Introduction to Rasters and Time-Dependent Rasters

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WARNING:

The first time you import an age-coded raster, GPlates will take time to create some cache files (this can take 5 or more minutes).

The cache files that GPlates creates in the same folder are quite large (up to 100 Mb each), meaning that you need to have enough storage space.

Background

GPlates gives us the functionality to do age-based masking of raster data,and 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. It is also possible to specify a surface extent of any longitude and latitude range for the raster, enabling rasters of a smaller size to be correctly sized and positioned on the globe.

In this tutorial we will be working on importing and visualising raster data in GPlates and rotating and masking raster data back through time. For all those computer illiterate folk out there, a raster is simply a file which is made of 2-dimensional grid of pixels and is stored as JPEGS or grid files like netCDF. This is different to vector data we have used in previous tutorials, that are composed of points, lines and polygons.

Included Files

Click here to download the data bundle for this tutorial.

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

- Time-dependent raster sequences of reconstructed ocean floor age as published by Müller, Sdrolias et al. [2008] from the EarthByte group.
- Sample raster images of time-dependent dynamic topography created by Bernhard Steinberger, based on a dynamic topography model published by Müller, Steinberger et al [2008]

- The MIT-P08 tomography model of the P-wave velocities published by Li et al [2008].
- A detailed colour image of the global topography and bathymetry color_etopo1_ice_low.jpg published by the US National Oceanic and Atmosphere Administration.
- A set of global polygons that represent the Coastlines in GPlates Seton_etal_ESR2012_Coastlines_2012.1_Polygon.gpmlz
- A rotation file which provides the plate kinematic model so we can rotate our feature (such as the coastline polygons) through time Seton_etal_ESR2012_2012.1

All these files-apart from the ETOPO1 image- are also available in the Sample data folder (see Appdix 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. (ETOPO1 jpeg is in the MCOSX)

This tutorial dataset is compatible with GPlates 1.5.

Exercise 1: Working with raster data

Loading raster data

This first exercise is going to walk you through the steps of importing a a raster into GPlates.

File→Import→Import Raster→
Raster_Tutorial_Data→color_etopo1_ice_low.jpg (fig1a)

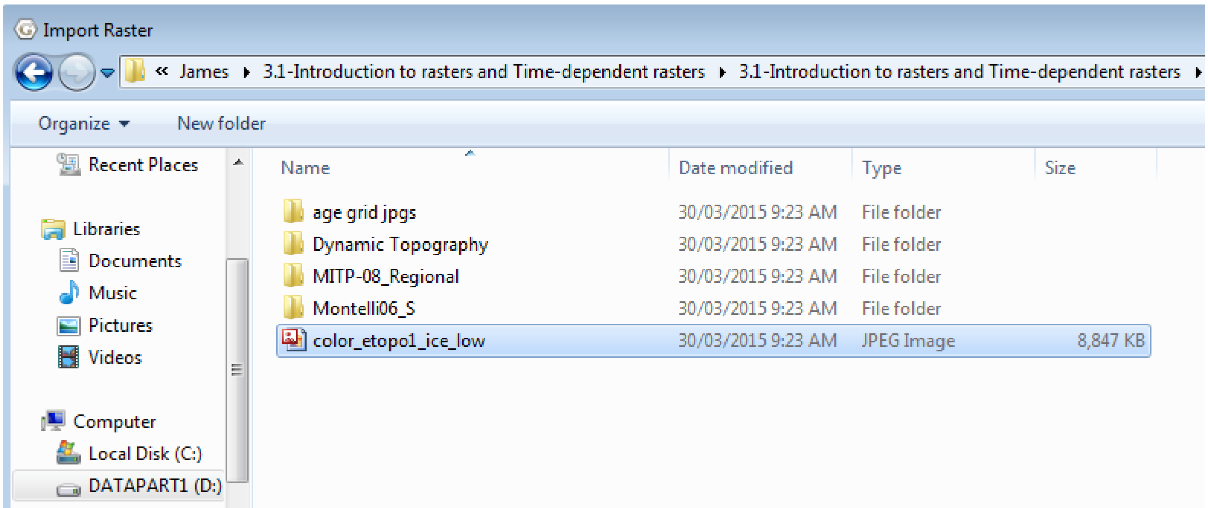


Figure 1a. How to import a raster

The dialogue then will ask you to assign a certain band to the raster image (Figure 1b). You can choose between the "band 1" when loading a normal raster (as you are now) or "age" depending on whether it is a Time-dependent raster. Chose "band 1". Select "Next".

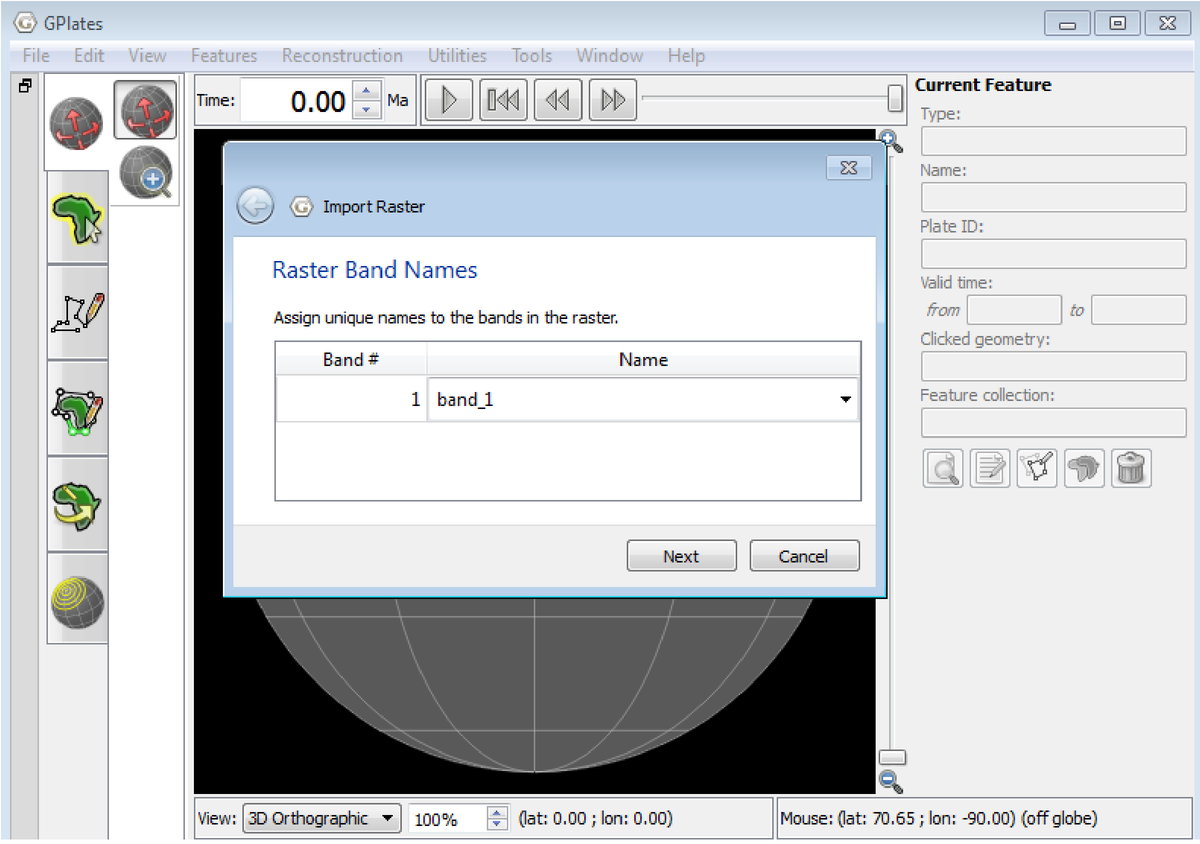


Figure 1b. Assigning Raster band names

A Georeferencing Box will open (fig.1c). This dialogue box enables you to set the geographic extent of the raster. The default is set to a global extent. As we want the raster to cover the globe check the extents are set to top and bottom as 90.000° and -90.000° respectively, and left and right as -180.000 and 180.000 respectively. Later on in this tutorial we will go through an example of using a regional raster. Select "Next".

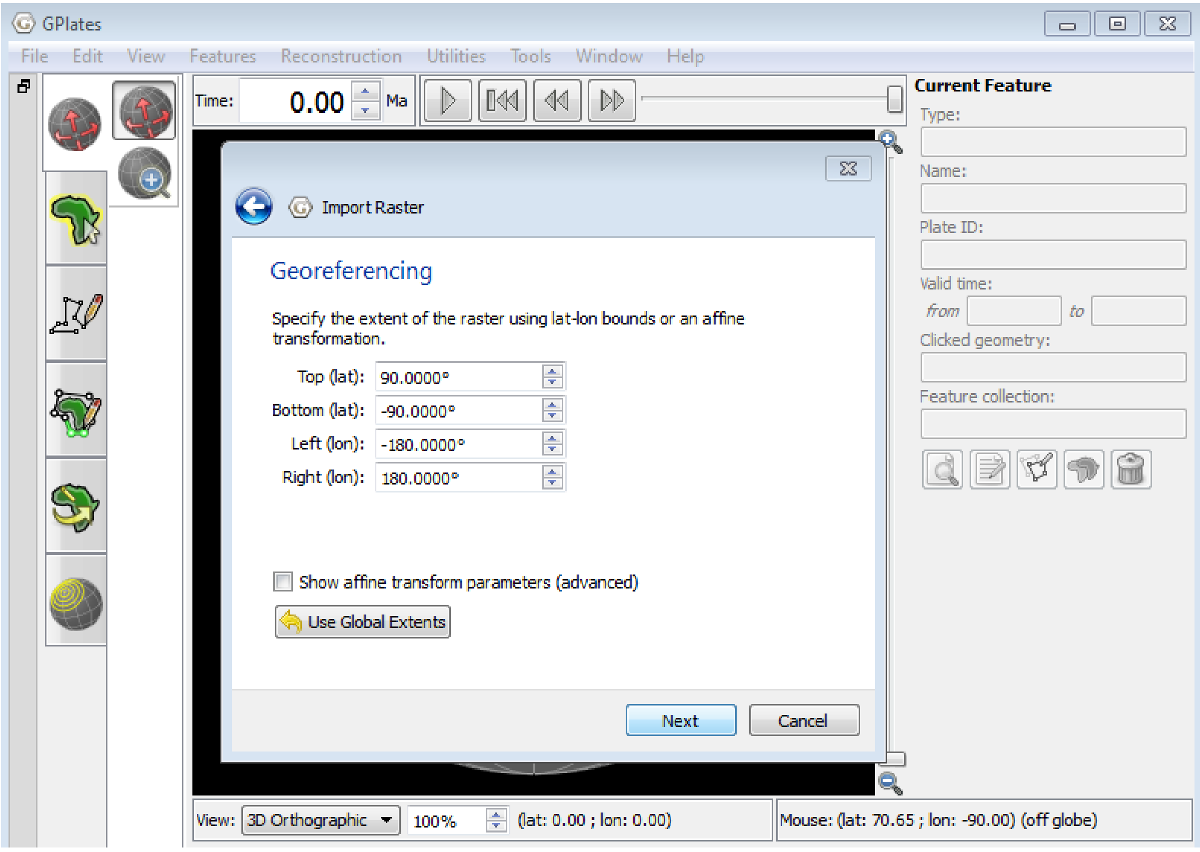


Figure 1c. Assigning Latitudinal and longitudinal extent to raster

The final step is to create a feature collection. Select "create new feature collection" and Select finish. Note in the bottom of this box there is a message informing you that the raster metadata (metadata is loosely defined as data about data) will be saved in a GPML file in the same directory. Instead of importing the raster again, you can simply go to File -->Open Feature collection

