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

With the release of version 0.9.10 of GPlates in 2010, 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 (Files\GPlates\GPlates [version]\Sample data.) Today we will be working with Raster Files. 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.

Files

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

1. The bundled tutorial data set includes time-dependent 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 (sample data). 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(wrong number).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. (ETOPO1 jpeg is in the MCOSX)

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.

Open File→Import raster→Raster_Tutorial_Data→Montelli06_S→ Montelli06_S-2 (fig12)

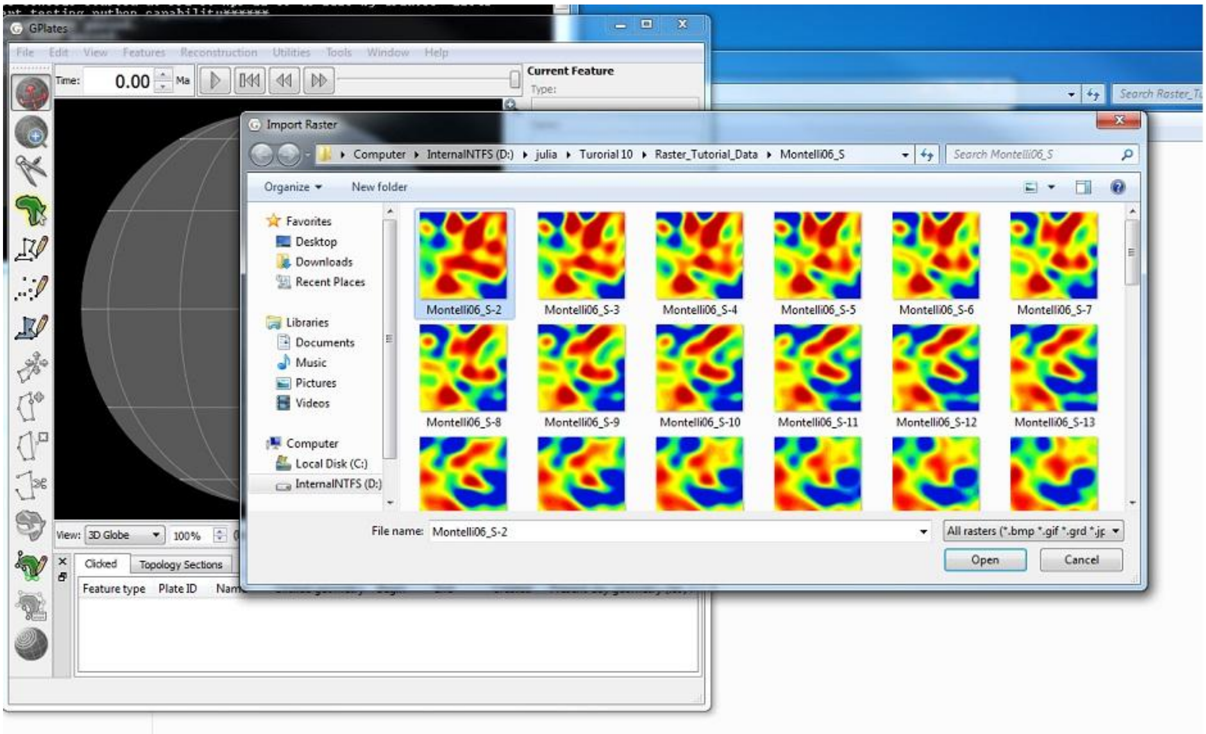


Figure 1a. How to import a raster

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”.

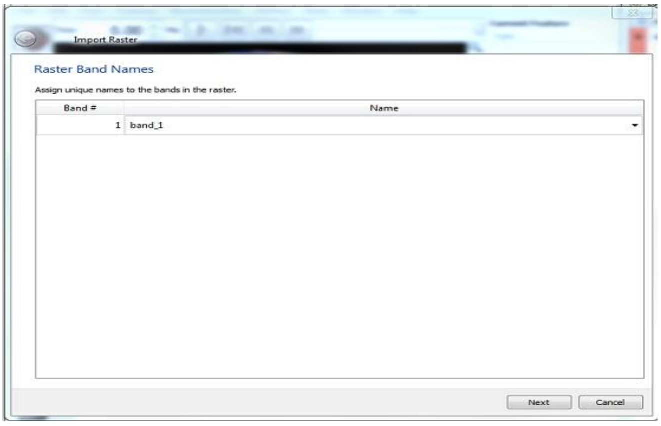


Figure 1b. Assigning Raster band names

A Georeferencing Box will open (fig.1c). It gives you the option to load a global raster or a regional rectangular raster which will cover the certain extents of the earth you are interested in. As we want the Raster to cover an Global extent select top, bottom as 90.000° and -90.000° respectively and left, right as -180.000 and 180.000 respectively. Select "Next".

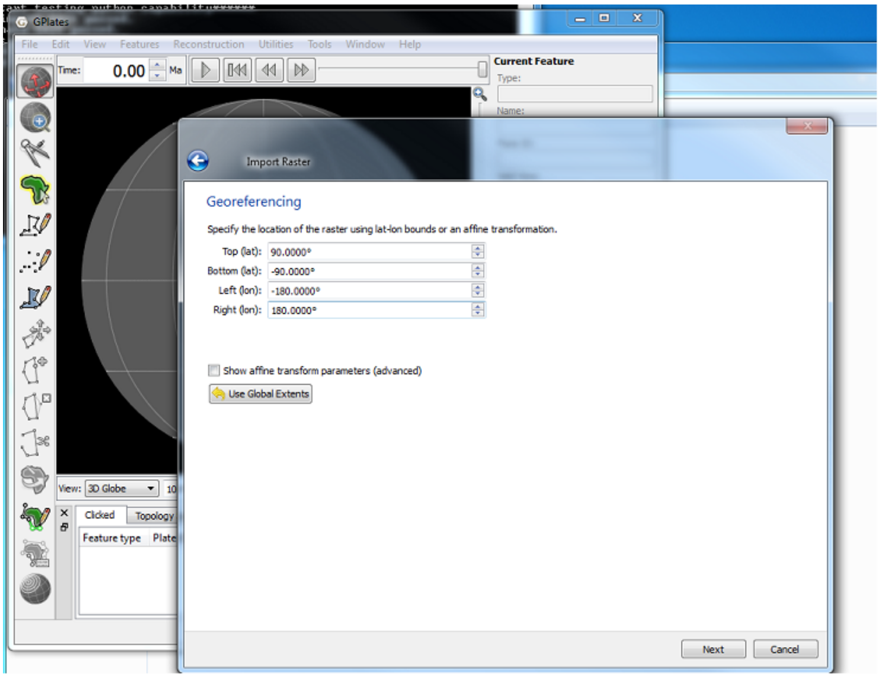


Figure 1c. Assigning Latitudinal and longitudinal extent to raste

The final step is to create a feature colletiont. 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.

