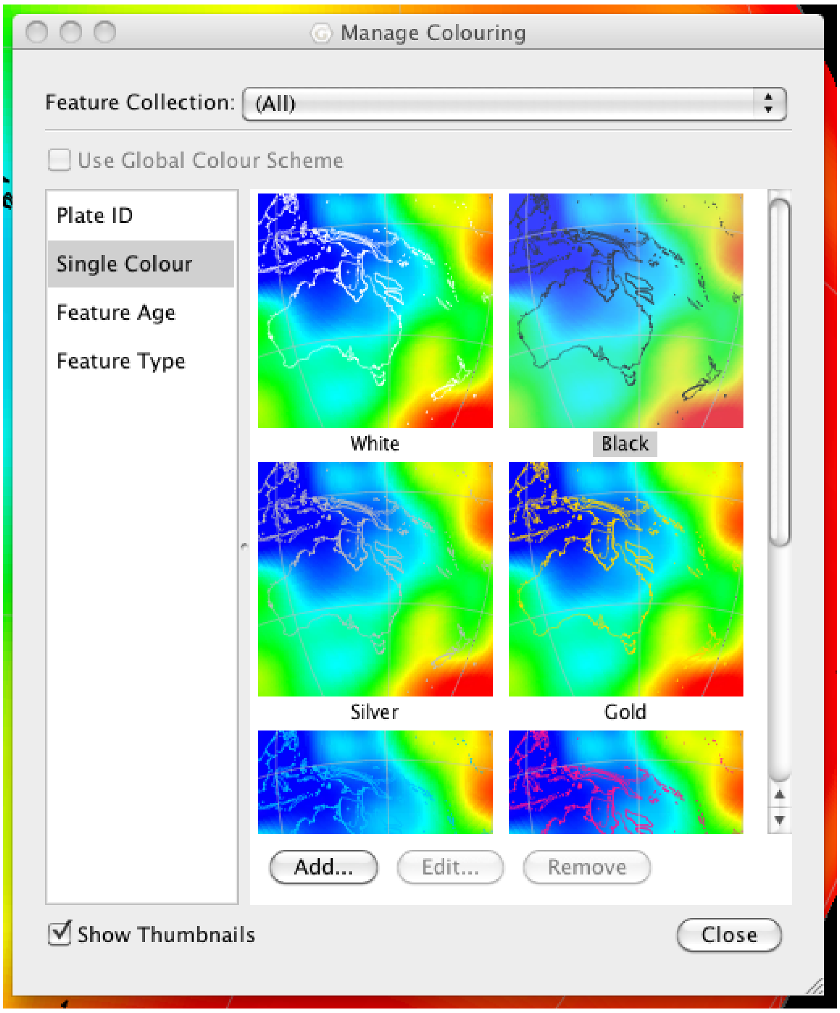


Figure 7: Altering the colouring of our loaded data sets and setting a uniform colour to all loaded feature collections using the colour dialogue.

4. Now play the animation through from 100–0 Ma (as you did previously at the end of Sec. 4.1).
   - How does the dynamic topography signal evolve in the focus areas we have loaded?
   - You will notice that the negative signal strengthens as Australia migrates in a north-northeasterly direction.

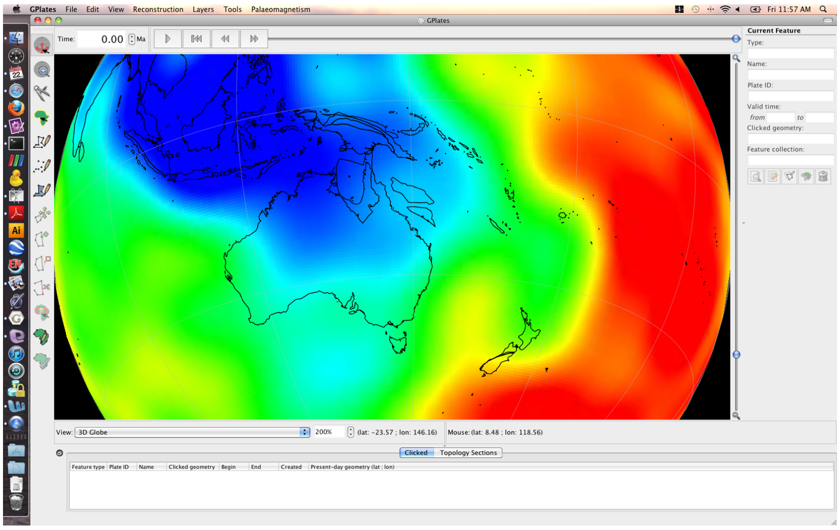


Figure 8: View of the Australian region with Gulf of Carpentaria basin outline and the Duyken-1 well (black dot) as well as the Marion and Queensland Plateau polygons and other well data. Background are time-dependent dynamic topography images.

4.3. Advanced time-dependent rasters: regional focus

We will now be using a combination of regional time-dependent rasters and reconstructable data sets to reveal an assumed Late Cretaceous-Early Tertiary slab window beneath Sundaland [Whittaker et al., 2007] a region of Southeast Asia comprising the Malay Peninsula, Borneo, Java, Sumatra and the surrounding islands. Check the Appdx. A if you are not familiar with the concept of slab windows and seismic tomography.