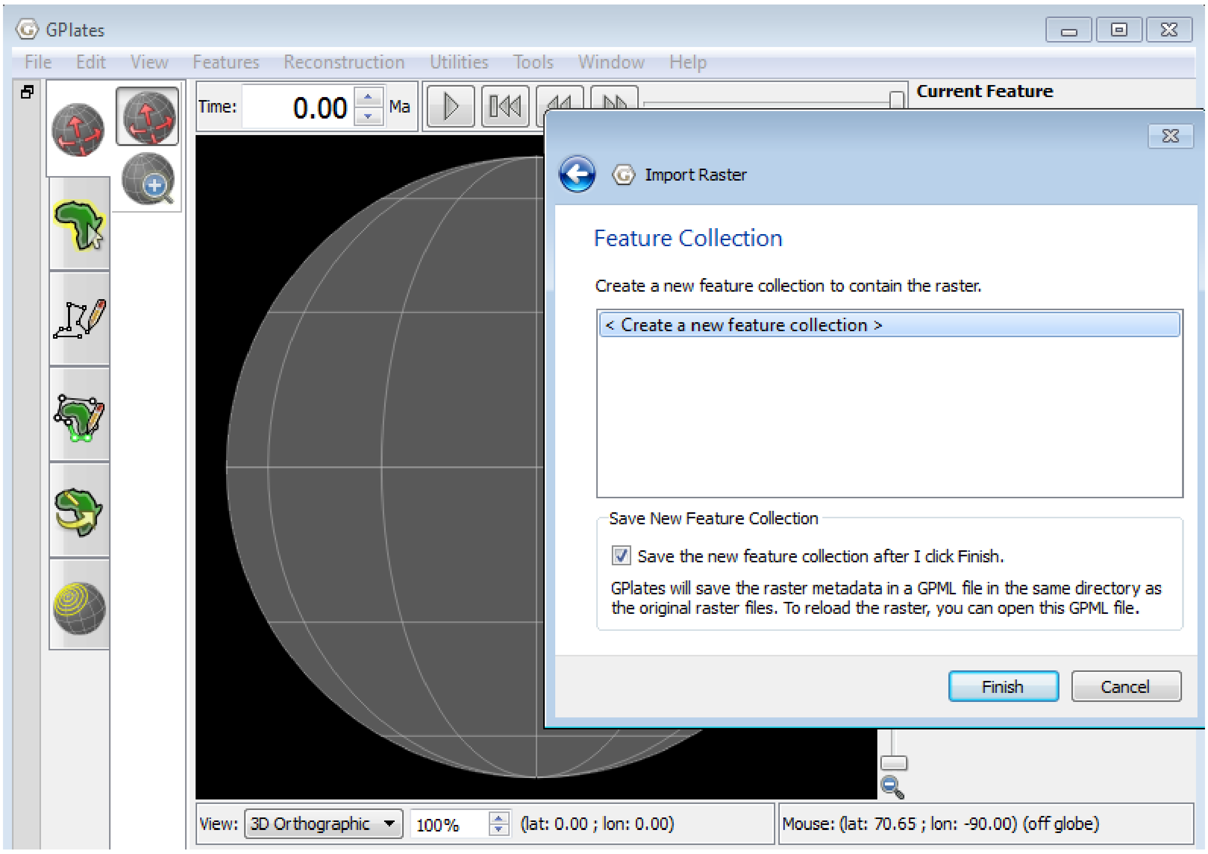


Figure 1d. Creating a feature collection for raster

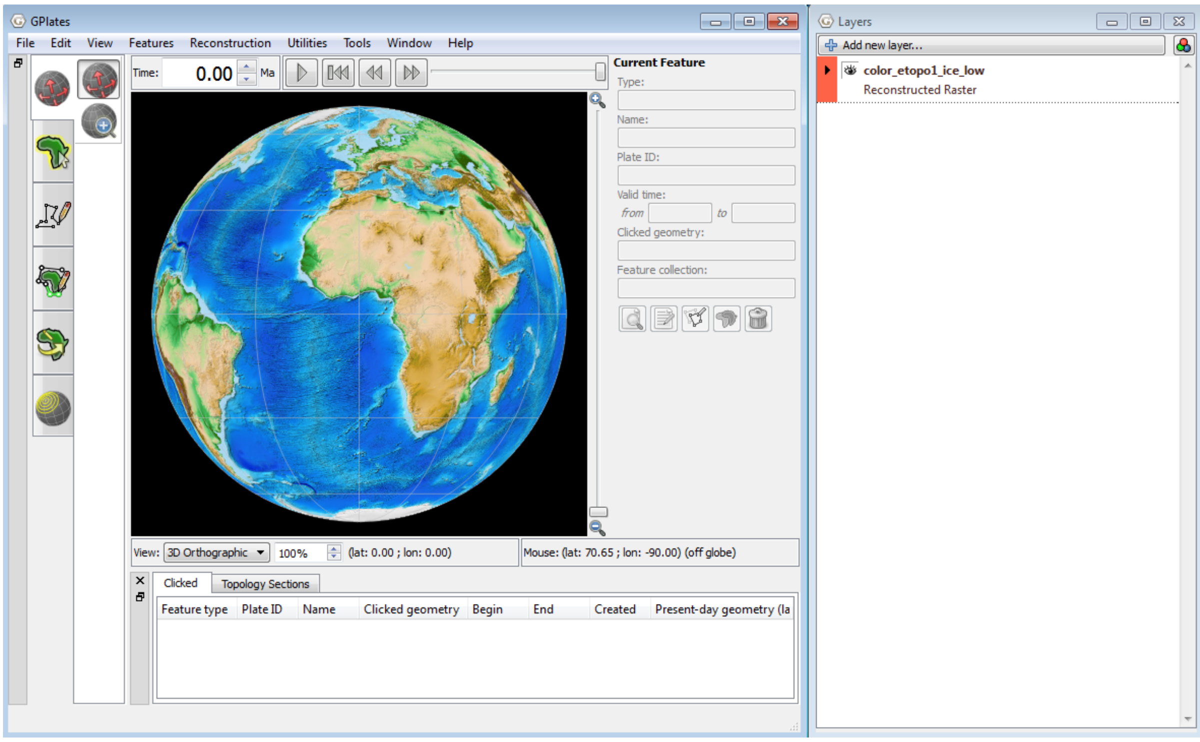


Figure 1e. color_etopo1_ice_low Raster imported into Gplates successfully.

Exercise 2: Time-dependent rasters

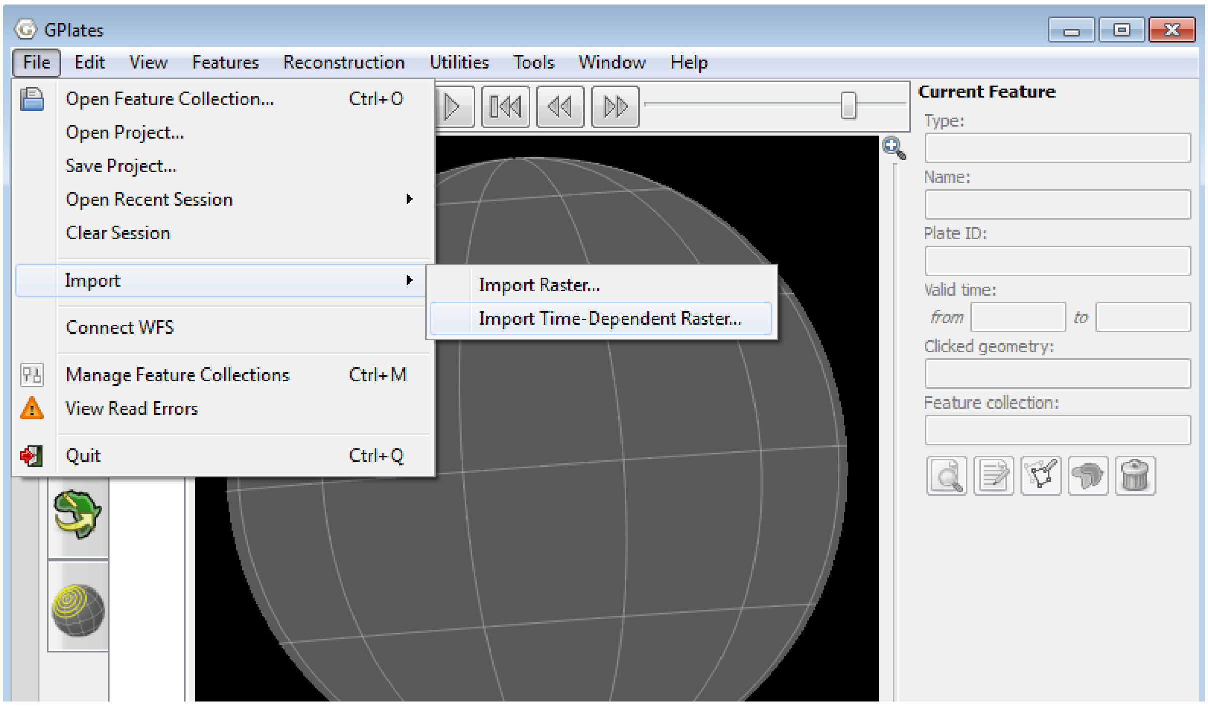
Now we will visualise time-dependent rasters in GPlates. Time depednent rasters are a series of rasters that have been age-coded so we can observe the evolution of a dataset through time. In the following exercises we will be observing snapshots of geodynamic models of dynamic topography (Appendix. A) and depth slices from seismic tomography models which are coded to geological age.

2.1 Time-dependent rasters: global dynamic topography

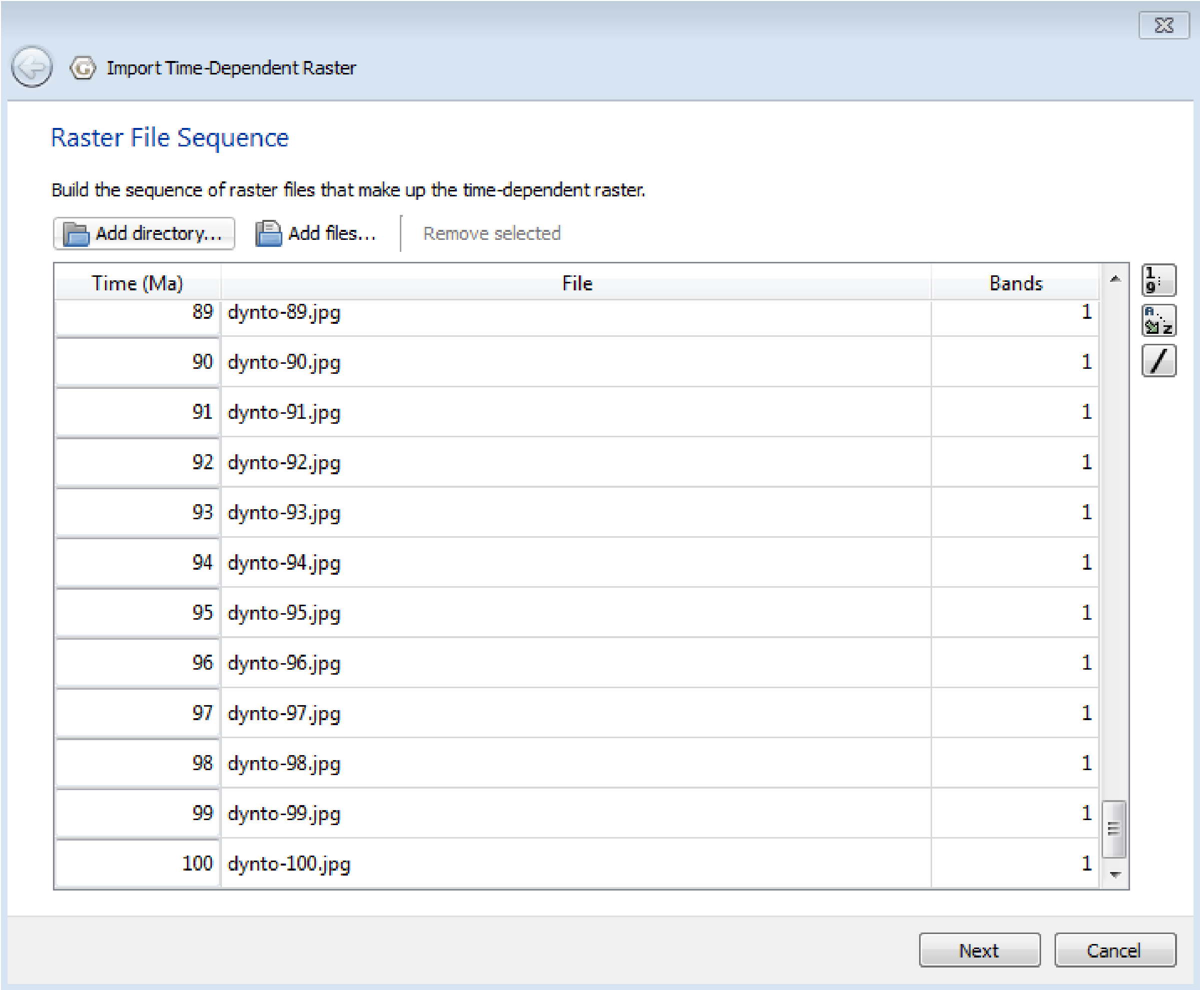
Dynamic topography is vertical motion of the Earths surface attributed to mantle processes. For example, dense, sinking material, such as subducting slabs, drag down over-lying crust, whereas buoyant upwellings push up overlying crust. For an informative overview of dynamic topography, the 2001 Scientific America article "Sculpting the Earth from Inside Out by Professor" by 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 (Figure 5a). Select the 'Add directory...' button and locate and select folder called "Dynamic Topography" → "jpg" in the tutorial data bundle (Figure 5b). Press 'Select Folder' (you cannot select an individual JPEG when loading a Raster Sequence), press 'Next", and leave the band name as "band 1". Press 'Next' and as our rasters are global, ensure that the lat-lon bounds are 90◦ to -90◦ and -180◦ to 180◦. Press 'Next' 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.


GPlates
File
Edit
View
Features
Reconstruction
Utilities
Tools
Window
Help
Open Feature Collection... Ctrl+O
Open Project...
Save Project...
Open Recent Session
Clear Session
Import
Import Raster...
Import Time-Dependent Raster...
Connect WFS
Manage Feature Collections Ctrl+M
View Read Errors
Quit Ctrl+Q
Current Feature
Type:
Name:
Plate ID:
Valid time:
from
to
Clicked geometry:
Feature collection:

(A)



(B)

Figure 5. (A) Navigating the menu bar to import time-dependent raster sequences. **(B)** Once a directory has been selected, the series of jpegs contained within that directory will be displayed next their corresponding age.

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 Seton_etal_ESR2012_Coastlines_2012.1_Polygon.gpmlz 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 Seton_etal_ESR2012_2012.1.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 faster seismic waves travelling through colder, denser material which pulls the lithosphere down resulting in negative dynamic topography, whereas reds indicate waves travelling through hotter less dense material which pushes the lithosphere up resulting in positive dynamic topography. To watch the evolution of the dynamic evolution of the Earth's 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.

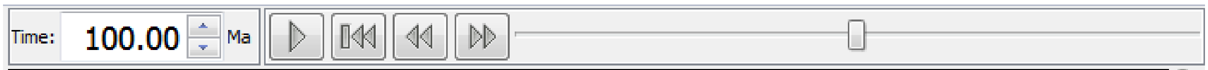


Figure 6. Time and Animation controls in the main window. You may use these controls to manually enter a time, move the slider to reconstruct the globe or animate from a selected time to the present.

2.2 Dynamic topography and tectonics in Australasia

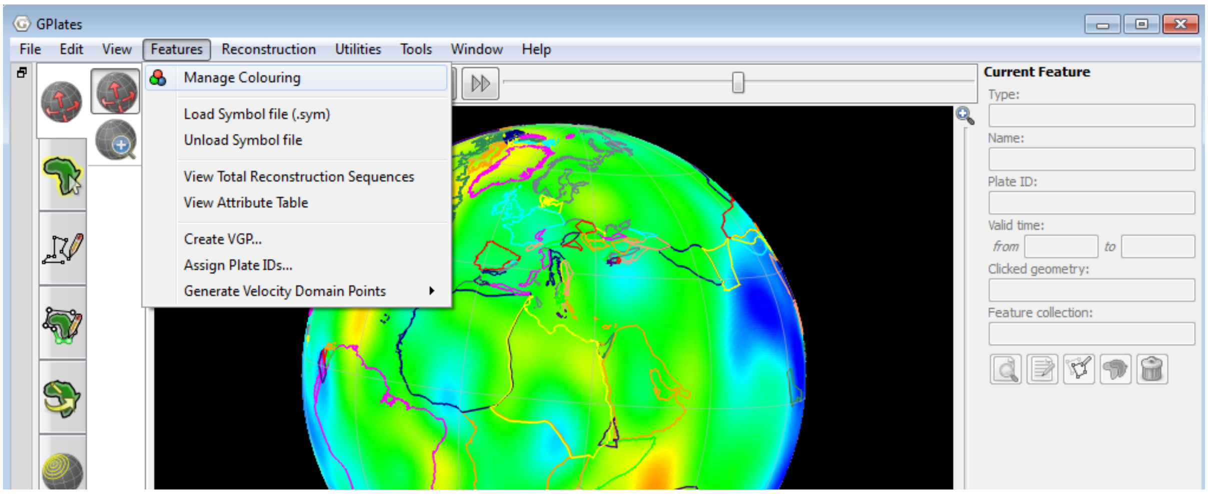
Time-dependent raster sequences can be combined with other reconstructable datasets in order to analyse and investigate features in the geological record. We will now exploit this functionality in order to see why dynamic topography is reflected in the geological record of several Australian basins and oceanic plateaus. 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 is the long term lithospheric sinking that can not be explained by the usual reasons. 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(the lithospheric topography changing due to mantle convection) 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]. If subsidence has occurred, a basin will form and sedimentation will increase.Thus if the rate of sedimentation in your well core is greater than the sediment contribution from lithospheric stretching then you can attribute it to dynamic subsidence,and would check this suspicion against mantle convection models. In our example the dynamic topography, including a 300 m downward tilt of the continent to the north- east, 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.