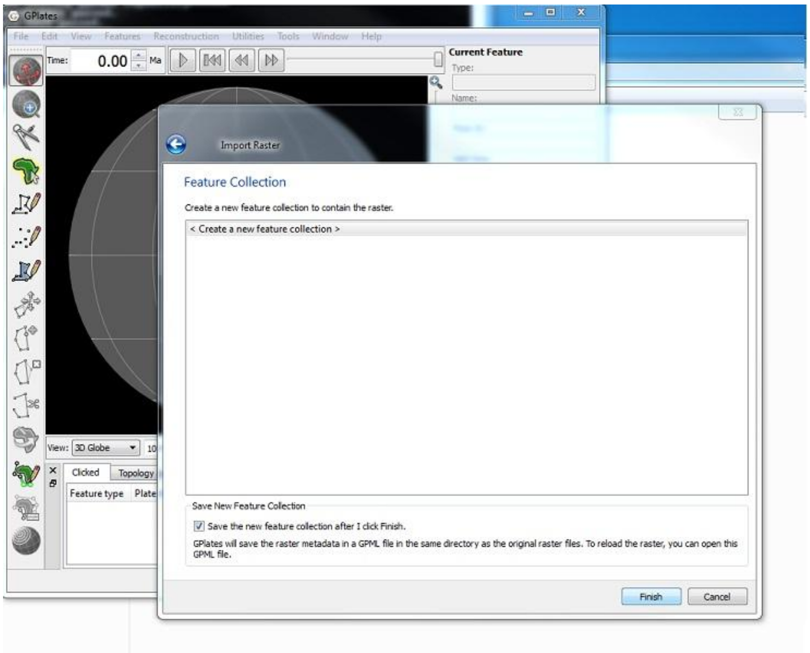


Figure 1d. Creating a feature collection for raster

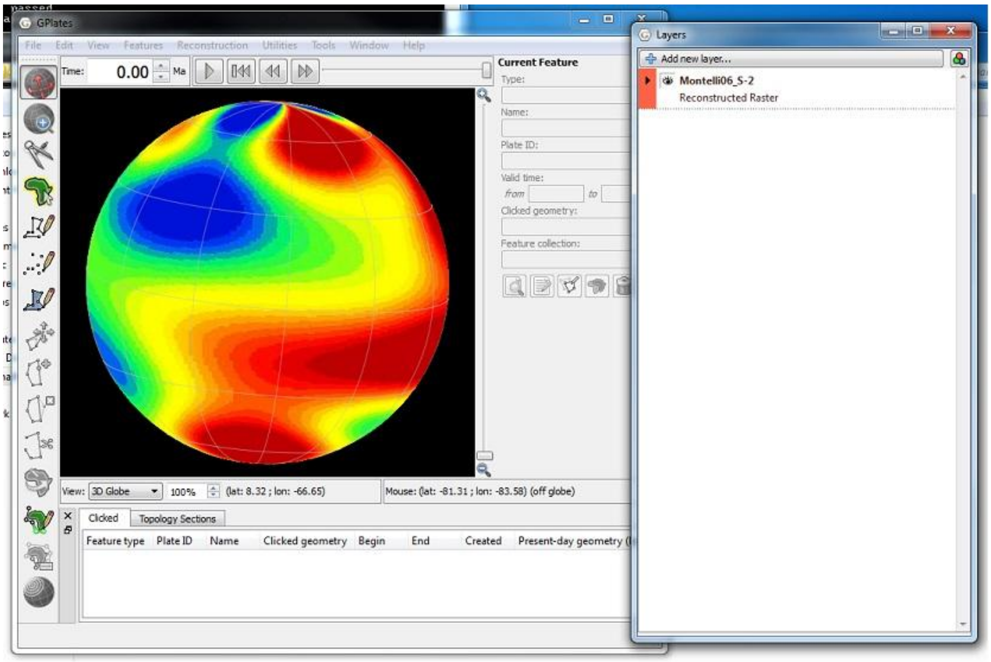


Figure 1e. Montelli06_S Raster imported into Gplates successfully.

Exercise 2: Time-dependent rasters

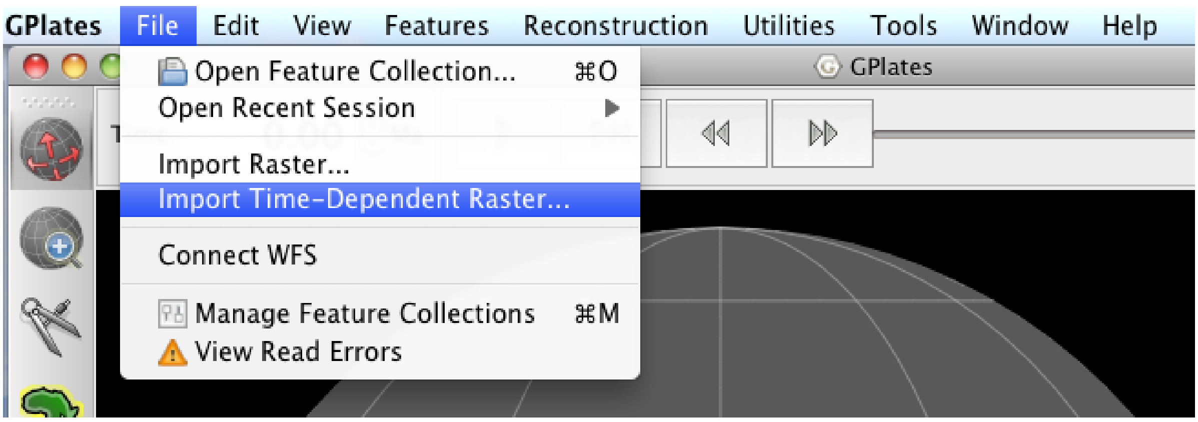
Now we will visualise time-dependent rasters in GPlates; i.e. snapshots of geodynamic models of dynamic topography (Appdx. A) and depth slices from seismic tomography models which are coded to geological age.