The data bundle for this Tutorial includes a sequence of regional time-dependent raster images showing seismic tomography. These images were generated from the seismic tomography model PRI-S05 [Montelli et al., 2006]. Although seismic tomography is a method for imaging the structure of the present-day mantle, by establishing a relationship between slab depth and slab age (i.e. when the slab was being subducted at the surface, NOT the age of the oceanic crust) we can use tomography data to learn about past subduction zones. By examining the relationship between subducted materials sinking velocity and its current depth, we can make estimates about the age of subducted material. Table 1 in Appendix B displays the corresponding depth of the age coded tomography slices.

1. To begin we need to unload the data used in Sec.4.2 that is not necessary for this part. Therefore, unload `CarpentariaBasin.gpml`, `Queensland-Plateau.gpml`, `MarionTerrane.gpml`, `Wells_Australia.gpml` and our

feature collection that contains the time-dependent dynamic topography sequence. We do not need to unload the coastlines as we want to see how the continents, specifically the Sunda Block, have moved through time with respect to the slabs inferred from the seismic tomography. Do all this by using the `Manage Feature Collections` dialogue and click the eject symbol that applies to each of the above-mentioned files (far right icon under the Actions tab, see Fig.9).

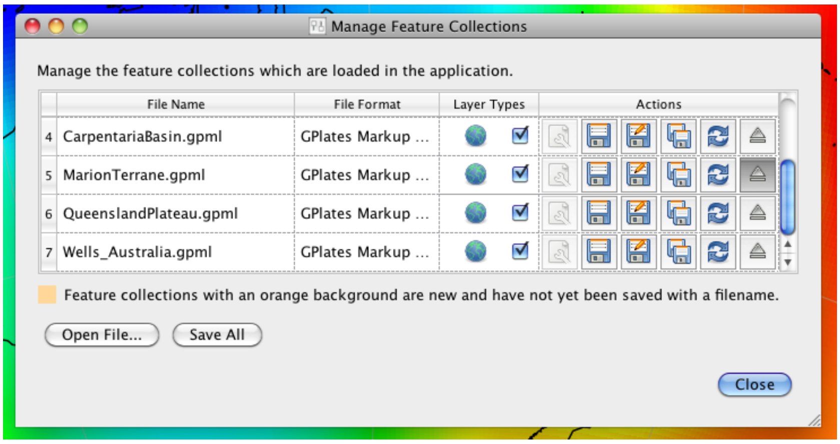


Figure 9: The eject button, under Actions (far right) allows data files to be unloaded from GPlates.

2. We will now load in the seismic tomography raster sequence from the folder called `MITP08` from the tutorial data bundle, in a similar fashion as in Sec. 4.1. The only difference is that the data is regional and we need to adjust the geographic bounding box accordingly.
3. When loading the data, in the `Georeferencing` section of the "Import raster" wizard, set the lat-lon bounds to the following (see also Fig.10) and load/save the new feature collection:
   - Top (lat): 30°,
   - Bottom (lat): -20°,
   - Left (lon): 80°; and
   - Right (lon): 130°
4. You will now be able to see a seismic tomography image in the region of Sundaland. However, before we can continue any further we need to change the order of the layers so that the regional raster is not covering up our coastlines. You need to use the "Layer tool" for this, as described in Sec. 3.2.2. Click and drag the coloured rectangle corresponding to the MITP08 raster sequence to the bottom of the list of layers. Your main window should now look similar to that shown in Fig.11.

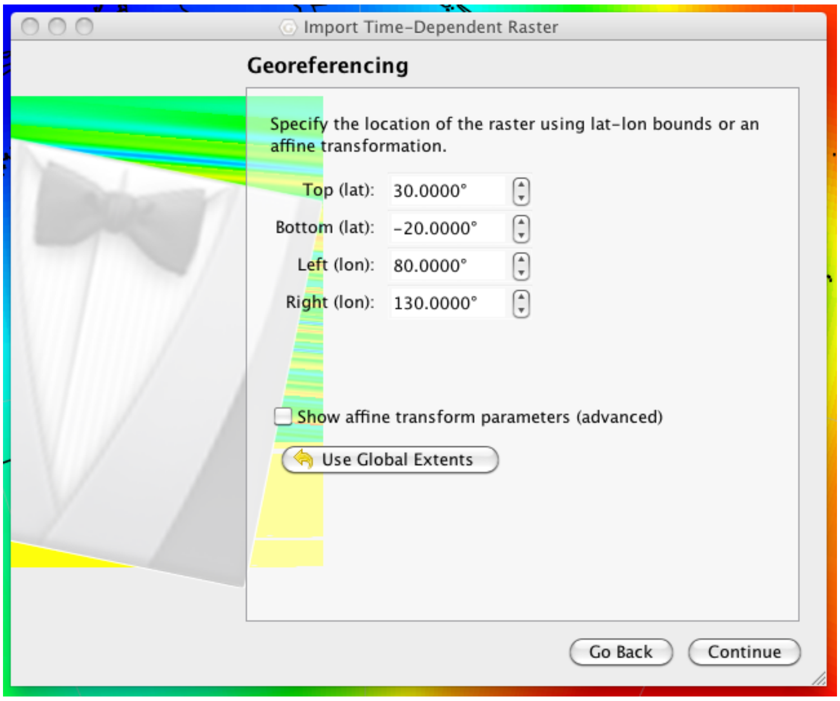


Figure 10: The Georeferencing window allows you to readjust the bounding latitudes and longitudes of regional rasters.

