Supplementary Material

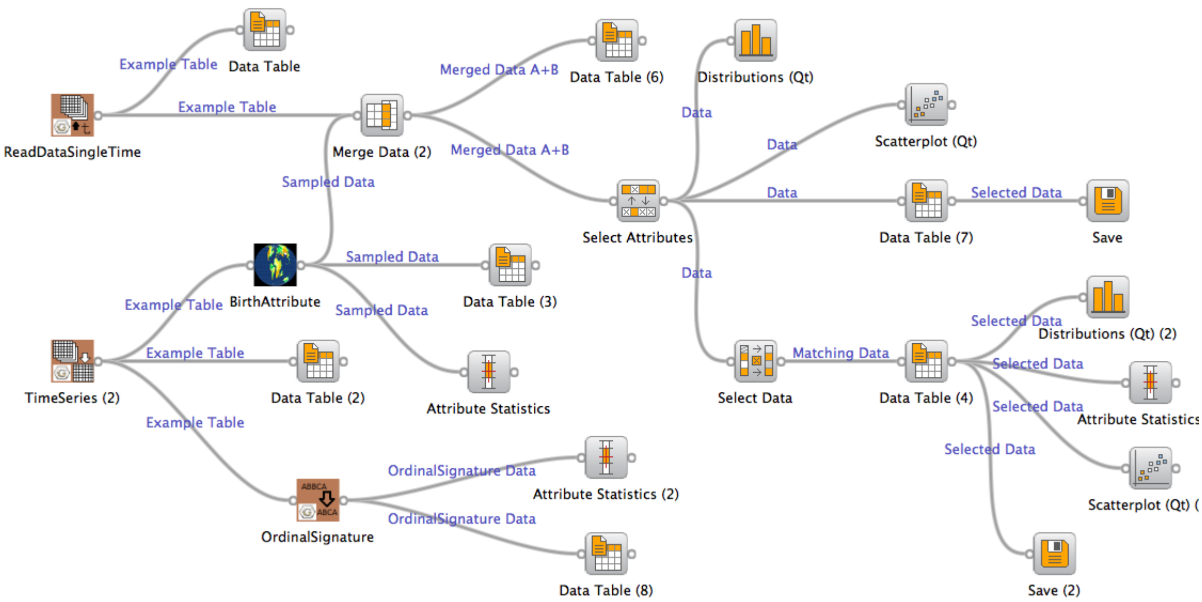
Input

We include a number of digital files in order to make our work replicable and testable. We provide the plate motion model used in our reconstructions; including a GPlates rotation file, continental outlines and present-day coastlines. The Paleogeographic Atlas from Geoscience Australia is also provided as an age-coded shapefile that can be used in *GPlates* (www.gplates.org), whose reconstructions can be exported as ASCII xy and time-dependent shapefiles for visualization in GIS packages such as *QGIS* (open source - www.qgis.org) and *ArcGIS*. We also include a sample of paleobiology data as tab-delimited text and shapefile for 200 to 100 Ma. Instructions on how to load and reconstruct data in *GPlates* can be found at http://www.gplates.org/docs.html and in the Readme PDF contained within the zipped folder. The complete Phanerozoic dataset can be accessed from our FTP address, located at:
ftp://ftp.earthbyte.org/papers/Wright_etal_Paleobiogeography/

Data Mining

We provide data mining output from *GPlates* at 402, 120, 110, 100 and 80 Ma and the open-source data analysis package *Orange* (orange.biolab.si) workflow that was used.

Wright_etal_Paleobiogeography.ows



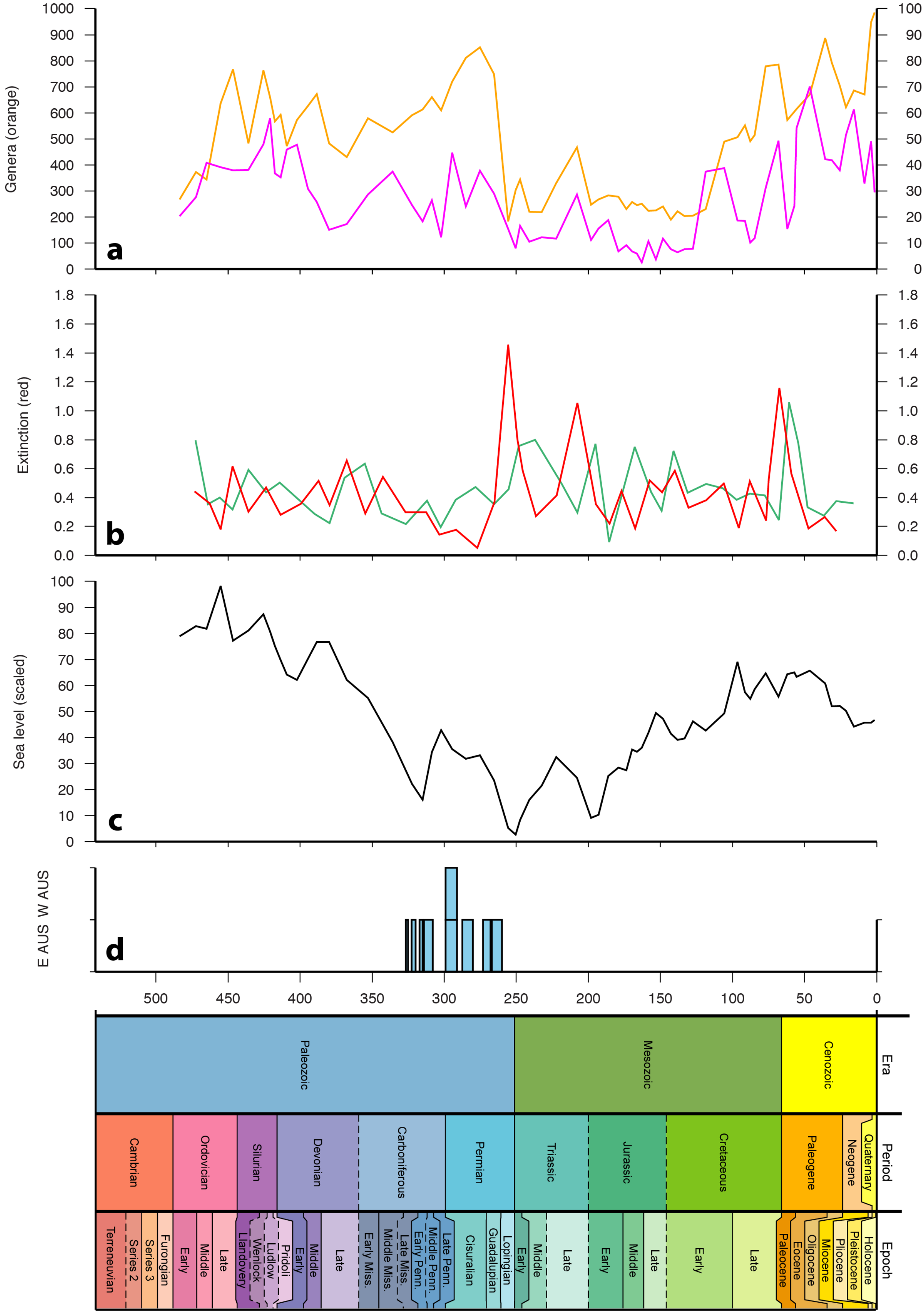


Figure 1. The Phanerozoic biological diversity has previously been measured using normalized genera counts and a sampling-standardized SQS method (Hannisdal and Peters, 2011) while also being punctuated by extinctions (b - red) and subsequent periods of ecosystem recovery (b – green). The long-term influencing factors include sea level fluctuations (c), continental arrangements, glaciations (d – Australia) and other local and global climatic influences.