2.1 Time-dependent rasters: global dynamic topography

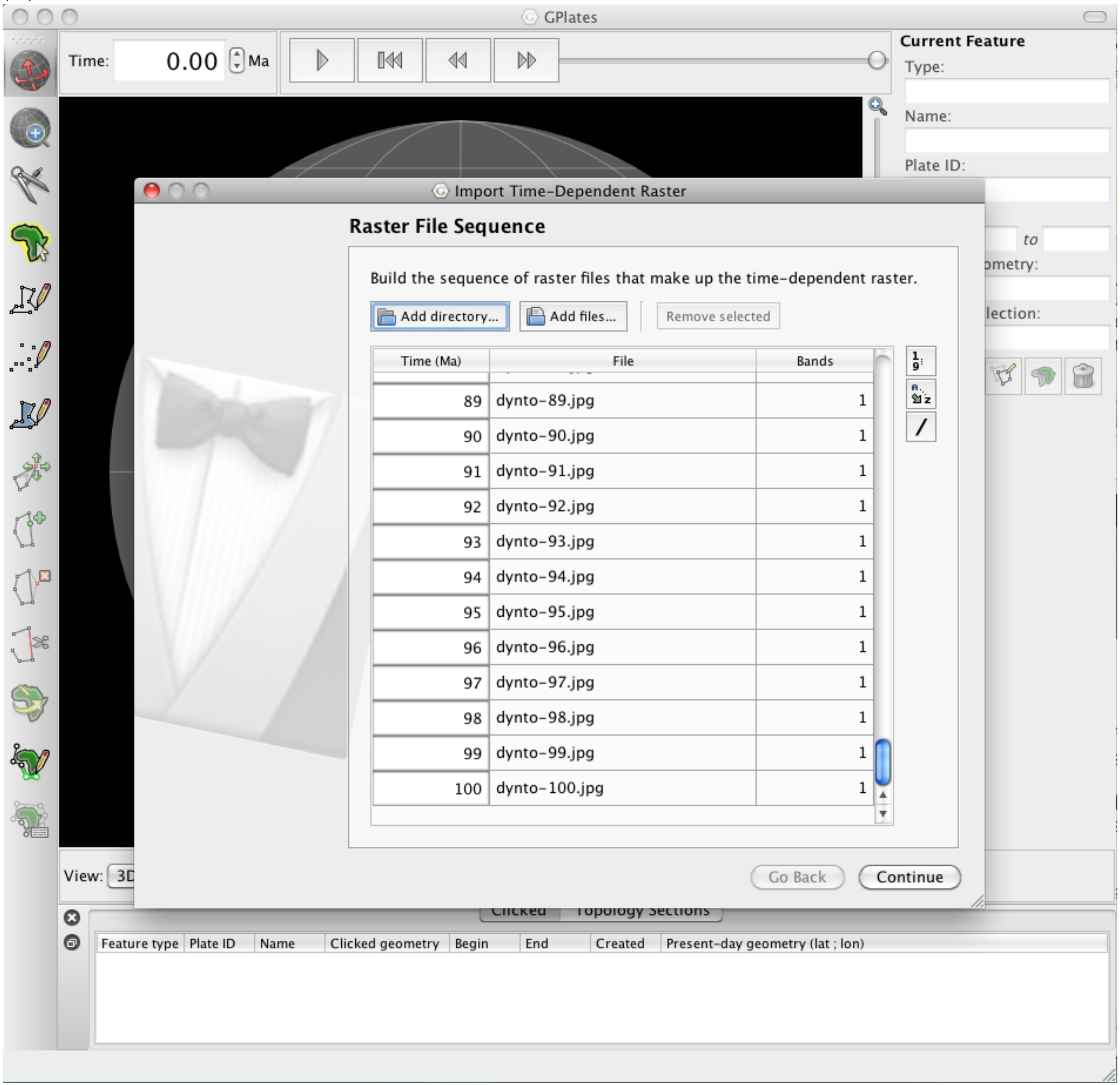
Dynamic topography is vertical motion of the Earths surface attributed to mantle processes. For example, subducting slabs viscously drag down over-lying crust as they sink through the upper mantle, whereas hot upwellings push up overlying crust. For an informative overview of dynamic topography, the 2001 Scientific America article "Sculpting the Earth from Inside Out by Professor" 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" in the tutorial data bundle (Figure 5b). 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.



(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 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 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.

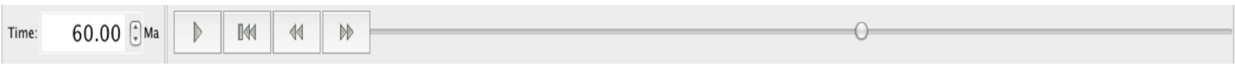


Figure 6. Time and Animation controls in the main window. You may use these controls to manually enter a time, move the slider to reconstruct the globe or animate from a selected time to the present.

2.2 Dynamic topography and tectonics in Australasia

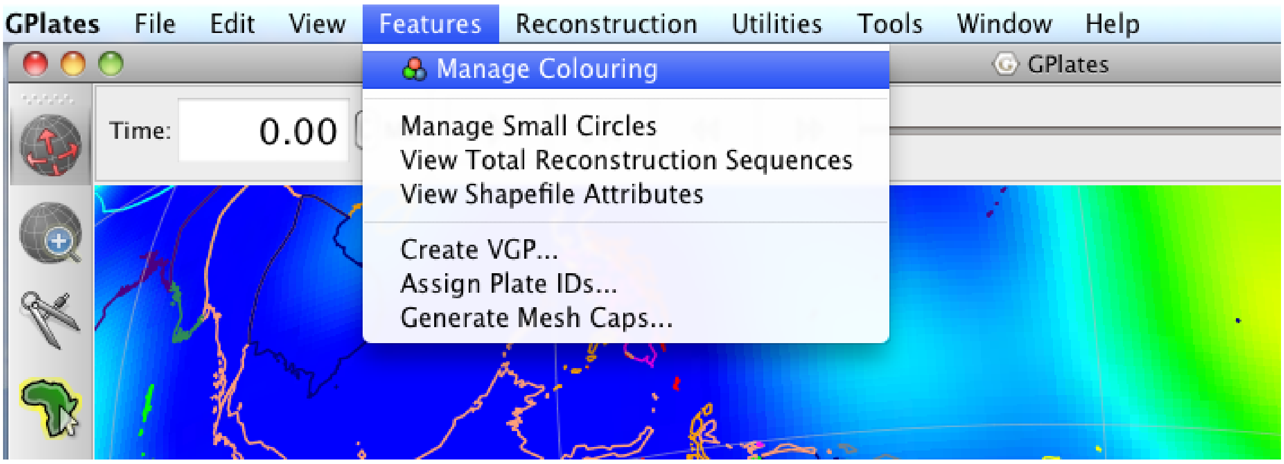
Time-dependent raster sequences can be combined with other reconstructable datasets in order to analyse and investigate features in the geological record. We will now exploit this functionality in order to see why dynamic topography is reflected in the geological record of several Australian basins and 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.