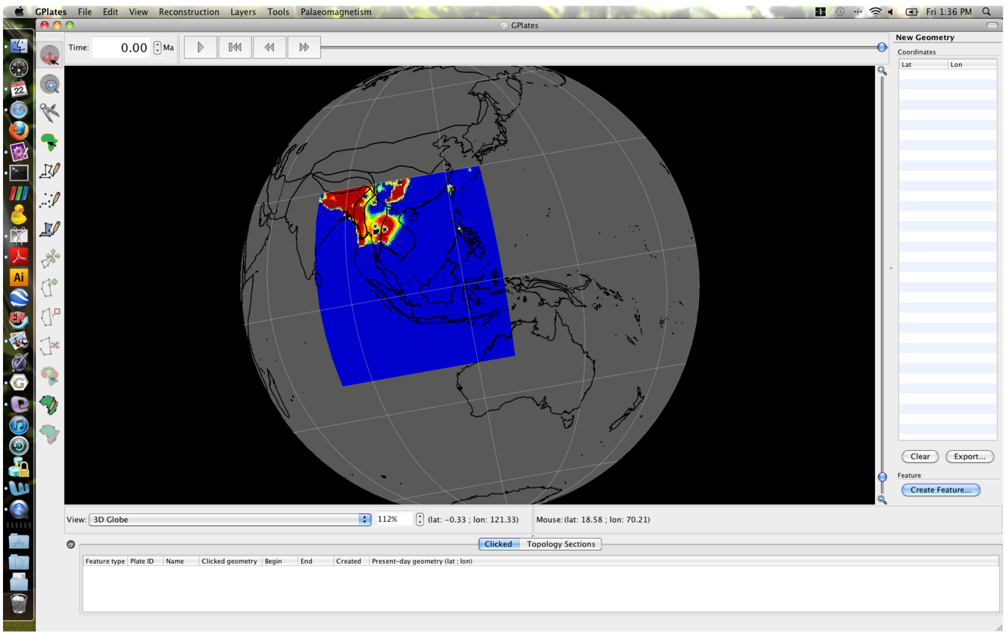


Figure 11: A regional raster displayed as the base layer on the GPlates globe.

5. We want to use this raster sequence to find the assumed slab window that was open between ≈70–43 Ma in the Late Cretaceous-Early Tertiary. Subduction zones can be identified from seismic tomography images as regions of anomalously fast velocities*. This is because the subducting slab is colder (and denser) than the ambient mantle. It thus follows that a slab window can be seen as a break in the fast velocity region. *Note Blues indicate anomalously fast velocities and so we will interpret these regions as subducting slabs.
6. Rather than animating 140 Myr worth of data, lets use the Animation controls to specify our 70 43 Ma timeframe: `Reconstruction` → `Configure animation`
   a) Animate from 70.00 Ma
   b) To 43.00 Ma
   c) With an increment of 1.00 M per frame.
   d) Frames per second: 3.00 (you can experiment with this if you like)
   e) Current time: 70.00 Ma
   f) When you have finished adjusting the animation controls click the Play button, make sure to move or close the Animate window so that it does not block your view of the GPlates globe.

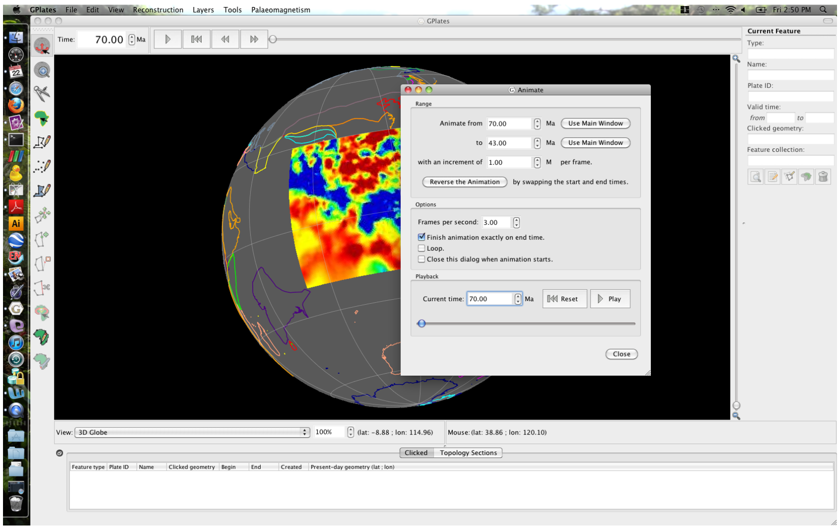


Figure 12: The Animate window enables you to specify a time period to animate on the globe.

- Can you see the slab window?
- Clue - Look for a break in the blue blobs.

7. Now that we have visualised the slab window lets digitise it. In this example we will digitise the position of the slab window at 60 Ma using

an oval shape. Figure below is an example of the 70 Ma slab window, use this as a guide when you make your 60 Ma slab window.