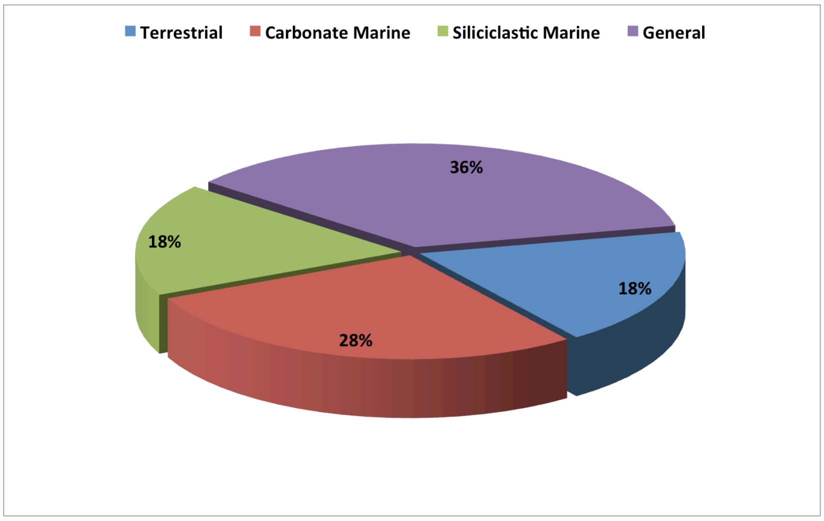


Figure 2. Fossils from the Paleobiology Database that contained well-defined temporal intervals and paleo-environments with a total of 122,381 collections covering the Phanerozoic.

Paleogeographic reconstructions using raw paleobiology data using GPlates[1]

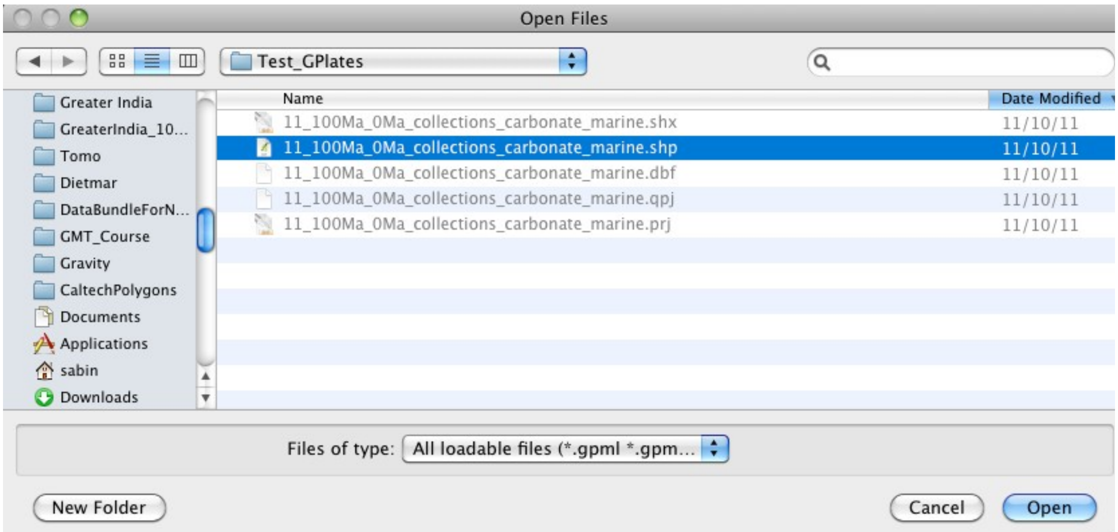
Note: The following instructions are to get raw data from the Paleobiology Database into GPlates. The data in the Supplementary material can be loaded straight into GPlates by following only Step 2a, as the Plate IDs and Begin/End Ages have been assigned.

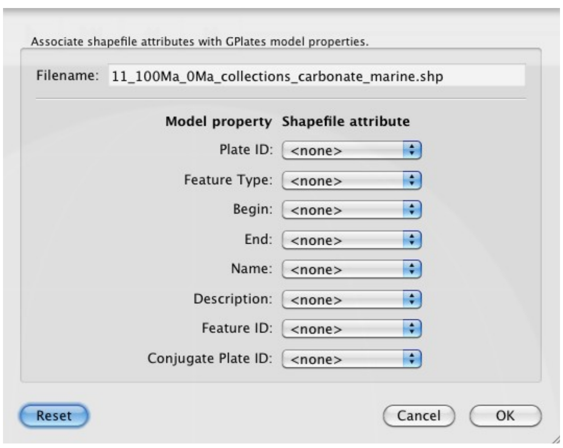
1. Create a shapefile of your points representing your fossil data. You can do this in ArcGIS or the open-source equivalent QGIS[2] (which actually has a simpler facility to import xy data from text files, csv, etc.). It is important that your fossil data has a "Begin" and "End" age representing the age range. These fields will be important for GPlates in the next step.

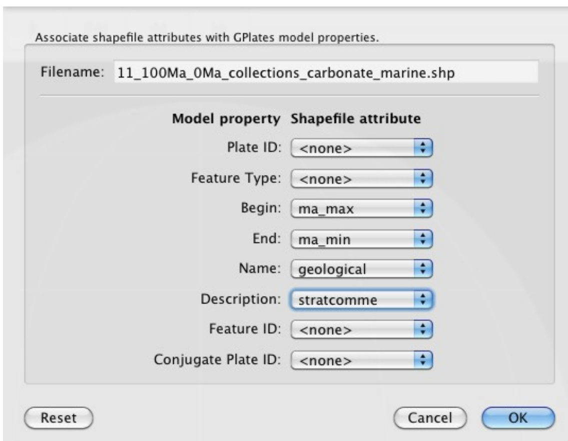
2a. You can now directly load that shapefile into GPlates. Open GPlates > Open Feature Collections > Navigate to your folder and select/open your shapefile.

2b. GPlates will ask you to "map" the shapefile fields. Make sure your "Begin" (ma_max) and "End" (ma_min) ages are assigned – this is crucial, as otherwise your fossil data will be reconstructed but will exist at all times.