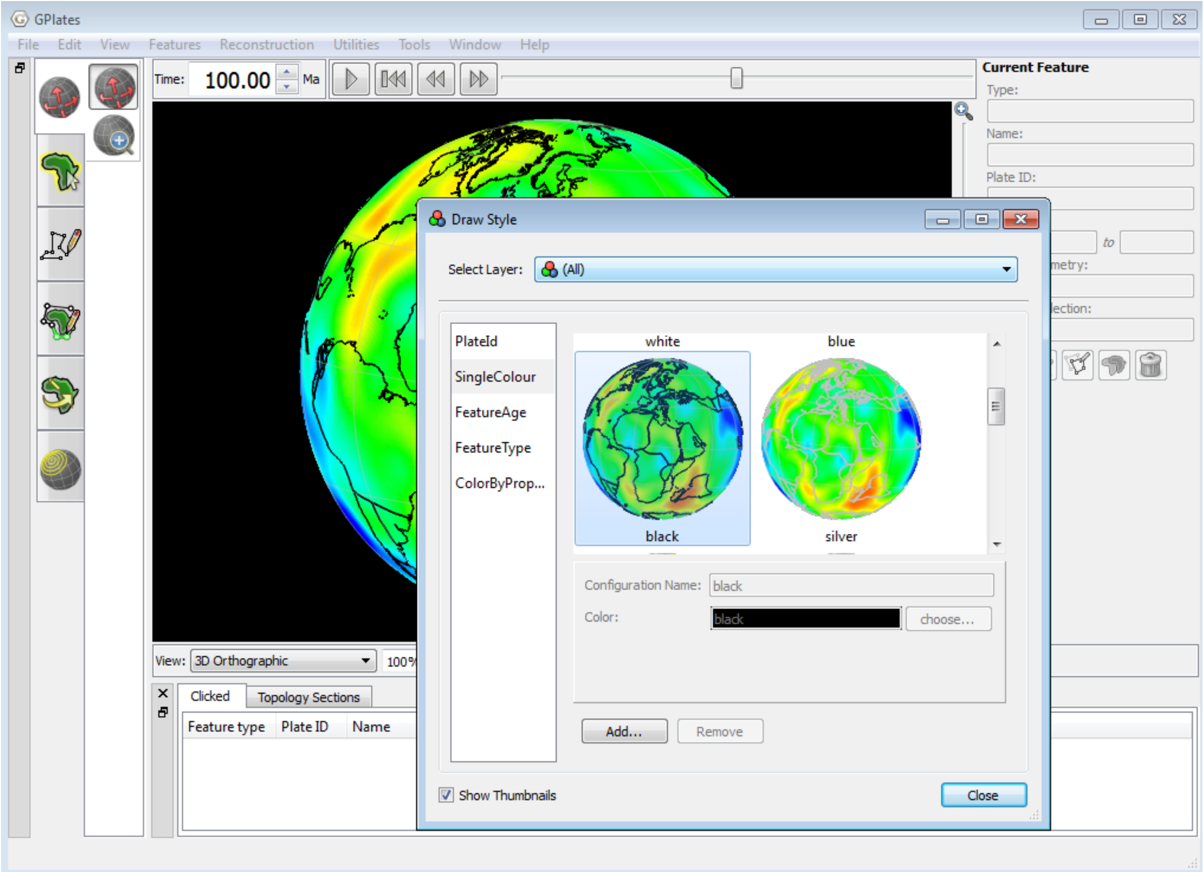
1. Locate and open the files CarpentariaBasin.gpml, QueenslandPlateau.gpml and MarionTerrane.gpml from the tutorial data bundle.

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 Features → 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.



(A)



(B)

Figure 7. Altering the colouring of our loaded data sets and setting a uniform colour to all loaded feature collections using the colour dialogue. (A) Navigating the menu bar to open the Manage Colouring window. (B) Changing the colour of all feature data to black.

4. Now play the animation through from 100–0 Ma (as you did previously at the end of ex 2.1).

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.

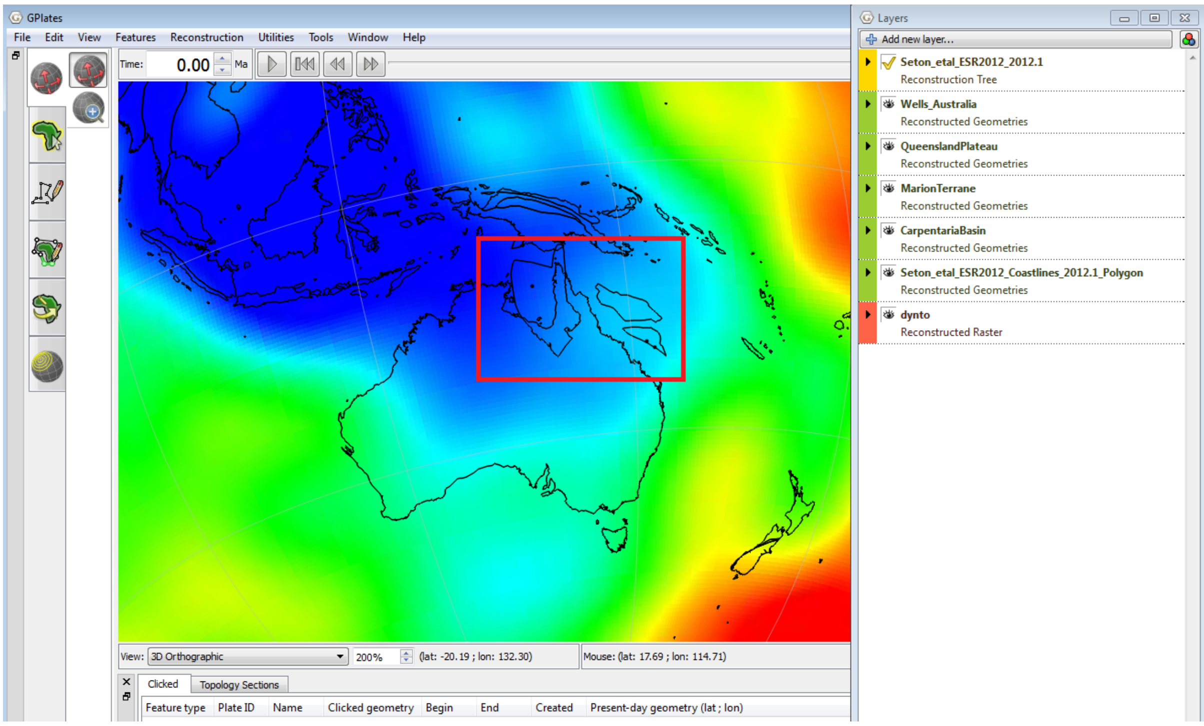


Figure 8. View of the Australian region with Gulf of Carpentaria basin outline and the Duyken-1 well (black dot) as well as the Marion and Queensland Plateau polygons and other well data. Background are time-dependent dynamic topography images.

2.3 Loading Time-dependent Raster Sequences and finding the Sundaland slab window

For the next exercise you will require the following two regional raster bundles included in the tutorial dataset:

Montelli06_S (Regional dataset)

MITP0-08 (Regional dataset)

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.

Slab Windows

Slab windows form as a result of spreading ridges intersecting subduction zones. 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 of imaging the Earth's interior to reveal 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. 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.

The included data bundle includes 2 sequences of regional time-dependent raster images, and one global time-dependent raster sequence, showing seismic tomography. These images were generated from the seismic tomography model PRI-S05 (Montelli et al., 2006) and model MIT-P08 (Li et al., 2008). 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 displays the corresponding depth of the age coded tomography slices.

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).

You can load Time-dependent Raster Sequences, which are raster images whose pixels change according to the reconstruction time.

Presently, GPlates can open RGBA images (which have a Red, Green, Blue and optional Alpha value for each pixel in the image) including common file formats such as JPEG (JPG), PNG, TIFF and GIF.

If you want to load your own time-dependent raster set, make sure:
- Each image is a jpg file
- All files are named: name-time.jpg
- The time-numbers are integers (time in Ma)

Example:
Montelli06_P-3.jpg
Montelli06_P-4.jpg
Montelli06_P-5.jpg
etc

For our region of interest time-dependent raster sets already exists. The seismic tomography data shows the mantle structure at different depths, which are assumed to represent certain ages in the past.

To load the Time-dependent Raster Sequence, select Import Time-dependent Raster from the File Menu (Figure 9a). This will open the first 'Import Time-Dependent Raster' window.

To add raster images, we have two options.

1. If we are using multiple files which are saved in a single folder, we can use the 'Add directory…' button and select the entire folder in which the images are saved.

2. Alternatively, if we are using multiple files which are saved alongside other files we do not want to load, or use the 'Add files...' button and select them all individually.

In this example, we will load the entire folder and use the Montelli tomography model. The importing Rasters data bundle also contains the MITP08 model, so feel free to try it out also. Keep in mind that for this SE Asia example, only the regional MITP08 model (MITP-08_Regional) is applicable.

Click the ‘Add directory’ button. Navigate to the folder in which your Montelli06_S folder is saved, select it and then click ‘Select Folder’ (Figure 9b). GPlates will take some time to add the raster file sequence. Don’t close the window!

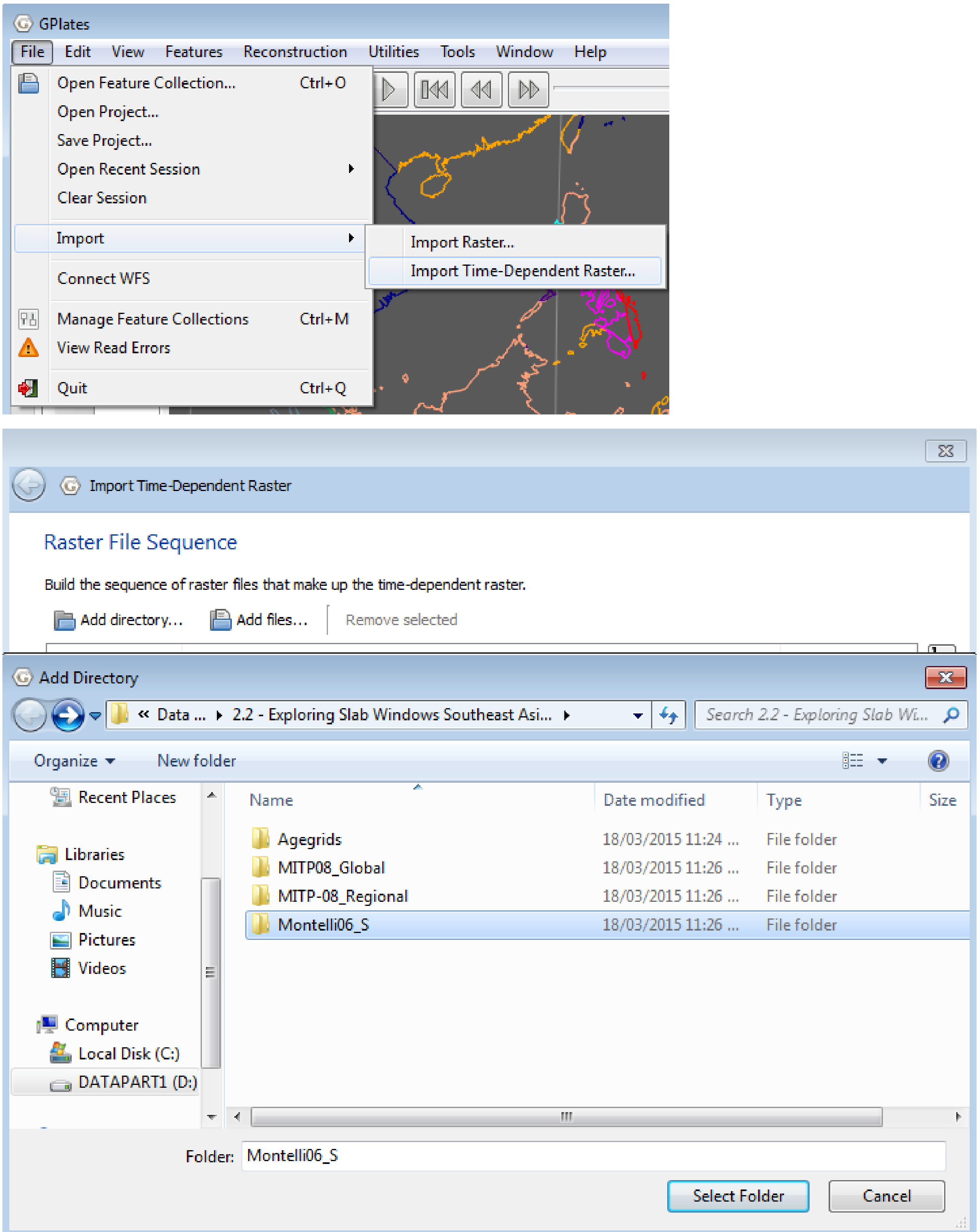


Figure 9. (a) Under the File tab, select ‘Import’, ‘Time-dependent Raster’. **(b)** Use the ‘Add directory’ button to select the folder in which your raster images are saved. In this

example, this is the folder 'Montelli06_S' included in the tutorial dataset.

You will see all the individual raster files loaded (Figure 10). Click Next.