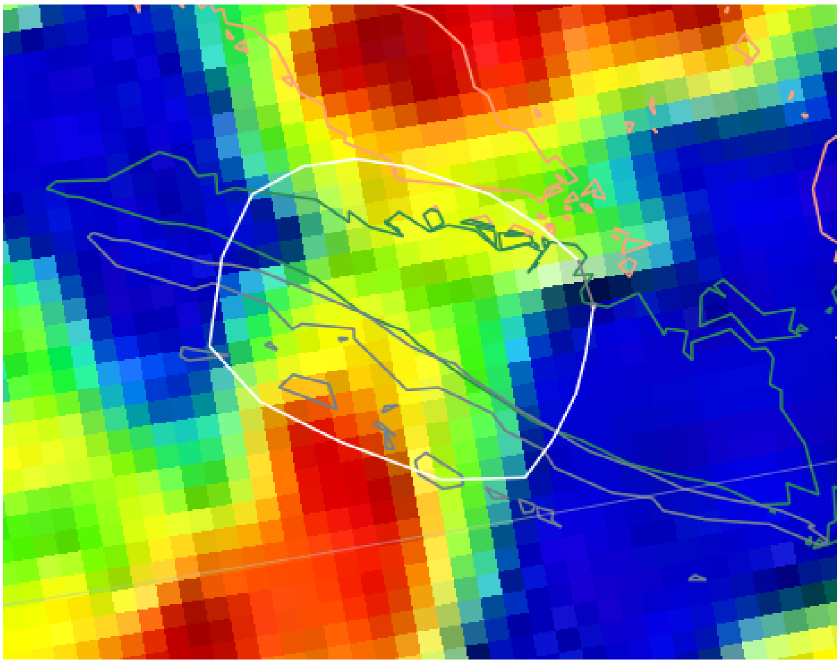


Figure 13: Digitised slab window at 70 Ma (white polygon).

8. Click the `Digitise New Polygon Geometry` icon (Shortcut: "g"; see right) located in the Tool Palette on the left hand side of the main window. Digitize a polygon around the slab window in an oval shape (use Fig. 13 above as a guide). Remember that if you make a mistake, or you are not happy with the shape of your polygon, then you can use the geometry editing tools from the Tool Palette to move the existing vertices, add new ones or delete them all together (Tool buttons pictured right).

   Create a new feature by pressing `Create Feature...` (from the New Geometry Table to the right of the main window) → Chose `gpml:(UnclassifiedFeature)` → Click Next → Leave the default setting for the property that best indicates the geometrys purpose → As reconstruction Method chose: `By Plate ID`. Set the other properties as specified:

   - `Plate ID`: 301 (the slab window lies on the Eurasian Plate)
   - `Begin` (time of appearance): 60.00 Ma
   - `End` (time of disappearance): 60.00 Ma
   - Choose a `Name` for the feature e.g. SundalandSlabWindow60Ma

   Create a new feature collection by clicking `Create a new Feature Collection` → `Create`.

You have now created your 60 Ma slab window and added it to a new Feature Collection. However, remember that you need to save it, so open the features manager window (`File` → `Manage Feature Collections`) and save the feature using a new name and the gpml format (see button on right). This Feature Collection can now be loaded into GPlates when you next open the program.

Alternatively you could have exported the polygon geometry as a file of longitudes and latitudes and visualised them, for example using GMT [Generic Mapping Tools; Wessel and Smith, 1998]. To do this follow the methodology you learnt in the Creating New Features Tutorial (i.e. you would select the Export button in the New Geometry Window to the right of the globe and chose the GMT file format).

From this exercise we have shown that seismic tomography combined with plate reconstruction software (GPlates) can help geoscientists to learn about past plate boundary configurations. Our slab window helps constrain the location of the spreading ridge that was being subducted 60 Ma (the Wharton Ridge).

GPlates can further be employed to compare the location of the slab window inferred from seismic tomography with its location inferred from other data sources, for example plate tectonic reconstructions. We will now load in EarthBytes time-dependent crustal age sequence from the "Importing Rasters" data bundle.

1. Select and load the age grid jpegs from the tutorial data bundle (you cannot select an individual JPEG when loading a Raster Sequence), leave the band as "`band_1`".
2. Spend some time reconstructing the raster sequence using the Animation and/or Time controls — you can see how old the oceanic crust is in various areas of the world.
3. We will now compare the location of the slab window that you inferred from seismic tomography to the location where the youngest oceanic crust (and hence the crust adjacent to the spreading ridge) is being subducted beneath Sundaland for simplification we will assume that the spreading ridge is positioned at the centre of the youngest oceanic crust (Fig. 14). In other words we will be comparing our slab window with the approximate location of the slab window inferred from a plate kinematic reconstruction. Note – youngest crust is coloured red.
4. Rotate the globe to centre on Sundaland and use the Time controls to jump to 60 Ma (Figure).
    - How does your digitised slab window compare to the location of subduction of the Wharton Ridge (and hence the kinematically inferred slab window)?

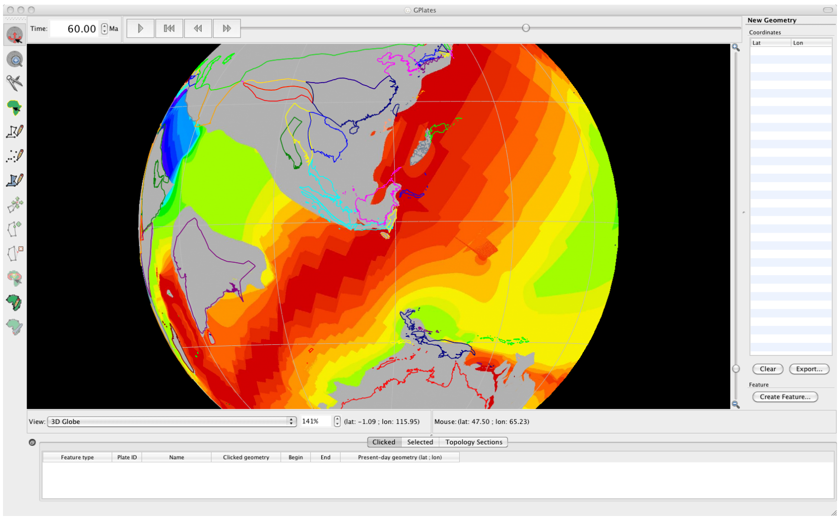


Figure 14: 60 Ma reconstruction of ocean floor ages and present-day coastlines. Notice that the youngest oceanic crust (and hence the spreading ridge) is converging with western most Sundaland.