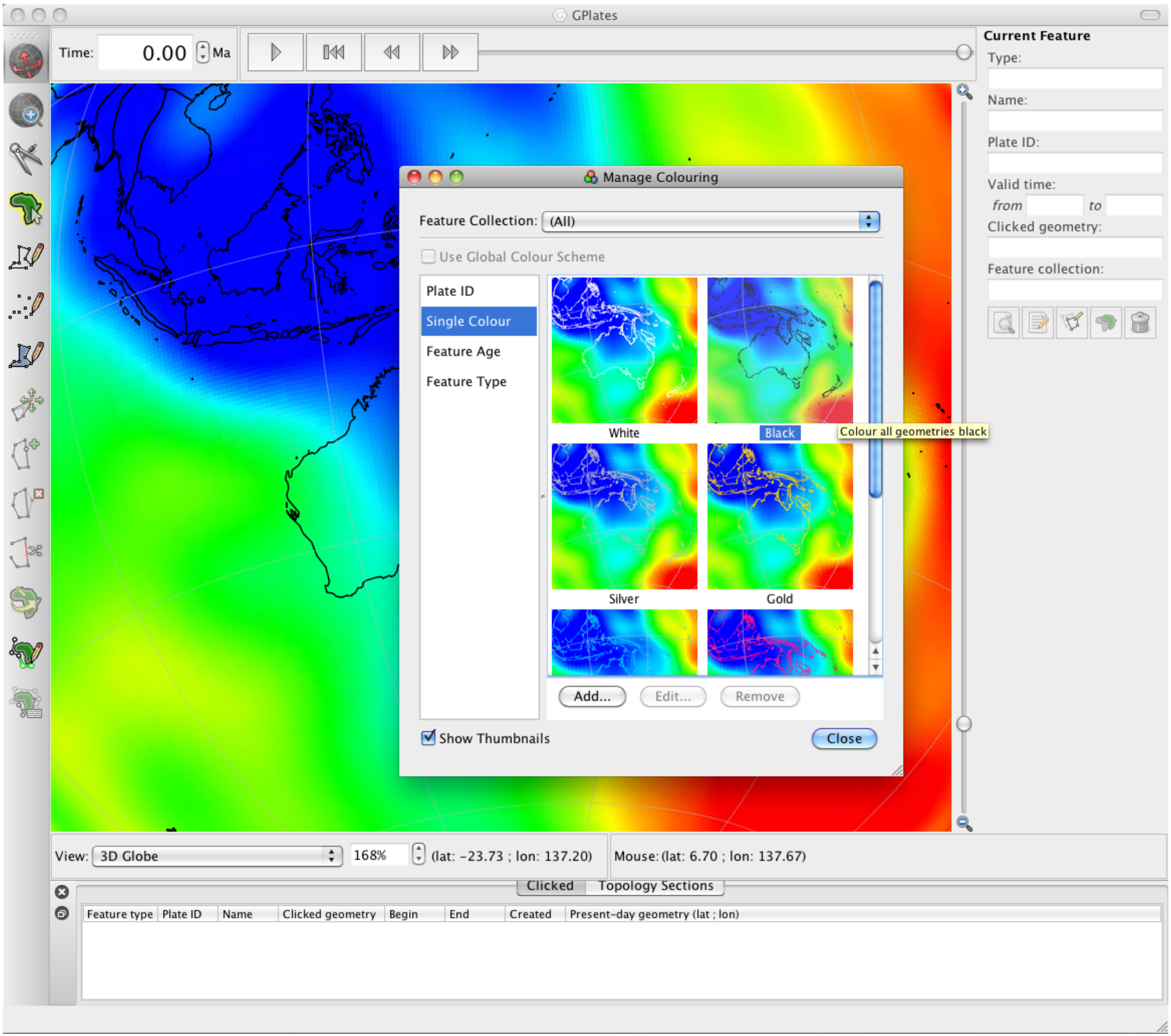
1. Locate and open the files CarpentariaBasin.gpml, QueenslandPlateau.gpml and MarionTerrane.gpml from the tutorial data bundle.

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.

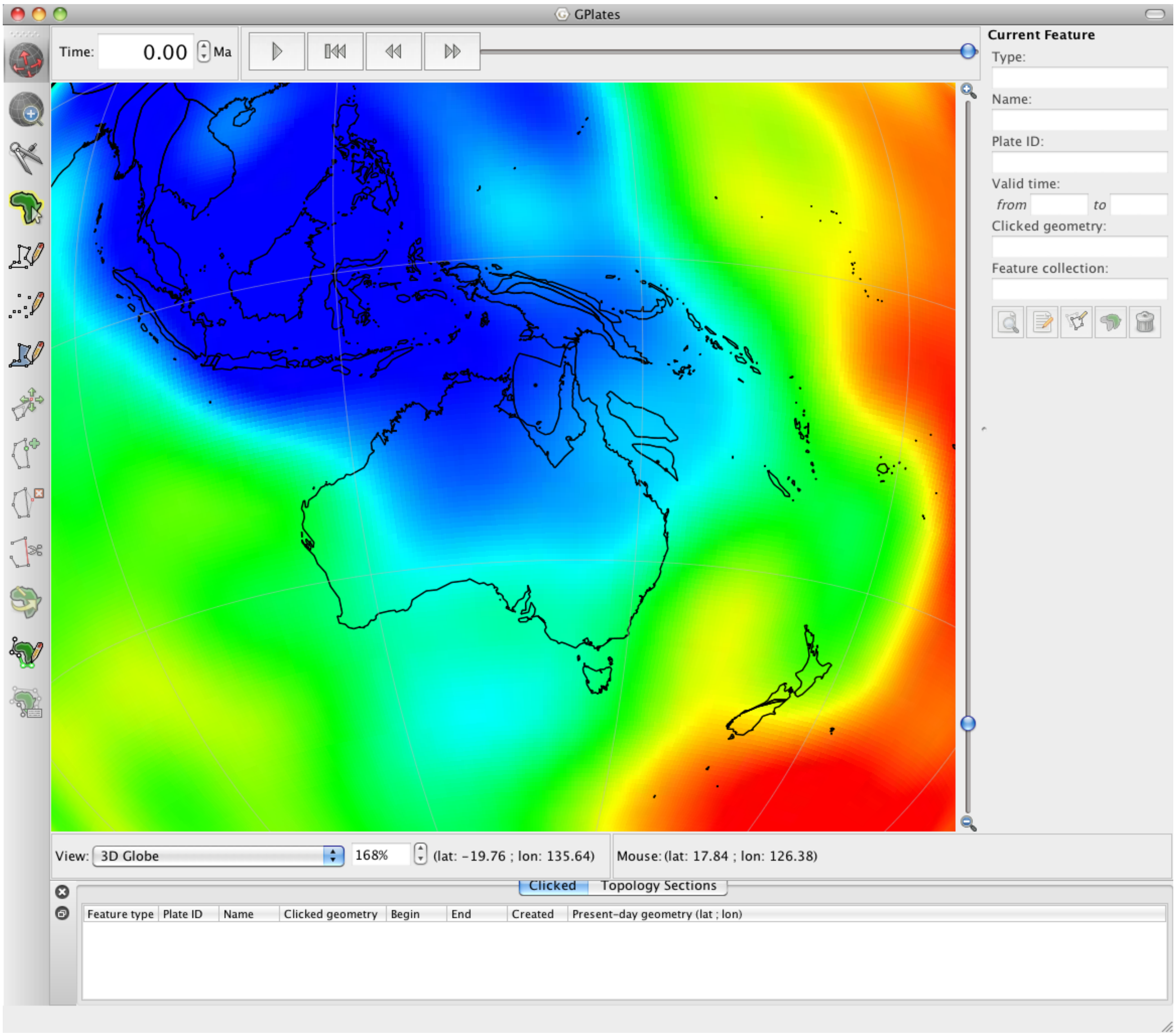


Figure 8. View of the Australian region with Gulf of Carpentaria basin outline and the Duyken-1 well (black dot) as well as the Marion and Queensland Plateau polygons and other well data. Background are time-dependent dynamic topography images.

2.3 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 MIT-P model (Buttersworth et. al, 2013) 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. The whole mantle sinking rate is approximately 1.4cm/yr.

