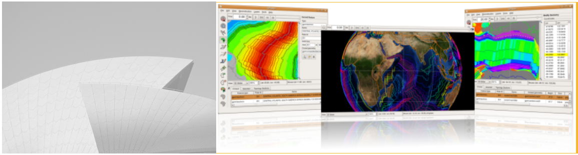

GPlates: open-source software for plate tectonic reconstructions

Macquarie Uni - 1/2 day course

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2013-05-30

Overview

Today's topcis

1. The GPlates project
2. Plate tectonic concepts and data models
3. The GPlates user interface
4. Basic workflows in GPlates
5. Playing with rotations
6. Working with rasters
7. Advanced tools

The GPlates project

Background

GPlates is developed by an international team of scientists and professional software developers at:

- the EarthByte Project (part of AuScope) in the School of Geosciences at the University of Sydney (under the direction of Dietmar Müller). Currently 2 developers
- the Division of Geological and Planetary Sciences (GPS) at CalTech (under the direction of Michael Gurnis). 1 developer
- the Center for Geodynamics at the Norwegian Geological Survey (NGU) (under the direction of Trond Torsvik, UiO). 1 developer, part time.

GPlates

Plate tectonics for the masses – for free!

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GPlates is open-source desktop software for the interactive visualisation of plate-tectonics.

- Plate-tectonic reconstructions, geographic information system (GIS) functionality, raster data visualisation, data mining and geodynamic modelling interfaces.
- Free of charge
- Comes with royalty-free data
- Runs on Windows, Mac OS X and Linux
- Teaching tool, research, mineral and hc exploration.

On the web: http://www.gplates.org

- online tutorials (through EarthByte)
- sample data (through EarthByte)
- the GPlates manual (PDF for print or html)

GPlates 1.3 was released 2013-05-30. It has matured over a few years to a spatio-temporal GIS and has the following exciting new functionality:

- A new meta-data rich rotation format called *.grot (details later).
- **Volume visualisation of 3D seismic tomographic/geodynamic models**
- **Raster shading**
- Kinematic boundary condition export for geodynamic modelling (CitcomS, Terra)

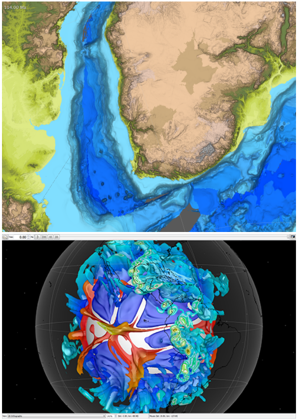

Plate tectonic concepts and data models

(A very short introduction)

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Euler's theorem

In three dimensional space, any motion of a rigid body on the surface of a sphere may be represented as a rotation about an appropriately chosen rotation pole, called an Euler pole. It also means that the composition of two rotations is also a rotation.

Key ingredients for plate kinematic models

- Rotation framework specifiying the displacement (Pole + rotation angle and time interval)
- Features/spatial data connected to certain plates

For details: Cox & Hart, 1986, *Plate tectonics: How it works*.

Data model in GPlates

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History

Since the early days of the PLATES software (Mid-1980's) which was the first interactive plate tectonic visualisation, the data model for plate kinematic modelling consisted of a rotation file and data files containing geospatial data ("features").

GPlates needs two things to reconstruct data into paleo-positions:

1. A rotation model (`*.rot` file) which describes the motions of plates relative to each other and to a fixed spin axis of the globe over geological times.
2. Data files which specify geometrical objects ("features") and map them through extra data (PlateID, FromAge, ToAge) to plates and geological time using the PlateIDs.

Data model in GPlates

Feature data

A “feature” is a geometrical object which can be represented by location and time data, such as points, lines, polygons, and multi-geometries on the globe.

- GPlates uses a newly devised data model called the GPlates markup language (GPML) to represent features internally.
- The format is based on XML (eXtensible Markup language) and includes features of GML (Geographic Markup Language).
- the `*.gpml` Files are plain text files which can be edited by hand (if you need to) and opened in a Text editor.
- GPlates read also ESRI `*.shp` files as well as the legacy PLATES4 data file format (formatted plain text)
- Data used in plate tectonic applications need to carry certain metadata with it in order to be reconstructed in space and time.