If you would like to learn more about how seismic tomography is being used to constrain the location of the Wharton Ridge and slab window beneath Sundaland during the Late Cretaceous to Early Tertiary [Fabian et al., 2010].

5. Tutorial 2: Rotating rasters and age-based masking of raster data

The following two tutorials will introduce you to the concept of working with raster data in GPlates. The first three tutorials will walk you through different options when working with time-dependent raster data, the fourth and fifth one will show how to cookie-cut polygons from rasters and rotate them to paleo-positions, whereas the second tutorial will dwell on GPlates new "age-based masking" functionality, using age grids to smoothly mask connected grids.

5.1. Rotating raster data

In order to split a global raster file into different polygons, load the sample data into GPlates. Specifically, load the following files which have already been discussed in Sec. 2.

1. The global rotation file
   (`Global_EarthByte_GPlates_Rotation_20100927.rot`)

2. The global static polygon file (Global_EarthByte_GPlates_PresentDay_StaticPlatePolygons_20100927.gpml)
3. The global topography/bathymetry image (color_etopo1_ice_low.jpg supplied with this tutorial) or the global gravity image supplied with GPlates (DNSC08GRA_6m.jpg).

Once this has been done, you should have a something on your GPlates main window which looks like in Fig.15.

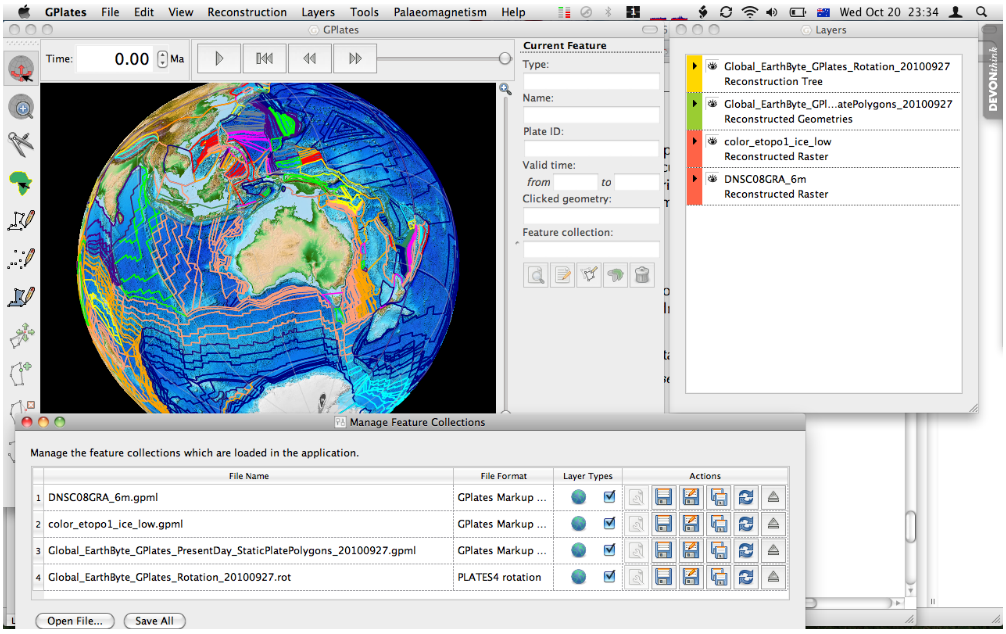


Figure 15: GPlates windows with sample data for tutorial 1 loaded.Here, we have two raster images loaded (red rectangle): the global topography and the global gravity. Both are automatically classified as “Reconstructed raster”.

The next step encompasses to tell GPlates to cut the raster into different pieces by using our global static polygon layer. It is important to note here that the polygon coverage needs to be global and it needs to assign PlateIDs to the individual pieces of the raster in order to be able to rotate them back through time. In case you find this confusing, consult the “Rotations tutorial”. To cut the raster into different pieces do the following:

1. Make sure your layers are in the right order with the raster images in the back and the vector data (polygons) on top. If this is not the case, drag the layers into the proper order.
2. Expand the image layer (either topography or gravity image) in the Layer window by clicking the little black triangle to the left in the colored rectangle of the layer.

3. In the “Input channels” section of the layer, now click the “Add new connection” button and select the static polygons from the list.
4. Depending on your graphics card power, you will see that GPlates will need some little time to think before the main window becomes responsive again.
5. Now you should be ready to go and able to drag the time slider to a desired time (or punch in the numbers) to rotate your global raster data to paleo-positions. See Fig. 16 for an example of the ETOPO1 dataset rotated back to 50 Ma in an Australia-centric view.
6. If you would like to see only the raster data and not have the polygons superimposed,simply toggle the polygon visibility off in the Layer manager.