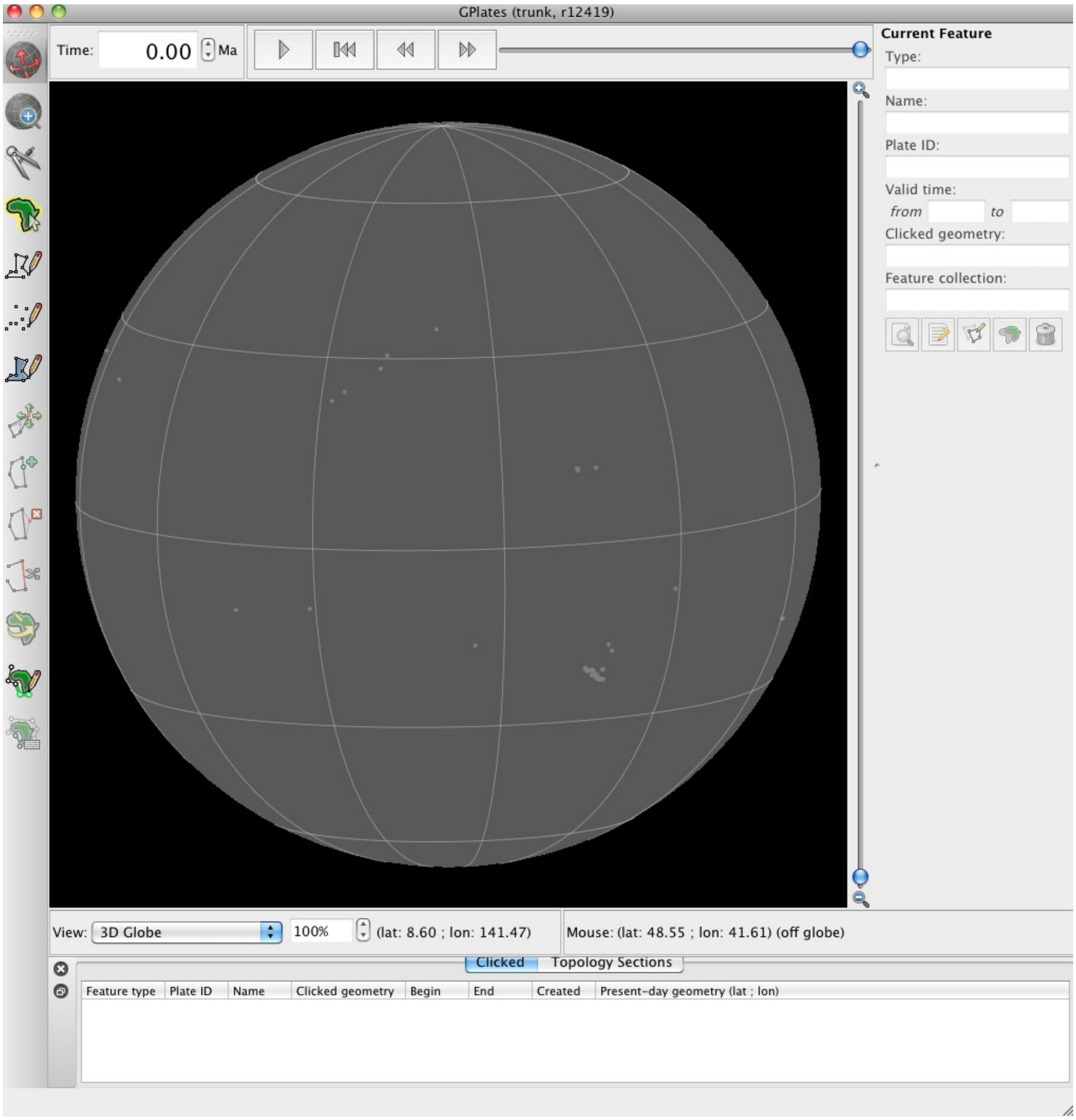
You can also attach fields that represent the Name and Description of each datapoint. Click OK, and your points should load without a problem.







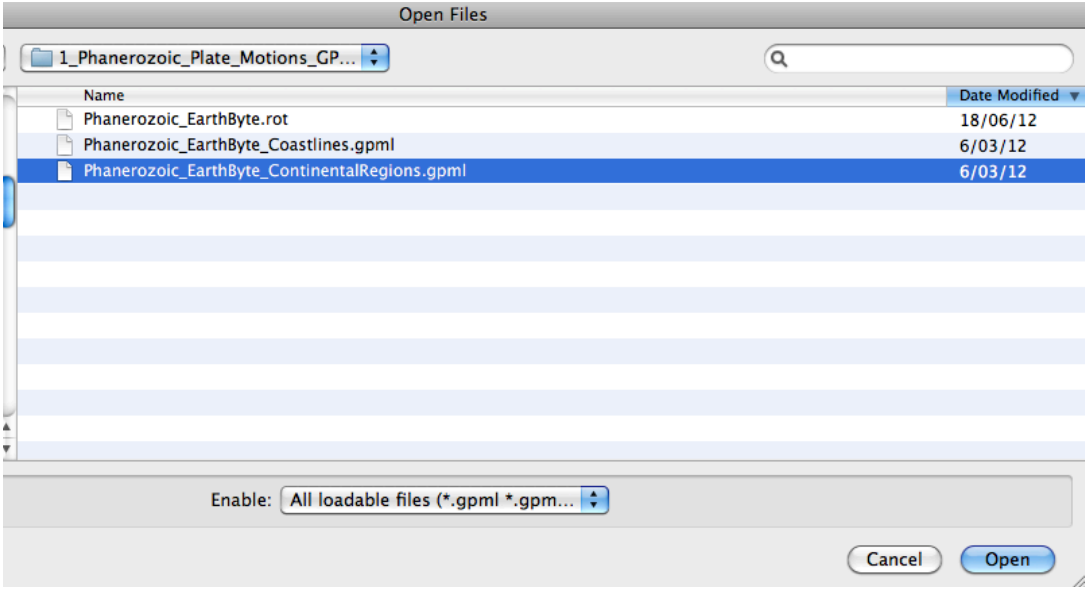
1 www.gplates.org
2 www.qgis.org

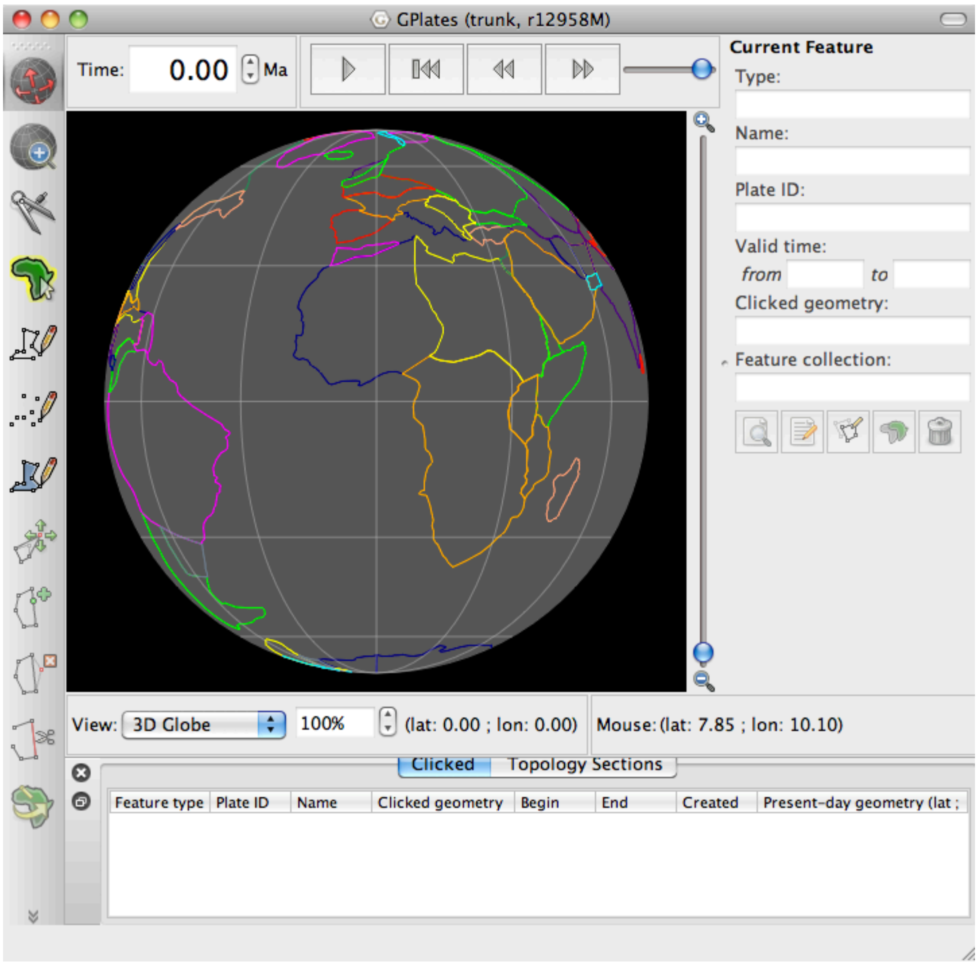

GPlates (trunk, r12419)
Time:
0.00
Ma
Current Feature
Type:
Name:
Plate ID:
Valid time:
from
to
Clicked geometry:
Feature collection:
View:
3D Globe
100%
(lat: 8.60 ; lon: 141.47)
Mouse: (lat: 48.55 ; lon: 41.61) (off globe)
Clicked
Topology Sections
Feature type
Plate ID
Name
Clicked geometry
Begin
End
Created
Present-day geometry (lat ; lon)