Data model in GPlates

Why?

The GPlates information model is a highly sophisticated part of GPlates, which sets it apart from other standard GISs. The reason is that certain features have

- **Topologies**: The shape of plates changes continuously over time, plate boundaries are highly dynamic. In order to capture and model the spatio-temporal plate tectonic evolution, topological polygons can be reconstructed using plate boundary segments.
- Plate boundaries
- Rock units, subduction zone dip, flat slabs - spatio-temporal associations and data mining.

Example GPML

Header meta data

```
<?xml version="1.0" encoding="UTF-8"?>
<gpml:FeatureCollection
xmlns:gpml="http://www.gplates.org/gplates"
xmlns:gml="http://www.opengis.net/gml"
xmlns:xsi="http://www.w3.org/XMLSchema-instance"
gpml:version="1.6"
xsi:schemaLocation="http://www.gplates.org/gplates ../xsd/gpml.xsd http://www.opengis.net/gml ../../../gml
<gml:featureMember>
<gpml:ClosedContinentalBoundary>
<gpml:identity>GPlates-946a0caf-b768-4ecd-ab89-eb92394c6895</gpml:identity>
<gpml:revision>GPlates-44202437-cbc0-4295-a2f0-f30a0d828e75</gpml:revision>
<gpml:boundary>

... more xml
```

Example GPML

The geometry part of a polygon


```
<gpml:unclassifiedGeometry>
            <gpml:ConstantValue>
                <gpml:value>
                    <gml:Polygon>
                        <gml:exterior>
                            <gml:LinearRing>
                                <gml:posList gml:dimension="2">-59.1153 -84.9161
-61.61 -90.16 -60.5813 -92.0449 -63.0635 -97.7606 -61.892 -99.8222 -63.5277
 -104.037 -62.9804 -105.368 -65.9361 -115.563 -64.8375 -117.343 -67.2924
 -129.353 -69.1684 -126.945 -70.6571 -139.023 -71.8117 -148.39 -72.1609
 -155.364 -72.5597 -163.328 -72.994 -171.286 -73.1827 -174.605 -73.1746
 -174.607 -71.5505 -170.187 -71.0025 -168.696 -70.9459 -168.542 -71.0526
 -161.223 -70.9413 -160.486 -70.1296 -160.045 -70.0202 -155.955 -70.4137
 -156.119 -70.2587 -153.439 -69.769 -153.329 -68.9707 -147.185 -68.8114
 -147.306 -67.9192 -135.918 -66.6425 -132.328 -67.1787 -130.648 -66.1228
 -128.147 -65.7518 -129.102 -65.0513 -127.498 -64.8824 -127.907 -61.8579
 -121.629 -63.9103 -116.311 -62.6078 -114.317 -62.3278 -114.454 -59.2736
 -110.655 -60.4047 -106.66 -60.4005 -106.654 -61.4634 -103.311 -60.3054
 -101.738 -60.7629 -100.104 -60.7305 -100.064 -61.7848 -96.1094 -59.5082
 -93.3633 -56.1598 -86.6223 -55.9506 -86.2541 -57.8266 -82.8183 -57.8555
 -82.7502 -59.1153 -84.9161 -59.1153 -84.9161 </gml:posList>
                            </gml:LinearRing>
                        </gml:exterior>
                    </gml:Polygon>
                </gpml:value>
                <gpml:valueType xmlns:gml="http://www.opengis.net/gml">gml:Polygon</gpml:valueType>
            </gpml:ConstantValue>
</gpml:unclassifiedGeometry>
```