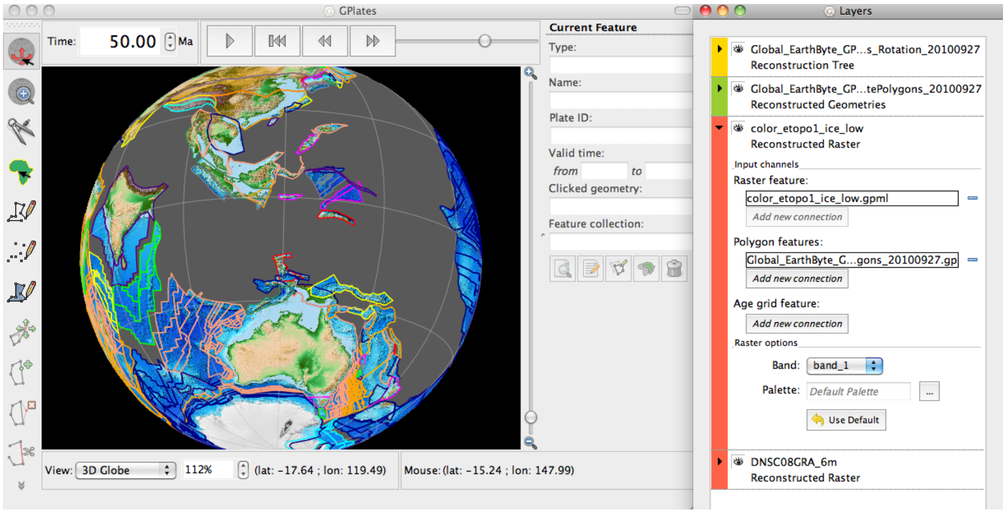


Figure 16: Raster data cut to polygons and rotated back to 50 Ma. Notice that GPlates has automagically removed polygons and raster data which were not existant at this time (using the FromAge and ToAge feature attributes).

5.2. Age-based masking of raster data

GPlates uses advanced features of the graphics card and the OpenGL language to perform on-the-fly operations on the raster data using age-grid features. For this tutorial you need to additionally load the `agegrid_6m.nc` file from the `Rasters` sample data folder. Before you can use the age-based masking functionality, you need to complete a few different steps:

1. When you import a new raster which can be used as age mask, select

"age" in the raster band assignment in the import raster dialogue (see Fig. 17).

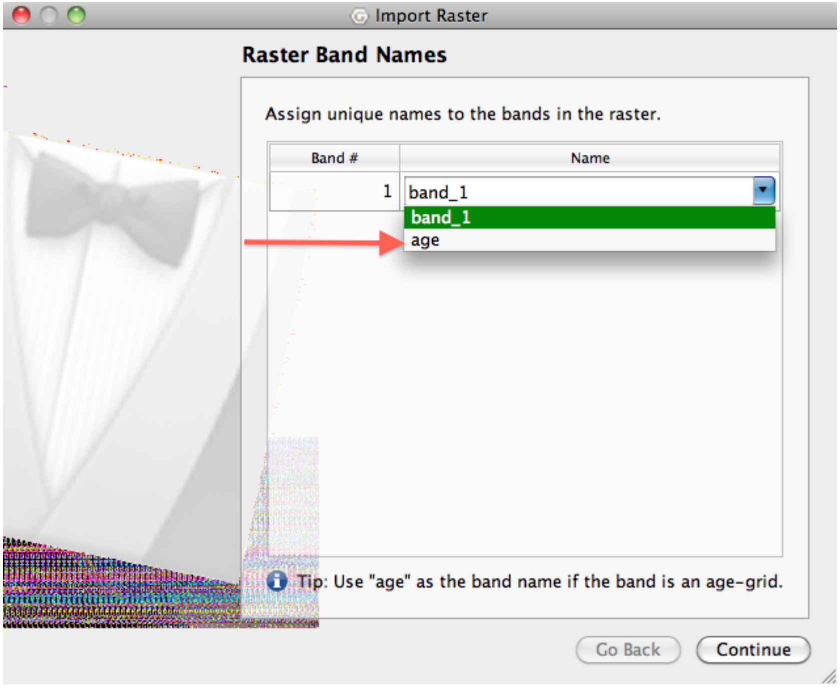


Figure 17: Import raster dialogue. Chose the "age" as the raster band when loading age grids.

2. Once you have complete the "Import rasters" dialogue you should see that the age grid is now loaded in the Layer manager. A turquoise rectangle should indicate that the loaded feature is an age mask.
3. You now need load the plate rotation file and the static polygon set as described above in Tutorial 1 (Sec. 5.1) into the GPlates application. *This can also be done by dragging and dropping the files into the main GPlates window.*
4. In order to be able to rotate the raster data, you will again need to assign plate IDs to subset of the raster by connecting the `DNSC08GRA_6m` reconstructable raster layer to the static polygon features, as in Tutorial 1, Step 3 (Sec. 5.1).
5. In addition to assigning a polygon "connection", you will now also connect an age grid feature to the global gravity data in a similar fashion as you have created the "Polygon feature" connection. Click the `Add new connection` button below the "Age grid feature" heading in the Input channel subsection of the layer (Fig. 19) and select the `agegrid_6m` from the list.

6. You should now have loaded:
   - a rotation file
   - a global raster file which has age grid and polygon input channels
   - a static polygon file
   - an age mask/age grid file
7. You should now be able to reconstruct rasters again back through time, but with the age-based masking functionality enabled. If you interrogate for example the South Atlantic, going back in time, you will see that the seafloor is succesively "eaten up" during the reconstruction at any timestep (Fig. 20). The transitions are very smooth and not like the polygon-based disappearance as you have seen in Tutorial 1.