3. Now you will need to cookie-cut (i.e. Assign Plate ID) your fossil data. GPlates uses GPlates rotation files that you are likely to be familiar with, and so every geometry needs to have a Plate ID. Here you can use your own polygons that have a Plate ID associated with them, or you can use the one provided in the Sample Data that comes with GPlates.

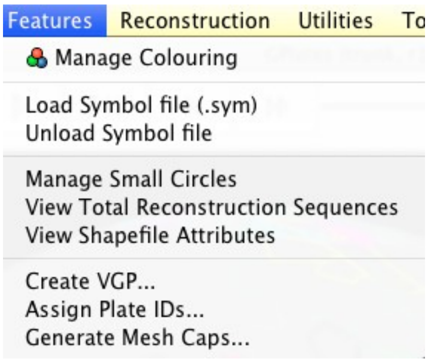
You will need to load in the Continental Polygons from our Sample Data. Go to File > Open Feature Collection > Navigate to supplementary material, select and load: "Phanerozoic_EarthByte_ContinentalRegions.gpml"

You will now see some coloured polygons in the main GPlates window.

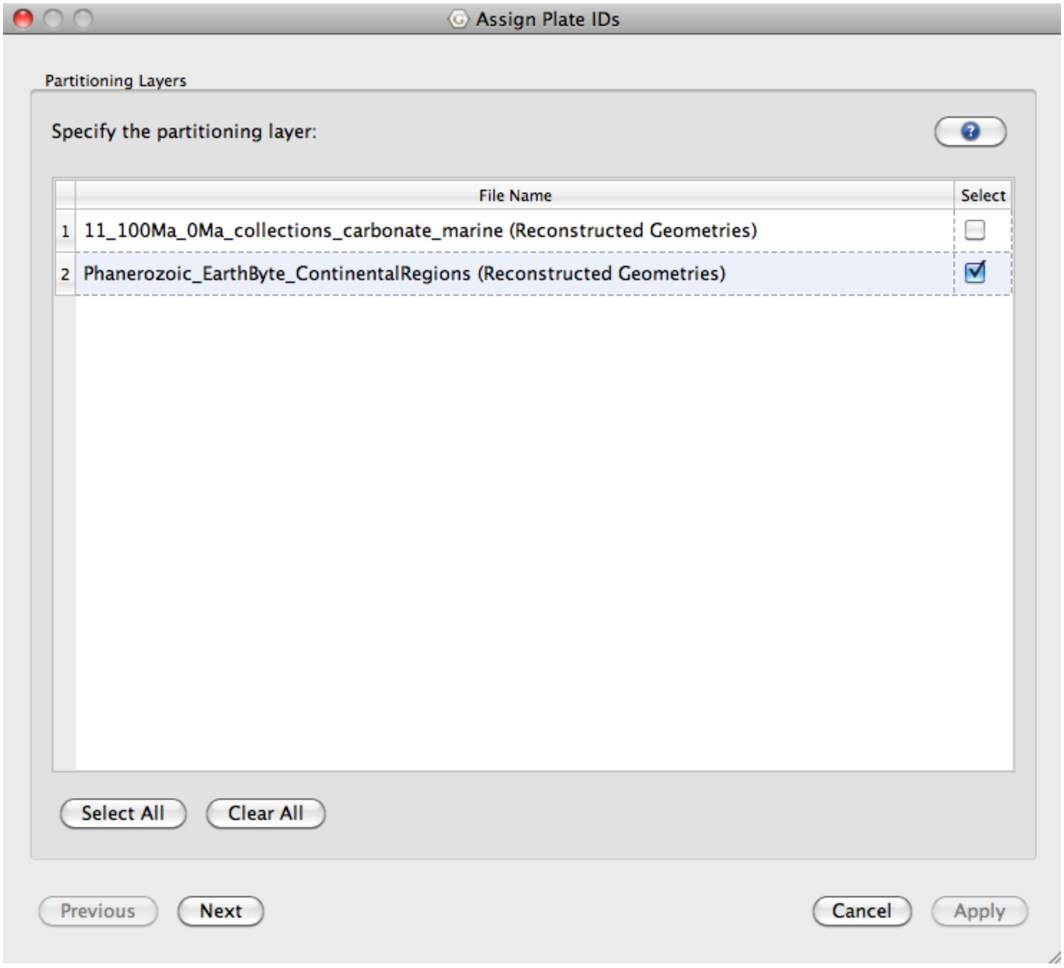




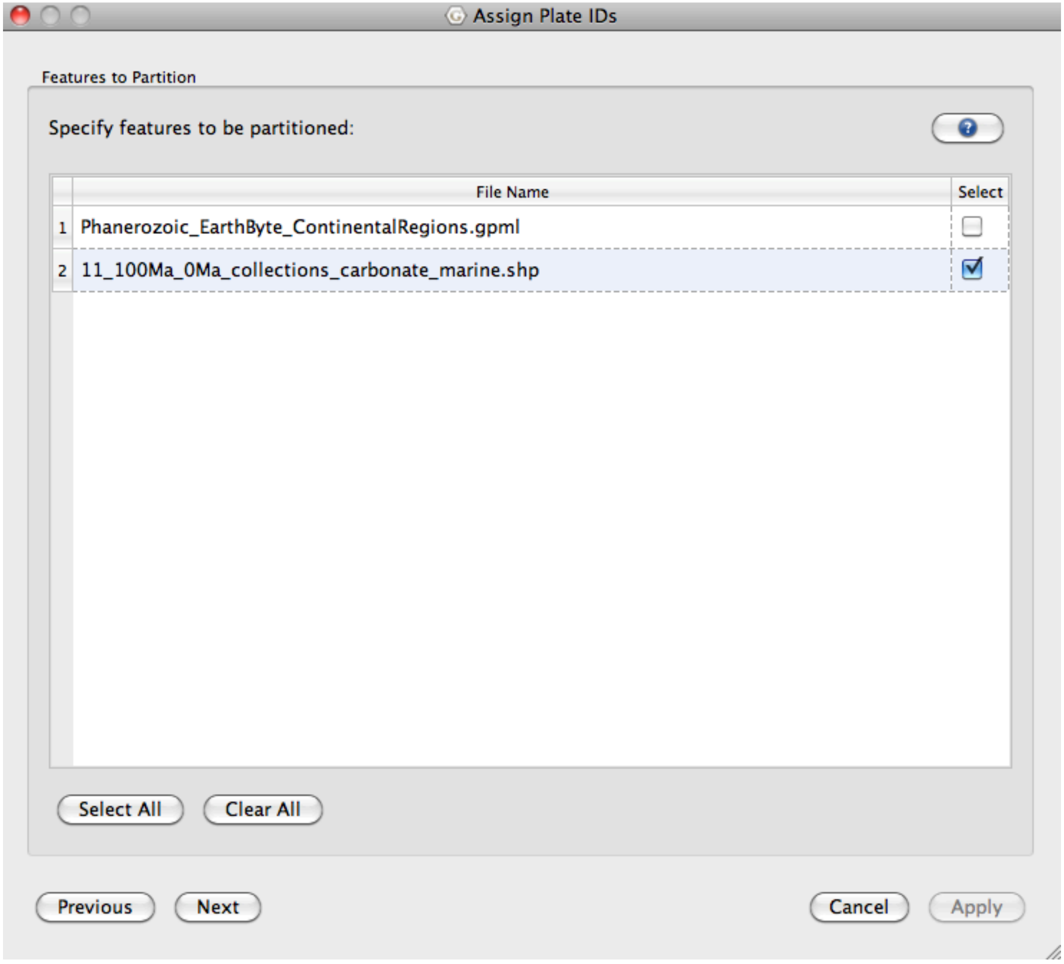
4. To assign Plate IDs, in the main GPlates window go to Features > Assign Plate IDs