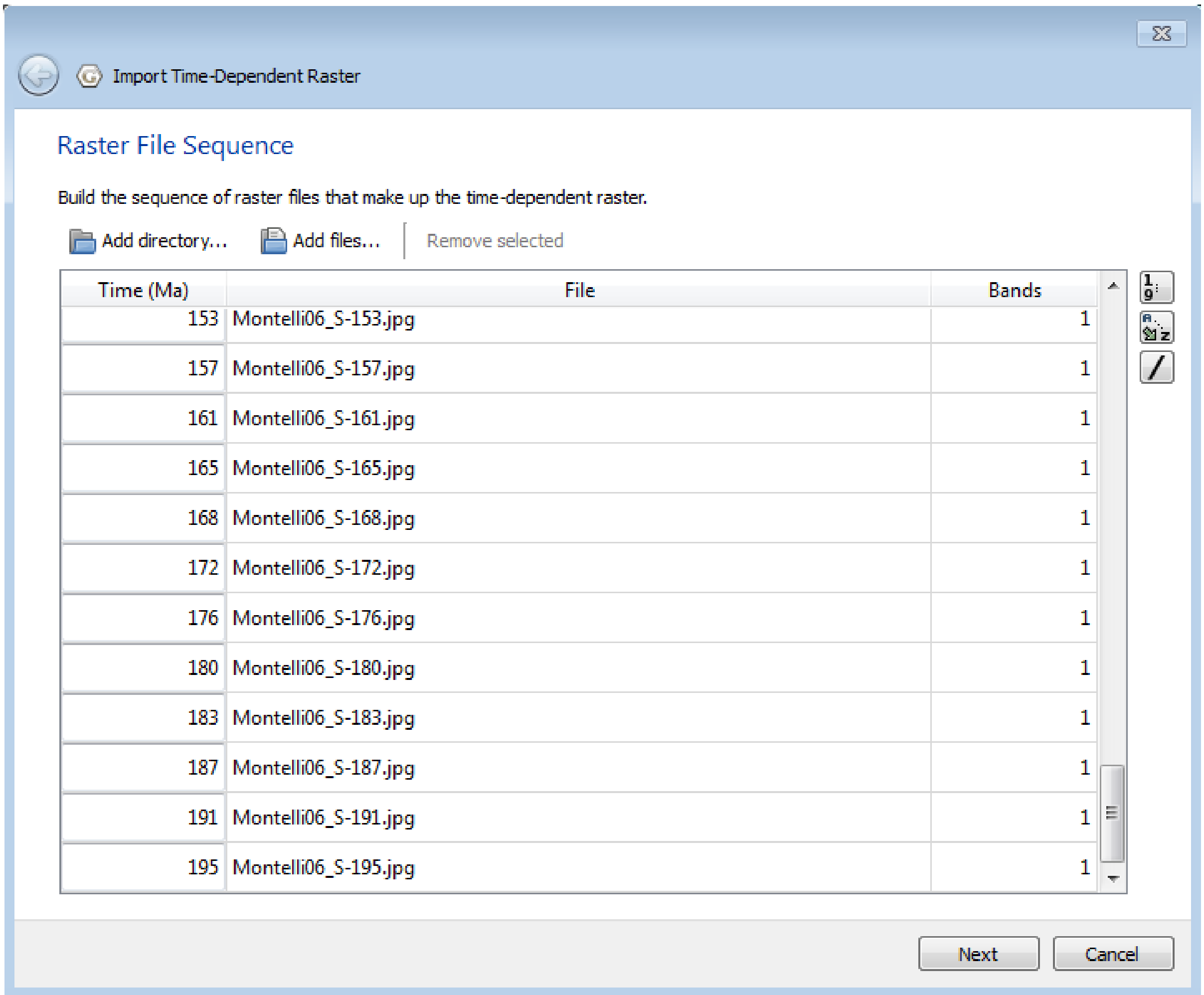


Figure 10. The first 'Import Time-Dependent Raster' window with all raster files loaded.

In the second window, you are asked to specify band names. Keep the default and click Next.

In the third window, under Georeferencing, you are asked to specify the location of raster using latitude and longitude. Since this is a regional raster, we are required to specify the position of the image to be in SE Asia. If we were instead loading a global raster, which spans the entire globe, we would keep the default location as is.

For the SE-Asia Montelli data, the coordinates are:

Top (lat): 30.0000°

Bottom (lat): -20.0000°

Left (lon): 80.0000°

Right (lon): 130.000°

Enter these coordinates in and click Next (Figure 11)

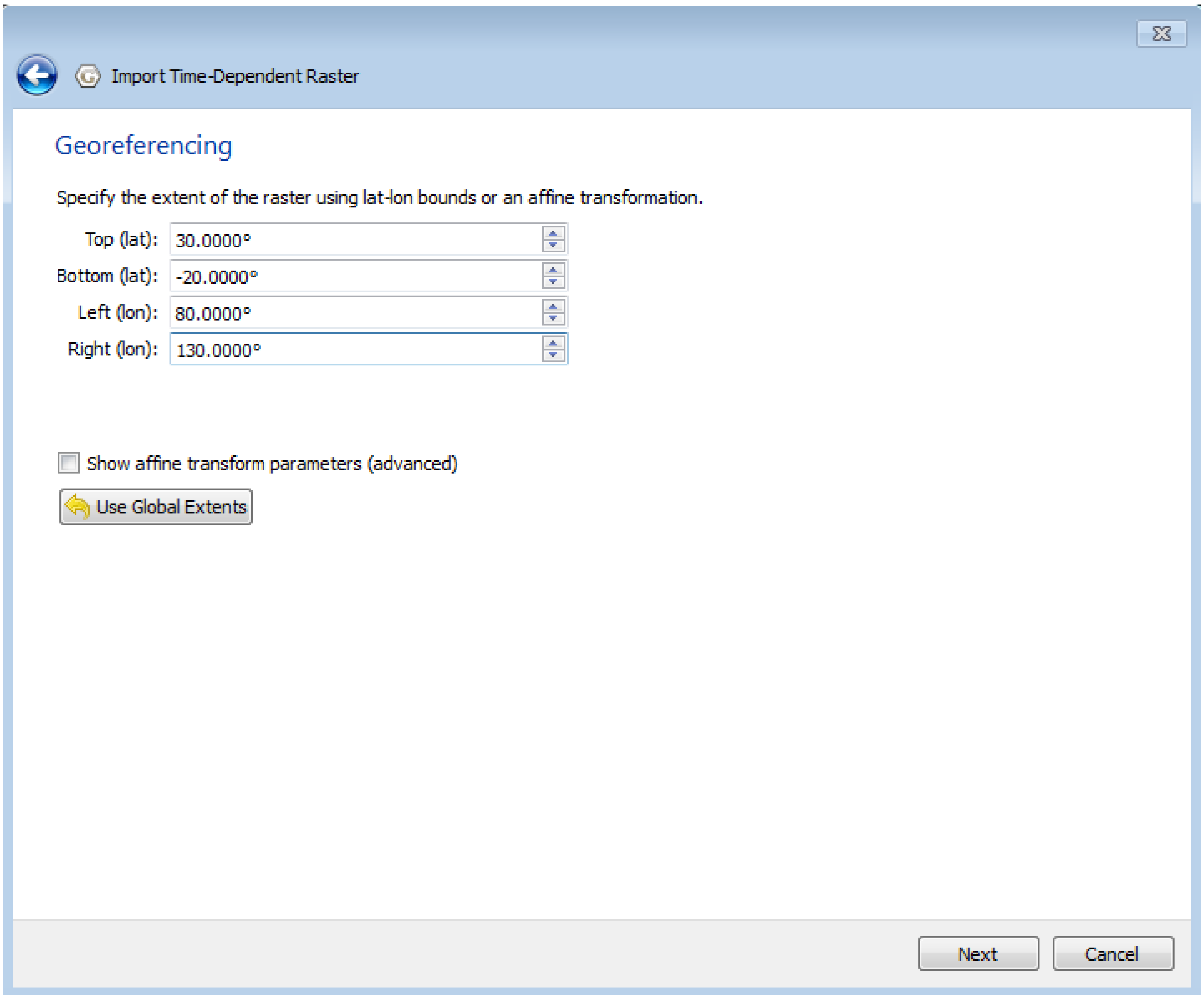


Figure 11. Enter the SE-Asia coordinates for the Montelli raster dataset (Top: 30°, Bottom: -20°, Left: 80° and Right: 130°) and click Next.

In the fourth window, you are prompted to create a new feature collection. Keep the default (< Create a new feature collection >) and press Finish.

After you have changed the Camera Position you should be able to see the seismic tomography for the SE-Asian region (Figure 12).

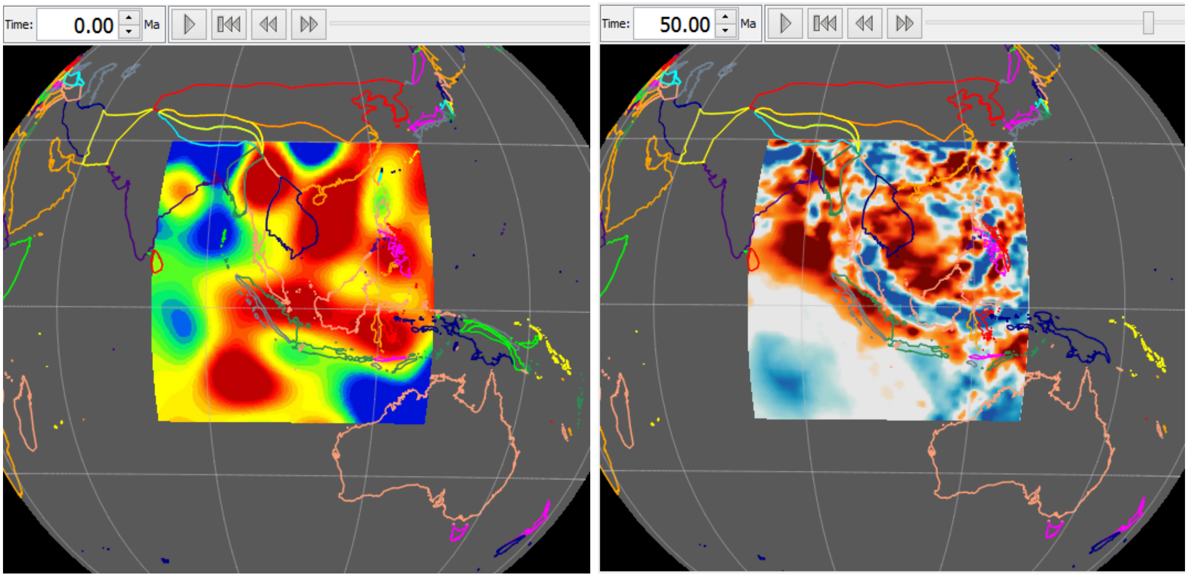


Figure 12. Seismic tomography of the SE Asian Region, with the raster surface extent set. **(a)** Tomography model is Montelli06_S at 0 Ma. **(b)** Tomography model is MITP08 at 50 Ma.

We want to use seismic tomography to find a hypothesised slab window beneath Sundaland in the late Cretaceous-Early Tertiary.

Slabs at subduction zones can be seen in seismic tomography images as regions of anomalously fast velocities (blue areas in our figures), because the slabs are colder and denser than the surrounding mantle.

A slab window can be seen as a break in the fast subducted slab.

The slab window is thought to have opened approximately between 70Ma and 43Ma and can be observed in different models at depths representative of these times.

Because the raster images are time-dependent we can animate the seismic tomography through time.

For the time-dependent raster sets that already exist for SE-Asia we can animate a period from 189 Ma to present day in 1 My time steps.

To animate the changes in seismic tomography through time we use the Animation Slider at the top of the interface. To reconstruct to a particular time, type the required age in Ma into the 'Time' text box and press Enter. As an example, reconstruct to 50 Ma using the Montelli model

(Figure 13).

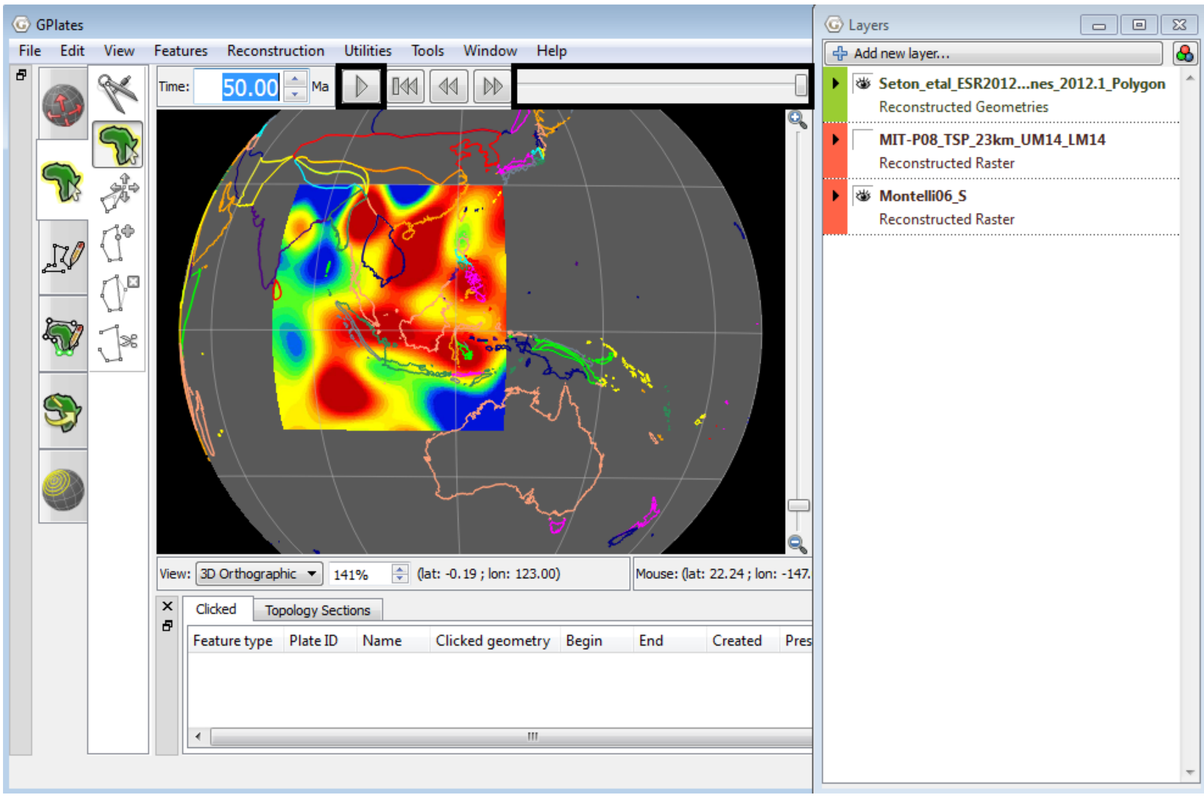


Figure 13. Reconstruct to a particular time frame by either typing the reconstruction time in Ma into the 'Time' text box (highlighted in blue, or using the Animation Slider to slide to the required reconstruction time (circled in black). Animate the changes in seismic tomography through time by pressing the Play button (circled in black)

To start the animation, press the Play button. The animation will start in the past (at the age at which you initially specified) and end at present day.

If you want to stop the animation press Pause (same button as Play).

By using the Fast Forward and the Rewind buttons you can watch the reconstruction in small steps. Press the Fast Forward/Rewind button once to adjust the current reconstruction time by one timestep forwards/backwards. The default timestep is 1 Ma.

You can also use shortcut keys:

Ctrl (CMD) + I = forwards

Ctrl (CMD) + Shift + I = backwards

By keeping the button pressed or the shortcut keys held down you can move forwards/backwards faster.