Plate Model

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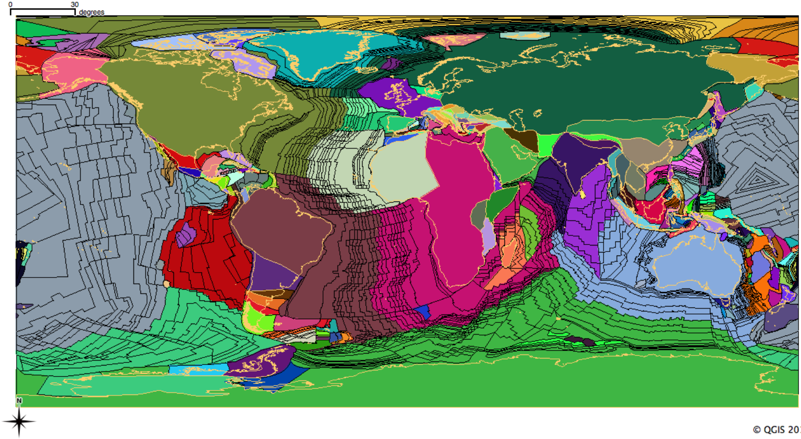
EarthByte plate polygon model:



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Rotation trees

Representation of relative plate motions over time

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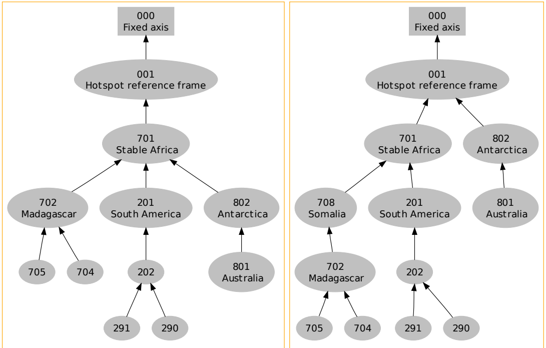
Plate rotations are expressed as sequence of concatenated relative rotations. This allows PlateIDs to be connected to Finite reconstruction poles for given stages. This is called Total Reconstruction Poles in GPlates.



Example - 20Ma

Example - 0Ma

[chhei -- www.earthbyte.org -- 2010-09-29 v1]

Example rotation trees for 20 Ma and 0 Ma (made up).

How does it look like in nature?

A *.grot example snippet

At the top

```
> @MPRS:id"001" @MPRS:code"AHS" @MPRS:name"Present day Atlantic-Indian hotspots"
> @C"fixed to 000" @GTS"Absolute" @AU"EByte" @PP"AHS-HOT"
001   0.0   0.0    0.0    0.0  000
001 200.0   0.0    0.0    0.0  000
```

Further down somewhere:

```
> @MPRS:id"201" @MPRS:code"SAM" @MPRS:name"South America"
> @C"Mesozoic rotation history based on Heine et al. 2013"
201   0.0    0.0    0.0      0.0   701 @PP"SAM-AFR" @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"
201  10.9   61.2   -39.7     3.68  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  20.1   58.5   -37.1     7.52  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  33.1   56.17  -33.64   13.41  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  40.1   57.1   -32.5    16.6   701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  47.9   57.5   -31.2    19.7   701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  55.9   61.35  -32.21   22.27  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  67.7   63.7   -33.5    25.39  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  83.5   61.88  -34.26   33.51  701 @REF"Mueller.99"  @DOI"10.1016/S1874-5997(99)80036-7"  @CHRONID"CAr
201  96.0   57.46  -34.02   39.79  701 @AU"CHHEI"  @T"2012-01-24" @C"artificial rotation, interpolated pos
201 120.6   51.28  -33.67   52.35  701 @AU"CHHEI"  @T"28/04/13 9:51:05 AM" @CHRONID"CM0ry" @C"XOVER"
201 120.6   52.26  -34.83   51.48  714 @PP"SAM-NWA" @AU"CHHEI"  @T"28/04/13 9:49:16 AM" @CHRONID"CM0ry" @C
201 126.57  50.91  -34.59   52.92  714 @AU"CHHEI"  @T"28/04/13 9:44:49 AM" @CHRONID"CM4o" @C"Matching M4no
#201 127.23  50.78  -34.54   53.04  714 @AU"CHHEI"  @T"28/04/13 9:39:40 AM" @CHRONID"CM7ny" @C"Using M7"
201 140.0   50.44  -34.38   53.4   714 @AU"CHHEI"  @T"22/03/13 10:45:25 AM"
201 200.0   50.44  -34.38   53.4   714 @AU"CHHEI"  @T"10/12/12 5:04:17 PM"
```