1. To begin we need to unload the data used in ex .2.2 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).

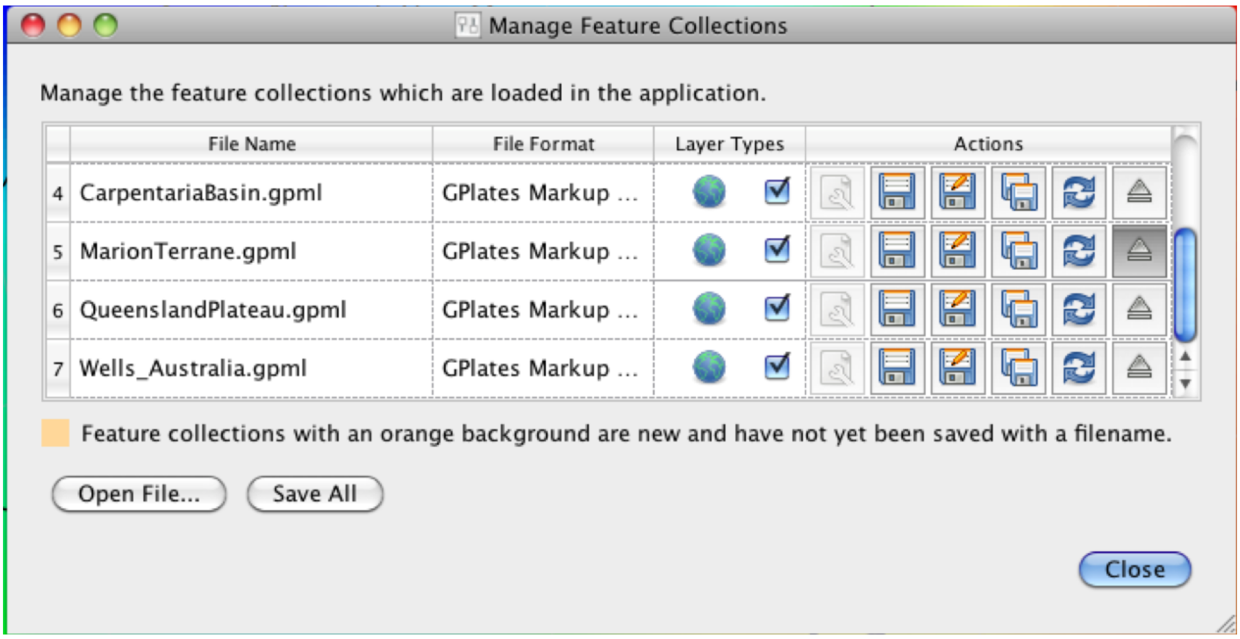


Figure 9. The eject button, under Actions (far right) allows data files to be unloaded from GPlates.

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 ex2.1 . 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): -29◦, • Left (lon): 80◦; and • Right (lon): 130◦

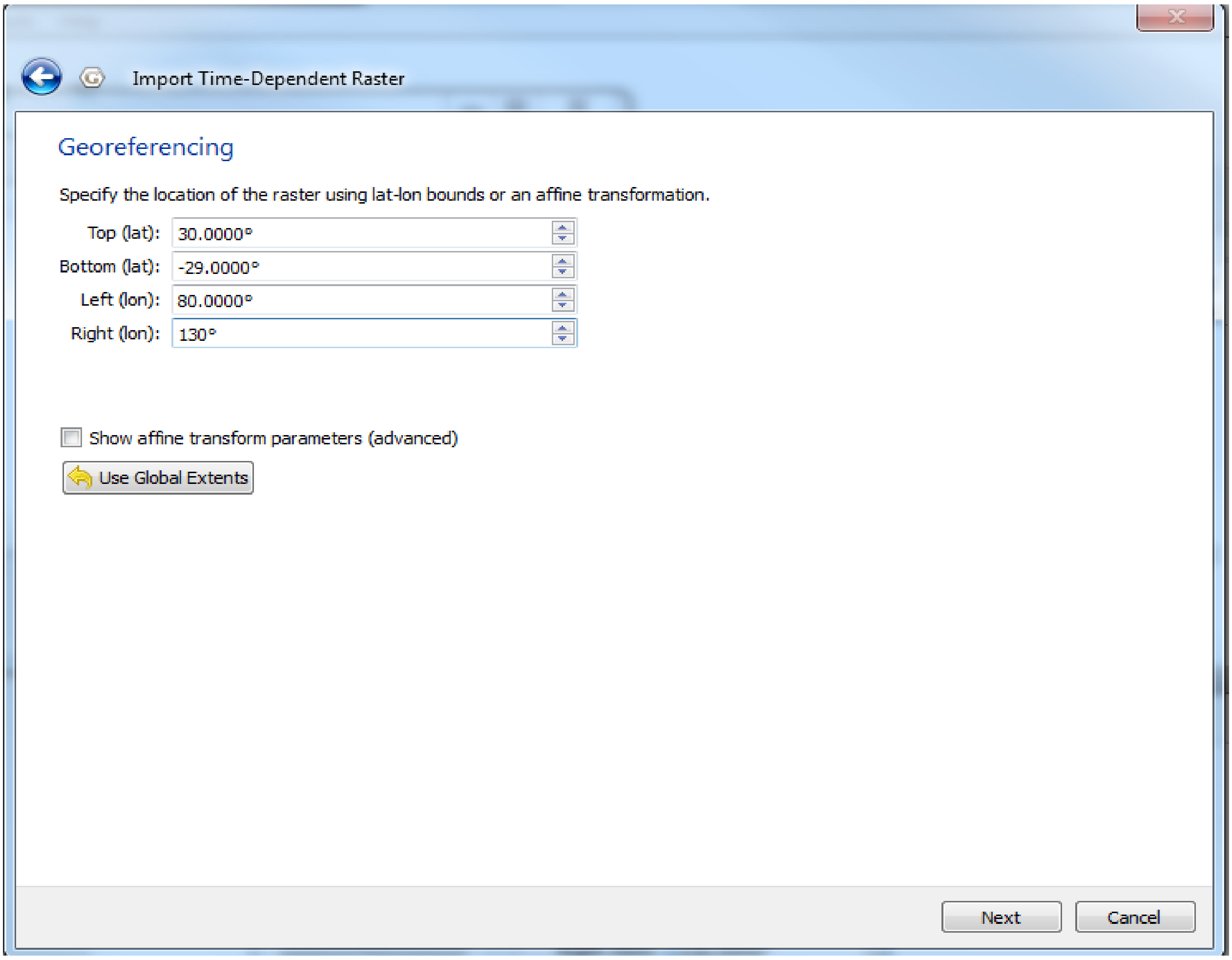


Figure 10. The Georeferencing window allows you to readjust the bounding latitudes and longitudes of regional rasters.

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.11b

Scales change for different tomography models. The scale below(fig.11a) is the one for MIT-P08. Positive velocity perturbation represent the wave moving faster (red) and negative represents the wave moving slower (blue).