In the Animation Dialog (Figure 14) you can adjust the start and the end time for your reconstruction. To access this click Reconstruction menu and select Configure Animation

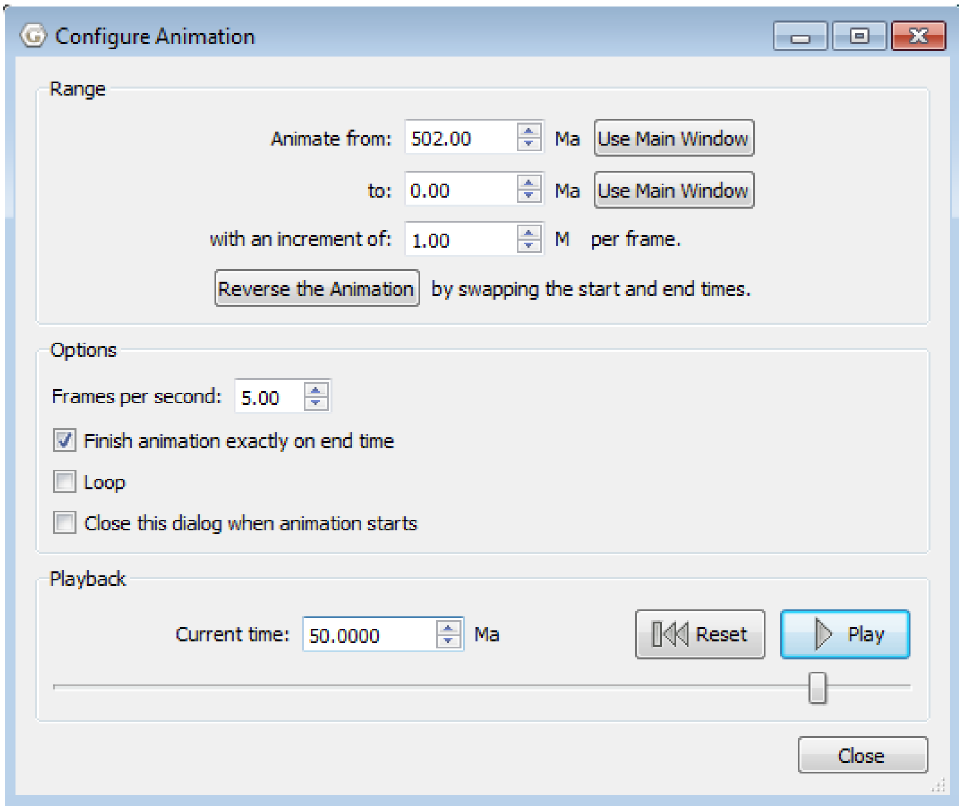


Figure 14. Animation Dialog

For our data you can choose any start time between 189 to 1 Ma.

In the Animation Dialog (Figure 14) you can also adjust the frames per second and the increment per frame.

Default settings are:

200 Ma for the start time and 0 Ma for the end time of the animation

5 frames per second

1 Ma increment per frame

If you want your animation to start at present day and go back in time you can choose Reverse the Animation from the Animation Dialog

To find our slab window we don't need our animation to start at 140 Ma. Change the start time for the animation to 80 Ma and the end time to 30 Ma.

Try to find the slab window in the different raster sequences. Look for red-yellow gaps that appear to break up a continuous blue band. The blue represents the colder oceanic slab being subducted, and the red representing the hot mantle upwelling through the gap or 'window'in the slabs.

You may find that turning off the coastlines layer by clicking the Eye in the 'Layers' window may make things less confusing (Figure 15).

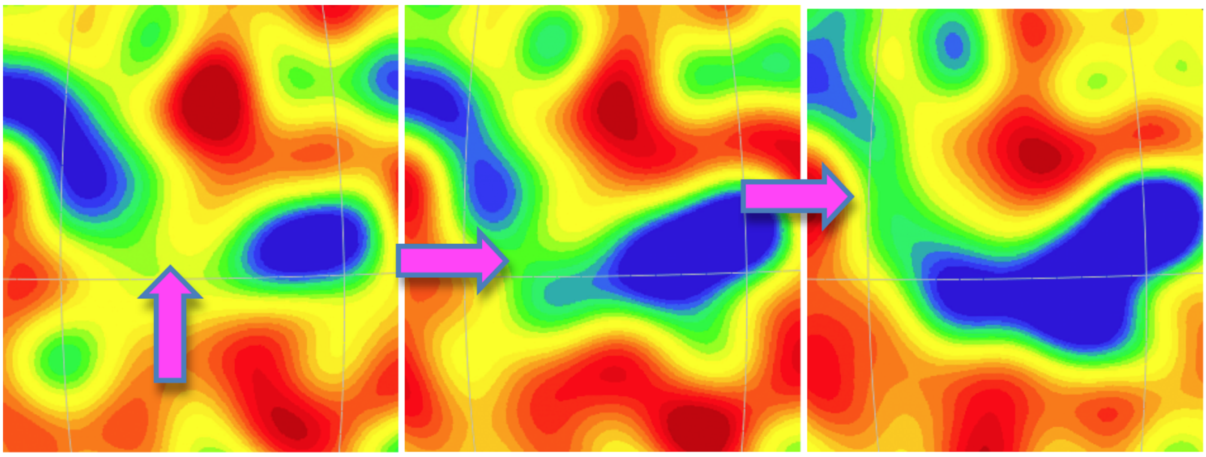


Figure 15. (a) Slab window in Sundaland using the Montelli06_S model at 70 Ma (left), 56 Ma (middle) and 43 Ma (right)

You will find that in the MITP08 model, a slab window begins to form at 63 Ma when a section of red intersects a blue band, and disappears at 38 Ma when the blue band becomes continuous once more (Figure 16).

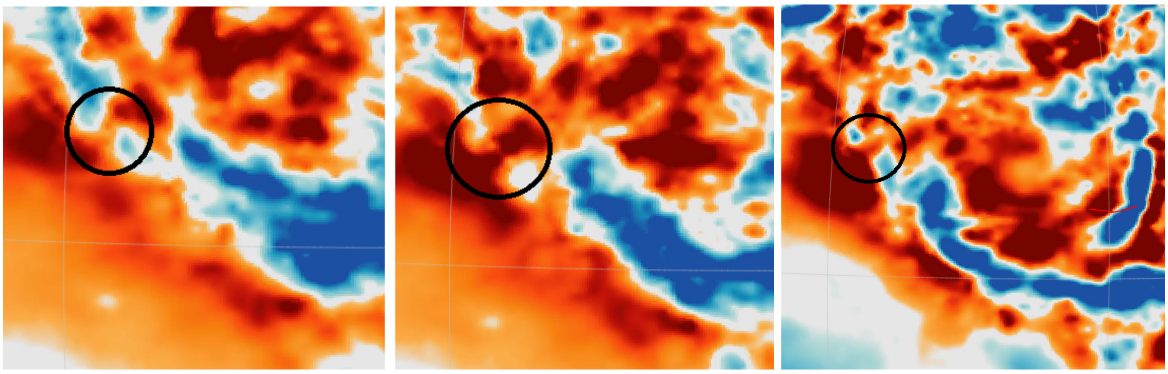


Figure 16. (a) Slab window in the MITP08 model at 63 Ma (left), 57Ma (middle) and 44Ma (right)

Exercise 3: Creating new features: Digitising a new slab window feature in Sundaland

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GPlates provides the opportunity to interactively create new features.

We want to digitise our slab window in Sundaland, create a new feature and export it in a format that can be used in other programs (e.g. GMT).

To digitize our slab window we need the 'Digitisation Tools' from the Tool Palette on the left hand side of the globe.

When you click on the 'Digitisation Tools' icon, seven further options appear (Figure 17). These include:

Measure

Digitise New Polyline Geometry

Digitise New Multi-Point Geometry

Digitise New Polygon Geometry

Move Vertex

Insert Vertex

Delete Vertex

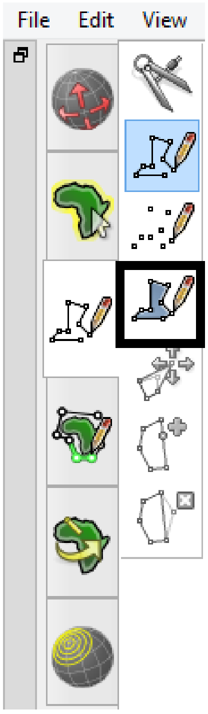


Figure 17. Under the 'Digitisation Tools' icon, you will find Measure, Digitise new Polyline Geometry, Digitise new Multi-Point Geometry, Digitise new Polygon Geometry (circled), Move Vertex, Insert Vertex and Delete Vertex.

Depending on which kind of feature you want to create you need a certain geometry.

For our slab window we will choose the Polygon Tool. Click on the 'Digitise New Polygon Geometry' button to select the tool (Figure 17).

After a digitisation tool has been selected every mouse click creates a new vertex. If you make a mistake, click 'Undo' under the Edit tab, or alternatively use the Undo shortcut on your keyboard (Ctrl + Z).

To digitise the position of our slab window, we will choose to draw an oval shape.

Note that GPlates can only digitise straight lines - to create an oval shape, we must digitise several points so that the polygon will appear oval-shaped, despite being composed of several straight lines.

Before we digitise the slab window, we need to do a few more things.

The slab window opened approximately beneath the Sunda-Java-Trench and extended to the north so it is helpful to see the coastline again. Tick the box beside the Coastlines layer in the 'Layers' window.

Change the Coastlines layer to black by using the 'Manage Colouring' tool under the 'Features' tab. Select the Coastlines layer in the drop-down menu, then on the left click SingleColour, then choose Black and click OK (Figure 18).

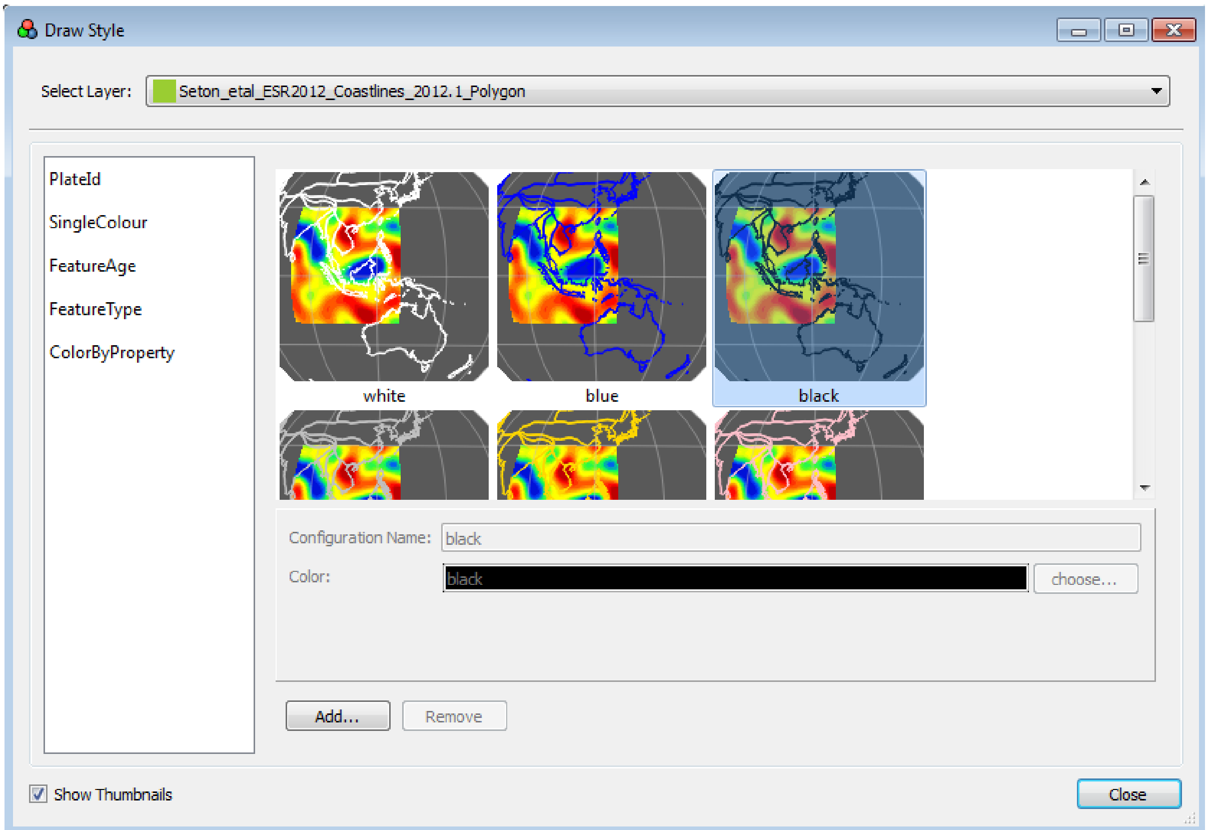


Figure 18. Changing the Coastlines layer to black using 'Manage Colouring'.

Because we want them to change position through time we need to load a rotation file as well. The rotation file contains Longitude, Latitude and the angle of rotation for each plate.

If you haven't already loaded it, use 'Open Feature Collection' and select the file Seton_etal_ESR2012_2012.1.rot from your data bundle. If it is already loaded, you should see it in the 'Layers' window.

We are now ready to digitise.

Ensure you have selected the 'Digitise New Polygon Geometry' tool.

Set the Reconstruction Time to 70 Ma and start digitizing the slab window by clicking successive points.

As before, click 'Undo' or use the shortcut Ctrl + Z to undo your last point if you make a mistake.

Your slab window should look approximately like the figure below (Figure 19).

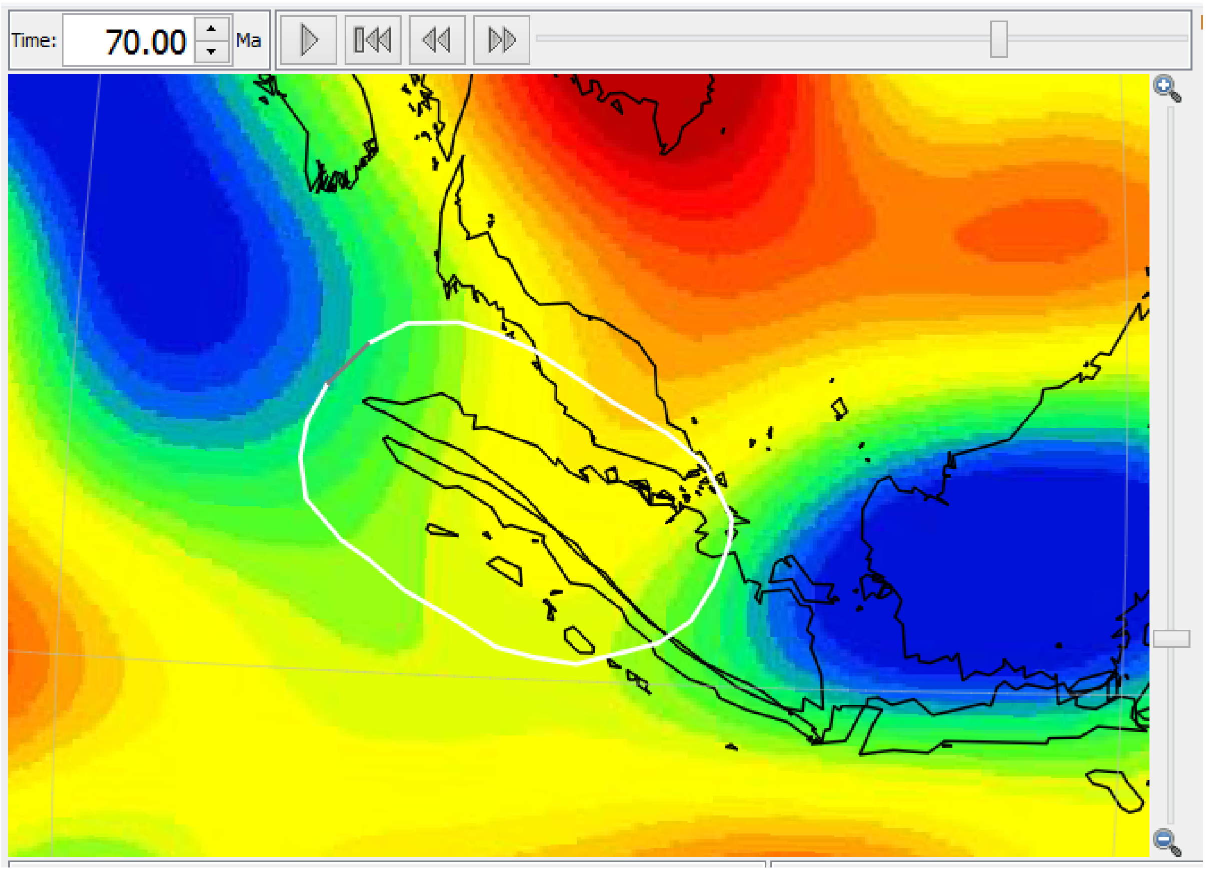


Figure 19. Sundaland slab window at 70 Ma digitised using the 'Digitise New Polygon Geometry' tool, based on the Montelli tomography model.