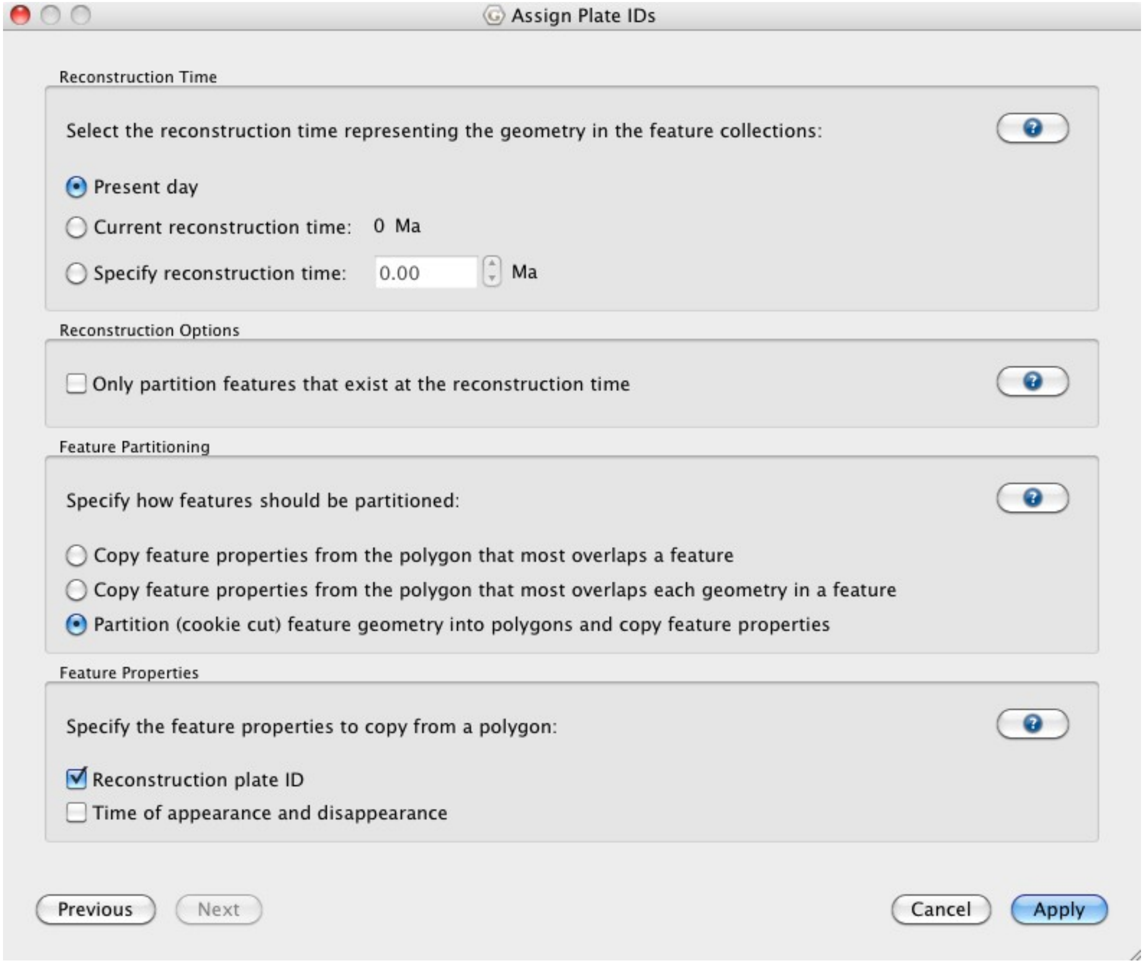
5. Specify the partitioning layer, which in this case are the Static Polygons. Click Next.



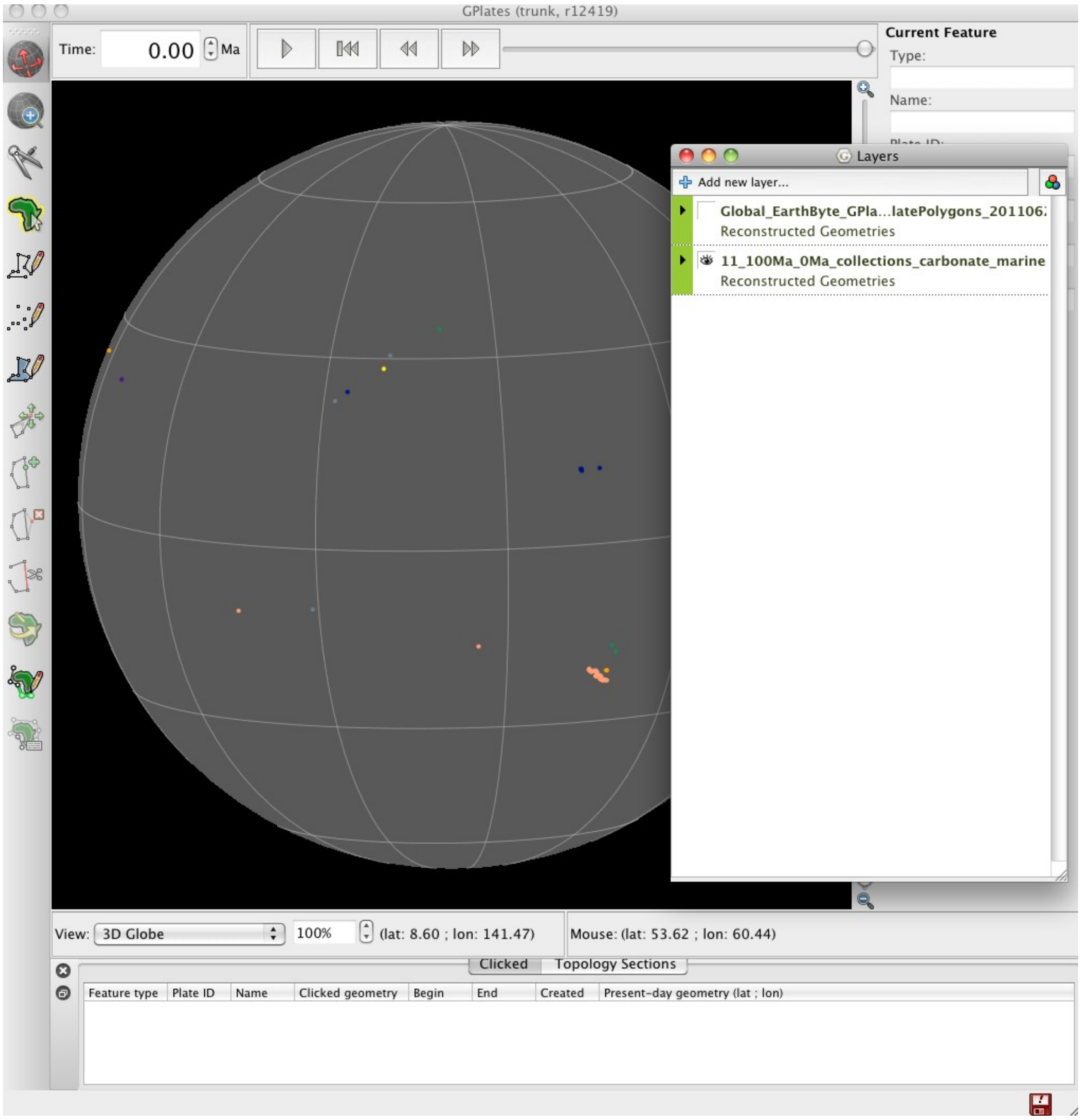
6. Specify the layer to be partitioned. In the example, it is the carbonates data from 100 to 0 Ma. Click Next.