Rotation file syntax explained

This is what is looks like in the file:

```
607 154.1 11.10 115.23 123.31 801 ! M25 Argo Christian
607 155.9 10.36 115.73 125.28 801 !
607 600.0 10.36 115.73 125.28 801 ! Fit Recon Burma-Australia
```

In plain text:

"From 600 Ma to 155.9 Ma the West Burma Block (PlateID 607) moves (here: is fixed as the rotation pole and angle don't change) around a finite rotation pole at 10.36° N 115.73° E and a rotation angle of 125.28° relative to Australia (PlateID 801)"

The general syntax of a rotation file is:

```
MovingPlateID FromAge PoleLat PoleLon Angle FixedPlateID
```

Resources

GPlates information model: GPGIM, GROT

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Online resources

- Community GPGIM (how are features defined, which features can GPlates handle): https://bitbucket.org/chhei/gpgim (everyone can tweak this part and generate a personal GPGIM)
- *.grot Syntax coloring for TextMate: https://bitbucket.org/chhei/grot-bundle
- The *.grot format documentation: http://www.gplates.org/grot

GPlates user interface

Basic elements

The GPlates user interface

Main window elements

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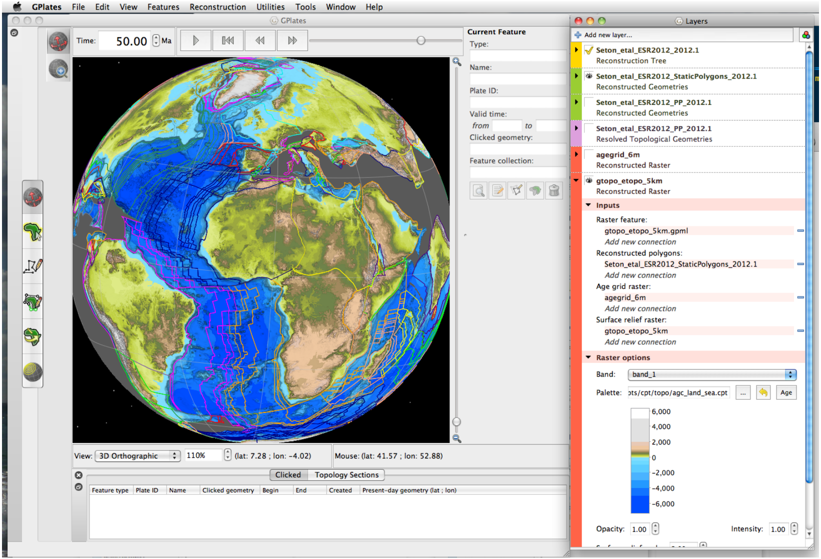
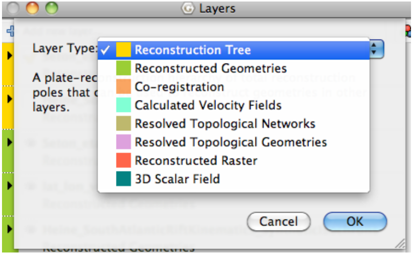
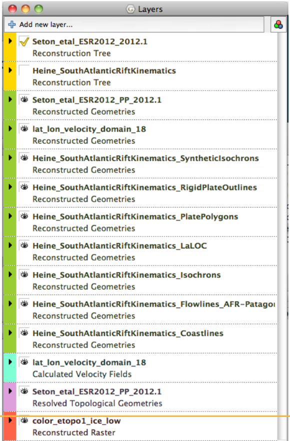


The GPlates user interface

Layer window

Layers in GPlates work akin to other applications - e.g. drawing programs (Inkscape etc.). The layer order controls the rendering, layers can be switched on or off (influences visibility & export) as well as they can be disabled/deleted. There are different layer types:





The GPlates user interface

The Main Tools & shortcuts

GPlates has 6 distinct views which contain a set of different tools:

Zoom/Turn

d, z

Select/Measure

s, f

(v, i, x, t)

Generate

s, l, m, g

(v, i, x)

Topologies

f, h, b, e

Rotations

f, p

Small circles

c

Basic workflows in GPlates

(Perparing data for GPlates, loading, visualising, exporting)

Preparing data for GPlates

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There are two ways to prepare data for loading in GPlates:

1. Add attributes ("Meta data") in ArcGIS. GPlates needs the core attributes as listed below to rotate data.
2. Load data in GPlates and map features to Plates using the built-in functionality in `"Reconstruction -> Assign PlateIDs"`. This requires a plate polygon model to be loaded (EarthByte plate polygon model is supplied with GPlates).

Required attributes for features

`PlateID1....`	short; 4	Unique plate identifier
`FromAge.....`	float; 8,3	Age of appearance
`ToAge.......`	float; 8,3	Age of disappearance

Loading data into GPlates

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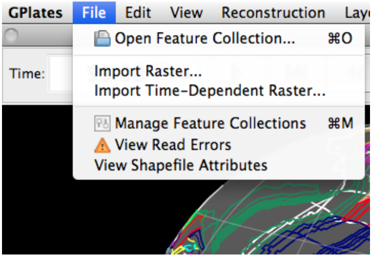
GPlates can read a multitude of different files: GPML, rotation files (PLATES 4 format), PLATES 4 data files, ESRI Shape files and GMAP VGP files.

- `File -> Load Feature collection`
- `ctrl/cmd + o`
- The loaded data is accessible through the "Manage layers dialogue" (`ctrl/cmd + m`)



Basic plate reconstructions

We will now have a go with GPlates, exploring the basic functionality. Try to:

- Load feature collections
- Do basic operations: zooming, reconstructing back in time
- Fix plates
- Animate reconstructions
- Query features
- Measure distances
- Change projections
- Manage feature collections
- Manage colouring
- Explore the layer functionality

See Interacting with features, Loading, Saving and colouring, and the Plate Reconstructions tutorials on the

Designed as geodynamic modelling tool, GPlates offers a variety of data export options (e.g. reconstructed geometries or velocity boundary conditions for mantle convection models). Of most interest here are reconstructed geometries.

Export options:

1. Reconstructed geometries
2. Projected geometries
3. Colat/lon velocity meshes
4. Resolved topologies
5. Relative total rotation
6. Equivalent total rotation
7. Equivalent stage rotation
8. Raster

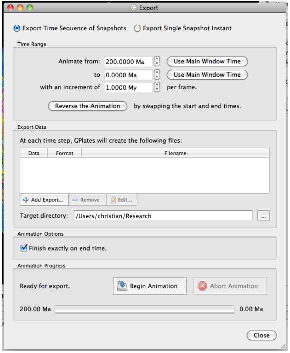
Format options for reconstructed geometries:

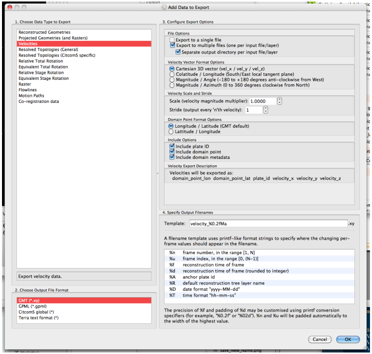
1. Shape files (for ArcGIS)
2. XY files (to be used with GMT)

→ Exercise!

Basic workflows in GPlates

Export dialogue





Under `Reconstruction→Export`, the user can export time series of data or single snapshots. Each export can consist of various data types, such as the reconstructed geometries, flowlines etc. in a variety of formats (`*.gpml`, `*.shp`, `*.gmt`, `*.svg`, rasters) or specialised geodynamic modelling input parameter formats (Terra, CitcomS).