You may have also noticed that for every vertex digitised, their coordinates can be seen in the 'New Geometry' Table on the right hand side of the globe (Figure 20).

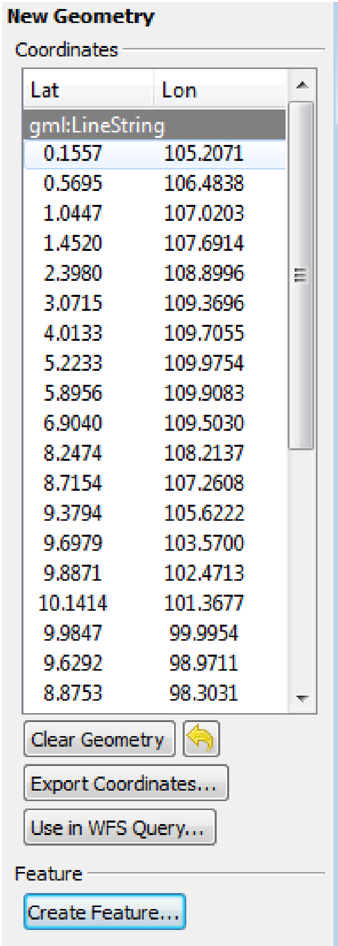
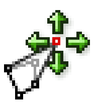
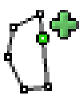


Figure 20. The latitude and longitude coordinates of the newly digitised vertices displayed in the New Geometry Table.

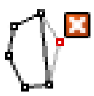
If you don't like the shape you can move the vertices, add new vertices or delete those you don't like using the editing tools from the tool palette.



Move Vertex



Insert Vertex



Remove Vertex

Figure 21 shows the digitized slab window after Move Vertex has been selected. Each vertex (dot) can now be moved.

If you want to add a vertex, select Insert Vertex and click on the line at the spot you want to add a dot.

You can move the new vertex later if you don't like the position.

If you want to remove a vertex, select Remove Vertex and click on the dot you would like to remove.

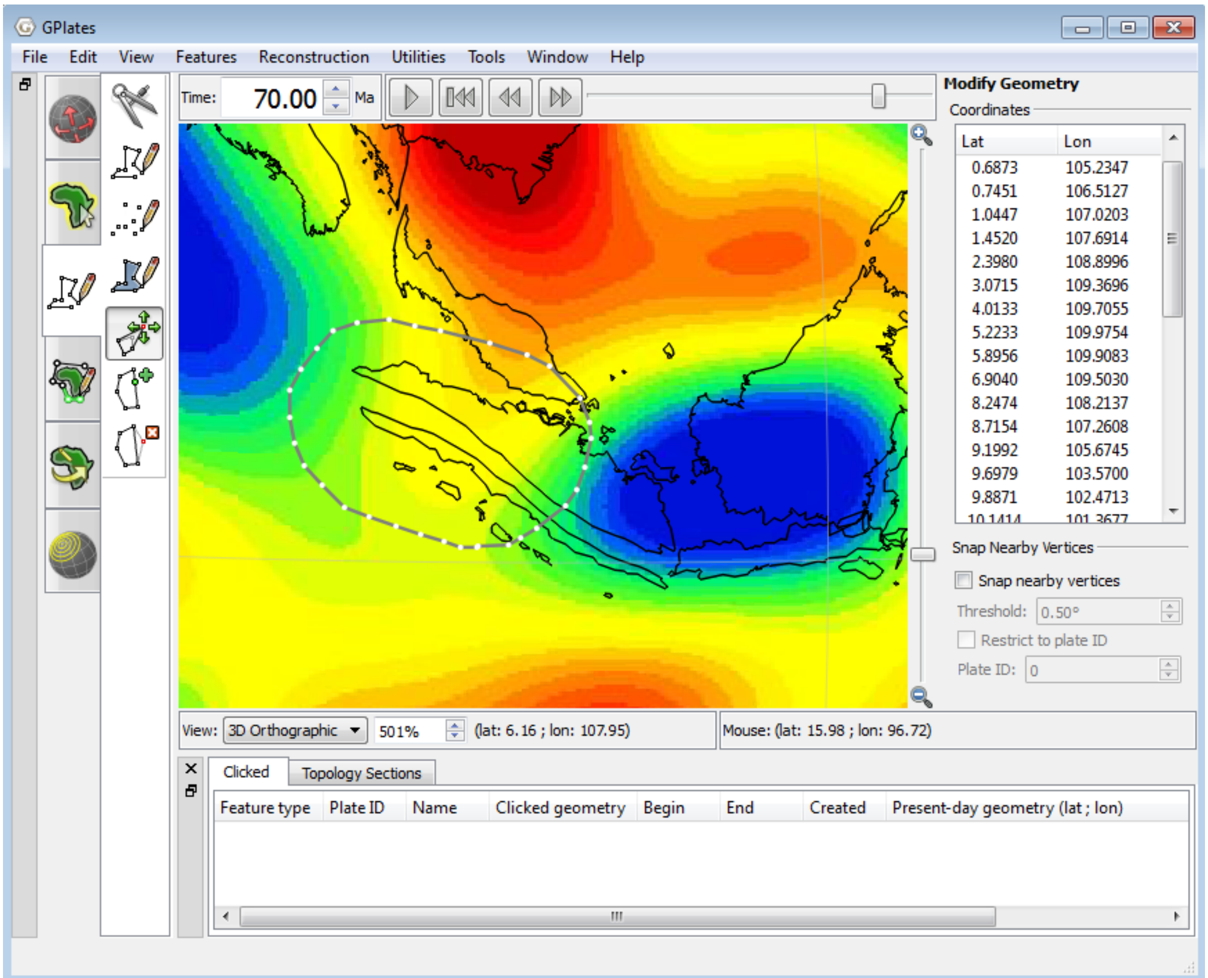


Figure 21. Digitised slab window after editing tool has been selected.

Once you are happy with the shape of your slab window you export it in a format GMT can read.

To export a feature the Digitization Tool (not the Vertex tool) has to be selected.

Click ‘Export Coordinates’ beneath the Geometry Table.

The Export Coordinates Window will open and ask you to choose a format, the coordinate order and a destination (Figure 22).

Choose the Generic Mapping Tools (GMT) format.

Make sure the Coordinate order is Latitude, Longitude.

Export destination as a ‘File’. Click ‘Export’, and navigate to the folder in which you would like to save your slab window to. Specify the filename. Click Save.

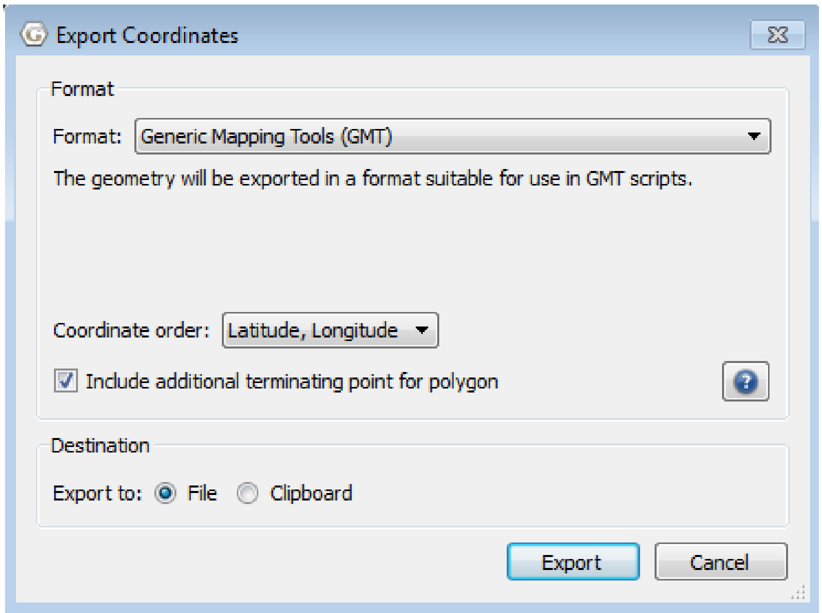


Figure 22. In the ‘Export Coordinates’ window, choose the Generic Mapping Tools (GMT) format, the coordinate order of Latitude, Longitude, a destination, and a filename. Click Export, after which you can specify the filename and destination.

If you want to load the feature in GPlates later again, you have to create a new feature using these coordinates.

To create a new feature click ‘Create Feature’ beneath the Geometry Table.

In the first Create Feature window, you will be asked to select a feature type. Select 'Unclassified Feature' for the slab window (Figure 23).

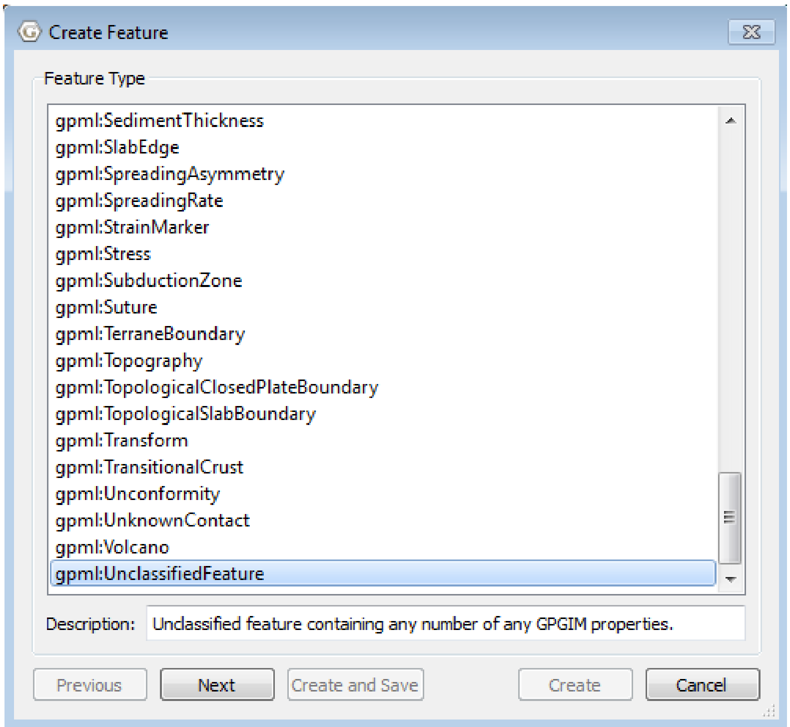


Figure 23. In the first 'Create Feature' window, select 'gmpl:UnclassifiedFeature' as the Feature type. Click Next.

Click Next.

In the next 'Create Feature' window, leave the default setting for the geometry's purpose (Boundary).

You have to give your feature a Plate ID (Figure 24). It has to be the ID of the plate your feature is located on. In our case the slab window is on the Eurasian Plate. Type 301 for Plate ID which is the Eurasian Plate ID.

You have to give your feature a time of appearance and disappearance. In our example, we digitized the slab window at 70Ma.

Select 70Ma for Begin (Figure 24).

For End you can either tick Distant Future if you don't know exactly when it disappeared or select an End time.

For our slab window tick Distant Future for End (Figure 24).

Finally, give it a name (e.g. SlabwindowMontelli06_S70Ma) and click Next.

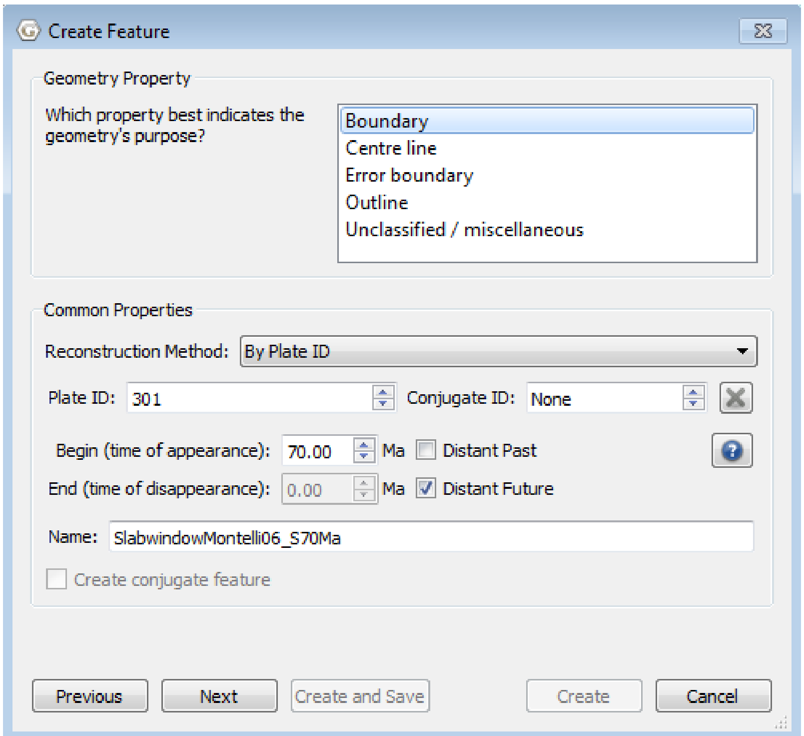


Figure 24. Create Feature Dialog. This is where most of the features attributes are set. Set the geometry property to Boundary, the Plate ID to 301 (the Eurasian Plate), the Begin time to 70 Ma, the End time to Distant Future, and the name (e.g. SlabwindowMontelli06_S70Ma).

In the third 'Create Feature' window, keep all defaults and click Next.

In the fourth 'Create Feature' window, select < Create a new Feature Collection > at the bottom of the list. Click Create.

You've now created a new feature, but it hasn't been saved yet.

Open your Manage Feature Collection Dialog and save the feature as a dat-file by clicking the Save As button. Specify a filename and location in the finder window. You have now saved your new slab window feature!

This is just an example using one tomography model. If you would like to compare the different models, go back to step 8 and load a new set of time dependant rasters from the folder called MIT-P08.

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 EarthByte's time-dependent crustal age sequence from the Importing_Rasters data bundle.