7. The next screen allows you to make a choice whether you want to cookie-cut your data at the present-day or at some other reconstruction time. For the purposes of reconstructing fossils and other similar data, you would normally choose Present Day. Set the options as in the screen grab below and click Apply.

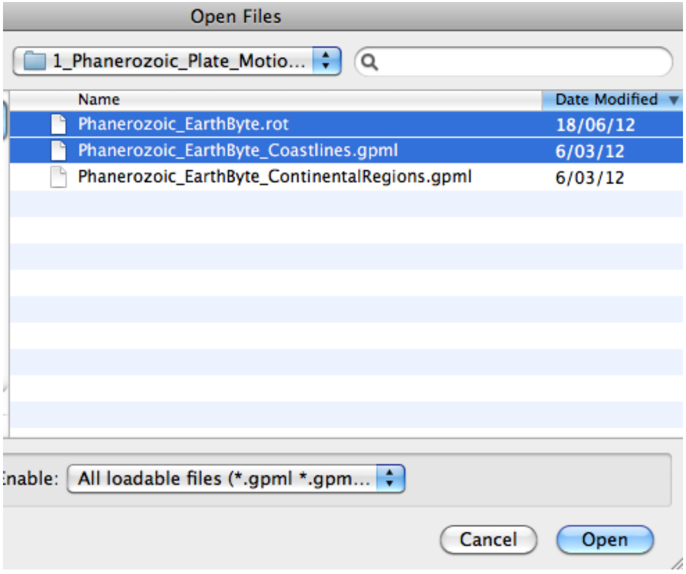


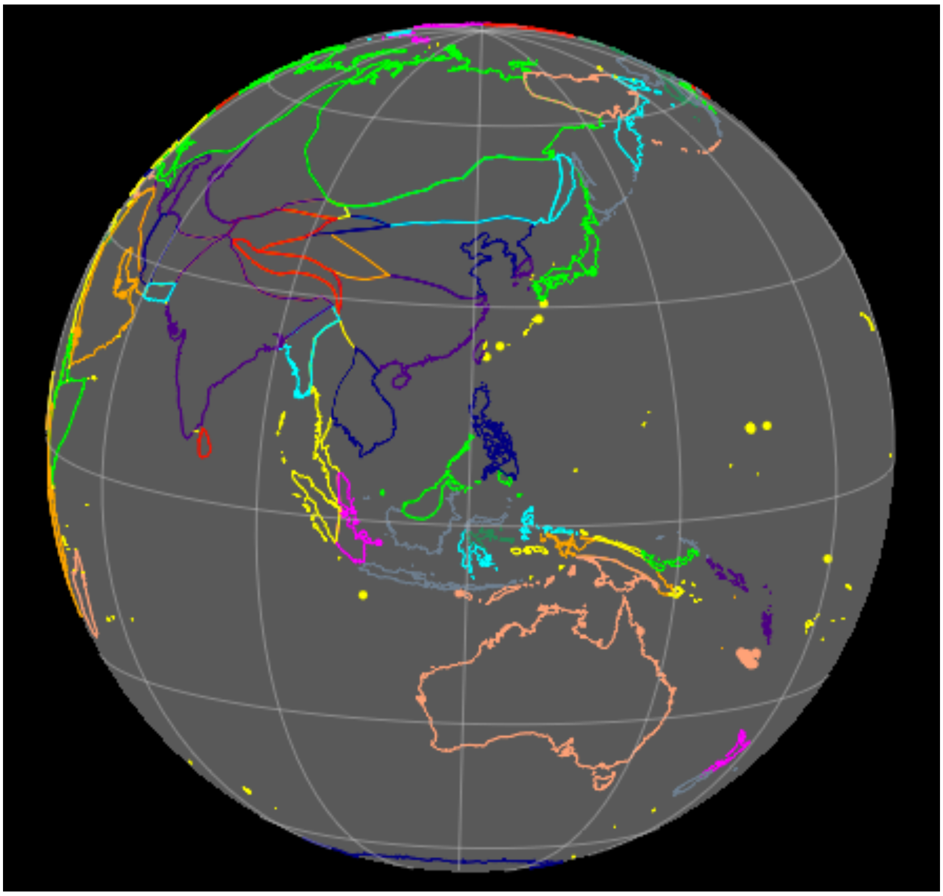
8. Your data is now ready to reconstruct. If you deactivate the Static Polygon layer visibility in the Layers window, you will see now that your data points have colours assigned based on the Plate ID. You can save the changes to your shapefile, or save out to a new shapefile or other format by going into File > Manage Feature Collections > "Save As" or "Save A Copy"



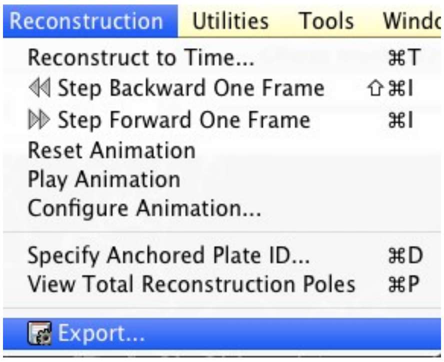
9. Load up the included plate motion model. Go to File > Open Feature Collection > Navigate to SampleData > DataBundleForNovices > Select the rotation (.rot) file and the coastline file for visual reference (.gpml).