Excercise

- Try to export a sequence of reconstructions as shape files using the "Export" functionality under the "Reconstruction" menu.
- Play with different configurations
- Try and export `*.svg` files and open them in a vector drawing application (Illustrator/Corel/Inkscape or Firefox/Acrobat)

Excercise

- In this exercise we will interrogate the rotation tree at different time steps to see how the relative rotations have changed.
- make a series of reconstructions and check the rotation hierarchy for the Indian Plate.
- Modify the fit reconstruction for India
- Save your changes to the rotation file (don't overwrite your existing master rotation file)
- Digitise a new block and set up a rotation history.

This follows the Rotations Tutorial

GPlates and raster data

Best buddies!

GPlates loves raster data - netCDF and image formats!

Highlights

- import netCDF grids (e.g. age of the ocean floor).
- Import and cookie-cut rasters using polygons
- use layers to stack different data types.
- rotate rasters.
- apply age-based masking using an age grid and a rotation model.

The latest release allows to apply shading to a raster (ie topography with topography, age grid with gravity etc.). Additional functionality are transparency and intensity when overlaying raster data sets.

Working with static rasters

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Excercise

- Load the ETOPO1 topography data
- Load other feature collections on top
- Digitise a new feature based on topographic data

Using time-dependent rasters

Time dependent rasters can be used to display data which has been gridded and can be keyed to certain time slices. This includes the reconstructed ocean depth (paleo-age grids), seismic tomography to mimick the position of subduction zones through time, or reconstructed continental topography from Earth Systems modelling

Excercise

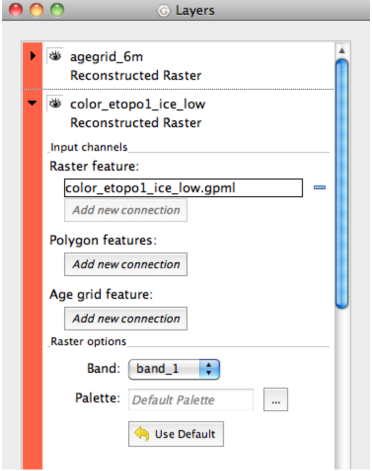
- Load time-dependent data through the `"File-> Open Time-dependent raster"`
- Load other feature collections
- Reconstruct back and forward in time.

Age-based masking

GPlates can use age-gridded information to selective mask data based on the age property.

Excercise

- Load the agegrid file
- Load the ETOPO1 topography jpg
- Load the static plate polygons
- Assign an age to the ETOPO1 jpg using the agegrid as "connection" in the layer dialogue ("Layers -> Show layers")



Topologies

In this excercise we will work with topological data: In GPlates, the user can construct topological polygons which can evolve over time, e.g. mimicking a growing oceanic plate.

Excercise

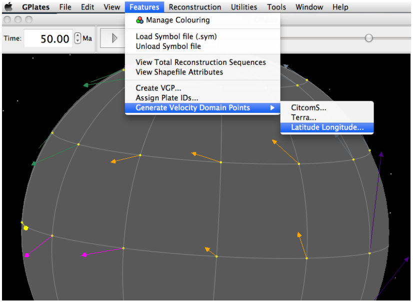
- Load the topologies sample dataset.
- Reconstruct the data back and forward through time.

Velocity meshes

Plate velocities are important boundary conditions for mantel convection models. As GPlates is designed as tool for geodynamic modelling, velocity meshes for the CitCOMs and TERRA mantle convection codes can be exported automatically. This also helps to visualise how plate velocities and directions in a given plate model can change over time.

Excercise

- Use your currently loaded sample data to generate velocity meshes and display the data in GPlates
- Use `"Features -> Generate velocity domains"`



Questions? Remarks?

Thanks for participating!!

Don't hesitate to contact me in case you have questions:

Email: christian.heine@sydney.edu.au

http://bitbucket.org/chhei
http://tectonicwaters.wordpress.com

GPlates Mailing list: http://mailman.ucc.usyd.edu.au/mailman/listinfo/gplates-discuss