Select 'Import Time-dependent Raster Sequences' from the File Menu.

A finder window will pop up. Use either the 'Add directory...' or 'Add files...' to select the 'AgeGrids' from the GPlates Sample Data/Rasters/Time-dependent raster sequences. Note that this will take time to load, like all raster sequences. Do not quit!

In the second window, we must assign band names to the bands in the raster. Leave the settings on default, and click 'Next'.

In the third window, you no longer to have specify the location of the raster since this is a global raster sequence. Therefore, keep the default coordinates (Top: 90°, Bottom: -90°, Left: -180° and Right: 180°).

Create a new feature collection and press Finish.

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. Note that the youngest oceanic crust is red.

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 (Figure 25).

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 once more that the youngest crust is coloured red, and that the edges of the coloured age grids signify continent-oceanic boundaries (COBs).

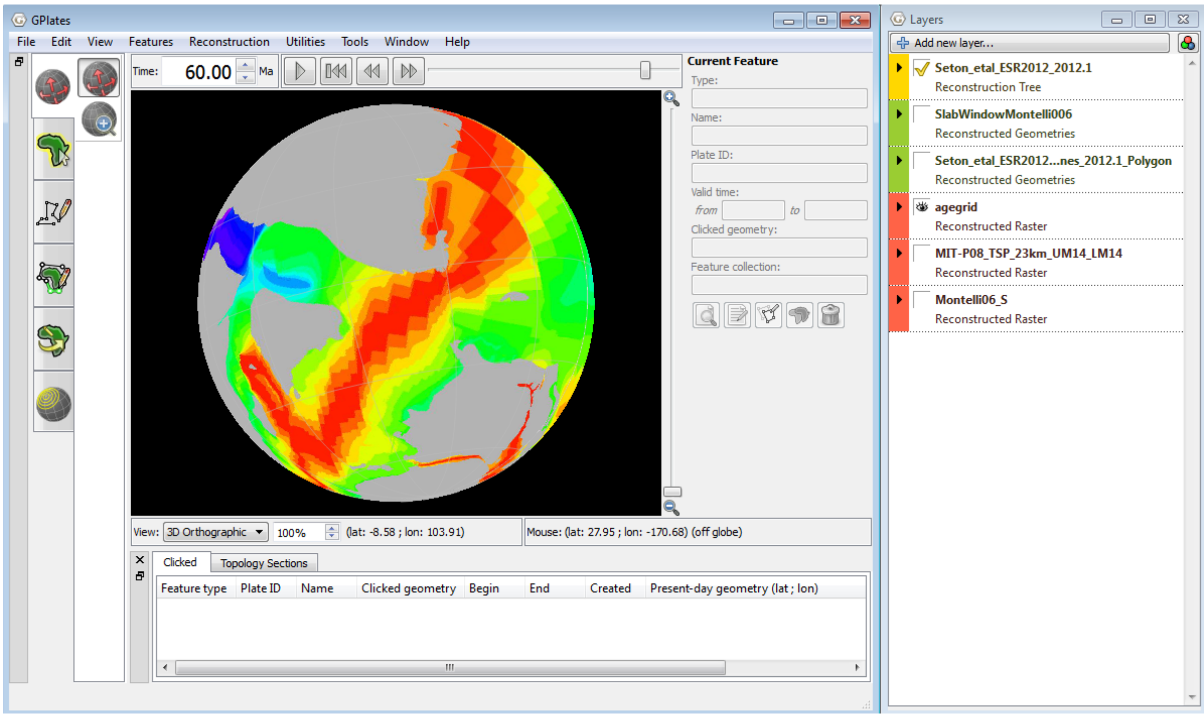


Figure 25. 60 Ma reconstruction of ocean floor ages and present-day coastlines. Notice that the youngest oceanic crust (and hence the spreading ridge) is converging with western most Sundaland. Compare this figure with your polygon you have digitised.

Rotate the globe to centre on Sundaland and use the Time controls to jump to 60 Ma. Turn the slab window layer back on.

* How does your digitised slab window compare to the location of subduction of the Wharton Ridge (and hence the kinematically inferred slab window)?

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, see Fabian et al. (2010).

* You will find that the digitised slab window tends to correlate with the younger ocean floor (red). This is consistent with the definition of slab window formation earlier: spreading ridges intersecting subduction zones.

Exercise 4: Finding and digitising the Caribbean slab window: how is it different to Sundaland's?

For the next exercise you will require the following global raster bundle included in the tutorial dataset:

MITP08 (-0.6 0.6 0.05) (Global dataset)

Similarly to the previous exercise, we will now be using a combination of global time-dependent rasters and reconstructable data sets to reveal an assumed Mid-Late Tertiary 'slab window' beneath the Caribbean (Breitsprecher and Thorkelson, 2009 and Van Benthem, 2012) - a region of Central America comprising the Cayman Islands, Cuba, Jamaica, Costa Rica, Panama and other neighbouring regions.

We will find and digitise the Caribbean slab window in much the same way as we did the Sundaland slab window. However, upon comparing the location of the digitised slab window relative to the subduction zone and other plate boundaries, we may find some differences.

Load the Time-dependent Raster Sequence comprising the global MITP08 dataset by selecting Import Time-dependent Raster from the File Menu.

Use either the 'Add directory...' to select the folder MITP0_Global from where it is saved, or the 'Add files...' button to select all 62 MITP08 raster images from the folder. When all the files are loaded, click Next (Figure 26).

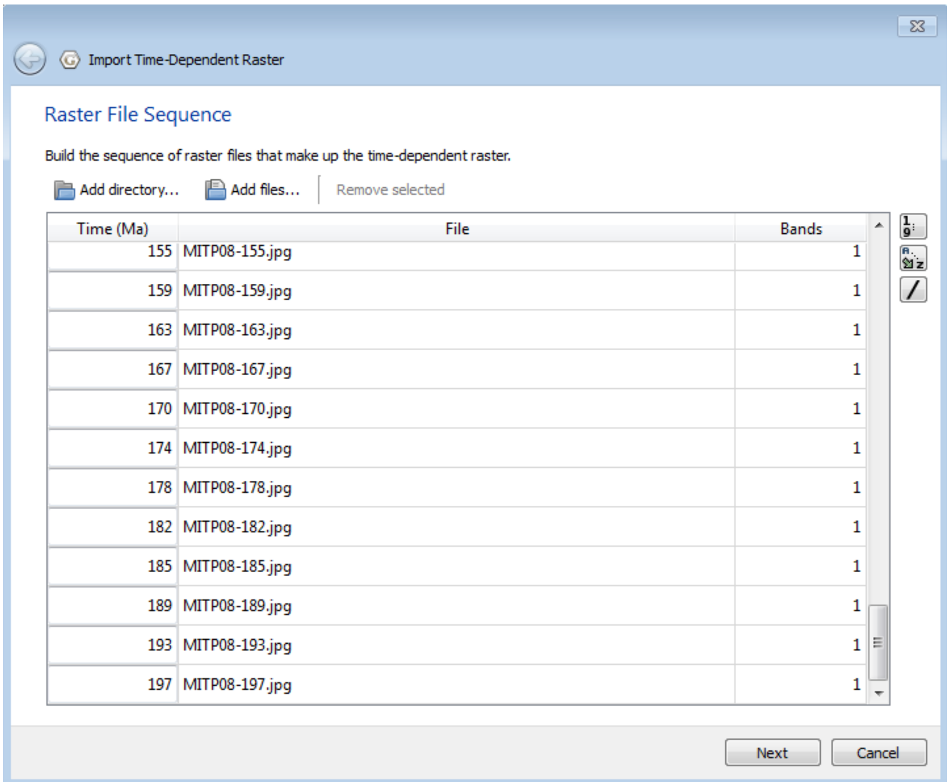


Figure 26. Once the complete raster sequence comprising the global MITP08 dataset is loaded in the Import Time-Dependent Raster window, click Next.

Click Next again. In the next window, keep the default Georeferencing coordinates since this is a global raster, then click Next. Keep the default Select <Create a new feature collection> in the next window, and press Finish.

We will now turn off all layers in the Layers dialog except for the Coastlines and the global MITP08 dataset we have just imported (Figure 27).

Centre the globe on Central America. Since the slab window is hypothesised to begin in the mid-late Tertiary, reconstruct to 40 Ma (Figure 27).

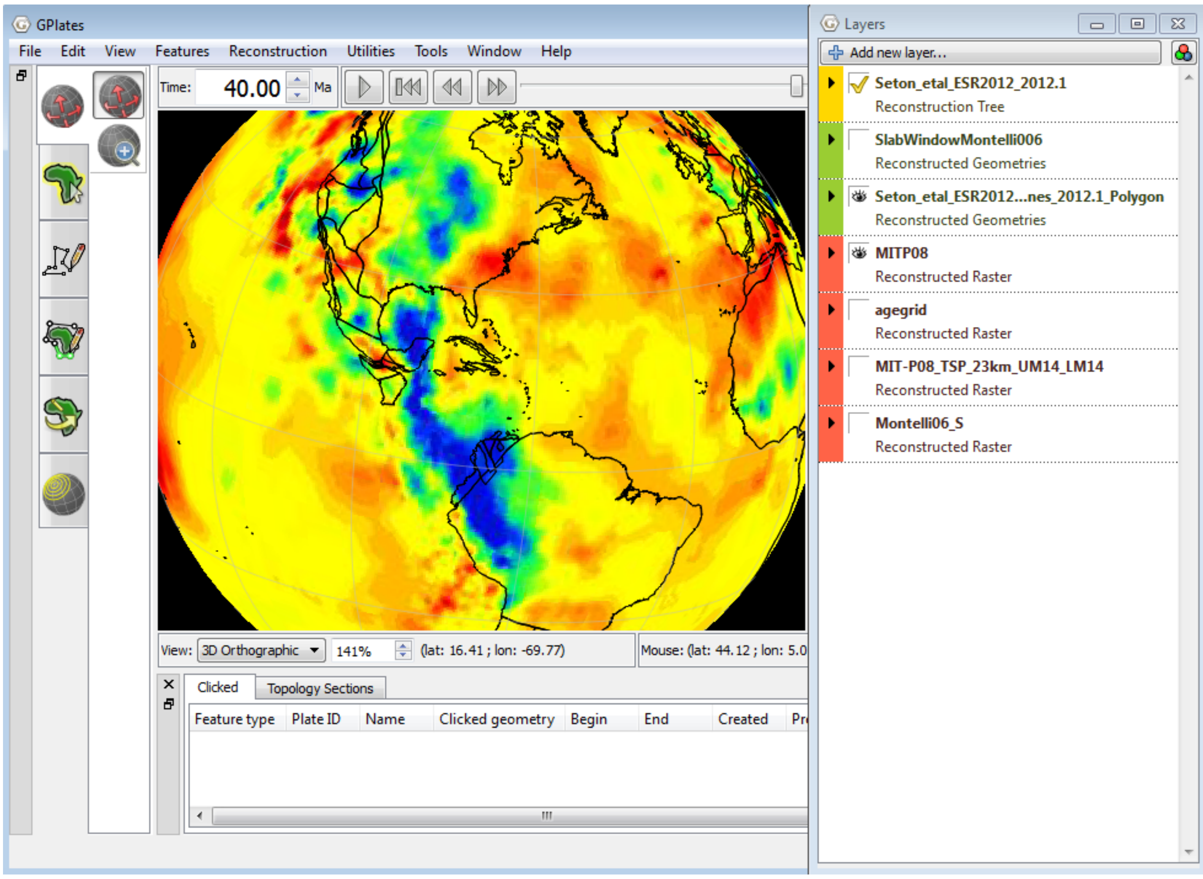


Figure 27. Turn on the Coastlines and the global MITP08 layers in the Layers dialog. Centre the globe on Central America and reconstruct to 40 Ma

Now we will attempt to locate the Caribbean slab window and determine when it began to form. Remember that you are looking for red-yellow gaps that intersect continuous blue band, which may indicate the presence of a slab window.

Animate back and forth from 40 Ma to present day using the time slider. Try to find the slab window, and again if you find the coastlines confusing, turn them off in the Layers window and just leave the raster visible.

You will find that a slab window begins to form at 24 Ma and continues until present day.

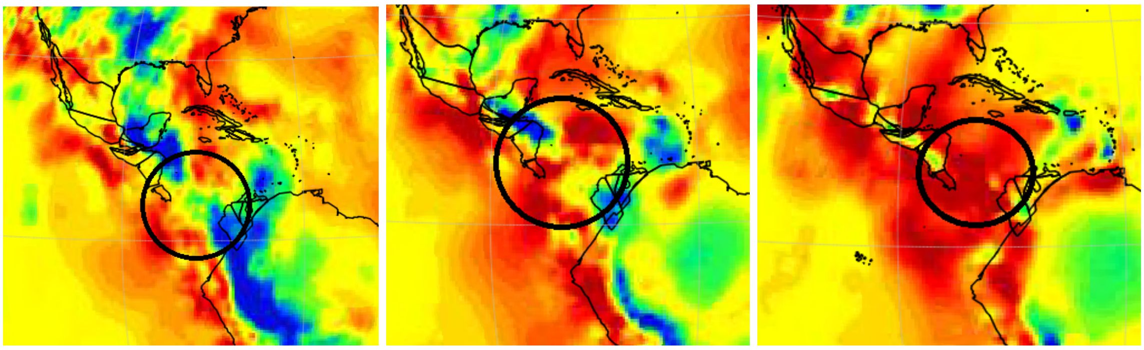


Figure 28. (a) Slab window in the Caribbean using the global MITP08 model at 24 Ma (left), 17 Ma (middle) and 7 Ma (right)

Digitise the slab window using the 'Digitise New Polygon Geometry' tool under the Digitisation button on the left. We will choose to draw an oval shape.

Reconstruct to any time between 24 and 0 Ma and use this reconstruction time as the basis for your slab window digitisation.

Keep in mind however that the slab window (the red section) seems to progressively get larger, so bear this in mind while digitising. It may be worthwhile digitising the entire extent of the slab window in its later stages rather than digitising a small window in its early days.

For this reason, we have chosen 10 Ma as our reconstruction time.

As before, click successive points to digitise the slab window, and click 'Undo' to remove your last digitised point if you have made a mistake.

Your slab window should look approximately like the figure below. Notice the coordinates of every vertex of your new polygon can be seen in the 'New Geometry' Table on the right hand side of the globe (Figure 29).