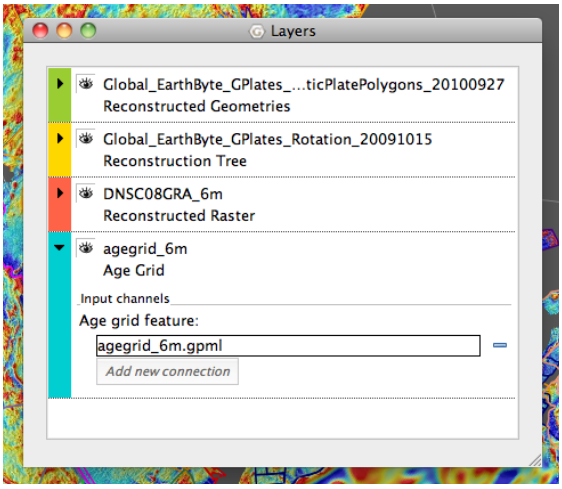


Figure 18: Layer manager with loaded age grid feature (bottom, indicated by turquoise rectangle).

The age-based masking functionality provides on-the-fly masking of raster data using an age grid feature. The age grid specifies which pixel of a connected raster file get masked at a certain time, using advanced features of the graphics card and OpenGL.

It is very important to note here that you need to be extremely careful when combining data sets by not mixing data using different rotation frameworks. For example, the age grid feature used for masking needs to be constructed with the same rotation parameters as the rotation file you are using to rotate your feature collections back through time.

Naturally, one can also apply the age-based masking workflow to non-global/regional raster data which has been accurately georeferenced (Fig. 21).

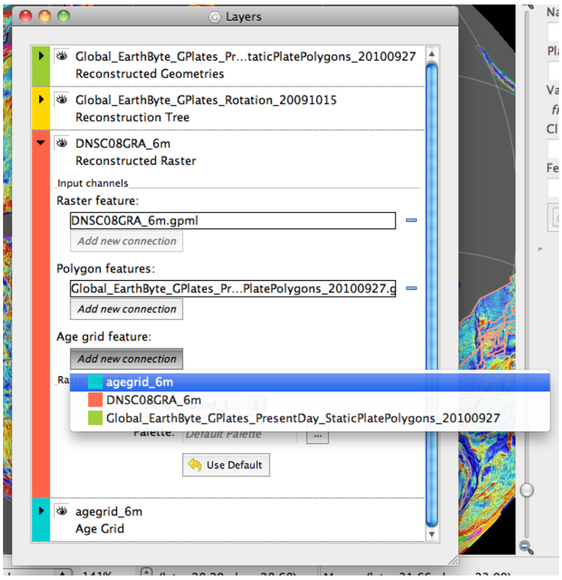
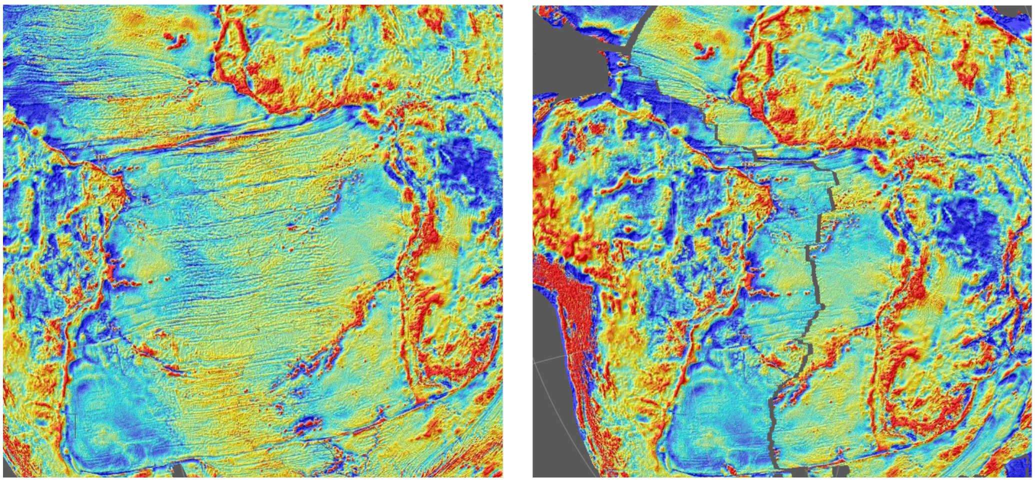


Figure 19: Adding an age-mask connection to a loaded raster feature.



(a) South Atlantic at 11 Ma **(b)** South Atlantic at 73 Ma

Figure 20: Age-based masking of gravity data focussing on the South Atlantic. The two reconstructions in an absolute reference frame illustrate how the age-based masking functionality of GPlates allows to smoothly "consume" ocean floor at the spreading ridge going backward in time using an age grid in combination with other raster data.

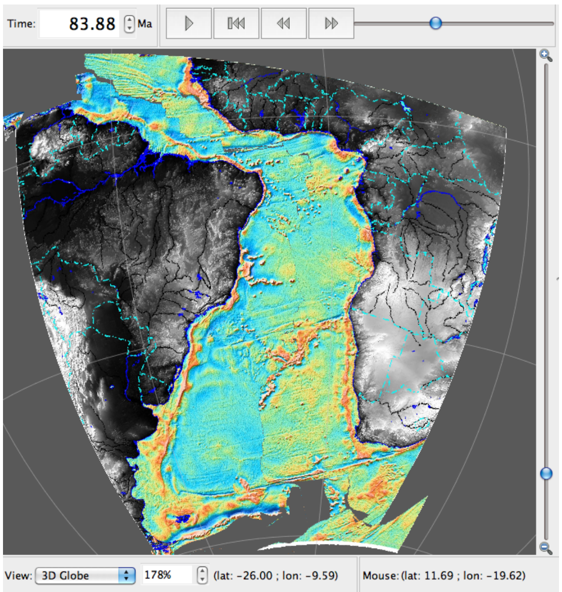


Figure 21: Regional combined SRTM (onshore) and free air gravity (offshore) image of the South Atlantic region rotated back to 84 Ma. The raster has been split into polygons and masked using the agregrid. Reconstruction in absolute reference frame.