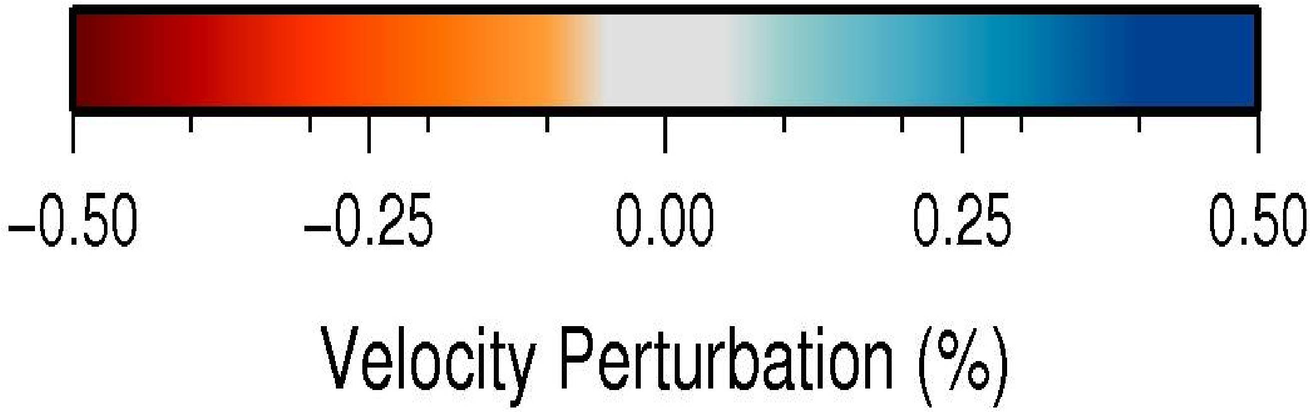


Figure 11a Velocity perturbation scale for MIT-P08 model

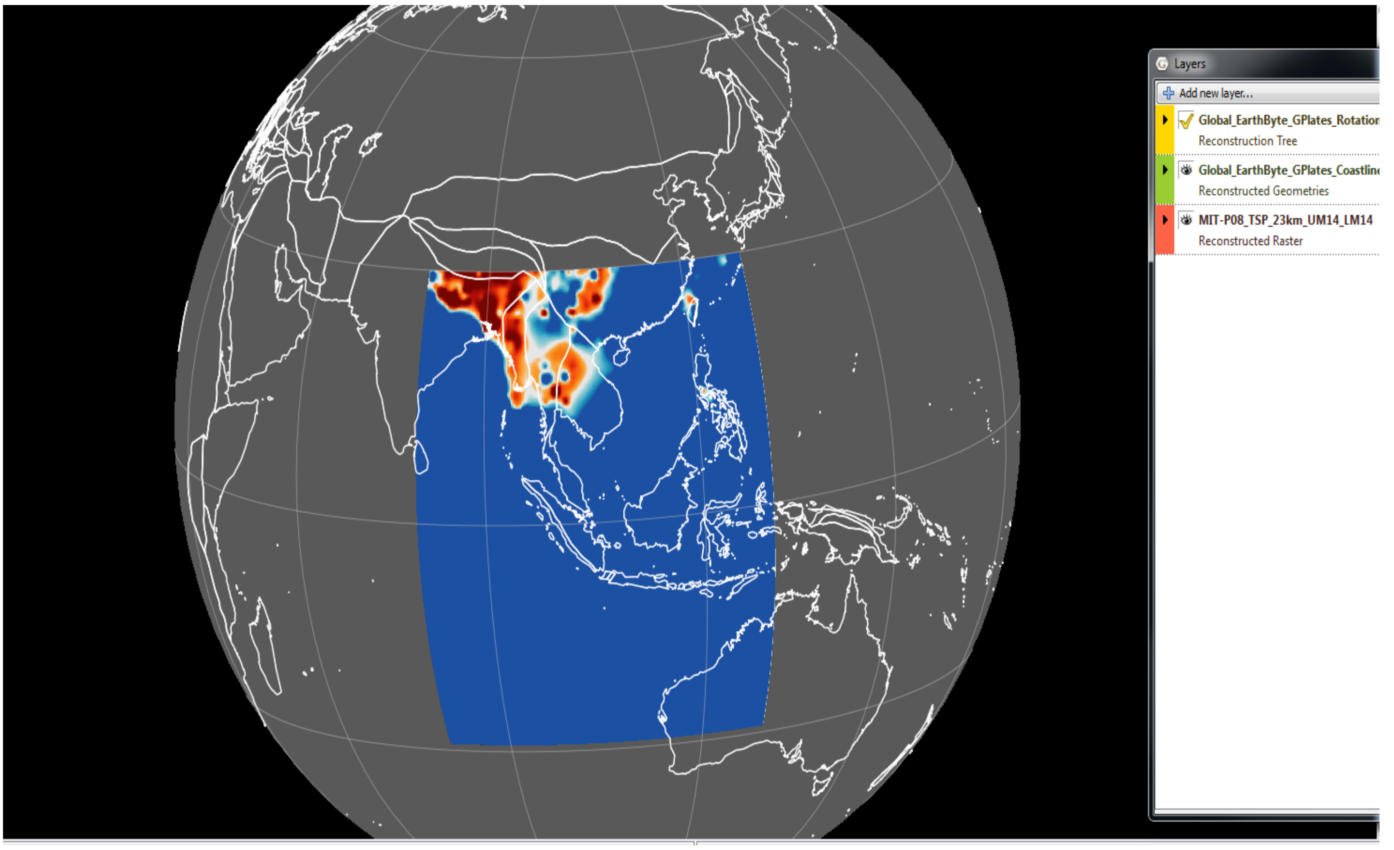


Figure 11b A regional raster displayed as the base layer on the GPlates globe.

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. The spatial relationship between the subducting oceanic plate, mid- ocean ridge and the Sundaland area is roughly shown in figure 12. 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: Blue indicates anomalously fast velocities and so we will interpret these regions as subducting slabs.

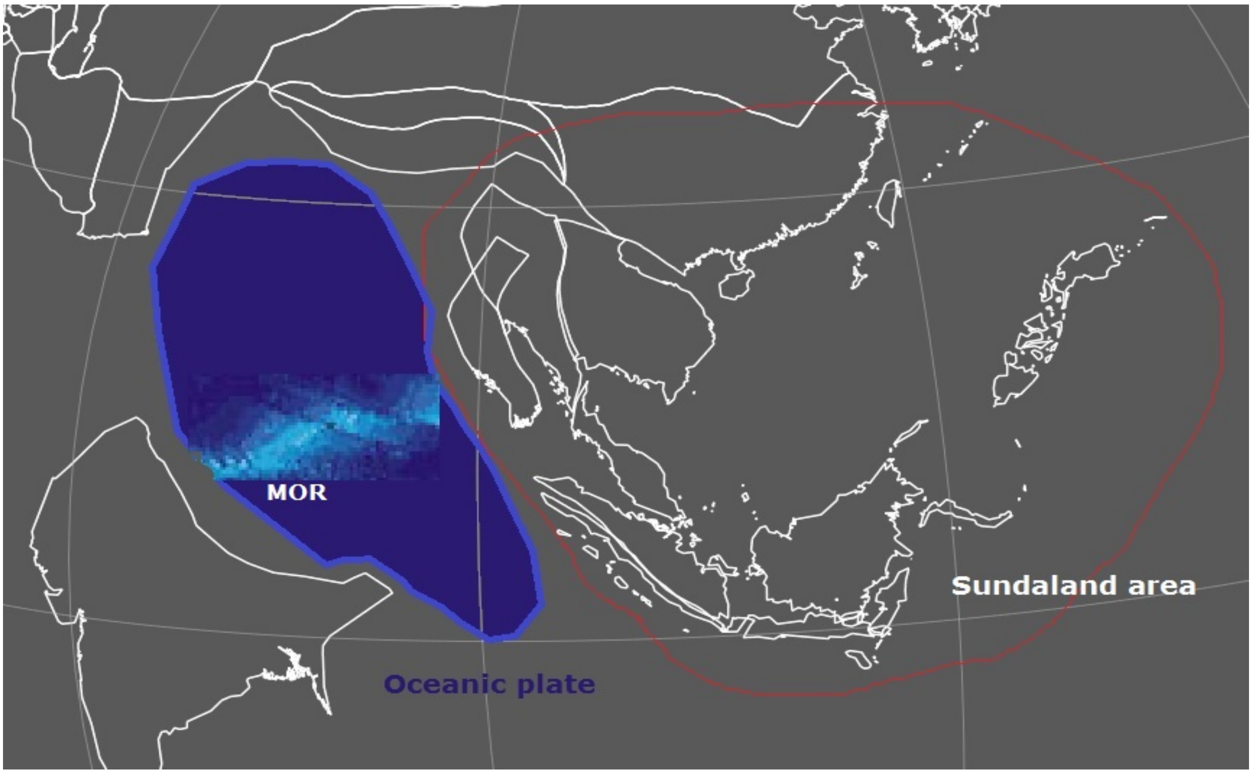


Figure 12. Rough diagram of the spatial relationship of plates at approximately 70 Ma**.**