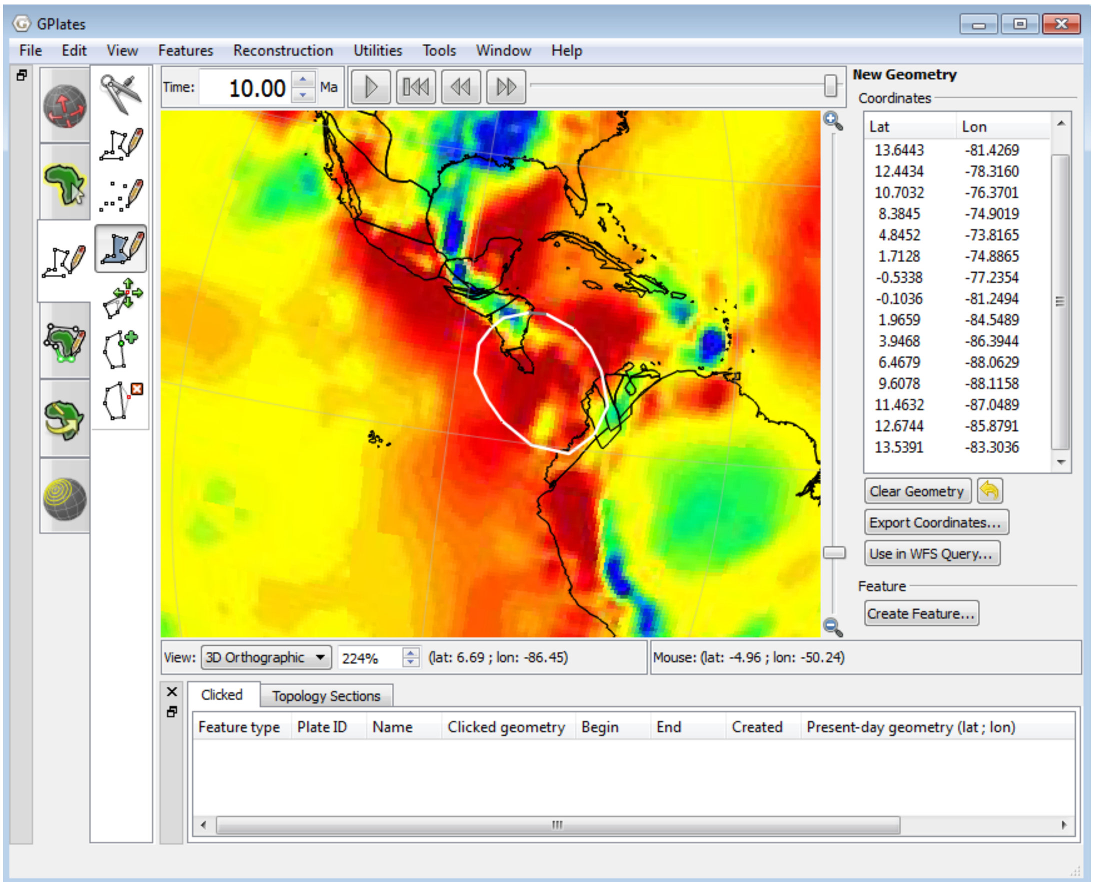


Figure 29. Caribbean slab window at 10 Ma digitised using the 'Digitise New Polygon Geometry' tool, based on the global MITP08 tomography model.

While not a necessary step, you may wish to export the digitised slab window in GMT format. To do this, click 'Export Coordinates' beneath the Geometry table.

In the Export Coordinates window, choose the Generic Mapping Tools (GMT) format and ensure the Coordinate order is Latitude, Longitude. Export destination as 'File', click 'Export' and then specify the filename and file destination before clicking 'Save'.

We will now save our digitised slab window as a feature which can be loaded into GPlates as a layer.

To do this, click 'Create Feature' beneath the Geometry Table. Select 'Unclassified Feature' for the slab window. Leave the geometry's purpose as 'Boundary' in the next window. Give your feature a plate ID of 201 (South American Plate), a Begin time of 24 Ma, and an End time of 'Distant Future'. Specify a name such as 'SlabwindowMITP08_24Ma' (Figure 30).

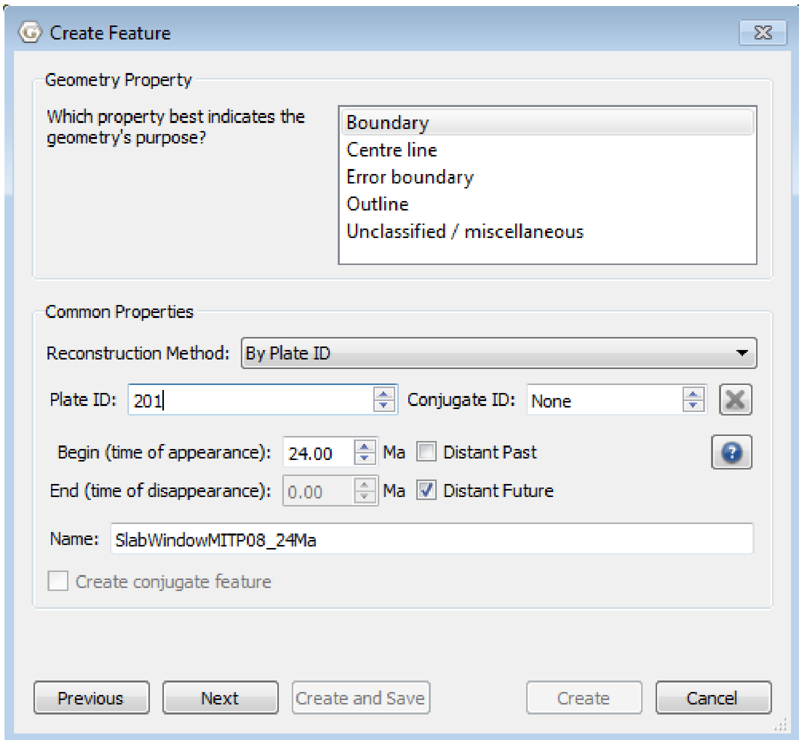


Figure 30. Create Feature Dialog. This is where most of the features attributes are set. Set the geometry property to Boundary, the Plate ID to 201 (the South American Plate), the Begin time to 24 Ma, the End time to Distant Future, and the name (e.g. SlabwindowMITP08_24Ma).

In the third 'Create Feature' window, keep all defaults and click Next. In the fourth 'Create Feature' window, select < Create a new Feature Collection > at the bottom of the list. Click Create.

Save the feature in the Manage Feature Collection Dialog by clicking the Save As button. Specify a filename and location in the finder window.

Now we have finished locating and digitising the Caribbean slab window.

We will now compare, as we did in Sundaland, the location of the slab window that you inferred from seismic tomography to where the youngest crust is, signifying the location of ridge.

Again, for simplification we will assume that the spreading ridge is positioned at the centre of the youngest oceanic crust (coloured red) and that the edges of the coloured age grids signify continent-oceanic boundaries (COBs).

Turn on the age grid layer in the Layers dialog and begin comparing it with the location of your digitised slab window.

If you cannot see your age grid layer, chances are it is sitting underneath the MITP08 layer. To rectify this, you can either turn off the MITP08 layer, or drag the age grid layer above the MITP08 layer but clicking and dragging the coloured bar beside the name. This positions the age grid layer on top of the MITP08 layer, and will instead hide the MITP08 layer despite it still being a 'visible', turned on layer.
Spend some time reconstructing the raster sequence back and forth in time using the Animation and/or Time controls. Your slab window should be in a similar position to this at 24 Ma when loaded with the age grids (Figure 31).

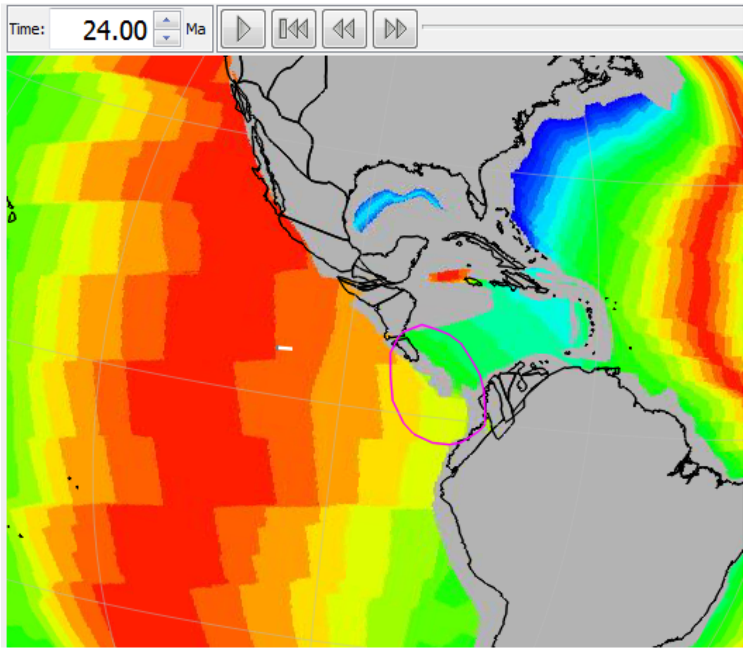


Figure 31. The digitised Caribbean slab window reconstructed at 24 Ma with age grids loaded. Red = youngest sea floor.

** How does the location of your digitised slab window relative to young seafloor and mid-ocean ridges differ from the location of Sundaland's slab window?

** You will find there is no mid-ocean ridge, nor younger seafloor (red), that correlates to the location of the digitised Caribbean slab window. This, in contrast to Sundaland, is not consistent with the definition of slab window formation.

An alternative explanation for the slab window is that it is actually a slab tear unrelated to the subduction of a mid ocean ridge. Slab tears may form when a zone of weakness in a plate is opened up during subduction, whereby allowing warm asthenosphere to flow through. For example, slab tears may possibly result from the intersection of transform faults or fracture zones with subduction zones.

We will use fracture zone data to investigate the location of our slab window relative to these fracture zones.

Load the following fracture zone dataset into GPlates using 'Open Feature Collection':

Matthews_etal_2011_Fracture_Zones.gpml

We are essentially looking for fracture zones which point towards and line up with our digitised slab window.

These lined-up fracture zones will become the plane of weakness by which the slab could have torn, resulting in the upwelling of mantle and what seems to be a 'slab window' in the tomography.

Note that these fracture zones are perpendicular to the spreading ridge and will continue to subduct underneath the Caribbean plate. Therefore you can extrapolate the present day fracture zones to the point of intersection with the subduction zone. There are no present day fracture zones adjacent to Central/North America at times in the past. The seafloor that was adjacent to North/Central America at times in the past has since been subducted and is in the mantle now!

*** Do any fracture zones correlate with the location of your digitised slab window?

*** You will find that there are a couple of fracture zones which point towards and correlate with the location of our slab window, suggesting that they may be the cause of what could be a slab tear instead of a slab window in the Caribbean (Figure 32).

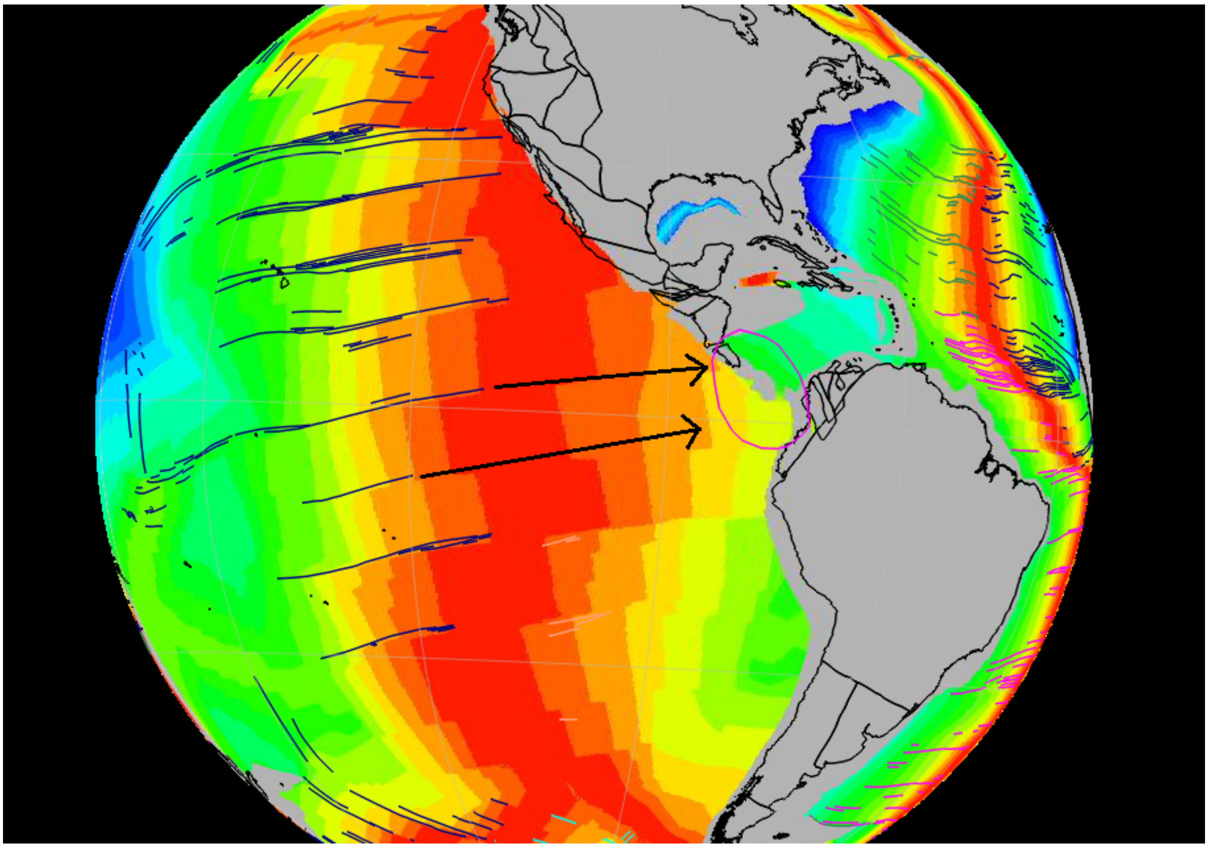


Figure 32. Fracture zone data correlated with the location of our digitised slab window (pink). The extrapolation of two potential fracture zones are symbolised by black arrows. The slab window shows no correlation with ridges of young seafloor (red).

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A. Terminology

GPML
The GPlates Markup Language. GPML is a "dialect" of XML, in- corporating features of the Geopgraphic Markup Language. Essentially, the GPlates data model is using markup language 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 ab- sence 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 anoma- lously 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 influ- enced by temperature, velocity can be used as a proxy for temperature (fast velocities = cold material, slow velocities = hot material). How- ever, mantle composition also affects the speed of wave propagation, and therefore establishing correlations between velocities and mantle structures is not simple.

B. Age-depth 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. Sinking Rate is approximately 1.3m/yr.

Depth(km)	Age(Ma)
0	0
100	8
200	15
300	23
400	31
500	38
600	46
700	54
800	62
900	69
1000	77
1100	85
1200	92
1300	100
1400	108
1500	115
1600	123
1700	131
1800	138
1900	146
2000	154
2100	162
2200	169
2300	177
2400	185
2500	192
2600	200
2700	208
2800	215
2900	223

Table 1: Age–depth relationship for tomography slices. Data is based on: The dynamics of sinking slabs Butterworth, N., Talsma, A.S., Müller, R.D., Seton, M, Bunge, H.-P., Schuberth, B.S.A., Shephard,G.E., in prep.