References

Lydia DiCaprio, Michael Gurnis, and R. Dietmar Müller. Long-wavelength tilting of the Australian continent since the Late Cretaceous. *Earth Planet. Sci. Lett.*, 278:175–185, 2009. doi: 10.1016/j.epsl.2008.11.030.

Lydia DiCaprio, R. Dietmar Muller, and Michael Gurnis. A dynamic process for drowning carbonate reefs on the northeastern australian margin. *Geology*, 38(1):11–14, 2010. doi: 10.1130/G30217.1. URL http://geology.gsapubs.org/cgi/content/abstract/38/1/11.

Theresa Fabian, Joanne M. Whittaker, and R. Dietmar Müller. Ground-truthing proposed slab window formation beneath Sundaland using Seismic Tomography. In *ASEG-PESA International Geophysical Conference and Exhibition*, Sydney, Australia, August 22nd-26th 2010.

Christian Heine, R. Dietmar Müller, Bernhard Steinberger, and Lydia DiCaprio. Integrating deep Earth dynamics in paleogeographic reconstructions of Australia. *Tectonophysics*, 438:135–150, 2010. doi: 10.1016/j.tecto.2009.08.028.

Carolina Lithgow-Bertelloni and Mark A. Richards. The dynamics of Cenozoic and Mesozoic plate motions. *Rev. Geophys.*, 36(1):27–78, 1998.

Raffaella Montelli, Guust Nolet, F. A. Dahlen, and Gabi Laske. A catalogue of deep mantle plumes: New results from finite frequency tomography. *Geochem. Geophys. Geosyst.*, 7(11):Q11007, 2006. doi: 10.1029/2006GC001248.

R. Dietmar Müller, Maria Sdrolias, Carmen Gaina, and Walter R. Roest. Age, spreading rates, and spreading asymmetry of the world's ocean crust. *Geochem. Geophys. Geosyst.*, 9(4):Q04006, 2008. doi: 10.1029/2007GC001743.

Paul Wessel and W. H. F Smith. New, improved version of Generic Mapping Tools released. *EOS Trans. Am. Geophys. Union*, 79(47):579, 1998.

Joanne M. Whittaker, R. Dietmar Müller, Maria Sdrolias, and Christian Heine. Sunda-Java trench kinematics, slab window formation and overriding plate deformation since the Cretaceous. *Earth Planet. Sci. Lett.*, 255: 445–457, 2007. doi: 10.1016/j.epsl2006.12.031.

A. Terminology

GPML The GPlates Markup Language. GPML is a "dialect" of XML, incorporating features of the Geopgraphic Markup Language. Essentially, the GPlates data model is using markup languange to represent any feature (ie. geographic object).

Sample data When you download GPlates from http://www.gplates.org, some sample data is included in your download. On Windows, this will be available after the installation in the GPlates folder at `C:\Program Files\GPlates\GPlates [version]\Sample data`. For the Mac, the download will leave you with a disk image (`*.dmg`) file. Mount the file by double-clicking, drag the GPlates application bundle into the Applications folder. The sample data is included as directory ("`sample-data`") in the top level of the disk image.

Raster data Raster images comprise 2-dimensional grids of pixels, or points of colour, that are stored in image files such as JPEGS or grid files like netCDF. Note that they differ from vector images that are composed of points and line segments.

Feature Any reconstructable object which can be loaded in GPlates. Features can be lines, points or polygons or multi-* geometries as well as raster images.

Slab Windows Slab windows form as a result of spreading ridges intersecting subduction zones (Dickinson and Snyder, 1979). When ridges are subducted the down-going plates continue to diverge, yet due to an absence of ocean water to cool the upwelling asthenosphere and form new oceanic crust, the plates no longer continue to grow and a gap develops and widens. Seismic tomography enables us to visualise slab windows from present-day and past subduction.

Seismic tomography Seismic tomography is a method for imaging the Earths interior; revealing regions of past and present subduction, and hot mantle upwellings. It involves establishing how fast seismic waves (elastic waves) travel through the mantle, for example seismic waves generated by earthquakes. This information is then used to infer regions of anomalously hot or cold material; anomalous is judged as deviating from a global reference model (e.g. PREM Dziewonski and Anderson, 1981). As the speed of seismic waves travelling through the mantle is influenced by temperature, velocity can be used as a proxy for temperature (fast velocities = cold material, slow velocities = hot material). However, mantle composition also affects the speed of wave propagation, and therefore establishing correlations between velocities and mantle structures is not simple.

B. Age-dpeth relationship for seismic tomography

The table below show the conversion of seismic tomography depth slice to a certain age. This can then be used as time-dependent raster sequence in GPlates.

Depth Slice [km]	Age [Ma]
0	0
240	5
480	10
684	15
744	20
804	25
864	30
924	35
984	40
1044	45
1104	50
1164	55
1224	60
1284	65
1344	70
1404	75
1464	80
1524	85
1584	90
1644	95
1704	100
1764	105
1824	110
1884	115
1944	120
2004	125
2064	130
2124	135
2184	140
2244	145
2304	150
2364	155

Table 1: Age–depth relationship for tomography slices based on Lithgow-Bertelloni and Richards [1998]