6. Rather than animating 140 Myr worth of data, lets use the Animation controls to specify our 70-43 Ma time-frame: 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.

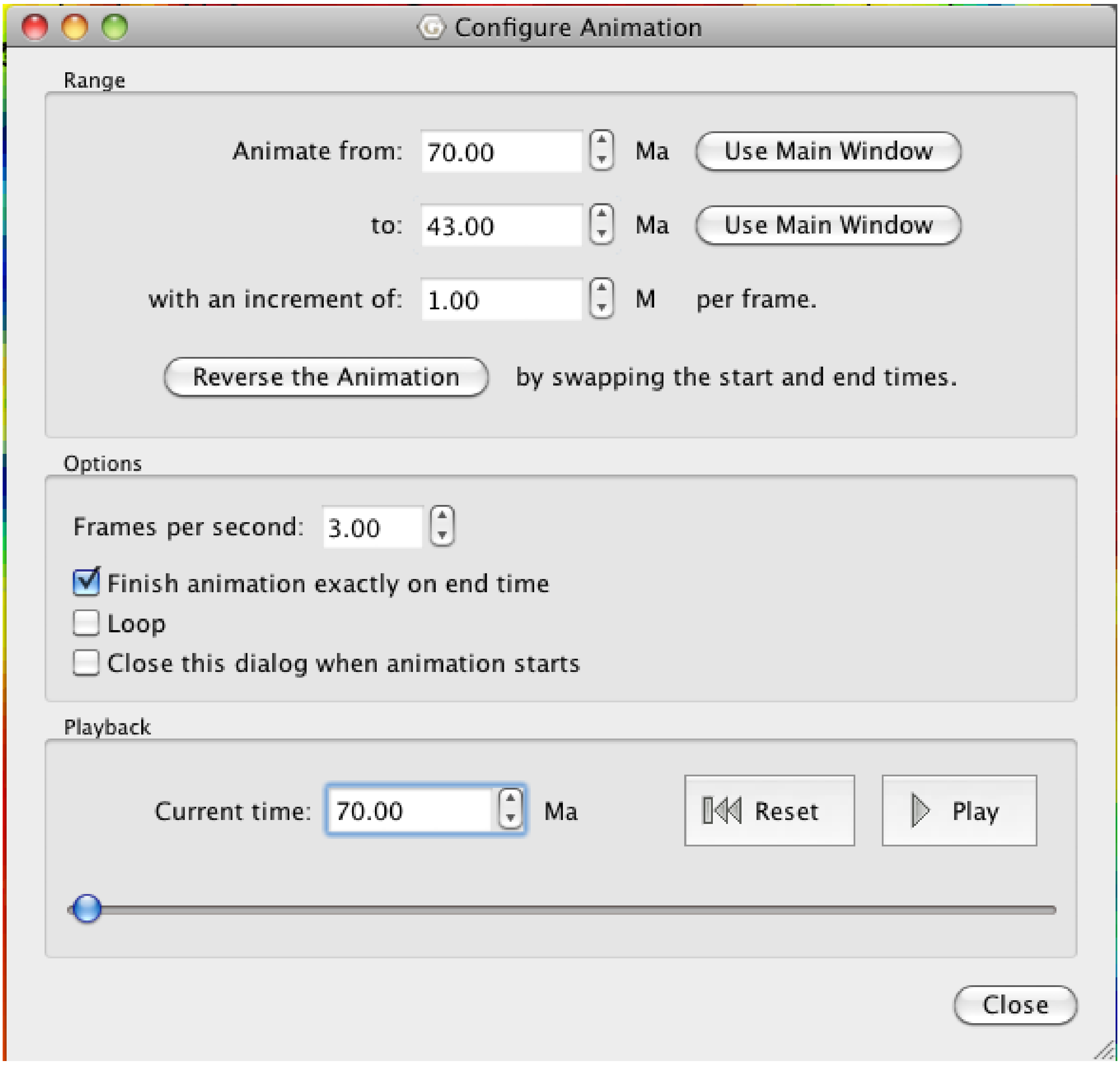


Figure 12. The Animate window enables you to specify a time period to animate on the globe.

- Can you see the slab window?
- How do we know this is an slab window and not just a tear in the slab from subduction occurring at different rates?
- Clue - Look for a break in the blue blob. Now that we have visualised the slab window lets digitise it. Below is an example of the 50 Ma slab window, use this as a guide when you make your 60 Ma slab window.