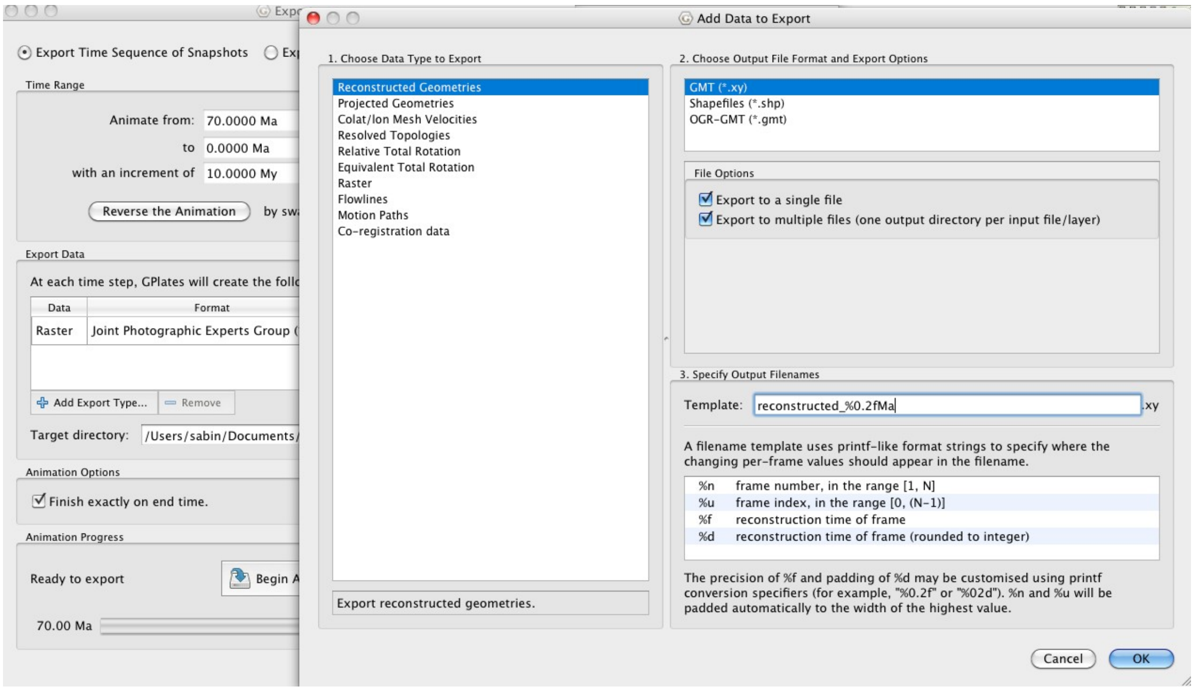
Phanerozoic_EarthByte_Coastlines.gpml
Phanerozoic_EarthByte.rot

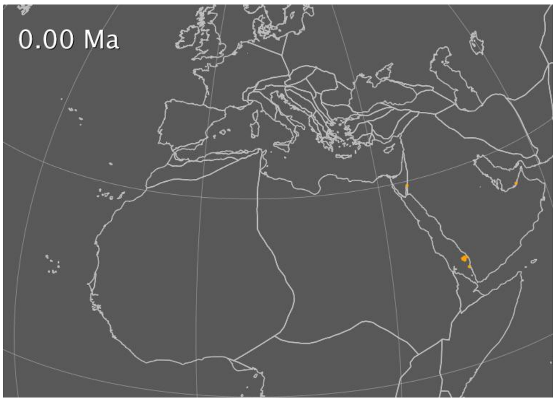


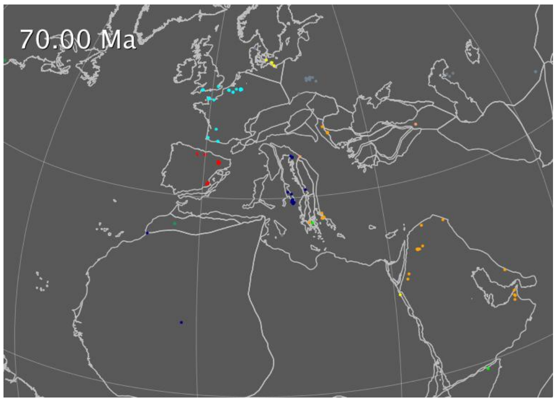


10. You can now reconstruct to any desired time, and choose to export animations as JPG files or other files. It is common to export Reconstructed Geometries as GMT XY or ESRI shapefile to create more detailed maps. Go to Reconstruction > Export > Select your time range > Click “Add Export Type” and choose Reconstructed Geometries > GMT (*.xy) (or any other type you want). Choose your export Target Directory. Click OK, and then click “Begin Animation”. GPlates will output your data into your desired directory.

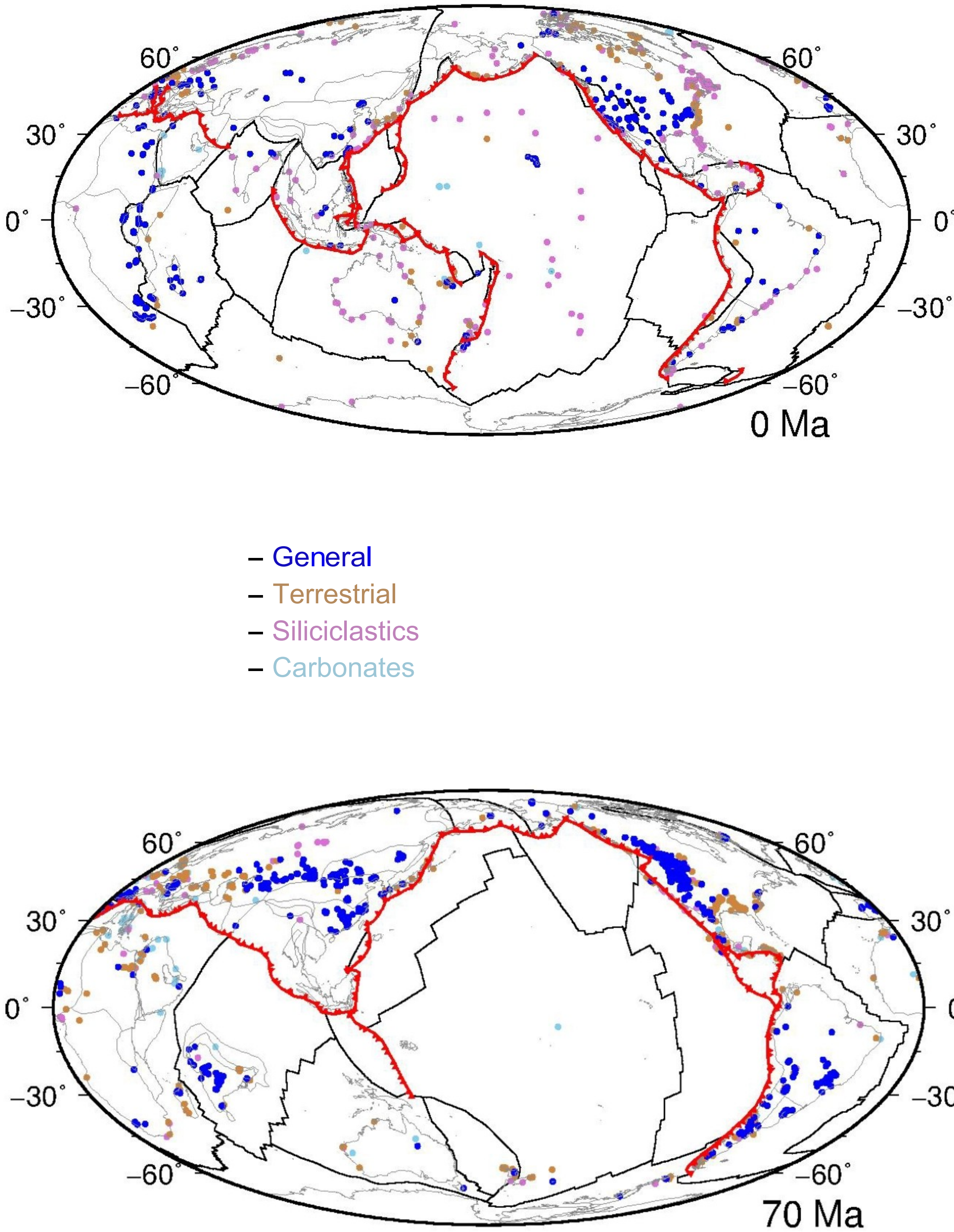








11. If exporting as GMT XY files, then you can write a script to extract header information from each data point. The example below shows a simple paleogeographical reconstruction exported from GPlates and plotted using GMT.