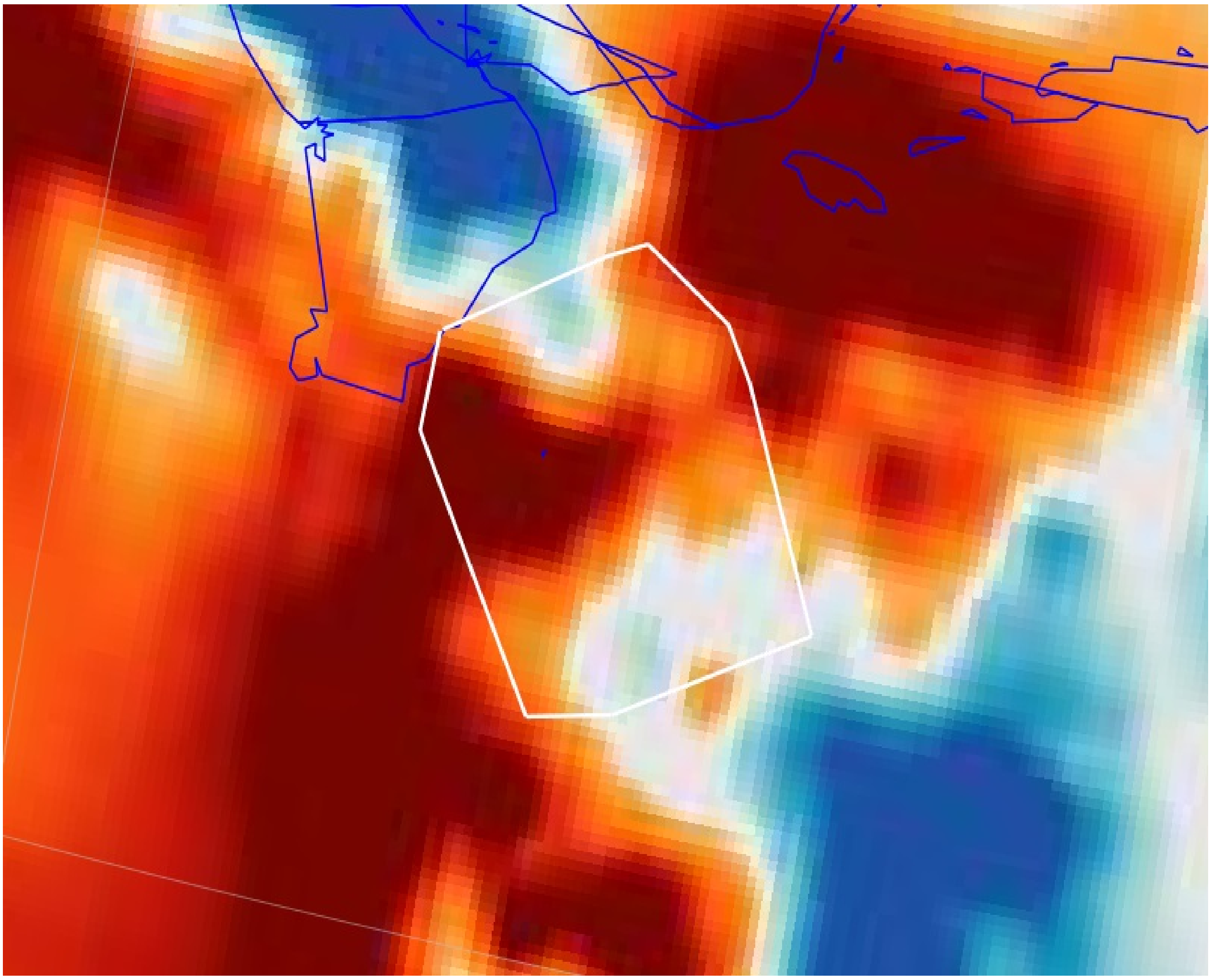


Figure 13. Digitised slab window at 50 Ma (white polygon).

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 altogether (Tool buttons pictured right).

Create a new feature by pressing Create Feature... (from the New Geometry Table to the right of the main window) → Choose 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. Sundaland Slab Window 60Ma

Create this new feature collection by clicking Next, and then in the next window select 'New Feature Collection' to add the polygon to a new dataset, finally choose Create and Save.

You have now created your 60 Ma slab window and added it to a new Feature Collection. In the Manage Feature Collections window tha appears 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. For this rasters scale red = Youngest oceanic crust and blue= eldest oceanic crust.

1. Select and load the age grid jpegs from the tutorial data bundle (you cannot select an individual JPEG when loading a Raster Sequence). File → Import Time-Dependent Raster → Add directory... → age grid jpgs → Choose → Continue → in the Raster Band Names window leave the band as “band 1” → Continue → the age grid images are global to leave the default ±90° lat ±180° lon → Continue → Done.

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)?

You will notice that the slab window you digitised from the seismic tomography is positioned to the west of the Wharton Ridge (from the age grid).

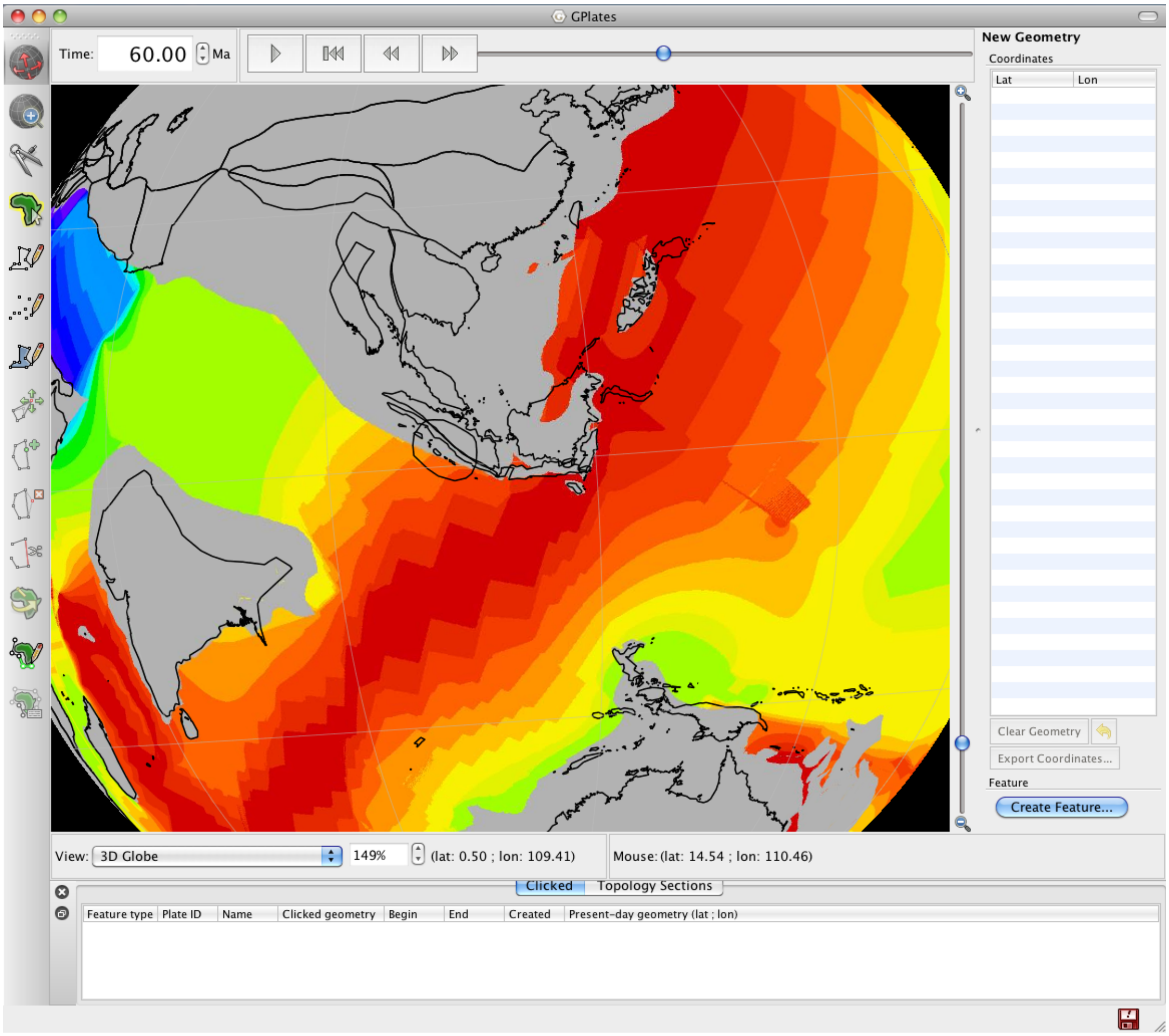


Figure 14. 60 Ma reconstruction of ocean floor ages and present-day coastlines. notice that the youngest oceanic crust (and hence the spreading ridge) is converging with western most Sundaland.

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].

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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 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.