Palaeogeographic Atlas of Australia
Timescales

The digital atlas exists as a series of snapshots through time, with numbered timesteps. However, using the paleogeographic atlas with other data requires converting the inherent timescale to a common one. In the case of the Palaeogeographic Atlas of Australia, it was necessary to standardize to the GTS2004 (Gradstein et al., 2004; Gradstein and Ogg, 2004). The Palaeogeographic Atlas of Australia used a combination of the Geoscience Australia time scale (internal) and the Young and Laurie (1996) and Harland (1989). Although all effort was taken to convert the timescales correctly, there were many instances where the Palaeogeographic Atlas ages did not correspond to any of the published time-scales, and for those instances a logical progression of stages was assumed.

The Excel spreadsheet documents the conversion. Importantly, the columns GA-H89 and GA-YL96 highlight the differences between the Geoscience Australia stage boundary ages and the ages from Harland (1989) and Young and Laurie (1996), respectively. For younger times the ages are not very different. However, for older times the differences are significant.

Field	Description
Ref_ID	Unique integer value for each time slice (71 in total)
NAME	Time slice name (e.g. Time Slice Devonian 2)
ABBREV	Name abbreviation from GA (e.g. T S D. 2)
GA_BOTTOM	Base age from the GA data dictionary most closely resembling the Young and Laurie (1996) timescale
GA_TOP	Young age from GA data dictionary
R G B	Red, Green and Blue values for each stage/period from the Commission for the Geological Map of the World (CGMW). This was difficult for timesteps that included multiple stages, so the colour of the oldest stage was assigned to that time slice.
STAGE	This field was interpreted based on the GA_BOTTOM and GA_TOP ages that correlated to stage boundaries in the Young and Laurie (1996) timescale. Many timesteps covered multiple stages, and in those cases a range is given, from an old to a younger stage. For example Permian 6 is likely to be Ufimian to Midian in age, inclusive.
PERIOD	Geological period.
FROMAGE_BOTTOM	The original GPlates "From Age" used for a Table Join operation in ArcGIS. This is the way the time scale is changed in the Shapefile. For example, if the original age was 5 Ma then ArcGIS can be used to change all instances of 5 Ma "From Age" to a new time scale equivalent, such as 5.332 Ma from GTS2004.

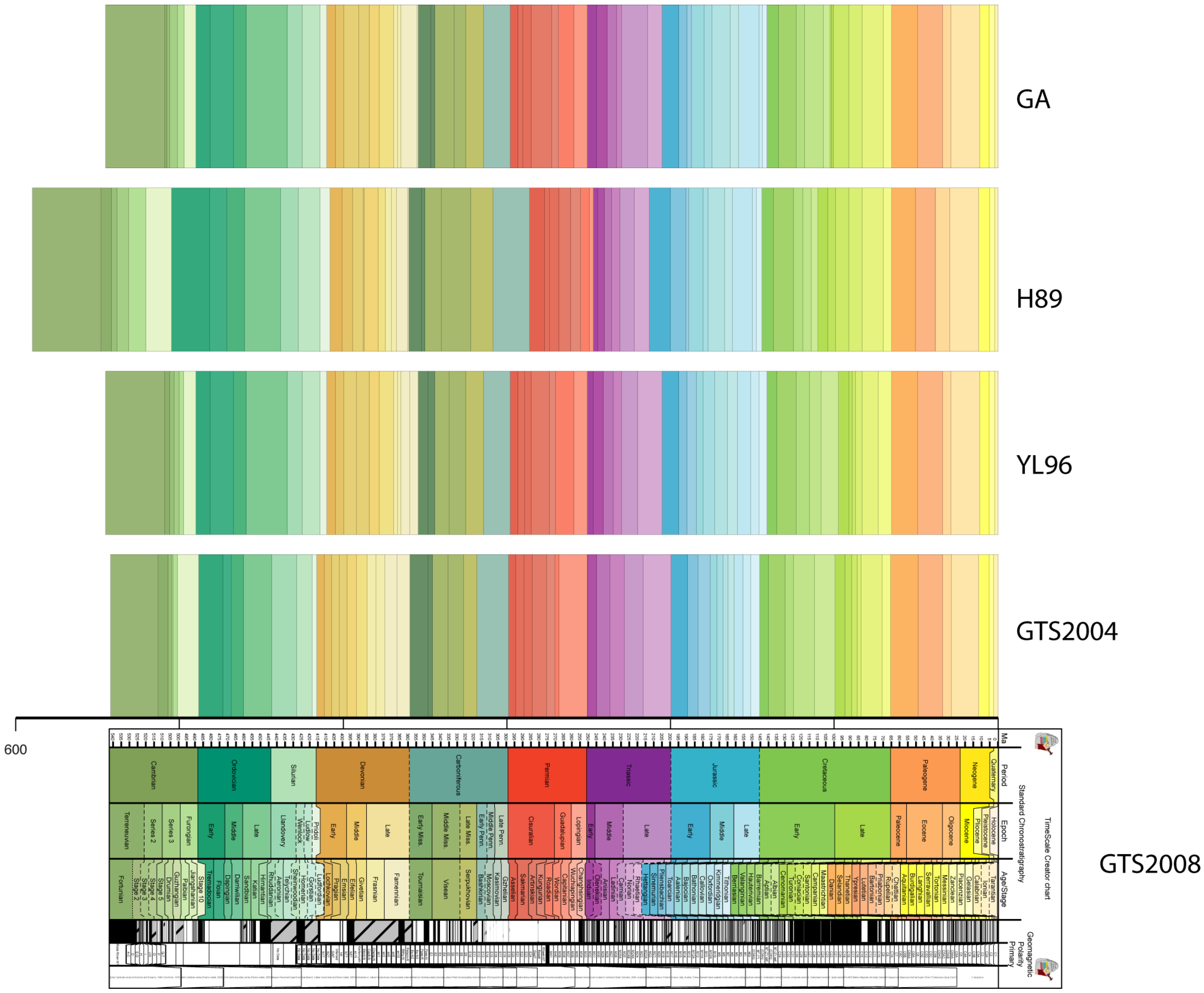


Figure 3. Timescale visual comparison showing significant differences that are especially important for older times.

References

Gradstein, F., and Ogg, J.: Geologic Time Scale 2004–why, how, and where next!, Lethaia, 37, 175-181, 2004.

Gradstein, F. M., Ogg, J. G., Smith, A. G., Bleeker, W., and Lourens, L. J.: A new geologic time scale, with special reference to Precambrian and Neogene, Episodes, 27, 83-100, 2004.

Hannisdal, B., and Peters, S. E.: Phanerozoic Earth System Evolution and Marine Biodiversity, Science, 334, 1121-1124, 2011.

Harland, W. B.: A geologic time scale 1989, Cambridge Univ Press, 1989.

Young, G. C., and Laurie, J. R.: An Australian Phanerozoic Timescale, Oxford University Press, 1996.